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Foreword

During 1992, the Ontario Geological Survey–Geoscience Branch carried out independent, detailed, regional and province-wide compilation studies throughout the province. In addition, projects were undertaken in co-operation with regional staff of the Information Services Branch of the Survey, other personnel from Mines and Minerals Division, Ministry of Natural Resources, universities and private consulting firms. Special geoscience programs were also undertaken in several areas under the Canada–Ontario Northern Ontario Development Agreement (NODA), and with support from the Northern Development Fund. Project involvement by the various participants is summarized in individual reports. Funding acknowledgements are included in the individual summaries.

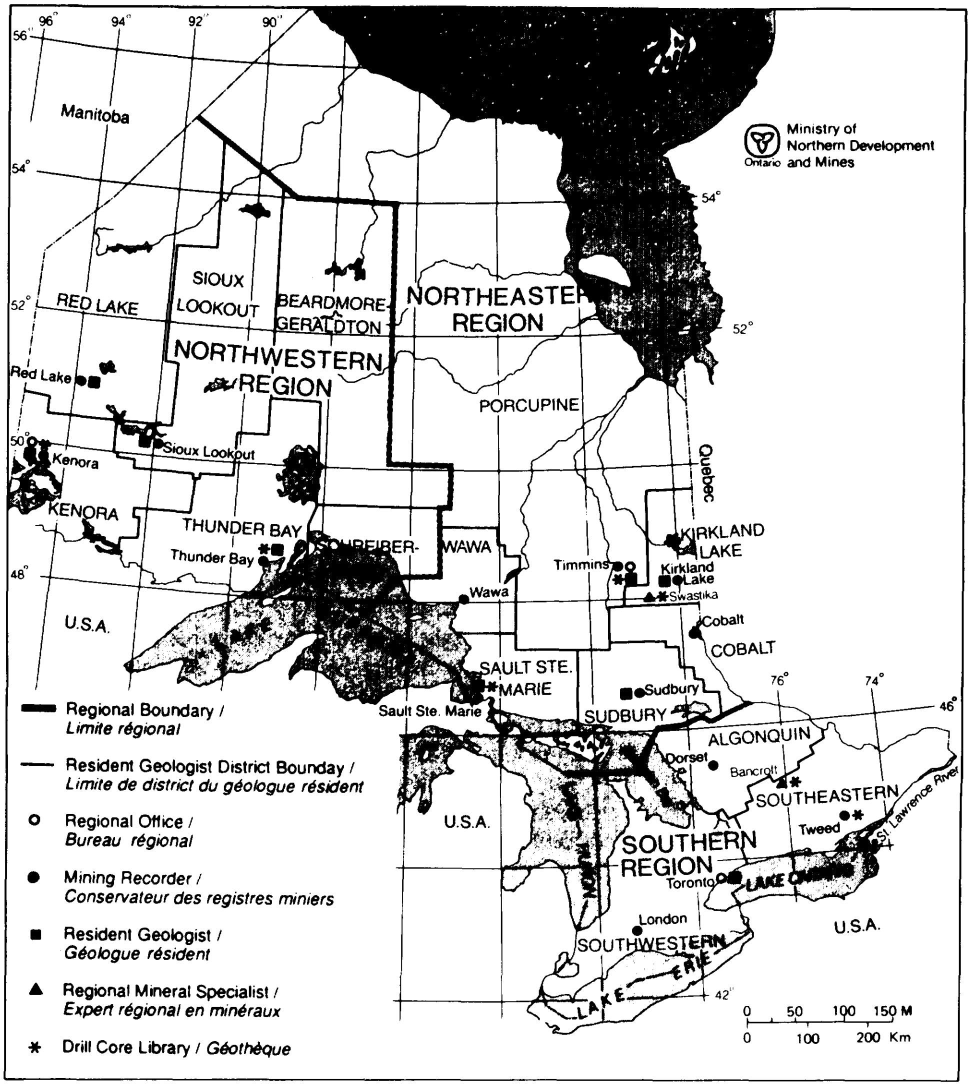
A major effort of the Survey in 1992 was its relocation from Toronto into its new home at the Willet Green Miller Centre in Sudbury in late summer. Amidst the immense amount of packing, inventorying of assets and moving of staff and families, field crews managed to organize and complete field programs on schedule. With the Survey under one roof once again, staff are optimistic and enthusiastic about working in their new environment.

The locations of the areas investigated in 1992 are compiled on two maps of the province at the beginning of this volume. Highlights of preliminary results of field work and other activities are summarized by Section Chiefs, and more extensive reports have been prepared by leaders and principal investigators for each of the projects. The aim of the Ontario Geological Survey in producing this summary immediately following the field season is to provide quick access to new information for these areas, which will be of immediate value in mineral exploration and land resource planning. In addition, the wide spectrum of research in this report is of interest to the geoscience community as a whole.

Survey geoscientists will conduct more detailed research and analysis of the field data through the winter and will be preparing reports on these investigations for publication. In the interim, uncoloured maps will be released as open file. Open file maps and reports are available at the Mines and Minerals Information Centre, Room M2–17, Macdonald Block, 900 Bay Street, Toronto; the Mines Library, Willet Green Miller Centre, 933 Ramsey Lake Road, Sudbury; or at Mines and Minerals regional offices. Notices of these releases will be mailed out to all persons or organizations on the Mines and Minerals Division publications release notification list. Selected releases may be publicized in technical journals and other media.

V.G. Milne

Director, Geoscience Branch
Ontario Geological Survey



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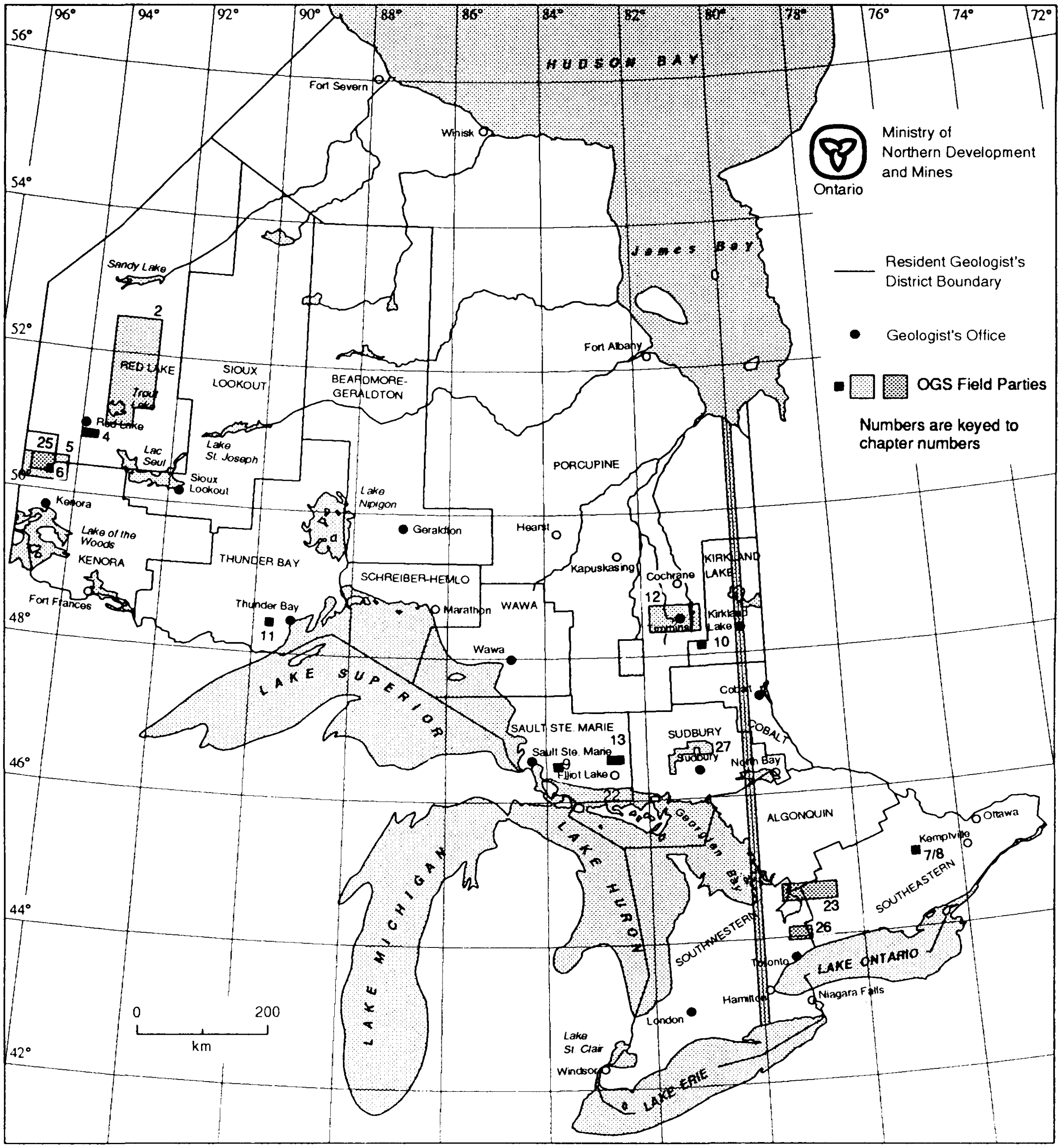

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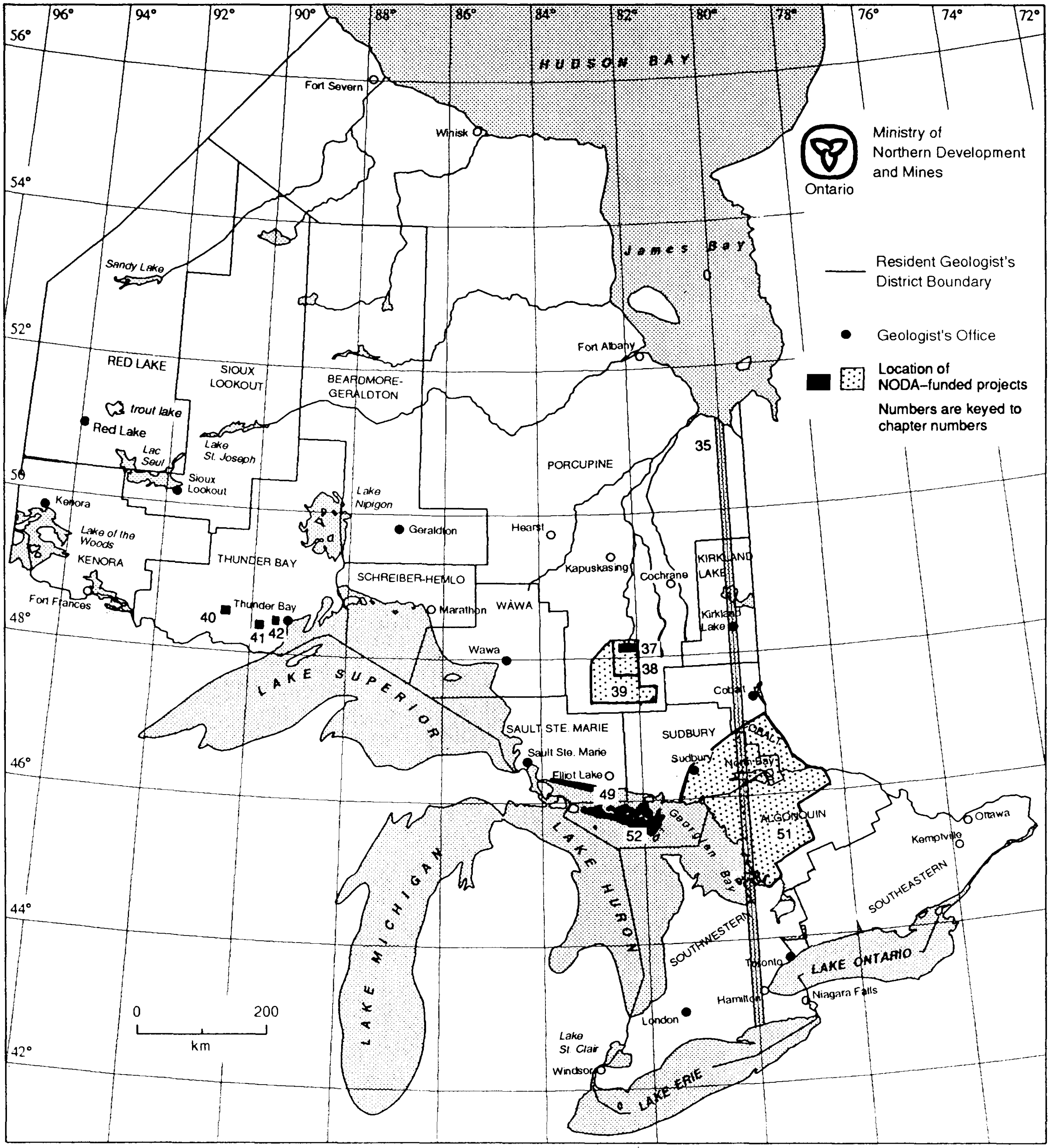

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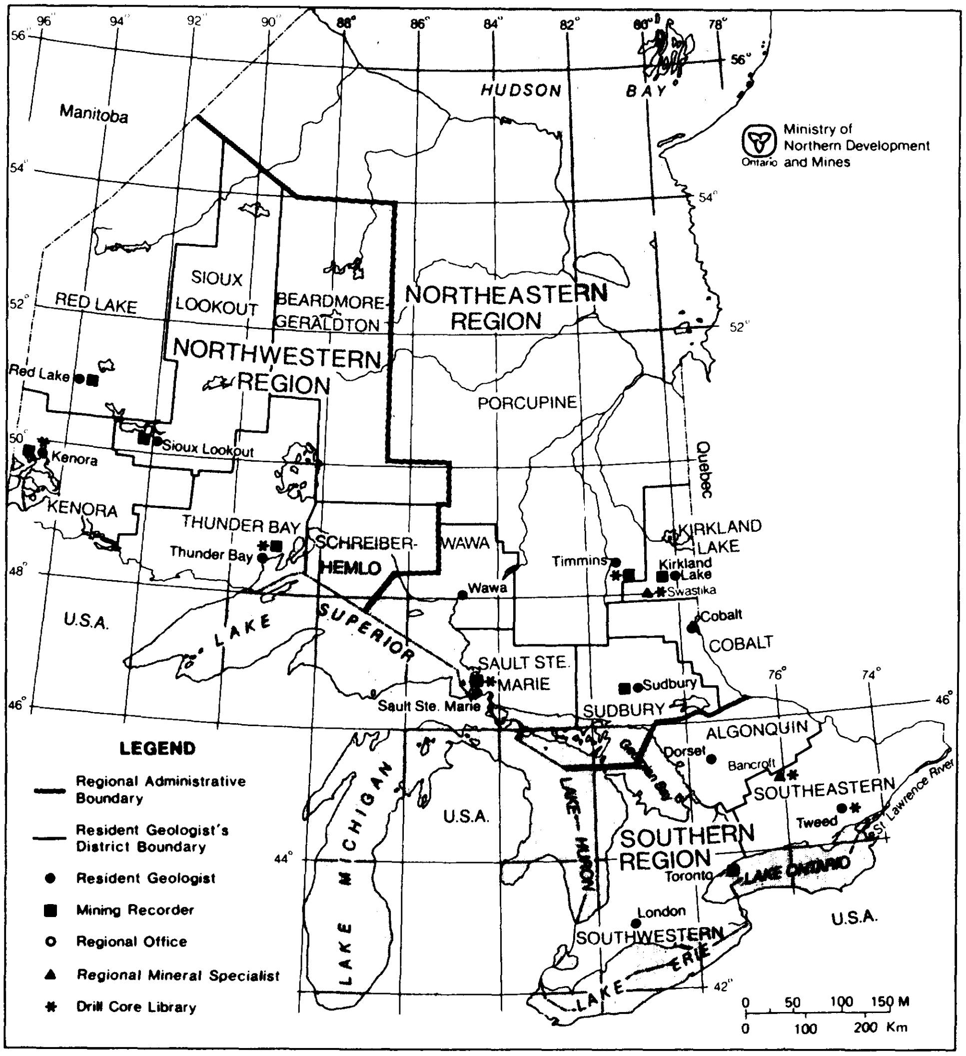

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Precambrian Geoscience Programs

1. Summary of Activities 1992, Precambrian Geoscience Section

B.O. Dressler

Precambrian Geoscience Section, Ontario Geological Survey– Geoscience Branch, Sudbury

INTRODUCTION

The field investigations reported in this volume were carried out by 14 field crews. As in 1991, the Section's program emphasized detailed and regional mapping. A small number of thematic and externally funded projects were also carried out.

The Base program funded 10 mapping parties: 5 in northwestern, 4 in northeastern and 1 in southern Ontario, respectively. Four additional mapping projects, 3 in the Thunder Bay District and 1 south of Timmins, were funded under the Northern Ontario Development Agreement (NODA).

MAPPING PROGRAM

Northeastern Ontario

John Ayer and R. Theriault continued a detailed, NODA mapping program in the northern Swayze greenstone belt of the Abitibi Subprovince to update an older, geological data base. The area has exploration potential, especially for gold.

Giorgio Siragusa of this Section and Pam Sangster of the Timmins Resident Geologist's Office initiated a multi-year program of detailed investigations of recently discovered gold occurrences in the Timmins area. They plan to intergrate their investigations with assessment file information and unpublished exploration data. This year's investigations were carried out in the Northern Night Hawk Lake area.

Murray Rogers completed detailed mapping of the Ompa Lake Area north of Elliot Lake and reports on some favourable mineralization environments. His investigations, and 2 other projects carried out by staff of the Geology Department of Laurentian University (Sudbury), are part of the Elliot Lake Initiative of the Ministry of Northern Development and Mines. M. Byron and R.E. Whitehead, in one of Laurentian University's project, completed a three-year, detailed, geochemical sampling program of the metavolcanic rocks of the Whiskey Lake greenstone belt, and D.C. Peck, P.T. Chubb and R.S. James, also of Laurentian University, investigated the copper-nickel and platinum groups element potential of the East Bull Lake Gabbro–Anorthosite Intrusion.

Larry Jensen assumed responsiblity for the detailed, 1:15 000 scale mapping of an area near Matachewan. He studied McNeil and Robertson townships, north of an area investigated by Kresz in 1991. In central Robertson Township, Queenston Mining Incorporated recently discovered copper-zinc mineralization under several metres of overburden. Several gold occurrences are also known in the 2 townships mapped by Jensen.

Steve Jackson and Ingrid Henderson geologically mapped the Aberdeen area east of Sault Ste. Marie, a structurally and stratigraphically complex area underlain by rocks of the Proterozoic Huronian Supergroup. Rocks encountered in the program may contain low-grade, large-tonnage copper mineralization.

Northwestern Ontario

Denver Stone continued regional, reconnaissance mapping of the Berens River Subprovince in the MacDowell Lake–Trout Lake area. The objective of this multi-year program is to come to a better understanding of the geology of a largely unknown terrane in northwestern Ontario.

Charlie Blackburn and Gary Beakhouse initiated a two- to three-year mapping project of the Separation Lake area north of Kenora. Blackburn is responsible of mapping the supracrustal rocks of the Separation Lake greenstone belt, while Beakhouse's investigations concentrate on the granitic and gneissic rocks north and south of the greenstone belt. Concurrently with the mapping of the Precambrian rocks of the Separation Lake area, a gravity survey was carried out by Vinod Gupta.

Tom Muir completed the 1:15 840 to 1:50 000 scale mapping of the Dixie Lake area south of Red Lake, an area that experienced some exploration activity in the recent past. The Dixie Lake gold occurrence include a zone containing 420 000 tons with an average grade of 0.13 ounces Au per ton.

In the Shebandowan area west of Thunder Bay, 3 NODA funded detailed mapping projects were carried out. Ben Berger investigated Marks and Adrian townships, Heather Brown mapped Oliver Township and Ikram Osmani studied the western Greenwater Lake area. All 3 areas have potential for gold and base metal mineralization. A new, promising amethyst occurrence was discovered in the area mapped by Berger.

Southern Ontario

R.M. Easton completed detailed and semi-detailed, 1:15 000 to 1:50 000 scale mapping of the northern Mazinaw Terrane (Palmerston Lake Area) of the Central Metasedimentary Belt of the Grenville Province and describes environments that might be favourable for radioactive mineralization.

Thematic Investigations

A total of 6 thematic investigations were carried out by staff of the Section or by researchers presently or previously associated with the Section. Two of these studies, by staff of the Geology Department of Laurentian University, are part of the Elliot Lake Initiative of the Ministry of Northern Development and Mines and are described above.

E.C. Walker, R.H. Sutcliffe and co-workers of the Department of Geology, the University of Western Ontario (London, Ontario) conducted a detailed investigation of the Coldwell Alkaline Complex, including its petrography and mineralization environments.

G.R. Edwards (Athabasca University, Athabasca, Alberta) and M.R. Stauffer (University of Saskatchewan, Saskatoon, Saskatchewan) investigated the structure and stratigraphy of Archean rocks in the Pipestone Lake area in northwestern Ontario. This study constitutes the continuation of a co-operative project of the 2 researchers and the Precambrian Geoscience Section, which was carried out in 1990.

F.D. Ford of Carleton University, Ottawa, carried out detailed stratigraphic/structural investigations of the Sunday Lake area in southeastern Ontario in conjunction with R.M. Easton's mapping of the Palmerston Lake area. The objective of these investigations is to review the stratigraphy and structural geology of Flinton Group rocks and to solve specific stratigraphic problems, such as the relationship of the "Ompah Conglomerate" with the Flinton Group.

R. Mussakowski of the Ontario Centre for Remote Sensing (Ministry of Natural Resources, Toronto) and N. Trowell of this Section conducted a remote sensing study of an area near Thunder Bay. Lineaments were interpreted from 3 data sources: Landsat Thematic Mapper, Airborne SAR Radar, and Digital Topographic Elevations Model. The authors demonstrated that comparison and integration of these data sets with each other provide a much better base for geological mapping than a single data set or aerial photography interpretation alone.

2. Project Unit 88–34. Geology of the MacDowell Lake–Trout Lake area, Northwest Ontario

D. Stone

Precambrian Geoscience Section, Ontario Geological Survey–Geoscience Branch, Sudbury

INTRODUCTION

The MacDowell Lake–Trout Lake area spans 10 000 km^2 of sparsely inhabited land northeast of Red Lake, Ontario. The geology of this area (Figure 2.1) is typical of the northwest Superior Province and comprises belts of complexly deformed supracrustal rocks (greenstone belts) separated by vast felsic plutonic areas.

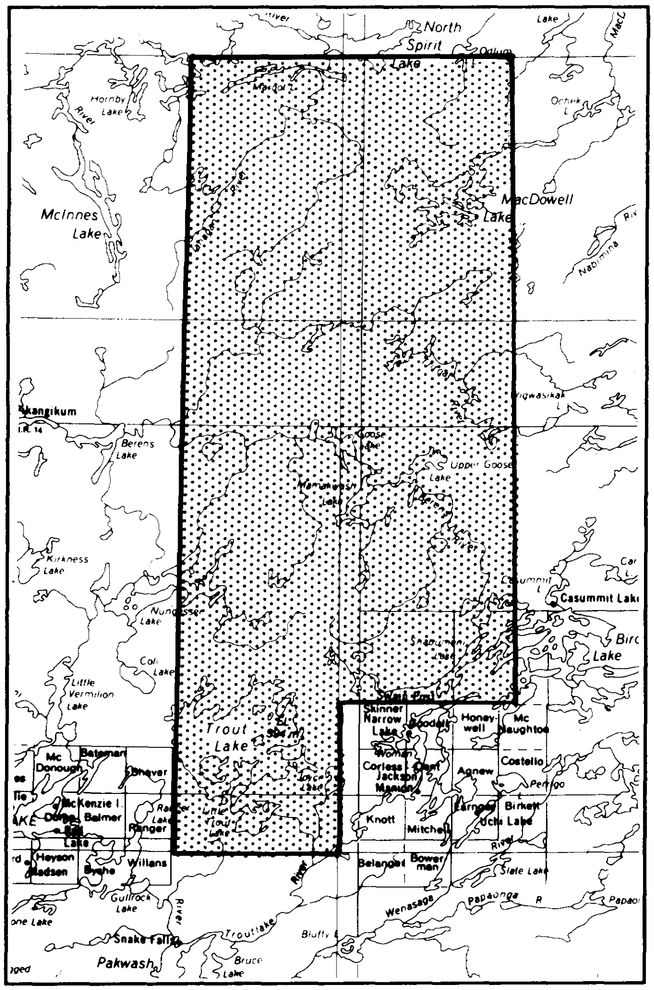

Figure 2.1. Location map, MacDowell Lake–Trout Lake area, scale 1:1 584 000.

The greenstone belts have been mapped in detail over the last few decades (e.g., Wood 1980; Thurston 1984) owing largely to their potential for economic mineral deposits, whereas felsic plutonic areas have had little attention. This disparity in the geologic data has hindered our understanding of crustal evolution and metallogeny in the Archean. Careful mapping of suites of felsic plutonic rocks, such as in the Winnipeg River Subprovince (Beakhouse 1991b), shows that multiple generations of felsic plutonic and gneissic rocks are typically present between greenstone belts. In places, the early felsic plutonic rocks have formed stable basement complexes for greenstone sequences (Thurston and Chivers 1990); elsewhere, emplacement of successive generations of felsic plutons together with deformation and metamorphism of their country rocks has profoundly affected the lithologic and structural character of the region and may have promoted gold mineralization (e.g., Andrews et al. 1986).

The present study is the continuation of mapping in felsic plutonic domains north of Red Lake and is focussed on the geology and structure of the area between the North Spirit Lake and Birch–Uchi greenstone belts. Data from this area provide a basis for refined models for evolution of both plutonic and supracrustal rocks, including the generation of mineral deposits in the Archean.

REGIONAL SETTING AND PREVIOUS WORK

The MacDowell Lake–Trout Lake area includes the North Spirit Lake greenstone belt, in the north, separated by extensive felsic plutonic rocks from the Birch–Uchi greenstone belt, in the south. This area spans parts of the Sachigo, Berens River and Uchi subprovinces that Card and Ciesielski (1986) distinguished on the basis of mainly volcanic and plutonic rocks (Sachigo and Uchi) or dominantly plutonic rocks (Berens River). Subprovinces are fault bounded in many places. The North Spirit Lake greenstone belt and plutonic rocks northeast of MacDowell Lake (Figure 2.2) are included within the Sachigo Subprovince. Plutonic rocks southwest of MacDowell Lake, in the Goose Lake area (Figure 2.3), and north of Trout Lake and Shabumeni Lake (Figure 2.4) make up the eastern Berens River Subprovince; the supracrustal and plutonic rocks lying south of Shabumeni and Trout Lakes are part of the Uchi Subprovince.

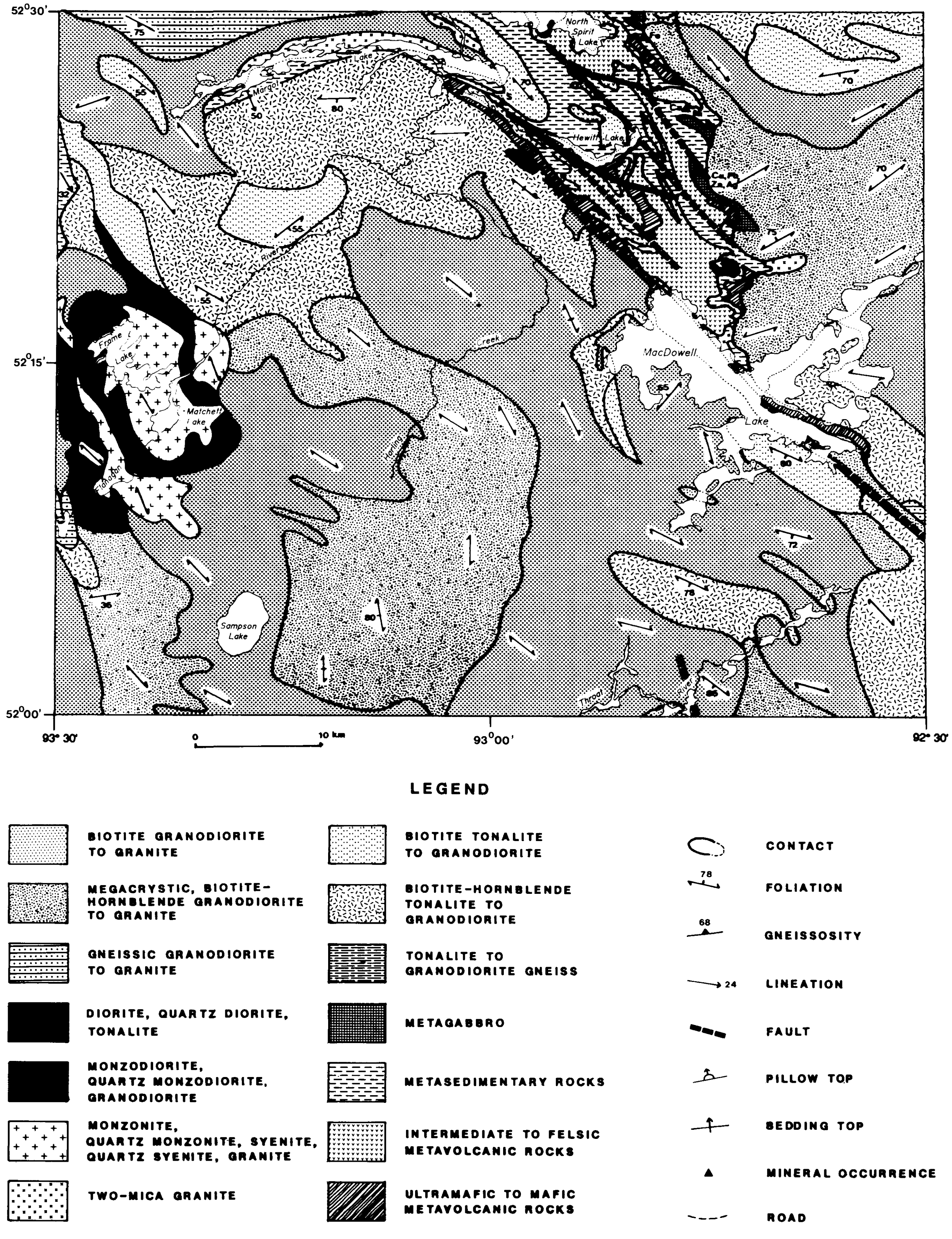

Figure 2.2. Geology of the MacDowell Lake area.

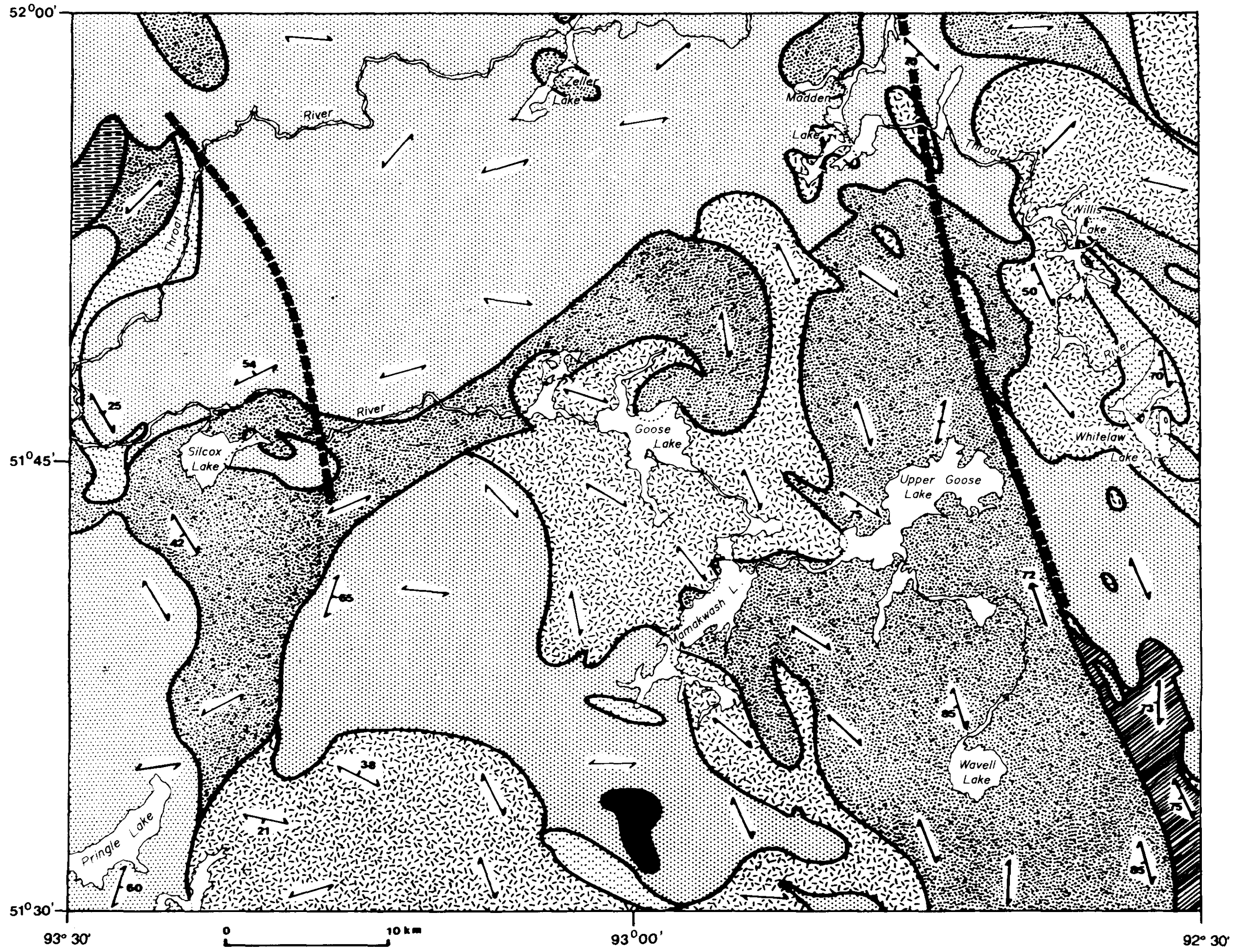

Figure 2.3. Geology of the Goose Lake area. *See* legend of Figure 2.2.

Thurston et al. (1991) noted that some volcanic rocks in the greenstone belts of the Sachigo Subprovince, including the North Spirit Lake greenstone belt and the northern rim of the Birch–Uchi greenstone belt, include pre-2800 million-year-old volcanic rocks in contrast with *circa* 2730 million-year-old volcanic rocks in the southwestern Superior Province. This and lack of a fault boundary between the Uchi and Berens River subprovinces prompted the above authors to group the Sachigo, Berens River and northern Uchi subprovinces into the newly defined North Caribou terrane that they regarded as an early microcontinent against which younger rocks such as those of the Pickle terrane (southern part of the Uchi Subprovince) were accreted.

Geologic mapping of the present area was initiated by Dowling (1896) who examined outcrops on the Berens River, Red Lake and Trout Lake and distinguished "Huronian schists and traps" at Red Lake and in the Shabumeni–Woman Lake area from plutonic rocks that were found at most other localities. Subsequent mapping focussed on these and other greenstone belts. Bateman (1939) examined the North Spirit Lake greenstone belt and Greig (1928), Bruce (1929), Furse (1934) and Bateman (1940) mapped parts of the Birch–Uchi greenstone belt. Subsequent reconnaissance surveys were made by Donaldson (1960), Donaldson and Jackson (1969), Davies et al. (1968) and Ayres et al. (1973).

The greenstone belts were remapped in recent decades and the latest data are incorporated here. Geology of the North Spirit Lake greenstone belt, shown in Figure 2.2, is compiled from maps by Wood (1977, 1980, 1988). Geology of the Birch–Uchi greenstone belt (*see* Figure 2.4) is compiled from maps by Beakhouse (1990, 1991a), Beakhouse and McNeil (1989), Beakhouse et al. (1989), Johns and Thurston (1977), Pryslak and Valliant (1977), Pryslak (1973, 1974, 1986) and Thurston (1984).

GENERAL GEOLOGY

Intrusive Rocks

Felsic plutonic rocks underlie approximately 90% of the MacDowell Lake–Trout Lake area. These are broadly grouped into gneissic, tonalitic, peraluminous, mafic and granitic suites whose major subdivisions and general characteristics including age determinations are summa-

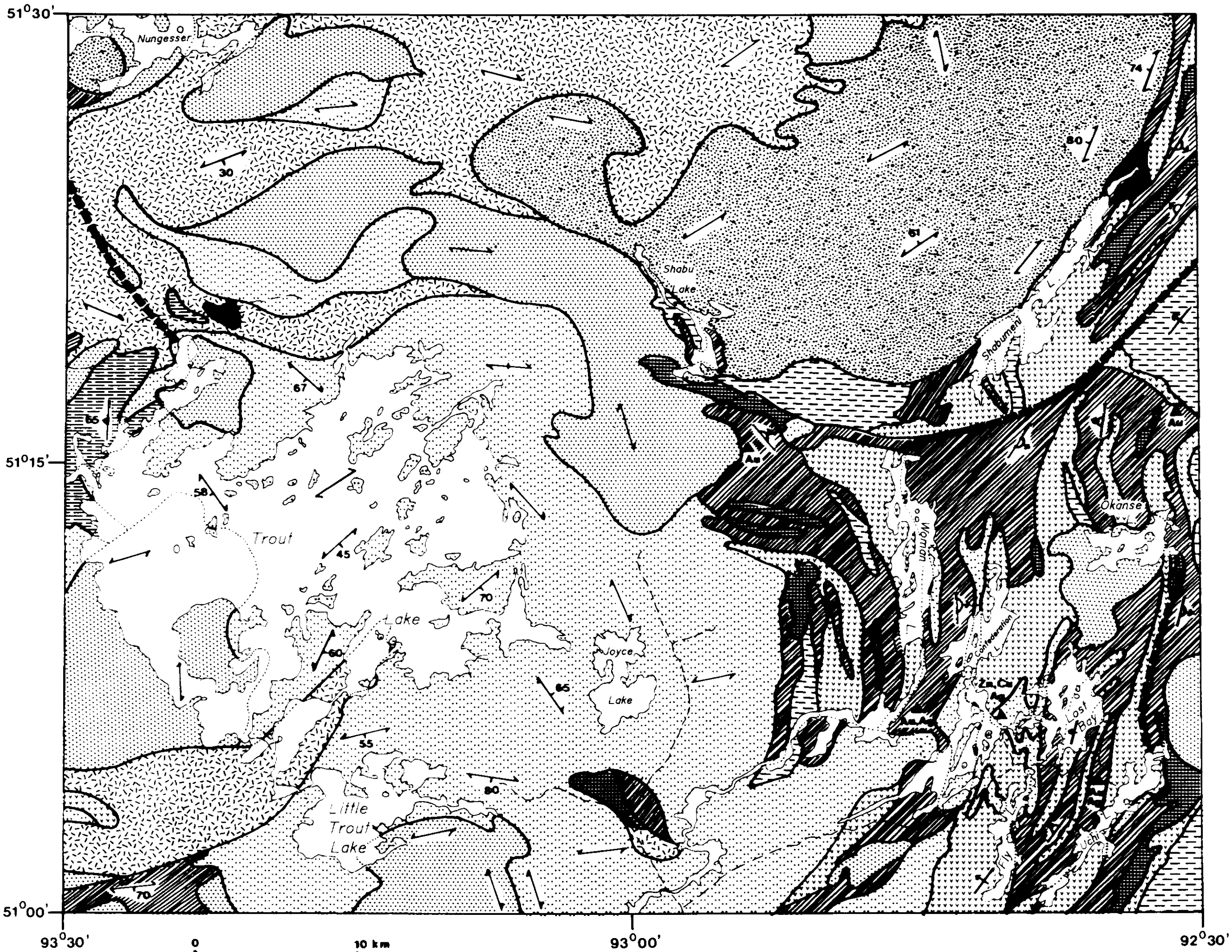

Figure 2.4. Geology of the Trout Lake area. *See* legend of Figure 2.2.

rized in Table 2.1. Beakhouse (1991b) and Breaks (1991) provided detailed descriptions of rocks from these suites in the Winnipeg River and English River subprovinces, respectively.

Biotite tonalite and gneissic rocks are among the oldest felsic plutonic rocks and are rare except for a large batholith at Trout Lake (*see* Figure 2.4). Biotite tonalite at Trout Lake is dated at 2838 Ma (Noble 1989) and has been intruded by most other suites of felsic plutonic rocks.

Hornblende tonalite to granodiorite is scattered throughout the area and typically occurs as irregular to variably tapered and bifurcated bodies invaded by lobes of younger granitic intrusions. Hornblende tonalite is dated at 2744 to 2731 Ma and marks the renewal of felsic plutonism 100 million years after the emplacement of the Trout Lake batholith. In many places, hornblende tonalite is transitional to hornblende-bearing, potassium feldspar megacrystic rocks of the granitic suite. Megacrystic granite is widely distributed and usually confined to large, irregular intrusions. A remarkably large crescentic body of megacrystic granite extends east from Shabu Lake to Shabumeni Lake (*see* Figure 2.4) and hence north through Wavell Lake to Upper Goose Lake (*see* Figure 2.3) and occupies a concave embayment in the northwest side of the Birch–Uchi greenstone belt.

Leucocratic biotite granite is the most voluminous felsic plutonic rock and occurs in a variety of forms ranging from large irregular bodies such as in the Throat River area (*see* Figures 2.2 and 2.3) to dikes and irregular masses that invade all other rocks. Large biotite granite bodies typically have gradational contacts and contain partly assimilated inclusions of tonalitic and supracrustal rocks.

Two–mica granites of the peraluminous suite are confined to small occurrences at the margins of the North Spirit Lake greenstone belt and a narrow arm extending west through Margot Lake (*see* Figure 2.2). Two–mica granites are closely associated with migmatized metasedimentary rocks from which they are probably derived by partial melting.

Several stocks and a pluton of quartz diorite have intruded felsic plutonic and supracrustal rocks at scattered localities. The largest of these at Frame Lake (*see*

Figure 2.2) is broadly oval to irregular in outline and compositionally zoned. Early quartz dioritic magma was succeeded by monzodiorite and megacrystic granite phases. Dated at 2696 Ma (Corfu and Ayres 1984), the Frame Lake pluton is the youngest major intrusion in the area. It is the subject of diploma research by M. Lange at the University of Münster, Germany.

Supracrustal Rocks

NORTH SPIRIT LAKE GREENSTONE BELT

The North Spirit Lake greenstone belt is elongate northwest for 40 km and attains a maximum width of about 17 km. Extremities of the belt are marked by narrow arms of highly metamorphosed supracrustal rocks that extend northwest of the present area to Favourable Lake, west through Margot Lake, southeast through MacDowell Lake and northeast of North Spirit Lake.

The North Spirit Lake greenstone belt is lithologically diverse and rich in intermediate to felsic volcanic and metasedimentary rocks. Donaldson and Ojakangas (1977) noted abundant quartz-rich beds in metasedimentary sequences and concluded that the sedimentary detritus must have been derived mainly from a felsic plutonic as opposed to volcanic protolith. Geochronologic work on detrital zircons and a tonalitic clast suggest an age of about 3000 Ma for some of the source material (Corfu and Wood 1986).

Thurston et al. (1991) divided the North Spirit Lake greenstone belt into 6 assemblages based on mapping and geochronology. These include 3023 million-year-old arc volcanic rocks at North Spirit Lake followed by 2986 to 2900 million-year-old arc and platform sequences including ultramafic flows and iron formation in the northeast part of the belt. These are unconformably overlain by alluvial fan deposits of uncertain age and late arc and alkalic volcanic rocks dated at about 2735 Ma. The youngest arc and alluvial fan sequences account for most of the North Spirit Lake greenstone belt and are disrupted by northwest-striking faults.

BIRCH–UCHI GREENSTONE BELT

The Birch–Uchi greenstone belt is one of the largest greenstone belts in the western Superior Province and composes the central segment of the Uchi Subprovince, which includes a chain of greenstone belts that extend several hundred kilometres east from Lake Winnipeg to Fort Hope. Thurston (1986) and Stott and Corfu (1991) divided the Birch–Uchi greenstone belt into 3 assemblages. These include the 2959 million-year-old Balmer assemblage, which comprises a mafic to felsic volcanic cycle occupying a crescentic area west of Woman Lake and intruded by the Trout Lake batholith (*see* Figure 2.4). The 2840 million-year-old Woman assemblage is made up of mafic to felsic volcanic rocks commonly capped by chemical and tuffaceous metasedimentary rocks. This assemblage occupies the northwest margin of the Birch–Uchi greenstone belt at Shabumeni Lake and extends south through Woman Lake. The Confederation assemblage of approximately 2735 million year age consists of several mafic to felsic volcanic cycles and, together with interleaved wacke and mudstone sequences, underlies central and southeast parts of the Birch–Uchi greenstone belt (*see* Figure 2.4).

STRUCTURE AND METAMORPHISM

Structural trends defined by foliations, gneissosity and lithologic contacts are variable, but are mainly north to northwest in greenstone belts and felsic plutonic areas. Foliations tend to be more strongly developed in older tonalitic rocks than in younger granitic intrusions and locally follow curved trajectories maintaining general parallelism with adjacent boundaries of intrusions.

Strata within greenstone belts are transposed and distorted and show variable intensity of cleavage development. Cores of greenstone belts are typically metamorphosed to greenschist facies; metamorphic grade increases to amphibolite facies and rocks become schistose and strained at the belt margins. Assemblages of garnet + biotite + andalusite + plagioclase + quartz and garnet + biotite + sillimanite + plagioclase + quartz occur in metasedimentary rocks at Margot Lake and northwest of Frame Lake, respectively (*see* Figure 2.2).

Local younging directions derived from pillows and graded beds have been used to define fold axes in greenstone belts (e.g., Thurston 1984). Assemblage boundaries constitute major structural features in greenstone belts, but tend to be poorly exposed. These may be either unconformities, disconformities or faults.

Several faults marked by north-northwest-trending zones of mylonite are mapped in felsic plutonic areas. Examples occur north of Trout Lake (*see* Figure 2.4), east of Silcox Lake and east of Upper Goose Lake (*see* Figure 2.3), however, little is known of the amount and sense of displacement.

Two–mica granite and megacrystic granite show protomylonitic textures along the southwest side of the North Spirit Lake greenstone belt at MacDowell Lake (*see* Figure 2.2). This fault could not be traced through the Margot Lake area and evidently does not connect with the Bear Head fault zone, which extends northwest of North Spirit Lake (*see* discussion by Stone 1990).

DISCUSSION

Geochronology indicates at least 3 major episodes of felsic plutonism at about 3000 Ma, 2840 Ma and 2744 to 2696 Ma. Mainly biotite tonalite and possibly tonalite gneiss were intruded during the early episodes of plutonism; whereas, the latter episodes involved several types of magma that began with hornblende tonalite succeeded by megacrystic granite and leucocratic biotite granite followed by plutons of the mafic suite.

Table 2.1. Characteristics of predominant felsic plutonic and gneissic rocks in the Berens River Subprovince; rock names after Streckeisen (1976). Map unit number refers to legend of 1:50 000 scale map to be produced by the present survey of the MacDowell Lake–Trout Lake area.

Rock Type	Map Unit No.	Colour	Grain Size	Fabric	% Mafic Minerals	Form	Age* (Ma)
Granitic Suite							
Biotite granodiorite to granite	15a	pink to white	variable, usually coarse	massive; has assimilated inclusions of older rocks	<15	large oval to lobate batholiths; irregular intrusions; dikes	2715 to 2697 (a, b)
K-feldspar megacrystic, biotite-hornblende granodiorite to granite	15c	pink to white to grey	coarse	weakly foliated; megacrystic	5 to 15	irregular intrusions; inclusions in 15a	2717 (c)
Mafic Suite							
Biotite-amphibole-pyroxene diorite, quartz diorite, tonalite; monzodiorite, quartz monzodiorite, granodiorite; monzonite, quartz monzonite, syenite, quartz syenite, granite	14	grey to pink to red	mainly medium to coarse	massive to weak magmatic layering; inequigranular; mafic clots	variable	oval plutons	2696, 2769 (b)
Peraluminous (S-type) Suite							
Two-mica granodiorite to granite (accessory garnet, cordierite, tourmaline, apatite)	13	white to pink	coarse to pegmatitic	massive; mylonitic	<10	elongate intrusions; dikes; with sedimentary rocks	–
Tonalitic Suite							
Biotite tonalite to granodiorite	12a	white to grey	fine to coarse	foliated to gneissic; quartz and feldspar megacrystic	5 to 15	irregular to crescentic and lobate bodies; inclusions in 15a and 12b	–
Biotite-hornblende tonalite to granodiorite (grades to quartz diorite)	12b	grey to white	coarse	foliated; granular; feldspar megacrystic; mafic clots	10 to 30	irregular bodies of variable size; inclusions in 15a	2731, 2744 (c, d)
Gneissic Suite							
Gneissic hornblende-biotite granodiorite to granite	15g	white to pink to grey	variable, mainly fine to medium	layered, folded, cut by dikes and masses of 15a	5 to 20	belts irregular masses	–
Biotite tonalite to granodiorite gneiss	11a	grey to white	variable between layers	foliated; folded; short discontinous layers	<15	belts; inclusions in units 15 and 12	–
Hornblende-biotite (mafic) tonalite to granodiorite gneiss	11b	grey to dark grey	variable between layers	foliated; folded; mafic inclusions; pronounced and continous layers	>15	belts; inclusions in units 15 and 12	–

* Age determinations are by the U/Pb method; errors are less ± 8 Ma except for the monzite age of 2769 $^{+63}_{-26}$ Ma.

a) Ermanovics and Wanless (1983)
b) Corfu and Ayres (1984)
c) Corfu and Andrews (1987)
d) Corfu and Wood (1986)

Evidence for the earliest plutonism is scarce and consists of tonalite cobbles in the North Spirit Lake greenstone belt. Isolated fragments of biotite tonalite situated at scattered localities around the belt (*see* Figure 2.2) are not dated, but could be remnants of the parent body from which the cobbles were eroded. The biotite tonalite fragments may also be remnants of early sialic basement on which platform sequences were deposited.

Plutonism of intermediate age is represented by the Trout Lake batholith (*see* Figure 2.4) that was emplaced approximately synchronous with volcanic rocks of the Woman assemblage. Although the Trout Lake batholith is large, there are few other biotite tonalite bodies in the area (*see*, for example, Figure 2.3). This implies that the 2 early generations of biotite tonalite were not extensive or else that some process has consumed the tonalitic rocks.

As might be expected, rocks emplaced during the youngest episode of plutonism are well preserved and voluminous. These provide a valuable record of deformation caused by intrusion of successive felsic magmas. For example, hornblende tonalite, which was emplaced at an early stage of the youngest plutonic episode, is foliated and recrystallized and hornblende is partly altered to biotite. Hornblende tonalite bodies have been invaded, dissected and compressed into variably curved and bifurcated belt-like shapes by intrusion, spreading and contact metamorphism of younger granite. The granitic rocks, particularly biotite granite, tend to be weakly foliated and are relatively unaltered with nonrecrystallized textures, such as irregular quartz grains with undulose extinction. Evidently, the youngest granitic bodies have distorted and recrystallized the older plutonic rocks, but have not been greatly deformed or metamorphosed themselves.

Greenstone belts have also been invaded by stocks, such as at Okanse Lake (*see* Figure 2.4) and external bodies that form concave embayments in the sides, for example, the large crescentic body of megacrystic granite in the Shabu–Shabumeni–Upper Goose lakes area (*see* Figures 2.3 and 2.4). This body is sufficiently large enough that it could have displaced overlying supracrustal rocks several tens of kilometres laterally by mechanisms of gravity sliding to form the large oval indentation in the side of the Birch–Uchi greenstone belt. The macroscopic shortening of the supracrustal strata would have caused massive internal deformation such as folding and reverse faulting. Fluid circulation through fracture zones developed at this time has been proposed as a probable source of gold mineralization in the Red Lake greenstone belt (Andrews et al. 1986).

The data suggest that emplacement of multiple phases of felsic magmas played a significant role in Archean crustal evolution of the MacDowell Lake–Trout Lake area. Each succeeding intrusion caused further assimilation and metamorphism and contributed to greater finite distortion of country rocks—both plutonic and supracrustal alike. In this way, the oldest rocks tend to have become progressively more deformed and obliterated.

MINERAL EXPLORATION AND ECONOMIC GEOLOGY

Previous mineral exploration has been concentrated in the greenstone belts. The North Spirit Lake greenstone belt was prospected for gold in the 1930s and several small showings were found in quartz diorite and metasedimentary rocks such as near Bijou Point on the shores of North Spirit Lake. Extensive banded iron formation on the northeast side of the belt was explored by several companies from 1953 to 1970. In 1977, Cominco Limited flew an airborne magnetic survey of the belt, and ground geophysical, geologic and geochemical surveys and drilling by a variety of companies ensued. Most exploration was directed at gold and base metal mineralization in mafic to ultramafic volcanic rocks and metasedimentary rocks on the east side of the belt (assessment files, Resident Geologist's office, Red Lake).

Prospecting in the Birch–Uchi greenstone belt began a year after the discovery of gold at Red Lake in 1925. By the mid-1930s, numerous gold properties were established, some of which became small mines. A total of 247422 ounces Au and 42994 ounces Ag were produced by 9 mines from 1928 to 1966 (Parker and Atkinson 1992).

The South Bay copper-zinc-silver massive sulphide deposit was discovered by Selco Exploration Company in felsic volcanic rocks at Confederation Lake and produced 1.6 million tons of ore from 1971 to 1981. The Birch–Uchi greenstone belt was extensively explored for base and precious metals in the 1980s. Detailed summaries of exploration work are given in a series of unpublished geologic data inventory folios at the Resident Geologist's office, Red Lake.

Dome Exploration (Canada) Limited, in 1979 to 1980, did an airborne magnetic survey, ground geophysical surveys and drilling on a series of anomalies along the fault zone extending between Trout Lake and Nungesser Lake (*see* Figure 2.4). Ground geophysical surveys and drilling were done mainly since 1979 by several companies on mafic metavolcanic rocks southwest of Trout Lake.

Few base and precious metal occurrences have been identified in felsic plutonic areas. Known base metal occurrences are typically associated with sodium-depleted and altered felsic metavolcanic and metasedimentary rocks in the Confederation assemblage of the Birch–Uchi greenstone belt. The Hewitt assemblage (Thurston et al. 1991), which underlies most of the western North Spirit Lake greenstone belt, has a comparable geology and age to the Confederation assemblage and is recommended for base metal exploration. Fracture-controlled, porphyry-type copper-molybdenum mineralization, such as occurs in the Setting Net Lake stock of the Favourable Lake greenstone belt (Ayres 1970), may be associated with stocks intruding the North Spirit Lake and Birch–Uchi greenstone belts.

Most of the past gold production has come from small deposits associated with deformed quartz vein systems in metavolcanic and metasedimentary rocks of the Woman assemblage (Parker and Atkinson 1992). The older mafic to ultramafic rocks characterized by iron carbonate alteration and silicification host the Campbell–Dickenson orebodies in the Red Lake greenstone belt. Similar types of mineralization should be sought in the Balmer and Woman assemblages of the Birch–Uchi greenstone belt and in mafic to ultramafic sequences of the North Spirit Lake greenstone belt. Alkalic rocks east of the present area at Springpole Lake in the Birch–Uchi greenstone belt are mineralized with gold and have been extensively explored (Parker and Atkinson 1992). Rocks of similar composition occur in the vicinity of the diorite body at Bijou Point of North Spirit Lake (*see* Figure 2.2). The sheared zone of felsic plutonic rocks extending from the north end of the Birch–Uchi greenstone belt at Upper Goose Lake (*see* Figure 2.3) is a potential source of shear-zone hosted gold mineralization.

Pegmatitic dikes in two-mica granite at the margins of the North Spirit Lake greenstone belt can be mineralized with rare metals such as lithium and beryllium. Occurrences of these rare metals are situated within two-mica granite units extending northwest of the present area (Stone 1990).

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REFERENCES

Andrews, A.J., Hugon, H., Durocher, M., Corfu, F. and Lavigne, M.J. 1986. The anatomy of a gold-bearing greenstone belt: Red Lake, northwestern Ontario, Canada; *in* Proceedings of Gold '86, an International Symposium on the Geology of Gold Deposits, Konsult International Inc., Toronto, p.3–22.

Ayres, L.D. 1970. Setting Net Lake area; Ontario Department of Mines, Preliminary Map P.538, scale 1:15 840.

Ayres, L.D., Raudsepp, M., Averill, S.A. and Edwards, G.R. 1973. Favourable Lake–Berens Lake, Kenora District; Ontario Division of Mines, Map 2262, scale 1:253 440.

Bateman, J.D. 1939. Geology of the North Spirit Lake area; Ontario Department of Mines, Annual Report, 1938, v.47, pt. 7, p.44–78.

——— 1940. Geology and gold deposits of the Uchi–Slate lakes area; Ontario Department of Mines, Annual Report, 1939, v.48, pt.8, p.1–43.

Beakhouse, G.P. 1990. Geology of the Casummit Lake area, District of Kenora (Patricia Portion); *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.18–21.

——— 1991a. Geology of the Casummit Lake area, District of Kenora (Patricia Portion); *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p. 13–15.

——— 1991b. Winnipeg River Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.279–301.

Beakhouse, G.P., Forsyth, D.M., Scott, K.V. and Wallace, H. 1989. Precambrian geology of the western Birch Lake area, southern half, District of Kenora, Patricia Portion; Ontario Geological Survey, Map P.3118, scale 1:15 840.

Beakhouse, G.P. and McNeil, A.M. 1989. Precambrian geology of the western Birch Lake area, northern half, District of Kenora (Patricia Portion); Ontario Geological Survey, Map P.3117, scale 1:15 840.

Breaks, F.W. 1991. English River Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.239–277.

Bruce, E.L. 1929. Gold deposits of the Woman, Narrow and Confederation lakes, District of Kenora (Patricia Portion); Ontario Department of Mines, v.37, p.1–51.

Card, K.D. and Ciesielski, A. 1986. DNAG #1. Subdivisions of the Superior Province of the Canadian Shield; Geoscience Canada, v.13, p.5–13.

Corfu, F. and Andrews, A.J. 1987. Geochronological constraints on the timing of magmatism, deformation and gold mineralization in the Red Lake greenstone belt, northwestern Ontario; Canadian Journal of Earth Sciences, v.24, p.1302–1320.

Corfu, F. and Ayres, L.D. 1984. U–Pb age and genetic significance of heterogeneous zircon populations in rocks from the Favourable Lake area, northwestern Ontario; Contributions to Mineralogy and Petrology, v.88, p.86–101.

Corfu, F. and Wood, J. 1986. U–Pb zircon ages in supracrustal and plutonic rocks, North Spirit Lake area, northwestern Ontario; Canadian Journal of Earth Sciences, v.23, p.967–977.

Davies, J.C., Pryslak, A.P., Ferguson, S.A. and Brown, D.D. 1968. Red Lake–Birch Lake sheet, Kenora District; Ontario Department of Mines, Map 2175, scale 1:253 440.

Donaldson, J.A. 1960. Geology North Spirit Lake, Kenora District, Ontario; Geological Survey of Canada, Map 50–1960, scale 1:253 440.

Donaldson, J.A. and Jackson, G.D. 1969. Geology Trout Lake, Ontario; Geological Survey of Canada, Map 1200A, scale 1:253 440.

Donaldson, J.A. and Ojakangas, R.W. 1977. Orthoquartzite pebbles in Archean conglomerate, North Spirit Lake, northwestern Ontario; Canadian Journal of Earth Sciences, v.14, p.1980–1990.

Dowling, D.B. 1896. Report on the country in the vicinity of Red Lake and part of the basin of Berens River, Keewatin; Geological Survey of Canada, v.7, pt.F, 54p.

Ermanovics, I.F. and Wanless, R.K. 1983. Isotopic age studies and tectonic interpretation of Superior Province in Manitoba; Geological Survey of Canada, Paper 82–12, 22p.

Furse, G.D. 1934. Geology of the Shabumeni–Birch lakes area; Ontario Department of Mines, v.42, p.21–58.

Greig, J.W. 1928. Woman and Narrow lakes area, District of Kenora (Patricia Portion); Ontario Department of Mines, v.36, p.85–110.

Johns, G.W. and Thurston, P.C. 1977. Honeywell and McNaughton townships, Kenora District; Ontario Geological Survey, Map 2404, scale 1:31 680.

Noble, S.R. 1989. Geology, geochemistry and isotope geology of the Trout Lake batholith and the Uchi–Confederation lakes greenstone belt, northwestern Ontario; unpublished PhD thesis, University of Toronto, Toronto, Ontario, 289p.

Parker, J.R. and Atkinson, B.T. 1992. Gold occurrences, prospects and past–producing mines of the Birch–Confederation Lakes area; Ontario Geological Survey, Open File Report 5835, 332p.

Pryslak, A.P. 1973. Shabumeni River–Narrow Lake area, District of Kenora (Patricia Portion); Ontario Division of Mines, Map P.901, scale 1:15 840.

——— 1974. Shabumeni River–Narrow Lake area, (Northwestern Part), District of Kenora (Patricia Portion); Ontario Division of Mines, Map P.973, scale 1:15 840.

——— 1986. Skinner Township, District of Kenora; Ontario Geological Survey, Map P.2953, scale 1:15 840.

Pryslak, A.P. and Valliant, W.W. 1977. Goodall Township, District of Kenora (Patricia Portion); Ontario Geological Survey, Map P.1216, scale 1:15 840.

Stone, D. 1990. Geology of the Red Lake and Varveclay–Favourable–Whiteloon areas, northwestern Ontario; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.5–17.

Stott, G.M. and Corfu, F. 1991. Uchi Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.145–236.

Streckeisen, A. 1976. To each plutonic rock its proper name; Earth Science Reviews, v.12, p.1–33.

Thurston, P.C. 1984. Confederation Lake, Precambrian Geology; Ontario Geological Survey, Map 2498, scale 1:50 000.

——— 1986. Volcanic cyclicity in mineral exploration; the caldera cycle and zoned magma chambers; *in* Volcanology and mineral deposits, Ontario Geological Survey, Miscellaneous Paper 129, p.104–123.

Thurston, P.C. and Chivers, K.M. 1990. Secular variation in greenstone sequence development emphasizing Superior Province, Canada; Precambrian Research, v.46, p.21–58.

Thurston, P.C., Osmani. I.A. and Stone, D. 1991. Northwestern Superior Province: review and terrane analysis; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.81–142.

Wood, J. 1977. Geology of North Spirit Lake area, District of Kenora (Patricia Portion); Ontario Division of Mines, Geoscience Report 150, 60p.

———1980. Geology of the Hewitt Lake area, District of Kenora, Patricia Portion; Ontario Geological Survey, Report 186, 122p.

———1988. Geology of the MacDowell Lake area, District of Kenora, Patricia Portion; Ontario Geological Survey, Report 261, 52p.

3. Project Unit 89–72. Stratigraphy and Sedimentation of the Metasedimentary Rocks of the Grenville Supergroup in Southeastern Ontario

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INTRODUCTION

Since the middle of the 19th century, the carbonate rocks of the Grenville Province in Ontario have contributed to the mineral production of Ontario. Iron was one of the earliest metals produced from marble-hosted deposits of the Grenville. In addition, graphite, copper, zinc, mica, talc, marble for building stone, and marble for lime production has come from Grenville marbles (Hewitt and Vos 1972; Storey and Vos 1981a, 1981b; Carter 1984; Malczak et al. 1985).

Mineral production from the clastic metasedimentary rocks has consisted mainly of pyrite for production of sulphur/sulphuric acid from stratabound, sedimentary-hosted lenses of pyrite such as those of the Blakely, the Canadian Sulphur Ore Company, and the Bannockburn Pyrite mines in Madoc Township, and the Hungerford Mine and Ontario Sulphur Mine northeast of Tweed, Hungerford Township (Malczak et al. 1985).

Several other sulphide-bearing prospects and occurrences are hosted by clastic and carbonate metasediments, frequently in association with volcanic rocks (Carter 1984; Malczak et al. 1985).

The author started a detailed (1:5000) mapping program in the metasedimentary rocks of the Madoc–Havelock area in order to determine if stratigraphic and sedimentation studies are possible in these metamorphosed and deformed rocks, so as to get a better understanding of the setting of the known mineralization and to provide possible leads to additional mineralization (Meyn 1988, 1989, 1990, 1991).

In 1992, detailed mapping (1:5000) was carried out in the area northeast of Belmont Lake, Belmont Township, Peterborough County (Figure 3.1).

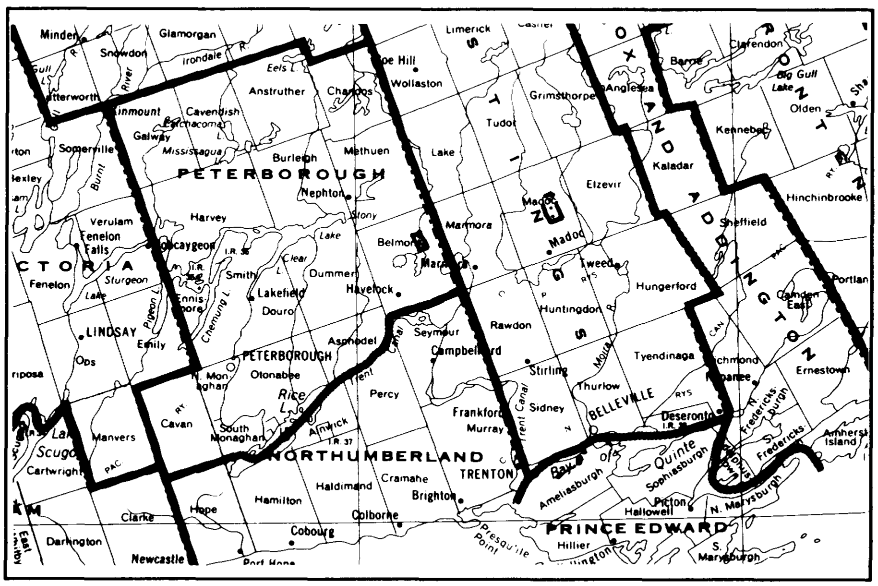

Figure 3.1. Location of the study area, scale 1:1 584 000.

GENERAL GEOLOGY

Little detailed work has been done on sedimentary rocks, in general, or the marbles in particular, in the Central Metasedimentary Belt of the Grenville Province in Ontario. Among the earliest workers were Adams and Barlow (1910), who recognized amphibolite layers in marble as metasediments and Miller and Knight (1914), who synthesized the Precambrian geology of Southeastern Ontario. A more general overview of the local and regional metasedimentary geology is given by Lumbers (1964) and Hewitt (1968).

This summer's field work was concentrated in Belmont Township, generally east of Belmont Lake. Immediately east of Belmont Lake north of the Crowe River exit there is a considerably greater thickness of clastic siliceous metasedimentary rocks exposed than is shown by Bartlett et al. (1982).

Bartlett and Moore (1985, p.53) define the Belmont Lake formation as follows: "Named for its areal restriction to the east shore and some islands of Belmont Lake, this formation comprises polymictic granule to cobble (rarely boulder) conglomerate with subordinate sandstone, mudstone, and dolomitic marble." Bartlett et al. (1982) have included most of the islands in Belmont Lake and some of the east shore in Unit 9 — Clastic Metasediments — of their map legend. It would seem safe to assume that Unit 9 constitutes the Belmont Lake formation. However, some other siliciclastic rocks, also on the northeast shore of Belmont Lake, were assigned by Bartlett et al. (1982) to Unit 6 — Siliceous Clastic Metasediments — on their map. The author found no clear break either along or across strike between the rocks of units 6 and 9 near the northeastern shore of Belmont Lake.

Further northeast away from Belmont Lake, a sequence of grey calcitic marbles is present between the rocks tentatively assigned to the Belmont Lake formation and additional clastic siliceous metasediments, and stromatolite-bearing dolomitic marble. Should the intervening marble and the additional clastic metasediments be assigned to the Belmont Lake formation? The definition of the Belmont Lake formation will probably need to be revised to accommodate the new information.

Further east, near the village of Cordova Mines, a sequence of problematic rocks is exposed. Bartlett et al. (1982) place them in their Unit 5 — Lithic Clastic Sediments — suggesting that these are older than the Belmont Lake formation — Unit 9. DeKemp (1984) labels the majority of these rocks metarhyolite (agglomerate and flow breccia). The author found that there are definite intrusive rocks, and definite metasedimentary rocks, and probably felsic extrusive rocks as well. Exposure is not good enough to get a clear picture of the physical and genetic relationships of these rocks.

A very prominent feature of this group of rocks are beds of fragmental rocks. The predominant (near 80%) clast lithology is pink-weathering felsic volcanic (rhyolite?) material. Other lithologies present are mafic volcanic, magnetite, pink chert, black chert, and vein quartz. The pink clasts are generally well rounded to subrounded. Some subangular to subrounded clasts are present, but most of them belong to the other lithologies.

Also prominent are bright green patches of epidote in this rock. Most of the epidote occurs as alteration of the centres of pink clasts; some of it occurs as patches in the finer grained material (matrix?).

In places, the rock is bright red because of the presence of bright red chert (jasper). In the zones of high jasper content, the jasper clasts seem to be jagged fragments of former reasonably rounded clasts.

Another group of rocks whose history is not fully understood occurs east of County Road 48 and north of the Crowe River. A typical outcrop of this rock contains some well-bedded rocks that look like reasonably good metasediments while other parts are quite massive, and look intrusive. All of these rocks are very heavy and it turns out they are almost pure garnet.

Both of the above problematic rock sequences are close to the Cordova Gabbro which is intrusive into the sedimentary sequence under study. Subsurface extensions of the gabbro underneath the present exposure may be responsible for the metamorphic and metasomatic effects that have altered these rocks, presumably mostly sediments, beyond easy recognition.

STRUCTURAL GEOLOGY

Just north of Belmont Lake, the base of the sedimentary sequence is a major fault. In the area away from the fault, faulting and folding is subdued but the sedimentary sequence is faulted in fault blocks, none of which extend more than a few hundred metres in any direction. The structural deformation coupled with the small and overgrown outcrops in the bush makes stratigraphic correlation difficult throughout the area.

ECONOMIC GEOLOGY

Mineral production from the metasedimentary rocks of Belmont Township is predominantly iron from skarn deposits in carbonate metasediments associated with several different intrusions. In the area mapped, the prominent iron deposit is that of the Belmont–Ledyard iron mine in Lot 19, Concession I, Belmont Township. This mine saw production in 1899 and 1900, and again from 1911–1913. The property was last examined in 1970 (MNDM files, Bancroft).

Also associated with the contact metamorphic halo of the Cordova Gabbro is the development of talc mineralization (LeBaron and van Haaften 1989).

There are numerous shallow exploration pits present in many parts of the field area. There is no record of most of these in the government's files, but all those encountered are plotted on the map.

REFERENCES

Adams, F.D. and Barlow, A.E. 1910. Geology of the Haliburton and Bancroft areas, Province of Ontario; Geological Survey of Canada, Memoir No. 6, 419p.

Bartlett, J.R., Moore, J.M., Jr. and Murray, M.J. 1982. Precambrian geology of Belmont and Southern Methuen townships, southern Ontario; Ontario Geological Survey, Preliminary Map P.2488, scale 1:15 840.

Bartlett, J.R. and Moore, J.M., Jr. 1985. Geology of Belmont, Marmora, and southern Methuen townships, Peterborough and Hastings counties; Ontario Geological Survey, Open File Report 5537, 236p.

Carter, T.R. 1984. Metallogeny of the Grenville Province, southeastern Ontario; Ontario Geological Survey, Open File Report 5515, 422p.

deKemp, E.A. 1984. Geology of the Belmont Lake meta-carbonate complex and the development of the thermal aureole of the Cordova metagabbro, NE Belmont Twp. Ontario; unpublished BSc thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 121p.

Hewitt, D.F. 1968. Geology of Madoc Township and the north part of Huntingdon Township; Ontario Department of Mines, Geological Report 73, 45p.

Hewitt, D.F. and Vos, M.A. 1972. The limestone industries of Ontario; Ontario Division of Mines, Industrial Mineral Report 39, 79p.

LeBaron, P.S. and van Haaften, S. 1989. Talc in southeastern Ontario; Ministry of Northern Development and Mines, Open File Report 5714, 240p.

Lumbers, S.B. 1964. Preliminary report on the relationship of mineral deposits to intrusive rocks and metamorphism in part of the Grenville Province of southeastern Ontario; Ontario Department of Mines, Preliminary Report 1964–4, 37p.

Malczak, J., Carter, T.R. and Springer, J.S. 1985. Base Metal, molybdenum, and precious metal deposits of the Madoc–Sharbot Lake area, southeastern Ontario; Ontario Geological Survey, Open File Report 5548, 374p.

Meyn, H.D. 1988. Stratigraphy and sedimentation of marbles and associated metasedimentary rocks of the Grenville Supergroup in southeastern Ontario; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.339–341.

——— 1989. Stratigraphy and sedimentation of the metasedimentary rocks of the Grenville Supergroup in southeastern Ontario; *in* Summary of Field Work and Other Activities 1989, Ontario Geological Survey, Miscellaneous Paper 146, p.176–179.

——— 1990. Stratigraphy and sedimentation of the metasedimentary rocks of the Grenville Supergroup in southeastern Ontario; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.135–139.

———1991. Stratigraphy and sedimentation of the metasedimentary rocks of the Grenville Supergroup in southeastern Ontario; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.123–125.

Miller, W.G. and Knight, C.W. 1914. The Pre-Cambrian geology of southeastern Ontario; Ontario Bureau of Mines, Annual Report, 1914, v.XXII, pt.II, 151p.

Storey, C.C. and Vos, M.A. 1981a. Industrial minerals of the Pembroke–Renfrew area, part 1: Marble; Ontario Geological Survey, Mineral Deposits Circular 21, 132p.

———1981b. Industrial minerals of the Pembroke–Renfrew area, part 2; Ontario Geological Survey, Industrial Minerals Circular 22, 214p.

4. Project Unit 91–04. Geology of the Dixie Lake Area

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INTRODUCTION

The Dixie Lake area was mapped this summer to evaluate the southwestern extension of the Birch Lake–Uchi Lake greenstone belt. Previous reconnaissance mapping indicated that the belt has been attenuated and thermally metamorphosed between a number of batholiths. Parts of the map area underlain by supracrustal rocks were mapped at a scale of 1:15 840, whereas areas underlain by granitoid rocks were mapped at a scale of about 1:50 000.

LOCATION

The Dixie Lake area is centred about 23 km south-southeast of Red Lake. The area, which encompasses 700 km^2, is bounded by latitudes 50°45'N and 50°56'N, and by longitudes 93°30'W and 94°00'W (Figure 4.1). Highway 105, which connects Red Lake with Vermilion Bay on the Trans-Canada Highway (Highway 17) to the south, traverses the northeastern part of the map area. Gullrock Lake, part of the Red Lake drainage system, and Pakwash Lake, part of the English River drainage system, lie partly in the northeastern and southeastern parts of the map area, respectively.

The eastern third of the area is characterized by extensive Quaternary glaciofluvial deposits, commonly on the order of 5 to 50 m thick. The western half of the area is characterized by well-exposed knolls or outcrop areas separated by sizeable areas of glacial cover. A system of logging roads provides access to the central and northeastern parts of the map area. A large forest fire in 1980 ravaged much of the western and central parts of the area. Moderate to large-scale, extensive wind damage (blowdown) to forested areas not affected by the above-mentioned fire occurred in the southern two-thirds of the map area during the summer of 1991 and, to a much lesser extent, the spring of 1992. Subsequent logging to harvest this blowdown has occurred in a few places in the map area and has locally aided access. Access to the western third and southeastern part of the map area is poor.

GENERAL GEOLOGY

The map area has previously received sparse detailed mapping because of thick glacial cover and lack of access, partly alleviated at present by the presence of logging roads. A detailed map (1:15 840) of the area immediately to the east of the map area, which included the Griffith iron mine, was released by Shklanka (1970). Reconnaissance mapping of the general area was undertaken in 1974 (Breaks et al. 1975), followed by a compilation map (Breaks et al. 1978), and further compilation

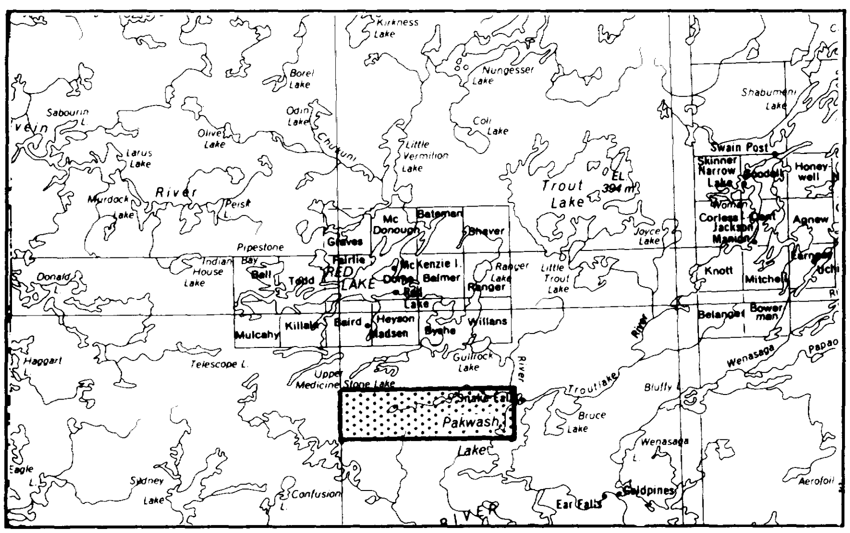

Figure 4.1. Location of the Dixie Lake area, scale 1:1 584 000.

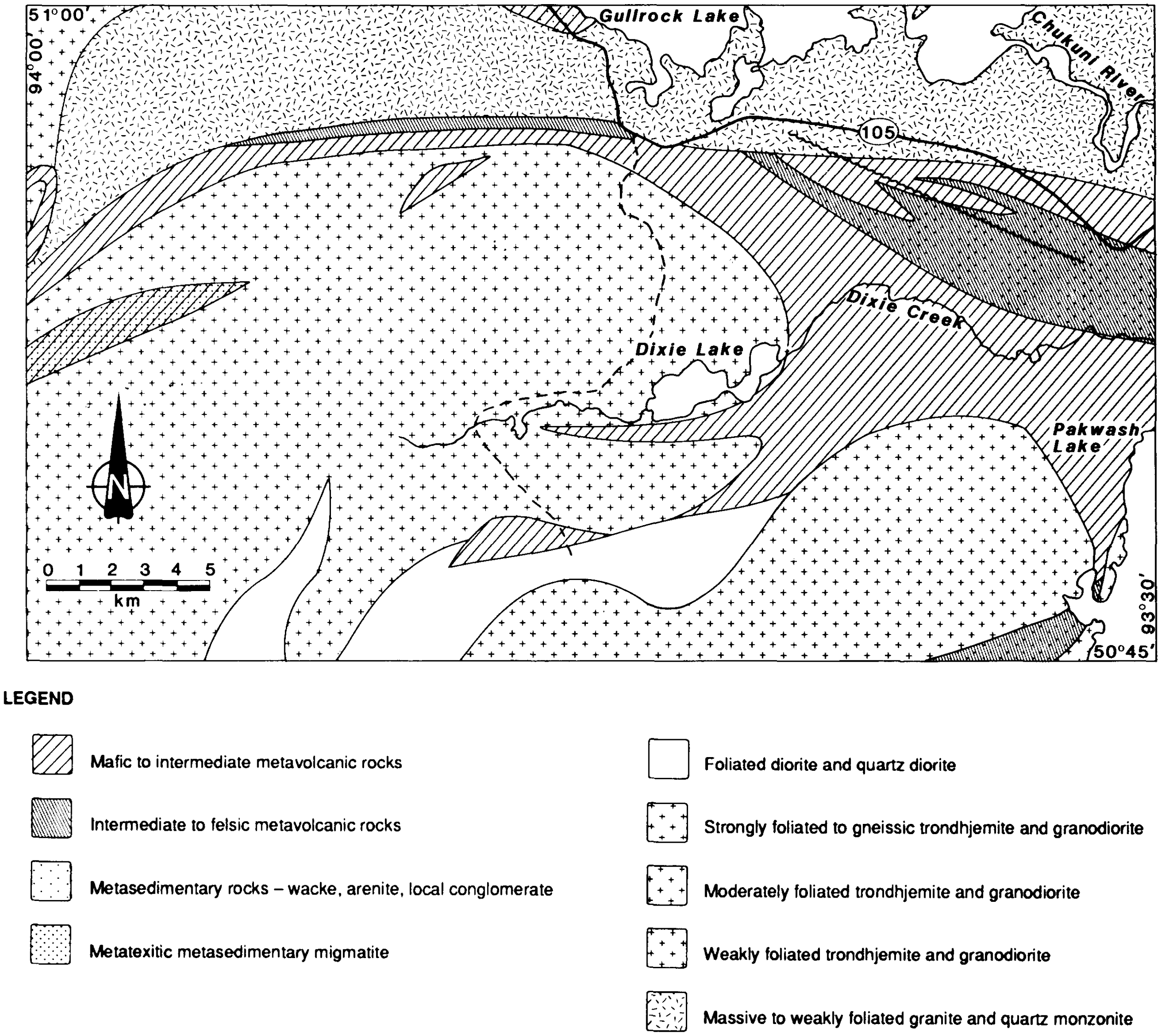

Figure 4.2. General geology of the Dixie Lake area (modified *after* Breaks et al. 1978).

emphasizing regional stratigraphy (Thurston and Paktunc 1985).

About 70% of the map area is underlain by various types of granitoid rocks (Figure 4.2). The remainder is underlain by supracrustal rocks, which represent the contiguous and dismembered southwestern end of the Birch Lake–Uchi Lake greenstone belt. As such, the main Dixie Lake area supracrustal rocks are spatially separated from the southern fringe of the 2.7 billion-year-old Red Lake greenstone belt assemblages by granitoid intrusions (*see* Figure 4.2).

Supracrustal Rocks

The most extensive area of supracrustal rock lies in poorly exposed terrain in the east-central part of the map area. Exposures indicate that the rocks comprise the following protoliths:

1. massive and pillowed, locally plagioclase-porphyritic, variolitic, or amygdaloidal, mafic and mafic to intermediate volcanic flows;
2. intermediate and felsic to intermediate, feldspar- and rarely quartz-feldspar-phyric volcanic deposits, many of which are fragmental units with some intermediate to mafic fragments and mafic phenocrysts;
3. feldspathic arenite and feldspathic siltstone, possibly representing reworked volcanic-derived material;
4. polymictic conglomerate containing a wide variety of metavolcanic and metasedimentary rocks as well as granitoid clasts;
5. varieties of wacke and dark grey siltstone, and;
6. a variety of banded iron formation consisting of magnetite layers interlayered with various combinations of silicate-rich, feldspar-rich, ferromagnesian-mineral-rich, and/or wacke-rich material.

Fragments of banded iron formation were noted locally in a few spatially quite separate conglomerate units, and in some feldspathic arenite units.

Moderately strong to intense deformation characterizes the bulk of the extensive area of supracrustal rocks. Locally, some of the units within the central part of this area are moderately to weakly deformed, at least in the horizontal plane of observation, and probably represent less-strained lithons. Primary layering and pillows were locally identified. Rarely, top indications, which invariably range from the northeast to the northwest, were determined by grading and pillow shape, respectively. However, relatively small-scale isoclinal folds, transposed layering and mylonitic fabrics in the more highly strained sections precludes attaching much regional significance to the top determinations.

Granitoid Rocks

The intermediate to felsic granitoid rocks can be characterized as follows:

1. the main sliver of supracrustal rocks that extends across the northern part of the area is separated from the assemblages of the Red Lake greenstone belt by weakly foliated, equigranular granite, and lesser amounts of quartz monzonite and granodiorite, as part of the Gullrock Lake Batholith;
2. the west-central part is underlain by metamorphosed, weakly to moderately foliated, locally gneissic tonalite and granodiorite of the Longlegged Lake Dome;
3. the southeastern part is underlain by metamorphosed, weakly foliated tonalite, which is separated from the Longlegged Lake Dome by an ill-constrained body of foliated quartz diorite.

Many areas of the granitoid bodies contain local to extensive areas of very large to small supracrustal pendants and xenoliths, particularly within 1 to 2 km of contacts with the supracrustal rocks. An additional ill-defined zone of mixed granitic, gneissic, and recrystallized supracrustal pendants and xenoliths lies between the western termination of supracrustal rocks to the south of Dixie Lake and a sliver of supracrustal rocks to the southeast of Bug Lake. The xenoliths consist of amphibolite, amphibolitic gneiss and, in some cases, intermediate to felsic metavolcanic rocks, clastic metasedimentary rocks, and rarely iron formation. Several of these rock types display various stages of gneissic development. Locally, enclaves and schlieren of supracrustal rocks are present in various amounts. Pegmatite and/or aplite dikes are almost ubiquitous in the Gullrock Lake Batholith (within the map area) and at least part of the Longlegged Lake Dome. In some cases, feldspar crystals, up to 40 cm long, are present in the pegmatite bodies.

Complex, multiple age relationships between granitoid rocks exist along the marginal zones with supracrustal rocks. This complexity and the large degree of stoping or incipient digestion of the supracrustal rocks in these zones preclude, in areas of small outcrops, a clear delineation of the contacts between the contiguous sections of supracrustal rocks. In fact, much of what appears to be a contiguous thin segment of supracrustal rocks across the north part of the map area is riddled with granitoid rocks such that the area underlain by supracrustal rocks is not as extensive as initially interpreted from reconnaissance mapping.

STRUCTURAL GEOLOGY

All of the rocks underlying the Dixie Lake area show some degree of penetrative planar fabric development with the exception of some of the Gullrock Lake Batholith granite/quartz monzonite. Superposed on these fabrics, at least in part, are planar fabrics, which are the result of shearing.

The overall degree and style of deformation has produced highly deformed, transposed, and dislocated supracrustal rocks in which primary features and stratigraphic continuity largely have been destroyed. Hence, in general terms, mapping of the supracrustal rocks can only delineate zones in which the supracrustal rock predominates over granitoid rock.

Zones of ductile, high strain in the form of mylonitization, and zones of fault breccia were noted within the supracrustal rocks and in the bordering granitoid rocks. Both types of zones postdate granitoid intrusion as most bodies display regularly to irregularly spaced sets of discrete shears consistent, in orientation and sense, with shears within the main zones of high strain.

Ductile Zones of High Strain

The ductile high-strain zones in the eastern third of the map area have a dextral horizontal component of movement and strike at about 110° to 120° with subsidiary, dextral-sense sets at about 140° and 010°. In the western part of the map area, in the vicinity of Bug Lake, the ductile high-strain zones locally display sinistral horizontal component of movement having one or more of the following approximate strikes: 030°, 045°, 060° and 075°. Locally developed zones of ductile shear strike at 090° and appear to have a dextral sense where determined. In the dextral zones, antipathetic (i.e., sinistral) shears are oriented at about 030° and 075°. General orientations of deformation zones in the Red Lake greenstone belt to the north of the map area strike from 035° to 055° and 110° to 120° (e.g., Stott and Corfu 1991).

Fault Breccias

Some zones of fault breccia occur within unmylonitized granitic and supracrustal rocks, whereas others occur within, and postdate, development of ductile high-strain zones (mylonitization). The fault breccias are characterized by multiple stages of brecciation involving, at various stages, introduction of considerable silica to form a network of small quartz veins and veinlets, which surround fragments of country rock. The fragmented rock has been feldspathized and/or silicified during, or post-dating, mylonitization. Spatially associated sulphide mineralization is rare and consists of scattered grains of subhedral to euhedral pyrite. Locally, chloritization appears to have been involved, although this may be a result of retrograde alteration of crushed mafic minerals in the host rock. Locally, units display considerable flattening and layer-parallel to subparallel faulting characterized by discordant layering, ultracataclasite, and possibly pseudotachylite.

Sydney Lake Fault System

The Sydney Lake Fault System (Breaks et al. 1975, 1978; Stone 1981) lies to the south of the map area and separates the Uchi Subprovince from the Northern Supracrustal Domain of the English River Subprovince. It is a predominantly strike-slip zone of dextral shearing in which mylonitic, cataclastic, and pseudotachylitic rocks are found (Stone 1981). An east- to northeast-striking branch of this system (Longlegged Lake–Pakwash Lake Cataclastic Zone) lies just outside the southern boundary of the map area. An east-northeast-striking branch extends to the east-central boundary of the map area in the vicinity of Snake Falls (Breaks et al. 1978), but was not traced into the map area because of lack of exposure.

ECONOMIC GEOLOGY

In 1991, work was undertaken on a property held by Mutual Resources Limited where the Dixie Lake gold occurrence lies. This occurrence is the largest one within the Dixie Lake area and consists of at least 420 000 tons at an average grade of 0.13 ounces Au per ton *(George Cross Newsletter,* Aug. 15, 1990). The deposit occurs in mafic metavolcanic and clastic metasedimentary rocks (Atkinson et al. 1990) and, based on a preliminary examination of diamond drill core, is spatially associated with sulphide- and/or magnetite-bearing iron formation as well as quartz veins.

What appeared to be altered, pyritic felsic rocks were noted last year along Highway 105, south of the north boundary of the map area. The unit contains relict quartz and feldspar phenocrysts as well as 5 to 10% pyrite as disseminated grains and grains along cleavage planes. The results of a whole rock analysis of this unit did not indicate anomalous abundances of major elements (Muir, unpublished data). Trace amounts of gold are present (3 ppb).

A few small trenches were noted several kilometres to the southwest of Dixie Lake during the course of mapping in 1991. In all trenches, considerable magnetite with various amounts of pyrite and pyrrhotite were found in mafic rocks (metavolcanic?) and/or clastic metasedimentary rocks. The magnetite did not appear to be layered in any of the trenches. Assays of a few samples returned low values for gold (less than 10 ppb) and base metals (less than 285 ppm Cu; less than 10 ppm Pb; less than 115 ppm Zn) (Muir, unpublished data). This season, a few small pits and minor stripped areas were noted in slightly pyritiferous, pillowed mafic metavolcanic rocks, north of Genesee Lake.

REFERENCES

Atkinson, B.T., Parker, J.R. and Storey, C.C. 1990. Red Lake Resident Geologist's District, 1989; *in* Report of Activities 1989, Resident Geologists, Ontario Geological Survey, Miscellaneous Paper 147, p.41–68.

Breaks, F.W., Bond, W.D., McWilliams, G.J., Gower, C.F. and Stone, D. 1975. Operation Kenora–Sydney Lake, Pakwash–Longlegged lakes sheet, District of Kenora; Ontario Division of Mines, Preliminary Map P.1027, scale 1:63 360.

Breaks, F.W., Bond, W.D., Westerman, C.J., Gower, C.F., Stone, D., Desnoyers, D.W., McWilliams, G.J., Harris, N. and Findley, D. 1978. Western English River Subprovince and parts of Uchi and Wabigoon subprovinces, general geology and lithophile type mineralization, districts of Kenora and Kenora (Patricia portion); Ontario Geological Survey, Preliminary Map P.1971, scale 1:253 440.

Shklanka, R. 1970. Geology of the Bruce Lake area, District of Kenora; Ontario Department of Mines, Geological Report 82, 27p.

Stone, D. 1981. The Sydney Lake Fault Zone in Ontario and Manitoba, Canada; unpublished PhD thesis, University of Toronto, Toronto, Ontario, 146p.

Stott, G.M. and Corfu, F. 1991. Uchi Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.145–236.

Thurston, P.C. and Paktunc, D. 1985. Western Uchi Subprovince stratigraphy (Trout Lake River area), Madsen sheet, District of Kenora (Patricia portion); Ontario Geological Survey, Preliminary Map P.2857, scale 1:50 000.

5. Project Unit 92–03. Geology of the Umfreville–Separation Lakes Area

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INTRODUCTION

During the summer of 1992, field work was commenced on a multi-year project to map, at scales from 1:15 840 to 1:50 000, the Precambrian geology of the Umfreville–Separation lakes area. The project area is bounded by longitudes 94°00'W and 95°10'W and latitudes 50°10'N and 50°30'N (Figure 5.1). Access to the area is provided by the major English River drainage system, of which Umfreville and Separation lakes are part. Numerous other smaller lakes in the study area drain into this system. Road access is provided to the eastern portion by a network of logging roads of which the English River Road is the main artery. This road extends northward from Highway 658 at Redditt, and links, via other logging roads, with Ear Falls and Red Lake. On July 18, 1991, a major windstorm blew down extensive areas of mature trees over a combined area of 164 000 Ha between Umfreville Lake in the southwest and Pakwash Lake in the northeast. This swath cut through the central east portion of the project area; salvage logging operations are in progress in parts of the blowdown, thus providing new access, but major parts of the blowdown have not been, and will not be, salvaged, thus severely restricting access.

Geological mapping was carried out by C.E. Blackburn and J.B. Young at a scale of 1:15 840 over the Separation Lake metavolcanic belt, and by G.P. Beakhouse at a scale of 1:50 000 over migmatitic and granitoid rocks adjacent and external to the belt. The majority of the western half of the metavolcanic belt was mapped over the field season, between longitudes 94°27'W and 94°45'N and latitudes 50°11'N and 50°21'N. Migmatitic and granitoid rocks north of the belt, and granitoid rocks south of the belt were mapped over a period of 6 weeks.

REGIONAL GEOLOGICAL SETTING

Previous geological mapping in the area of the present survey was done at a scale of 1:63 360 (Breaks et al. 1975a, 1975b).

The Umfreville–Separation lakes map area straddles the boundary between the Winnipeg River and English River subprovinces. The Separation Lake metavolcanic belt lies at this boundary, and has been considered to be the eastern continuation of the southern part of the Bird River metavolcanic-metasedimentary belt in Manitoba

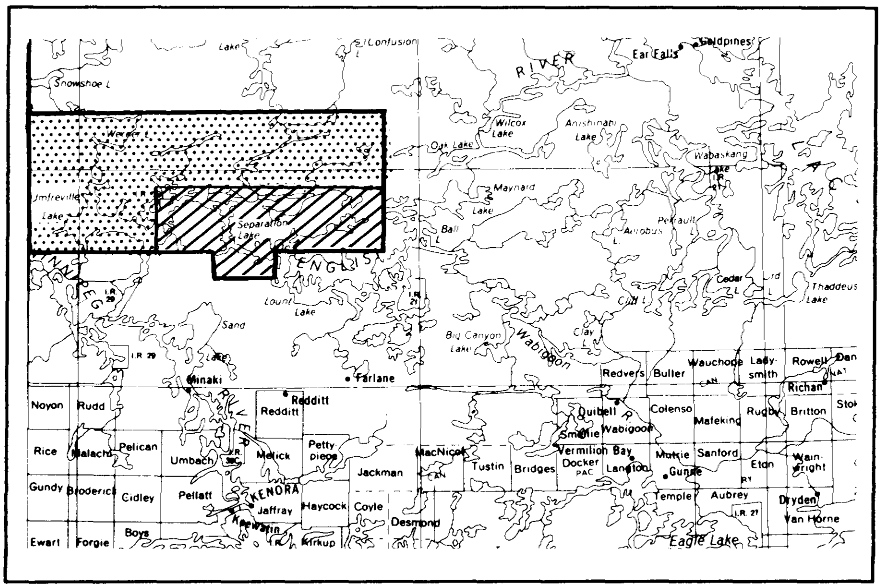

Figure 5.1. Location map of the study area, scale 1:1 584 000. The smaller, diagonally hatched area will be mapped at 1:15 840 over a two-year period.

(Černý et al. 1981). A proposal to elevate the Bird River belt to subprovincial status has been made by Card and Ciesielski (1986); Beakhouse (1991) favoured this interpretation.

The English River Subprovince, lying to the north of the Separation Lake belt, underlies half of the map area. It comprises metasedimentary migmatites (50%), and felsic to intermediate plutonic rocks of two major suites, a tonalitic suite and a granodiorite to granite suite (Breaks 1991). Metamorphic grade varies from amphibolite to granulite, and has affected all rocks except those of a peraluminous suite at the north margin of the area (Breaks 1991).

The Winnipeg River Subprovince, south of the Separation Lake belt, is comprised of felsic to intermediate plutonic rocks of 2 suites, an early tonalitic suite and a later granitic suite (Beakhouse 1991). Rocks of the tonalitic suite in the subprovince are metamorphosed to amphibolite to granulite grade, while granitic suite rocks were either synchronous with or postdated regional metamorphism (Beakhouse 1991).

The Separation Lake metavolcanic belt is comprised predominantly of mafic metavolcanic rocks, with intercalated magnetite-bearing iron formation, and subordinate felsic metavolcanic rocks. A thin discontinuous unit of polymictic conglomerate lies along its northern margin. Metamorphic conditions have not been documented in detail, but are probably amphibolite grade throughout the belt.

Mineral Deposits

A diversity of mineral deposits is associated with a variety of geological settings.

Base metals: zinc and copper occurrences in the Separation Lake metavolcanic belt are associated with mafic metavolcanic rocks. Copper is associated with migmatitic metasedimentary rocks at Bug Lake, near Rex Lake.

Gold occurrences in the Separation Lake belt are in sulphide zones contained within amphibolites derived from mafic volcanic rocks.

Nickel, copper, cobalt, and platinum group elements (PGE) are associated with ultramafic pods along the Werner–Rex lakes lineament. The Gordon Lake mine produced copper and nickel and by-product platinum and palladium in the 1960s, and cobalt was briefly mined at the Werner Lake Cobalt Mine during World War II.

Uranium is present in low amounts in granitic rocks and in metasedimentary migmatites on either side of and within the Separation Lake metavolcanic belt.

Graphite is present in metasedimentary migmatites of the English River Subprovince.

Rare metals: rare beryl crystals have been noted in granitic pegmatites in the Separation Lake metavolcanic belt. Highly productive rare metal pegmatite deposits occur across the border in Manitoba.

SEPARATION LAKE METAVOLCANIC BELT

Mineral Exploration

Record of exploration in the Separation Lake greenstone belt and adjacent granitic and gneissic rocks extends back to the 1940s, when A. Gauthier discovered gold, along with zinc and other base metals, at Umfreville Lake (formerly Oneman Lake), and gold was discovered at Helder Lake at the east end of the belt. In the period 1948 to 1959, studies were done by W.S. Moore Company of Duluth, Tombill-Glen Echo Mines, and Centurion Mines of the iron potential of the formation outcropping sporadically along the belt in the vicinity of Separation Lake. From 1968 to 1976, uranium was explored for by Can-Fer Mines Limited, Consolidated Summit Mines Limited, and Noranda Inc at the east end of Umfreville Lake, and was also discovered near Treelined Lake, in proximity to graphitic rocks that were investigated in 1988 by Bellwether Resources Limited. Base metal exploration was carried out in the 1970s, mostly at a reconnaissance scale, by Selco Mining Corporation Limited and Sherritt Gordon Mines Limited (Breaks et al. 1975a, 1975b); however, there is no record of this work in the assessment files at the Kenora Resident Geologist's office.

In 1985, the Gauthier (or Oneman Lake) occurrence at Umfreville Lake was examined by Sparton Resources Inc for both gold and base metal potential. In 1988, following the discovery by M. Thorburn of Kenora of a single loose piece of high-grade, chalcopyrite-bearing "float" beside the English River Road approximately 2 km north of the Separation Lake bridge, Noranda Inc did lithogeochemical and soil geochemical surveys in the immediate area, but subsequently dropped the option.

In 1987, Shabu Gold Mines Limited began a program of exploration for gold at Helder Lake that has been continued by Champion Bear Resources Limited under the direction of Independent Exploration Services Limited. Following an airborne geophysical survey and a subsequent diamond drilling program in 1988 at Helder Lake, the company extended its claim holdings westward along the belt for a distance of 45 km to the Gauthier occurrence, and conducted an airborne survey over the additional claims in 1989. Field work in 1989 was concentrated on the Gauthier occurrence, which was stripped and sampled, and the company reported (Champion Bear Resources Limited, press release, September 5, 1989) that continuous mineralization had been traced over a strike length of more than 1000 m and a width of 100 m, and that assay values from grab samples were up to 0.70 ounce Au per ton, 1.87 ounces Ag per ton and 4% Zn. In 1990, exploration was continued over a strike length of 10 km to the east from the Gauthier occurrence, in an attempt to trace the zone along strike. New copper-zinc mineralization was discovered during the geologic mapping. The zone at the Gauthier prospect was not traceable and it was realized that the newly investigated occurrences could be in a different geologic setting. In early 1991, 40 holes, for a total of 4324 m, were diamond drilled on targets at the west end of the property. Twenty-two of these holes were drilled to test the Gauthier prospect, and a further 18 holes were drilled to test the new base metal targets along strike to the east (assessment files, Resident Geologist's office, Kenora). In a press release in April, 1991, the company stated that at the Gauthier prospect gold is associated with subparallel silicified breccia zones that had been drilled over a strike length of 900 m and to a depth of 100 m. Company geologists interpreted the mineralization at the newly discovered occurrences to occur at the contact between rhyolite and basalt, and to be different from the gold-arsenic association at the Gauthier prospect. They stated that this contact had been traced for a strike length of 30 km and that low copper and zinc values were obtained in assays from all 13 holes that intersected it, over widths of up to 24 m, in semi-massive and stringer sulphide-bearing zones. Best values found included 0.30% Zn over 24 m, 0.34% Zn over 9.3 m, and 0.45% Zn over 4.3 m (assessment files, Resident Geologist's office, Kenora). During the summer of 1991, further geological mapping, trenching and sampling was conducted on the base metal targets outlined by geophysical surveys (L. Chastko, Champion Bear Resources Limited, personal communication, 1991).

General Geology

Metavolcanic rocks occur discontinuously along the English River–Winnipeg River subprovincial boundary from the Ontario–Manitoba border in the west to western Lac Seul in the east, a distance of about 100 km.

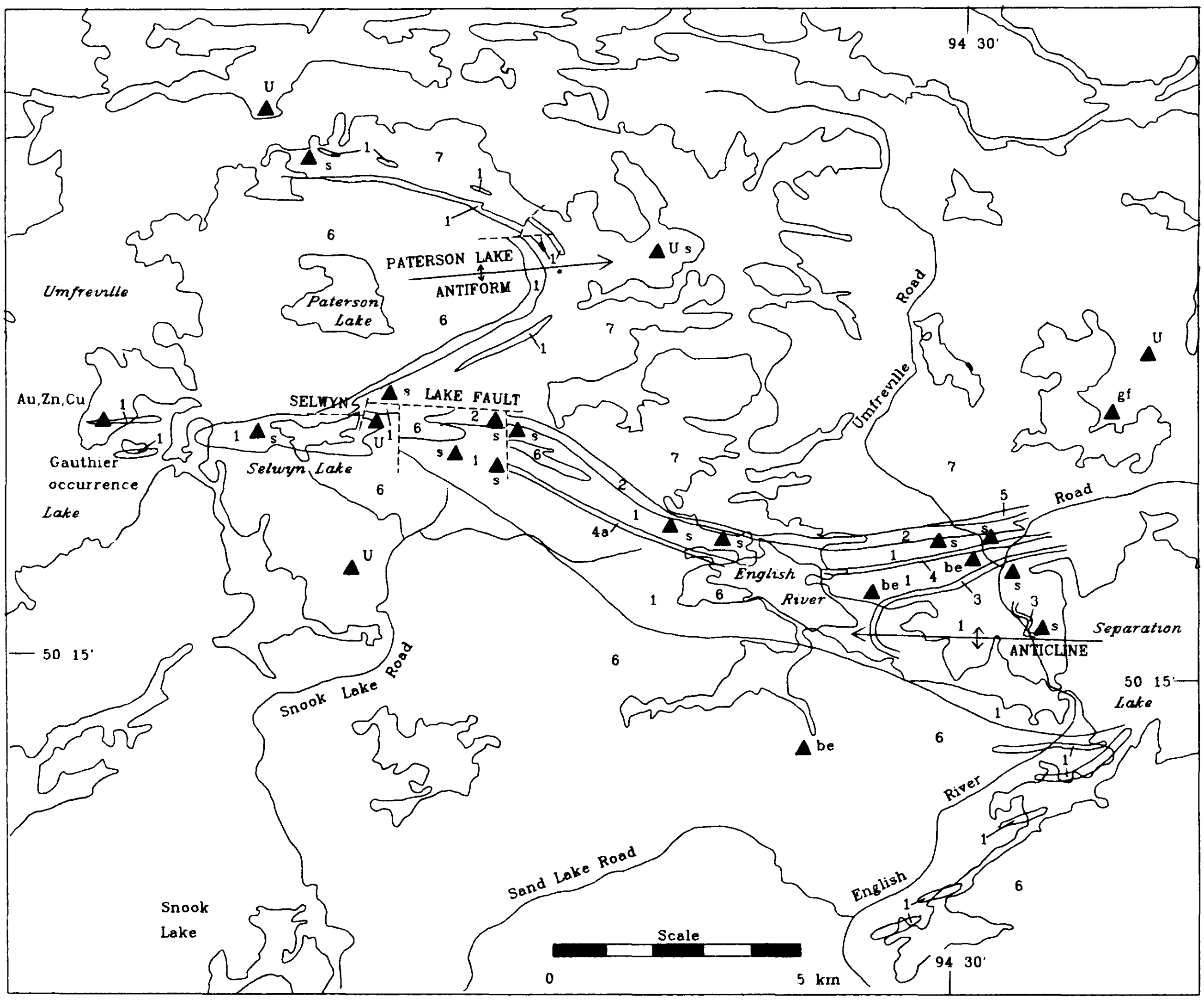

Figure 5.2. Western Separation Lake greenstone belt: general geology and mineral occurrences. Legend: rock types 1) mafic metavolcanic rocks (pillowed and massive flows); 2) felsic metavolcanic rocks (tuff, lapilli tuff); 3) chemical metasedimentary rocks (magnetite iron formation, chert); 4) and 5) clastic metasedimentary rocks (4: feldspathic arenite and wacke; 4a: garnet-staurolite-bearing unit, 5: polymictic conglomerate); 6) granitic intrusive rocks; 7) migmatitic rocks. Mineral symbols: Au, gold; be, beryl; Cu, copper; gf, graphite; s, sulphide-rich zones; U, uranium; Zn, zinc.

These metavolcanic rocks represent the eastern extension of the Bird River metavolcanic belt in Manitoba (Černý et al. 1981). The Separation Lake metavolcanic belt is the largest segment, extending from the east shore of Umfreville Lake to Helder Lake, a distance of 45 km, and with a maximum width of 5 km.

The Separation Lake belt was previously mapped at reconnaissance scale only (Breaks et al. 1975a, 1975b) during a helicopter-supported regional-mapping program conducted between 1972 and 1976 (Breaks et al. 1978). In the 1988 field season, Sanborn–Barrie (1988) studied the boundary zone between the Winnipeg River and English River subprovinces, from the Manitoba border in the west to eastern Lac Seul in the east, and briefly discussed the general geology of the Separation Lake belt; that author concluded, based on structural relationships at the boundary, that the boundary between the subprovinces lies at the northern margin of the metavolcanic belt. During the 1992 field season, mapping was carried out over the western portion of the belt only, from the west end of Separation Lake to Umfreville Lake, and the following account deals predominantly with this portion (Figure 5.2).

An east-trending lineament, which is in part defined by a fault, here named the Selwyn Lake fault, conveniently divides the mapped area into two parts. To the south of the lineament, supracrustal sequences face homoclinally northward, except in the east where broad folding is defined by magnetite-bearing iron formation units. Facing of sequences is defined by scarce top determinations in pillowed mafic metavolcanic rocks: flattening deformation, further discussed below, has rendered the vast majority of pillow shapes useless for such determinations. To the north of the lineament, amphibolites, interpreted to be derived predominantly from mafic volcanic rocks, are folded about a broad, steeply to moderately westerly plunging fold, here named the Paterson Lake antiform.

METAVOLCANIC ROCKS

The Separation Lake belt is characterized by a bimodal volcanic sequence comprising predominant mafic flows and subordinate felsic pyroclastic rocks.

Mafic metavolcanic rocks, metamorphosed to amphibolites, comprise approximately 80% of the north-facing sequence, south of the Selwyn Lake lineament. Felsic metavolcanic rocks comprise the remaining 20%. Mafic amphibolites comprise all of the identified volcanic rocks around the Paterson Lake antiform north of the fault. In the latter case, quartz-rich phases of the migmatites that have been included with the metasedimentary rocks may be of felsic volcanic origin. However, textural, structural and mineralogical observations made in the field suggest that the quartz-rich phases are more likely sedimentary in origin.

Pillowed flows are typical of the mafic metavolcanic sequence; however, intense deformation has rendered reliable top determinations impossible in all but a few cases. Commonly, the flows take on the aspect of an interbanding of hornblende-rich and plagioclase-rich layers, on the scale of 1 to 4 cm. Grain size is commonly fine to medium grained, and primary textures, where preserved, include rare amygdules. Coarser gabbroic textured mafic rocks may be flows or subvolcanic sills. Metamorphic mineral assemblages are hornblende + plagioclase ± garnet and ± epidote. Garnet commonly is abundant in pillow selvages and, in some places, is so prevalent as to suggest hydrothermal alteration prior to metamorphism.

Tuff and lapilli tuff are typical of the felsic metavolcanic rocks. Because of their position between the mafic metavolcanic sequence to the south and the metasedimentary migmatite rocks to the north, and the location of a broad deformation zone in this vicinity, primary structures and textures have, in many places, been obliterated, hindering precise identification of the precursor rock.

METASEDIMENTARY ROCKS

Chemical metasedimentary rocks, in the form of magnetite-bearing iron formation, occupy 2 presently identified stratigraphic levels within the mafic metavolcanic sequence south of the Selwyn Lake lineament. Typically, the units are layered chert-magnetite beds on the order of 1 to 5 m wide with intervening mafic metavolcanic rocks that may be aggregated into zones on the order of tens of metres wide. Sulphide minerals, predominantly pyrrhotite with subordinate pyrite, locally replace magnetite. The units are folded on meso- and macroscopic scale, but insufficient mapping has been done to date to define the fold structures.

Clastic metasedimentary rocks occur at 2 stratigraphic levels, 1 within the mafic metavolcanic sequence, and 1 overlying the felsic metavolcanic rocks in the east of the mapped area. A narrow unit of feldspathic arenite to wacke, on the order of 30 m wide, occurs within the mafic metavolcanic rocks about 500 m below its contact with the felsic metavolcanic rocks. The unit of feldspathic arenite to wacke has been positively identified in the east, where it is crossed by the English River Road. This unit is tentatively correlated with a unit of similar width west of the English River, that contains abundant garnet and, in places, staurolite. In support of this correlation, similar rocks were intersected in subsurface drilling done by Champion Bear Resources Limited beneath a creek that flows westerly into the English River (A.P. Pryslak, personal communication, 1992). Presence of these aluminous metamorphic minerals indicates derivation from either primary alumina-rich sedimentary rocks, or hydrothermally altered sedimentary rocks similar in composition to the feldspathic arenite and wacke with which they are correlated.

Polymictic conglomerate, in places interbedded with wacke, occurs over a width up to 30 m, lying immediately above the metavolcanic sequence east of the English River. The unit pinches out to the west, and has not been identified west of the English River. Similar rocks are observed along strike up to a few kilometres to the east beside the English River Road, but their continuity has yet to be established. No reliable top determinations have been made in this sedimentary sequence, but presence of mafic and felsic volcanic clasts, in addition to granitoid, dioritic, and quartzose clasts, indicate that they overlie the metavolcanic rocks.

GRANITIC INTRUSIVE ROCKS

South of the Selwyn Lake lineament, granitic rocks invade or disrupt the continuity of the volcanic-sedimentary sequence at three places: 1) in the west, at Selwyn Lake; 2) in the central section as a body contained wholly within the mafic metavolcanic rocks; and 3) in the east, along the English River. All of these granitic bodies contain remnants of volcanic rocks varying from metre scale to large, mappable enclaves up to a few hundred metres in long dimension. Foliation within the granitic bodies is oriented in the same general direction as that in the volcanic remnants, indicating pre- to syn-tectonic emplacement. The rocks are granitic to granodioritic, and some phases contain potash feldspar megacrysts. Along the English River, coarse pegmatitic phases are common and, in this area, beryl crystals were noted in a few of these phases.

Deformation

Preliminary analysis of structural data suggest that the Selwyn Lake lineament demarks the boundary between 2 structural, and possibly metamorphic, zones. Further to the east, the contact between the felsic metavolcanic rocks of the Separation Lake greenstone belt and the migmatites of the English River Subprovince, is a continuation of this structural boundary. The open, east-plunging Paterson Lake antiform, north of this line, contrasts with predominantly homoclinal, vertical to steeply dipping sequences, with locally westerly plunging folds in the vicinity of the English River Road, to the south of the line. Mineral lineations and minor fold axes around the Paterson Lake antiform plunge between 45° and 75° to the east, while those associated with folds at the English River Road plunge between 45° and 70° to the west and southwest.

Although mafic metavolcanic rocks are ubiquitously metamorphosed to amphibolites, those to the north of the Selwyn Lake lineament occur in attenuated units, many of which are lensoid, and are interspersed within migmatitic quartzofeldspathic rocks and granitic phases. Preliminary interpretation indicates that the quartzofeldspathic rocks are metasedimentary, but may be remnants of felsic metavolcanic rocks. Which ever is the case, the lineament also demarks the boundary between migmatized and non-migmatized supracrustal rocks.

Within the homoclinal metavolcanic sequence, the degree of deformation increases from south to north across the width of the belt. In the south, pillowed flows are relatively weakly deformed such that top determinations were made in a few cases. In the north, increasing deformation has imparted a gneissosity to the same rocks such that their derivation from pillowed flows is not obvious. The overlying felsic metavolcanic rocks are mylonitized in places, and pseudotachylite was observed in a few outcrops. Evidently, a zone of intense deformation coincides with the transition from felsic metavolcanic rocks of the Separation Lake greenstone belt to metasedimentary rocks of the English River Subprovince.

Foliations measured throughout the mapped area are consistently oriented east-west, in most places conformable with regional trend of units. Foliation transects the regional trend of units in major fold structures such as the Paterson Lake antiform and the folds in the vicinity of the English River Road. Lineations referred to above lie in the plane of these foliations.

MIGMATITES AND GRANITOID ROCKS OF THE ENGLISH RIVER SUBPROVINCE

The English River Subprovince is characterized lithologically by highly metamorphosed and migmatized sedimentary rocks along with strongly peraluminous granitoid rocks related to the migmatization process (Breaks 1991). Leucocratic, metaluminous, to weakly peraluminous plutonic rocks of tonalitic to granitic composition, occurring in several discrete stocks and batholiths, are interpreted to be unrelated to the migmatization process.

The migmatitic metasedimentary rocks display considerable diversity due to both primary differences in their composition and depositional characteristics and superimposed metamorphic/migmatitic processes. The sedimentary origin of the migmatite paleosome is evident from the local preservation of bedding and the pelitic composition of many of these rocks. The most common variety is composed of feldspar + quartz + biotite ± garnet and ± cordierite. Commonly, this variety has alternating layers of finer grained (0.5 to 1 mm), granoblastic material and coarser grained (1 to 2 mm), porphyroblastic material with the latter having a higher proportion of biotite and garnet. These layers are interpreted to reflect primary interbedding of wacke and finer grained, more clay-rich (siltstone or mudstone) deposits. More quartz-rich, less pelitic metasedimentary rocks are widespread as a minor component within the more typical variety and locally predominate in units up to 200 m thick. Polymictic conglomerate is present in several locations that contrast with those previously recognized at the margins of the subprovince (Breaks 1991) in being well within the subprovince and interlayered with the finer grained migmatitic metasedimentary rocks. Rare, concordant layers of diopside + garnet + carbonate + quartz and feldspar + amphibole ± pyroxene are of uncertain origin.

The primary sedimentary characteristics exert considerable control on the superposed secondary processes. The more pelitic layers are more coarsely recrystallized and commonly contain large (less than 3 cm) garnet porphyroblasts. The more pelitic layers also contain a higher proportion of granitic mobilizate as discussed below.

The granitic component of the migmatites typically constitutes from 20 to 40% of the rock, but ranges from 5 to 70%. As its abundance increases, the migmatite grades into peraluminous granite. These rocks range in composition from biotite granite to granodiorite and are distinctive by virtue of the near ubiquitous occurrence of garnet and, less commonly, muscovite and cordierite. Where the granitic component of the migmatite is minor (less than 20%), these rocks are invariably pegmatitic and concentrated as concordant lenses, commonly with mafic selvages, in the more pelitic layers. At high (greater than 50%) percentages of granitic component and in relatively more homogeneous peraluminous granites, the texture is commonly medium grained equigranular with irregular alkali granite pegmatitic patches. The latter may have very coarse blocky potassium feldspar, banded aplitic zones and occasionally have more exotic mineralogy (muscovite rosettes, apatite).

GRANITOID ROCKS OF THE WINNIPEG RIVER SUBPROVINCE

Granitoid rocks of the Winnipeg River Subprovince intrude the south side of the Separation Lake greenstone belt. These rocks have not been investigated in detail. Microcline-megacrystic granodiorite along with subordinate equigranular granite predominate with locally abundant foliated to gneissic tonalite inclusions and granitic pegmatitic dikes. The latter are locally uraniferous.

MINERALIZATION

Base metals and gold present the greatest potential for mineral discovery in the portion of the Separation Lake belt mapped during the 1992 field season. There is potential for rare metal mineralization in alkali granite pegmatites both within the greenstone belt, where rare beryl crystals were noted during the present survey and previously by Breaks et al. (1975b), and within the migmatites of the English River Subprovince. Storey (1990) reported anomalously high beryllium from 1 of 3 pegmatite samples taken along the English River Road during a regional pegmatite reconnaissance program. Uranium has previously been detected in low amounts in granitic rocks near Selwyn Lake and in granitic pegmatitic phases in migmatites of the English River Subprovince. Graphite concentrations occur in the migmatites. Uranium and graphite occurrences were not investigated during the 1992 season.

Sulphide zones of varying type and mineral association have yielded, to date, anomalous to low amounts of gold, copper and zinc. These sulphide zones occur within metavolcanic rocks, predominantly in the mafic metavolcanic rocks south of the Selwyn Lake lineament. Preliminary investigation indicates that the sulphide zones belong to 3 distinct types. The first type is exemplified by the Gauthier occurrence, where gold, zinc and copper occur in an arsenopyrite-rich, sulphide-bearing, brecciated zone that is about 100 m thick, within amphibolites that are the westernmost extension of the greenstone belt south of the Selwyn Lake lineament. Sulphide minerals present, in addition to abundant arsenopyrite that can be on the order of 30 to 40%, are pyrite, pyrrhotite, sphalerite, and minor chalcopyrite and galena. Gold values obtained by Champion Bear Resources Limited (assessment files, Resident Geologist's office, Kenora) are erratic, but may be related to arsenopyrite abundance (L. Chastko, Independent Exploration Services Limited, personal communication, 1989 and 1990). The occurrence had not been visited at time of writing, but was visited in previous years by the senior author (*see* Blackburn et al. 1992, p.17–21).

A second type of sulphide zone occurs in silicified shear zones, characteristically near the top of the mafic metavolcanic sequence, close to, or in some cases, at the transition into, felsic metavolcanic rocks. The conformable, siliceous zones are on the order of 5 to 10 m wide, and can be traced along strike for distances up to at least 1000 m. Disseminated to massive sulphide minerals are unevenly distributed within the zones and, in some cases, impart a layering. Massive portions may contain barren pyrite-pyrrhotite or may contain chalcopyrite, which is either intimately intermixed with the barren sulphides or disposed within late fractures. Champion Bear Resources Limited reported very low gold values for this type of sulphide zone (L. Chastko, Independent Exploration Services Limited, 1991).

The third type of sulphide zone, hosted in iron formation, is found at various places within the folded magnetite-bearing to chert-rich chemical metasedimentary units within the mafic metavolcanic rocks east of the English River. Pyrrhotite and pyrite occur within the more-or-less magnetite-bearing layers and, in some places, completely replace magnetite. No assay values are available for this type of zone.

REFERENCES

Beakhouse, G.P. 1991. Winnipeg River Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.279–301.

Blackburn, C.E., Hailstone, M.R., Storey, C.C. and Perrault, M.E. 1992. Kenora Resident Geologist's District – 1991; *in* Report of Activities 1991, Resident Geologists, Ontario Geological Survey, Miscellaneous Paper 158, p.3–28.

Breaks, F.W. 1991. English River Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.239–277.

Breaks, F.W., Bond, W.D., McWilliams, G.H., Gower, C.F. and Findlay, D. 1975a. Operation Kenora–Sydney Lake, Oak–Indian lakes sheet, District of Kenora; Ontario Geological Survey, Map P.1029, scale 1:63 360.

Breaks, F.W., Bond, W.D., McWilliams, G.H., Gower, C.F., Findlay,

D. and Stone, D. 1975b. Operation Kenora–Sydney Lake, Umfreville–Separation lakes sheet, District of Kenora; Ontario Geological Survey, Preliminary Map P.1028, scale 1:63 360.

Breaks, F.W., Bond, W.D. and Stone, D. 1978. Preliminary geological synthesis of the English River Subprovince, northwestern Ontario, and its bearing on mineral exploration; Ontario Geological Survey, Miscellaneous Paper 72, 55p.

Card, K.D. and Ciesielski, A. 1986. Subdivisions of the Superior Province of the Canadian Shield; Geoscience Canada, v.13, p.5–13.

Černý, P., Trueman, D.L., Ziehlke, D.V., Goad, B.E. and Paul, B.J. 1981. The Cat Lake–Winnipeg River and the Wekusko Lake pegmatite fields, Manitoba; Manitoba Department of Energy and Mines, Economic Geology Report ER80–1, 216p.

Sanborn–Barrie, M. 1988. Geology of the tectonic boundary between the English River and Winnipeg River subprovinces, northwestern Ontario; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.12–17.

Storey, C.C. 1990. An evaluation of the industrial mineral potential of parts of the districts of Kenora and Rainy River; Ontario Geological Survey, Open File Report 5718, 259p.

6. Project Unit 92–04. Gravity Profiles in the Separation Lake Area of the English River Subprovince

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INTRODUCTION

A gravity survey project was initiated in 1992 to delineate and define the gravity characteristics of a remnant greenstone belt in the Separation Lake area of the English River Subprovince. Remnant greenstone belts are usually small, with limited depth extent and, therefore, this year's investigation was designed to test the usefulness of gravity in detailed geological mapping carried out concurrently by Blackburn and Beakhouse (this volume).

A small test area for gravity profiling was selected on the basis of favourable geology. The area is bounded by latitudes 49°58'N and 50°45'30"N, and longitudes 94°09'W and 94°32'W (Figure 6.1). Access by motor vehicle is provided mainly by Highway 658, which joins the English River Road and continues northward as Pakwash Road.

GRAVITY SURVEY

About 200 gravity stations were established by a five-man field party. Two Lacoste–Romberg gravimeters, G–294 and G–626, were used for the survey. The gravity station separation was variable. A station spacing of 300 m was employed along detailed, levelled, gravity profiles. A station spacing of about 2 km was established for gravity stations along various sections of the English River and Pakwash roads.

The gravity observations were tied to a local base station (9351-92), established on an outcrop along the English River Road. This station was, in turn, tied to the control stations at Red Lake, Ear Falls, Vermilion Bay and Dryden, forming part of the National Gravity Network International Gravity Standardization Net 1971, established by the Canada Department of Energy, Mines and Resources, Ottawa. For the purpose of determining the gravity meter drift, the Lacoste–Romberg meters were read at a controlled base station every day at the start and end of each gravity traverse.

Near gravity station sites, fresh rock samples were obtained for density measurements.

ELEVATIONS

Vertical control (or elevation) for, detailed, 300 m spacing gravity stations was provided using a combination of precise optical levelling and electronic chain and levels (Models C and D). Model D was equipped with an electronic note pad. The levelling was tied to the elevation of the Separation Lake bridge deck level, north side, which was, in turn, measured relative to the water level of the Separation Lake. The elevation of the Separation Lake water level was estimated from Manitou Falls water elevation provided by Ontario Hydro.

Wallace and Tiernan altimeters, in pairs, were also used for vertical control of gravity stations. The altim-

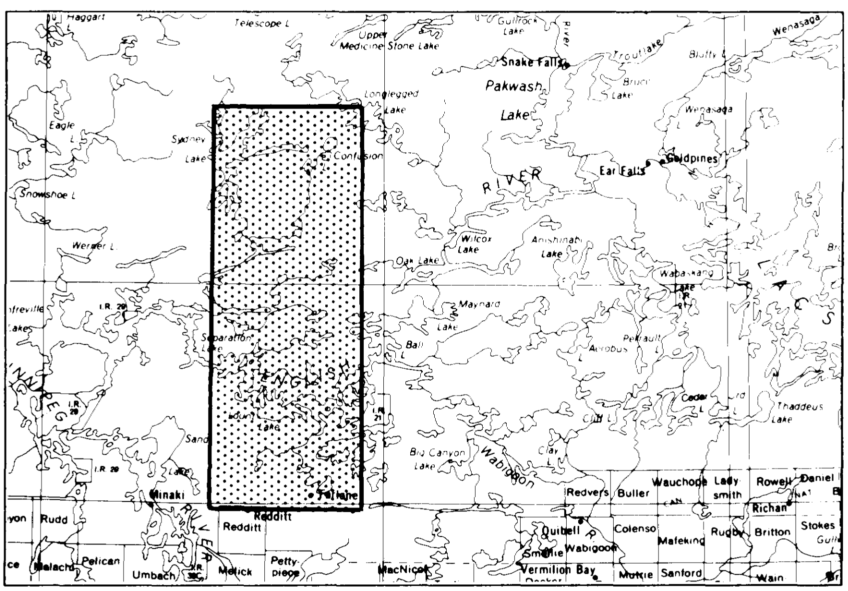

Figure 6.1. Location map of the study area, scale 1:1 584 000.

eters were tied to known elevations every 1 to 2 hours. Appropriate corrections for temperature and humidity variations were also applied by the use of motorized psycrometers.

HORIZONTAL CONTROL

The gravity stations were established at identifiable sites and were located precisely on aerial photographs. The station positions were then transferred onto 1:50 000 NTS maps and digitized with a precision of ± 25 to 50 m.

DATA REDUCTION

The gravity survey was carried out to the national specifications and procedures of the Geophysics Division of the Geological Survey of Canada. The survey data will be processed and Bouguer gravity profiles will be compiled by the Ontario Geological Survey.

7. Project Unit 92–05 (Part 1). Geology of the Palmerston Lake Area

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INTRODUCTION

The Palmerston Lake area (NTS 31F/2SW)(Figure 7.1) is located 95 km north of Kingston, and approximately 250 km northeast of Toronto. The map area covers about 280 km², and is bounded by latitudes 45°00'00"N and 45°07'30"N and longitudes 77°00'W and 76°45'W. The area lies within Frontenac and Lanark counties, and includes parts of North and South Canonto, Clarendon, Lavant, Miller and Palmerston townships. The hamlet of Ompah is located near the south-central boundary of the map area. Access is provided by Highway 509 and several forest-access and township roads.

The present study completes mapping in the northern Mazinaw Terrane of the Grenville Province (Figure 7.2) started in 1987 (Easton 1988). It also traces units from the Mazinaw area mapped in 1991 (Easton and Ford 1991) into an area of higher metamorphic grade, and completes a detailed study of the Flinton Group undertaken by F.D. Ford of Carleton University (*see* Ford, this volume; and Ford, in prep.).

MINERAL EXPLORATION

Little exploration has been conducted within the map area, and may have been discouraged by lack of detailed geologic maps, limited access, and the high metamorphic grade of the area. The only past producers in the map area are the Summit Lake magnetite deposit, which operated in 1977–78, and a talc deposit east of Mosque Lake, which operated between 1939–41. Geological Data Inventory Folios (GDIF) are available for North Canonto (OGS 1984b), South Canonto (OGS 1984c), Clarendon (OGS 1984d), Miller (OGS 1984a) and Palmerston (OGS 1984e) townships.

GENERAL GEOLOGY

The Palmerston Lake area is underlain by Precambrian rocks of Middle to Late Proterozoic age which form part of the Central Metasedimentary Belt of the Grenville Structural Province. The map area lies predominantly within the Mazinaw Terrane (Easton 1992), however, in the extreme northern part of the area, the Mazinaw Terrane is in tectonic contact with the Bancroft Terrane (*see* Figure 7.2). Northwest- to west-striking faults, most likely of Paleozoic-age and probably related to the Ottawa–Bonnechere graben system, cut the map area (Figure 7.3). These faults have significant (typically 500 m or more) apparent sinistral and dextral displacements, however, abrupt metamorphic discontinuities across many of these faults (e.g., the Plevna Fault) suggests a large vertical component of movement.

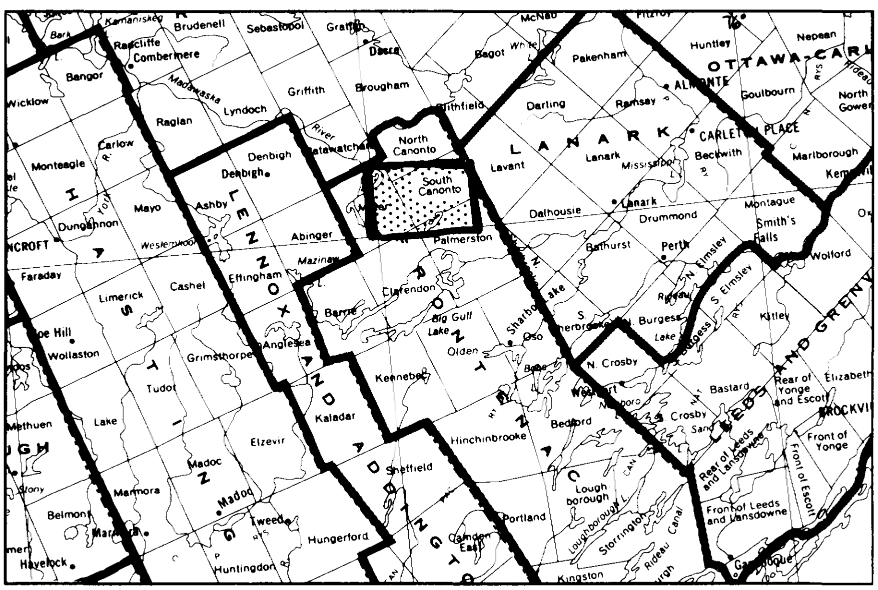

Figure 7.1. Location map of the study area in the Grenville Province, scale 1:1 584 000.

Mazinaw Terrane

INTRODUCTION

The Mazinaw Terrane within the map area can be divided into 2 lithotectonic domains (*see* Figure 7.3):

1. A supracrustal-dominated domain in the east and southeastern part of the map area containing both Grenville Supergroup and Flinton Group strata and showing a map pattern dominated by type 3 interference fold structures (Ramsay 1967); and
2. An orthogneiss-dominated domain in the west and central part of the map area consisting mainly of tonalite and granitic orthogneisses, as well as an infolded belt of impure calcitic marbles. This domain shows a map pattern of domes and basins (type 1 interference fold structures, Ramsay 1967).

The northern Mazinaw Terrane (Easton and Ford 1991; Easton 1992) (*see* Figure 7.2), consists of, from oldest to youngest: (i) metatonalite and metagranodiorite intrusions of ca. 1270 Ma age (e.g., the Cross Lake Tonalite south of the map area) locally forming intrusion breccias containing Killer Creek Suite gabbros (Easton 1992; Easton and Ford 1991); (ii) basalt-andesite-dacite-rhyolite metavolcanics of calc-alkalic affinity (Moore and Morton 1986); metavolcanic rocks are rare in the map area; (iii) siliciclastic metasedimentary rocks (metawacke, semi-pelites, paramphibolites), in part derived from metavolcanic rocks; (iv) calcitic and dolomitic marbles; (v) heterogeneous dioritic to gabbroic intrusions; (vi) fine- to medium-grained, heterogeneous granitic rocks; and (vii) the Flinton Group (ca. 1157 Ma, Kinsman and Parrish 1990), which unconformably overlies all older rock units.

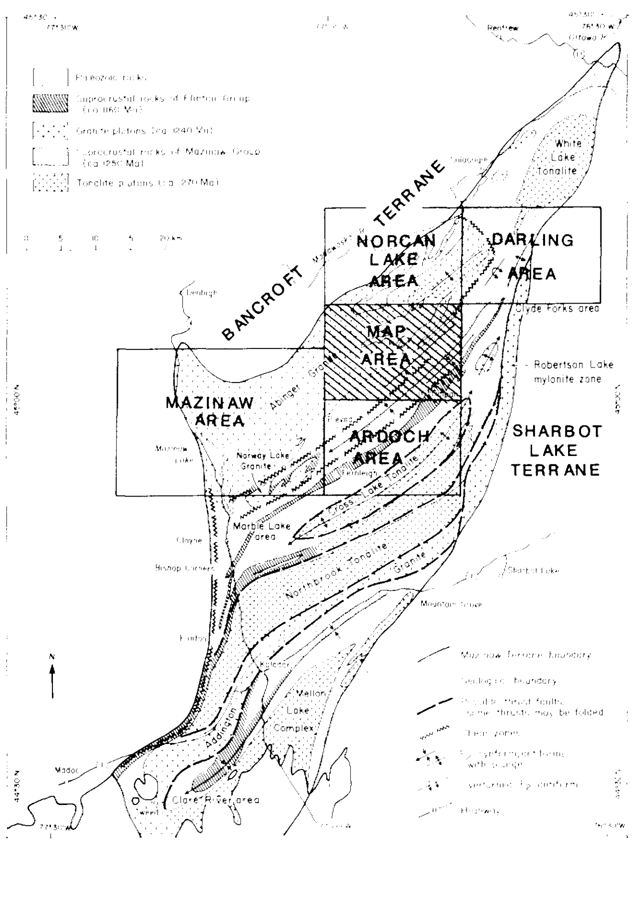

Figure 7.2. Geology of the Mazinaw Terrane of the Central Metasedimentary Belt (*after* Easton 1992). Box shows position of the map area; adjacent map areas noted in the text are also indicated. Northwest- and west-trending faults are not shown for clarity.

The Mazinaw Terrane has been subjected to at least 2 regional metamorphic episodes. The first, M_1, reaching upper amphibolite and perhaps granulite facies locally, affected all rocks older than the Flinton Group, and was accompanied by intense deformation (D_1) including thrusting. M_1 is likely greater than 1160 Ma in age. The second metamorphic event (M_2) affected the Flinton Group, as well as all older rocks, and is less than 1150 Ma in age. The metamorphic pattern in the map area reflects M_2, with upper amphibolite (sillimanite) facies assemblages occurring throughout the map area. Metamorphic grade increases from west to east across the map area.

In the lower grade part of the Mazinaw Terrane to the southwest, Easton and Ford (1991) recognized 2 pre-M_2 east-northeast-trending shear zones along the northern and southern flanks of the Norway Lake granite (*see* Figure 7.2). The northern and southern shear zones were termed the Shabomeka and Swamp Lake shear zones, respectively. Within the Shabomeka shear zone, pods of metagabbro, predominantly of the Killer Creek Suite, are common, containing relatively undeformed cores, but becoming progressively mylonitized toward the margins of the pods until the rocks can only be described as finely laminated, mafic gneisses.

These shear zones are rendered obscure within the Palmerston Lake area because of recrystallization related to M_2 metamorphism. Within the map area, the Shabomeka shear zone continues northeastward on strike from the Mazinaw area along the south shore of Grindstone and Mosque lakes, and through Summit Lake (*see* Figure 7.3). Within the Palmerston Lake area, the Shabomeka shear zone lies near, and may mark, the boundary between supracrustal sequence A, which dominates the east and southeastern part of the map area, and the orthogneiss and supracrustal sequence (B) which dominates the western and central part of the map area. As in the Mazinaw area, pods of less deformed gabbroic rock, some recognizable as being of the Killer Creek Suite, occur along the trace of the Shabomeka shear zone in the Palmerston Lake area. The trace of the Swamp Lake shear zone is more equivocal, but appears to coincide with the westernmost margin of the Ompah structure (*see* Figure 7.3).

SOUTHEASTERN DOMAIN

Supracrustal Sequence A

Metasedimentary rocks predominate in the southeastern domain, and consist mainly of calcitic and dolomitic marbles, and mafic, intermediate and felsic paragneisses, commonly garnetiferous, representing highly metamorphosed and deformed volcanic-derived wackes, wackes, feldspathic litharenites and calcareous wackes. Other rock types include minor metapelite (generally alumina-poor), calc-silicate rocks, and intercalated calcitic marbles and metapelite and metawacke. Deformation and regional metamorphism have destroyed most primary textures in these rocks, and 2 phases of tight to isoclinal folding have transposed bedding making stratigraphic analyses in the southeastern domain difficult. A broad, north-plunging antiform through the centre of Palmerston

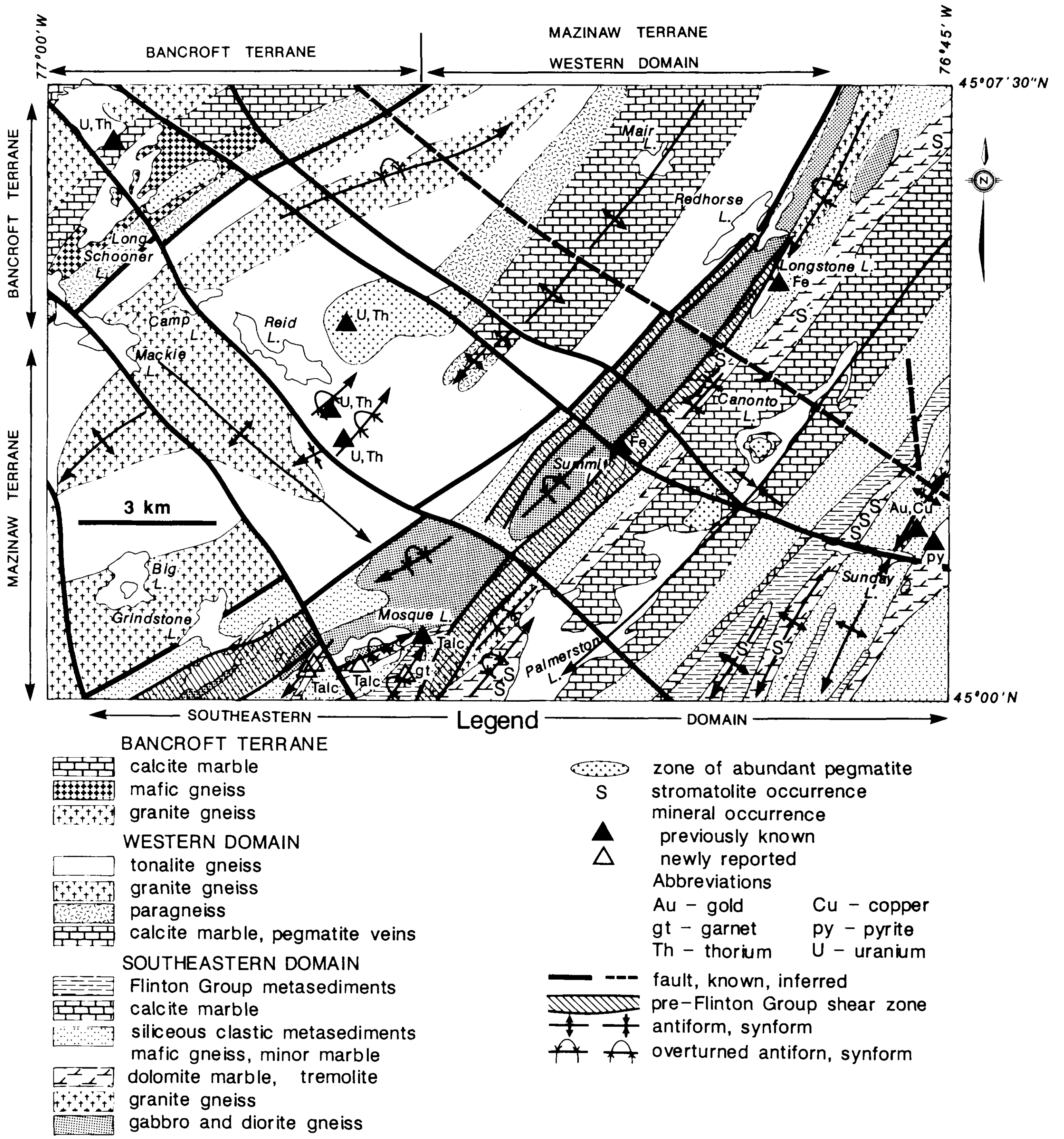

Figure 7.3. Geologic sketch map of the Palmerston Lake area showing major rock units, structures and mineral occurrences. Note not all folds are shown.

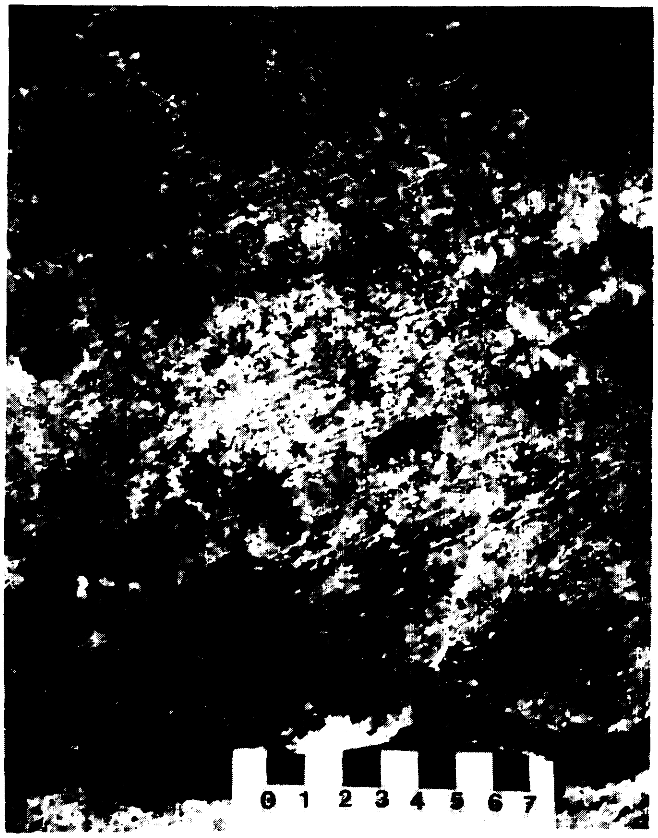

Photo 7.1. *Eozoon canadenese* (algal-mat stromatolite) from Grenville Supergroup rocks on the north shore of Sunday Lake (UTM 18T 360050E 4987900N).

and Canonto lakes appears to be the dominant structure in the southeastern domain, grossly repeating stratigraphy. Several smaller scale folds locally complicate this larger structure.

The oldest rocks in the supracrustal sequence consist of a variety of mafic gneisses and amphibolites, commonly laminated to thinly layered, containing varied amounts of biotite and hornblende. Thin section examination of some of these rocks indicates a high quartz content, suggesting a metasedimentary rather than metavolcanic origin. Black amphibolites in the Sunday Lake area contain little quartz, and may represent mafic metavolcanic rocks.

Spatially associated with the mafic gneisses and amphibolites are dolomitic marbles, commonly stromatolitic, and commonly containing coarse tremolite or diopside segregations. Stromatolites (Photo 7.1) are most common in the belt of dolomitic marbles that can be traced from Palmerston Lake to Lavant Long Lake, as indicated in Figure 7.3, but also occur near Sunday Lake.

The bulk of the supracrustal sequence consists of calcitic marbles and metawackes to metalitharenites, locally thinly interbedded. The siliciclastic metasediments locally contain garnet, sillimanite, or muscovite porphyroblasts.

Metaplutonic Rocks

A variety of metamorphosed dike rocks occur in the southeastern domain, cutting all rock units except the Flinton Group. These include metagabbro dikes, metadiabase dikes, and plagioclase-porphyritic mafic dikes. These dike rocks are particularly abundant in the calcitic marble sequence.

Metaplutonic rocks are most abundant in the western part of the domain, and include deformed pods and stocks of Killer Creek Suite gabbros (melanogabbro-gabbro-anorthositic gabbro association), mesocratic to melanocratic biotite diorite to quartz diorites, gabbro and quartz diorite, and monzogranites, locally with augen textures. Most of these metaplutonic bodies have lozenge-shaped or lenticular forms. The margins of all these bodies are strongly deformed, only the cores of the bodies preserve relict igneous textures. A gabbro body west of Summit Lake has late garnet porphyroblasts developed only within 200 m of the margin of the body, suggesting fluid interaction with the country rocks during M_2 regional metamorphism.

White tonalite and pink granite pegmatite veins occur throughout the southeastern domain, but are most abundant between Palmerston and Canonto lakes, where they are intrusive into calcite marbles. In this area, they have west to northwest trends, roughly coincident with F_3 fold axes in the southeastern domain (Table 7.1).

Flinton Group

Moore and Thompson (1980) formally defined 4 formations within the ca. 1160 million-year-old (Kinsman and Parrish 1990) Flinton Group, which unconformably overlies the Grenville Supergroup. The Bishop Corners, Myer Cave, and Fernleigh formations crop out within the map area. In the Palmerston Lake area, the Flinton Group strata are located in the previously known, 0.5 to 2 km wide northeast-trending Ompah structure (*see* Figure 7.3). The Ompah structure is described in detail by Ford (this volume). Field party personnel also located 3 new occurrences of Flinton Group strata, 2 small occurrences marginal to a granite body near Grindstone Lake, and a more extensive belt southeast of Mosque Lake (*see* Figure 7.3).

Flinton Group strata southeast of Mosque Lake are found in a north-plunging, overturned synform at least 3 km long and 1 km wide at its widest point. The synform extends south into the Ardoch area, however, Pauk (1987) did not report any Flinton strata on strike with the synform. At least 2 formations of the Flinton Group are present southeast of Mosque Lake, kyanite-muscovite schists and micaceous meta-arenites of the Bishop Corners Formation, and garnet-sillimanite-biotite schists of the Myer Cave Formation. Garnet-hornblende schist of the Ore Chimney Formation (Grenville Supergroup) are also present, and may represent a regolith developed on adjacent garnetiferous gabbroic rocks. All 3 formations

Table 7.1. Structural history of the Palmerston Lake area.

BANCROFT	WESTERN	SOUTHEASTERN
unknown	thrusting, shear zones form, M_1	thrusting, shear zone, M_1
Mazinaw-Bancroft terrane boundary forms		unconformity, Flinton Group deposited
	F_0 NE-trending isoclinal folds, preserved within gneiss layers	F_1 NE-trending, recumbent, isoclinal folds
F_1 NE-trending tight folds of bedding?	F_1 NE-trending, tight, recumbent folds of gneissosity and lithology	F_2 NE-trending, tight, upright folds,
		F_1-F_2 folds form Ramsay (1967) type 3 interference pattern M_2 peak?
F_2 NE-trending, broad folds	F_2 NW-trending tight, upright?, folds of gneissosity and lithology	F_3 NW-trending, broad folds, shallow plunges
	M_2 peak?	
F_1-F_2 folds form Ramsay (1967) type 1 interference pattern in Norcan Lake area	F_1-F_2 folds form Ramsay (1967) type 1 interference pattern (domes and basins)	
most units dip shallowly to the W and NW	most units dip moderately to the NW	most units dip moderately to steeply to the SE

are tightly infolded, and a repeated stratigraphic sequence is not evident within the synform at our 1:10 000 mapping scale. The synform is associated with intermediate gneisses, possibly representing recrystallized mylonites of the Shabomeka shear zone. Easton and Ford (1991) have previously noted an association between the early shear zones and occurrences of the Flinton Group.

On the north shore of the peninsula in Grindstone Lake, field party personnel found a spectacular outcrop of matrix-supported, granite cobble conglomerate with a coarse biotite-diopside-calcite matrix (Photo 7.2). The granite cobbles are angular to subround and range from 2 to 3 cm long to angular blocks up to 40 cm across. The fine-grained granite cobbles closely resemble the granite present in a small intrusion 200 m to the southeast. Although differing in matrix composition, this conglomerate resembles Flinton Group conglomerates present around the margin of the Norway Lake Granite (Mazinaw area, Easton and Ford 1991) in both clast type and geologic setting. About 500 m east of Grindstone Lake is an outcrop of biotite-garnet-(sillimanite?) schist, similar to Flinton Group strata in the Mosque Lake area. This outcrop occurs along the east flank of the granite body along which the conglomerate is found (*see* Figure 7.3). Thick till cover in the Grindstone Lake area may cover additional Flinton Group outcrops.

Structural Style

Table 7.1 provides a synopsis of the structural history of the Palmerston Lake area. Most units within the southeastern domain dip moderately to steeply to the southeast, in contrast to the northwesterly trends typical of the remainder of the map area. The southeastern domain is dominated by 2 early, tight to isoclinal, recumbent, folding events about similar northeast-trending axes, which produce a type 3 interference pattern on the map. This map pattern is further complicated by a late, broad warping about west to northwest axes (F_3) and uplift across northwest- to west-trending faults. The 3 folding events are all post-Flinton Group deposition. Pre-Flinton Group deformation and metamorphism served to form regional shear zones, and probably established the pattern of alternating supracrustal versus orthogneiss lithotectonic domains present throughout the Mazinaw Terrane. Our structural history in the southeastern domain is roughly consistent with the observations of Thompson (1972) and Rivers (1976). However, higher metamorphic grade within the Palmerston Lake area has almost completely transposed the F_1 and F_2 structures, making stratigraphic and structural analysis within the area difficult (*see* also Ford this volume).

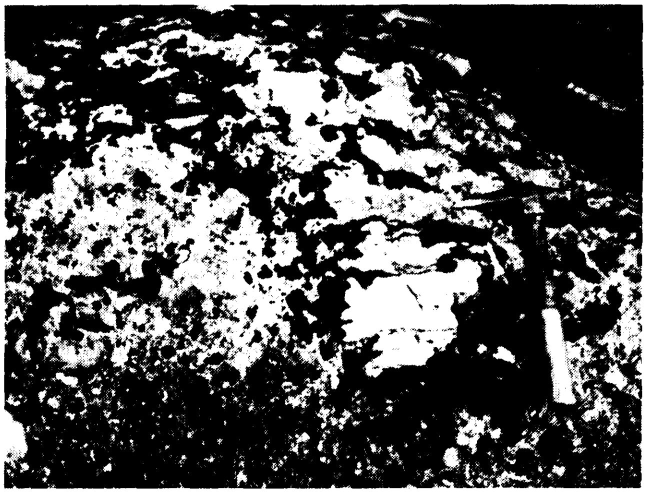

Photo 7.2. Matrix-supported conglomerate containing angular, locally derived granite cobbles in a calcite-diopside-phlogopite matrix, Grindstone Lake (UTM 18T 346495E 4986000N). This conglomerate is correlated with the Flinton Group.

WESTERN DOMAIN

Supracrustal Sequence B

Biotite-graphite calcite marble, biotite-hornblende-diopside calcite marble and calc-silicate rocks constitute the bulk of the supracrustal sequence within the western domain. Associated with these rocks are rusty-weathering, thin-layered, heterogeneous biotite-rich tonalite gneisses that may represent highly metamorphosed siliciclastic metasediments. Unlike the southeastern domain, no sedimentary features are preserved within these heterogeneous gneisses.

Gneisses and Metaplutonic Rocks

The bulk of the western domain consists of orthogneisses of 2 general types. Migmatitic, grey to white weathering, thin- to medium-layered, homogeneous tonalite orthogneisses and migmatitic, medium-layered, homogeneous syenogranite orthogneisses. The syenogranite orthogneisses appear to be the younger of the 2, based on locally preserved, angular crosscutting relationships. In addition, a variety of heterogeneous gneisses of unknown protolith occur in parts of the area. These include the rusty weathering tonalite paragneiss noted above; interlayered tonalite and granitic gneisses, possibly representing granitic sheets intrusive into the older tonalite gneisses; agmatitic granitic gneisses containing pods of layered amphibolite and tonalite gneiss; and heterogeneous tonalite-diorite-amphibolite gneisses. The latter may represent areas of extensive mafic diking, now highly transposed and metamorphosed. Most of these gneisses correspond to the heterogeneous gneiss unit of Karboski (1980) within the Norcan Lake area immediately north of the map area.

Deformed and undeformed white tonalite and pink granite pegmatites occur throughout the western domain, particularly within supracrustal sequence B. Tonalite pegmatites are most common in the marbles. The deformed pegmatites are protomylonitic and, if they are the same age as pegmatites in the southeastern domain and the Bancroft Terrane, this suggests deformation continued in the western domain while activity was waning elsewhere in the region.

Structural Style

Most units within the western domain dip moderately to the northwest and, as a result, there is considerable topographic control on the resultant map pattern, particularly given the rugged relief present within this domain. As illustrated in Table 7.1, the western domain differs from the southeastern domain in having a map pattern typical of a type 1 fold interference pattern. As outlined in Table 7.1, one possible explanation for the difference in structural style between the 2 domains is that the F_1 folds of the southeastern domain were completely transposed in the western domain, so that F_1 and F_2 can no longer be distinguished. This hypothesis is supported by the presence of deformed pegmatites in the domain, and the more prominent development of northwest-trending folds.

Karboski (1980) regarded the Norcan Lake area to the north as being characterized by a type 3 interference pattern, however, most of his detailed study area lay within the Bancroft Terrane, which may indeed be characterized by a type 3 pattern. Within the Mazinaw Terrane, Karboski's (1980) map shows the dome and basin pattern characteristic of a type 1 interference pattern.

Lower grade equivalents of all the orthogneisses of the western domain occur along the Buckshot Road 15 km west of the map area, and the orthogneisses of the western domain can be regarded as a highly deformed and metamorphosed equivalent of an Elzevir Suite (Easton 1992) tonalite body with intrusion breccia zones and younger dikes that was subsequently intruded by Methuen Suite (Easton 1992) granites. Both regional metamorphic events were intense and produced partial melts, which resulted in the formation of felsic leucosomes in both the metaplutonic and metasedimentary rocks in both domains within the map area (Photo 7.3).

Bancroft Terrane

ROCK TYPES

Three main rock types are found within the Bancroft Terrane in and adjacent to the Palmerston Lake area. Layered to bedded, medium-grained, calcite marbles, locally cut by white tonalite and pink granite dikes; thin- to medium-layered amphibolites representing metavolcanics, volcanic-derived metasediments, and mylonitized gabbros; and monzogranite to syenogranite foliated to gneissic plutons. Marble tectonic breccias occur locally.

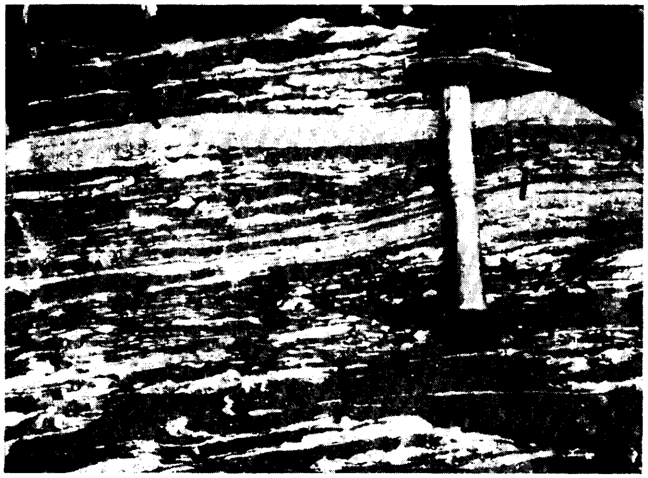

Photo 7.3. Metawacke from supracrustal sequence A of the Grenville Supergroup showing development of 2 leucosome phases (UTM 18T 355275E 4990250N). The earlier leucosome phase (related to M_1?) has been folded and refolded forming a series of isoclinal folds. The second leucosome phase (upper part of photo) cross-cuts the earlier phase at a slight angle, and is presumably related to M_2. M_1 and M_2 were both sufficently intense to induce partial melting in both supracrustal and plutonic rocks in the Palmerston Lake area; similar relationships between an earlier folded leucosome and a younger leucosome are found in tonalite and syenogranite orthogneisses within the map area.

MAZINAW-BANCROFT TERRANE BOUNDARY

The Bancroft Terrane crosses the northwest corner of the map area. The boundary is marked by a 250 to 750 m thick zone of straight gneisses of intermediate composition, which are probably derived from tonalitic and granitic rocks found south of the boundary and paramphibolites to the north. The straight gneisses are older than M_2, as flattened quartz lenticles within the straight gneisses have been recrystallized into equant quartz grains. Recrystallization has also increased the mean grain size of the straight gneisses, although the thinly laminated character of these rocks still persists. The straight gneisses dip to the northwest at 25° to 30°, and most units within the Bancroft Terrane dip shallowly to the northwest (*see* Table 7.1). The boundary has been traced from the lower metamorphic grade Mazinaw area into the Palmerston Lake area, however, this boundary has been offset to the northwest by Paleozoic-age faulting.

The boundary cuts across different rock types of the Mazinaw Terrane from west to east. In the extreme west, it places granitic gneisses of the Mazinaw Terrane against amphibolites of the Bancroft Terrane; moving east, the boundary juxtaposes Mazinaw Terrane tonalite orthogneisses against amphibolites and metawackes; farthest east, Mazinaw Terrane tonalite paragneisses are in contact with Bancroft Terrane marbles.

In contrast to the Mazinaw area, where metamorphic grade appeared to be higher on the Bancroft Terrane side of the boundary, metamorphic grade drops rapidly to the northwest in the Bancroft Terrane with increasing distance from the terrane boundary. This is most evident in the Round Schooner Lake area, where 500 m from the boundary, marbles are massive and coarse grained, yet 750 m from the boundary, they are medium grained and preserve bedding (likely transposed). This suggests that M_2 metamorphism in the western domain overprinted the terrane boundary, and that the boundary may have been established as early as 1160 Ma.

Paleozoic Strata

As shown in Figure 7.4, several small outliers of Paleozoic strata were found in the Palmerston Lake area. Northeast of Sunday Lake (UTM 18T 361780E 4987810N), a rusty-weathering, hematite-cemented, clast-supported conglomerate, consisting of angular to sub-angular fragments of Grenville Supergroup rocks, crops out. Near Twin Lakes, in the northeast corner of the map area (UTM 18T 361480 4996285), a calcite-cemented quartzite contains large hematite fragments; and northeast of Redhorse Lake (UTM 18T 358980E 4996225N), a calcitic limestone contains angular quartz grit and rare cobbles of gneiss and pegmatite. All these Paleozoic units are locally derived, with little transport, and probably represent the basal part of the Paleozoic sequence within the map area. They may be correlative with either the Covey Hill or Shadow Lake formations, which are generally regarded as Cambrian in age (Johnston et al. 1992).

Precambrian rocks within the eastern part of the Palmerston Lake are extremely friable and appear to have undergone extensive weathering. A possible explanation for this phenomenon is that the current level of exposure lies close to the position of the now eroded Precambrian–Paleozoic unconformity and we are seeing partial preservation of a pre-Paleozoic weathering surface that has been described elsewhere in southern Ontario (e.g., Di Prisco and Springer 1991).

Northwest- to West-Trending Faults

Northwest- to west-trending faults are prevalent throughout the Mazinaw Terrane in the map area (*see* Figures 7.3 and 7.4). Both right- and left-lateral faults with sizable offsets are present; 500 m along the right-lateral Plevna fault and 500 m along the left-lateral fault running along the west shore of Mosque Lake (*see* Figures 7.3 and 7.4). Although the existence of this fault set had been recognized previously (e.g., Plevna Fault, Smith 1958; Pauk 1987), the abundance of faults of this trend in the area, and the scope of movement along them was previously unknown.

Easton and Ford (1991) documented the presence of a similar set of left- and right-lateral northwest-trending faults in the Mazinaw area (*see* Figure 7.4), but were unable to establish the age of these faults. South of the Palmerston Lake area, the Plevna fault trends westerly (Smith 1958), but rotates into a northerly to northwesterly trend within the map area (*see* Figure 7.4). The

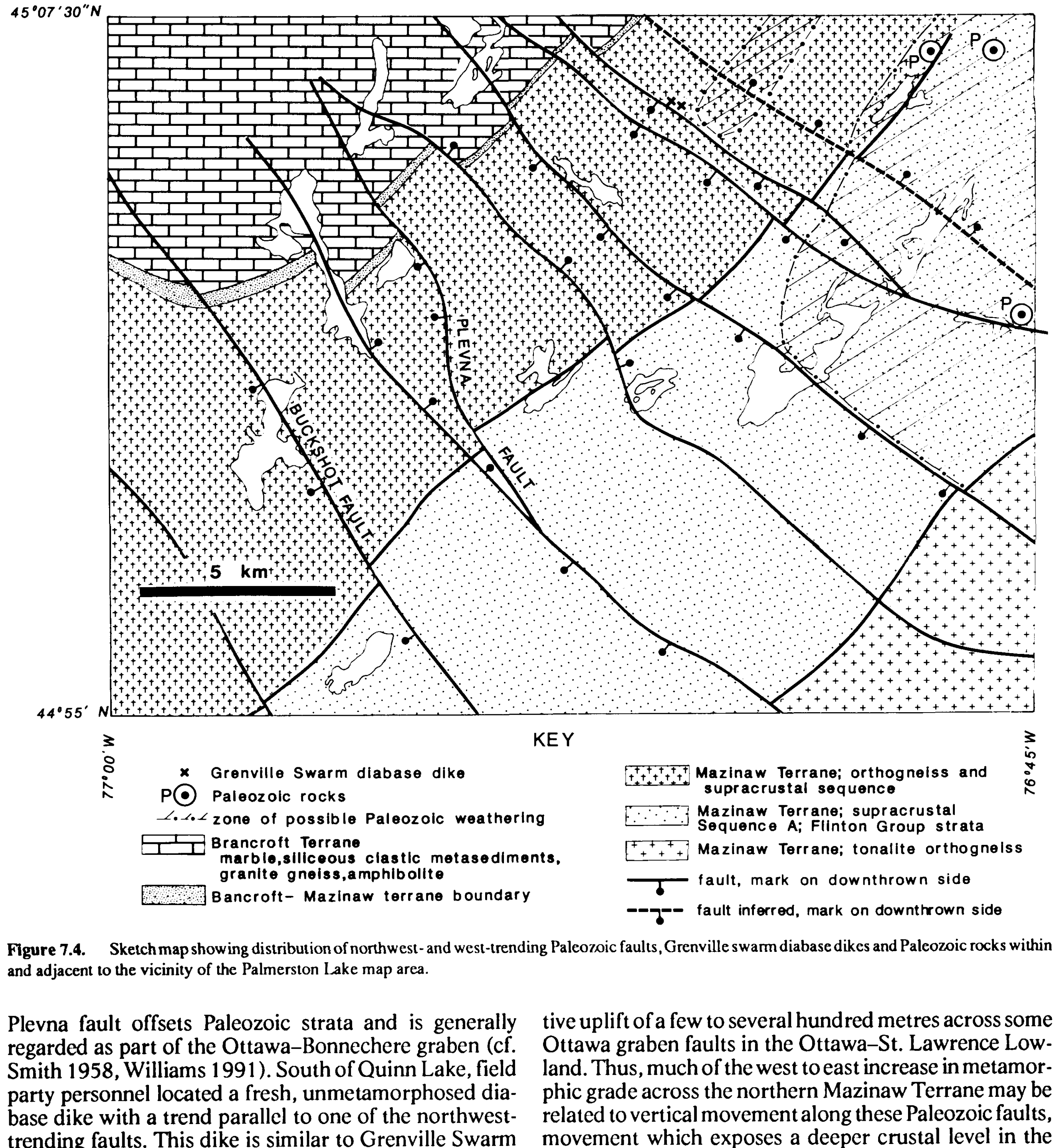

Figure 7.4. Sketch map showing distribution of northwest- and west-trending Paleozoic faults, Grenville swarm diabase dikes and Paleozoic rocks within and adjacent to the vicinity of the Palmerston Lake map area.

Plevna fault offsets Paleozoic strata and is generally regarded as part of the Ottawa–Bonnechere graben (cf. Smith 1958, Williams 1991). South of Quinn Lake, field party personnel located a fresh, unmetamorphosed diabase dike with a trend parallel to one of the northwest-trending faults. This dike is similar to Grenville Swarm diabase dikes associated with Ottawa–Bonnechere graben faults north of the map area (e.g., Lumbers 1982; Easton 1992), however, it has no expression on the regional aeromagnetic map (GSC 1952). Both the change in strike of the Plevna fault and the spatial association with unmetamorphosed diabase dikes suggests that the northwest-trending faults are Paleozoic in age. Metamorphic grade rises sharply across the Plevna fault, and it is likely that much of the apparent sinistral and dextral movement along these faults may be the result of vertical, not lateral movement. Williams (1991) documents relative uplift of a few to several hundred metres across some Ottawa graben faults in the Ottawa–St. Lawrence Lowland. Thus, much of the west to east increase in metamorphic grade across the northern Mazinaw Terrane may be related to vertical movement along these Paleozoic faults, movement which exposes a deeper crustal level in the northeastern Mazinaw Terrane.

The economic significance of these faults is unclear. In the Mazinaw area, Easton and Ford (1991) noted the common development of hematite, chlorite, and epidote adjacent to these faults, and epidotization is present at the western end of Sunday Lake along the trace of a west-striking fault. In addition, the only 2 areas of significant radioactive mineralization within the map area are spatially associated with these faults (*see* Economic Geology). Calcite-barite-fluorite-galena veins are commonly

Table 7.2. Assay results from samples collected by field party personnel from the Mazinaw area. All analyses by the Timiskaming Testing Laboratories, Ontario Geological Survey–Information Services Branch.

Sample Number	UTM Co-ordinates	Au (ounces per ton)	Cu (ppm)	Zn (ppm)	Other (ppm)	Comment
91RME–0232	338315E 4974800N	nil	23	<10		NW-trending fault in Norway Lake granite
92RME–0057	352280E 4984200N	nil	6	22	Ni=24	impure marble with pyrite, pyrrhotite
92RME–0080	349980E 4985100N	nil	46	116	Ni=16	rusty biotite-garnet-sillmanite schist, Myer Cave Fm.
92RME–1025A	361450E 4985315N	nil	56	70	Ni=27	rusty schist
92RME–1025B	" " " "	nil	39	11	Ni=18	quartz vein
92RME–1028	361475E 4984990N	nil	267	11	Ni=15	rusty schist
92RME–1054	361780E 4987810N	nil	419	22	Ni=82, Pb=40	gossan zone in mafic metawackes
92RME–1056	361275E 4987990N	trace	59	38	Pb=26	veins in granite
92RME–2010	354000E 4986180N	trace	59	14		sulphide in marble

Detection limit for Au is 0.01 ounces Au per ton, <10 ppm for Cu, Ni, Zn and Pb. Background levels in area are generally close to detection limits. All samples analyzed for Pb and Ni, only significant values reported.

associated with Ottawa graben faults closer to the Ottawa River. The Marlhill calcite mine (Smith 1958) was sited in a calcite vein along the Plevna fault 20 km southeast of the map area, but no such veins have yet been reported from the map area.

ECONOMIC GEOLOGY

Assay Results

Field party personnel collected samples for assay from a variety of rock types within the map area; results are presented in Table 7.2.

Sulphide Mineralization

Both Smith (1958) and Pauk (1983) report the presence of stratiform layers and lenses of massive pyrite and pyrrhotite up to 70 cm thick and at least 2 m long occurring intermittently over a strike length of 1.5 km, northeast of Sunday Lake. The sulphide mineralization forms gossans near the contact between hornblende-biotite schists (volcanic-derived metawackes?) and siliceous metasedimentary rocks (metawackes to meta-arenite). Sample 92RME–1054 (*see* Table 7.2) from one of the gossan zones near rusty-weathering, Paleozoic conglomerate may have been concentrated during pre-Paleozoic weathering (cf. Di Prisco and Springer 1991).

Pauk (1983) describes a second mineralized zone, 13 m wide and 500 m long, hosted in a fine-grained granite north of Sunday Lake. Mineralization consists of quartz veins containing stringers of galena, sphalerite, chalcopyrite and pyrite. Sample 92RME–1056 (*see* Table 7.2) is a grab sample from one of these veins.

Magnetite Mineralization

The Summit Lake magnetite deposit (UTM 18T 354730E 4990100N) operated in 1977–78 producing magnetite concentrate for high density aggregate with waste rock used as road fill, and contains at least 1 200 000 tonnes of ore (Carter et al. 1980). Surface stripping around the deposit provides spectacular exposures of both the ore zone and the host rocks. Massive magnetite mineralization is hosted in clinopyroxenite and gabbro. The clinopyroxenite appears to be hosted in a recrystallized shear zone consisting of fine-grained, white to pink weathering quartzofeldspathic gneisses. The shear zone lies along the southeastern edge of a large area of gabbro and gabbroic gneisses, both locally garnetiferous. The clinopyroxenite is altered to a coarse-grained grossularite-diopside gneiss; this alteration generally occurs in a zone 50 to 250 m distant from the magnetite ore. Carter et al. (1980) regarded the deposit as a skarn deposit, however, marbles and calc-silicate rocks are not found near the deposit. The deposit, however, is locally cut by calcite veins. Many skarn deposits are zoned, with magnetite abundant near the heat and fluid source, grading outward into garnet endoskarn and finally, pyroxene endoskarn. If the Summit Mine is indeed a skarn, then potential for copper-gold mineralization may occur within the pyroxene endoskarn which lies beyond the mine property. On the other hand, ultramafic pods and oxide mineralization occur in gabbroic rocks of the Killer Creek Gabbro Suite (Easton 1992) at a lower grade and at a similar stratigraphic level southwest of the Mazinaw area; it is possible that this deposit represents a metamorphosed magmatic deposit. The complex deformational and metamorphic history, however, renders any conclusions on the origin of this deposit equivocal. The Summit Lake deposit was discovered through the use of aeromagnetic surveys (Carter et al. 1980), and it is noteworthy that the deposit is not evident on the regional areomagnetic map of the Clyde Forks area (GSC 1952). Consequently, undiscovered deposits of similar-size could be present in the Palmerston Lake area, and at the same stratigraphic level to the southwest.

Smith (1958) and Carter et al. (1980) describe a magnetite deposit on the southeast shore of Longstone Lake near a marble-paragneiss contact. Field party personnel could not locate this deposit, which apparently was originally prospected prior to 1909. This deposit is roughly on strike with the Summit Lake deposit.

Field party personnel located an area of compass unreliability approximately 350 m in diameter on the north-central shore of Redhorse Lake (UTM 18T, centred at 358725E 4995000N) hosted in a deformed, Killer Creek Suite type gabbro-anorthositic-hornblendite body. This anomaly may represent a magnetite deposit associated with the hornblendite phase of the deformed pluton.

Industrial Minerals

A 300 to 500 m wide belt of coarse-grained white dolomitic marbles, with layers, pods and segregations of coarse-grained, white to pale-green tremolite and diopside occurs along the southwest shore of Palmerston Lake (UTM 18T approximately 352700E 4985400N), and has a strike-length of at least 2 km. Photo 7.4 illustrates the grain size and form of the tremolite aggregates within this zone, which probably represents the higher metamorphic grade equivalent of a belt of pure, blue-grey dolomitic marbles present within the Ardoch map area, traceable from Plevna to Palmerston Lake (LeBaron and MacKinnon 1990). LeBaron and MacKinnon (1990) report analyses of the lower grade dolomites indicating high-purity and low brightness. The high-grade equivalents are much whiter than the low-grade rocks, and it is likely that brightness is higher than in the low-grade rocks. Thin-section examination of the high-grade rocks indicates high-purity (less than 2% impurities). This belt has the potential of producing high-purity and high-brightness dolomite, and possibly tremolite and diopside.

Also associated with these dolomitic rocks are quartz segregations, some of which contain the fine laminations typical of algal-mat stromatolites (cf. Photo 7.1). This belt of dolomites can be traced discontinuously along strike from Palmerston Lake to Lavant Long Lake, and several possible stromatolite occurrences have been noted along this belt by field party personnel, as indicated on Figure 7.3.

Another area of coarse-grained, white, high-purity dolomite marble occurs east of Sunday Lake (UTM 18T 361720E 4987725N). Within the Bancroft Terrane, coarse-grained, white, calcite marbles containing less than 5% impurities occurs in cliffs along the western shore of Long Schooner Lake (UTM 18T 343910E 4996390N). Thin-section examination indicates fine-grained apatite and oxides are the main impurities.

Smith (1958) described a talc deposit southeast of Mosque Lake (UTM 18T 350610E 4986055N) that operated between 1939 and 1941. Although described as a talc schist, the host rock consists of a belt of calc-silicate, dolomite, and tremolite, with local development of talcose zones. LeBaron and Van Haaften (1989) show a sketch map of this deposit showing the location of 5 prospect pits and 2 shafts on the property. Subsequent to their study, additional exploration was conducted on this property, in the form of 3 trenches dug perpendicular to strike of the talc-dolomite unit across pits 2, 3 and 4, and in a talc-tremolite band located 150 m to the north (UTM 18T 350600E 4986150N). A grab sample from the northern trench collected by field party personnel consisted entirely of pale green to white tremolite.

As shown in Figure 7.3, this talc-tremolite-dolomite band extends through Mosque Lake, and is offset along a northwest-trending fault. The talc-tremolite-dolomite belt is isoclinally folded, overturned to the north, and plunges to the east. On an island in the centre of Mosque Lake, talc-serpentine schist is present (UTM 18T 349250E 4985440N). On another island, at the extreme west end of Mosque Lake (UTM 18T 348380E 4985520N), field party personnel located an area of pure, white to pale green talc schist. Our observations suggest that the purest and highest grade talc deposits may be located in and under Mosque Lake, and that the previously operated deposit is located in a poor-quality part of the belt.

The Flinton Group within the map area potentially hosts garnet, sillimanite, or muscovite deposits, however, no sizable concentrations were found by field party personnel. Large garnets occur in Flinton Group rocks southeast of Mosque Lake, and may potentially be used as gemstones. Myer Cave Formation pelitic rocks within the map area are generally garnet-sillimanite bearing, and have the best potential for these 2 commodities. Muscovite-rich zones are generally found within the Bishop Corners Formation pelites. Field party personnel visited the Turcott Lake mica prospect (Storey and Vos 1981), and noted that the pelites at this site are no richer in muscovite than elsewhere in the map area.

No building stone prospects have been documented from the map area, nor have any quarries operated within the map area (LeBaron et al. 1989). Mair Lake is a previously undescribed marl lake.

Radioactive Mineralization

Airborne gamma-ray spectrometric maps of the area (GSC 1976) show 2 areas of radioactive mineralization in the map area, the largest of which is located southeast of Reid Lake, the other being located northeast of Round Schooner Lake along the northern boundary of the map area. Masson and Gordon (1981) describe exploration activity and occurrences from both areas. Southeast of Reid Lake, uranium and thorium mineralization is associated with a large area of granite pegmatite dikes, commonly containing smokey quartz, that intrude tonalite orthogneiss. South of South Quinn Lake is a large area of granite pegmatite outcrop (*see* Figure 7.3), however, it is not anomalous in uranium or thorium on the gamma-ray maps. All of these pegmatites were explored in 1969 and 1976–77, according to Masson and Gordon (1981), with the highest mineralization being reported from the Bordun occurrence (1.4% Th; 3800 ppm U_3O_8, UTM 18T ap-

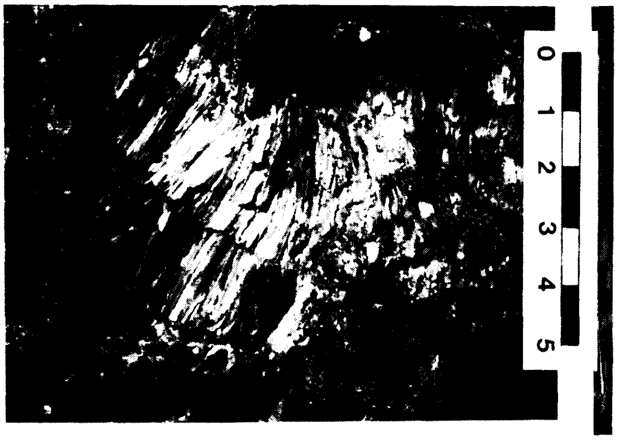

Photo 7.4. Coarse, white to pale green tremolite aggregates associated with massive white dolomite and white to pale green diopside on the southwest shore of Palmerston Lake (UTM 18T 352720E 4985400N).

proximately 349680E 4990710N). Field party personnel located several trenches and diamond drillholes related to this previous exploration activity.

In the Round Schooner Lake area, Masson and Gordon (1981) reported radioactive mineralization from several granite and diorite pegmatite dikes intruded into carbonate rocks of the Bancroft Terrane. These dikes, first explored in 1954, are small and not as abundant as in the Reid Lake area. The highest assay values reported by Masson and Gordon (1981) were 490 ppm U_3O_8 and 390 ppm Th.

Field party personnel located a series of trenches in granite pegmatite dikes intrusive into granitic and tonalitic gneisses on the south shore of Long Schooner Lake (UTM 18T approximately 345350E 4996000N) for which no previous exploration activity has been described. These pits appear to date from the mid-1970s. Scintillometer readings were only slightly higher than background, and no significant mineralization was noted by field party personnel.

Both areas of radioactive mineralization occur near northwest-trending faults (*see* Figure 7.3) and, given the fact that pegmatite dikes occur throughout the map area, this spatial association may be significant. Masson and Gordon (1981) reported the highest mineralized values in sheared, biotite-rich rocks, and it is possible that late-stage fluid-movement related to these faults may have served to remobilize and concentrate pre-existing radioactive mineralization, similar to the Paleozoic-hosted South March occurrence (*see* Masson and Gordon 1981, p.94).

REFERENCES

Carter, T.R., Colvine, A.C. and Meyn, H.D. 1980. Geology of base metal, precious metal, iron and molybdenum deposits in the Pembroke–Renfrew area; Ontario Geological Survey, Mineral Deposits Circular 20, 186p.

Di Prisco, G. and Springer, J.S. 1991. The Precambrian–Paleozoic unconformity and related mineralization in southeastern Ontario; Ontario Geological Survey, Open File Report 5751, 122p.

Easton, R.M. 1988. Precambrian Geology of the Darling area; Ontario Geological Survey, Open File Report 5693, 208p.

——— 1992. The Grenville Province and the Proterozoic history of central and southern Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.713–904.

Easton, R.M. and Ford, F.D. 1991. Geology of the Mazinaw area; *in* Summary of Field Work and Other Activities, Ontario Geological Survey, Miscellaneous Paper 157, p.95–106.

Ford, F.D. in preparation. Stratigraphy and metamorphism of the Flinton Group; unpublished PhD thesis, Carleton University, Ottawa, Ontario.

Geological Survey of Canada 1952. Clyde Forks; Geological Survey of Canada Map 68G, Aeromagnetic Series, scale 1:63 360.

——— 1976. Federal–Provinical uranium reconnaissance program, airborne gamma-ray spectrometry data, Pembroke (31F), Ontario–Quebec; Geological Survey of Canada Open File 331, scale 1:250 000.

Johnston, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G. and Rutka, M.A. 1992. Paleozoic and Mesozoic Geology of Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.905–1008.

Karboski, F. 1980. Structure and stratigraphy of the Norcan Lake area, Grenville Province, southeastern Ontario; unpublished MSc thesis, Carleton University, Ottawa, Ontario, 100p.

Kinsman, A. and Parrish, R.R. 1990. U-Pb age of detrital zircons from five quartzites in the Central Metasedimentary Belt of the Grenville Province; Geological Association of Canada–Mineralogical Association of Canada, Program with Abstracts, v.15, p.A70.

LeBaron, P.S. and MacKinnon, A. 1990. Precambrian dolomite resources in southeastern Ontario; Ontario Geological Survey, Open File Report 5712, 134p.

LeBaron, P.S. and Van Haaften, S. 1989. Talc in southeastern Ontario; Ontario Geological Survey, Open File Report 5714, 240p.

LeBaron, P.S., Verschuren, C.P., Papertzian, V.C. and Kingston, P.W. 1989. Building stone potential in eastern Ontario; Ontario Geological Survey, Open File Report 5706, 539p.

Lumbers, S.B. 1982. Summary of metallogeny, Renfrew County; Ontario Geological Survey, Report 212, 58p.

Masson, S.L. and Gordon, J.B. 1981. Radioactive mineral deposits of the Pembroke–Renfrew area; Ontario Geological Survey, Mineral Deposits Circular 23, 155p.

Moore, J.M. and Morton, R.L. 1986. Geology of the Marble Lake area; Ontario Geological Survey, Report 238, 63p.

Moore, J.M. and Thompson, P. 1980. The Flinton Group: A Late Precambrian metasedimentary succession in the Grenville Province of eastern Ontario; Canadian Journal of Earth Sciences, v.17, p.1685–1707.

Ontario Geological Survey 1984a. Miller Township, Frontenac County; Ontario Geological Survey, Geological Data Inventory Folio 81, 16 p. and 2 maps.

——— 1984b. North Canonto Township, Frontenac County; Ontario Geological Survey, Geological Data Inventory Folio 82, 14 p. and 2 maps.

——— 1984c. South Canonto Township, Frontenac County; Ontario Geological Survey, Geological Data Inventory Folio 83, 16 p. and 2 maps.

——— 1984d. Clarendon Township, Frontenac County; Ontario Geological Survey, Geological Data Inventory Folio 88, 22 p. and 2 maps.

——— 1984e. Palmerston Township, Frontenac County; Ontario Geological Survey, Geological Data Inventory Folio 89, 24 p. and 2 maps.

Pauk, L. 1983. Sunday Lake area and Ardoch–Dalhousie Lake–Lavant area, Frontenac and Lanark counties; *in* Summary of Field Work, 1983, Ontario Geological Survey, Miscellaneous Paper 116, p.84–87.

——— 1987. Geology of the Ardoch area; Ontario Geological Survey, Report 241, 57p.

Ramsay, J.G. 1967. Folding and fracturing of rocks; McGraw–Hill, New York, 566p.

Rivers, T. 1976. Structures and textures of metamorphic rocks, Ompah area, Grenville Province, Ontario; unpublished PhD thesis, University of Ottawa, Ottawa, Ontario, 281 p.

Smith, B.L. 1958. Geology of the Clarendon–Dalhousie area; Ontario Department of Mines, Annual Report, 1956, v.45, pt.7, p.1–46.

Storey, C.C. and Vos, M.A. 1981. Industrial minerals of the Pembroke–Renfrew area, Part 2; Ontario Geological Survey, Mineral Deposits Circular 22, 214p.

Thompson, P.H. 1972. Stratigraphy, structure and metamorphism of the Flinton Group in the Bishop Corners–Madoc area, Grenville Province, eastern Ontario; unpublished PhD thesis, Carleton University, Ottawa, Ontario.

Williams, D.A. 1991. Paleozoic geology of the Ottawa–St. Lawrence Lowland, southern Ontario; Ontario Geological Survey, Open File Report 5770, 292p.

8. Project Unit 92–05 (Part 2). Geology of the Fernleigh and Ompah "Synclines", Palmerston Lake Area

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INTRODUCTION AND PREVIOUS WORK

This report describes part of the Palmerston Lake area, centred around Sunday Lake (*see* also Easton, this volume) (Figures 8.1 and 8.2). This part of the project had several specific aims: 1) to review the general geology of the Sunday Lake area, 2) to study the stratigraphic and structural relationship between Flinton Group units within the Ompah structure, 3) to determine the relationship, if any, between the Ompah Conglomerate and other, previously described, Flinton Group rocks.

Several researchers have previously mapped and described the geology of the area. Miller and Knight (1914) included a map of the area in their reconnaissance study of the Precambrian geology of southeastern Ontario. Smith (1958) mapped the study area at a scale of one inch to one mile (1:63 360) as part of the Clarendon–Dalhousie map sheet. Based on this mapping, Smith (1969) subsequently described the stratigraphy of "Hastings Series" rocks within the Ompah "syncline" and their relationship with the surrounding Grenville Supergroup rocks. Rivers (1976) included the area in a study focussing on structure, stratigraphy and metamorphism. One inch to half mile (1:31 680) scale mapping by the Ontario Geological Survey has been conducted south (Ardoch area, Pauk 1987), east (Lavant area, Pauk 1989b) and south-east (Dalhousie Lake area, Pauk 1989a) of the study area. The regional geologic setting of the study area has been summarized in the accompanying report by Easton (this volume) and is not repeated here.

GENERAL GEOLOGY

The study area is cut by two major linear structures (*see* Figure 8.2), which contain metasedimentary rocks assigned by Moore and Thompson (1972, 1980) to the Flinton Group, a sequence of metamorphosed siliceous clastic and carbonate sediments which unconformably overlie older Grenville Supergroup metavolcanic and metasedimentary rocks and associated gabbroic and granitoid intrusions. The northernmost structure has been termed the Fernleigh syncline by Moore and Thompson (1972, 1980). The southern structure has been called the Ompah syncline (Smith 1958, 1969; Moore and Thompson 1972, 1980; Pauk 1983, 1987). In this report, we refer to these structures as the Fernleigh structure and the Ompah structure, respectively. These 2 structures are surrounded by mafic to intermediate metavolcanic rocks, volcanic metasediments, siliceous clastic metasediments and marbles assigned to the Grenville Supergroup. The geology of the 2 structures and the older intervening rocks will be discussed separately.

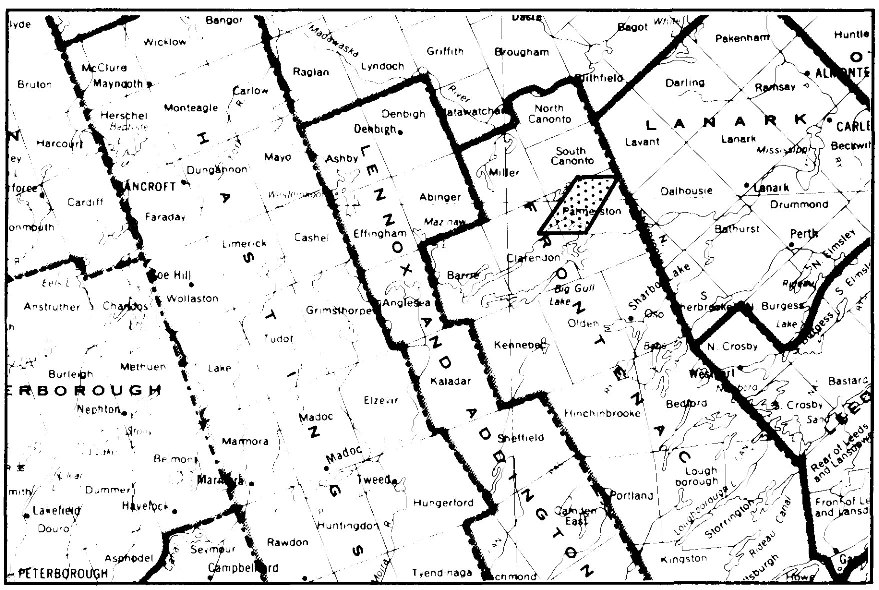

Figure 8.1. Location map of the study area in the Grenville Province, scale 1:1 584 000.

GEOLOGY OF THE FERNLEIGH STRUCTURE

The geology of the Fernleigh structure within and southwest of the study area has been documented by Smith (1958), Moore and Morton (1986) and Pauk (1983, 1987, 1989b). Highway 509 east of Ompah provides a representative section through the Flinton Group. A detailed description of this section is warranted because increasing deformation and metamorphism make the stratigraphy less recognizable to the northeast, an observation also made by Moore and Thompson (1972) and Rivers (1976).

The basal unit on the northern limb of the Fernleigh structure is a muscovite-rich pelite of the Bishop Corners Formation. This unit strikes approximately 045° and is well exposed up strike along the power line which extends to the northeast. In thin section, this unit contains mostly quartz, muscovite and biotite, with porphyroblasts of oxide minerals and radiating sillimanite needles. The unit displays some evidence of retrograde metamorphism. Most biotite grains have been altered to chlorite containing a fine mat of rutile needles. This retrogression, and other alteration such as epidotization of Ompah Conglomerate rocks at the west end of Sunday Lake, may be associated with the Fernleigh–Clyde fault, identified by Smith (1958). The fault trends northeast, subparallel to the northern margin of the Fernleigh structure and can be traced as a prominent airphoto lineament. The Fernleigh–Clyde fault may be similar in age to other northwest- and west-trending faults in the area (*see* Easton, this volume). Truncation of the Bishop Corners pelite near the west end of Sunday Lake, suggests that a component of fault movement is dextral. It should be noted that several previous workers (Moore and Thompson 1972; Rivers 1976; Pauk 1983) have questioned the existence of the Fernleigh–Clyde fault.

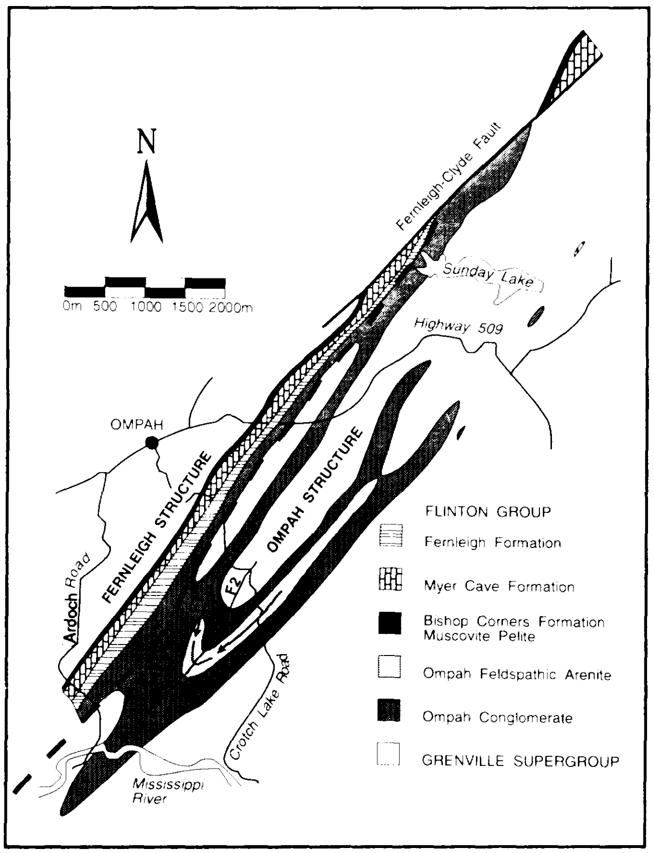

Figure 8.2. Geological sketch map of the study area. Dashed line marks boundary between the Ompah and the Fernleigh structures.

A thin unit of Myer Cave Formation pyritic biotite schist overlies the muscovite pelite. This rock is fine grained and massive with no visible bedding. The pyritic schist is overlain by coarse-grained calcite marble of the Myer Cave Formation. The marble is indistinguishable from surrounding Grenville Supergroup marbles and is assigned to the Flinton Group on the basis of map position (it lies between Bishop Corners Formation muscovite pelite and Fernleigh Formation calc-silicate schist).

The marble is overlain by an interbedded sequence of compositionally varied, fine-grained, biotite schists of the middle part of the Myer Cave Formation. Compositional layering occurs on a metre-scale and may reflect primary bedding. Some layers are garnet-rich, whereas others contain sulphide (typically pyrite).

The upper part of the Myer Cave Formation is a distinctive garnet-biotite-sillimanite pelite, similar to Myer Cave Formation pelites previously mapped to the southwest (Ford, in prep.; Easton and Ford 1991). Myer Cave Formation pelites have a uniform, iron-rich bulk composition, and are rich in biotite and garnet, whereas Bishop Corners pelites are more aluminous, muscovite-rich and span a larger iron to magnesium bulk compositional range. This pelite unit is similar in appearance to Myer Cave Formation pelites from the Green Bay area to the southwest (Ford, in prep.), but lacks staurolite which breaks down by metamorphic reaction to form additional biotite-garnet-sillimanite. This staurolite-out isograd is located immediately southwest of the map area, running north-south, roughly through the centre of Mud Lake (Ford, in prep.)(*see* Figure 8.2). The pelite described above appears to be partly interbedded with the overlying unit, a biotite schist, similar in appearance to the previously described biotite schists.

A thin, laminated, biotite-diopside calc-silicate schist, assigned to the Fernleigh Formation, is the highest stratigraphic unit encountered. Thin alternating diopside-rich and biotite-rich layers (beds) characterize the unit. Metamorphic reaction has produced the diopside-rich layers from carbonate-rich layers, present in lower grade equivalents (Moore and Thompson 1980). A second type of calc-silicate schist appears to overlie the typical Fernleigh Formation schists. This rock is more massive with irregularly spaced calc-silicate bands instead of well-developed laminations.

On the southern limb of the Fernleigh structure, a clast-supported conglomerate of the Bishop Corners Formation (Photo 8.1) appears to be in direct contact beneath the Fernleigh Formation, implying that the Myer Cave Formation is absent. The conglomerate is clast-supported and monomictic, composed mainly of vein quartz pebble, with a micaceous matrix. This conglomerate is readily distinguished from an underlying conglomerate, and although relatively thin, appears to have a strike-length of at least 8 km.

It should be noted that the Myer Cave Formation units, absent from the southern limb of the Fernleigh structure near Highway 509, appear to be present north of Sunday Lake (*see* Figure 8.2), where siltstone, iron-rich pelite and calcite marble are found between the Fernleigh Formation and Bishop Corners Formation quartz-pebble conglomerate.

In the Highway 509 area, the lowermost Flinton Group unit on the southern limb of the Fernleigh structure is a matrix-supported, polymictic conglomerate with a mafic matrix, similar to the Ompah Conglomerate. This unit will be described in detail in the following section.

Ompah Conglomerate

The basal unit on the southern limb of the Fernleigh structure in the study area is a matrix-supported conglomerate with an amphibole and biotite-rich matrix (Photo 8.2). The conglomerate contains a wide variety of clasts, in order of abundance they are: 1) fine-grained granodiorite to tonalite, 2) quartzite, 3) vein quartz, 4) medium-grained granite, 5) mafic clasts (now composed mostly of biotite, and 6) rare, pink, calcite marble clasts. Clast size varies from 1 to 30 cm.

The matrix of this conglomerate is unique among Flinton Group conglomerates, being unusually rich in amphibole and biotite. In thin section, the matrix is composed predominantly of granoblastic quartz and plagioclase and pleochroic green amphibole. Minor phases include epidote, opaque minerals, carbonate and titanite. A small amount of plagioclase has been altered to sericite and texturally late, radiating chlorite crystals overgrow earlier amphiboles. Garnet was observed in the matrix at several outcrops. The matrix amphibole may have grown as the result of a carbonate breakdown reaction which consumes calcite and produces calcic amphibole. This suggestion is supported by the decreasing proportion of marble clasts in the conglomerate as one moves up metamorphic grade to the northeast.

In this paper, the conglomerate described above will be referred to as the Ompah Conglomerate even though this conglomerate occurs in both the Fernleigh and Ompah structures.

An amphibole-biotite rock resembling the matrix of the Ompah Conglomerate, but lacking pebbles, was mapped at several locations by field party personnel. This unit may have originally been a calcareous mud.

Other Units

A fine-grained, homogeneous, pink-weathering, metasandstone (feldspathic arenite) in the vicinity of Sunday Lake is assigned to the Myer Cave Formation. This unit is interbedded with a more biotite-rich lithic wacke which commonly contains garnet. The metasandstone is distinguished from Bishop Corners Formation quartzites by composition and by a lack of primary bedding structures, such as heavy mineral-rich crossbeds. A similar rock is described by Moore and Thompson (1980) as the micaceous quartzofeldspathic psammite member of the Bishop Corners Formation.

Correlation Between the Ompah and Fernleigh Structures

The conglomerate bands within the Ompah structure are lithologically identical to the conglomerate found at the

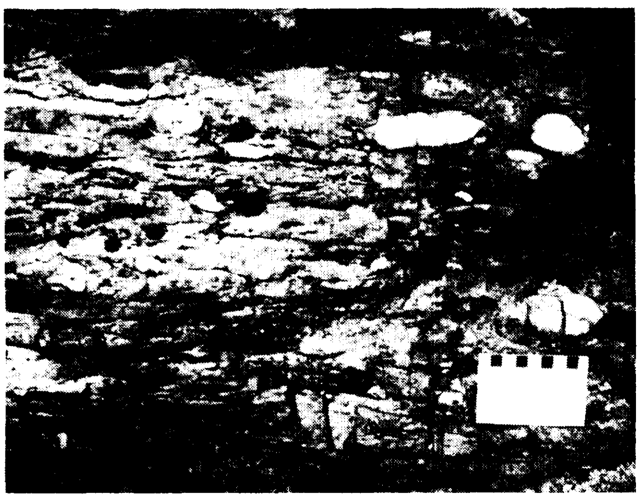

Photo 8.1. Monomictic, clast-supported quartz pebble conglomerate with a micaceous matrix of the Bishop Corners Formation.

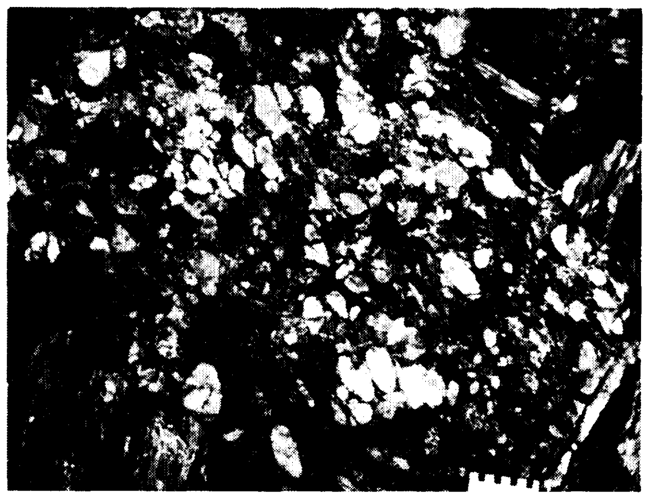

Photo 8.2. Matrix-supported, polymictic Ompah Conglomerate, Bishop Corners Formation. The matrix consists mainly of amphibole and biotite.

base of the southern limb of the Fernleigh structure. The similarity of the 2 conglomerates can be used to support the assignment of the Ompah structure conglomerates to the Flinton Group, as the conglomerate in the Fernleigh structure is clearly part of the Flinton Group. In addition to lithologic similarity, mapping by the author indicates that the 2 structures are in direct contact northeast of the Ardoch Road bridge over the Mississippi River (*see* Figure 8.2). Diopside-bearing, rhythmically layered schists of the Fernleigh Formation are in sharp contact with Bishop Corners Formation, clast-supported, quartz-pebble conglomerate with a micaceous matrix. This conglomerate is in sharp contact with Ompah-type conglomerate which persists with good outcrop coverage for a kilometre to the southeast. Previous mapping by Moore and Thompson (1980) and Pauk (1983) indicated that the 2 structures ("synclines") were separated by a narrow anticline of pre-Flinton Group marble, however, in the map area, there is insufficient room for a marble band to occur between the 2 structures (*see* Figure 8.2).

Age of the Ompah Conglomerate

It is not possible to tell if the Ompah Conglomerate on the south limb of the Fernleigh structure is older than the muscovite pelite on the north limb because stratigraphy is not repeated across the structure. The pattern on the map (*see* Figure 8.2), however, suggests that foliation and layering within the Ompah structure are truncated by the Fernleigh structure. Rivers (1976) states that this truncation is due to the structural attenuation of certain units causing convergence of contacts. However, where observed by the author, this truncation appears to be a stratigraphic, rather than a structural phenomenon, because there is no evidence of a structural discontinuity between Fernleigh structure rocks and the Ompah Conglomerate. This suggests that the Ompah Conglomerate may be older than other Flinton Group rocks in the Fernleigh structure.

This suggested age difference within rocks of the Flinton Group may also be present southwest of the study area near Northbrook, where Flinton Group conglomerates contain quartzite pebbles similar in appearance to underlying Flinton Group quartzites, implying that the quartzite was lithified, eroded and transported prior to conglomerate deposition.

GEOLOGY OF THE OMPAH STRUCTURE

Stratigraphy

PREVIOUS WORK

Despite the large amount of mapping within the Ompah structure, only 3 previous workers, Miller and Knight (1914), Moore and Thompson (1972, 1980) and Pauk (1983, 1987), recognized the presence of an unconformity at the base of the Ompah Conglomerate and attempted to interpret the structure by assigning units above the unconformity to the Flinton Group. The current study assumes that an unconformity is present.

Miller and Knight (1914) briefly described the geology near Ompah. Due to the reconnaissance scope of their project, they only distinguished the Ompah Conglomerate, which they assigned to the Hastings Series, from the surrounding Grenville Supergroup rocks, which they assigned to the Grenville Series. Smith (1958) identified the Ompah Conglomerate as being "Hastings-type" and recognized that it, and the quartzite of the Ompah structure, rests on older marbles. Smith (1958, 1969) also recognized that rhythmically bedded schists, assigned by Moore and Thompson (1972, 1980) to the Fernleigh Formation, lay stratigraphically above the Ompah Conglomerate found at the base of the Fernleigh structure northeast of Mud Lake. Smith (1969) identified the Ompah Conglomerate as the basal unit of the Ompah structure. He noted an isolated exposure of coarse conglomerate east of the Lavant post office (Highway 509 and Lanark County Road 12 junction) where the conglomerate appears to rest on older marbles south of the syncline, but did not specifically identify this relationship as an unconformity.

Moore and Thompson (1972, 1980) assigned the conglomerate and quartzite in the Ompah structure to the Bishop Corners Formation of the Flinton Group. These authors, in addition to others (Smith 1958; Pauk 1983), suggested that the fine-grained, laminated to massive, hornblende-biotite and hornblende schists on the east end of Sunday Lake lie stratigraphically above, and are therefore younger than, the Ompah Conglomerate.

Rivers (1976) stated that there was no direct evidence for an unconformity in the map area, suggesting that if it were present, it was obscured by lack of outcrop and by parallelism of unit contacts imposed by several periods of coaxial deformation. Rivers (1976) questioned the assignment by Moore and Thompson (1972) of conglomerate and pelitic units in the Ompah structure to the Flinton Group, noting that metavolcanic rocks occur in the Ompah structure, structurally and possibly stratigraphically above the Flinton Group, which, by definition, contains only metasedimentary rocks.

THIS STUDY

Key to the understanding of the stratigraphy of the Ompah structure is the realization that the metavolcanic rocks, volcanic metasediments and dolomitic marbles which occur in the core of the structure near Sunday Lake (*see* Figure 8.2) must be correlative with the Grenville Supergroup, and are therefore older, not younger, than the Ompah Conglomerate. Several observations, discussed below, support this conclusion.

1. Stromatolites in the dolomitic marble belt which runs through the centre of Sunday Lake (*see* Figure 8.2; *see* also Easton, this volume, Photo 7.1) indicate an affinity with the Grenville Supergroup. As noted by Easton (this volume), stromatolites are common in this belt of dolomitic marbles which can be traced

Photo 8.3. Cross-bedding in the Ompah feldspathic arenite. Beds are overturned since they dip to the south and top to the north.

from Sunday Lake to Lavant Long Lake. Whereas stromatolites are relatively common in the Grenville Supergroup, only a single occurrence of stromatolites in Flinton Group marbles has been documented to date (Bright 1986; Easton 1992). The apparent rarity of stromatolites in the Flinton Group, combined with the presence of Grenville Supergroup stromatolitic marbles to the north and the west (Easton, this volume, Figure 7.3) suggests that it is most reasonable to assign the Sunday Lake dolomitic marbles to the Grenville Supergroup.

2. The suggestion by Moore and Thompson (1972) and Pauk (1983) that mafic rocks at the east end of Sunday Lake be assigned to the Flinton Group must be rejected. Although some of these rocks are clearly sedimentary, being quartz-rich and thinly laminated, probably mafic turbidites, others are more massive and finer grained, with less quartz and more hornblende and plagioclase, suggesting a mafic volcanic origin. It is unlikely that these mafic metavolcanic rocks belong to the Flinton Group as there has been no previous discovery of Flinton Group volcanic rocks.
3. Although some of the mafic turbidites are laminated, and therefore grossly similar to the Fernleigh Formation in appearance, they lack the carbonate or diopside-rich interbeds of this formation. To assign these mafic turbidites to the Flinton Group would require the creation of a new, separate unit. Given the high degree of metamorphism in the area, such an assignment should be made only if there is irrefutable evidence that the rocks in question are Flinton Group in age. Since no such evidence exists, it seems more reasonable to assign this package of mafic metavolcanic and metasedimentary rocks to the Grenville Supergroup.

OMPAH FELDSPATHIC ARENITE

Cross-bedding (Photo 8.3) found in 2 locations confirms that a feldspathic arenite, termed quartzite by previous workers, lies above the Ompah Conglomerate. This rock weathers buff-white and is fine grained. Bedding is varied, some outcrops contain abundant 1 cm thick beds, whereas other outcrops are massive. The arenite is similar in appearance to the Myer Cave Formation arenite found in the Fernleigh structure.

STRATIGRAPHIC SUMMARY

The presence of stromatolites and mafic rocks of probable volcanic origin suggests that the belt of marbles and mafic rocks near Sunday Lake belong to the Grenville Supergroup. Metaconglomerates in the Ompah structure are lithologically identical to, and in direct contact with, Flinton Group metaconglomerates in the Fernleigh structure and must therefore belong to the Flinton Group. Therefore, there is strong stratigraphic evidence to suggest that the Ompah structure is an anticline, rather than a syncline.

Consequently, the oldest rocks of the Grenville Supergroup are found near Sunday Lake, forming the core of the Ompah anticline. The succession consists of a basal unit of dark, fine-grained amphibolites grading stratigraphically upward into massive and laminated mafic metasediments, which, in turn, grade into calcareous clastic sediments and dolomitic marbles. These Grenville Supergroup rocks are, in turn, unconformably overlain by conglomerates and feldspathic arenites of the Flinton Group.

South of Highway 509, a medium-grained, massive tonalite to granodiorite intrudes mafic rocks in the core of the anticline. This rock is similar in appearance to the Ompah feldspathic arenite described above, and has previously been identified as such by several workers (Smith 1958; Pauk 1983, 1987), however, the tonalite lacks any evidence of bedding and has a more interlocking texture. Further, the Ompah Conglomerate contains pebbles similar in appearance to this rock.

Structure

Previous authors have identified the Ompah structure as a northeast-plunging syncline. Current mapping indicates that there has been at least 2, possibly 3, periods of deformation and folding.

The first period of deformation (D_1) produced northeast-trending, isoclinal, possibly recumbent folds. These first phase folds (F_1) are only evident from the map pattern. No distinctive structural fabric associated with F_1 was recognized by the author.

The second period of deformation (D_2) resulted in a second set of northeast-trending folds (F_2) coaxial with

F_1 folds. F_2 folding produced the major anticlinal structure previously identified as the Ompah "syncline" The F_2 folds plunge to the southwest and are overturned to the north. A steeply dipping axial planar cleavage, striking approximately 045°, is well preserved. The intensity and preservation of D_2 fabrics, combined with the elimination of pre-existing D_1 fabrics, suggests that D_2 was the strongest deformation in the area. The realization that the Ompah anticline is a D_2 fold supports the suggestion, first made by Moore and Thompson (1980), that D_2 structures are restricted to areas of relatively high-grade metamorphism.

Pebbles in the Ompah Conglomerate are deformed into prolate ellipsoids to produce an intense stretching lineation that plunges shallowly (5° to 15°) to the northeast and which has not yet been associated with any specific deformation event.

Northwest-trending F_3 folds have not been positively identified in the area, however, the map pattern suggests that F_1 and F_2 folds may, in some cases, be doubly plunging. The three-phase deformational history given above is in agreement with Thompson (1972), Rivers (1976) and Moore and Thompson (1980). Both Rivers (1976) and Moore and Thompson (1980) identify the Ompah "syncline" as a D_1, rather than a D_2 structure.

CONCLUSIONS

Some of the main results of this study are the following (order does not indicate importance).

1. In general, the stratigraphy of the Fernleigh structure in the study area is similar to that outlined in less metamorphosed regions, however, the stratigraphy becomes increasingly obscure to the northeast due to increased deformation and metamorphism.
2. The Ompah Conglomerate is a distinctive member of the Bishop Corners Formation, Flinton Group. It is a matrix-supported, polymictic conglomerate with a mafic, amphibole-biotite-rich matrix.
3. The map pattern and stratigraphic position suggest that the Ompah Conglomerate may be the oldest Flinton Group unit in the study area.
4. Stromatolitic marbles and mafic rocks near Sunday Lake belong to the Grenville Supergroup.
5. There is strong stratigraphic evidence to suggest that the structure south of Ompah is an anticline, not a syncline as previously suggested.
6. The area has undergone 2, and possibly 3, deformation events. Preservation of structures associated with the second deformation event suggest that it was the most intense.

ACKNOWLEDGMENTS

This work constitutes part of a doctoral dissertation at Carleton University by the author.

REFERENCES

Bright, E.G. 1986. Geology of the Mellon Lake area; Ontario Geological Survey, Open File Report 5598, 156p.

Easton, R.M. 1992. The Grenville Province and the Proterozoic history of central and southern Ontario; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.713–904.

Easton, R.M. and Ford, F.D. 1991. Geology of the Mazinaw area; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.95–106.

Ford, F.D. in preparation. Stratigraphy and metamorphism of the Flinton Group; unpublished PhD thesis, Carleton University, Ottawa, Ontario.

Miller, W.G. and Knight, C.W. 1914. The Pre-Cambrian geology of southeastern Ontario; Ontario Bureau of Mines, Annual Report, v.22, pt.2, p.77–82.

Moore, J.M. and Morton, R.L. 1986. Geology of the Marble Lake area; Ontario Geological Survey Report 238, 63p.

Moore, J.M and Thompson, P. 1972. The Flinton Group, Grenville Province, Eastern Ontario; 24th International Geological Congress, Montreal, Proceedings, Section 1, p.221–229.

——— 1980. The Flinton Group: A late Precambrian metasedimentary succession in the Grenville Province of eastern Ontario; Canadian Journal of Earth Sciences, v.17, p.1685–1707.

Pauk, L. 1983. Sunday Lake area and Ardoch-Dalhousie Lake-Lavant area, Frontenac and Lanark counties; in Summary of Field Work, 1983, Ontario Geological Survey, Miscellaneous Paper 116, p.84–87.

——— 1987. Geology of the Ardoch area; Ontario Geological Survey, Report 241, 57p.

——— 1989a. Geology of the Dalhousie Lake area; Ontario Geological Survey, Report 245, 57p.

——— 1989b. Geology of the Lavant area; Ontario Geological Survey, Report 253, 61p.

Rivers, T. 1976. Structures and textures of metamorphic rocks, Ompah area, Grenville Province, Ontario; unpublished PhD thesis, University of Ottawa, 281p.

Smith, B.L. 1958. Geology of the Clarendon–Dalhousie area; Ontario Department of Mines, Annual Report 1956, v.45, pt.7, p.1–46.

——— 1969. The Ompah syncline in relation to the Grenville stratigraphy of eastern Ontario; in Age relations in high-grade metamorphic terrains, Geological Association of Canada, Special Paper 5, p.225-228.

Thompson, P.H. 1972. Stratigraphy, structure and metamorphism of the Flinton Group in the Bishop Corners–Madoc area, Grenville Province, eastern Ontario; unpublished PhD thesis, Carleton University, Ottawa, Ontario.

9. Project Unit 92–06. Geology of the Aberdeen Area with an Emphasis on the Stratigraphy, Structure and Alteration of the Lorrain and Gordon Lake Formations and Potential Copper Mineralization

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INTRODUCTION AND GENERAL GEOLOGY

The present investigation is concerned with the regional stratigraphy, structure, and alteration of the Huronian Supergroup in the Aberdeen area (Figures 9.1 and 9.2A and 9.2B). In this summary, those features that may have a bearing on evaluation of sedimentary-hosted copper mineralization are emphasized. The project area lies principally within Aberdeen and Johnson townships, being bound: to the west by the western boundary of Meredith and Johnson townships; to the east by the eastern boundary of Aberdeen and Johnson townships; to the north by latitude 46°30′; and to the south by the southern boundary of Aberdeen Township and the approximate line between Round Lake and northern Desbarats Lake in Johnson Township. The project area is readily accessible by driving north from Highway 17 on Centre Line Road (located just west of the town of Bruce Mines).

The Huronian Supergroup is a deformed, Paleoproterozoic, south-facing, sedimentary-volcanic prism consisting predominantly of regionally extensive marine, fluvial, and glaciogenic sedimentary units. Economically significant mineralization within the rocks of the Huronian Supergroup and spatially associated Paleoproterozoic mafic intrusions includes vein-related copper (Bruce Mines), unconformity-related uranium (Elliot Lake), and magmatic nickel-sulphides (Sudbury) (Innes and Colvine 1984). These mineral deposits are either unique (e.g., Sudbury) or are now only of historical interest since they have been superseded by more economically viable deposits (e.g., Saskatchewan uranium deposits versus the Elliot Lake deposits). Consequently, there is some interest in evaluating the Huronian Supergroup for other prospective types of mineralization. Two types of mineralization within the Huronian Supergroup that have received recent attention are placer-gold (Colvine 1983; Rice 1988; Debicki 1990) and sedimentary-hosted copper mineralization (Chandler 1989). Neither type of mineral deposit is readily amenable to geophysical exploration and, consequently, the potential for an area to host such deposits must be evaluated using a variety of geological and geochemical databases and techniques.

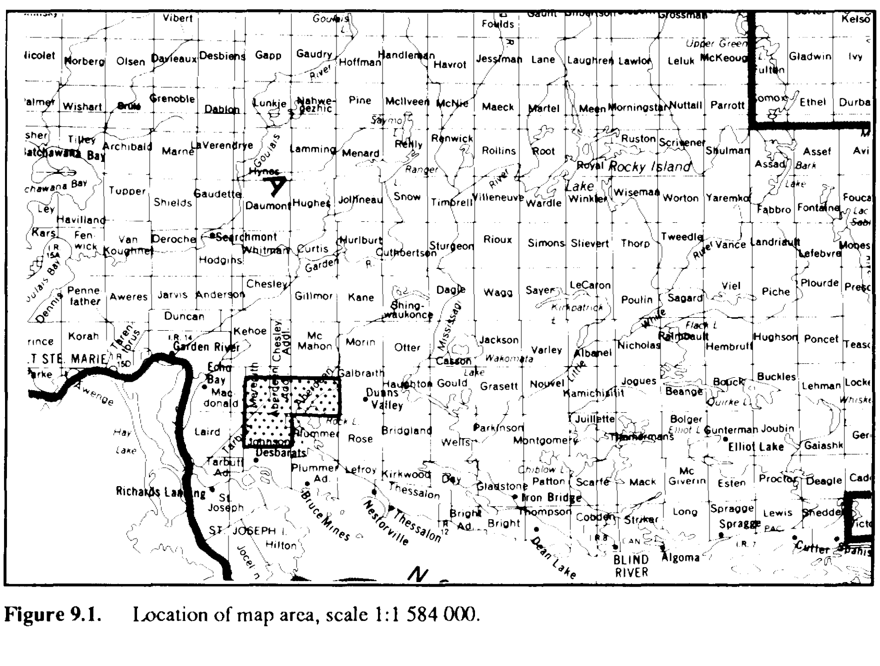

Figure 9.1. Location of map area, scale 1:1 584 000.

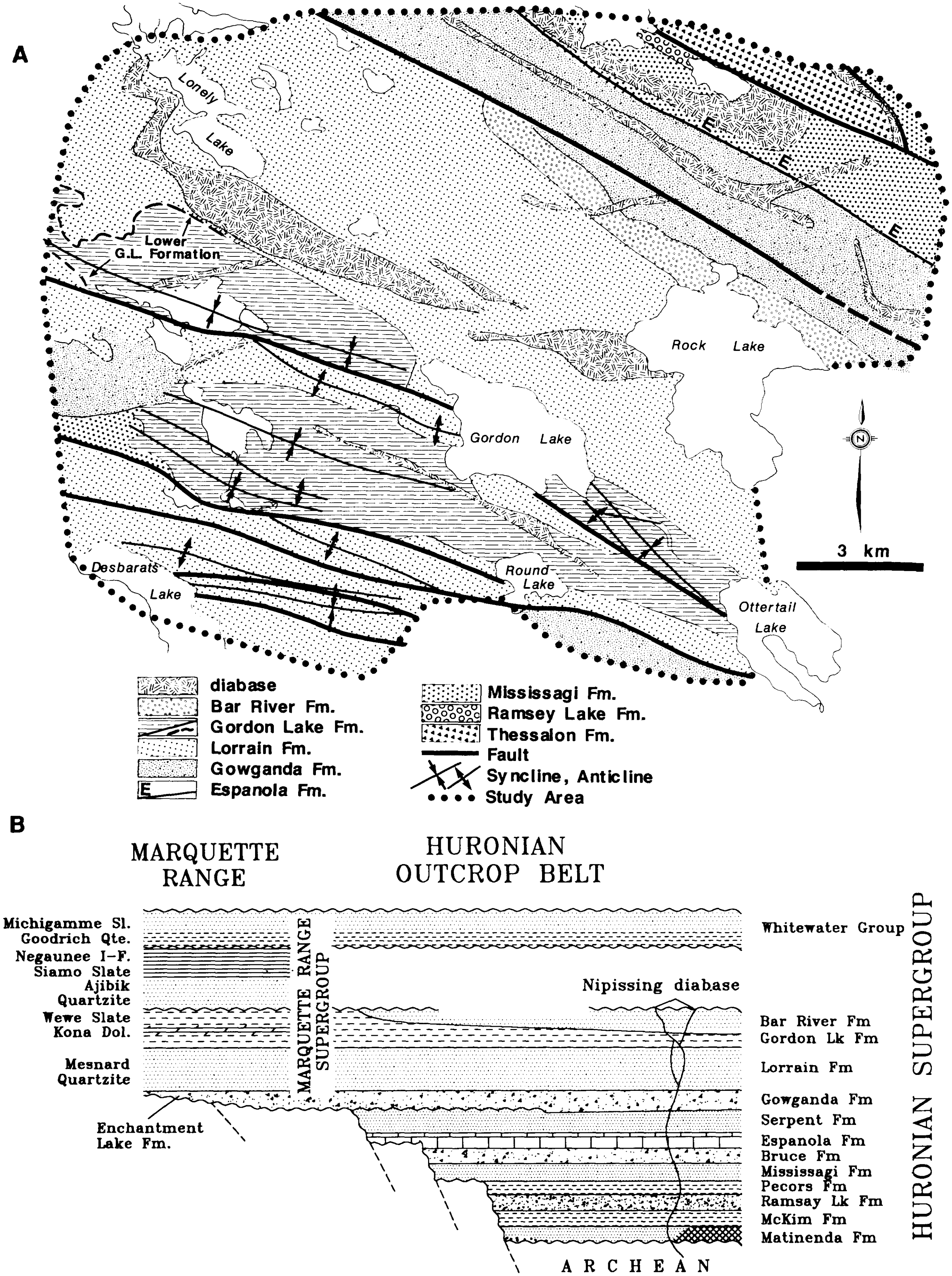

Figure 9.2. A) General geology of the Gordon Lake area. B) Stratigraphic correlations between the Huronian Supergroup and the Marquette Range Supergroup (from Young 1983).

MINERAL EXPLORATION

Historically, uranium exploration was carried out in Kehoe Township, to the west of the map area. Gold occurrences (Kirk prospect, Aberdeen Township) and deposits (Havilah Mine, Galbraith Township) are localized in quartz-carbonate veins that cut Nipissing gabbro (Ferguson et al. 1971). Historic copper exploration focussed on quartz veins. Currently, there is no metallic mineral production from this area, nor was any exploration carried out in the map area during the 1992 summer (E.J. Leahy, Resident Geologist Office, Sault Ste. Marie, personal communication, 1992).

STRATIGRAPHY

The Huronian Supergroup contains 4 groups, 3 of which display cyclic sedimentation with a lower unit containing diamictite, a middle fine-grained unit and an upper, cross-bedded, coarse-grained, sandstone unit (*see* Figure 9.2B) (Young 1983). Although the Gordon Lake area contains representative rock types from many formations of the Huronian Supergroup (*see* Figures 9.2A and 9.2B), only the Gowganda, Lorrain, and Gordon Lake formations of the Cobalt Group were examined in sufficient detail to warrant comment. Descriptions of the other formations can be found in Frarey (1977).

Gowganda Formation

The Gowganda Formation in the Gordon Lake area consists predominantly of interbedded arkose and argillite and/or siltstone and subordinate diamictite units (*see* schematic section Figure 9.3). Arkosic units tend to be massive; however, cross-bedding and parallel lamination were observed locally. Argillite/siltstone units vary from very well laminated to poorly laminated and poorly bedded. Diamictite units are generally massive, but locally crudely stratified, matrix supported and poorly sorted. The thickness and abundance of arkose units decrease upward in the formation, whereas the abundance and volume of argillite/siltstone increase upward. In general, then, the Gowganda Formation in the Gordon Lake area may represent a fining-upward succession punctuated with coarser diamictite units.

Regionally, the Gowganda Formation is considered to be underlain by the Serpent Formation and overlain by sandstones of the Lorrain Formation (e.g., Young 1983). In the Gordon Lake area, the unit designated by Frarey (1977) as Serpent Formation may, alternatively, be lowermost Gowganda (Long 1976). Long (1976) cited the occurrence of a diamictite unit beneath the "Serpent Formation" and the similarity of the so-called Serpent Formation to other sandstone units of the Gowganda as supporting evidence. Both observations were corrobo-

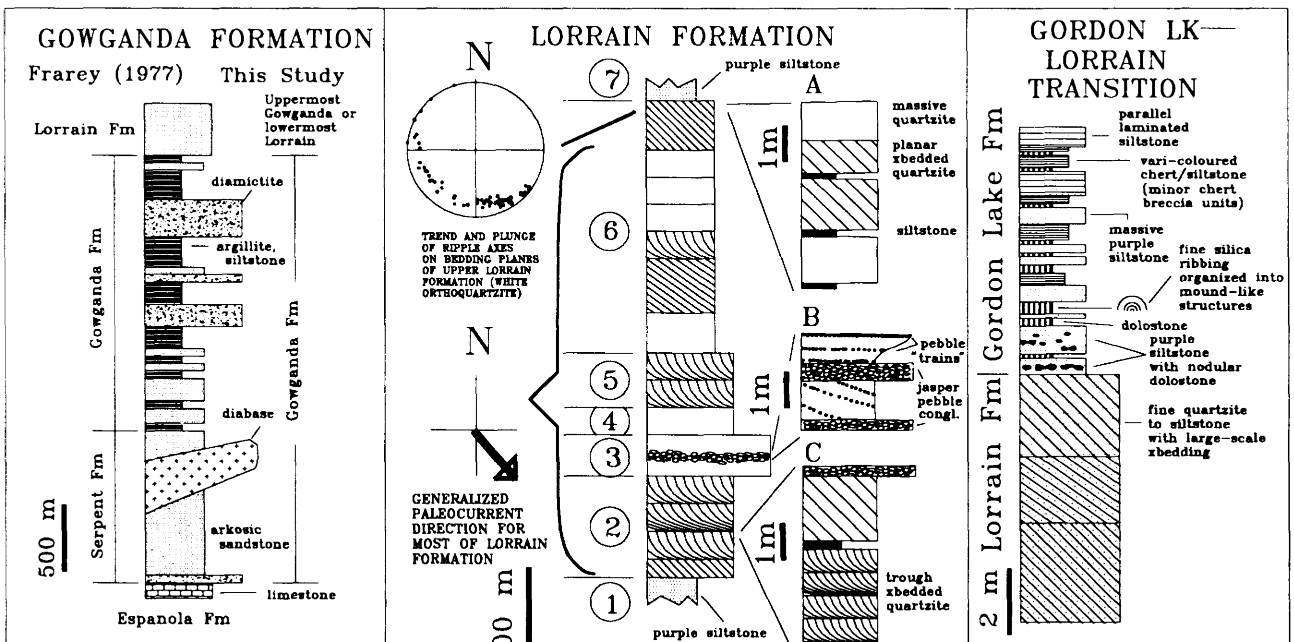

Figure 9.3. Schematic sections of the Gowganda Formation and Lorrain Formation and a detailed measured section of the transition from the Lorrain Formation into the Gordon Lake Formation. Note that in the Lorrain Formation schematic section, there are 3 schematic detailed sections of representative bedding organization for some of the large-scale subdivisions (units numbered 1 to 7). Units of the Lorrain Formation represented in the section are as follows: 1: purple siltstone; 2: red, trough cross-bedded quartz arenite (commonly observed features include: graded foresets, pebble trains along foresets, centimetre-scale pebble beds at base of foreset cosets); 3: jasper pebble conglomerate beds in pebbly quartz arenite (pebble trains along planar beds and planar cross-bed sets); 4 (not present everywhere): white orthoquartzite; 5: red, trough cross-bedded quartz arenite comparable to unit 2; 6: white quartz arenite (common features include massive to graded metre-scale beds, planar cross-bedded metre-scale beds, and trough cross-bedded units); and 7: purple siltstone. Note that most paleocurrent directions in the Lorrain formation are directed toward the southeast whereas in the upper several hundred metres, the paleocurrent become multidirectional with some portions of the section displaying nearly random paleocurrent.

rated during this field study. The definition of the boundary between the Gowganda Formation and Lorrain Formation is problematic in that most of the Lorrain Formation consists of quartz arenite or feldspathic quartz arenite, whereas the unit designated by Frarey (1977) as lowermost Lorrain Formation (his "basal arkose member") appears more similar in terms of grain size, relative mineral abundance, and sedimentary structures to arkosic units within the Gowganda Formation. More petrographic work is needed to clarify the interpretation of the arkosic unit between the Gowganda and Lorrain formations.

Lorrain Formation

Excluding the problematic arkosic unit marking either the base of the Lorrain Formation or top of the Gowganda Formation, the Lorrain Formation consists of numerous quartz arenite and/or conglomerate units, which can be locally grouped into members on the basis of their internal features and/or stratigraphic position (Frarey 1977). A generalized stratigraphic section, modified from Frarey's (1977) work, and brief unit descriptions are given in Figure 9.3. General descriptions can be found in Frarey (1977). Although most of the Lorrain Formation exhibits trough and/or planar cross-beds indicative of paleocurrent flow to the southeast, the uppermost Lorrain Formation commonly, although not pervasively, exhibits bimodal paleocurrent flow directions. In addition, the upper Lorrain Formation is locally profusely rippled with a variety of paleocurrent flow directions implied (*see* Figure 9.3). During deposition of the upper Lorrain Formation, then, there was a dramatic change in the paleocurrent regime from unidirectional southeast-directed current to multidirectional current. This correlates with the transition to the tidally (Wood 1973; Chandler 1989) influenced deposits of Gordon Lake Formation.

Gordon Lake Formation

The Gordon Lake Formation consists predominantly of very fine- to fine-grained sandstone and siltstone, chert, chert breccia, and minor siliceous dolostone (e.g., Wood 1973; Frarey 1977; Chandler 1989). The transition between the Lorrain and Gordon Lake formations is conformable and abrupt. The Gordon Lake–Bar River contact was not observed during this mapping project. One measured section of the Lorrain–Gordon Lake transition is shown in Figure 9.3. Within 10 to 20 m of the base of the Gordon Lake Formation, there are siliceous dolostone and stratabound nodular to amoeboid-shaped carbonate-replacement lenses several centimetres thick and several to tens of centimetres long. Hofmann et al. (1980) identified fenestral fabric in some of the carbonate layers near Plummer indicating microbial involvement in the formation of the carbonate beds. Nodules associated with the carbonate beds in the lower Gordon Lake Formation require additional petrographic work to determine if, as in the copper-mineralized Cobre Lake and Flack Lake areas (Chandler 1989), the carbonate is a replacement of original anhydrite nodules. The presence of anhydrite may indicate deposition in a sabkha environment (Chandler 1989). The identification of carbonate beds, albeit only several to tens of centimetres thick at the base of the Gordon Lake Formation supports previous correlations of the Gordon Lake Formation with the Kona Dolomite and Wewe Slate (upper Chocolay Group of the Marquette Range) (e.g., Young 1983; G. Bennett, Resident Geologist Office, Sault Ste. Marie, personal communication, 1992). This correlation is significant since the Kona Dolomite contains copper mineralization (Taylor 1972).

STRUCTURAL GEOLOGY

The Huronian Supergroup in the Gordon Lake area displays open, upright, gently plunging, west of northwest-striking folds and west of northwest-striking faults (*see* Figure 9.2A). In the fine-grained units of the Gordon Lake and Gowganda formations, a spaced cleavage is commonly present that strikes west of northwest and dips moderately to steeply north or south. Bedding-cleavage intersections in the Gordon Lake Formation are

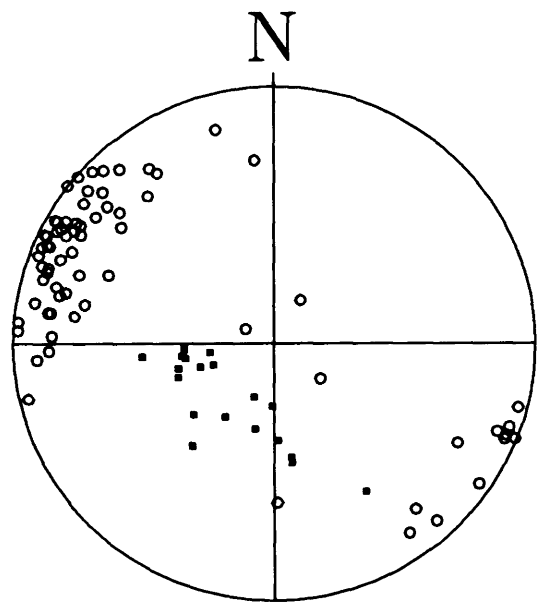

Figure 9.4. Stereographic plot of bedding-cleavage intersections in the Gordon Lake Formation. Bedding-cleavage intersections commonly plunge gently to the west of northwest, in agreement with the general plunge of map-scale folds. Stretched amygdules in the Thessalon Formation metavolcanic rocks plunge steeply to the southwest. The orientation of regional cleavage (west of northwest-striking; not shown in figure), bedding-cleavage intersections, and stretch lineations are interpreted to result from regional south of southwest-north of northeast directed compression and subvertical extension at high crustal levels during regional folding and faulting.

generally shallowly west of northwest plunging (Figure 9.4); however, many are shallowly east of southeast plunging. The subparallelism of the bedding-cleavage intersections and regional fold axes is consistent with cleavage-formation during fold-related compression of Huronian strata.

The Thessalon Formation structurally overlies the younger Mississagi Formation (Frarey 1977) and displays west of northwest-striking cleavage and steeply southeast-plunging stretched amygdules. These relationships suggest that the Thessalon Formation has been reverse faulted over the Mississagi Formation. Other faults (*see* Figure 9.2A) also display the "older against younger" relationships which suggests that they are at least late reverse faults that were formed, or reactivated, during the same compression that generated the folds, cleavage, and stretch lineations.

ALTERATION OF GORDON LAKE AND LORRAIN FORMATIONS

Two main alteration types were observed in the Gordon Lake Formation. Firstly, carbonate replacement in the form of nodules and amoeboid forms is conspicuous in lowermost Gordon Lake Formation and is co-spatial with beds of siliceous dolostone. Secondly, alteration in the Gordon Lake Formation is also reflected in the wide variety of colour displayed by the formation including green, grey, pink, beige, peach and maroon. In general, pink and maroon colour is overprinted by peach to beige colour. The pink to maroon colours are presumed to reflect a relatively high hematite content representing a relatively oxidized state. The peach to beige and green/grey colours are presumed to reflect a relatively low hematite content and a relatively reduced state. Locally, colour appears to be confined to certain stratigraphic intervals. This may indicate strata-parallel flow of oxidizing and/or reducing fluids. Crosscutting fractures are also associated with colour changes and indicate some fluid migration perpendicular to bedding.

Within several hundred metres of the top of the Lorrain Formation there are concentrically zoned, oblately ellipsoidal, hematite-bearing alteration zones. The ellipsoids are generally several to tens of centimetres thick in a direction perpendicular to bedding and tens of centimetres in diameter parallel to bedding planes. The most completely zoned ellipsoids display a slightly buff-coloured, carbonate-bearing core ringed outwardly by a quartz-rich zone and then a red to grey hematite-rich zone.

RECOMMENDATIONS FOR MINERAL EXPLORATION: SEDIMENT-HOSTED COPPER

The contact between the Lorrain Formation and Gordon Lake Formation, in the Gordon Lake area, is associated with several features which suggest further evaluation for sediment-hosted copper mineralization is warranted.

1. The contact between the Lorrain Formation and Gordon Lake Formation is continuous and transitional from a lower, unidirectional, fluvial (?) environment to a shallow, tidally influenced environment (Wood 1973; Chandler 1989) (possibly sabkha).
2. Oxidizing and reducing fluids migrated through the upper Lorrain and lower Gordon Lake formations leaching and depositing metals (at least iron and possibly copper). The timing of fluid migration is uncertain.
3. Siliceous dolostone beds within the lowermost Gordon Lake Formation strongly encourage correlation with the copper-mineralized (e.g., Taylor 1972) Kona Dolomite of the Marquette Range.
4. In the Huronian Supergroup of Ontario, disseminated copper mineralization, possibly akin to the sediment-hosted, stratabound copper type (e.g., White Pine or African copper belt; Maynard 1991) is recognized in the following settings: 1) in the Lorrain Formation (Pearson 1980); 2) along, or close to, the contact between the Lorrain Formation and the Gordon Lake Formation (Pearson 1980; Chandler 1989); and 3) within the Gordon Lake Formation (Chandler 1989; Bennett et al. 1992).

The presence of disseminated copper mineralization in the Kona Dolomite and Gordon Lake Formation, widespread reduction- and oxidation-related alteration, and deposition of Gordon Lake Formation sediments in a sabkha (?) environment collectively indicate that there is potential for sediment-hosted, stratabound copper mineralization at, or near, the contact between the Lorrain Formation and the Gordon Lake Formation in the Gordon Lake area.

ACKNOWLEDGMENTS

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REFERENCES

Bennett, G., Leahy, E.J. and Walmsley, J. 1992. Sault Ste. Marie Resident Geologist's District – 1991; *in* Report of Activities 1991, Resident Geologists, Ontario Geological Survey, Miscellaneous Paper 158, p.215–228.

Chandler, F.W. 1989. Lower Proterozoic sabkha-related copper mineralization, paleoenvironment and diagenesis, Cobre Lake, Ontario; *in* Sediment-hosted stratiform copper deposits, Geological Association of Canada, Special Paper 36, p.225–244.

Colvine, A.C. 1983. Mineral deposit studies in the Huronian Supergroup; *in* Summary of Field Work 1983, Ontario Geological Survey, Miscellaneous Paper 116, p.253–255.

Debicki, R.L. 1990. Stratigraphy, paleoenvironment and economic potential of the Huronian Supergroup in the southern Cobalt Embayment; Ontario Geological Survey, Miscellaneous Paper 148, 154p.

Ferguson, S.A., Groen, H.A. and Haynes, R. 1971. Gold deposits of Ontario: Part 1, districts of Algoma, Cochrane, Kenora, Rainy River and Thunder Bay; Ontario Division of Mines, Mineral Resource Circular 13, 315p.

Frarey, M.J. 1977. Geology of the Huronian Belt between Sault Ste. Marie and Blind River, Ontario; Geological Survey of Canada, Memoir 383, 87p.

Hofmann, H.J., Pearson, D.A.B. and Wilson, B.H. 1980. Stromatolites and fenestral fabric in Early Proterozoic Huronian Supergroup, Ontario; Canadian Journal of Earth Sciences, v.17, p.1351–1357.

Innes, D.G. and Colvine, A.C. 1984. The regional metallogenetic setting of Sudbury; *in* The geology and ore deposits of the Sudbury Structure, Ontario Geological Survey, Special Volume 1, p.45–56.

Long, D.G.F. 1976. The stratigraphy and sedimentology of the Huronian (Lower Aphebian) Mississagi and Serpent Formations; unpublished PhD thesis, The University of Western Ontario, London, Ontario, 291p.

Maynard, J.B. 1991. Copper: Product of diagenesis in rifted basins; in Sedimentary and diagenetic mineral deposits: a basin analysis approach to exploration: Society of Economic Geologists, Reviews in Economic Geology, v.5, p.199–207.

Pearson, W.B. 1980. Copper metallogeny, north shore of Lake Huron, Ontario: unpublished PhD thesis, Queen's University, Kingston, Ontario, 403p.

Rice, R.J. 1988. Regional geology and sedimentology of the Lorrain Formation, Cobalt Plain: southeastern and southern outliers; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.288–296.

Taylor, G.L. 1972. Stratigraphy, sedimentology and sulphide mineralization of the Kona Dolomite; unpublished MSc thesis, Michigan Technological University, Houghton, Michigan, Part I, 47p.; Part II, 37p.; Part III, 28p.

Wood, J. 1973. Stratigraphy and depositional environments of the upper Huronian rocks of the Rawhide Lake–Flack Lake area, Ontario; *in* Huronian stratigraphy and sedimentation, Geological Association of Canada, Special Paper 12, p.73–95.

Young, G.M. 1983. Tectono-sedimentary history of early Proterozoic rocks of the northern Great Lakes region; *in* Early Proterozoic geology of the Great Lakes region, Geological Society of America, Memoir 160, p.15–32.

10. Project Unit 92–07. Geology of McNeil and Robertson Townships, District of Timiskaming

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INTRODUCTION

The 1992 field investigation of McNeil and Robertson townships represents the second year of a two-year study of the Abitibi greenstone belt north of Matachewan to assist mineral exploration. In 1991, the adjoining townships of Argyle and Baden, to the south, were mapped by Kresz (1991). In 1990, a significant copper-zinc discovery in Robertson Township prompted the Ontario Geological Survey to initiate the mapping of this block of 4 adjoining townships. Previous to this program, McNeil and Robertson townships had remained largely unmapped.

Mineral exploration began in the 1800s as early explorers and fur traders crossed the height-of-land in southern Robertson Township between the Montreal River and the Mattagami River systems (Bell 1876). In 1916, a economic discovery of gold was made in Powell Township (Young–Davidson Mine) near the present townsite of Matachewan. From here, numerous prospectors fanned northward along the waterways and inland to prospect the area encompassed by McNeil, Robertson, Argyle, Baden and other ajoining townships. Several surface occurrences of precious and base metals were found by these prospectors during the 1920s and 1930s (Dyer 1936). During the 1980s, renewed interest in many of these mineral occurrences led to the initiation of several exploration programs by mining companies throughout the area including Robertson and McNeil townships.

Previous mapping of the bedrock by the Ontario and Federal geological surveys has been largely proximal to Matachewan and Highway 66, beginning with Burrows (1918) who mapped Baden, Alma, Powell, and Cairo townships. This was followed by a regional reconnaissance of the Matachewan area by Cooke (1919) and further studies of the gold finds of the area by Burrows (1920) and Hopkins (1924). Further mapping was carried out in Argyle, Hincks, Bannockburn and Montrose townships by Rickaby (1932) and followed by a reconnaissance of 10 townships east of Matachewan by Dyer (1936), many of which were remapped during the 1960s by Lovell (1967). Argyle and Baden townships were remapped by Kresz (1991) as a part of this present mapping program. Both access and bedrock exposure are limited in Robertson and McNeil townships. A thin mantle of sandy till and esker and dune sand combined with old growth forest masks the bedrock highs. However, recent logging and mineral exploration has aided in the exposure of the bedrock in parts of McNeil Township and facilitated access to both McNeil and Robertson townships. At present, the main access is by roads extending 15 to 20 km north from Highway 66 to the south boundaries of McNeil and Robertson townships.

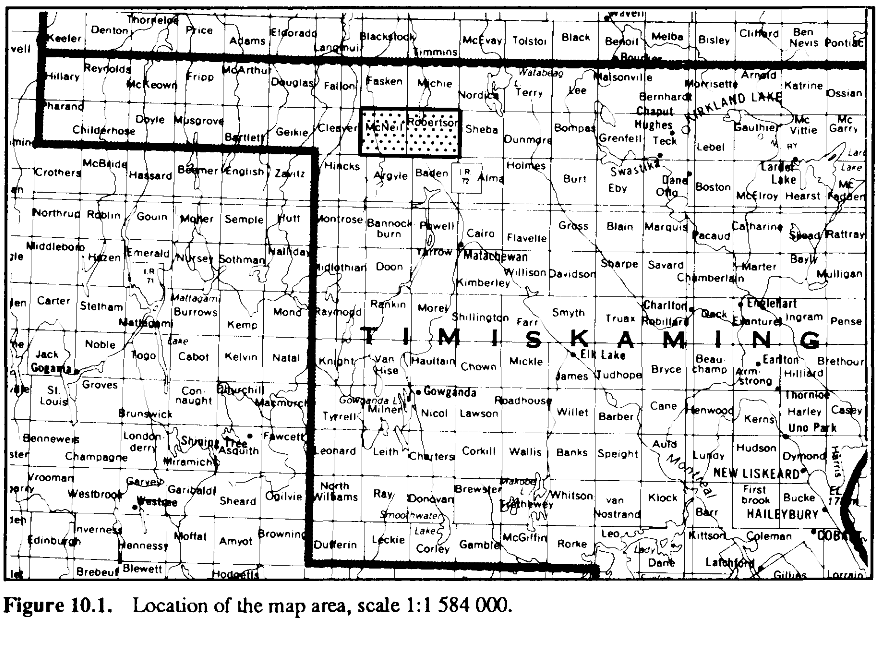


Figure 10.1. Location of the map area, scale 1:1 584 000.

From here, all-terrain vehicles can be used to travel rough logging and exploration trails that extend farther north. A similar type of access is possible from Timmins and Watabeag Lake to the north part of the two townships. Float-equipped aircraft may be landed on Whitefish Lake in McNeil Township and on an unnamed lake in northeasten Robertson Township. Canoe access is hampered by numerous portages between lakes and along narrow streams at the height of land.

MINERAL EXPLORATION

Following the discovery of gold mineralization in Powell Township in 1916, intense surface prospecting was carried out in McNeil and Robertson townships by several prospectors (Hopkins 1924; Dyer 1936; Holley 1988). Evidence of this early prospecting can be seen in the form of pits and trenches now largely obscured by vegetation throughtout both townships. Three old exploration shafts were examined by the author.

More recent exploration has involved the use of heavy equipment and diamond drilling to further expose and explore the most promising mineralized zones found by the early prospecting. The copper-zinc discovery under several metres of overburden in central Robertson township represents a recent discovery. The results of the more recent exploration have been summarized from the Assessment Files Research Office, Ontario Geological Survey unless otherwise stated. The location of more recent exploration is shown on Figure 10.1.

McNeil Township

EARLY PROSPECTING

Early prospectors uncovered numerous gold-bearing pyritic quartz-veins associated with carbonatized volcanic rocks cut by lamprophyre, syenite and feldspar porphyry in the central and southeast parts of McNeil Township. Many of these individual properties have been described by Hopkins (1924) and Dyer (1936). Consolidation of these properties into large holdings has facilitated subsequent large-scale exploration programs.

ARGYLE VENTURES PROPERTY

The Argyle Ventures Property is a twelve-claim area located at Tom Fox Lake in the southeast part of McNeil Township. This property was previously held by Goldyke Mines Limited. This company made numerous pits and trenches and diamond-drilled several holes. A cribbed shaft of unknown depth is present on the property.

In 1984, Argyle Ventures Incorporated Limited conducted magnetic and electromagnetic surveys over the area. In 1985 and 1986, the company did extensive trenching and pitting followed by detailed mapping and sampling of several zones of potential mineralization. Nine holes totalling 402.7 m were diamond-drilled. Of 178 samples from surface exposures and drill core, 22 samples returned values from 1000 to 10 000 ppb Au and 41 returned values of 100 to 1000 ppb Au.

In 1987 and 1988, Kerr Addison Mines Limited optioned the Argyle property and did ground magnetic and electromagnetic surveys. The company diamond-drilled 4 holes totalling 689 m. No assay results were reported.

FAIRLAND PROPERTY

In 1985, Fairland Resources Limited did magnetometer, electromagnetic and geological surveys over a seventeen-claim area on the southwest shore of Whitefish Lake. The property straddled the contact between the granodiorite stock to the north and metavolcanic rocks to the south. No further work was reported and the claims were allowed to lapse.

JOHNS–MANVILLE CANADA PROPERTY (BOJO GROUP)

In 1982, Johns–Manville Canada Incorporated staked 12 claims southeast of Tom Fox Lake which were once, in part, held by Goldyke Mines Limited. Pits, trenches and diamond-drilling were done prior to the efforts of Johns–Manville Canada Limited. From 1983 to 1985, Johns–Manville Canada Limited did magnetic, electromagnetic and geological surveys over the area followed by the diamond-drilling of 10 holes totalling 371.4 m. Assays as high as 0.19 ounces Au per ton were obtained from the property by the company.

In 1986 and 1987, Kerr Addison Mines Limited obtained the property and did magnetic and electromagnetic surveys in conjuction with their surveys on the Argyle Property. No further work was reported by the company.

SALO PROPERTY

The Salo property is located in north-central McNeil Township along the contact between the metavolcanic rock and the granodiorite stock north of Whitefish Lake. In 1978, Noranda Exploration Company Limited diamond-drilled a 144 m hole that intersected altered, sulphide-bearing felsic volcanic rocks. After being restaked by L. Salo, the property was optioned by Queenston Mining Incorporated in 1990 and 1991. The company did airborne magnetic, electromagnetic and resistivity surveys over the area. No further work has been reported.

WEEKLEY PROPERTY

The Weekley Property in central McNeil Township is the amalgamation of several earlier found gold prospects. Between 1979 and 1986, following ground magnetometer and electomagnetic surveys, Mr. Weekley and associates diamond-drilled 30 holes totalling 2382.25 m. Values as high as 1.1 ounces Au per ton and 0.9 ounces Ag per ton over a width of 3 feet, were reported with 1 diamond-drill log.

In 1987 and 1988, Kerr Addison Mines Limited optioned the Weekley property. After conducting ground magnetic and electromagnetic surveys over the property, the company diamond-drilled 13 holes totalling 1520 m. The highest value was 2103 ppb Au over a 2.02 m width in hole KMN 88–11.

Robertson Township

WILLY PROPERTY

Three closely spaced electromagnetic anomalies in central Robertson Township were revealed by the release of an airborne electromagnetic and total intensity magnetic survey of Robertson Township by the Ontario Division of Mines in 1975 (OGS 1975). Following the release of this data, Imperial Oil Limited confirmed the presence of an electromagnetic anomaly by follow-up ground electromagnetic and magnetic surveys. In 1977, the company diamond-drilled a 337 feet deep (102.7 m) hole to intersect the most conductive of the 3 anomalies. This hole comprised iron-rich tholeiitic basalt interlayered with altered, mineralized felsic volcanic tuff. The best section was a 28 feet long intersection with felsic volcanic rocks that contains up to 30% pyrite with stingers of chalcopyrite and sphalerite. No assay results were released.

In 1989, Cominco Limited optioned a group of 21 mining claims from Allen Willy, which included the above mentioned electromagnetic anomalies on claim 983165. The company did ground magnetic and electromagnetic surveys over 14 claims of the property and confirmed an electromagnetic anomaly in the bedrock at a depth of 30 to 40 m on claim 983165. No further work was reported by the company.

In 1990, Queenston Mining Incorporated initiated a diamond-drilling program on the Willy Property. The first hole was drilled in July, 1990, for Henry M. Batisse on claim 983165. The hole totaled 149.35 m in depth and contained several pyritic intersections with chalcopyrite and sphalerite mineralization. No assays for Cu or Zn were reported. Subsequent to this first drill hole, Queenston Mining Inc. optioned the property in a joint venture with Strike Minerals Limited and diamond-drilled an additional 17 holes totalling 6264 m between December 1990 and July 1991. In 1990, Queenston Mining Incorporated announced a 9.4 metre intersection averaging 1.45% Cu and 4.7% Zn (*Northern Miner Press*, May 4, 1992). In 1991, Queenston Mining Incorporated expanded the original sixteen-claim block to 135 contiguous claims and, in 1992, optioned the total 135 claims to Falconbridge Limited (*Northern Miner Press*, May 4, 1992, p.1). Exploration work by Falconbridge Limited is presently in progress (C. Page, Queenston Mining Incorporated, personal communication, 1992).

RYSACK PROPERTY

In 1956, Cobalt Consolidated Mining Corporation Limited diamond-drilled 8 holes totalling 640 m on claim 22936, located approximately 760 m southeast of Whitefish Lake in southwest Robertson Township. The company reported intersecting quartz diorite with minor amounts of chalcopyrite and pyrite in sparse veinlets of calcite. All assays returned less than 0.12% Cu.

OROFINO RESOURCES LIMITED

In 1991, Orofino Resources Limied did magnetic, electromagnetic and geological surveys over a sixteen-claim area located 2 km northeast of the Willy Property in central Robertson Township. Aim of the work was to locate possible extentions of base-metal mineralization along strike from the Willy Property.

NEKOMIS LAKE AREA

In 1965, Denison Mines Limited did airborne magnetic and electormagnetic surveys over much of the southwest quarter of Robertson Township, resulting in the detection of 3 weak conductive anomalies under Nekomis Lake. No further work was done by the the company.

In 1972, Noranda Exploration Company Limited did a follow-up ground magnetic and electromagnetic survey over parts of Nekomis Lake which confirmed weak conductive zones beneath the lake. No further work was reported.

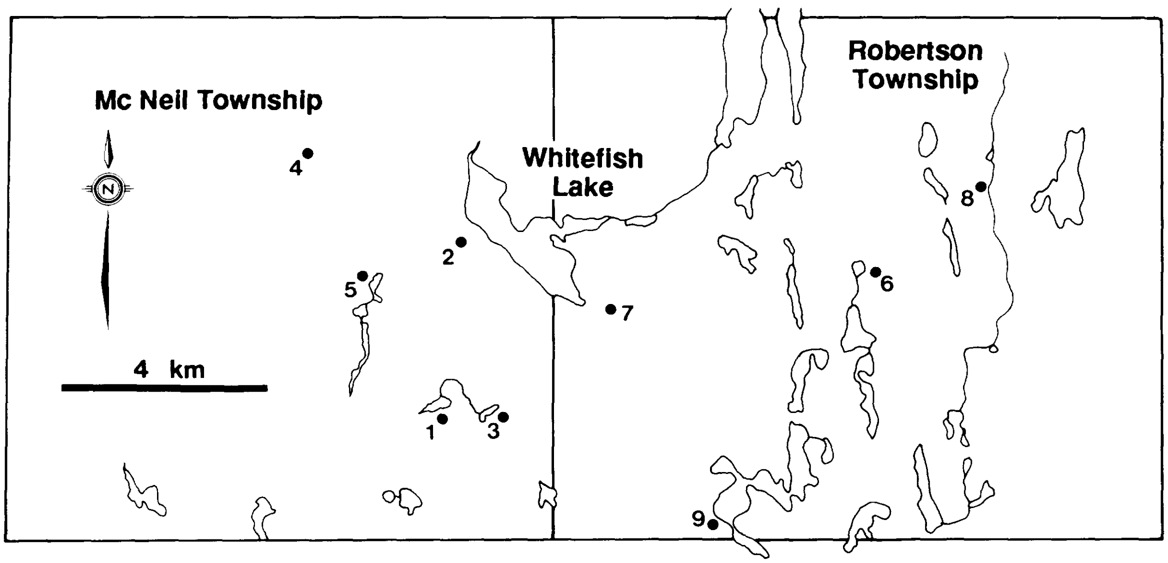
GENERAL GEOLOGY

McNeil and Robertson townships occur within the Abitibi greenstone belt. Bedrock consists of metavolcanic rocks intruded by intermediate to felsic granitoid rocks of Archean age (Figure 10.2). A few thin units of interflow metasedimentary rocks are present within the volcanic succession. Numerous north-trending diabase dikes of the Matatchewan swarm and a few east-northeast trending diabase dikes or the Proterozoic Abitibi swarm (not shown on Figure 10.2) cut the metavolcanic and plutonic rocks.

Metamorphism of the volcanic rocks ranges from lower greenschist to middle amphibolite facies. Penetrative deformation, as well as the metamorphism of the metavolcanic rocks, ranges from very low in the south part of McNeil Township to very strong near the margins of the felsic granitoid stocks in the north parts of McNeil and Robertson townships. Narrow zones of carbonate alteration associated with quartz veining and alkalic felsic dikes is present in numorous places along late, north-northwest- to northwest-trending faults in the metavolcanic rocks in McNeil Township.

METAVOLCANIC ROCKS

Four geographically distinct units of metavolcanic rock underlie McNeil and Robertson townships (*see* Figure 10.2). A unit of magnesian tholeiitic basalts (MGTB) occurs in the north parts of McNeil and Robertson townships. Some basaltic komatiite may be present with the MGTB. In McNeil Township, the MGTB are underlain by calc-alkalic dacite and rhyolite tuffs and tuff breccias that are restricted to a narrow zone close to the granodiorite stock. The third unit of metavolcanic rocks are iron-rich tholeiitic basalts (FETB) that strike east



1 Argyle Ventures Property
2 Fairland Property
3 Johns-Manville Canada
4 Salo
5 Weekley
6 Willy
7 Rysack
8 Orofino Resources
9 Nokomis Lake

Figure 10.2. Property locations, McNeil and Robertson townships.

across the south and central parts of McNeil and Robertson townships. The fourth unit is calc-alkalic basalts and andesites (CAB&A) found in the south part of McNeil Township.

The MGTB and the underlying calc-alkalic dacites and rhyolites are confined to the north part of McNeil Township, west of the granodiorite stock. In northern Robertson Township, the MGTB occur at Radisson Lake between the 2 granitoid stocks. In both areas, these basalts strike north to northwest and form a steeply dipping west- to southwest-younging volcanic succession of pillowed and massive flows. Their younging direction indicates that they are younger than the underlying calc-alkalic felsic metavolcanic rocks. Basalts of iron-rich tholeiitic composition are largely absent from the succession and, in places, some flows appear to have sufficiently elevated magnesium contents that they may be komatiitic flows. Based on field observations, no preserved pyroxene spinifex or polysuture textures were noted to positively identify komatiities. Close to the granitoid stocks, these rocks and the underlying calc-alkalic felsic metavolcanic rocks are strongly schistose.

Along their unposed, southern contact with the FETB, the strike of the MGTB appears to be truncated by the FETB. The contact between these two groups of metavolcanic rock is either an east-striking shear zone or an east-trending unconformity.

The FETB form a 3 to 4 km wide, east-striking, south-facing succession of massive flows that alternate with sections of variolitic pillowed flows, pillow breccias and hyaloclastite. These flows have a high magnetic expression on published airborne magnetic maps (OGS 1975a, 1975b). These flows extend across the south half of McNeil Township and into Robertson Township. In Robertson Township, the FETB succession contains interflow units of andesite, dacite and rhyolite tuff and metasedimentary rocks composed of argillite and metawacke with magnetite-rich layers. In central Robertson Township, the iron-rich tholeiitic basalts are displaced northward on the east side of a north-striking fault zone through Radisson Lake. From here, these basalts, along with the interflow felsic tuffs and metasediments, continue to strike east to east-northeast. The copper-zinc mineralization of Queenstone Mining Incorporated is within the interflow units and is described later in this report. In the east part of Robertson Township, the FETB succession is bifurcated by a diorite sill. The lower part of the FETB succession strikes northeast and northward around the southeast and east margins of the granitoid stock located in north-central Robertson Township. The upper part of the FETB succession continues to strike east.

Calc-alkalic basalts and andesites underlie the south parts of McNeil and Robertson townships and extend south into Argyle and Baden townships where they are described by Kresz (1991). They are mainly hornblende- and plagioclase-phyric flows and fragmental pyroclastic rocks. A sharp, apparently conformable, contact occurs between the iron-rich tholeiitic basalts and the calc-alkalic rocks, and according to the pillow facings in the tholeiitic basalts, the calc-alkalic rocks are younger than the tholeiitic basalts.

Intrusive Rocks

Except for the diabase dikes, the only mafic subalkalic plutonic rocks are small pyroxenite plugs that cut the calc-alkalic metavolcanic rocks in the south part of McNeil Township. These plugs are less than 500 m in diameter and are rare. Similar intrusive bodies were noted by Kresz (1991) to the south in Argyle Township.

Metre- to kilometre-size sills and stocks of hetrogeneous, medium- to coarse-grained diorite and quartz diorite intrude the iron-rich tholeiitic basalts in Robertson Township. The largest body of diorite occurs in the south part of Robertson Township where it cuts the calc-alkalic metavolcanic rocks as well as the iron-rich tholeiitic basalts. This body has phases of tonalite near its center in Robertson Township and appears to grade into tonalite southward into Baden Township (Kresz 1991).

The second largest body of diorite and quartz diorite is a 3 km long by 500 m wide sill located southeast of Whitefish Lake. Several other small sills are located along strike within the iron-rich tholeiitic metavolcanic rock in the east and central parts of Robertson Township.

The plutonic rocks in the north parts of McNeil and Robertson townships are homogeneous intrusions of 2 to 3 mm grain-size granodiorite with 25% 0.5 to 1 cm feldspar phenocrysts. Scattered, rounded, mafic xenoliths from 1 cm to 1 m in size occur in the granitic rocks. A 100 m wide zone of migmatized metavolcanic rock occurs at the margins of the stocks.

In places, metre-wide dikes that range in composition from lamprophyre to intermediate, and felsic syenite and syenite porphyry intrude both the magnesium and iron-rich tholeiitic basalts. In many places, they are both closely associated with, and have, carbonate alteration and quartz veining.

Structural Geology

The metavolcanic rocks exhibit an intense ductile-deformation fabric parallel to the contact with the granitoid stocks in the north part of McNeil and Robertson townships. Pillows are strongly elongated and partly rotated to face away from the granitoid stocks. This deformation decreases toward the southwest part of McNeil Township where the metavolcanic rocks show no deformation.

The deformation caused by the granitoid stocks in northern McNeil and Robertson townships obscures the contact between the MGTB and the FETB. Where this contact is not intruded by the granodiorites, the metavolcanic rocks have been foliated and the pillows rotated. These features extend across the contact from the MGTB into the FETB and the contact between the 2 groups of metavolcanic rock can only be regionally recognized by the change in basaltic rock-types and strike of the metavolcanic rocks. This would suggest that the fault or unconformity between the MGTB and FETB was present prior to the emplacement of the granitoid rocks and has been modified by the granitoid rocks.

South of the contact between the MGTB and FETB, all the metavolcanic rocks young and dip steeply south. Based on the regional magnetic maps (GSC 1970) and the work of Kresz (1991), the FETB and CAB&A are considered to occupy the north limb of a large east-plunging syncline in Argyle and Baden townships. However, it remains uncertain whether or not the MGTB farther north are part of this structure or are part of a separate folded, structural block or assemblage to the north and west.

Late north-striking to northwest-striking faults have affected the area to produce narrow, intense zones of shearing in the metavolcanic rocks. Of interest are the 340° to 310° faults that steeply dip southwest. Many are associated with closely spaced brittle fractures and have carbonate alteration, syenitic dikes, and quartz veining that carry gold mineralization.

ECONOMIC GEOLOGY

Base-Metal Mineralization

The base-metal mineralization intersected in central Robertson Township by Queenston Mining Incorporated is hosted by the stongly magnetic succession of FETB with intercalations of thin units of fine-grained, calc-alkalic andesite, dacite and rhyolite tuff and tuff breccia, and lesser amounts of interflow metasedimentary rocks. The base-metal mineralization is concentrated in the felsic volcanic rocks and metasedimentary rocks. Here, the mineralization forms bands of massive to disseminated sulphides accompanied by carbonate and epidote alteration of the felsic metavolcanic and volcaniclastic argillites and wackes.

Field investigations suggest that minor sulphide mineralization can be found along the length of the stongly magnetic succession of FETB that extend the width of Robertson Township. Disseminated sulphides, including minor chalcopyrite, were noted to occur within the calc-alkalic tuff units and metasedimentary rocks of the FETB succession in several widely spaced locations. The mineralization does not appear to be restricted to one particular zone within the FETB succession, but instead occurs where felsic volcanic and metasedimentary rocks are present. Carbonate alteration was not obvious in most of the sulphide occurrences and mineralization tends to be stratiform and stratabound. A few old trenches and pits were observed on some of these zones of mineralization.

In McNeil Township, calc-alkalic felsic tuffs and interflow metasedimentary rocks appear to be rare within the iron-rich tholeiitic basalt succession and sulphide occurrences appear to be less numerous. However, stongly altered iron-rich hyaloclastite in the west part of McNeil Township is similar to alteration associated with the base-metal mineralization in Robertson Township.

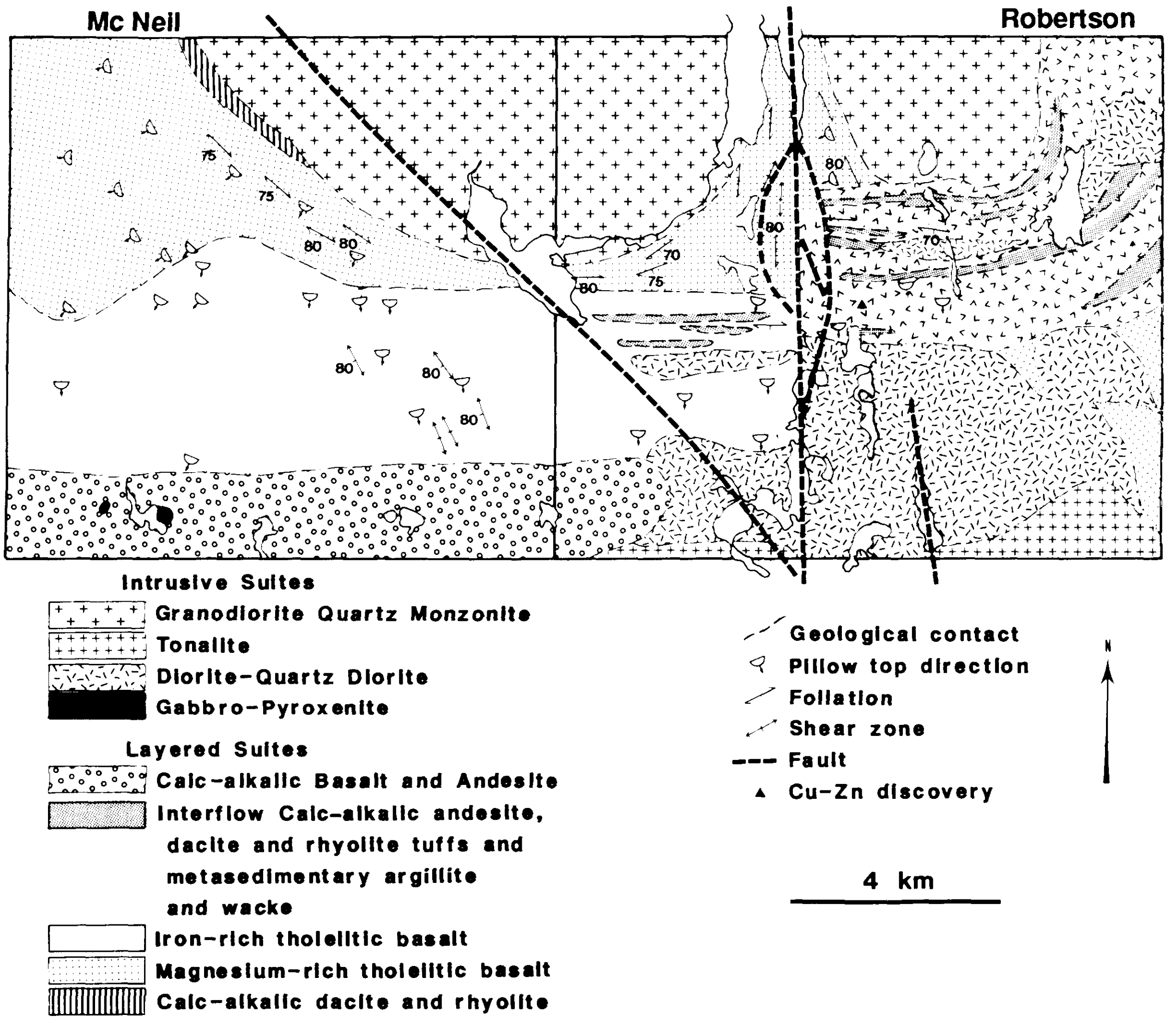


Figure 10.3. Geological sketch map of the area with selected stratigraphic younging information.

Gold Mineralization

Gold mineralization is associated with zones of carbonate alteration of the metavolcanic rocks in McNeil Township. These zones of carbonatization occur mainly in the FETB succession across the width of McNeil Township and to a lesser extent in the MGTB. The largest and most intense zones of carbonatization occur on the south side of the contact between the MGTB and FETB in central McNeil Township, and in the vicinity of Tom Fox Lake.

The carbonate zones are concentrated along sets of closely spaced, parallel fractures. At Tom Fox Lake, the fractures strike 340° and in central McNeil Township, 320° to 310°. The fractures and associated carbonate zones are from 50 to 300 m apart and dip steeply west to southwest. In the western part of McNeil Township, the fracture pattern is mainly 340° and gradually changes to 310° northward toward the MGTB–FETB contact, based on limited outcrop exposures. Thus, the carbonate zones crosscut the volcanic stratigraphy in most places, and are locally parallel to subparallel to one another.

The carbonate zones form a broad outer zone of calcite alteration and an inner, small zone of ankerite alteration. Regionally, the metavolcanic rocks show little or no penetrative carbonate alteration and only have some calcite along narrow fractures. Within a few tens of metres of a given carbonate zone, the host metavolcanic rocks have penetrative calcite alteration, but retain their diagnostic features and textures.

The inner ankeritic zone of the most intensely developed carbonate zones consists of hard, pale white- to buff-coloured rock that forms a thick rusty-coloured weathered surface. This rock represents a 1 to 5 m wide zone of complete replacement of the the country rock by silica, ankerite and siderite in which all primary textures of the host metavolcanic rock are destroyed. For example, the pillow selvages, and variolites of a black, magnetic iron-rich basalt can be observed to fade into a pale white, carbonate rock that resembles dacite or rhyolite over a width of 1 to 10 cm.

Many of the ankeritic cores of the carbonate zones have a medial, 1 to 10 cm wide quartz vein or stockwork that parallels the strike and dip of the carbonate zone. Others have quartz and quartz-siderite lenses.

Dikes of intermediate to felsic syenite, feldspar porphyry, and lamprophyre occur proximal to carbonate zones and many contain a high content of carbonate. Many of the dikes parallel the carbonate zones in the core ankeritic zones and have quartz veining. Others cut the carbonate zones at a wide range of angles.

Pyrite content of the carbonate cores, quartz veins and igneous dikes varies from less than 0.5% to more than 3%. The pyrite ranges from fine-grained disseminated pyrite to coarse-crystalline euhedral pyrite. Based on the assays in the assessment work files, gold content is very unevenly distributed both within a given carbonate zone and from one carbonate zone to another.

RECOMMENDATIONS FOR EXPLORATION

The FETB succession remains a favourable zone for base- and precious-metal exploration. Because of the limited exposure of FETB succession, most of area underlain by these rocks has not been fully explored. Base-metal mineralization in the FETB succession tends to be disseminated rather than massive and located in the felsic and metasedimentary interflow units of the tholeiitic basalts. This mineralization, like the base-metal discovery by Queenston Mines Limited, gives weak geophysical reponses and thus can be missed by normal geophysical methods. The thin layer of locally derived sandy till in the area may make soil geochemical surveys a favourable alternate exporation technique.

Most of the carbonate zones uncovered to date are close to surface and were discovered by early prospectors. Some of these carbonate zones, particularly those south of the MGTB–FETB contact, have significant gold values. The strike of the carbonate zones suggests that known carbonate zones may be projected along strike into areas of little bedrock exposure and tested by diamond-drilling. New carbonate zones may also be located by detecting broad areas of penetrative calcite alteration of the metavolcanic rock and by soil geochemical survey. It is the author's opinion that a very small percentage of the existing carbonate zones have been found and explored.

The MGTB–FETB contact may represent an unexposed unconformity or a cryptic, major, east-striking fracture zone. Its significance for gold mineralization is unknown and its relationship to the fracture patterns and zones of carbonatization located on its south side are also unknown. Future work should be directed toward locating and testing this contact for precious minerals.

ACKNOWLEDGMENTS

The author appreciated the assistance of D. Pekeski and J. Bean. Discussions with and information supplied by D. Kresz were very helpful. Thanks is extended to the staff of the Resident Geologist's office and the Drill Core Library of the Ministry of Northern Development and Mines in Kirkland Lake, and to the staff of the District Office of the Ministry of Natural Resources, also in Kirkland Lake, for their assistance and support.

Special thanks is extended to Chief R. Batisse for permission to travel through the Indian Reserve south of Robertson Township.

Thanks is also extended to the people of Matachewan, in particular G. Bernatchez, Reeve of Matachewan, for their support and hospitality. The author also benefitted greatly from information willingly provided by H.L. Lovell and by numerous prospectors and exploration geologists active in the Matachewan and Kirkland Lake areas.

REFERENCES

Bell, R. 1876. Report on an exploration in 1875 between James Bay and lakes Superior and Huron; Geological Survey of Canada, Report of Progress for the Year 1875–1876, p.294–342.

Burrows, A.G. 1918. The Matachewan gold area; Ontario Bureau of Mines, Annual Report, 1918, v.27, pt.1, p.215–240.

——— 1920. Matachewan gold area; Ontario Department of Mines, Annual Report, 1920, v.29, pt.3, p.53–64.

Cooke, H.C. 1919. Geology of the Matachewan district, northern Ontario; Geological Survey of Canada, Memoir 115, 60p.

Dyer, W.S. 1936. Geology and ore deposits of the Matachewan–Kenogami area; Ontario Department of Mines, Annual Report, 1935, v.44, pt.2, p.1–55.

Holley, F. 1988. Just passing through: The people and the places north of Matachewan; [published by] The Highway Book Shop, 90p.

Hopkins, P.E. 1924. Notes on gold in McNeil and other townships; Ontario Department of Mines, Annual Report, 1924, v.33, pt.3, p.34–40.

Kresz, D.U. 1991. Geology of Argyle and Baden townships, District of Timiskaming; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.91–94.

Lovell, H.L. 1967. Geology of the Matachewan area, District of Timiskaming; Ontario Department of Mines, Geological Report 51, 61p.

Ontario Geological Survey 1975a. Airborne electromagnetic and total intensity magnetic survey, Robertson Township, District of Timiskaming; Ontario Geological Survey, Preliminary Map 1016, scale 1:15 840.

——— 1975b. Airborne electromagnetic and total intensity magnetic survey, McNeil Township, District of Timiskaming; Ontario Geological Survey, Preliminary Map 1015, scale 1:15 840.

Geological Survey of Canada 1970. Radisson Lake, Timiskaming District; Geological Survey of Canada, Map 290G (Rev.), scale 1:50 000.

Rickaby, H.C. 1932. Bannockburn; Ontario Department of Mines, Annual Report for 1932, v.41, pt.2, p.1–24.

11. Project Unit 92–08. Geology and Mineral Potential of the Tower Syenite Stock, Conmee Township, District of Thunder Bay

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INTRODUCTION

The purpose of the study is to determine the geology and mineral potential of the Tower syenite stock using petrography, and geochemical methods. The investigation is to be based mainly on diamond drill core and data in the assessment work files, Ministry of Northern Development and Mines. During August 1992, about 4 weeks were spent examining core and diamond drill logs deposited by Noranda Exploration Company Limited at the Core Library, Thunder Bay, field mapping, and sample collection. Drill core from the Tower syenite program of Inco Gold Company was not examined. All samples for future work were surface samples as the core had already been split and only half was available at the library.

The stock is centred about 36 km northwest of Thunder Bay in north-central Conmee Township, southwest of Sistonens Corners and south of Sunshine in the Shebandowan portion of the Wawa Subprovince (Figure 11.1).

PREVIOUS WORK

During 1985, the township of Forbes and Conmee were mapped (Carter 1990) and the stock was outlined and named. It comprises an oval-shaped, intrusive, southeasterly trending body, which on the basis of current mapping, is 3.5 km long by 1.4 km wide (on average) and consists of pink quartz monzonite and grey and grey-green monzodiorite, diorite and syenite (Figure 11.2). It intrudes the surrounding Keewatin-type metavolcanic-metasedimentary rocks. The rocks of the stock are massive and medium and fine grained; fine-grained facies and apophyses occurring in the contact regions of the stock. Two facies were observed: a pink hornblende quartz monzonite phase confined to the northwestern and eastern parts of the stock; and a medium-grey and dark grey-green biotite/hornblende/augite monzodiorite and diorite forming the central part of the stock. The rocks are locally prophyritic and contain phenocrysts of feldspar or hornblende.

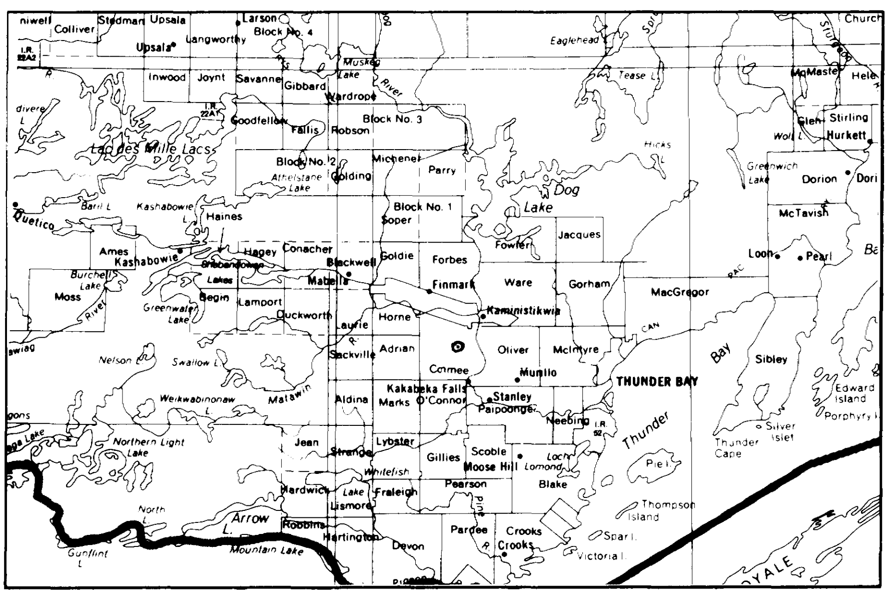

Figure 11.1. Location of map area, scale 1:1 584 000.

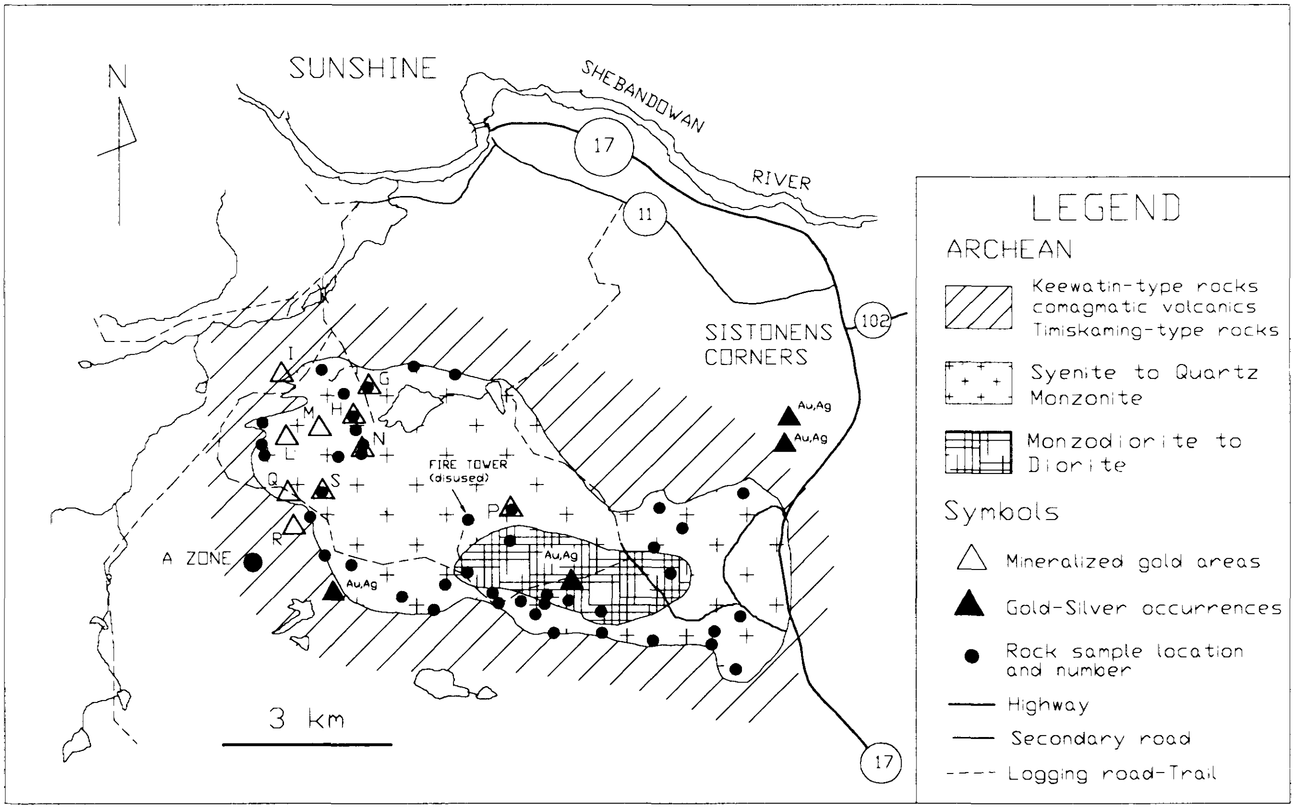

Figure 11.2. Generalized geology of the Tower syenite stock.

Two exploration grids were set out over the stock and adjacent areas by Noranda Exploration Company Limited in 1985 and 1986, and by Inco Gold Company in 1988.

During the period 1985–1987, Noranda Exploration Limited mapped geologically the western part of the stock and the immediately adjacent contact area, and carried out soil and rock geochemical surveys, ground very low frequency electromagnetic (VLF–EM), magnetometer and induced polarization (IP) surveys, trenching and diamond drilling (Dal Bello and Carriere 1985; Mooney 1988; Brown 1990). A total of 17 trenches were excavated and 38 diamond drill holes were drilled for a total length of 2880.5 m in the marginal zone of the western contact of the stock. Petrographic and electron microprobe work were also carried out. This work led to the discovery of the "A Zone" 380 m southwest of the western margin of the stock which contains 60 000 tonnes of material grading 3 g Au/t (Brown 1990). Two of the drill holes, totalling 486.5 m in length, penetrated the stock and syenite, syenite breccia and feldspar porphyry were encountered. The pink "syenitic" facies of the stock is clearly intrusive into the surrounding volcanic rocks, but it may not cut nearby Timiskaming-type conglomerates. Drill logs indicate that the syenite is red to brown in colour, and contains pyrite disseminations and stringers 1 to 3 mm wide. The pyrite grains are about 0.5 mm across and range from 8 to 15% of the rock. Locally, the syenite contains feldspar and hornblende phenocrysts, exhibits a trachytic texture, and is locally brecciated. The syenite is cut by quartz, carbonate, and quartz-carbonate veins and stringers. Pyritic mineralization was encountered in the syenite and a best assay of 2.57 g Au/t over 1 m was obtained from the drilling.

During the period 1988–1990, Inco Gold Company held the property under option and carried out line cutting, geological mapping, a proton magnetometer survey, trenching, grab- and channel-sampling, and drilled 22 diamond drill holes for a total length of 2594.5 m in the western part of the stock and the surrounding volcanic rocks. This work delineated the western boundary of the stock in detail. The stock was described as pink to red syenite, pinkish grey monzonite and grey diorite, all containing variable amounts of hornblende. The study also showed that the rocks are silicified, pyritized and carbonatized with iron carbonate. The western half of the stock contains 11 zones of surface anomalous gold mineralization (regarded by the company as areas assaying greater than 1 ppm or 1 g Au/t). These zones were referred to as G, H, I, L, M, N, P, Q, R, and S (*see* Figure 11.2) and are described by the company as follows:

Zone G: Carbonatized, moderately to strongly hematized syenite-monzonite exhibits calcite fracture fillings with 15-20% pyrite and up to 8.02 ppm gold;

Zone H: Moderately to strongly hematized monozonite with 4-5% fine pyrite and up to 6.69 ppm gold;

Zone I: Carbonatized syenite-monzonite with 10% pyrite and up to 1.29 ppm gold;

Zone L: Moderately hematized syenite with 3% pyrite and up to 7.25 ppm gold;

Zone M: Moderately hematized syenite with 3% pyrite and up to 1.33 ppm gold;

Zone N: Moderately to strongly hematized syenite with 2-3% pyrite and 3.51 ppm gold;

Zone P: Strongly silicified diorite with 4-5% pyrite, 1-2% galena and trace chalcopyrite contains up to 11.0 ppm gold;

Zone Q: Syenite-monzonite with 3% pyrite contains up to 1.59 ppm gold;

Zone R: Syenite-monzonite with 3% pyrite contains up to 1.19 ppm gold; and

Zone S: Syenite-monzonite with 3% pyrite contains up to 1.55 ppm gold. (Mooney 1988).

Five diamond drill holes, totalling 363.63 m, were drilled to test these mineralized zones. Syenite, monzonite and diorite were encountered, up to 10% pyrite mineralization was observed, and a best gold assay of 1.82 g Au/t across 0.18 m true width in monzonite was obtained in the P Zone.

Detailed exploration work led to a revision of the grade of the "A Zone" of Noranda Exploration Limited to 40 000 tons (drill proven) grading 3.0 g Au/t gold. (Inco Gold Company 1988).

CURRENT WORK

The cores of 2 diamond drill holes (*see* Figure 11.2) drilled by Noranda Exploration Limited (S-85-04 and S-85-05), were examined along with the drill logs at the MNDM's Core Library at Thunder Bay because these holes intersected syenite and penetrated the stock at depth. Mineralization was intersected in hole S-85-04. The pink "syenitic" phase as observed by the author, is medium grained, red-brown or brick red in colour, and is dominantly massive, but locally phenocrysts of feldspar and hornblende define a porphyritic and/or trachytic texture. Some sections were yellow due to sericitic alteration. The company regards locally developed orange hues as areas of potassic alteration. In hole S-85-5, syenite breccia occurs consisting of angular syenite fragments in a dark fine-grained matrix. Characteristically the syenite shows fine-grained disseminated pyrite up to 12%. The pyrite also occurs as stringers and veinlets and also as grains in quartz and white carbonate veins. The pyrite ranges from 0.1 to 0.5 mm in size, but locally is coarser and then occurs in grains about 1 mm in diameter. Molybdenite in quartz stringers within volcanic breccia in hole S-85-5 is described in the company logs, but was not observed by the writer.

In August 1992, rock samples were collected from the western part of the stock using the grid cut by Inco Gold Company in 1988, and from the rest of the stock, including some areas of cut-over within the grid where outcrops were located using pace-and-compass traversing methods (*see* Figure 11.2). Collection of rock samples in the western part of the stock as outlined by Inco Gold Company using their grid showed that the stock extended further to the west than that shown on the map by Carter (1990). In this area, the rocks of the stock are fine grained and massive, and are interpreted by the writer as chilled facies of the stock, as no features suggesting a volcanic character were observed. The rocks in this area are best described as microsyenite and micromonzonite. On this basis, the western limits of the stock are as shown in Figure 11.2, and conforms to that shown by Inco Gold Company in the assessment files. Rock samples for petrographic and lithogeochemical studies and for assay were selected to cover the entire stock and were collected both from areas which were not reported to be mineralized in the company reports, and from areas designated in company reports as mineralized zones and referred to alphabetically as previously described. Field observations showed that the mineralized areas, i.e., those showing greater than 1 g Au/t differed from the unmineralized areas in having: 1) fine disseminated pyrite ranging from 5 to 20%; 2) a higher level of hematization, causing the rocks to appear darker red than usual or to be brick red in colour; and 3) abundant limonitic staining and encrustations reflecting iron carbonate and high pyrite concentrations, and discrete areas of white and brown carbonate.

SUMMARY AND RECOMMENDATIONS

The Tower syenite stock consists of 2 major phases: a pink massive and porphyritic, variously hematized hornblende quartz monzonite phase surrounding a central, grey and dark grey-green massive and porphyritic hornblende/biotite/augite monzodiorite and diorite phase. The age relationships are not known. On the basis of its massive character, its intrusive relationship to alkalic, apparently co-magmatic, lavas and breccias, the stock is considered by the author to represent a high-level, subvolcanic intrusion forming the eroded relic of a central-type, volcanic edifice in a subvolcanic environment (Carter 1987). The occurrence of a porphyritic facies, disseminated pyrite-gold mineralization associated with reported chalcopyrite, galena and molybdenite in the rocks, suggests a porphyry-type gold stock (Stanton 1972, p.386-398; Sawkins 1990, p.18-24). Previous mapping by Carter (1990) indicated that the stock is surrounded by areas mineralized with gold, and company reports by Noranda Exploration Company Limited and Inco Gold Company (Assessment Work Files, Ministry of Northern Development and Mines, Sudbury) show that gold also occurs in the stock itself in amounts ranging up to 11.0 ppm (11 g Au/t) in its western part. The occurrence of gold in the stock and in its contact areas suggest a causal relationship (of the mineralization) with the Tower syenite stock. These observations, along with the occurrence of gold in areas to the northeast and east-southeast of the stock, indicate that the central and eastern parts of the stock, in addition to its already prospected western parts, should be prospected in detail. The stock as such should thus be prospected in detail as a porphyry-type gold occurrence. The area underlain by the stock locally represents the highest topography of the area–a region rising from 381 m to 549 m. This indicates that for this geological subvolcanic zone, which is a high-level volcanic environment, the stock has not been deeply unroofed, probably because it was preserved from deep erosion by overlying Timiskaming-type sediments. This implies that much of the hood region of the stock, an area where porphyry-type deposits form (Sawkins 1990, p.33), has been preserved. As the gold mineralization is associated with pyrite, IP surveys in those parts of the stock that have not been prospected should be carried out. As high-content gold porphyry-type systems typically contain significant amounts of magnetite (Sillitoe 1979), ground magnetic surveys could assist in studying alteration patterns which could be used to detect mineralized areas within the stock.

ACKNOWLEDGMENTS

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REFERENCES

Brown, G. 1990. Diamond drilling report, Stewart–Lee Option, Conmee Township, Thunder Bay Mining Division, NTS:52–A–12; Inco Exploration and Technical Services, Incorporated; assessment files, Ministry of Northern Development and Mines, Toronto, 10p. and Appendix 1.

Carter, M.W. 1987. Alkalic rocks of Thunder Bay area; in Summary of Field Work and Other Activities 1987, Ontario Geological Survey, Miscellaneous Paper 137, p.109–116.

—— 1990.Geology of Forbes and Conmee townships; Ontario Geological Survey, Open File Report 5726, 188p.

Dal Bello, A., and Carriere, D.R. 1985. Geological and geophysical report, Stewart Option, NTS 52 A/12, Northwestern Ontario Division; Noranda Exploration Company Limited, 5p. and Appendix 1.

Inco Gold Company. 1988. Stewart Option gold showing/targets, A Zone detail, compilation map 1A, scale 1:10,000.

Mooney, S.J. 1988. Assessment Report, Geological Survey, Stewart Option, Thunder Bay Mining Division, NTS:52–A–12; Inco Gold Company; assessment files, Ministry of Northern Development and Mines, Toronto, 9p. and Appendix 1.

Sawkins, F.J. 1990. Metal deposits in relation to plate tectonics; Springer–Verlag, New York, 461p.

Sillitoe, R.H. 1979. Some thoughts on gold-rich porphyry copper deposits; Mineralium Deposita, v.14, p.161–174.

Stanton, R.L. 1972. Ore petrology; McGraw–Hill, New York, 713p.

12. Project Unit 92–11. Gold Mineralization in the Northern Night Hawk Lake Area of the Abitibi Greenstone Belt

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INTRODUCTION

Recent exploration of gold occurrences in the area of, and east of, the North Peninsula, Night Hawk Lake (Figure 12.1), has yielded data on lithology, structure, alteration and, in some cases, ore reserves of these occurrences. This project, initiated by the Ontario Geological Survey (OGS) in the summer of 1992, comprises compilation of exploration data, their integration with relevant field work, and investigation of accessible underground workings. The project is primarily aimed at identifying geological parameters which could aid exploration at the local or regional scale. P.J. Sangster (Resident Geologist's Office, Timmins) will be responsible for the collection of recorded exploration data, as liaison person between the industry and the OGS, and for organizing the clearing of outcrops where desirable. G.M. Siragusa will be responsible for mapping, obtaining relevant analytical data, and synthesis of industry- and OGS-derived information.

In the summer of 1992, all the underground workings in the North Peninsula and East Peninsula areas of Night Hawk Lake, including the (Asarco) Aquarius Mine, were flooded. Therefore, the field work was restricted to shoreline mapping of the North and East peninsulas and adjacent islands, detailed mapping and sampling of Deadman Island, reconnaissance visits to carbonatized outcrops near the boundary of Thomas and Macklem townships, a visit to the site of the (Asarco) Aquarius Mine (no outcrops), and a half-day underground tour of the Stock Mine led by O. Zavesiczky (Chief Geologist, St. Andrew Goldfields Ltd.).

GENERAL SETTING

This area of limited bedrock exposure extends from northeastern Cody Township through northern Macklem township, to southwestern Stock township (Figure 12.2). The Destor–Porcupine Fault (DPF) is approximately coincident with the north shore of Northeast Bay (*see* Leahy 1971, accompanying Map 2222; Pyke et al. 1973). The DPF separates clastic metasedimentary rocks north of the fault, from extremely altered rocks south of it. As mapped by Leahy (1971), these extremely altered rocks

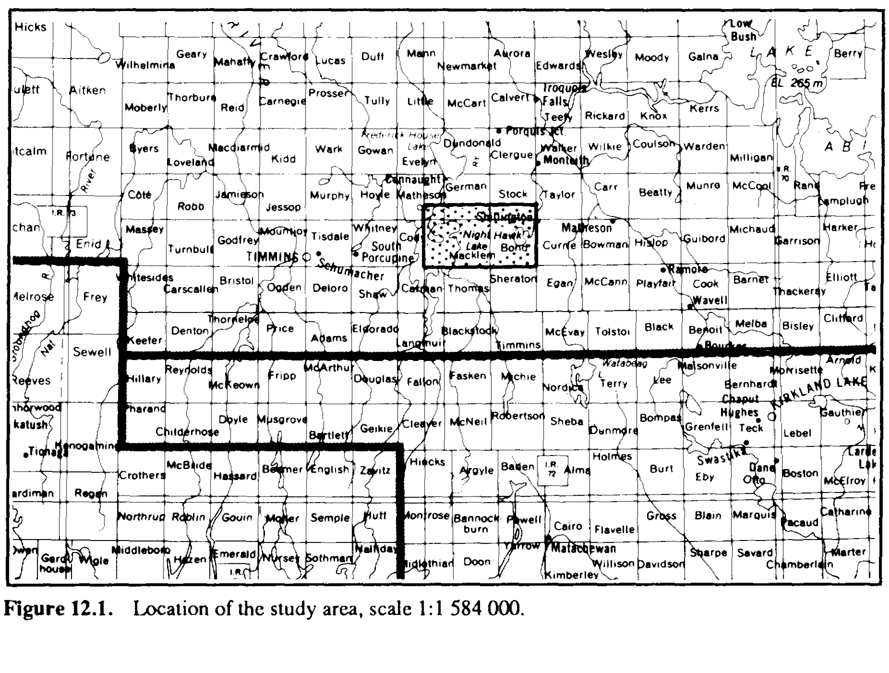

Figure 12.1. Location of the study area, scale 1:1 584 000.

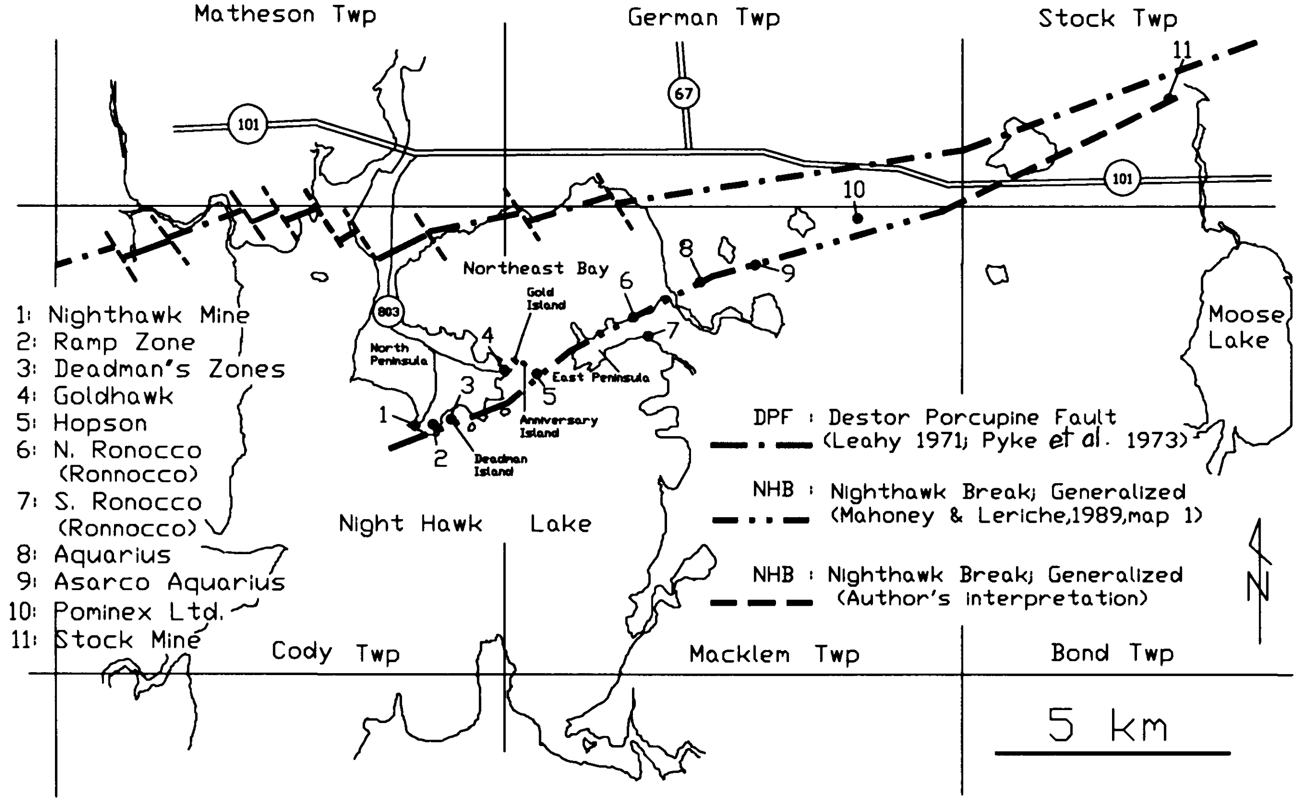

Figure 12.2. Sketch map showing the locations of gold occurrences in the northern Night Hawk Lake area. The names of the occurrences, labelled 1 to 9, are taken from Mahoney and Leriche (1989, Map 1).

comprise chlorite-carbonate schist, talc-chlorite-carbonate schist, chlorite-sericite-quartz schist, serpentine schist, and carbonate rock. They are highly deformed and host the gold mineralization in the area. Faulting, described in detail by Leahy (1971), comprises a succession of 5 fault- or fracture-systems characterized by different trends.

The structure of more direct interest in the present context is a fault locally known as the Night Hawk Break (NHB) (*see* Figure 12.2). It strikes approximately 070°, and has been interpreted as a splay off the DPF, converging with the latter in Stock Township (Mahoney and Leriche 1989). Relevant to this matter, it should be noted that: 1) the Stock Mine, adjacent to, and south of the DPF (O. Zavesiczky, St. Andrew Goldfields Ltd., personal communication, 1992), is situated at an azimuth of approximately 070° along strike from the (Asarco) Aquarius Mine; and 2) southwest-striking fractures, some of which host prominent quartz veins containing visible gold, were observed in the underground workings of the Stock Mine. These relationships indicate that the Stock Mine is likely to be the site where the NHB joins the DPF. At the time of writing, however, it is not known whether the NHB splays off, or intersects with, the DPF.

SALIENT ECONOMIC DATA

Data contributed by J. Houle (Exploration Eastern Canada, Royal Oak Mines Inc.) and P. Harvey (Royal Oak Mines Inc.) indicate that exploration, done in 1989, comprised dewatering and rehabilitation of the Nighthawk Mine, 18 514 feet of underground drilling, and 1504 feet of surface drilling. This work and the method used to calculate ore reserves were described in detail by Mahoney and Leriche (1989). The total mineral inventory of the Nighthawk Mine, Ramp Zone, and Deadman's Zones, is 1 593 627 tons grading 0.167 ounces Au per ton (Mahoney and Leriche 1989, Table 1). Past gold production of the Nighthawk Mine (1924–1927) was 99 000 tons at 0.32 ounces Au per ton (Mahoney and Leriche 1989, p.5). The Nighthawk Mine area continues to be an active exploration target and, at the time of writing, further surface drilling was imminent (J. Houle, Royal Oak Mines Inc., personal communication, September 4, 1992).

As of 1990, the mineable ore reserves of the (Asarco) Aquarius Mine consisted of 179 300 tons at an uncut grade of 0.316 ounces Au per ton, and a cut grade of 0.180 ounces Au per ton; the cut grade was calculated by lowering all the gold values greater than 1.00 ounce Au per ton, to 1.00 ounce Au per ton (J.H. Houtman, Manager Aquarius Mine, LAQ Canada, Ltd., personal communication, 1992). From 1984 to 1989, the Aquarius Mine produced 26 372 ounces of gold (J.H. Houtman, LAQ Canada Ltd., personal communication, 1992).

The Stock Mine is an active producer with a reserve, comprising mineable and possible ore, of 0.6 million tons grading 0.193 ounces Au per ton (O. Zavesiczky, St. Andrew Goldfields Ltd., personal communication, 1992). From the time it opened (1989), to the end of July 1992, the Stock Mine produced 81 657 ounces of gold (O. Zavesiczky, St. Andrew Goldfields Ltd., personal communication, 1992).

PRESENT MAPPING

Tholeiitic Basalt and Main Pre-faulting Structure

Foliated to massive, vesicular, pillowed, tholeiitic basalt crops out along the southern shore of the North Peninsula, and the southern and western shores of the East Peninsula. These flows are south-facing and are locally overturned. Along the south shore of the North Peninsula, foliation in these basalt flows strikes approximately 100° and dips subvertically. On the west side of a promontory directly east of Deadman Island, the 100°-striking foliation is severed by the 070°-striking Night Hawk Break (NHB). Correspondingly, over a distance of a few metres, the appearance of the rock changes from green (chlorite) metabasalt, to reddish-orange (ankerite) schist rich in quartz-carbonate veins of complex pattern, typical of the extremely altered rock. The 100°-striking foliation registers pre-NHB deformation that resulted in shortening along the 010° direction.

Extremely Altered Rocks and Related Structures

Generally, narrow exposures of the extremely altered rock are found along the northeast shoreline of the North Peninsula, on some of the nearby islands (e.g., Gold Island, Anniversary Island), and along the northern shore of the East Peninsula. Outstanding exposures of these rocks occur on Deadman Island, the western half of which was stripped of overburden. This work was carried out by Pamorex Minerals Inc., in 1989, and the exposures on the island are highly representative of what has been observed in the underground workings of the Nighthawk Mine (P. Harvey, Royal Oak Mines Inc., personal communication, 1992).

In the following descriptions, the steeply south-dipping, 070°-striking shear foliation that is exposed on Deadman Island is referred to, for brevity, as the NHB. It must be realized, however, that the characteristics of shearing, as exposed on Deadman Island, is not necessarily representative of the NHB in its entirety. Previous experience in a linear deformation zone (Siragusa 1990) has shown that a central high-strain subzone can merge laterally with subparallel or splay subzones of alternating low- and high-strain, the ductility contrast of different protoliths being a main reason for the width and complexity of the whole structure.

Deadman Island

Regardless of protoliths, tectonites exposed on the island weather to a rather uniform reddish-orange colour due to the oxidation of ubiquitous trace pyrite and widespread ankerite (the colours mentioned below pertain to fresh cuts). The other prominent feature shown by these rocks is the abundance and complexity of the quartz veins.

The dominant tectonite (T_1) is a hard, silicified, finely foliated, aesthetically appealing, rock with bright green colour. This green colour is attributed to the presence of chrome-rich mica and is indicative of an ultramafic protolith. In separate localities, about 12 m north and the same distance south of the NHB, foliation in this rock strikes approximately 100°. This foliation is emphasized by foliation-parallel quartz veins. As previously noted, the 100°-striking foliation predates the foliation associated with the NHB. The preservation of the 100°-striking foliation at such distances from the NHB indicates that the zone of high strain associated with the NHB (or a NHB subzone), can be quite narrow.

Subordinate tectonites, hosted by T_1, include variably fractured, distorted, rotated, and partially mylonitized relics of pre-deformation intrusive rocks of at least 2 kinds. The most frequent of these (T_2) is a conspicuously silicified, medium- to dark-grey rock showing incipient to well-developed flaser structure. A cluster of T_2 relics in the northwest part of the island is moderately mineralized by disseminated pyrite cubes up to 2 to 3 mm in size. The other tectonite (T_3) is an extremely hard, dense rock that is possibly a silicified albitite. It has a whitish colour. The frequency and complexity of the quartz veins tend to increase at the contacts of T_1 with T_2 or T_3 relics. These relics, particularly if small, can imperceptibly merge with quartz.

A straight, north-trending bay up to a few metres wide, splits the exposure on Deadman Island into 2 outcrop areas. It is the locus of a dextral fault that offsets the NHB by approximately 6 m. Numerous north-striking fractures, with little or no appreciable displacement, occur primarily to the west of this fault; virtually no quartz veins are associated with these fractures. Subhorizontal, load-relief fractures, with unknown displacement and dip angles of about 27° or less, are commonly occupied by straight, very thin quartz veins.

Fold breccia, comprising complex quartz-ankerite plications, discrete quartz-albite lenses, and T_3 relics, occurs a few metres south of the NHB. The curviplanar fabric in this rock defines a 6 m wide, Z-type fold partially covered by an overburden patch. This fold has a subvertical axial plane that strikes approximately 100°. Nearby crenulation (west rim of the overburden patch) indicates that the Z-type fold plunges to the east at about 60°. Drawn-out, partially severed, Z-type plications of similar attitude, but shallower eastward plunge (40° to 46°), also occur adjacent to the NHB. These features indicate that, at Deadman Island, the NHB is characterized by dextral, south-down, displacement. If the observed relationships are representative, then fold breccia may exist at depth, down-plunge of the Z-type folding exposed at the surface.

Twenty-seven bulk samples, of exactly 9 kg each, were collected by the senior author and analyzed for gold and other elements by the Temiskaming Testing Laboratories (TTL); each sample represents a (sawed) rock volume of approximately 30 by 30 by 8 cm. The gold concentrations reported below are in ounces Au per ton (TTL Report No. CB 12148): 1) 3 samples, from different T_2 relics north and south of the NHB, yielded 0.584, 0.344 and 0.311 ounces Au per ton; 2) 1 quartz sample, from the north limb of Z-folded breccia adjacent to a T_3 relic, yielded 0.275 ounces Au per ton; 3) 21 samples, comprising T_1 tectonite and a few quartz-carbonate veins, yielded gold concentrations ranging from 0.03 to 0.107 ounces Au per ton and averaging 0.041 ounces Au per ton; and 4) 2 samples of sheared and partly mylonitized rock, 1 of which came from the very locus of the NHB, yielded traces of gold.

Northeast Shore of the North Peninsula

Relatively good exposures of the extremely altered rock crop out along the rim of a deep pond (flooded pit) at the eastern tip of the peninsula (Goldhawk Property, *see* Figure 12.2), and along the shore of the peninsula about 30 m north of the pond. These exposures are very similar to those on Deadman Island with respect to the abundance and complexity of complex quartz veins, the presence of chrome-rich mica and ankerite, and the occurrence of intrusive tectonite relics. Characteristics of these intrusive tectonite relics indicate that some represent pyrite-bearing syenite. The least-altered and least-silicified syenite seen by the senior author is exposed on a nearby tiny island, approximately 100 m south of Gold Island.

Most of the numerous outcrops of extremely altered rock found elsewhere along the northeast shore are poorly exposed, narrow, and stained by the lake water such that textures are obscured. Locally, recognizable structures include straight to curviplanar foliation, plications, and partially exposed, drawn-out folds up to a few metres in length. Close to the eastern tip of the peninsula, these folds are north-northwest-trending, whereas further west they are west-northwest-trending with a shallow eastward plunge. This rotation in fold trend is probably an important feature that can be interpreted in several different ways. Discussion of these conjectural interpretations is deffered pending acquisition of additional data.

The southern rim of the largest bay in the eastern half of the shoreline consists, almost exclusively, of intrusive relicts (T_2), some of which contain a little pyrite. Prominent, complex quartz vein arrays occur along short segments of the lakeshore, close to the sandy isthmus connecting the peninsula with the mainland.

North Shore of East Peninsula

The outcrops of extremely altered rock found here are also poorly exposed and are less numerous than those that crop out along the northeast shore of the North Peninsula. Carbonatized and silicified schists are complexly folded, but are too poorly exposed to collect reliable structural data. The structure more commonly noted is a subvertical, straight to slightly curviplanar, southeast-striking foliation. The southeasterly strike may have resulted from a moderate clockwise deflection of the pre-faulting, 100°-striking foliation, brought about by later movement along the Night Hawk Break.

PRELIMINARY SYNTHESIS

The Night Hawk Break (NHB) is a steeply south-dipping fault or fault-system that strikes approximately 070°. It has been interpreted by previous authors as a splay off the Destor–Porcupine Fault (DPF) that converges with the DPF in Stock Township. Present observations indicate that the Stock Mine is likely to be the site where the NHB joins the DPF. At this time, insufficient data are available to test if the NHB is a splays off of, or intersects with, the DPF. Gold deposits, some of which have significant ore reserves, are hosted by extremely altered rocks close to, or adjacent to, the NHB. The extremely altered rocks comprise deformed, carbonatized, and silicified mafic to ultramafic metavolcanic rocks, and relics of pre-NHB intrusive rocks of alkalic affinity.

In 1992, the best surface exposures of the NHB and associated extremely altered rock were found on Deadman Island. This island was mapped and sampled in detail to characterize structural styles, the relative structural chronology, and to determine the distribution of gold-bearing features. The structural relationships between the NHB and north-northwest- to west-northwest-trending zones of extremely altered rock along the northeast shore of the North Peninsula could be important, but are presently obscure due to poor exposure along this shoreline.

The samples from Deadman Island, of the same weight, were collected from small areas of constant size. Hence, the assay results are regarded to be reasonably representative of the gold concentrations in the specific feature that each sample was intended to test (e.g., folds, plications, narrow shearing, derivatives of ultramafic protoliths, intrusive relics, individual quartz veins). The results indicate that, directly or indirectly, the presence of relics of intrusive rock is probably the single feature of greater economic merit.

The relics of intrusive rock are generally referred to as "porphyries". They were recognized in the Nighthawk Mine (Mahoney and Leriche 1989), the (Asarco) Aquarius Mine (J. Reddick, Asarco Exploration Co. of Canada, Ltd., personal communication, 1992), and the Pominex property (Bradshaw 1984). The best ore mined thus far at the Stock Mine occurs in a rock known as "pyritic porphyry" (O. Zavesiczky, St. Andrew Goldfields Ltd., personal communication, 1992), which, in hand specimen, appears to be very similar to the T2 relics from Deadman Island.

REFERENCES

Bradshaw, R.J. 1984. Gold Discovery on the property of Pominex Ltd., Macklem Township, Ontario; Timmins Resident Geologist's Files, File T-3081, 18p.

Leahy, E.J. 1971. Geology of the Night Hawk Lake area, District of Cochrane; Ontario Department of Mines and Northern Affairs, Geological Report 96, 74p.

Mahoney, E.J. and Leriche, T.H. 1989. Pamorex Minerals Inc., Timmins Division, Regional Exploration Department, Nighthawk Mine Project, Ore Reserves and Mine Geology; Royal Oak Mines Inc., unpublished company file, 29p.

Pyke, D.R., Ayres, L.D. and Innes, D.G. 1973. Ontario Division of Mines, Geological Compilation Series Map 2205. Scale 1:253 440.

Siragusa, G.M. 1990. Deformation and associated auriferous quartz veining in Keith Township, Northern Swayze Belt; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.86–90.

13. Project Unit 92–13. Geology of the Ompa Lake Greenstone Belt, District of Algoma

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INTRODUCTION

Investigations of the Archean rocks near Elliot Lake were initiated in 1990 to expand the geological data base in the area and to stimulate mineral exploration following the recent closures of mines in the region. The Whiskey Lake greenstone belt to the east of Elliot Lake was the first to be mapped in the region (Jensen in press; Rogers 1992). Geological mapping of the Archean Ompa Lake greenstone belt was initiated during the 1991 field season and completed during the 1992 season.

The Ompa Lake greenstone belt is a 30 km long, linear belt of Archean metavolcanic and metasedimentary rocks lying approximately 20 km north of Elliot Lake. The area is bounded by latitudes 46°32´N to 46°36´N and longitudes 82°26´W to 82°48´W (Figure 13.1).

The present mapping program is a reassessment of areas that have been previously mapped by Robertson (1977) and Wood (1975). The Ompa Lake greenstone belt comprises portions of Raimbault, Hembruff, Hughson, Bouck, Buckles and Poncet townships. The entire greenstone belt and the bounding rock units, which comprise an area of about 115 km^2, were mapped at a scale of 1:15 840.

Coincident with this mapping program, lithogeochemical studies of the Archean rocks of the western part of the Ompa Lake belt were conducted by the Centre in Mining and Mineral Exploration Research at Laurentian University (Byron and Whitehead 1991).

Highway 639 passes northward through the eastern end of Raimbault Township. Boat access from Flack Lake and an all terrain vehicle trail to Samreid Lake provide access to the western end of the belt. The western portion of Hembruff Township is accessible from Semiwite and Ompa lakes. The south-central part of the area is accessible from Little Quirke Lake. Rooster, Harry and Applesauce lakes provide float-plane access to the eastern and north-central portions of the region.

MINERAL EXPLORATION

The search for uranium deposits near the base of the Proterozoic, sedimentary Matinenda Formation has been the focus for past exploration in the Elliot Lake area. Very limited exploration for base metals in the Ompa Lake greenstone belt has been carried out, mainly in Raimbault Township. To date, no known exploration programs for precious metals have been conducted in the map area.

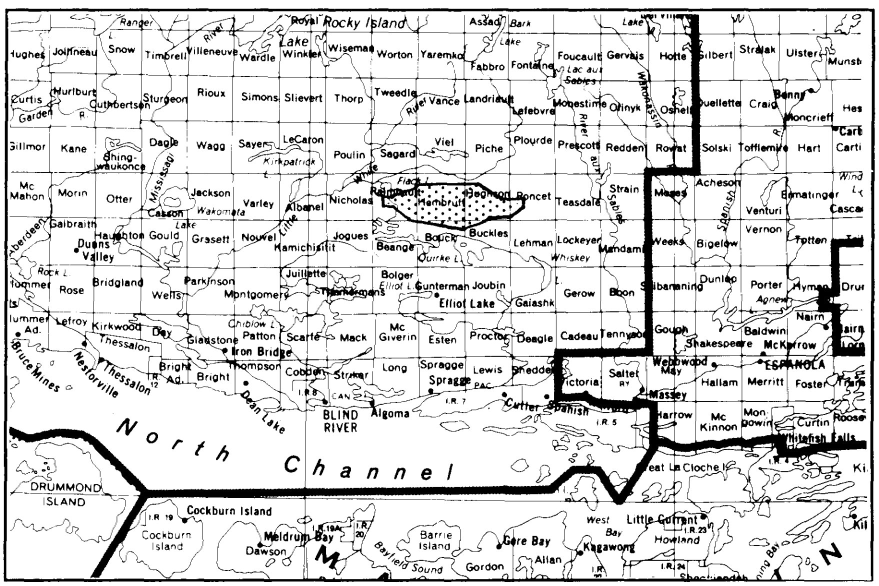

Figure 13.1. Location map of the Ompa Lake greenstone belt area, scale 1:1 584 000.

The following information has been summarized from the files of the Assessment Files Research Office, Ontario Geological Survey, Toronto.

In 1937, the Sudbury Prospecting Syndicate and Erie Canadian Mines Limited carried out a prospecting, trenching and rock sampling program of the sulphide facies ironstone unit to the west of Samreid Lake. Low Ni values were locally encountered.

The same iron formation was outlined by Talvey Metal Mines Limited with a ground magnetometer survey in 1955. In 1957, the ironstone was tested with 29 diamond drill holes totalling 8281 feet (2525 m). Subeconomic assays of Fe and S were reported.

In 1954, both Seabord Oil and Mines Limited and Maniwaki Kid Uranium Mining Corporation conducted geological mapping and radiometric surveys on claim groups to the south of Little Quirke Lake in Bouck Township.

Ground magnetometer and geological mapping surveys were conducted by Trinity Chibougamau Mines Limited, in 1965, on their Iron Lake property in Hughson and Poncet townships. This was followed by 2 diamond drill holes totalling 1541 feet (470 m). Assays for Fe and S were reported.

A number of individuals and companies carried out airborne magnetometer and electromagnetic surveys over portions of the map area from 1969 to 1975. These include surveys by Moody and Pelchat, Hollinger Mines Limited, Sutherland, Robertson and Associates, Denis et al. and Consolidated Morrison.

Jandon Mines Limited conducted geological mapping on a claim group to the south of Little Quirke Lake in Bouck Township in 1969.

In 1969, Chemalloy Minerals Limited carried out ground magnetometer and electromagnetic surveys and geological mapping in portions of Raimbault Township.

In 1976, Consolidated Morrison diamond drilled 2 holes totalling 2332 feet (710 m) to test 2 separate geophysical anomalies in Raimbault Township. No assays were reported.

Doug Sprague carried out a program of line cutting, geological mapping and rock sampling on a property in western Hembruff Township in 1991.

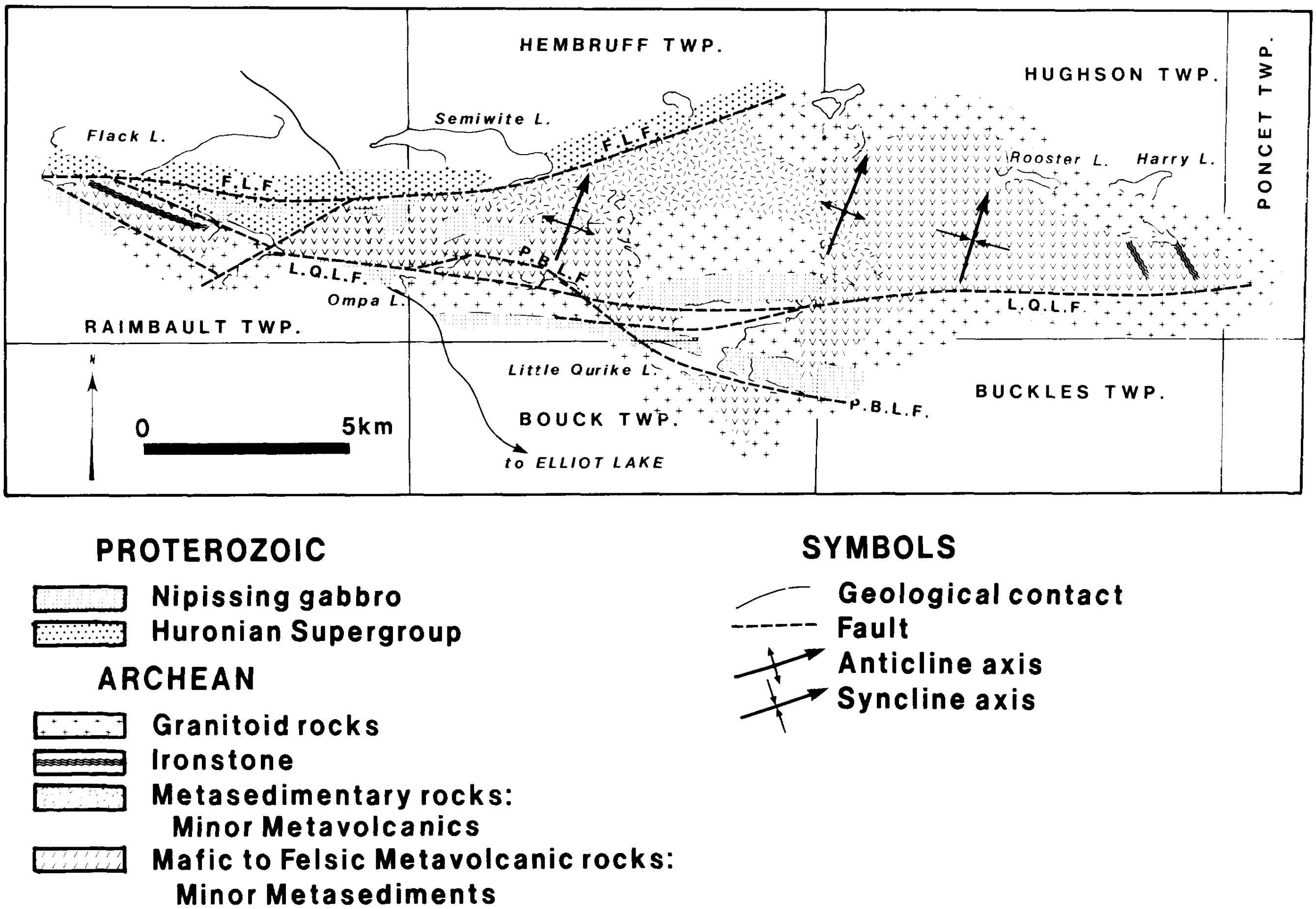

Figure 13.2. General geology of the Ompa Lake greenstone belt.

GENERAL GEOLOGY

The Ompa Lake greenstone belt of Archean supracrustal rocks forms an easterly trending, 30 km long belt that is 5 to 6 km wide at its widest point. The greenstone belt extends from near the western end of Raimbault Township eastward to the western margin of Poncet Township. The general geology of the belt is represented in Figure 13.2 and the general interpreted sequence of geological events is outlined in Table 13.1.

Proterozoic sedimentary rocks of the Huronian Supergroup form the northern boundary of the Archean supracrustal rocks in the west. Gabbroic and granitoid rocks of Proterozoic and Archean age occur to the south of the belt and to the north of the eastern portion of the belt. The Flack Lake and Little Quirke Lake faults form respective north and south fault boundaries to the supracrustal rocks in a number of localities.

The metamorphosed Archean supracrustal rocks in the map area consist mainly of intermediate to felsic tuff and lapilli tuff, arenaceous and argillaceous sedimentary rocks and massive and pillowed mafic flows. Rare sulphide and oxide facies ironstone units also occur in the sequence. Narrow Archean gabbro dikes and sills intrude the supracrustal rocks.

Regional metamorphism ranging from middle greenschist to staurolite-almandine lower amphibolite facies has affected the Archean supracrustal rocks and the Archean gabbros. The metamorphic grade appears to show a general increase across the belt from south to north.

Three main varieties of Archean granitoids intrude the greenstone belt along the southern and northeastern margins. These consist of diorite, tonalite and a granodiorite-quartz monzonite suite.

Sedimentary rocks of the Huronian Supergroup were found in fault contact with the Archean rocks in the western portion of the area.

Nipissing gabbro and diabase of Proterozoic age occurs commonly as plugs and dikes cutting the supracrustal rocks and as large intrusive bodies adjacent to the supracrustal belt in some localities.

Alteration of the Archean supracrustal rocks, generally in association with fault zones, includes silicification, carbonatization, chloritization and sulphidization.

Two large, easterly trending faults, the Flack Lake Fault and the Little Quirke Lake Fault, are the dominant structural features of the map area. Folding in the region is represented by generally broad, steep-north plunging, antiformal and synformal structures.

A penetrative schistosity is apparent in the Archean supracrustal rocks and gabbros which generally displays an increase in intensity from west to east. Pillow facing directions and graded bedding indicate stratigraphic top directions to the north for most of the area.

Exploration potential in the map area exists for structurally controlled gold deposits associated with altered fault zones; for volcanogenic massive sulphide deposits associated with the intermediate to felsic pyroclastic units and related exhalite horizons; for stratabound base metal and gold mineralization related to sulphide facies ironstone and for building stone.

Archean

METAVOLCANIC ROCKS

The metavolcanic rocks of the map area consist mainly of intermediate to felsic tuff and lapilli tuff and massive and pillowed mafic flows. All of these rocks are found interlayered with each other and with the Archean metasedimentary rocks on scales of metres to hundreds of metres.

The intermediate to felsic pyroclastic rocks extend through the map area with the thickest accumulations to the east of Ompa Lake and between Rooster and Little Quirke lakes. Individual units range from less than 5 m to greater than 200 m in width. These rocks are generally fine grained (0.5 to 2 mm), but occasional horizons may be found with fragment sizes exceeding 10 mm. One narrow (20 m) horizon of felsic tuff-breccia interpreted to be of proximal facies was traced for over a kilometre along strike to the southwest of Rooster Lake. The majority of the pyroclastic rocks consist of angular to subrounded, well-sorted, lithic fragments. Quartz-feldspar porphyry horizons are common in the western half of the map area, but are rare in the east. Coarse-grained (greater than 1 cm), poorly to moderately sorted, heterolithic, pyroclastic debris flows were mapped locally throughout the area. Massive to bedded chert horizons were occasionally found in association with the pyroclastic units, generally at or near the tops of the units.

Mafic flows occur only locally in the western portion of the region, but comprise a major lithology in the eastern part. Individual units range from less than 10 m to greater than 200 m in width. These consist of massive and pillowed varieties with equigranular and plagioclase porphyritic textures. The mafic flows have developed into chloritic and amphibolitic schists to the south of Semiwite Lake due to the increase in the degree of metamorphism and deformation.

METASEDIMENTARY ROCKS

Metasedimentary rocks occur throughout the map area except in the thick volcanic sequence to the southwest of Rooster Lake. The thickest concentrations lie across the northern portion of the region to the south of Semiwite and Applesauce lakes. Both arenite and argillite are common and are found both as thick sequences of up to several hundred metres and as intercalated units within the metavolcanic rocks. These rocks probably represent epiclastic deposits from the erosion of the volcanic rocks as they are similar in composition to the volcanic rocks and exhibit conformable stratigraphic relationships.

Table 13.1. Interpreted sequence of geological events in the map area.

ERA	INTRUSIVE/DEPOSITIONAL EVENT	TECTONIC/METAMORPHIC EVENT
	Intrusion of olivine diabase dikes of the Sudbury Swarm	
	Intrusion of Nipissing gabbro and diabase sills and dikes	
PROTEROZOIC		
		Last major displacements along the Flack Lake Fault, Little Quirke Lake Fault and associated faults
	Deposition of Huronian sedimentary rocks	
	Intrusion of Matachewan-type plagioclase-phyric diabase and gabbro dikes	
	Intrusion of foliated and massive granodiorite-quartz monzonite; locally porphyritic	
	Intrusion of foliated and massive to nalite	Syn-intrusive development of foliation
	Intrusion of foliated and massive diorite	
		Regional folding along sub-vertical, north-plunging axes
ARCHEAN		
		Greenschist to lower amphibolite facies regional metamorphism; regional isoclinal folding along an east-west axis; creation of penetrative schistosity
	Deposition of massive and pillowed mafic flows; intermediate to felsic pyroclastics; epiclastic and chemical sedimentary rocks; subvolcanic(?) gabbro dikes and sills	

Arenites are schistose and are composed of variable quantities of quartz, feldspar, muscovite and biotite. Argillites generally consist of biotite-quartz-feldspar schists with local muscovite. Almandine garnet, staurolite and andalusite, commonly developed as products of metamorphism in the sequence, are found to the south of Semiwite Lake.

Chemical sedimentary rocks are also found. In addition to the exhalitive chert horizons that were mentioned in the previous section, sulphide and oxide facies ironstone units also occur. A 3 km long unit of discontinuous, pyrite-pyrrhotite, sulphide facies ironstone occurs in Raimbault Township. A series of folded and discontinuous units of magnetite-quartz-pyrite ironstone lie to the south of Allen Lake in Hughson Township.

GABBROIC ROCKS

Rare, wide (greater than 10 m) and numerous, narrow (less than 3 m) dikes and sills of Archean gabbro intrude the supracrustal sequence. The gabbro is fine to medium grained (less than 1 to 2 mm), equigranular, displays the regional schistosity and has been subjected to the regional metamorphism. The gabbros are most commonly found in association with the thick mafic volcanic sequence to the southwest of Rooster Lake and are interpreted to represent subvolcanic feeders to the mafic volcanism.

GRANITOID ROCKS

Archean granitoid rocks bound the greenstone belt to the south and to the north in the eastern portion of the belt. The 3 main varieties, from oldest to youngest, include a grey, massive to foliated, medium-grained diorite; a white to grey, massive to foliated, medium-grained tonalite; and pink, massive to foliated, medium-grained granodiorite to quartz monzonite. All 3 varieties contain xenoliths of the supracrustal rocks. Porphyritic granodiorite-quartz monzonite with potassium feldspar phenocrysts of up to 3 cm occurs in certain locales. A brick-red, porphyritic granite lies to the southeast of Little Quirke Lake.

Proterozoic

HURONIAN SEDIMENTARY ROCKS

Proterozoic sedimentary rocks of the Huronian Supergroup are in fault contact to the north of the western portion of the greenstone belt. These comprise siltstone, arenite and conglomerate of the Gowganda Formation to the north of Samreid Lake and quartz arenite of the Bar River Formation north of the Flack Lake Fault. Wood (1975) provides detailed descriptions of the Huronian sedimentary rocks in the area.

MAFIC INTRUSIVE ROCKS

Large dikes and sills of Nipissing gabbro and diabase are found locally along the southern boundary of the greenstone belt, along portions of the northern boundary in Raimbault Township and as intrusions into the Archean supracrustal sequence. Numerous narrow dikes intrude the sequence in the eastern portion of the belt and to a lesser degree in the west, generally along subparallel trends to the schistosity. The larger intrusions generally display a gabbroic texture whereas the narrow dikes are generally diabasic. These rocks are fine to medium grained and comprise melanocratic, mesocratic and leucocratic varieties.

Rare, plagioclase porphyritic gabbro and diabase dikes which intrude the supracrustal sequence may be Matachewan-type intrusions. The large plagioclase phenocrysts are characteristic of this type of mafic intrusion.

Rare Proterozoic olivine diabase dikes of the Sudbury swarm were found in the western portion of the map area.

STRUCTURAL GEOLOGY

Three regional faults, the Flack Lake, Little Quirke Lake and Polar Bear Lake faults, are the dominant structural features in the map area. The Little Quirke Lake Fault branches from the Flack Lake Fault near the western end of the belt (*see* Figure 13.2) and the Polar Bear Lake Fault, in turn, branches from the Little Quirke Lake Fault in the vicinity of Ompa Lake.

The Flack Lake Fault trends east-northeast, forming the northern boundary to the western portion of the greenstone belt. A reverse movement with a 72° south dip and a north side downdrop has been inferred by Wood (1975).

The Little Quirke Lake Fault trends east-southeast to east along the southern portion of the map area, representing the southern margin of the belt for much of the area. It is represented by a wide (greater than 50 m) zone of strongly deformed rocks generally within a linear topographic depression. Mylonitic and cataclastic fabrics, shearing, fault breccia and silica and carbonate alteration are locally evident. This fault consists of a group of subparallel faults in the region between the upper part of Little Quirke Lake and Ompa Lake.

The Polar Bear Lake Fault is a major splay from the Little Quirke Lake Fault. It extends from Ompa Lake through the lower part of Little Quirke Lake and is similar in character to the Little Quirke Lake Fault.

A penetrative schistosity is apparent in all of the Archean metavolcanic and metasedimentary rocks and in the Archean gabbros. It increases in intensity from west to east across the area. A weak to moderate schistosity is developed from the west end of the belt to approximately the east end of Ompa Lake. A strongly developed schistosity is apparent in the remainder of the belt. This directly reflects the relative amount of regional strain the rocks have undergone. Pillowed flows also reflect this change in the regional strain. The schistosity is bedding-parallel to -subparallel, steeply dipping and generally displays an easterly to southeasterly strike.

Wood (1975) has suggested a folding history for the area with which the author agrees. It involves initial folding along a subhorizontal, east-trending axis which produced isoclinal folds and the schistosity and later folding along almost vertical, north–plunging axes which has produced a series of generally broad and locally tight antiforms and synforms in the belt. Top directions as indicated by pillowed flows and graded bedding are northerly across most of the belt.

ECONOMIC GEOLOGY

Due to the lack of exploration in the area the mineral potential of the Archean Ompa Lake greenstone belt was largely unknown. The area has a varied geological environment suitable for hosting precious and base metal mineralization.

1. The potential exists for the occurrence of structurally controlled gold mineralization associated with the fault zones in the region. Both the Flack Lake and Little Quirke Lake faults are large, regional structures which may have originated in the Archean. The Little Quirke Lake Fault, in particular, occurs as a wide zone of sheared, brecciated, cataclastized and mylonitized rock which is locally silicified and carbonatized. Minor (1 to 3 %), disseminated pyrite

is locally associated with it. Subsidiary splays off of this fault are similar in character.

2. The intermediate to felsic pyroclastic rocks and the associated chert horizons in the region could host volcanogenic massive sulphide mineralization. The most promising area in the authors opinion lies approximately 1 km southwest of Rooster Lake where a narrow, continuous horizon of felsic tuff-breccia and associated lapilli tuff and pyroclastic debris flows have been interpreted to represent a proximal volcanic facies. Rock grab samples from pyritic (1 to 5%) tuff and chert units in the general area have assayed locally anomalous Cu (up to 829 ppm) and Zn (up to 1170 ppm) values.

3. The pyrite-pyrrhotite, sulphide facies ironstone unit located in Raimbault Township to the west of Samreid Lake has been traced intermittently along strike for over 3 km. It has been previously examined, particularly at the east end, but may still offer some potential for stratabound base metal and gold mineralization. Rock grab samples have assayed up to 2800 ppm Cu and 48 ppb Au.

4. Minor (less than 5%) chalcopyrite-pyrite mineralization occurring as veinlets and disseminations locally may be found hosted by the mafic volcanic units, in particular the pillowed flows.

5. Narrow, discontinuous, calcite-quartz veining with local, minor (less than 5%) chalcopyrite-pyrite is occasionally found in association with the Nipissing intrusions, particularly the larger bodies.

6. Some potential for building stone may exist for the granitoid intrusions which lie to the north and south of the belt. The pink, medium-grained and locally porphyritic granodiorite-quartz monzonite which lies to the south in the more accessible areas may offer the most potential.

7. The Stag Lake stratiform copper occurrence lies just to the north of the central portion of the greenstone belt. It was examined by diamond drilling in the 1960s (Sutherland and Associates 1964, 1965). Low grade (less than 0.25%) copper, occurring as disseminated chalcopyrite and rare bornite and chalcocite, was found locally over large (greater than 10 m) intervals, hosted by the upper member of the Lorrain Formation arenite. The potential for a bulk tonnage mining situation may exist. The remaining core should also be examined for possible associated metals such as cobalt and silver.

REFERENCES

Byron, M. and Whitehead, R.E. 1991. Lithogeochemical study of the Archean volcanic rocks of the Whiskey Lake and Ompa Lake greenstone belts, Algoma District, Ontario; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.57–63.

Jensen, L.S. in press. Geology of the Whiskey Lake area, west half; Ontario Geological Survey, Open File Report, in press.

Robertson, J.A. 1977. Nicholas and Raimbault townships; Ontario Division of Mines, Geological Map 2347, scale 1:31 680.

Rogers, M.C. 1992. Geology of the Whiskey Lake area, east half; Ontario Geological Survey, Open File Report 5834, 110p.

Sutherland and Associates 1964,1965. Assessment file diamond drill reports on the Stag Lake occurrence, Hembruff Township, Ontario Geological Survey.

Wood, J. 1975. Geology of the Rawhide Lake area, District of Algoma; Ontario Division of Mines, Geoscience Report 129, 67p.

14. Comparison of Remote Sensing and Digital Evaluation Data for Geological Lineament Interpretation, Thunder Bay Area, Ontario

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INTRODUCTION

The Ontario Geological Survey and the Provincial Remote Sensing Office of the Ministry of Natural Resources are continuing a joint effort to evaluate the usefulness of remote sensing techniques in geological mapping. To this end, a lineament analysis of 1:20 000 scale, digital elevation data is compared with similar analyses of LANDSAT Thematic Mapper and airborne C-band Synthetic Aperture Radar (SAR) for the Thunder Bay area. Since both digital elevation data and SAR data are acknowledged sources of terrain or landform information, it would be beneficial to assess their relative merits and limitations and in turn compare these results with that obtained from examination of spectral data, specifically Landsat Thematic Mapper and SPOT data (Mussakowski and Trowell 1991).

The Provincial Mapping Office of the Land and Resource Information Branch, Ministry of Natural Resources generates digital topographic data (Ontario Digital Topographic Data Base) for the province, at 1:20 000 scale for Northern Ontario and 1:10 000 for Southern Ontario. This data base includes point elevations that can be converted to a raster image with spatial pixel resolutions that rival those of orbital remote sensing data and even possibly airborne radar data. The derived elevation image can be used in much the same way as conventional topographic maps or remote sensing imagery, as a source for terrain or landform information.

In this study, we conducted a lineament analysis on digital topographic files that were enhanced using image processing techniques available on an image analysis system (IAS). These were then compared with lineaments mapped from a digitally enhanced LANDSAT Thematic Mapper colour composite and an airborne C-band SAR image. A cursory evaluation of a SPOT panchromatic image was also done.

STUDY AREA

The study area selection criteria were based on the availability of digital topographic data files over terrain suited for lineament mapping. The test area, covering

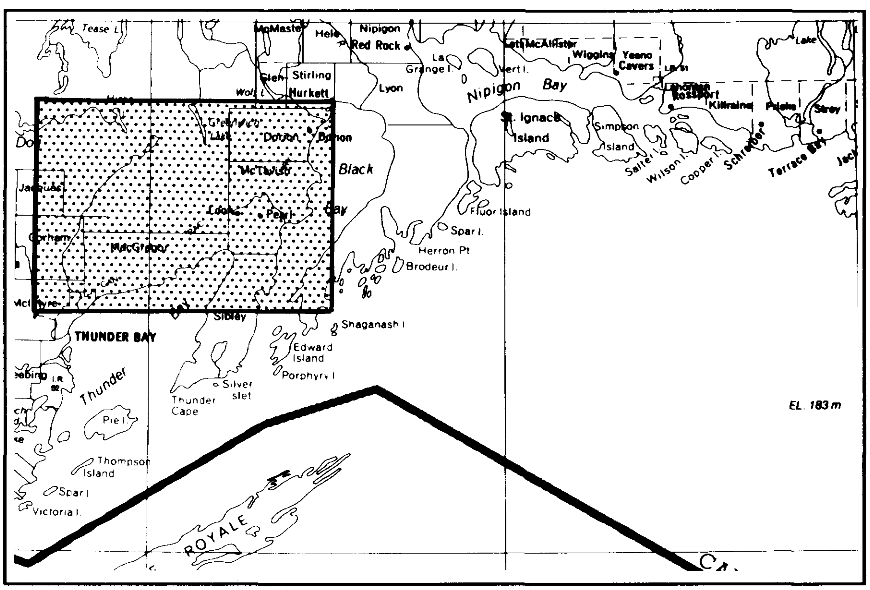


Figure 14.1 Location map for the Thunder Bay area, District of Thunder Bay, scale 1:1 584 000.

2400 km², lies immediately northeast of the city of Thunder Bay (Figure 14.1). The landscape is dominated by highly dissected, rugged uplands with notable local relief and is characterized by deep valleys and high rocky knobs that have elevation differences in excess of 350 m. Thin and discontinuous glacial deposits of bouldery, sand-rich till overlay much of this area. The terrain immediately south of the upland area is generally flat and slopes gently toward Lake Superior.

All the rocks in this area are of Precambrian age. Major regional lineaments transect the study area, trending northeast, north-northeast, and northwest. The eastern part of this area is dominated by Proterozoic sediments cut by mafic dikes and sills. The sills are tilted to the south, forming mesas, cuestas, and long, narrow, steep sided ridges (Mollard and Mollard 1981).

DIGITAL TOPOGRAPHIC DATA BASE

The Province's Ontario Digital Topographic Data Base (ODTDB) is a digital version of the medium-scale topographic mapping of the Ontario Basic Mapping program (OBM). Northern Ontario is mapped at a scale of 1:20 000 from 1:50 000-scale aerial photography, whereas Southern Ontario is mapped at a scale of 1:10 000 from 1:30 000-scale aerial photography. Map files for Northern Ontario are divided into 10 by 10 km grid cells and for Southern Ontario into 5 by 5 km grid cells based on the Universal Transverse Mercator (UTM) Projection and Grid system. Each map includes hydrographic features (streams, rivers, lakes, marshes, etc.), planimetric features (roads, railways, buildings, power lines, etc.), vegetation outlines and elevations in the form of contours or digital spot heights. Maps that have been digitized are available in DLG (3), ISIF, ARC/INFO EXPORT and straight ARC/INFO file format (Zillmer 1990), and can be transformed to AUTOCAD DXF format with the appropriate conversion software.

Where hard copy OBM maps only existed, elevation data was digitized directly from the OBM contour lines. However, when the OBM program became fully digital, photogrammetric stereo compilation methods were adapted for the collection of elevation data. Points are digitized along scan lines in a static mode at a density of 2 mm at photographic scale. Scan lines are 2 mm apart. Thus, there is a point every 100 m in Northern Ontario and a point every 60 m in Southern Ontario. Points are also collected at up to 3 times the scan density along "break lines". These include crowns of hills, bottoms of depressions, water courses, lake edges, roads, railways, etc. The elevations are considered accurate to within one quarter of the contour interval or 2.5 m for 1:20 000-scale maps and 1.25 m for 1:10 000-scale maps (Houweling 1990).

The Thunder Bay study area contains twenty-four 10 by 10 km DTDB map files totalling 2400 km². Point elevation data were converted to a 25 by 25 m raster file using point to grid transformations resulting in a file of 400 lines by 400 pixels for each map sheet. The 24 raster elevation files were then merged to form a file of 2400 lines and 1600 pixels and these data were then converted to a grey scale image. For viewing compatibility, the range of elevation values are converted to grey tones. Black tones represent areas of minimum elevation and white tones represent areas of maximum elevation. A continuous grey tone image, therefore, represents the full range of elevations recorded (Photo 14.1).

The hydrographic and planimetric vector files for each map sheet were merged and transferred to the larger raster data base.

METHODOLOGY

The process of converting point elevation files to an image file has previously been documented (Mussakowski and Trowell 1991; Mussakowski 1991). The image file consists of 25 m pixels covering an area of 2400 km². The spatial resolution of the digital elevation data is based on sampling density of point elevations consistent with the map scale. At 1:20 000, this is about 33 m. The range of

Photo 14.1. Elevation image derived from elevation point files of the Ontario Digital Topographic Data Base (ODTDB).

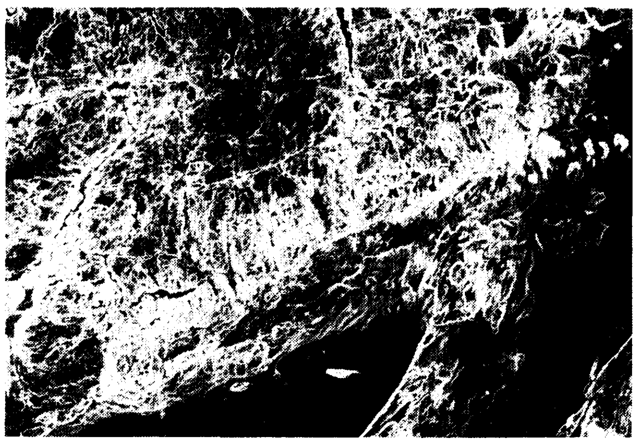


Photo 14.2. Slope-elevation image derived from elevation point files of the ODTDB.

pixel values represents the range between the minimum and maximum elevations recorded in the test area (395 m). These data are then presented in image form (*see* Photo 14.1) using the terrain analysis package from an image analysis system (IAS).

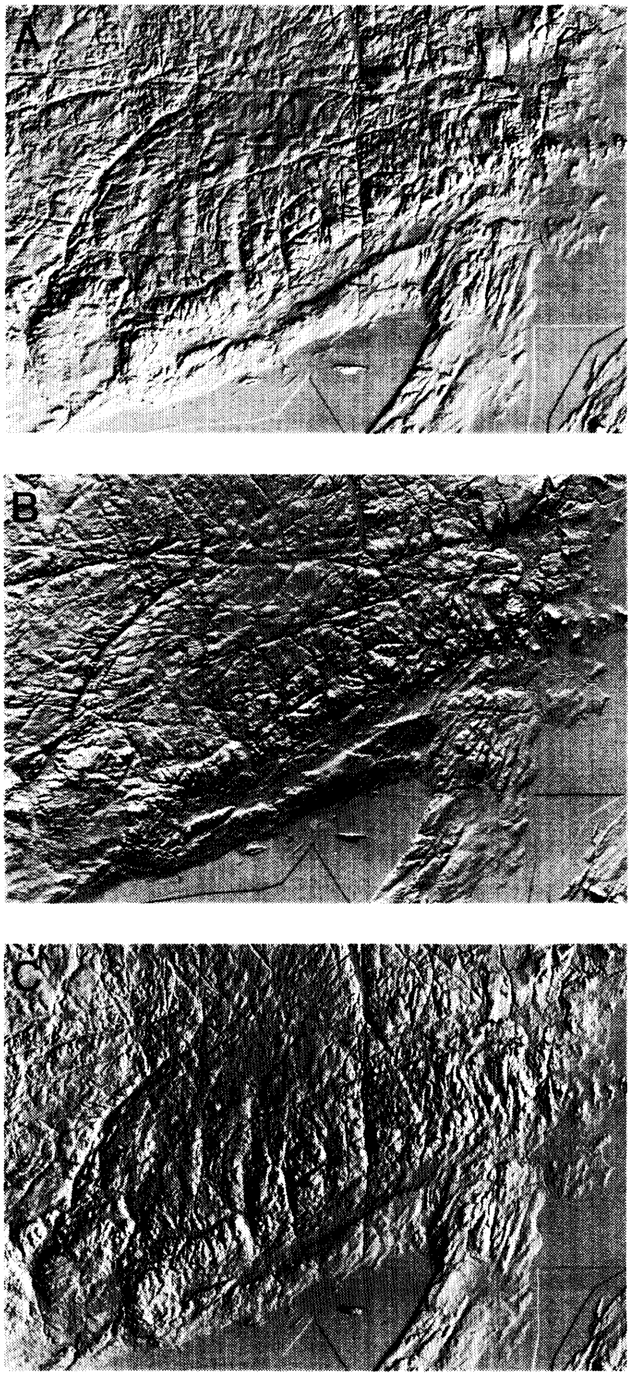


Photo 14.3. A) Shaded relief image derived from elevation point files of the ODTDB. Illumination direction N to S. Illumination angle 40°. Scale 1:100 000. B) Shaded relief image derived from elevation point files of the ODTDB. Illumination direction E to W. Illumination angle 40°. Scale 1:100 000. C) Shaded relief image derived from elevation point files of the ODTDB. Illumination direction SE to NW. Illumination angle 40°. Scale 1:100 000.

Two useful presentations of the elevation image for geological mapping are shaded relief and slope (Photo 14.2) and shaded relief images. These images are created interactively using raster-based terrain analysis software on an image analysis system.

Slope, defined as the rate of change of elevation is imaged by increasing brightness (i.e., the darkest tone represents areas of minimum slope, and the brightest tone represents areas of maximum slope).

Shaded relief images simulate the effect of shining a light onto a three-dimensional surface. The illumination source (i.e., inclination angle and azimuth) is the interactive variable for generating these images. Photo 14.3A, 14.3B and 14.3C are shaded relief images illuminated from various azimuths at a 40° inclination angle.

A LANDSAT Thematic Mapper image, recorded on May 27, 1989, was geo-coded and georeferenced to the elevation data base using the drainage vector file to collect tie-down points. The image was then resampled to 15 m pixels (Photo 14.4A). Conventional linear stretching was applied to each of the the LANDSAT Thematic Mapper band 4, 5 and 7 images to create a colour composite.

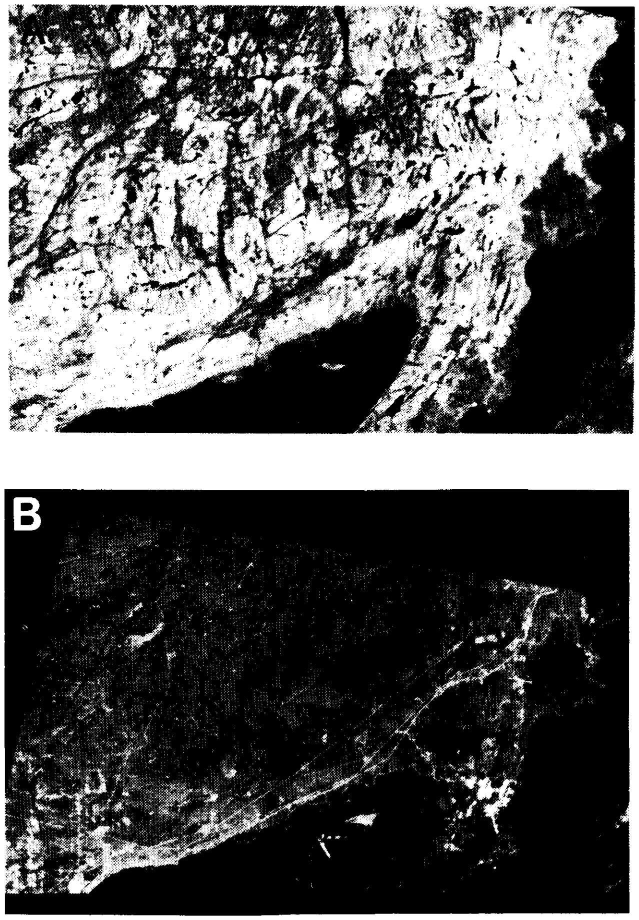


Photo 14.4. A) LANDSAT Thematic Mapper image (Bands 4,5 and 7) recorded May 27, 1989. B) SPOT panchromatic image recorded May 6, 1988.

The SPOT panchromatic image (*see* Photo 14.4B), recorded on May 6, 1988, was subjected to the same geometric correction process as the LANDSAT Thematic Mapper image, however, it was not possible to collect tie-down points with sufficient accuracy to include in this study due to the extreme off-nadir view.

For the present study, airborne C-band SAR data in wide swath mode was flown by the Canada Centre for Remote Sensing under the Radar Data Development Programme (CCRS 1988) for the Thunder Bay study site. The data was geometrically registered using the drainage and transportation vector files of the ODTDB to collect tie-down points. The image was then resampled from the original 10 by 20 m to an averaged 15 by 15 m pixel resolution (Photo 14.5). Low pass filtering and a histogram equalization enhancement were also applied to the SAR image. These procedures allowed visual interpretation and comparison to be carried out on imagery that have similar interpretation biases; i.e., terrain features that are not in line with the look or illumination direction are enhanced and features that are in line with the look or illumination direction are suppressed. A shaded relief enhancement of the digital elevation data with the same illumination direction was also generated and used for comparison. All 3 images used in the evaluation are therefore illuminated from the same direction and each image has been optimally enhanced for maximum terrain information.

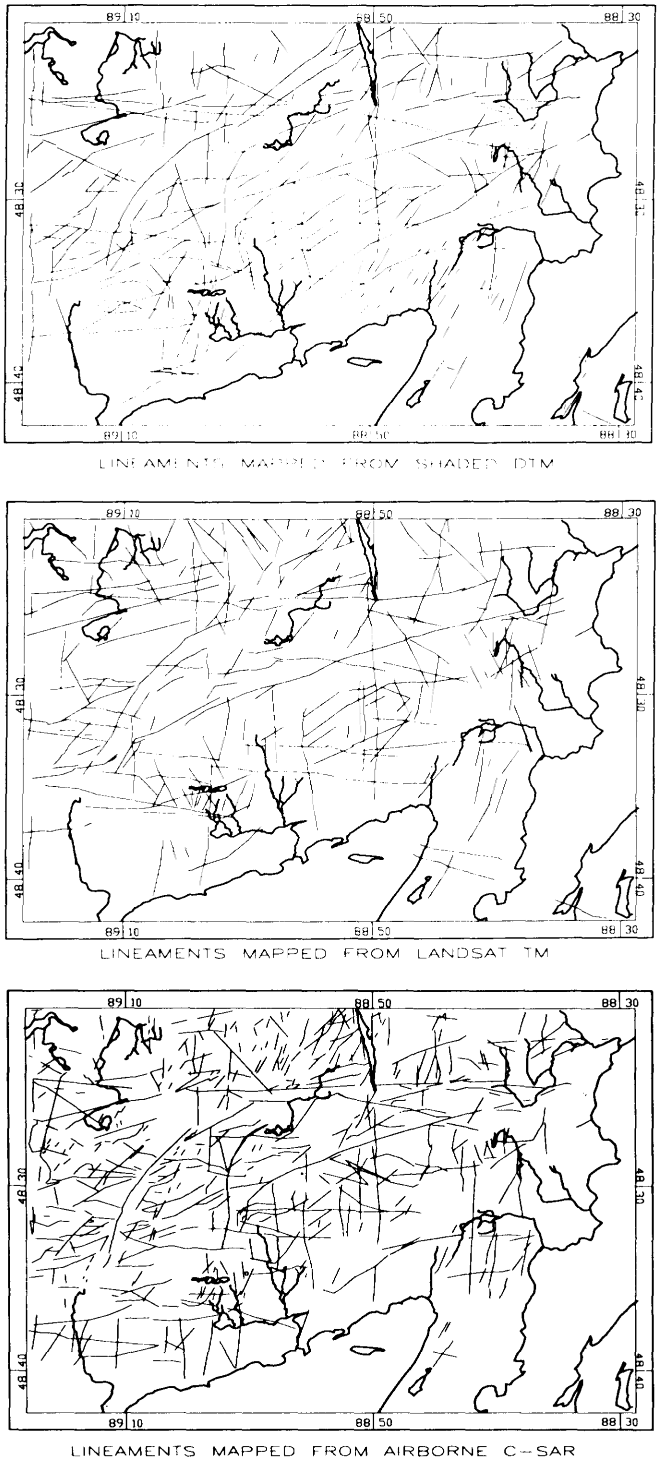
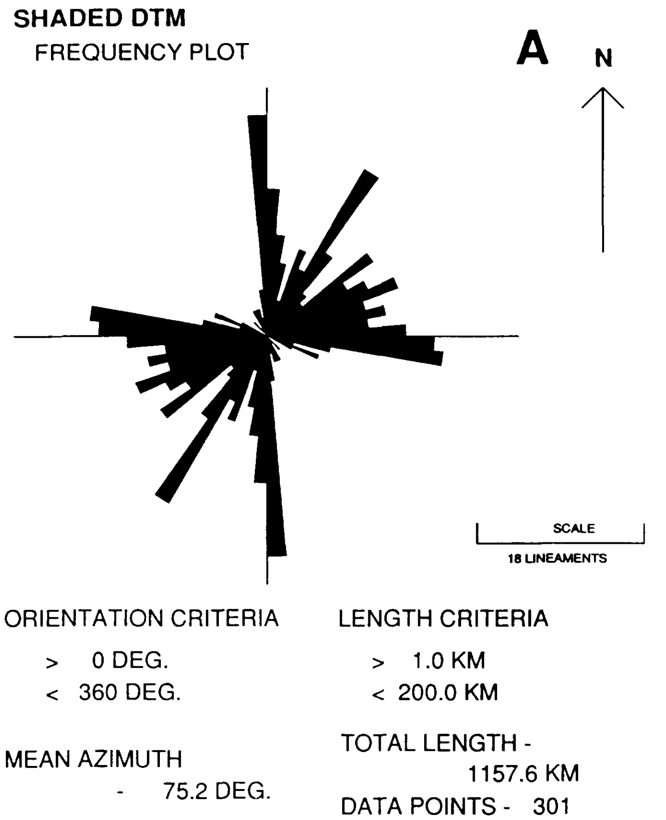


Figure 14.2. A) Lineament study of the Thunder Bay area mapped from shaded Digital Terrain Model (DTM) image. B) Lineament study of the Thunder Bay area mapped from LANDSAT Thematic Mapper image. C) Lineament study of the Thunder Bay area mapped from airborne SAR image.

Photo 14.5. Airborne wide-swath SAR (Synthetic Aperture Radar) image.

Photo 14.6. Composite image of shaded digital terrain and LANDSAT Thematic Mapper image.



INTERPRETATION

Linear and curvilinear features were digitized directly from images displayed on the screen monitor from each of the 3 data sets (Figures 14.2A, 14.2B and 14.2C). For comparative purposes, the SAR lineaments were overlain with lineaments mapped from the digital elevation and LANDSAT Thematic Mapper images. It was intended that the results would reveal which data types most effectively displayed the lineaments despite any potential interpreter bias. The lineaments at this time were not assessed for their geological relevance.

Of the total number of lineaments mapped from both the SAR and shaded relief, digital elevation image, 20% were identified from both data sets, 55% were identified from the SAR image only and 24% were identified from the shaded elevation image only. A similar comparison with the LANDSAT image revealed that, of the total number of lineaments identified from the SAR and LANDSAT TM image, 15% were common to both, while 52% were identified from the SAR image and only 33% were identified from LANDSAT only. Table 14.1 summarizes the results, while Figures 14.3A, 14.3B and 14.3C present cluster diagrams of the lineaments as determined on each data set.

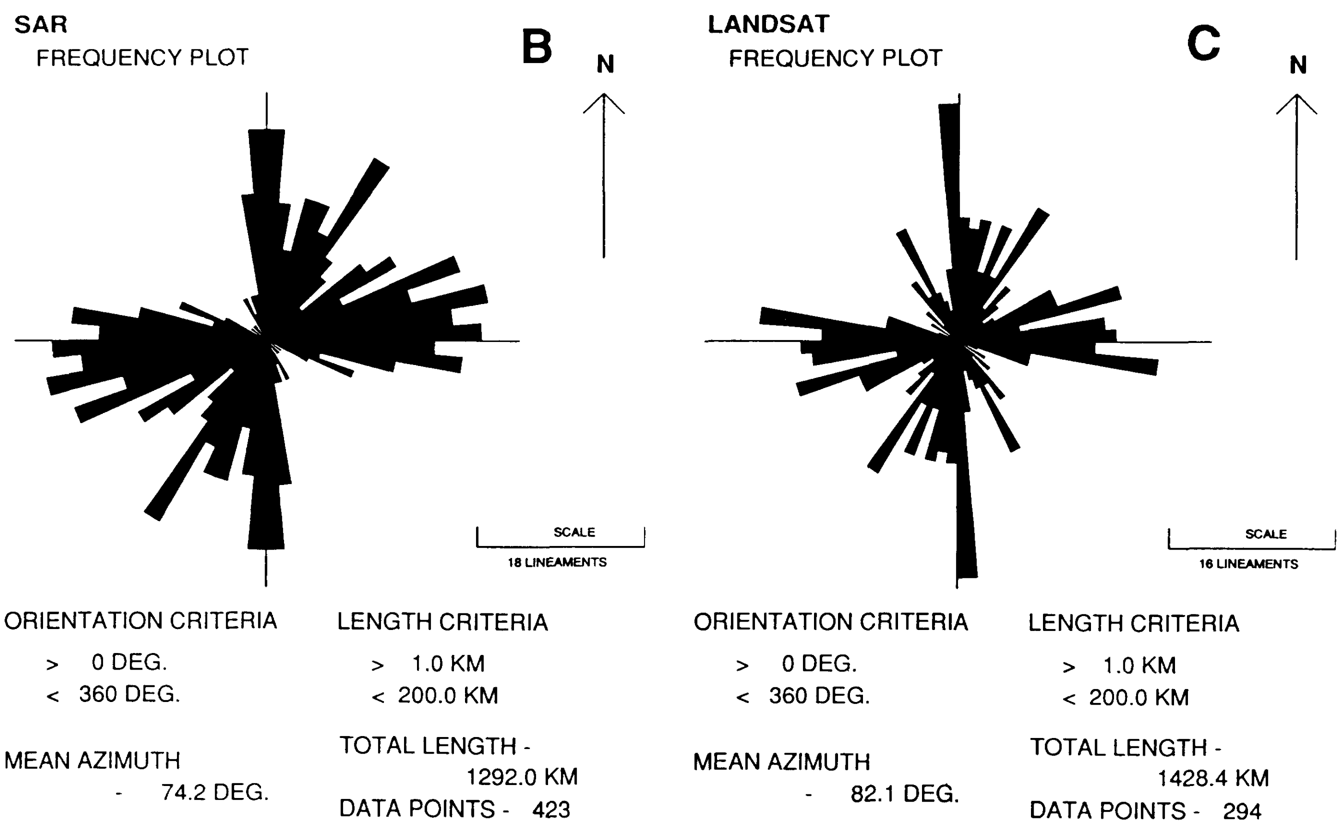


Figure 14.3. A) Lineament analysis showing DTM Frequency Plot. B) Lineament analysis showing LANDSAT Thematic Mapper Frequency Plot. C) Lineament analysis showing airborne SAR Frequency Plot.

Table 14.1. Summary count of lineaments mapped from SAR, Landsat TM and digital elevation data, Thunder Bay study area.

Data Type	No. of Lineaments	Percentage of Total Identified
SAR + Elevation	177	20
SAR Only	477	55
Elevation Only	211	24
Total SAR	654	75
Total Elevation	388	44
SAR + Landsat TM	136	15
SAR Only	468	52
Landsat TM Only	304	33
Total SAR	604	67
Total Landsat TM	440	48

Photo 14.6 is a composite image of shaded digital terrain image and LANDSAT Thematic Mapper image.

No systematic geological interpretation is attempted here. Interpretation must be verified in the field. As well, any "ground truthing" should involve geoscientists with local expertise.

CONCLUSIONS

This study shows that medium-scale digital topographic data aids lineament identification. The raster elevation images can be used in much the same way as conventional topographic maps or remote sensing imagery, that is, as a source for terrain or landform information.

The results of this study reveal that a significantly larger number of lineaments were identified from the SAR image than either the digital elevation image or LANDSAT TM image. This appears to be largely due to the higher resolution of the SAR data. The shaded relief image, however, was but a single enhancement selected to coincide with the illumination direction of both the LANDSAT TM and SAR image. Results from the previous study (Mussakowski and Trowell 1991) show that the number of lineaments interpreted from the digital elevation image increased by a factor of 3 with the use of shaded relief enhancements illuminated from a selected number of orientations (Mussakowski and Trowell 1991). Achieving a similar affect with SAR would require multiple flights and recordings with the same selected orientations. The SPOT image showed very few of the lineaments identified from the other data sets due to high illumination angle and low spectral contrast.

Also of significance is the low proportion of lineaments that are common to either data set indicating that each data set is potentially a valuable contributor to the mapping of terrain units.

It is reasonable to assume that orbital SAR data will similarly contribute to the information base, the only concern which has yet to be assessed is the impact that layover and foreshortening may have on terrain analysis due to the very steep depression angles inherent in satellite data.

Digital topographic data bases greatly improves the flexibility of data presentation. The conversion of elevation data to images illuminated from variable directions assists in human perception of shape much better than points or contours plotted on a map.

REFERENCES

Canada Centre for Remote Sensing. 1988. CCRS/OCRS cooperate in SAR application development; Remote Sensing in Canada, v.16, no.3, Winter.

Houweling, J., 1990. A 3D perspective; Ministry of Natural Resources, Geographic Information Systems Seminar, Toronto, September 1990, p.70–86.

Mollard, D.G. and Mollard, J.D. 1981. Black Bay area, District of Thunder Bay; Ontario Geological Survey, Engineering Geology Terrain Study 58.

Mussakowski, R. 1991. Ontario's Digital Topographic Data Base: a new source of data for geoscientists; Ministry of Natural Resources, Geographic Information Systems Seminar, Toronto, November 25–26.

Mussakowski, R. and Trowell, N.F. 1991. Lineament analysis of digital elevation data and a comparison with LANDSAT Thematic Mapper and Spot panchromatic data, Thunder Bay, Ontario area; Proceedings of the 14th Canadian Symposium on Remote Sensing, May 6–10, Calgary, Alberta.

Zillmer, G., 1990. The Ontario Digital Topographic Mapping Mapping Program; GIS for the 1990s, Ottawa, March 5–8, Proceedings, p.291–299.

15. Building Stone Evaluation of District of Muskoka, and parts of Haliburton, Simcoe, and Victoria Counties

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INTRODUCTION

This summary describes the research and fieldwork conducted in this initial season to evaluate the dimension stone potential within 35 townships in the counties of Haliburton, Simcoe and Victoria, and in the district of Muskoka. The study area is limited to areas which are directly underlain by the Grenville Province and consequently excludes the middle Ordovician Simcoe Group rocks to the south (Figure 15.1). Air photo interpretation located several large outcrops, some of which were eliminated as potential economic sites upon field investigation.

CURRENT PRODUCTION AND EXPLORATION

Presently, there are no producing dimension stone quarries in the study area, however, there has been an increase in staking activity and it is anticipated that some large test blocks will be extracted for testing in the near future.

Small flagstone deposits and operating quarries are also receiving more attention by prospectors and developers.

CURRENT PROGRAM

Emphasis has been placed on locating and evaluating sites which have potential for extraction of large blocks for the purposes of cutting and polishing. However, several areas have been noted as possibly having potential for thinly splitting stone (flagstone). A map showing these areas is available for viewing at the Resident Geologist's office in Dorset.

Air Photo Interpretation

Air photo interpretation was completed for the study area during the spring and early summer of 1992. Most of the photos viewed were 1984, 1:30 000, "regular leafless photos". In many instances, outcrop was identified without the use of magnification or stereoscopes. Significant outcrops within 2 km of a driveable road were

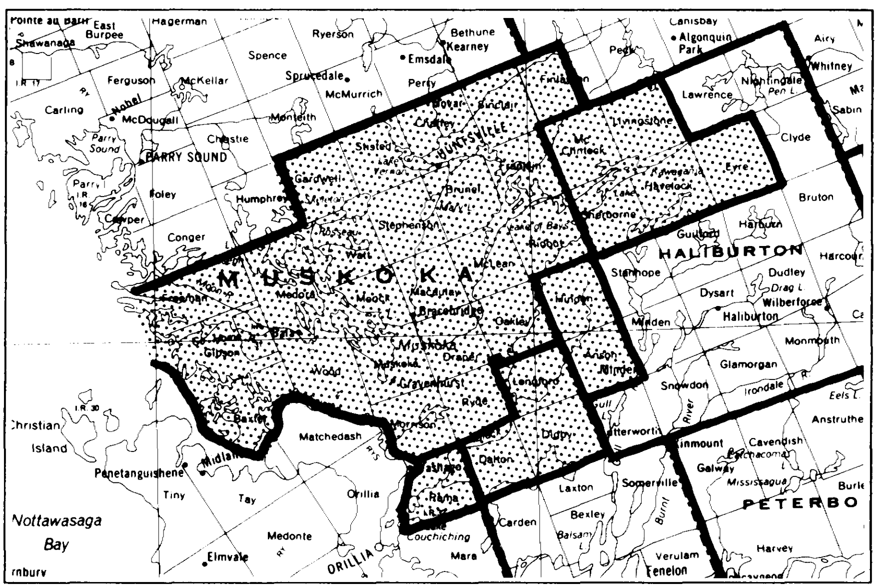

Figure 15.1. Location map of the study area, scale 1:1 584 000.

noted. Details and exact locations of these may be viewed on 1:50 000 topographic maps at the Algonquin District Office.

Field Work

Outcrops visited were evaluated and most were rejected as dimension stone sites for one or more of the reasons discussed below. A substantial amount of outcrop is required to properly assess any deposit. Some were covered with moss, lichen or light soil and vegetation and so were rejected at this time.

A uniformity in rock type over several metres increases dimension stone potential. Some sites contained large pods or boudins, or hosted several lithologies. Other localities contained networks of pegmatitic material in varying configurations.

Jointing in the rock may reduce the size of blocks which can be removed from the site and thus lower its potential value. The orientation of the joint sets in many sites is random and often at an angle to the rock fabric. Sites with vertical joints at right angles to gneissosity (if present), spaced greater than 2 m, and with favourably spaced or no horizontal jointing (if possible) have higher potential.

The presence of certain deleterious minerals such as mica, pyrite, and garnet adds a negative factor to a site. Many sites were rejected because of biotitic partings creating planes of weakness. Other minerals may pluck out during cutting and polishing processes.

Resistance to weathering, durability and overall appearance or attractiveness of the rock are also considered in dimension stone evaluations.

MUSKOKA ROAD 13–SOUTHWOOD ROAD, WOOD TOWNSHIP

Located in lots 5 and 6, Concession XII in Wood Township, approximately 8.3 km off Highway 169 on Muskoka Road 13 is a large outcrop of migmatitic gneiss approximately 1 km long, 50 to 100 m wide and 3 to 8 m high, trending approximately 300°. This rock comprises medium- to fine-grained grey layers ranging randomly from 3 to 10 cm true thickness, interlayed with pink, medium- to coarse-grained granitic material. These layers dip from 25° to 40° east. Vertical joints are spaced 1 to 5 m apart and trend about 50°. A minor set of joints strikes approximately 300°.

There are also some crosscutting pegmatitic dikes within the deposit ranging in size from 1 to 20 cm in width and appear to be concentrated in areas which could be segregated from the other migmatite. There is potential to take some large blocks from this site which would produce attractive panels. There may be possibilities of producing 2 varieties of stone due to the variation in amounts of orthoclase.

CORMACK DEPOSIT, MONCK TOWNSHIP

A very attractive stone was located on Lot 11, Concession A, in Monck Township. It is a homogeneous migmatitic gneiss trending 310° with coarse-grained swirls and siliceous layers 1 to 6 cm thick. Some aplitic and pegmatitic dikes are spaced 3 to 5 m apart. Joint spacing is 3 to 4 m in the outcrop nearest the road. Southward along the ridge, exposure is poorer, making evaluation more difficult, but joint density appears to be fairly low and the rock is homogeneous. This deposit has the potential to provide large blocks, which may be suitable for cutting or polishing.

KING DEPOSIT, BAXTER TOWNSHIP

Two large outcrops of pink granitic material were located on Lot 33, Concession III, in Baxter Township, approximately 2 km southwest of Highway 69 on Honey Harbour Road. The deposit is just west of a previously described prospect (Bax–03, *in* Verschuren et al. 1986). The rock is red-orange, medium to coarse grained, with granitic pegmatites ranging in size from 1 to 40 cm in width. Joints trend both 115°, with spacings of 1 to 3 m, and 80°, with spacings of approximately 1 m. Graphic texture is present throughout the westerly ridge.

BARDWVILLE DEPOSIT, MONCK TOWNSHIP

Located 2 km east of Highway 118 on Lot 21, Concession X is an outcrop of grey and pink gneiss partially exposed for 430 m north of Eggs and Butter Road. It contains clots of siliceous material in an amphibolitic matrix. Near the margins of the body, pink clots have become augen shaped with mica and hornblende defining the gneissosity. Joint spacing is 0.5 to 2 m, trending 320° and due north. There are also some mafic pods and a few pegmatitic dikes scattered throughout, which may lessen its potential.

PROPOSALS FOR FURTHER WORK

Field work should continue to evaluate remaining bedrock targets already identified using conventional air photos. In addition, the use of larger photos and satellite imagery should be tried in areas of high potential. Priority should be given to spending time where bedrock exposure and land availability coincide. There are several townships within the study area which meet such criteria. Some of them are listed below:

TOWNSHIP	% CROWN LAND
Matchedash	64
Morrison	35
Wood	58
Baxter	53
Freeman	84

Areas, therefore, within the Moon River, Go Home, and Rosseau subdomains should be given priority for future research and exploration.

ACKNOWLEDGMENTS

The author wishes to thank the staff of the Resident Geologist's office in Dorset: D. Villard, C. Marmont, J. Reed, J. Jones and T.L. Mathias for their support during this past field season.

REFERENCES

Verschuren, C.P., Papertzian, V.C., Kingston, P.W. and Villard, D.J. 1986. Reconnaissance survey of building stones of eastern and central Ontario; Ontario Geological Survey, Open File Report 5585, 302p.

RELEVANT LITERATURE

Fouts, C.R. and Marmont, C. 1989. Gneisses of the Parry Sound–Muskoka area: flagstone resources; Ontario Geological Survey, Open File Report 5725, 72p.

Marmont, C.R. 1991. Building stone, feldspar and limestone resources in central Ontario; Ontario Geological Survey, Open File Report 5760, 499p.

Marmont, C.R. and Johnston, M. 1987. Mineral deposit studies in the Huntsville–Parry Sound–Powassan area—a progress report; Ontario Geological Survey, Open File Report 5647, 221p.

Martin, W. 1983. Industrial minerals of the Algonquin region; Ontario Geological Survey, Open File Report 5425, 316p.

Ministry of Northern Development and Mines, Staff of the Resident Geologist's Office, Dorset, Ontario 1989. Building Stone Opportunities in Central Ontario; Interim Report, 16p.

16. Lithogeochemical Study of the Archean Volcanic Rocks of the Whiskey Lake Greenstone Belt, Algoma District, Ontario

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INTRODUCTION

During the 1992 field season, detailed mapping and sampling was carried out at 4 locations within the Whiskey Lake greenstone belt. This report summarizes the activities of the past field season, and includes sample locations for the western portion of the Ompa Lake greenstone belt (collected in 1991). There was no further sampling in the Ompa Lake belt this past field season. The purpose of the study is to document certain lithogeochemical characteristics of the Whiskey Lake greenstone belt suggestive of possible economic mineralization, and to provide a data base to assist the mining industry in carrying out mineral exploration in the region. The project is being conducted collaboratively by staff from the Department of Geology, Laurentian University and the Ontario Geological Survey. Funds were provided by a grant from the Ministry of Northern Development and Mines to Laurentian University, as part of the Ontario Government's Elliot Lake Initiative.

Based on the preliminary results to date (Byron and Whitehead 1991b), 4 areas in the Whiskey Lake greenstone belt were singled out for further evaluation. Areas of interest were mapped and sampled in detail to help explain the lithogeochemical anomalies (e.g., structural control, geological contacts, rock types, alteration, or nugget effect), to better constrain the areal extent of lithogeochemical anomalies, and to assess the effectiveness of regional lithogeochemical surveys, of this nature, for targeting areas of economic mineral potential.

The Whiskey Lake greenstone belt is situated approximately 6 km southeast of the town of Elliot Lake (bounded by latitudes 46°27'N to 46°31'N and longitudes 83°26'24"W to 82°46'54"W)(Figure 16.1). Its border is defined by rocks of the Huronian Supergroup,

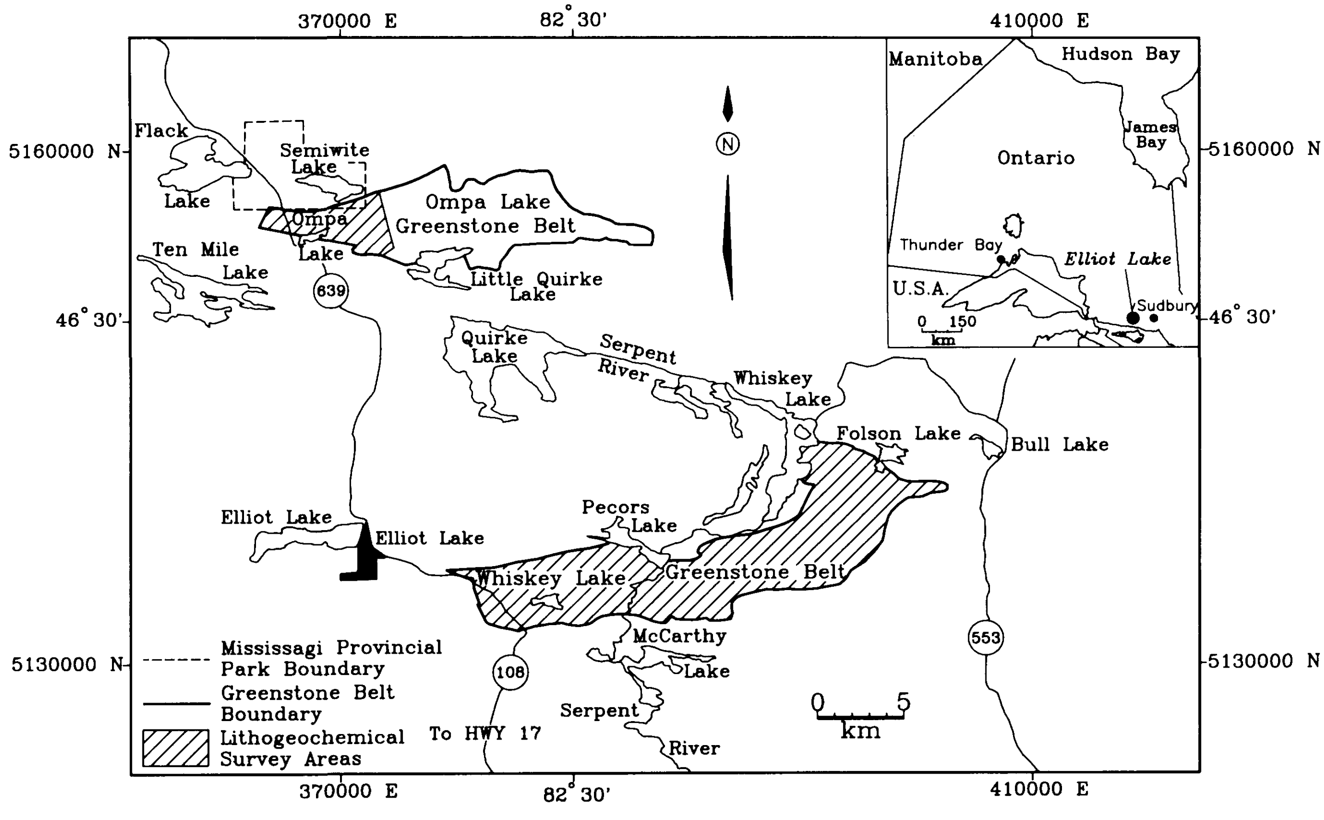

Figure 16.1. Location map for Whiskey Lake and Ompa Lake greenstone belts.

preserved in the Quirke Syncline to the north, and Archean granitoid rocks to the south. Access to the western portion of the belt is by Highway 108, which connects the town of Elliot Lake with Highway 17 to the south. The Nordic Mine Road, approximately 4 km south of Elliot Lake on Highway 108, and the Ontario Hydro power line road, which continues east to Highway 553 north of Massey, can be used to access the northern and eastern sections of the greenstone belt. Portions of the study area have been previously mapped, including: Joubin Township, formerly Township 143 (Robertson 1961); Gaishaik Township, formerly Township 137 (Robertson 1962); Proctor and Deagle townships (Robertson 1977a). The Whiskey Lake area or Gerow Township, previously Township 130, was mapped originally by Douglas (1926) and most recently by McCrank et al. (1982). Jensen (1990) and Rogers (1991a, 1992) provide detailed descriptions of the geology of the Whiskey Lake greenstone belt.

The Ompa Lake greenstone belt is located approximately 15 km north of the town of Elliot Lake in parts of Raimbault, Hembruff, Hughson, and Poncet townships (bounded by latitudes 46°32'12"N to 46°35'30"N and longitudes 82°26'W to 82°47'W). The western portion of the belt is accessed by Highway 639, which is the continuation of Highway 108 north of the town of Elliot Lake. Access to the eastern portion is limited to helicopter support, or fixed wing float plane landings on Harry and Rooster lakes. The Flack Lake Fault marks the northern boundary of the belt with the Proterozoic sedimentary rocks of the Huronian Supergroup, while to the south, Paleoarchean granitic rocks and Nipissing diabase separate the belt from rocks of the Quirke Syncline. Segments of the Ompa Lake greenstone belt have been previously mapped by Robertson (1977b, Raimbault Township), and Wood (1975, Hembruff and Hughson townships). For descriptions of the geology of the area, see Rogers (1991b, this volume), Robertson (1977a, 1977b), and Wood (1975).

METHODOLOGY

Nine hundred and fify-six samples were collected over the past 3 field seasons from the Whiskey Lake greenstone belt (Figure 16.2). During the second field season, 111 samples were collected from the western section of the Ompa Lake greenstone belt (Figure 16.3). Samples were collected at 400 m intervals along pace and compass traverse lines. For a detailed accounting of the methodology, techniques and preliminary results, see Byron and Whitehead (1990, 1991a, 1991b, in press). All samples were analyzed for silver (Ag), arsenic (As), gold (Au), barium (Ba), bromine (Br), calcium (Ca), cerium (Ce), cobalt (Co), chromium (Cr), cesium (Cs), europium (Eu), iron (Fe), hafnium (Hf), iridium (Ir), lanthanum (La), lutetium (Lu), molybdenum (Mo), sodium (Na), neodymium (Nd), nickel (Ni), rubidium (Rb), antimony (Sb), scandium (Sc), selenium (Se), samarium (Sm), strontium (Sr), tantalum (Ta), terbium (Tb), thorium (Th), uranium (U), tungsten (W), ytterbium (Yb), and zinc (Zn) by neutron activation. Major oxides, copper (Cu), lead (Pb), zinc (Zn), strontium (Sr), rubidium (Rb), yttrium (Y) and zirconium (Zr) were analyzed by X-ray fluorescence on selected samples. Niobium (Nb), gallium (Ga), platinum (Pt), palladium (Pd), and CO_2 analyses were determined on a smaller group of samples. Using the abundances of pathfinder elements known to be elevated in proximity to massive

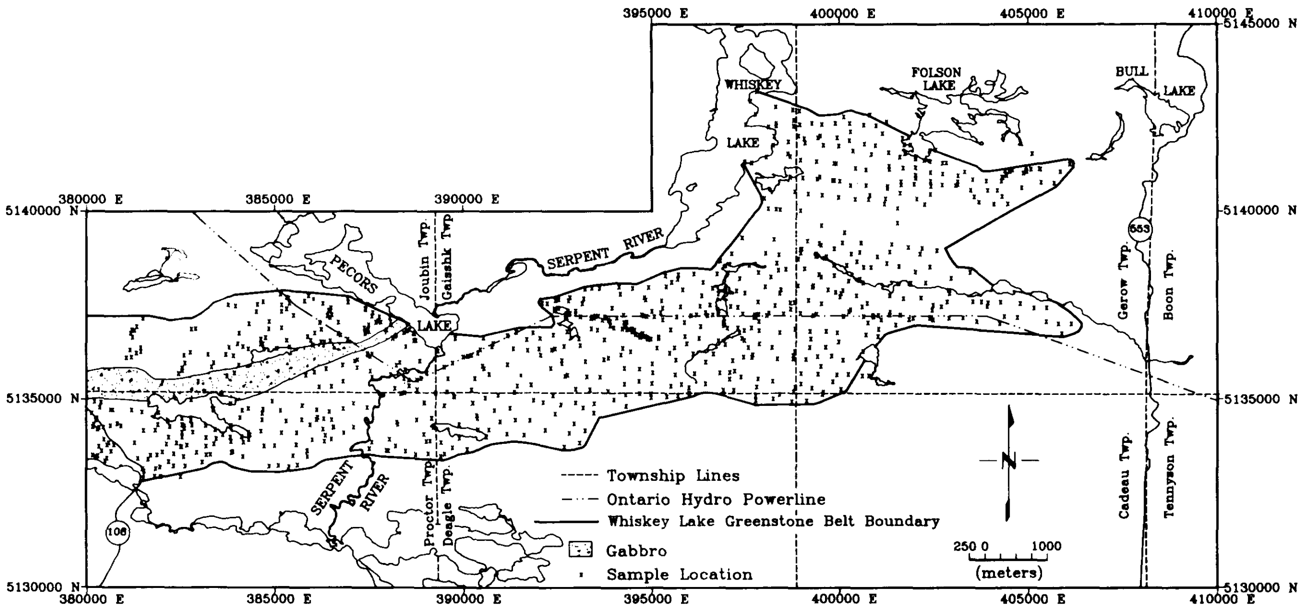

Figure 16.2. Sample locations: Whiskey Lake greenstone belt.

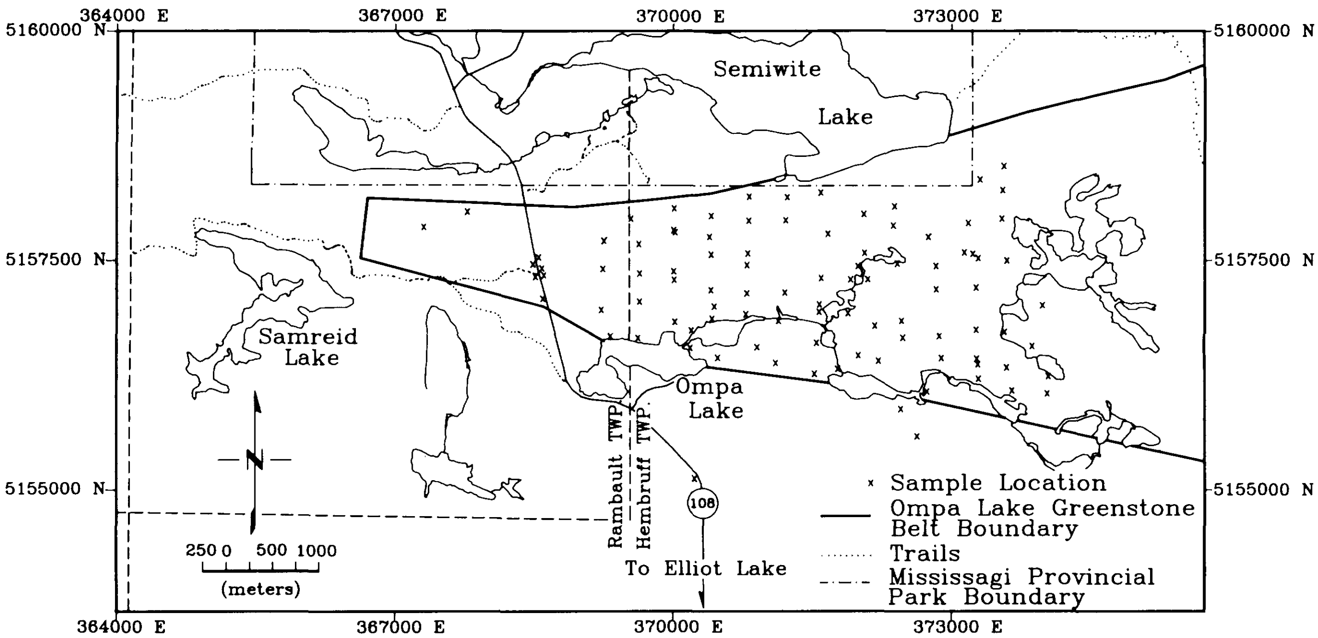

Figure 16.3. Sample locations: Ompa Lake greenstone belt.

base metal sulphide and gold mineralization (Davies et al. 1982; Govett 1983; Thurston and Fryer 1983; Lesher et al. 1986; Beaudoin et al. 1987; Parslow 1987; Whyte and Nichol 1987; Whitehead and Davies 1988; Byron 1990), the lithogeochemical data were evaluated for anomalous metal concentrations. Evaluation of geochemical variations are done in the context of the geology of the study area (Jensen 1990; Jensen in press; Rogers 1991a, 1992). Preliminary results of the lithogeochemical study have been presented on anomaly maps in order to help delineate areas which possess geochemical and geological features suggestive of economic mineralization, and to provide geochemical data to assist in the interpretation of the regional geology (Byron and Whitehead 1991a; Byron and Whitehead in press).

SUMMARY OF ANOMALY TRENDS

The preliminary lithogeochemical anomaly maps generated to date depict 2 trends within the Whiskey Lake greenstone belt; a northwest anomaly trend parallel to subparallel to stratigraphy, and a northeast anomaly trend related to late stage discordant regional structures. Based on anomalous concentrations of gold, and gold pathfinder elements, arsenic and CO_2, the following areas hold the greatest potential for gold mineralization: 1) iron formations in the vicinity of Pecors Lake; 2) northwest-striking faults and shear zones approximately 2.5 km south-southwest of the foot of Whiskey Lake; and 3) northeast-trending lineaments east to southeast of Pecors Lake. Copper, lead, and zinc anomaly patterns indicate that the northeast-striking structures also represent exploration targets for base metal mineralization, possibly massive sulphide mineralization. Based on anomalous concentrations of gold, copper, nickel and platinum group elements (PGE), the sheared contact zone between the East Bull Lake Intrusion and the Whiskey Lake greenstone belt represents an exploration target for possible economic PGE mineralization.

AREAS OF INTEREST

The 4 areas investigated over the past field season (Figure 16.4) were chosen on the basis of preliminary gold, arsenic, carbon dioxide, copper, lead, and zinc lithogeochemical anomaly maps (summarized in Byron and Whitehead, in press).

Area 1

Work in Area 1 (Figure 16.5) concentrated on a 2.5 km long fault zone (272°/60°N; Photo 16.1). Samples containing anomalous concentrations of gold and carbon dioxide were collected along the strike extent of the fault to define the limits of the anomalies and to investigate for possible geological factors responsible for the anomalous values. Deformation and alteration have destroyed most primary rock textures within the fault zone; therefore, traverse lines were run perpendicular to the fault to help maintain control over the changing geology (gabbro, and iron- and magnesium-rich tholeiitic basalt). Chlorite and carbonate alteration are ubiquitous. Pyrite is the most common sulphide mineral with chalcopyrite present to a lesser degree. The fault zone runs roughly parallel to stratigraphy, making determinations on the scale and orientation of displacement difficult. To the southeast, the fault terminates against a gabbroic mass, while the unconformity between the Archean and Proterozoic rocks marks the northwest extent of the fault.

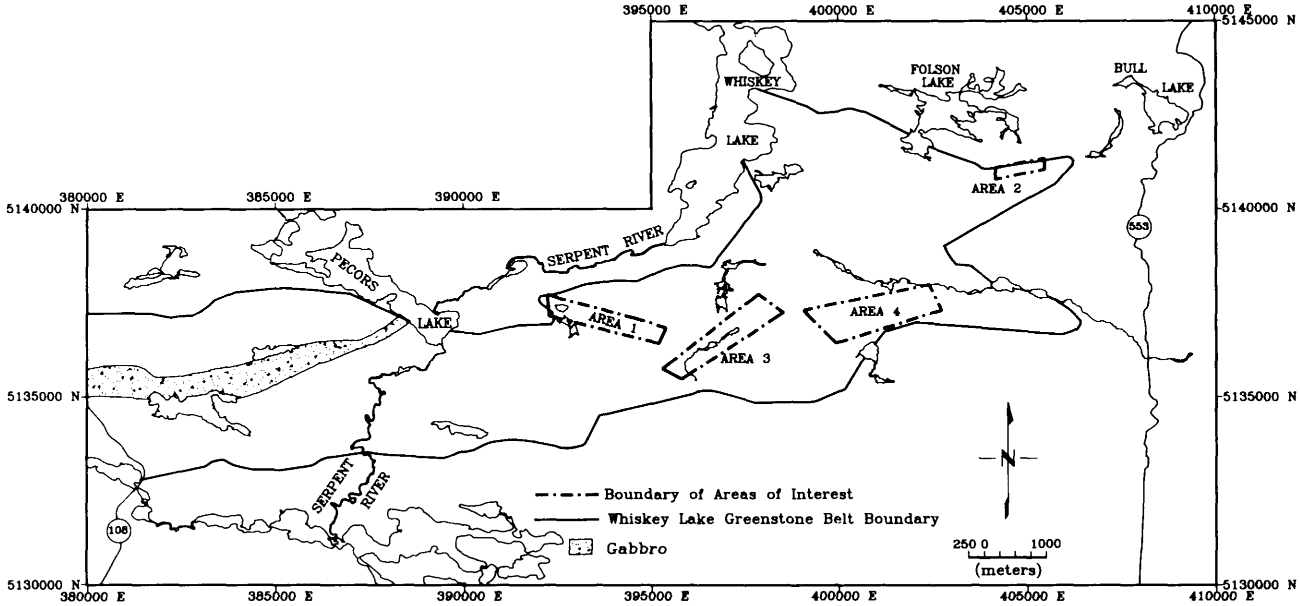

Figure 16.4. Areas of interest in the Whiskey Lake greenstone belt, in which rocks have anomalous geochemistry. These areas of interest were studied and sampled in detail during the 1992 field season.

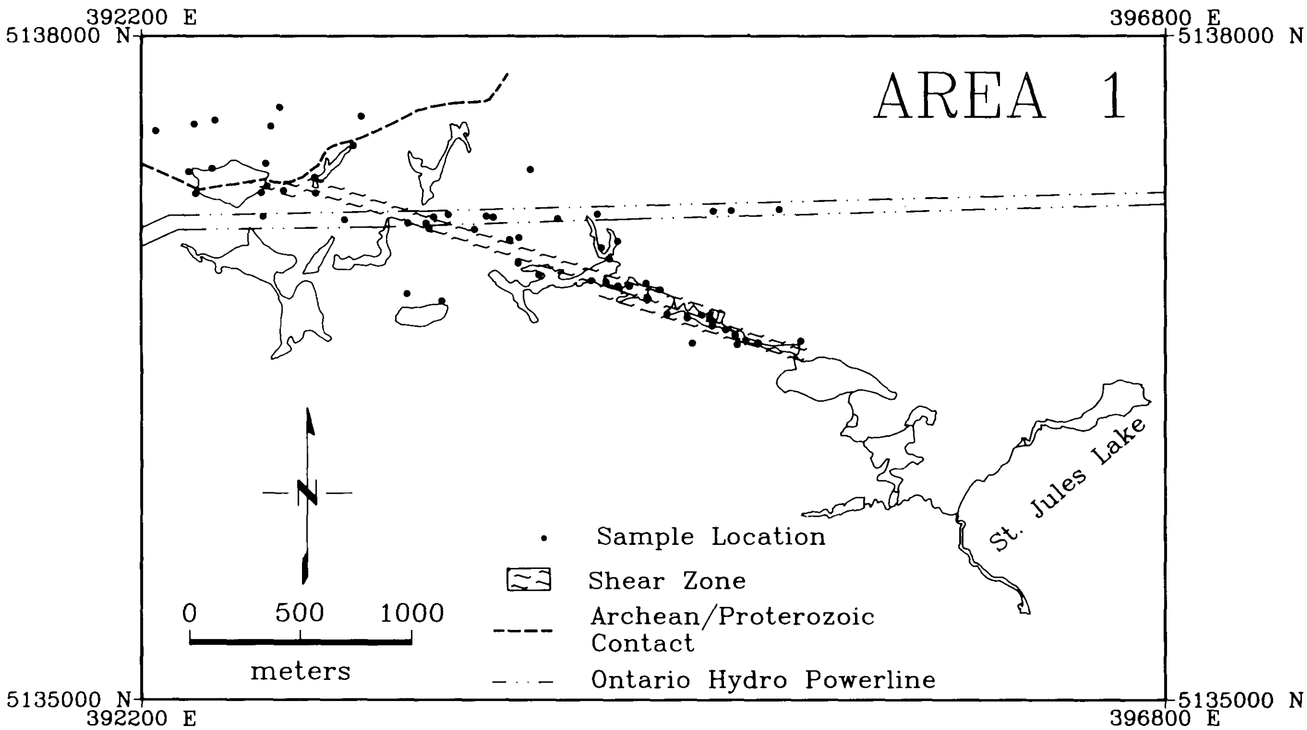

Figure 16.5. Area of interest, #1, Whiskey Lake greenstone belt, in which detailed sampling was conducted along a zone of sheared and carbonatized rock.

Photo 16.1. Shear zone in area of interest #1 that strikes 270° and dips 60° to the north. The fault zone consists of intensely sheared and altered gabbro. Looking east.

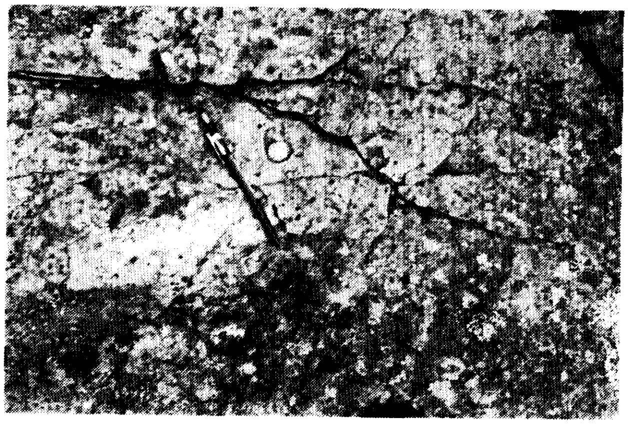

Photo 16.3. Unstrained spherical amygdules within a Huronian andesite flow that unconformably overlies sheared, Archean metavolcanic rock.

Photo 16.2. Unconformable contact between highly strained, Archean, pillowed andesite (bottom of picture) and Huronian, amygdaloidal iron-rich tholeiitic basalt (top of picture).

At the northwest boundary of the shear zone, Archean pillowed andesite is unconformably overlain by massive amygdaloidal Huronian iron-rich tholeiite. Deformation abruptly ends at the contact between the strongly sheared Archean flow and the relatively unaltered and undeformed Huronian flow (Photo 16.2). Spherical amygdules in the Huronian flow, close to the contact, are relatively undeformed (Photo 16.3).

Area 2

During the 1991 field season, anomalous concentrations of gold, platinum, palladium, nickel, and copper were identified in association with the sheared contact between the East Bull Lake intrusion and mafic metavolcanic rocks of the Whiskey Lake greenstone belt (Figure 16.6). Photo 16.4 illustrates the contact between the sheared mafic volcanic rock and the fine-grained, relatively undeformed gabbro. The penetrative foliation in the volcanic rock, as well as the flow structures in the gabbro, near the contact zone run parallel to the contact. Within the contact zone, small concordant masses of fine-grained gabbro have been injected into the volcanic rocks (Photo 16.5). The injected gabbro masses are elongate parallel to the foliation in the volcanic rocks with strong conformable foliation along the border zones. This relationship clearly illustrates the intrusive nature of the gabbro (Balk 1948).

Sulphide mineralization occurs along the contact zone as small, isolated, discontinuous pods rich in magnetite, pyrite, chalcopyrite, and chlorite. Typically massive pyrite and magnetite mineralization is associated with intensely sheared and chloritic xenoliths of mafic volcanic rock enclosed in the fine grain gabbro. For additional information on the East Bull Lake gabbro, *see* Peck et al. (this volume).

Areas 3 and 4

Areas 3 and 4 (Figures 16.7 and 16.8) are characterized by northeast-trending normalized copper anomaly patterns that delineate 2 regional fault zones. Investigations were concerned with the possible correlation between these regionally prominent fault zones and anomalous chemistry.

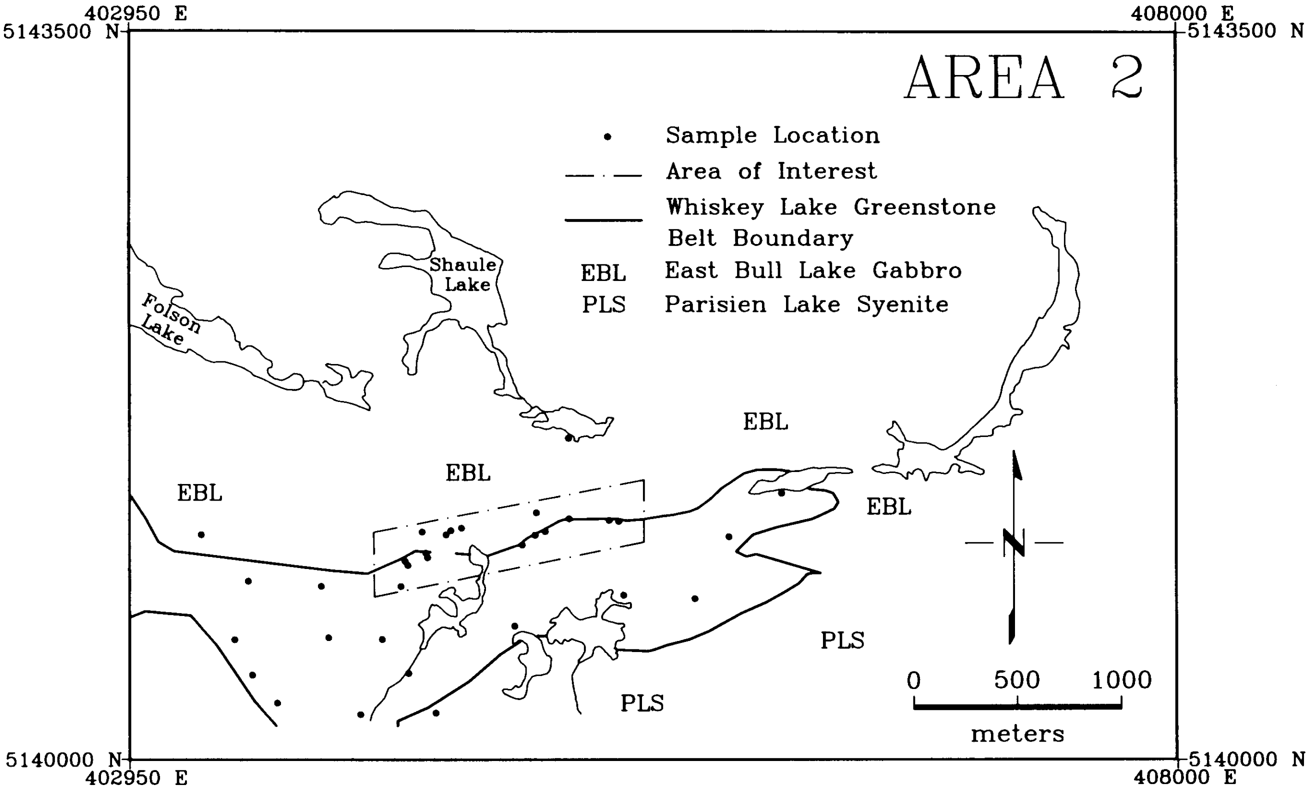

Figure 16.6. Area of interest, #2, Whiskey Lake greenstone belt, in which detailed sampling was conducted during the 1992 field season.

Photo 16.4. Contact between East Bull Lake intrusion and sheared metavolcanic rocks of the Whiskey Lake greenstone belt.

FUTURE WORK

Over 1000 lithogeochemical samples have been analyzed from the Whiskey Lake and Ompa Lake greenstone belts. The sampling program is complete and the database is currently being processed. The geology of the Whiskey Lake greenstone belt, as described by Jensen (1990) and Rogers (1991a, 1992), has been compiled and simplified by the authors in order to be merged with the lithogeochemical, structural, and NASA landsat databases, to present correlations between geology, structure, and anomalous chemistry. Areas within the Whis-

Photo 16.5. Intrusive, gabbro pod (marked by pencil) within the contact zone between the East Bull Lake Intrusion and sheared metavolcanic rocks of the Whiskey Lake greenstone belt. The elongation of the pod parallel to the foliation in the metavolcanic rock indicates that the East Bull Lake Intrusion intruded the Whiskey Lake greenstone belt.

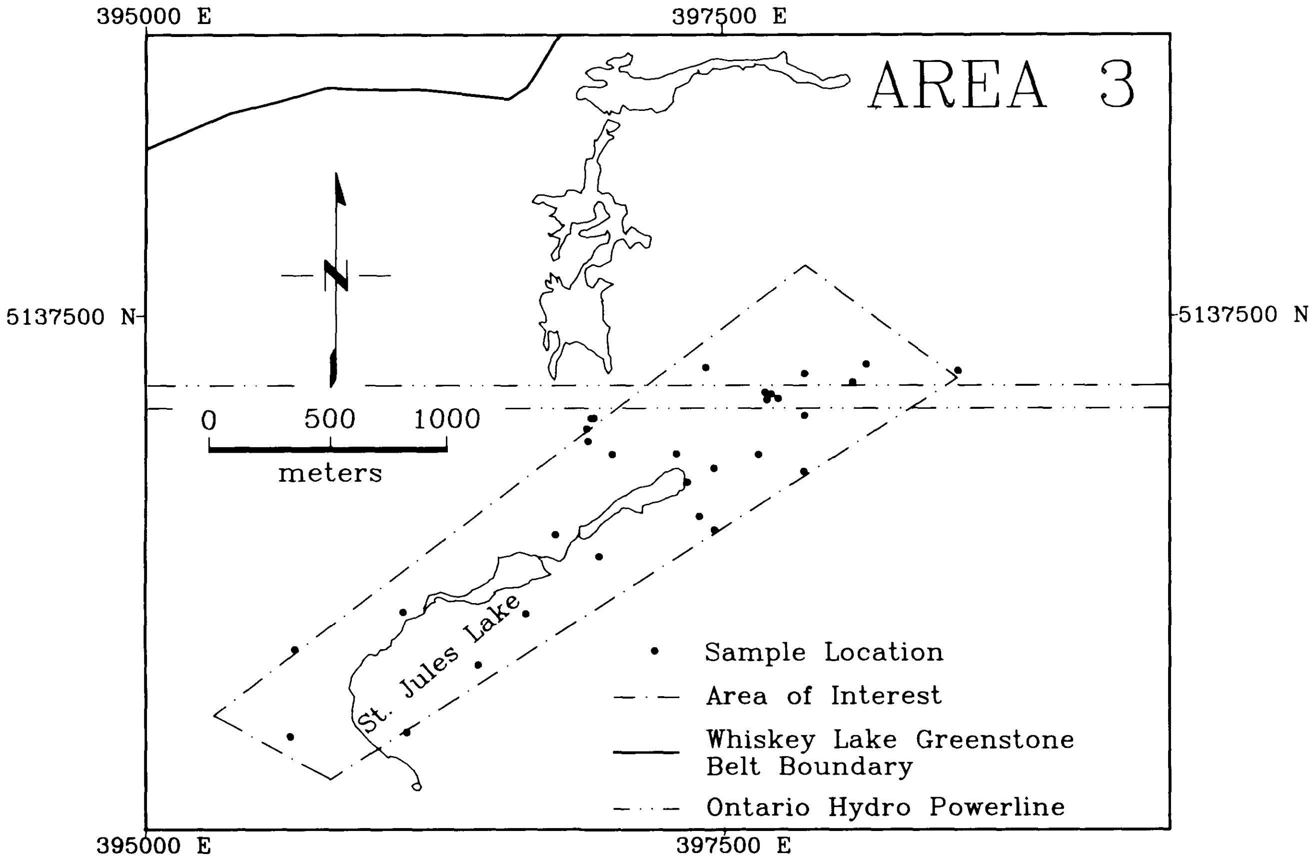

Figure 16.7. Area of interest, #3, Whiskey Lake greenstone belt, in which detailed sampling was conducted during the 1992 field season.

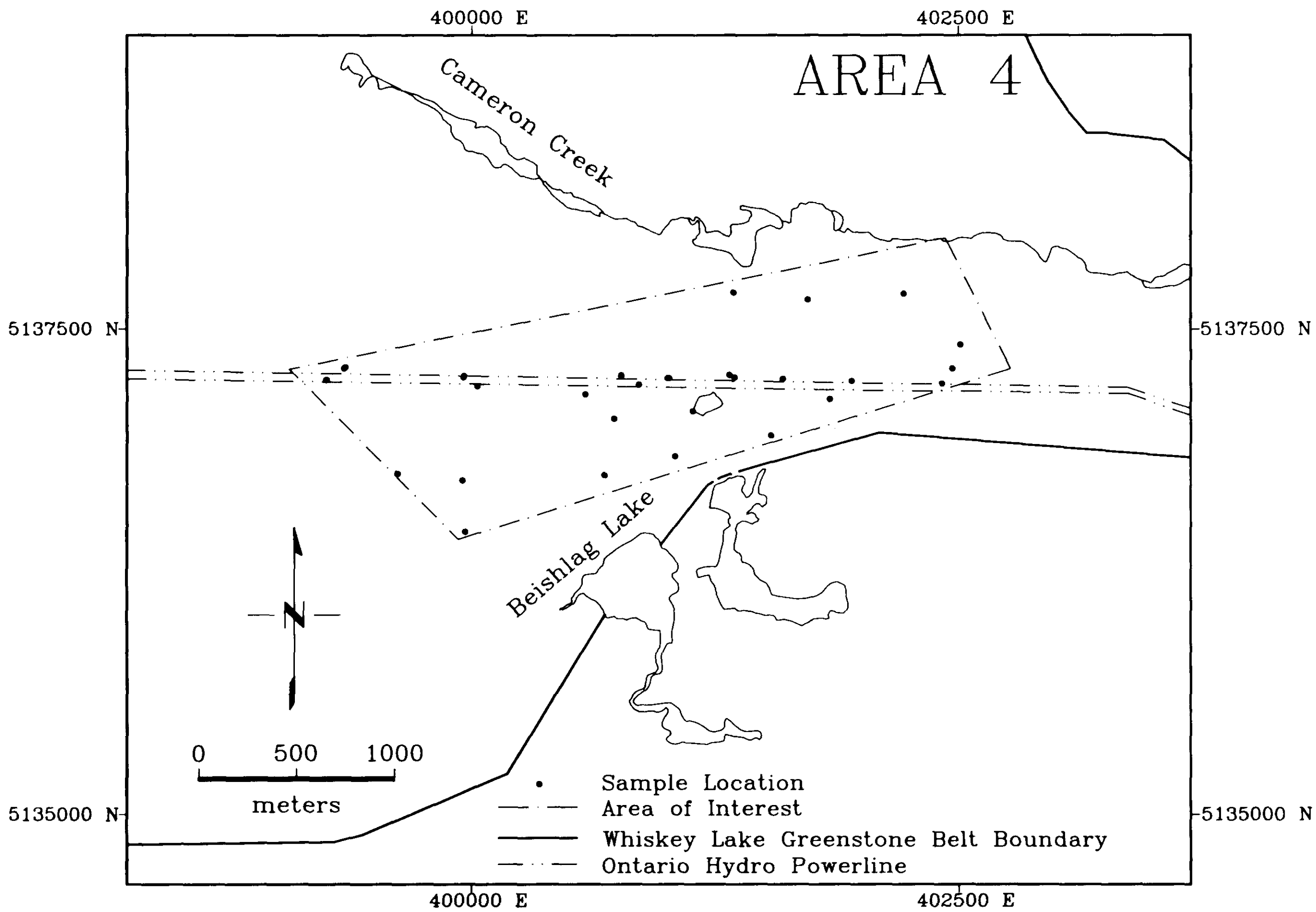

Figure 16.8. Area of interest, #4, Whiskey Lake greenstone belt, in which detailed sampling was conducted during the 1992 field season.

key Lake greenstone belt which exhibit distinct, continuous, linear anomaly patterns are being examined. The results will help identify those factors that correlate with the lithogeochemical anomalies, and assist in determining the effectiveness of regional lithogeochemical surveys, in association with geological data, for locating areas of possible economic mineralization.

REFERENCES

Balk, R. 1948. Structural behavior of igneous rocks; Edward Brothers, Ann Arbor, Michigan, 177p.

Beaudoin, A., Perrault, G. and Bouchard, M. 1987. Distribution of gold, arsenic, antimony and tungsten around the Dest–Or orebody, Noranda District, Abitibi, Quebec; Journal of Geochemical Exploration, v.28, p.41–70.

Byron, M. 1990. Pathfinder and immobile element evaluation of the Upper Canada Option, Gauthier Township, Ontario; unpublished report, Inco Exploration and Technical Services, 17p.

Byron, M. and Whitehead, R.E. 1990. Lithogeochemical study of the Archean volcanic rocks of the Whiskey Lake greenstone belt, Algoma District, Ontario; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.59–61.

——— 1991a. Lithogeochemical study of the Archean volcanic rocks of the Whiskey Lake and Ompa Lake greenstone belts, Algoma District, Ontario; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.57–63.

——— 1991b. Lithogeochemical study of the Archean volcanic rocks of the Whiskey Lake greenstone belt, Algoma District, Ontario; Ontario Geological Survey, Open File Report 5814.

——— in press. Lithogeochemical study of the Archean volcanic rocks of the Whiskey Lake greenstone belt, Algoma District, Ontario; Ontario Geological Survey, Open File Report, in press.

Davies, J.F., Whitehead, R.E.S., Cameron, R.A. and Duff, D. 1982. Regional and local patterns of CO_2-K-Rb-As alteration; a guide to gold in the Timmins area; *in* Geology of Canadian gold deposits, Canadian Institute of Mining and Metallurgy, Special Volume 24, p.1–14.

Douglas, G.V. 1926. The Whiskey Lake area, District of Algoma; Ontario Department of Mines, Annual Report, 1925, v.34, pt. 4.

Govett, G.J.S. 1983. Rock geochemistry in mineral exploration, v.3, Handbook of exploration geochemistry; Elsevier, Amsterdam, 461p.

Jensen, L.S. 1990. Geology of the Whiskey Lake greenstone belt, districts of Algoma and Sudbury; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.53–58.

Jensen, L.S. in press. Geology of the Whiskey Lake area, west half; Ontario Geological Survey, Open File Report, in press.

Lesher, C.M., Goodwin, A.M., Campbell, I.H. and Gorton, M.P. 1986. Trace-element geochemistry of ore associated and barren, felsic metavolcanic rocks in the Superior Province, Canada; Canadian Journal of Earth Sciences, v.23, p.222–237.

McCrank, G.D.F., Stone, D., Kamineni, D.C., Zayachkivski, B. and Vincent, G. 1982. Regional geology of the East Bull Lake Area, Ontario; Geological Survey of Canada, Open File 873.

Parslow, G.R. 1987. Lithogeochemical data from the East Amisk area of the Flin Flon–Snow Lake volcanic belt: Implications for mineral exploration; Journal of Geochemical Exploration, v.28, p.133–148.

Robertson, J.A. 1961. Geology of townships 143 and 144; Ontario Department of Mines, Geological Report 4, 65p.

——— 1962. Geology of townships 137 and 138, District of Algoma; Ontario Department of Mines, Geological Report 10, 94p.

——— 1977a. Geology of the Cutler area, District of Algoma; Ontario Department of Mines, Geological Report 147, 73p.

——— 1977b. Nicholas and Raimbault townships, Algoma District; Ontario Division of Mines, Map 2347, scale 1:31 680.

Rogers, M.C. 1991a. Geology of the Whiskey Lake greenstone belt, districts of Algoma and Sudbury; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.46–51.

——— 1991b. Geology of the Ompa Lake greenstone belt, District of Algoma; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.52–56.

——— 1992. Geology of the Whiskey Lake area, east half, District of Algoma; Ontario Geological Survey, Open File Report 5834, 110p.

Thurston, P.C. and Fryer, B.J. 1983. The geochemistry of repetitive cyclical volcanism from basalt through rhyolite in the Uchi-Confederation greenstone belt, Canada; Contributions to Mineralogy and Petrology, v.83, p.204–226.

Whitehead, R.E. and Davies, J.F. 1988. Discriminant analysis involving CO_2/CaO and arsenic in gold exploration; Journal of Geochemical Exploration, v.30, p.243–253.

Whyte, J.B. and Nichol, I. 1987. Geochemical alteration associated with the Selbaie copper-zinc-silver deposit; Journal of Geochemical Exploration, v.28, p.165–182.

Wood, J. 1975. Geology of the Rawhide Lake area, District of Algoma; Ontario Division of Mines, Geoscience Report 129, 67p.

17. Structure and Stratigraphy of Archean Rocks in the Pipestone Lake area, Wabigoon Subprovince

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INTRODUCTION

This report describes the results of field work in structurally complex, Archean metavolcanic and metasedimentary rocks in a 75 km² region at the northern end of Pipestone Lake in northwestern Ontario (Figure 17.1). The area of study extends from north of the Rainy Lake batholithic complex south to the Manitou Stretch–Pipestone Lake shear zone and from the Helena–Pipestone Fault in the west, east to Sucan Lake (Figure 17.2). It includes an interpretation of our earlier work in part of the area reported previously (Edwards and Stauffer 1988, 1990). Work by Edwards and co-workers (Edwards 1980, 1983a, 1983b) in the area (Straw Lake area, Edwards 1983a) provides a base for the present detail, but important earlier mapping was also done by Thompson (1935, 1936), Coleman (1895, 1897), and Lawson (1889). Regional geological relationships were synthesized by Goodwin (1965) and compiled by Blackburn (1981). The Vista Lake area, immediately east of the Straw Lake map sheet, was mapped recently by Smith (1990a, 1990b).

This study was motivated by the recognition of significant structural/stratigraphic anomalies, possibly resulting from thrust faulting in the area (Edwards 1983a, 1983b). The follow-up investigation, which is ongoing (Edwards and Stauffer 1988, 1990; and field work in 1991), extended the earlier work and resulted in changes in the locations of contacts. The main goal of this study is to fathom the structural history of part of the Wabigoon Subprovince. A significant component in achieving this goal will be to determine the structural effects of pluton emplacement on the greenstones.

All rocks in the area have been metamorphosed to the lower greenschist facies, but as the original features of the rocks are almost always clear, the prefix "meta" is dropped in this report.

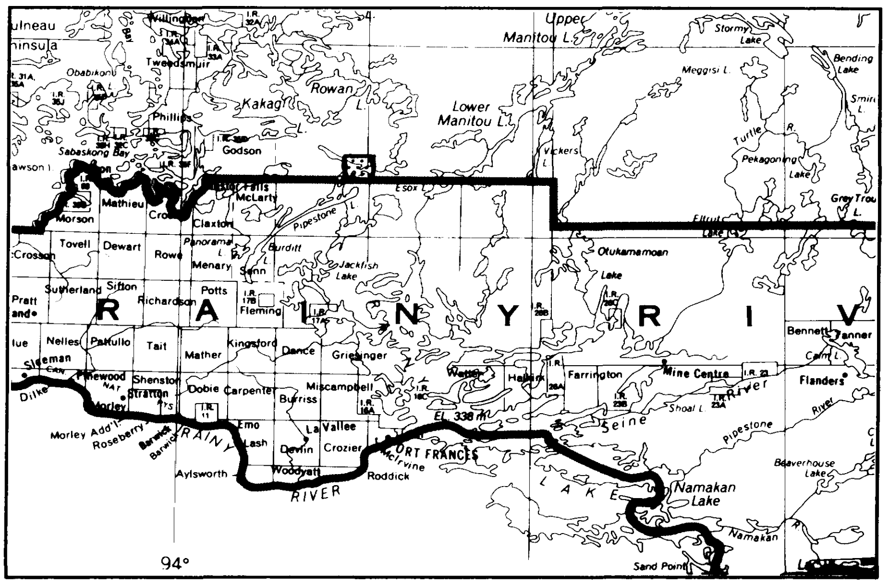

Figure 17.1. Location map of the Pipestone Lake area, scale 1:1 584 000.

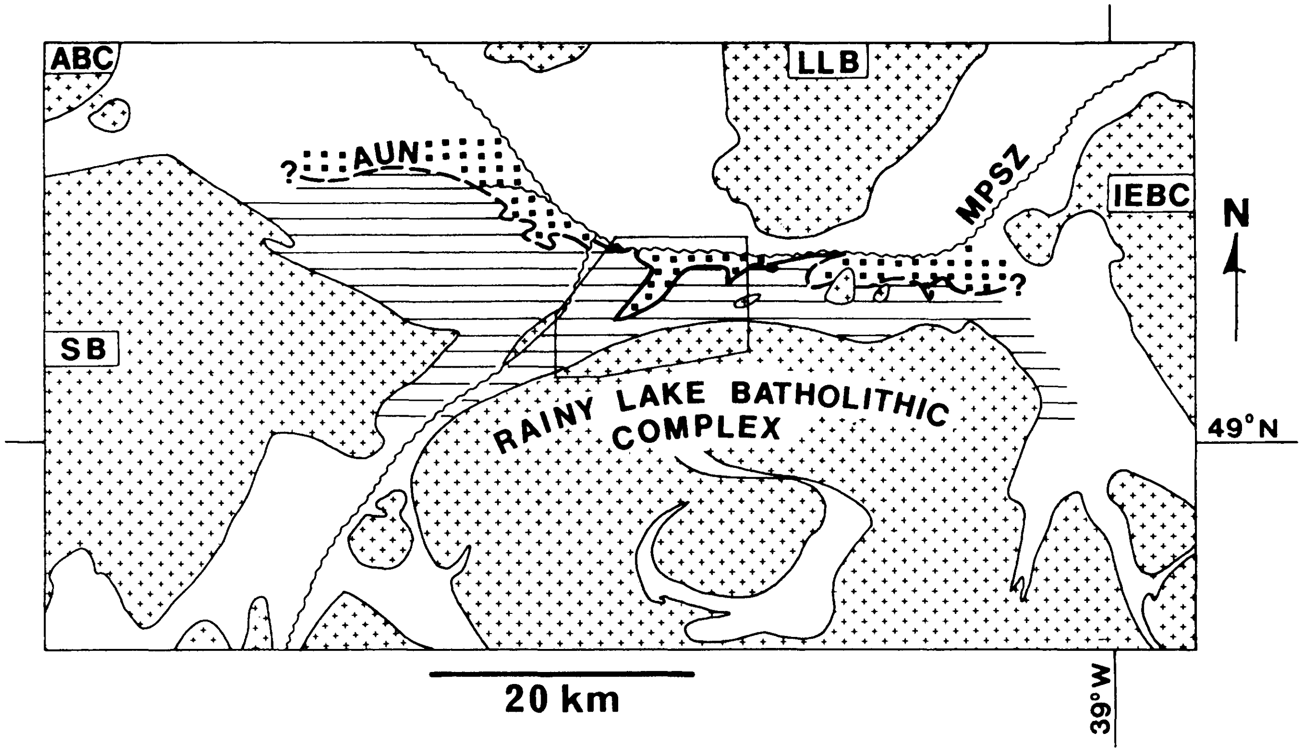

Figure 17.2. Map showing the regional geological setting of the Pipestone Lake area in the western Wabigoon Subprovince. MPSZ, Manitou Stretch–Pipestone Lake shear zone; AUN, angular unconformity. Rocks above the angular unconformity are shown by horizontal shading. Rocks above the angular unconformity are shown by square dot pattern. Greenstone whose relationship to the uncomformity has not been determined are left unpatterned. Plutons are shown by cross pattern. Legend: ABC, Aulneau batholithic complex; SB, Sabaskong batholith; LLB, Lawrence Lake batholith; IEBC, Irene–Eltrut lakes batholithic complex.

GENERAL GEOLOGY

Pipestone Lake (*see* Figure 17.2) lies at the confluence of 4 greenstone assemblages which are lodged between the Rainy Lake batholithic complex, the Lawrence Lake batholith, the Sabaskong batholith and the Irene–Eltrut lakes batholithic complex (Blackburn 1981). In the Pipestone Lake area, folded pillowed basalts are unconformably overlain by basaltic-andesitic fragmental rocks and subordinate flows, which, in turn, are overlain comformably by sedimentary rocks. Detailed lithologic and petrographic descriptions of many of the rock types are given by Edwards (1983a, 1983b) (Table 17.1).

Pipestone Lake Formation

The older pillowed basalts consist predominantly of plagioclase phyric, pillowed basalt flows, which have variably developed variolitic texture. A characteristic of this unit is that the flows are intruded by composite, layered mafic to ultramafic sills and less common, discordant mafic to ultramafic masses. Sparse, isolated and altered ultramafic sheets with rare spinifex texture may represent komatite flows in the central Pipestone Lake area. The widest exposed homoclinal panel of the pillowed basalts is 2.25 km wide.

Thompson Bay Volcanics

This unit comprises a 1 km wide sequence, largely composed of basalt to andesite flow breccia and pyroclastic rocks. Low in the stratigraphic section northeast of Line Bay and between Thompson Bay and Sucan Lake, the pyroclastic rocks are probably dacitic. The basalt-andesite fragmental rocks are overlain by the Thompson Bay sediments, but the contact between these units at Sucan Lake is partly gradational. The sediments at Sucan Lake are the along-strike, thickened extension of the sediments that lie on the unconformity at the base of the basalt-andesite fragmental unit. The upper part of the unit is marked by a rapid upward transition to the basalt-andesite fragmental rocks. In the transition zone north of Sucan Lake, mafic to intermediate tuff and lapilli tuff, some of which are probably pyroclastic flows, are interbedded with sedimentary rocks. Thus, for the purposes of this report, the sediments at Sucan Lake are included as part of the Thompson Bay volcanics and are stratigraphically distinct from the Thompson Bay sediments.

Thompson Bay Sediments

The Thompson Bay sediments (TBS) lie above the basalt-andesite fragmental rocks with which they are rapidly upward transitional. The sediments range from unbedded, poorly sorted, granular but rarely pebbly, arkosic wacke to finely laminated silt and mudstones typical of turbidites. Graded beds, load casts, flame structures, rip-up clasts and disrupted bedding are common, occuring where bedding is well developed. Except for the presence of a few outcrops of relatively distal rhythmically bedded

Table 17.1. Table of lithologic units

Thompson Bay sediments	Wacke; tuffaceous sediments; turbiditic fine sandstone to mudstone; minor pyroclastic rocks.
Thompson Bay volcanics	Massive and pillowed plagioclase-phyric and pyroxene-phyric basalt to andesite flows, flow breccias and pyroclastic rocks; minor dacite to rhyodacite pyroclastic rocks and flows; minor tuffaceous sediments; minor fine sandstorne to mudstone and carbonaceous, pyritic mudstone.
————unconformity————	
Pipestone Lake formation	Pillowed basalt flows; plagioclase phyric and variolitic basalt flows; stratiform, layered, mafic to ultramafic intrusions; minor ultramafic flows; minor interflow sediments or tuff.

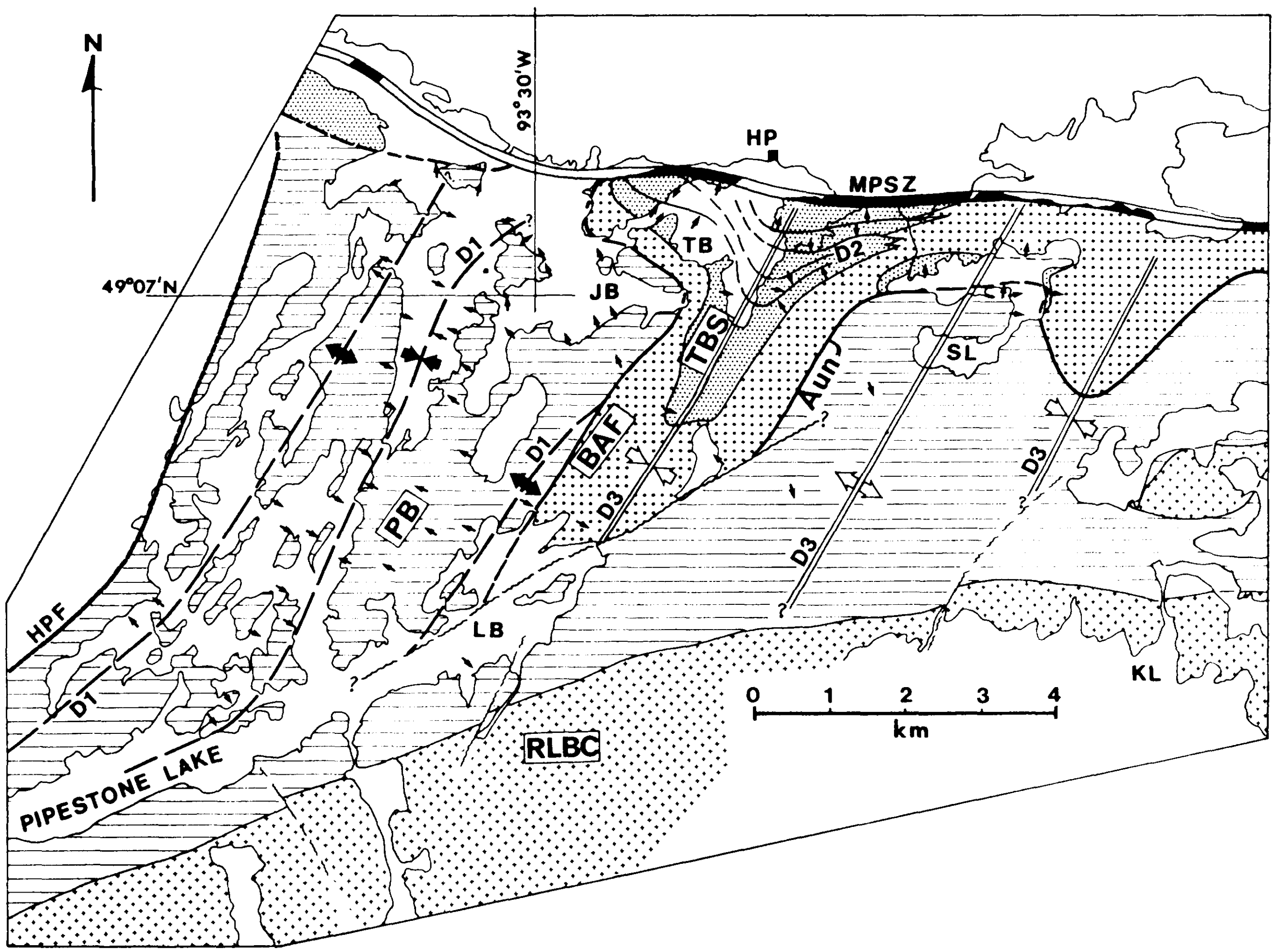

Figure 17.3. Geological map of the northern Pipestone Lake area (*modified*, with further mapping, *from* Edwards 1983a). Geographic legend: JB, James Bay on Pipestone Lake; TB, Thompson Bay on Pipestone Lake; LB, Line Bay on Pipestone Lake; SL, Sucan Lake; KL, Kaishkons Lake. Lithological legend: RLBC, Rainy Lake batholithic complex (cross pattern); TBS, Thompson Bay sedimentary rocks (small dot pattern); BAF, fragmental basalt to andesite with some pillowed lava and sedimentary rocks (large dot pattern); AUN, angular unconformity; PB, pillowed and massive basalt. Structural legend: Arrows indicate stratigraphic facing. Axial Traces: D_1, medium-weight, long-dash lines; D_2, light-weight lines; D_3, double light-weight lines. Faults: MPSZ, Manitou Stretch–Pipestone Lake shear zone; HPF, Helena–Pipestone Lake Fault.

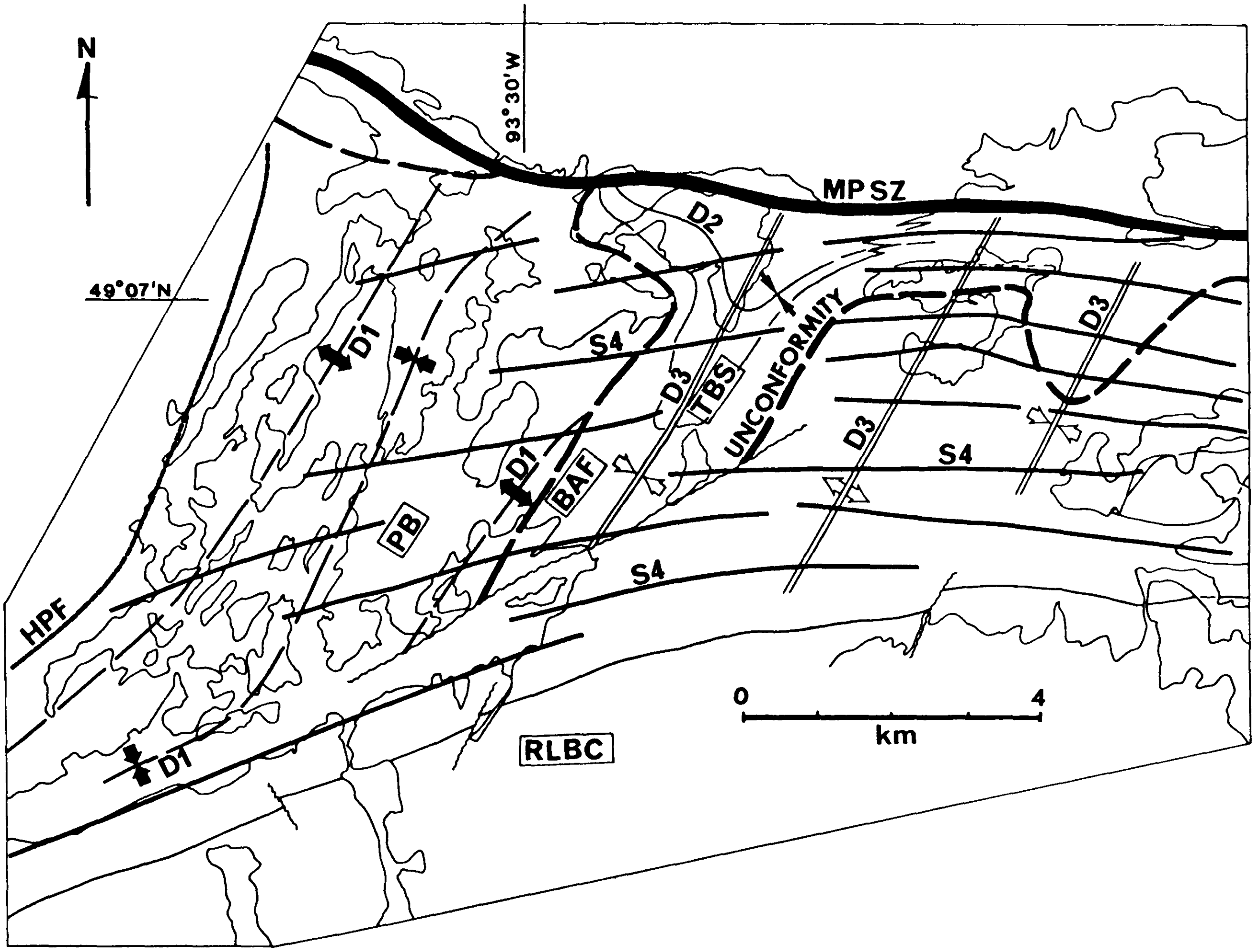

Figure 17.4. Structural Map; legend: D_1, first fold-phase axial traces (in PB only); D_2, second fold-phase axial traces (only major syncline shown) (recognized in TBS only); D_3, third fold-phase axial traces; S_4, late crenulation cleavage, parallel to margin of JLP. Other symbols as in Figure 17.3.

turbiditic fine sandstone to mudstone in the upper part of the sequence, we belive that most of the TBS sediments were deposited near an active volcanic environment.

Regolith

Carbonaceous, pyritic mudstone to fine sandstone (cf. Thomson 1935, p.9–11) marks the base of the fragmental unit, where observed in James Bay, Sucan Lake and between Thompson Bay and Sucan Lake. Below these sediments, presumably at the erosional surface of the Pipestone formation, there is a breccia of basalt fragments in a carbonaceous shale matrix that grades downward into a mafic lava flow with unusually extensive fracturing occurring over a few metres. The fractures are up to 1 cm wide and normally comprise comminuted mafic material, although some carbonaceous material may be present. The breccia is interpreted as a feature of paleoweathering at the unconformity on the older pillowed basalt unit. Similar breccias, perhaps also a result of paleoweathering are present in subvolcanic quartz-feldspar porphyry underlying correlative sedimentary rocks at Esox Lake.

STRUCTURAL GEOLOGY

Strata north of the Rainy Lake batholithic complex (RLBC, Figures 17.2, 17.3 and 17.4) and south of the Manitou Stretch–Pipestone Lake shear zone (MPSZ) are complexly folded. A scheme involving 7 phases of deformation has been developed to explain the structural history of the area (Edwards and Stauffer 1990), however, 2 or more of the last 4 phases may be interrelated.

The first phase of deformation (D_1) is a major episode of isoclinal folding that lacks cleavage and occurred prior to the deposition of the BAF and TBS (*see* Figure 17.3 legend). The axial traces are recognized as boundaries of panels of oppositely facing pillow lavas (PB) and do not cross the angular unconformity (Aun) (*see* Figures 17.3 and 17.4). All bedding seen is subvertical, regardless of strike, thus, both the axial planes and the fold hinge lines are probably also subvertical. Pillows have been moderately deformed; most have axial ratios of about 6:2:1 with the XY plane parallel to the D_1 axial planes and X subvertical.

The second phase of deformation (D_2) comprises folds found only above the unconformity and, in com-

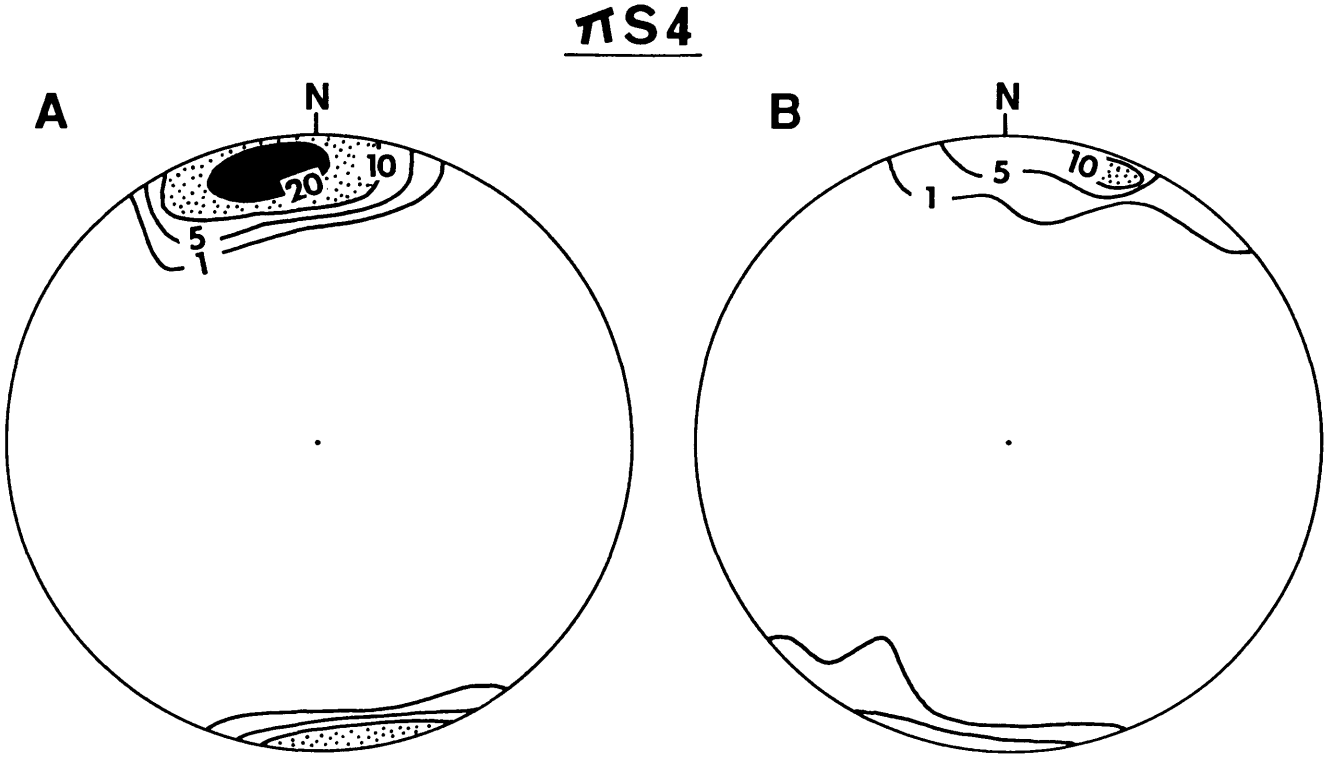

Figure 17.5. Stereograms of poles to S_4. Contour lines at 1%, 5%, 10%, and 20% per 1% area. A) 158 poles in the western half of the area. B) 103 poles in the eastern half of the area.

mon with many Wabigoon Subprovince volcanic units (Blackburn 1981), they have not been recognized in the PB (*see* Figures 17.3 and 17.4). However, at the northern ends of the westernmost 2 D_1 folds, there are irregularities in the way-up pattern that might be due to D_2 folding (near the ? symbols on Figure 17.3). Lack of outcrop makes it impossible to be certain. At present, D_2 folds are identified by panels of oppositely facing TBS. They have subvertical axial planes, and may have subvertical hinge lines. There is no deformational fabric (cleavage or lineation) that appears to be related to this fold episode.

The third phase of deformation is represented by 3 folds that distort both the angular unconformity and the D_2 fold axial traces (*see* Figures 17.3 and 17.4). D_3 axial traces strike north-northeast–south-southwest and are subvertical. Hingelines plunge moderately to steeply to the north-northeast. The D_3 folds cannot be traced through the PB below the unconformity, and this is probably because their axial planes are so close to parallel to the D_1 axial planes that the D_3 deformation merely tightened existing D_1 folds, and did not create new folds.

The fourth phase of deformation is represented mainly by a pervasive, although irregularly developed, cleavage (S_4) that transects D_1, D_2 and D_3 structures, and is axial planar to locally developed small folds. In the northeastern part of the area, S_4 is parallel to the axial planes of D_2 folds and, due to poor exposure, various small folds present cannot be assigned to a specific deformational phase. The local expression of S_4 varies from a crenulation cleavage to a pressure solution striping to small faults, most of which display sinistral offsets on horizontal surfaces. Other attributes of this cleavage were discussed by Edwards and Stauffer (1990).

An examination of Figures 17.4 and 17.5 shows that S_4 cleavage forms an arcuate pattern across the area mapped and that the cleavage strikes parallel to the northern margin of the Rainy Lake batholithic complex (RLBC). It is also dramatically better developed in a several-hundred-metre wide zone near the contact and, thus, is interpreted to be the result of emplacement of the RLBC. The S_4 cleavage is the youngest pervasive deformation feature present and its age would approximate the end of tectonic deformation in this area. Although the age of S_4 is unknown, it should be bracketed by the crystallization age of trondhjemite-tonalite-granodiorite gneiss at the core of the RLBC and the age of the posttectonic Jackfish Lake–Weller Lake pluton (approximately 2698 Ma; D.W. Davis and R.H. Sutcliffe, unpublished data) which occupies the margin of the RLBC.

Three other deformational phases were discussed by Edwards and Stauffer (1990) but only D_6, the Manitou Stretch–Pipestone Lake shear zone (MPSZ), will be discussed here. The MPSZ is probably somewhat older than previously thought, partly because its regional trend (*see* Figure 17.2) appears to have been deflected by intrusion of the various plutons. Thus, it may have been initiated before the S_4 cleavage formed. This possibility should be investigated further. It is possible, although untested at the present, that S_4, initiation of the MPSZ, and emplacement of the RLBC were coeval and were tectonically related events.

SUMMARY AND REGIONAL STRATIGRAPHIC CORRELATION

Rocks in the Pipestone Lake area represent 2 distinct age groups — older, deformed basalts unconformably overlain by basaltic-andesitic volcanic rocks and coeval sediments. Similar relations were seen by Smith (1990a, 1990b) in the Vista Lake area where "Timiskaming-type" sediments between Esox and Alonghill lakes to the east of Pipestone Lake, lie unconformably on older (Keewatin) volcanic rocks (Thomson 1935). In contrast, however, the Thompson Bay sediments in the Pipestone Lake area do not lie directly on the deformed pillow basalts. Instead, they conformably overlie (and are locally intercalated with) the basaltic-andesitic fragmental rocks, which, in turn, lie unconformably on the older pillowed basalts. Nevertheless, the unconformity seems to be common to the 2 areas and rocks above and below the uncomformity probably correlate.

The stratigraphic/structural sequence — folded basalt unconformably overlain by volcanics and/or sediments — may have analogues in other greenstone belts. For example, on the south side of the RLBC (not very far away if the RLBC were removed), in the Rainy Lake area, Poulsen et al. (1980) describe a similar sequence in which (Keewatin) mafic and ultramafic volcanic rocks structurally overlie (Couchiching) sedimentary rocks and other (related?) volcanic rocks and the entire sequence was apparently inverted before upright isoclinal folding (cf. Davis et al. 1989, and structural interpretations therein). Here, the "Keewatin" volcanic rocks could be equivalent to the Pipestone Lake formation. The Couchiching and other volcanic rocks would be equivalent to the Thompson Bay sediments and the Thompson Bay volcanic, respectively. If this is a valid correlation and the contact between Keewatin volcanic rocks and Couchiching sediments was originally an unconformity as in the Pipestone Lake area, then the inversion of Couchiching (and related volcanic rocks) must have occurred during the equivalent of D_2-D_3 deformation in the Pipestone Lake area.

Based on the overlapping range of U-Pb ages of zircon grains, Davis et al. (1989) correlate Couchiching sediments with Quetico sediments (2704 Ma, maximum depositional age). If the Thompson Bay sediments also correlate with these sediments, perhaps the stratigraphic transition from western Wabigoon Subprovince to Quetico Subprovince is more similar to that in the Beardmore-Geraldton part of the subprovince than previously supposed. The Thompson Bay volcanics are, therefore, also relatively young compared with the usual age range for volcanism in the western Wabigoon Subprovince (approximately 2732 to 2711 Ma).

The absolute ages of the Pipestone Lake formation or the older Keewatin volcanics in inverted succession in the Rainy Lake area have not been ascertained geochronologically. In the meantime, it is tempting to correlate them either with the 3 billion-year-old rocks in the Lumby Lake greenstone belt (Davis and Jackson 1988) or a sequence near Savant Lake, dated at 2775 Ma, because of the presence of ultramafic volcanic rocks in each.

The Pipestone Lake formation differs from the Katimiagamak basalt formation, dated at 2732 Ma (Davis and Edwards, 1986), which is west of the Helena–Pipestone Lake Fault (*see* Figure 17.3). Unlike the Pipestone Lake formation, the Katimiagamak formation is about 40% gabbro sills, some of which grade laterally into flows. The Helena–Pipestone Lake Fault, therefore, may represent a significant tectonic boundary. Felsic volcanism associated with the Katimiagamak formation occurred at 2728 Ma, an age similar to those reported by Davis et al. (1989) for felsic volcanism east of Mine Centre, in the Bad Vermilion Lake area, in the core of the Rice Bay dome and west of Rice Bay at Commissioner's Bay.

SUGGESTIONS FOR FURTHER WORK

Good access to rock exposures of low metamorphic grade and low strain make Pipestone Lake an excellent and perhaps critical area to decipher the structural and stratigraphic evoluation of the western Wabigoon Subprovince. The groundwork has been laid and much work is yet to be done on specific problems. These problems are interrelated and include: 1) tracing the unconformity on the Pipestone formation; 2) absolute dating of volcanic and sedimentary units; 3) analyzing movement history of the Manitou Stretch-Pipestone Lake shear zone; and 4) continued refinement of the structural analysis and correlation of deformational fabrics with regional events.

ACKNOWLEDGMENTS

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REFERENCES

Blackburn, C.E. 1981. Kenora–Fort Frances; Ontario Geological Survey, Map 2443, scale 1:253 440.

Coleman, A.P. 1895. Gold in Ontario: Its associated rocks and minerals; Ontario Bureau of Mines, Annual Report, 1894, v.4, pt.2, p.35–100.

——— 1897. Third report on the west Ontario gold region; Ontario Bureau of Mines, Annual Report, 1896, v.6, pt.2, p.71–124.

Davis, D.W. and Edwards, G.R. 1986. Crustal evolution of Archean rocks in the Kakagi Lake area, Wabigoon Subprovince, northwest Ontario, as interpreted from high precision zircon U-Pb geochronology; Canadian Journal Earth Sciences, v.23, p.182–192.

Davis, D.W. and Jackson, M.C. 1988. Geochronology of the Lumby Lake greenstone belt: A 3 Ga complex within the Wabigoon Subprovince, northwest Ontario; Geological Society of America Bulletin, v.100, p.818–824.

Davis, D.W., Poulsen, K.H. and Kamo, S.L. 1989. New insights into Archean crustal development from geochronology in the Rainy Lake area, Superior Province, Canada; Journal of Geology, v.97, p.379–398.

Edwards, G.R. 1980. Geology of the Schistose Lake area, District of Kenora; Ontario Geological Survey, Report 194, 67p.

——— 1983a. Geology of the Straw Lake area, districts of Kenora and Rainy River; Ontario Geological Survey, Report 222, 67p.

——— 1983b. Geology of the Bethune Lake area, districts of Kenora and Rainy River; Ontario Geological Survey, Report 201, 59p.

Edwards, G.R. and Stauffer, M.R. 1988. Stratigraphy and structure of Archean metasediments and metavolcanics in the Thompson and James Bay areas (Pipestone Lake), Wabigoon Subprovince; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.120–122.

——— 1990. Stratigraphy and structure of Archean metasediments and metavolcanics in the Pipestone–Sucan Lakes area, Wabigoon Subprovince; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.140–144.

Goodwin, A.M. 1965. Preliminary report on volcanism and mineralization in the Lake of the Woods–Manitou Lake–Wabigoon region of northwestern Ontario; Ontario Department of Mines, Preliminary Report 1965–2, 63p.

Lawson, A.C. 1889. On the geology of the Rainy Lake region; Geology and Natural Historical Survey of Canada, Annual Report 1887–88 (New Series), v.3, Report F, 183p.

Poulsen, K.H., Borradaile, G.J. and Kehlenbeck, M.M. 1980. An inverted succession at Rainy Lake, Ontario; Canadian Journal of Earth Sciences, v.17, p.1358–1369.

Smith, P.M. 1990a. Precambrian geology, Vista Lake area, west part; Ontario Geological Survey, Preliminary Map P.3178.

——— 1990b. Precambrian geology, Vista Lake area, east part; Ontario Geological Survey, Preliminary Map P.3179.

Thomson, J.E. 1935. Geology of the Straw–Manitou Lakes area; Ontario Department of Mines, Annual Report, 1934, v.43, pt.4, 32p.

——— 1936. Geology of the Rowan–Straw lakes area; Ontario Department of Mines, Annual Report, 1935, v.44, pt.4, p.1–28.

18. Detailed Geological Investigations of the Mineralized Border Zone and Anorthosite Subzone, East Bull Lake Intrusion

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INTRODUCTION

This report summarizes the results of detailed geological mapping conducted at 2 key localities of the East Bull Lake intrusion (EBLI), districts of Sudbury and Algoma, Ontario. These areas are important because they provide an excellent opportunity to describe and understand both the geological setting of platinum-group element (PGE) and Cu-Ni sulphide mineralization, which is well developed along the base of the intrusion (see Peck et al. 1991), and the emplacement and crystallization history of the EBLI. This report follows on previous accounts of the geology and mineralization of the Bull Lake area (Peck and James 1990, 1992; Peck et al. 1991) completed as part of an ongoing three-year investigation into the mineral potential of mafic intrusive rocks occurring within Boon, Gerow, Lockeyer, Mandamin and Shibananing townships (Figure 18.1). The majority of this research has been directed toward the EBLI, which is the best documented of several of Paleoproterozoic anorthositic to gabbroic intrusive bodies that occur within the Elliot Lake–Espanola region (*see* Peck et al. 1991). The geology of the EBLI is summarized in Figures 18.2 and 18.3.

Funds to support this project were provided by a grant from the Ministry of Northern Development and Mines to Laurentian University, as part of the Ontario Government's Elliot Lake Initiative.

The first part of this report documents the results obtained from detailed geological mapping carried out Moon Lake area (shown on Figure 18.2) on a 1 by 1 km grid. The second part of this report describes field observations obtained from the Goulding Lake area, which links the western and eastern lobes of the EBLI (*see* Figure 18.3).

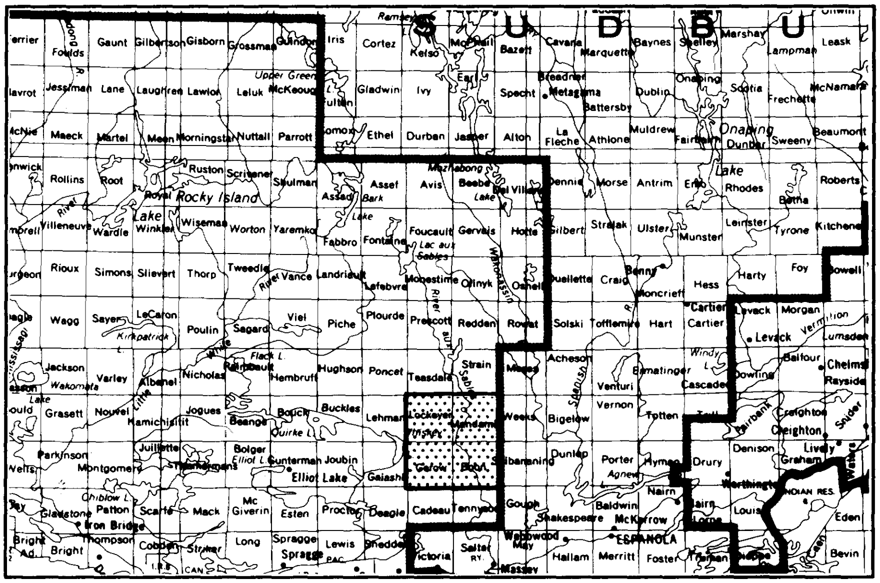

Figure 18.1. Location map of the study area for the current project, scale 1:1 584 000.

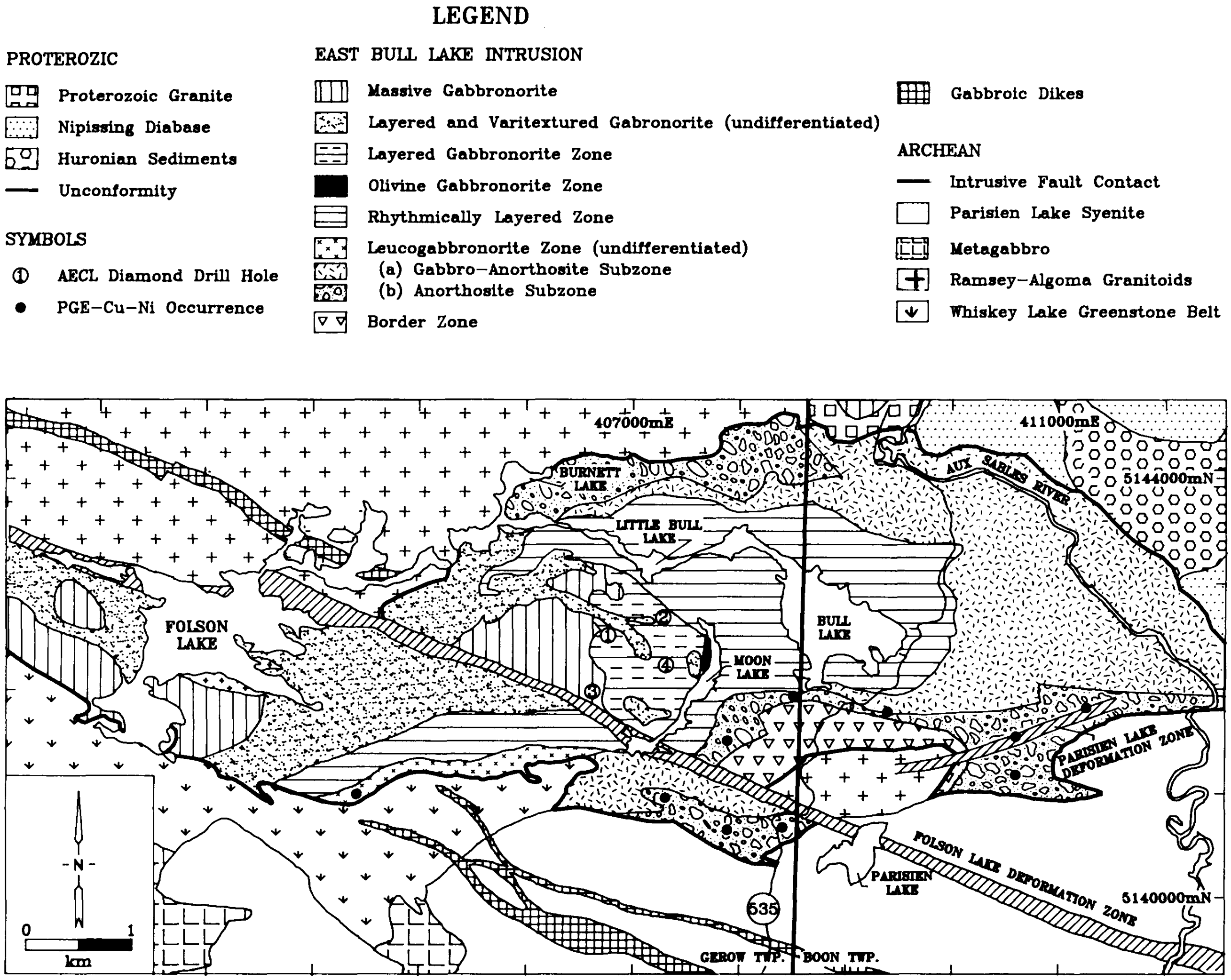

Figure 18.2. Generalized geology of the western part of the East Bull Lake intrusion. *Modified after* Peck et al. (1991).

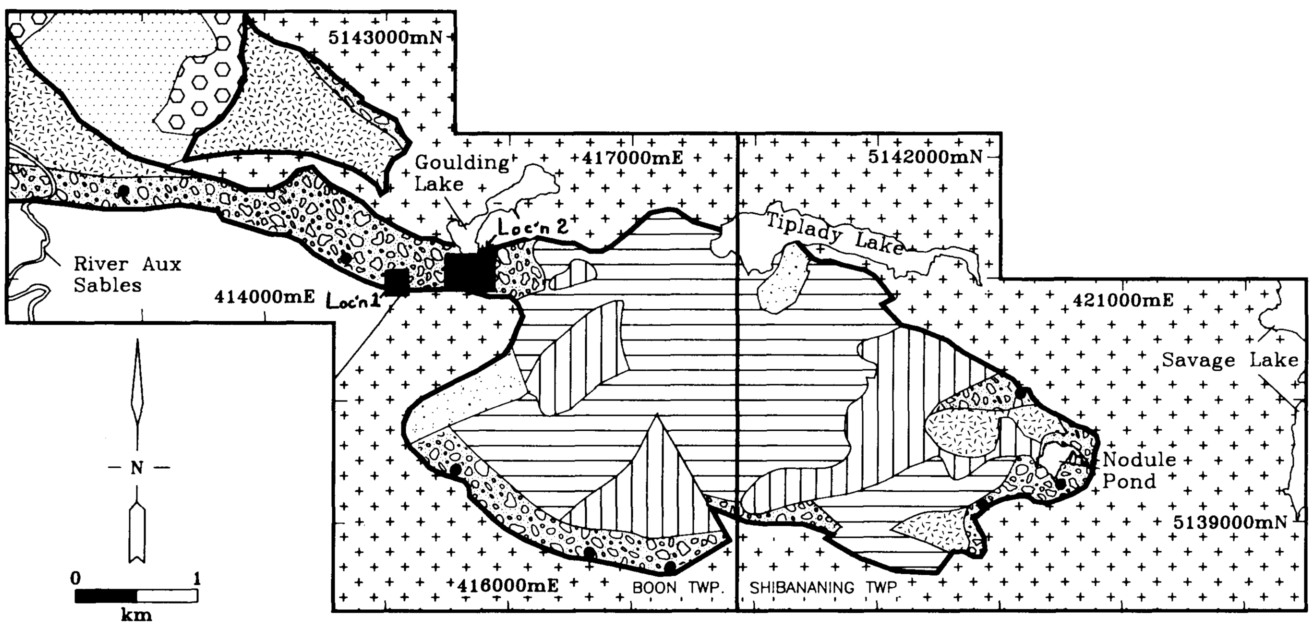

Figure 18.3. Generalized geology of the eastern part of the East Bull Lake intrusion. *See* Figure 18.2 for legend. *Modified after* Peck et al. (1991).

EXPLORATION ACTIVITY

Previous exploration activity in the Bull Lake area is summarized in Peck and James (1990) and Peck et al. (1991). INCO Exploration and Technical Services Incorporated (INCO E.T.S.) currently holds the majority of claims covering both the western and eastern parts of the East Bull Lake intrusion. INCO E.T.S. has staked and acquired 217 claims contained within 19 contiguous claim blocks. Approximately 150 of these claims were optioned from Gallo Exploration Services Incorporated (Toronto) in 1991. The remaining portions of the East Bull Lake intrusion are a 13 km² area within the central portion of the western part of the East Bull Lake intrusion (presently held by the Atomic Energy of Canada Limited) and a 5 km² area at the easternmost end of the East Bull Lake intrusion (currently held by Manitou Stone of Canada Limited). The EBLI hosts many excellent exposures of nodular-textured anorthosite (Peck et al. 1991). This rock type is currently being examined by Manitou Stone as a potential decorative building stone.

INCO E.T.S. continued their exploration of the EBLI (initiated in 1991) during the current year. Activity included geophysical surveying (induced polarization (IP)) and geological mapping and sampling along 2 cut grids, which are situated along the northern and southern margins of the western part of the intrusion, respectively. Reconnaissance mapping was also conducted along 500 m-spaced traverse lines that extend across the Parisien Lake Deformation Zone (*see* Figure 18.2). Reconnaissance mapping of the eastern part of the intrusion was conducted in August.

GEOLOGY OF THE MOON LAKE AREA: A PROBABLE IGNEOUS FEEDER COMPLEX WITH ASSOCIATED MINERALIZED CUMULATES

The Moon Lake area hosts mineralized anorthositic to pyroxenitic cumulates belonging to the Anorthosite Subzone (Peck et al. 1991), and an underlying suite of anorthositic to gabbroic veins and dikes that have inter-

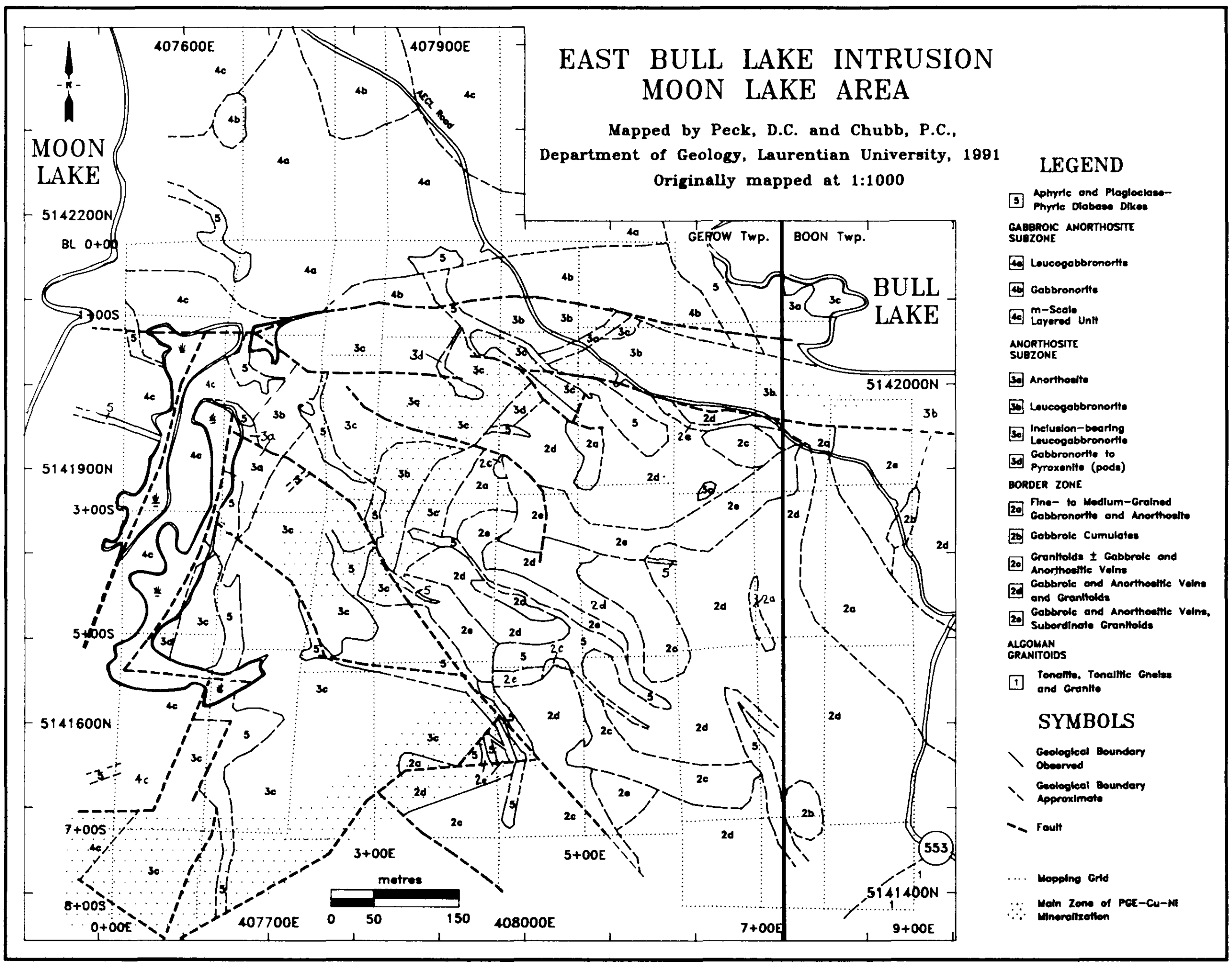

Figure 18.4. Generalized geology of the Moon Lake area, East Bull Lake intrusion.

Photo 18.1. Quartz-poor tonalite fragment (T) enclosed by gabbroic vein material (G) from the Border Zone, East Bull Lake intrusion.

acted extensively with Archean tonalitic and granitic basement rocks. The net result of this interaction is the development of a chaotic-looking marginal series to the EBLI, which is referred to as the Border Zone. Mapping of the Moon Lake area, at a scale of 1:1000, was completed over 2 field seasons (1991, 1992). The results of this mapping are summarized in Figure 18.4. A MSc thesis (S. Hardy, Laurentian University) has recently been initiated in order to better characterize the geology and geochemistry of this intriguing part of the EBLI.

Border Zone

The Border Zone, as exposed in the Moon Lake area, was originally described by Peck et al. (1991). Results from the 1992 field season have aided in advancing our understanding of this geologically complex zone. The Border Zone consists, in part, of irregularly shaped fragments of Archean felsic plutonic and metaplutonic rocks that range in size from less than 1 mm to several metres. The fragments appear to have formed during the emplacement of the EBLI. They are most commonly tonalitic in composition, and have much lower modal quartz contents (commonly less than 5%) than is seen in abundant Archean tonalitic gneiss (part of the Algoman gneiss domain; Card 1979) that crops out in many parts

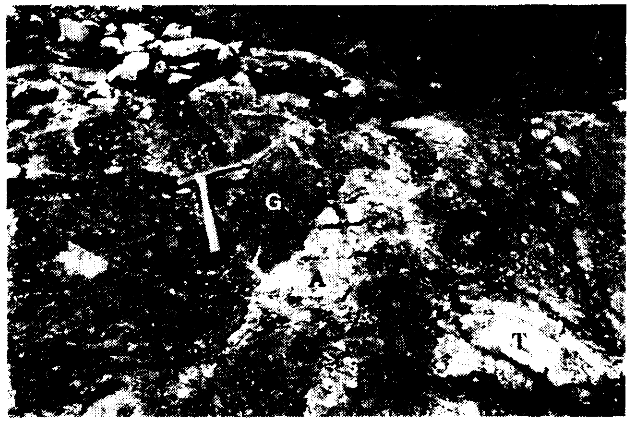

Photo 18.2. Anorthosite veins (A) cutting gabbronorite veins (G) and containing tonalite fragments (T), from the Border Zone, East Bull Lake intrusion.

of the Bull Lake area (*see* Figures 18.3 and 18.4). A very small percentage of the fragments are granitic in composition, and are believed to correlate with potassic intrusive rocks associated with the Parisen Lake syenite (*see* Figure 18.2). The fragments are commonly lensoidal to ovoidal in shape (Photos 18.1 and 18.2), and are locally sheared and boudinaged. Some of the deformational features displayed by the fragments are probably attributable to the effects of the Penokean Orogeny (*ca.* 1.8 Ga). However, much of the brecciation and alteration of the Archean basement is more clearly linked to both physical and chemical interaction with mafic and anorthositic magmas, as evidenced by: 1) the development of quartz-rich gabbroic reaction zones between quartz-poor felsic fragments, and typically quartz-poor gabbroic veins; 2) the common presence of fine-grained trains of fragmental material, enclosed by anorthosite or gabbro, eminating from larger felsic clasts; and 3) the presence of pull-apart structures in many of the fragments, which are invaded by the enclosing gabbroic or anorthositic veins.

Veins occurring within the Border Zone are quite variable in their distribution, size, orientation and mineralogy. The veins display a general increase in abundance as the base of the Anorthosite Subzone is approached from the footwall, ranging from less than 10% in the southeastern part of the Border Zone (*see* Figure 18.4) to greater than 90% in the immediate vicinity of the Anorthosite Subzone-Border Zone contact. The distribution of vein material is quite erratic on a given outcrop, and the width of the veins varies from a few millimetres to a few metres. The veins generally strike at right angles to the Border Zone-Anorthosite Subzone contact, but, on a local scale, display extreme variations in their orientation that are largely a function of the geometry of the basement fragments which they enclose. The veins range in composition from nearly pure anorthosite to melanogabbronorite, but are most commonly represented by leucogabbronorite or gabbronorite. Grain size is commonly between 1 to 5 mm, but both aphanitic and coarse-grained rock types are locally observed. Curiously, anorthositic veins are commonly seen to intrude into the gabbroic veins (*see* Photo 18.2), but the reverse situation has not been observed. This observation suggests that the mafic veins are slightly older than the plagioclase-rich veins, and that a minimum of 2 distinct magma types were formed during the evolution of the EBLI.

Small bodies of plagioclase-rich cumulates occur within the Border Zone. Several of these occurrences are shown on Figure 18.4. These "pockets" of cumulates are indistinguishable from cumulate rocks belonging to the Anorthosite Subzone.

Mafic dikes (map unit 5, *see* Figure 18.4) do not appear to be as abundant in the Border Zone as they are in the overlying Anorthosite Subzone (*see* Figure 18.4). These dikes are commonly aphyric, massive and fine grained. However, many of the largest mafic dikes (i.e., greater than 10 m wide) observed in the EBLI display aphyric, fine-grained margins, and coarser grained, plagioclase-phyric cores. One such dike is developed along grid line 7+00 mE, within the southern part of the mapping grid (*see* Figure 18.4). This dike is locally glomeroporphyritic, and appears to grade into a pocket of cumulate-textured gabbronorite (map unit 2b, *see* Figure 18.4). This key locality will be examined in more detail in the forthcoming field season, because it provides the first solid field evidence linking the diabase dikes to the EBLI.

Vari-textured, quartz-bearing gabbronorite bodies are locally developed within the Border Zone. These bodies are commonly less than 1 m in width and irregular in shape. They are most prolific in the uppermost parts of the Border Zone, and cut across the contact between the Border Zone and the Anorthosite Subzone. They are believed to represent evolved, volatile-rich residual magma that formed during the terminal stages of crystallization of the EBLI.

Sulphide mineralization is erratically developed within the Border Zone. Anorthositic veins seldom contain any sulphides, whereas more mafic veins commonly contain up to 2 to 3% disseminated, fine-grained pyrite and/or pyrrhotite ± chalcopyrite. Sulphides are also present in both the vari-textured gabbronorite bodies and the cumulate "pockets" developed in the Border Zone. A critical feature of the sulphide mineralization from the Border Zone is the great abundance of pyrite, which is a minor constituent of the sulphide mineralization developed in the overlying Anorthosite Subzone. Furthermore, there appears to be a general increase in the amount of chalcopyrite relative to pyrrhotite with increasing proximity to the basal contact. The onset of sulphide precipitation within the Border Zone is believed to have resulted from the combined effects of rapid cooling of the feeder magmas and incorporation of silica derived from the tonalitic fragments, as discussed in more detail by Peck et al. (in prep.).

The Border Zone grades into coarse-grained anorthositic and gabbroic rocks which constitute the base of the cumulate succession (Anorthosite Subzone) of the EBLI. As a consequence, it is not possible to precisely define the position of the basal contact between the Border Zone and the overlying Anorthosite Subzone. The transition between these two zones occurs over a distance of several metres. This transition is marked by a gradual increase in silicate grain sizes and sulphide abundances, and a gradual decrease in the concentration of pyrite and the abundance of felsic fragments. The sense of veining disappears, and is replaced by igneous banding that strikes parallel to the basal contact.

Formulation of a comprehensive model for the evolution of the Border Zone awaits the completion of much additional detailed geological and geochemical investigations. However, the general impression we have of the Border Zone is that it represents a footwall breccia, perhaps analogous to that which is recognized beneath the Sublayer of the Sudbury Igneous Complex (Dressler 1984). In the case of the Border Zone, the "breccia" varies from being clast-supported at its base, to matrix- (i.e., vein) supported near the floor of the EBLI. The general petrological similarities between the vein material in the Border Zone and the coarser grained cumulates from the Anorthosite Subzone, and the gradational nature of the basal contact, suggest that the veins may be representative of the parental magmas to the basal parts of the EBLI. In this scenario, the Border Zone represents a feeder complex, which evolved in response to the dynamic interaction between the Archean felsic basement and anorthositic to gabbroic magmas.

Anorthosite Subzone

In the Moon Lake area, the base of the Anorthosite Subzone is typically defined by a pyroxene-rich rock types, comprising medium- to coarse-grained gabbronorite or melanogabbronorite, and locally, pyroxenite (map unit 3d, *see* Figure 18.4). These rock types commonly occur as a series of relatively thin (i.e., generally less than 5 m thick) bands that interdigitate with coarse-grained leucogabbronorite or anorthosite. Locally, the pyroxene-rich bands are cut by anorthositic veins eminating from the underlying Border Zone. The banding commonly trends parallel to the basal contact, but is quite irregular and laterally discontinuous, and therefore, is not referred to as layering.

The basal mafic unit is overlain by, or grades laterally into, an inclusion-bearing leucogabbronorite unit (map unit 3c, *see* Figure 18.4). The latter unit derives its name from the great abundance of inclusions which it contains. Inclusion types comprise pyroxenite and melanogabbronorite pods, felsic basement xenoliths, and rarely, anorthosite nodules. Anorthosite inclusions are quite rare in the Moon Lake area, but are predominant in the inclusion-bearing leucogabbronorite unit in the eastern part of the intrusion.

The remainder of the Anorthosite Subzone comprises massive to weakly nodular-textured anorthosite and leucogabbronorite. These rock types are overlain by a modally layered leucogabbronorite-gabbronorite sequence that belongs to the Gabbroic Anorthosite Subzone (map unit 4, *see* Figure 18.4).

The Moon Lake area hosts the greatest concentrations of disseminated sulphide mineralization in the EBLI. The mineralization is referred to as contact sulphide mineralization (Peck et al. 1991), and comprises blebs, up to 1 cm in diameter, of pyrrhotite and/or chalcopyrite, with lesser pentlandite and pyrite. The sulphides locally display an intercumulus habit and are believed to have crystallized from contaminated, mafic residual magmas that were formed during the crystallization of the Anorthosite Subzone. The sulphides have been strongly recrystallized, and as a result, form fine-grained disseminations eminating from originally coarser grained blebs. Maximum metal concentrations obtained from mineralized surface samples from the Moon Lake area are 9400 ppb Pd, 2500 ppb Pt, 450 ppb Au, 1% Cu and 0.3% Ni. All currently available assay data for the Moon Lake area are given in Peck et al. (1992). The petrology and geochemistry of the mineralization is described elsewhere (Peck et al. 1991).

The great abundance of sulphide mineralization in the Moon Lake area is attributed to magmatic processes; this area is believed to represent an upturned, fault-bounded block originating from a deeper part of the intrusion than is typically exposed along the present erosional surface. It is postulated that immiscible sulphide liquids evolved during the terminal stages of crystallization of the parental magmas to the Anorthosite Subzone. Field and geochemical results (Peck et al. in prep.) suggest that magmatic sulphide liquids were concentrated together with mafic residual magmas, and that both of these liquids percolated downward toward the floor of the intrusion. Some of the mafic magmas (and associated sulphides) were trapped within the host anorthositic or leucogabbroic cumulate pile from which they originated (pyroxenite pods, and irregular clots of intercumulus pyroxene), whereas other magmas escaped to form sulphide-rich bands along the floor of the intrusion. Evidence for the existence of sulphide liquids during the crystallization of the EBLI has recently been found from marginal gabbroic cumulates occurring along the base of the Anorthosite Subzone in the eastern part of the EBLI. In this area, rounded sulphide blebs display mineralogic and textural features suggesting that they were crystallized from high-temperature monosulphide solutions. The blebs display pyrrhotite-dominant mineral assemblages, with subordinate, exsolved pentlandite and chalcopyrite. The sulphide blebs occur in abundances of up to 10%, and lack the intercumulus habit that characterizes sulphide occurrences from other parts of the EBLI.

We anticipate that the greatest concentrations of sulphide mineralization (and associated PGE) will be found at the base of the central part of the intrusion, or within structural traps developed along the sidewalls of the intrusion. Sulphide minerals are most effectively concentrated in association with pyroxene-rich units and in the pyroxene-dominated intercumulus volumes of plagioclase-rich cumulates.

GEOLOGY AND MINERALIZATION OF THE GOULDING LAKE AREA

The Goulding Lake area (*see* Figure 18.3) was selected for detailed mapping and lithogeochemical sampling because it hosts excellent exposures of the mineralized parts of the Anorthosite Subzone, in addition to numerous outcroppings of nodular anorthosite. These occurrences of the basal parts of the EBLI form a narrow (less than 500 m wide) conduit linking the western and eastern parts of the intrusion. The entire geology of this conduit is composed of outcroppings of Anorthosite Subzone and related Border Zone rocks, which form a trough-like sequence having flat-lying layering orientations within the central part of the conduit, and more steeply dipping margins. The base of the intrusion is probably not more than 50 m beneath the surface at any location within this conduit, so that the Goulding Lake area is an ideal location for mineral exploration.

The objectives of the mapping were to characterize the outcrop-scale distribution of the sulphide mineralization and to better define the petrological features and distribution of the nodular anorthosite unit. In order to fascilitate the examination of the mineralization within the Anorthosite Subzone, a program of detailed mapping and sampling of a previously delineated mineralized zone (Peck et al. 1991) was undertaken. Two sites were selected for study. The first of these, location 1, is situated along the southern margin of the intrusion, approximately 500 m to the south and west of Goulding Lake (*see* Figure 18.3). The second study site, location 2, is situated immediately to the south of Goulding Lake (*see* Figure 18.3). We report on preliminary results obtained from both of these study sites.

Location 1 (Gallo Pond Site)

Mapping of location 1 was carried out on a control grid having a 5 m line spacing. The geology of location 1 consists primarily of a syenite-rich Border Zone, diabase, and rocks belonging to the Anorthosite Subzone, including a marginal fine- to medium-grained gabbronorite

Photo 18.3. Stringers of anorthosite nodules (N) hosted by gabbronorite (G) from the Anorthosite Subzone, location 2, Goulding Lake area, East Bull Lake intrusion.

unit, and an inclusion-bearing leucogabbronorite unit. The syenite-rich Border Zone is similar in appearance to the Border Zone from the Moon Lake area. At Goulding Lake, the Border Zone consists of syenite (greater than 75%) that has been intruded by (leuco)gabbroic and pyroxenitic veins and dikes. Mineralization within the veins and dikes consists of up to 2% disseminated to clotty pyrite and/or pyrrhotite ± chalcopyrite.

The contact between the Border Zone and the overlying Anorthosite Subzone is gradational, and is defined by decreasing abundances of syenitic rocks with increasing stratigraphic elevation. The base of the Anorthosite Subzone is represented by a 10 m thick "layer" of mafic rocks comprising fine-grained diabase and coarser grained (leuco)gabbronorite. Some of the coarser grained rocks within this "layer" appear to represent "pockets" of cumulates, which have developed within the finer grained diabase matrix. Alternatively, these cumulate "pockets" are fragments derived from pre-existing cumulate layers. It is not clear whether this basal mafic "layer" represents a dike or a chilled margin. Sulphide mineralization within this unit consists of up to 2% blebs and fine-grained disseminations of pyrite and/or pyrrhotite ± chalcopyrite.

Photo 18.4. Stringers and plumes of nodular anorthosite (N) interfingering with gabbronorite (G) along the irregular contact between the nodular anorthosite unit and the inclusion-bearing leucogabbronorite unit, Anorthosite Subzone, Goulding Lake area, East Bull Lake intrusion.

The contact between the marginal mafic unit and the overlying semi-nodular-textured inclusion-bearing leucogabbronorite unit is not exposed within location 1. The inclusion-bearing leucogabbronorite unit consists of medium- to very coarse-grained leucogabbronorite, which contains up to 20% inclusions of pyroxenite (grading to melanogabbronorite) and anorthosite. The pyroxenite inclusions are generally ovoidal and less than 0.5 m in diameter. They are typically equigranular and may contain minor amounts of quartz and up to several percent disseminated chalcopyrite ± pyrrhotite. The anorthosite inclusions consist of approximately 80 to 90% randomly oriented, coarse-grained plagioclase crystals that form spheroidal to ovoidal aggregates (nodules) up to several centimetres in diameter. These morphologies are similar to those developed in the overlying nodular anorthosite unit. The anorthosite inclusions commonly occur in stringers and clusters (Photos 18.3 and 18.4), some of which appear to enclose pyroxenite pods. Rarely, individual anorthosite nodules are partially embedded within the pyroxenite inclusions. The matrix of the inclusion-bearing leucogabbronorite unit consists of medium- to very coarse-grained leucogabbronorite that grades into gabbronorite. The matrix mineralogy comprises abundant cumulus plagioclase and poikilitic, postcumulus pyroxene, and up to 2% colourless to blue-coloured postcumulus quartz, and 1 to 2% postcumulus leucoxene (replacing titaniferous magnetite).

Sulphide mineralization (up to 5%) is associated with the postcumulus minerals and their metamorphic replacement products (calcic amphiboles, epidote-group minerals, biotite and quartz). Sulphide assemblages include chalcopyrite + pyrrhotite ± pentlandite ± pyrite. The texture, distribution and PGE tenor of the sulphide mineralization is similar to that described above for the inclusion-bearing leucogabbronorite unit from the Moon Lake area.

Grab samples were obtained for all of the major rock types present in location 1. Additional mapping and sampling of location 1 was conducted on a 6 by 6 m grid covering a single, representative outcrop occurring within the inclusion-bearing leucogabbronorite unit and, subsequently, on a 1 by 1 m grid situated within the larger grid. Sampling was carried out using a hand-held diamond drill, with samples taken at intervals of 1 m (6 by 6 m grid) and 20 cm (1 by 1 m grid). All of the samples have been submitted for the determination of their PGE and chalcophile element abundances.

Location 2

Location 2 provides a cross-section through the Anorthosite Subzone, and extends in a southerly direction for approximately 500 m from the southern end of Goulding Lake (*see* Figure 18.3). Nodular anorthosite forms a series of prominent, east-facing cliffs that have a maximum relief of 15 m. Fabric analysis conducted at 4 locations within the nodular anorthosite unit revealed that the nodules are not elongated in any particular direction, but do display a small increase in abundance (relative to the matrix) with increasing stratigraphic elevation. Sulphide mineralization is sporadically developed within the nodular anorthosite unit. Sulphides (typically less than 1% of the rock) are restricted to the pyroxene-rich matrix and include disseminated and blebby chalcopyrite + pyrrhotite.

The inclusion-bearing leucogabbronorite unit is well developed along the southern shoreline of Goulding Lake. One particularly good exposure of this unit was stripped, washed, mapped in detail, and sampled using a rock saw (channel samples). Preliminary interpretation of our field observations indicate that the inclusion-bearing leucogabbronorite from this locality is a magmatic breccia, in which many discrete volumes of (leuco)gabbroic to pyroxenitic magma have interacted physically. These discrete magmas crystallized to form a chaotic mixture of very thin bands, lenses and pods of leucogabbronorite, gabbronorite, vari-textured gabbronorite, and pyroxenite. Inclusions of one rock type within another are commonly observed, and contacts between individual units are very irregular. Stringers of anorthosite nodules are locally developed (*see* Photos 18.3 and 18.4), and appear to have been derived from the overlying nodular anorthosite unit.

The contact between the nodular anorthosite unit and the inclusion-bearing leucogabbronorite unit is well exposed on many of the cliff faces present in location 2. This contact is typically irregular (*see* Photo 18.4). The general attitude of this contact is approximately horizontal within the main part of location 2, but steepens toward the southern margin of the intrusion, where it dips to the north at approximately 60°. The many irregularities along this contact, and the presence of stringers and clusters of nodules within the leucogabbronorite unit, are attributed to instabilities developing along the base of the nodular anorthosite unit. These instabilities appear to have resulted from sinking of dense, mafic residual magma, carrying entrained anorthosite nodules, through the nodular anorthosite unit, and to erosion of the base of the nodular anorthosite unit by hotter and less crystalline gabbroic magmas.

SUMMARY AND GUIDELINES FOR EXPLORATION

The results obtained from detailed geological investigations along the margins of the EBLI suggest that the base of the intrusion is a feeder complex (Border Zone) in which brecciated Archean footwall rocks were infiltrated by anorthositic and gabbroic magmas. Anorthositic veins cut gabbroic veins, and the former are more clearly related to the overlying cumulates. The very existence of anorthosite feeders is intriguing, and has important implications to one of the major petrological problems of recent times, namely, the petrogenesis of anorthositic intrusions and anorthositic magmas. Evidence exists for the presence of multiple, discrete magma volumes within the basal, inclusion-bearing cumulate layer, and for gravitational instability in the overlying nodular anorthosite unit.

Sulphide mineralization is well developed along the base of the East Bull Lake intrusion, both in the basal cumulates, and in feeder veins within the footwall. The sulphide assemblages include pyrrhotite, chalcopyrite, pentlandite and pyrite, and have very high concentrations of platinum-group elements. The mineralization is preferentially concentrated within pyroxene-rich rock types, or in association with postcumulus minerals in plagioclase-rich cumulates. The sulphide mineralization is still being investigated, but preliminary results suggest that it comprises both intercumulus, magmatic sulphides and the crystalline material formed from immiscible sulphide liquids.

Exploration for this marginal style of PGE-Cu-Ni mineralization should focus along the base of the intrusion. Attempts should be made to identify irregularities along the basal contact which may have provided structural traps for dense sulphide liquids. This type of mineralization should be traceable into the subsurface using IP surveys. Much additional detailed mapping and lithogeochemical sampling, both on the surface (channel, grab) and in the subsurface (diamond and rotary-percussion drilling), is warranted. This work will provide a better definition of the magnitude of metal enrichment (PGE, copper and nickel) and the abundance and distribution of sulphide mineralization along the margins of the East Bull Lake intrusion. The marginal-type mineralization is but 1 of 3 distinct and promising styles of PGE + copper + nickel mineralization observed from the EBLI (*see* Peck et al. in prep.). Our results suggest that the potential exists for economic concentrations of these metals in the EBLI, and equally, in the other Paleoproterozoic anorthositic intrusions that occur within the Elliot Lake–Sudbury region.

ACKNOWLEDGMENTS

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REFERENCES

Card, K.D. 1979. Regional geological synthesis, central Superior Province; *in* Report of Activities, Part A, Geological Survey of Canada, Paper 79–1A, p.87–90.

Dressler, B.O. 1984. The effects of the Sudbury Event and the intrusion of the Sudbury Igneous Complex on the footwall rocks of the Sudbury Structure; *in* The geology and ore deposits of the Sudbury Structure, Ontario Geological Survey, Special Volume 1, p.97–136.

Peck, D.C., Chubb, P.T. and James, R.S. 1991. Magmatic platinum-group elements and copper + nickel mineralization along the base of the East Bull Lake gabbro-anorthosite intrusion; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.64–72.

Peck, D.C. and James, R.S. 1990. Mineral potential studies of mafic and ultramafic intrusive rocks in the Elliot Lake area; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.62–66.

——— 1992. Preliminary report on the geology and platinum-group element-sulphide mineralization of the East Bull Lake gabbro-anorthosite intrusion; Ontario Geological Survey, Open File Report 58–13.

Peck, D.C., James, R.S., Chubb, P.C., Keays, R.R., Reeves, S.J., Lightfoot, P.C. and Kamineni, D.C. in preparation. Precious-metal, chalcophile-element and rare-earth element geochemistry of the Bull Lake area, districts of Algoma and Sudbury, Ontario; Ontario Geological Survey, Open File Report.

19. Geology of the Port Coldwell Alkalic Complex

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INTRODUCTION

This summary presents the results of the second field season of a geologic mapping and research program on the Port Coldwell alkalic complex. Major results of this program to date include: 1) the completion of 1:20 000 scale mapping of the complex; and 2) the identification of several new occurrences of rare metal (niobium, yttrium, zirconium, rare earth element [REE]) mineralization in the complex. The potential for rare and precious metal concentration is being investigated through mapping, petrological and chemical studies in order to develop genetic and exploration models.

The 580 km² Port Coldwell alkalic complex, the largest alkalic intrusion in North America, is situated between Pic River and Dead Horse Creek, on the north shore of Lake Superior, 275 km east of Thunder Bay (Figure 19.1). The town of Marathon is located within the eastern part of the Port Coldwell alkalic complex. The southern part of the complex can be easily accessed by Highway 17, the Canadian Pacific Railway and the Lake Superior shore.

MINERAL EXPLORATION

Mineral occurrences in the Port Coldwell alkalic complex include: base and precious metals (copper, nickel, palladium, platinum and associated vanadium and titanium), rare metals (niobium, yttrium, zirconium, REE), building stone, industrial minerals (nepheline) and gemstones. The reader is referred to Walker et al. (1991) for background information on previous exploration activity. The following is a brief summary of the mineral exploration activity in the Port Coldwell alkalic complex in 1991 and 1992.

Redstone Resources Incorporated explored gabbroic rocks in the north part of the Eastern Gabbro in the vicinity of Wullie Lake. In Grain Township, Redstone Resources Incorporated diamond drilled 4 holes (600 m) into a zone containing chalcopyrite-magnetite mineralization with up to 0.56% Cu, 300 ppb Pt and 682 ppb Pd. In the southeast part of the complex, Noranda Exploration Limited diamond drilled 2 holes (400 m) in the Dunlop Copper occurrence, located near Highway 17, in gabbroic rocks. They intersected weakly disseminated chalcopyrite mineralization that contained up to 0.35% Cu.

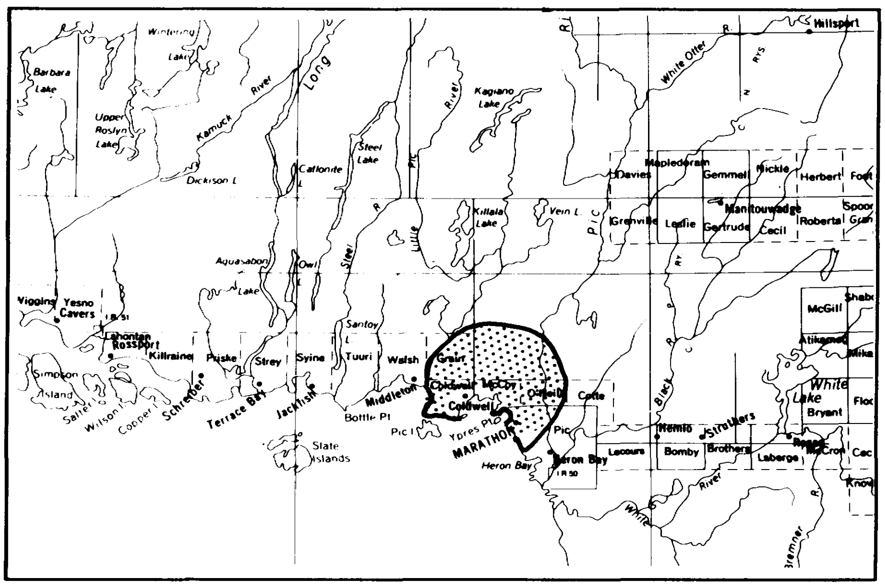
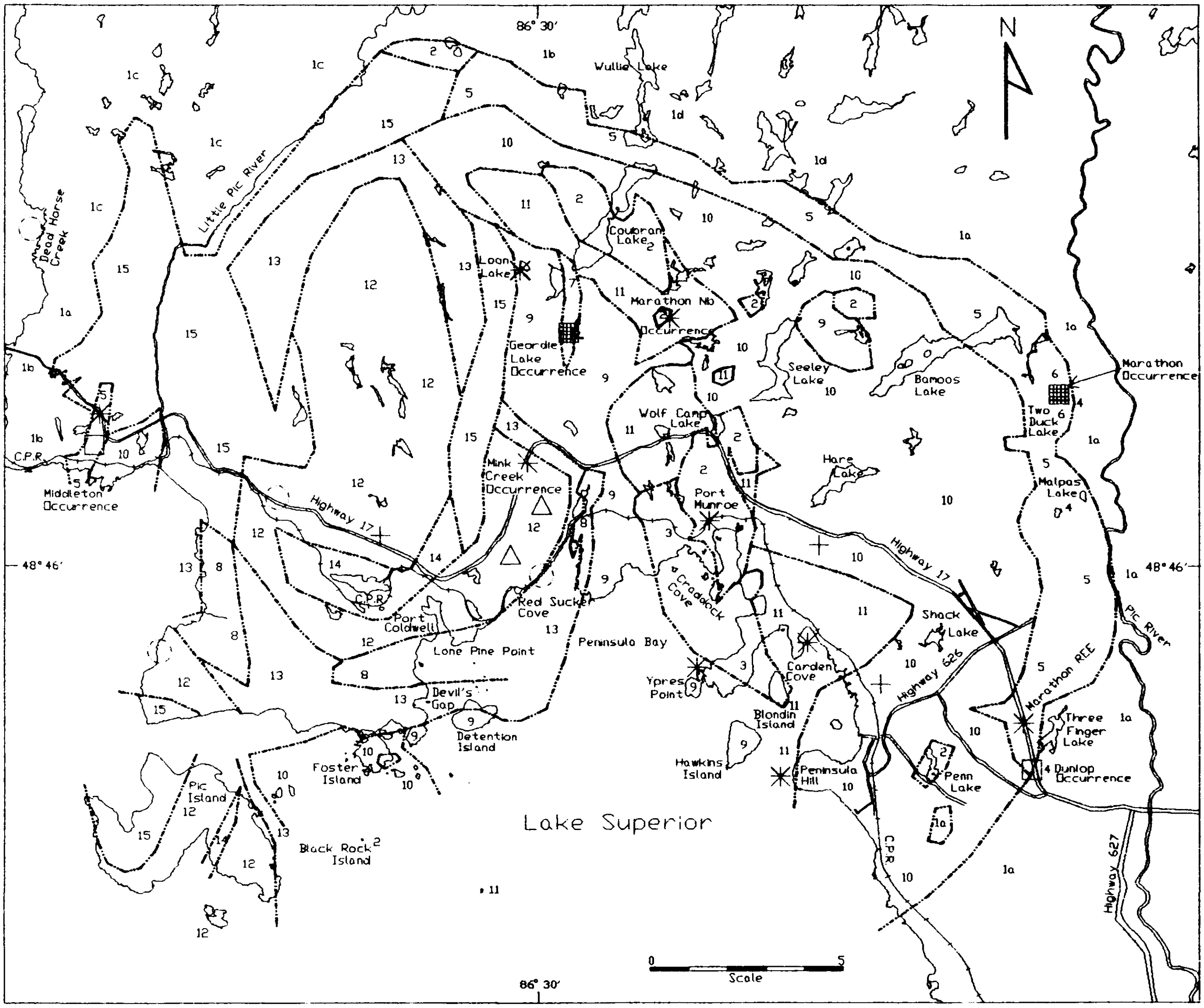


Figure 19.1. Location map of the Port Coldwell alkalic complex, scale 1:1 584 000.



Proterozoic

15	Amphibole quartz syenite
14	Coarse–grained amphibole quartz syenite
13	Heterogeneous amphibole nepheline syenite
12	Amphibole nepheline syenite
11	Feldspar porphyritic amphibole syenite
10	Iron–rich augite syenite
9	Recrystallized amphibole quartz syenite
8	Alkaline gabbro
7	Geordie Lake Gabbro
6	Two Duck Lake Gabbro
5	Eastern and Western Gabbro
4	Rheomorphic breccia
3	Monzodiorite
2	Basaltic xenolith

Archean

1d	Granite
1c	Granodiorite trondhjemite
1b	Metasedimentory rocks
1a	Metavolcanic rocks
▦	Base and precious metals (Cu, Pd, Pt)
□	Base metals (Cu)
✳	Rare metals (REE, Nb, Y, Zr)
Δ	Industrial minerals (nepheline)
+	building stone
/	Geological contacts
○	Diatremes

Figure 19.2. Geology map of the Port Coldwell alkalic complex.

Mr. and Mrs. J. Ferguson of Terrace Bay, Ontario have started extraction of very coarse-grained iridescent feldspars from several pegmatites hosted in the iron-rich augite syenite near Shack Lake. The polished minerals are being marketed as spectrolite, the Marathon gemstone.

GENERAL GEOLOGY

The Port Coldwell alkalic complex was emplaced into Archean rocks of the Wawa Subprovince of the Superior Province during the early stages of the Mesoproterozoic Midcontinent Rift at 1108± 1 Ma (Heaman and Machado 1992). The complex is located at the north end of the Thiel fault, a zone of faulting that separates grabens with different subsidence history in the rift (Cannon et al. 1989). A north-trending magnetic high occurs between the rocks of the Port Coldwell alkalic complex and those of the Midcontinent Rift beneath Lake Superior (Gupta 1991). Samples of different magmatic suites from the Port Coldwell alkalic complex dated by the U–Pb zircon-baddeleyite method (Heaman and Machado 1992) are all within analytical error.

The Port Coldwell alkalic complex consists of a variety of felsic syenites and gabbroic rocks (Figure 19.2). Mitchell and Platt (1977, 1978) subdivided the Port Coldwell alkalic complex into 3 centres of alkalic magmatism emplaced by cauldron subsidence associated with major faults. This study supports this hypothesis.

DESCRIPTION OF ROCK TYPES

In the following section, the map units of the Port Coldwell alkalic complex and adjacent Archean host rocks are described in the interpreted stratigraphic order. The mineralogy, textures, intrusive relations and economic associations for each of the rock types are summarized in Table 19.1.

Archean Rocks

The Port Coldwell alkalic complex intrudes Archean metavolcanic, metasedimentary and granitic rocks. Detailed descriptions of the Archean rocks to the east and southeast of the complex are given by Milne (1967) and Muir (1982), and to the west and northwest by Walker (1967). Both eastern and western contacts of the complex truncate bedding or fabrics within the Archean rocks. The eastern contact between the complex and the Archean rocks has a regular arcuate shape; however, the west contact is irregular and apparently modified by faults.

Metamorphism of the Archean rocks to pyroxene hornfels grade can be detected within approximately 50 m of the contact with the complex. Locally, on the eastern contact of the complex, metamorphism has caused the suprasolidus recrystallization of the Archean rocks and the development of rheomorphic breccia.

Proterozoic Rocks — Port Coldwell Alkalic Complex

BASALTIC XENOLITHS

The intrusive rocks of the Port Coldwell alkalic complex are emplaced into a sequence of basaltic rocks. The intrusion of gabbroic and syenite magma into the basalts has caused large- and small-scale brecciation and assimilation of this unit, leaving basaltic xenoliths from less than 1 m to over a km in size. These xenoliths form a roof pendant overlying the central part of the Port Coldwell alkalic complex. Varieties of this unit have been observed as xenoliths in many of the major rock units throughout the complex.

The basaltic rocks are divided into 3 main types: 1) aphanitic to fine-grained massive basalt with rounded structures that may be amygdules; 2) medium-grained diabasic basalt; and 3) aphanitic to medium-grained feldspar-phyric diabasic basalt. All 3 of the basaltic rock types are highly fractured and, locally, have magnetite-filled fractures up to 4 cm wide. The basalts are considered to be Proterozoic in age due to the absence of strong penetrative fabrics and dissimilarity to Archean rocks exposed outside of the complex.

The aphanitic to fine-grained basalts are black and massive. The amygdule-like structures are rounded to elliptical, range from a few mm to 2 cm in diameter and are filled with fine- to medium-grained epidote and quartz. Well-defined zones with the amygdule-like structures dip 8°SW in the Wolf Camp Lake–Port Munroe area. In the southern parts of the Port Coldwell alkalic complex at Black Rock Island and on Penn Lake, the basalts exhibit fragmental textures similar to flow-top breccias.

Medium-grained basalt with a diabasic texture occurs mainly on top of Bamoos Mountain and in the Coubran Lake area. The medium-grained basalt locally contains miarolitic cavities filled with feldspar and quartz and commonly occurs in the northern part of the complex, whereas the amygdaloidal basalts occur as xenoliths in the southern part of the complex.

Aphanitic to medium-grained feldspar-phyric basalts containing lath-shaped feldspar phenocrysts up to 1 cm in length occur with both aphanitic to fine-grained and medium-grained basalts. The feldspar phenocrysts can occur either separately or in glomeroporphyritic aggregates.

MONZODIORITE

A shallow-dipping sheet of monzodiorite is emplaced into the basalts in the south-central part of the complex. The unit is 1.5 km wide by 13 km long and extends from Craddock Cove to Blondin Island on Lake Superior. Contact relationships indicate that the monzodiorite was emplaced concordantly to the basalt and appears to have been chilled against the basalt. At the contact, the monzodiorite has a medium-grained, subophitic texture

Table 19.1. Mineralogy, texture, intrusive relations and economic associations summarized for each of the rock units. Centres are as defined by Mitchell and Platt (1977, 1978). Rock Unit numbers from Figure 19.1 are listed beside the rock name.

Rock Type	Mineralogy	Texture	Intrusive Relations	Economic Associations	Centre (*)
Amphibole Quartz Syenite (15)	Albite, Kspar, amphibole, quartz	Massive, equigranular, porphyritic,	Intrudes units 14,13,12,11, 10,9,8,2		3
Coarse-Grained Amphibole Quartz syenite (14)	Albite, Kspar, amphibole, olivine, clinopyroxene, quartz	Massive, porphyritic	Appears to intrude amphibole nepheline Syenite (12)		3
Heterogeneous Amphibole-Nepheline Syenite (13)	Albite, Kspar, amphibole, biotite zeolites, nepheline	Variable, granular, porphyritic, layered, foliated, pegmatitic	Intrudes units 12,10,9,8,2	Possible industrial mineral potential (nepheline) rare metals?	2
Amphibole Nepheline Syenite (12)	Albite, Kspar, amphibole, biotite zeolites, nepheline	Massive to well layered and foliated, pegmatitic	Intrudes basaltic xenoliths 2	Industrial Mineral potential (nepheline) rare metals	2
Feldspar Porphyritic Amphibole Syenite (11)	Albite, Kspar, amphibole, magnetite	Massive to porphyritic, pegmatitic	Intrudes units 10,9,3,2	Rare metals	1
Iron-rich Augite Syenite (10)	Albite, Kspar iron-rich augite, fayalite, magnetite, amphibole	Massive to well layered, pegmatitic	Intrudes Eastern Gabbro (5), basaltic xenoliths (2)	Building stone, gems, rare metals in cross cutting syenite dikes	1
Recrystallized Amphibole Quartz Syenite (9)	Albite, Kspar, amphibole, quartz	Massive, anhedral granular, migmatized	Intrudes basaltic xenoliths (2)	Rare metals	1
Alkaline Gabbro (8)	Plagioclase, biotite, clinopyroxene, olivine, magnetite apatite, amphibole	Massive, inclusion rich to well layered	Coeval with heterogeneous amphibole nepheline syenite (13)		2
Geordie Lake Gabbro (7)	Plagioclase, olivine, clinopyroxene, magnetite, Kspar	Massive, pegmatitic	Intrudes 9?	Cu, PGE	1
Two Duck Lake Gabbro (6)	Plagioclase, olivine clinopyroxene, magnetite, amphibole, orthopyroxene	Medium to coarse grained, pegmatitic	Intrudes Eastern Gabbro (5)	Cu, PGE	1
Eastern and Western Gabbro (5)	Plagioclase, biotite, olivine, magnetite, clinopyroxene, amphibole	Massive to well layered to pegmatitic	Intrudes basaltic xenoliths (2), Archean rocks	Cu, Ti, V rare metals in crosscutting syenite dikes	1
Rheomorphic Breccia (4)	Feldspar, quartz, biotite, amphibole, tourmaline, prehnite	Granular	Intrudes and brecciates Archean rocks		1
Monzodiorite (3)	Plagioclase, Kspar, clinopyroxene, amphibole, epidote, magnetite	Massive to layered, pegmatitic	Intrudes basaltic xenoliths (2)	Rare metals in crosscutting syenite dikes	1
Basaltic Xenolith (2)	Clinopyroxene, plagioclase, Kspar, magnetite	Massive, diabasic, with amygdaloidal structures		Rare metals in cross cutting syenite dikes	1

that grades upward into an intergranular texture. The contact between the monzodiorite and basalt is typically separated by a fine-grained, red feldspar-phyric trachyte. In the middle part of the monzodiorite sheet, medium- to coarse-grained pegmatitic patches are present. Toward the top of the monzodiorite, the feldspars become reddened, and the red monzodiorite is texturally very similar to the recrystallized amphibole quartz syenite. The contact between these 2 rocks is marked by the appearance of quartz within the quartz syenite.

RHEOMORPHIC BRECCIA

Rheomorphic breccia occurs along the eastern contact of the Port Coldwell alkalic complex where the Eastern Gabbro is in contact with Archean intermediate to felsic volcanic and sedimentary rocks. The breccia consists of Archean metavolcanic and metasedimentary rock fragments and gabbroic clasts of probable Proterozoic age in a matrix of fine-grained quartz and feldspar with traces of biotite and amphibole. Clasts range in size from less than 1 cm to more than 1 m and are commonly angular with 1 to 2 cm reaction rinds. In the area near Two Duck Lake, the breccia contains diabasic gabbro clasts and Archean metavolcanic clasts, which have been boudinaged and sheared. Local granitic veins cut the breccia, and these commonly contain traces of tourmaline and prehnite.

EASTERN GABBRO

The Eastern Gabbro forms a crescent-shaped body around the eastern and northern margin of the Port Coldwell alkalic complex. In this study, the Eastern Gabbro has been subdivided into 4 subunits: 1) fine-grained gabbro, which forms dikes and xenoliths; 2) layered gabbro; 3) feldspar-phyric gabbro; and 4) the coarse-grained to pegmatitic Two Duck Lake gabbro.

Dikes of fine-grained ophitic to subophitic gabbro are common in the Two Duck Lake area, where they appear to be intruded by both layered gabbro and the Two Duck Lake gabbro. Xenoliths of similar rock type are found in the Two Duck Lake gabbro, as clasts in rheomorphic breccia and sporadically throughout the northwestern part of the gabbro.

The layered gabbro subunit forms the main phase of the Eastern Gabbro and ranges from massive to layered. The layered gabbro contains plagioclase, clinopyroxene, olivine and magnetite with biotite and amphibole. Layering in this subunit is typically continuous over distances of up to 50 to 60 m. Layering in the northern part of the Eastern Gabbro is very discontinuous and is interrupted by anorthosite inclusions and folding of layers. The presence of these features indicates that layering is probably modified by the slumping of magma from the walls of the chamber.

Feldspar-phyric gabbro occurs from Highway 17 along the shore of the Pic River and west to Malpas Lake, where it is terminated by a fault. This gabbro is typically fine to medium grained with pyroxene, olivine and magnetite and has subhedral to euhedral feldspar phenocrysts 0.2 to 1 cm long.

Coarse-grained Two Duck Lake gabbro with pegmatitic patches occurs south of the Bamoos Lake powerline. The distribution of this subunit may be fault controlled. This study has used the division of the Two Duck Lake gabbro presented by Good (1992) in which the Two Duck Lake gabbro is divided into Upper and Lower zones. The Upper zone is massive to well layered with a lamination of feldspars and contains pegmatitic gabbro pods. The Lower zone of the Two Duck Lake gabbro is typically massive and coarse to very coarse grained, is ophitic to subophitic with common pegmatitic patches and has zones containing up to 3% sulphides. The Upper and Lower zones of the Two Duck Lake gabbro are separated by a xenolith of "old" gabbro (Wilkinson 1983; Good 1992). In this study, this subunit is considered to be similar to the fine-grained gabbro that predates the main phase of gabbro emplacement.

GEORDIE LAKE GABBRO

The Geordie Lake Gabbro appears to be a low-angle sheet dipping approximately 10° to 20°W, cutting the recrystallized amphibole quartz syenite. The Geordie Lake Gabbro is medium to coarse grained and, in addition to pyroxene and plagioclase, contains olivine, magnetite, potassium feldspar and apatite. Good (1992) considers the Geordie Lake Gabbro to be similar to the Eastern Gabbro. Mulja and Mitchell (1991), however, concluded that it represents a more evolved mafic magma than the Eastern Gabbro.

Outcrops of gabbro were also found along steep-sided hills south and east of the Geordie Lake Gabbro. These gabbroic outcrops may be xenoliths in the host syenite or evidence of additional gabbroic sheets below the thin syenite cap rock. The latter alternative is significant with respect to the possibility of more gabbro-hosted base and precious metal deposits occurring within this area.

ALKALINE GABBRO

An arcuate body of heterogeneous alkaline gabbroic rocks dominate the Coldwell Peninsula, stretching from Red Sucker Cove in the east to Prisoner's Cove in the West. The body is approximately 7 km in length and 1.5 km at its widest point. Near Port Coldwell, the measurements of foliation, layering and sheeted, dike-like bodies indicate a steep dip towards the north.

Based on mineralogical and textural criteria, the alkaline gabbro can be subdivided into 4 subunits: 1) biotite gabbro with tabular feldspar; 2) biotite-olivine gabbro to olivine-clinopyroxene leucogabbro; 3) heterogeneous enclave-rich biotite-olivine and biotite-clinopyroxene gabbro; and 4) heterogeneous breccia zones composed of microgabbroic enclaves with lobe and cuspate margins within a matrix of amphibole nepheline syenite. The first 3 subunits may represent rocks most closely associated with a gabbroic parent. The last subunit may represent contemporaneous gabbroic and syenitic magmatism that occurred following emplacement of the first 3 subunits.

The biotite gabbro with tabular feldspars occurs near Lone Pine Point near Port Coldwell. The rock is composed of approximately 60% plagioclase; 25% prismatic, green clinopyroxene; 10% large poikilitic, brown biotite; and 5% olivine with iron oxide alteration and accessory magnetite. The tabular plagioclase feldspars are generally foliated approximately east to west. Locally, this unit displays rhythmic modal layering at 10 cm intervals. This unit also occurs as angular enclaves within nepheline-natrolite acicular amphibole syenite. Enclaves range in size from submetre to outcrop scale.

Biotite-olivine gabbro to olivine-clinopyroxene gabbro occurs in distinctive tabular bodies of alternating gabbroic composition. Individual bodies display a consistent width varying from 10 to 15 cm and are generally traceable over several metres. Two compositionally different gabbroic rock types produce a distinctive weathering profile. The more easily weathered type is coarse-grained, green olivine-rich gabbro containing 45% olivine partially altered to iron oxides; 40% interstitial plagioclase; 10% prismatic, green clinopyroxene; and 5% poikilitic, brown biotite. The harder lithology is a coarse-grained, dark grey to black biotite gabbro composed of 55% prismatic plagioclase; 20% prismatic, green clinopyroxene; 10% black equant amphibole; 10% poikilitic, brown biotite; and 5% olivine partially altered to iron oxides. Locally, the biotite gabbro cuts the olivine-rich gabbro. The distinctive occurrence of this unit may be the result of the biotite gabbro intruding the olivine-rich gabbro.

The heterogeneous, enclave-rich, biotite-olivine gabbro and biotite-clinopyroxene gabbro to leucogabbro unit has a very distinctive highly pitted weathered surface. Centimetre- to decimetre-scale pits are produced by the differential weathering of mafic enclaves from the syenitic matrix. The enclaves vary in composition from biotite-olivine gabbro to biotite-clinopyroxene gabbro to leucogabbro. The matrix is a fine- to coarse-grained nepheline syenite, with minor natrolite, acicular amphibole and poikilitic biotite. Rare blebs of fine-grained pyrite are found within this unit. In general, the enclaves are rounded, fine to medium grained and compose 80 to 95% of the rock. Locally, elongated enclaves are weakly aligned. The enclave-rich unit cuts the tabular structures in subunit 2.

Heterogeneous breccia zones represent the most predominant unit within the Coldwell Peninsula area. The breccia zones consist of microgabbroic enclaves, generally with lobe and cuspate margins, within a matrix of nepheline-natrolite-acicular amphibole syenite. The enclaves range from aphanitic to fine-grained gabbroic rocks with approximate modes of plagioclase 60%, clinopyroxene 30% and olivine 10%. Some enclaves show clinopyroxene alteration to amphibole suggesting hydration reactions. Locally, microgabbroic enclaves compose up to 75% of the rock, although 20 to 30% is typical. In several localities, enclaves occur in elongated trains, a morphology suggestive of disrupted dikes.

RECRYSTALLIZED AMPHIBOLE QUARTZ SYENITE

The recrystallized amphibole quartz syenite appears to represent the first major phase of syenite magmatism within the Port Coldwell alkalic complex. It outcrops in an area 2 km wide and 14 km long, extending from Coubran Lake to Detention Island in Lake Superior. The recrystallized amphibole quartz syenite is bounded, to the west, by a sharp vertical contact with alkaline gabbro and heterogeneous amphibole nepheline syenite and, to the east, by basaltic xenoliths of the roof pendant, feldspar porphyritic amphibole syenite and monzodiorite. The recrystallized amphibole quartz syenite intrudes the basaltic xenoliths and is intruded by the feldspar porphyritic amphibole syenite.

The recrystallized amphibole quartz syenite is typically red and contains medium-grained, anhedral feldspar, quartz and alkali amphibole forming a granular texture. Locally, the syenite has feldspar and/or amphibole phenocrysts, with a fine- to medium-grained groundmass. The granular texture is considered to be a result of recrystallization caused by the later intrusion of syenite.

IRON-RICH AUGITE SYENITE

The iron-rich augite syenite outcrops over an area of approximately 150 km^2 and dominates the eastern half of the Port Coldwell alkalic complex, occurring between the Eastern Gabbro and the basaltic xenoliths of the roof pendant. (The name iron-rich augite replaces ferroaugite for the clinopyroxene of Moroimoto 1989). Smaller units of this rock type also occur west of the Little Pic River, as inclusions in the amphibole quartz syenite east of the Little Pic River and along the Little Pic River south of where the trend of the river changes from southwest to south.

The iron-rich augite syenite appears to be a low-angle sheet-like intrusion, which dips approximately 15° toward the centre of the complex. It intrudes the basaltic xenoliths of the roof pendant and the Eastern and Western Gabbro, and it has inclusions of recrystallized amphibole quartz syenite. A variation in mineralogy from the bottom to the top through the sheet is present and consists of: fayalite-iron-rich, augite-magnetite syenite; iron-rich augite syenite; fayalite-iron-rich augite syenite; and amphibole syenite.

The fayalite, magnetite-bearing iron-rich augite syenite, which occurs at the base of the intrusion, is black, mesocratic to melanocratic with cumulus fayalite, iron-rich augite and magnetite.

Iron-rich augite syenite, which forms the majority of the intrusion, typically contains iridescent tabular to lath-shaped feldspars with cryptoperthitic intergrowths and up to 30% interstitial, iron-rich augite. Variable amounts of fayalite, amphibole, aenigmatite and rare quartz occur in the subunit. The rock is generally black to olive-brown, coarse grained and massive. In the basal and central parts of the sheet, layering defined by higher proportions of interstitial mafic minerals is present. Layering dips at 25° to 45° toward the centre of the complex.

Stratigraphically above the iron-rich augite syenite is an irregular zone of fayalite-iron-rich augite syenite. Texturally this is similar to the iron-rich augite syenite, but the rock has significantly more fayalite, is coarser grained and is locally pegmatitic.

At the top of the sheet, below the basaltic xenoliths, is a red to pink, mesocratic amphibole syenite.

FELDSPAR PORPHYRITIC AMPHIBOLE SYENITE

Feldspar porphyritic amphibole syenite occurs west of the iron-rich augite syenite and east of the recrystallized amphibole quartz syenite. It hosts large blocks of basaltic xenoliths, up to 1 km in size, and is closely related to rare metal-bearing pegmatites. In most places, the feldspar porphyritic amphibole syenite occurs as an irregular-shaped intrusion below the basaltic xenoliths and is above the iron-rich augite syenite. The feldspar porphyritic amphibole syenite has extensively assimilated the inclusions of basaltic xenoliths and monzodiorite. Pegmatites, which appear to have originated from the feldspar porphyritic amphibole syenite, occur along fractures within the basaltic xenoliths and at the contact between the feldspar porphyritic amphibole syenite and iron-rich augite syenite.

The feldspar porphyritic amphibole syenite characteristically contains 2 textural variants: 1) a feldspar porphyritic amphibole syenite with an aphanitic to medium-grained groundmass and interstitial amphibole; and 2) a later intrusion of medium-grained amphibole syenite with columnar feldspar and interstitial amphibole. Although distinct contacts can be observed between the 2 textural end members, the textural change in places is also gradational. The gradation between textures and the similar whole rock and mineral chemical compositions between these 2 subunits is considered to indicate that the differences between the 2 are a function of rates of cooling; the feldspar porphyritic rock cooling faster than the nonporphyritic rock.

MONZODIORITE DIKES

Monzodiorite dikes were seen cutting the Western Gabbro, feldspar porphyritic amphibole syenite and iron-rich augite syenite. The dikes are 1 to 5 m wide with sharp near-vertical contacts. The dikes weather easily and form continuous lineaments up to 2 km long. They are medium grained, pinkish black and subophitic with amphibole, clinopyroxene and plagioclase rimmed by potassium feldspar.

AMPHIBOLE NEPHELINE SYENITE

There are 2 areas of amphibole nepheline syenite within the Port Coldwell alkalic complex: 1 centred over Pic Island and the other between Little Pic River and Red Sucker Cove within the western part of the complex. Both areas are typified by a texturally variable suite of syenite types with gradational contacts. The variation is complicated by brecciation and assimilation resulting from the intrusion of a second phase of heterogenous amphibole nepheline syenite and later amphibole quartz syenite.

The amphibole nepheline syenite is white to black, medium grained with variable proportions of nepheline, amphibole, biotite, apatite and zeolites. Locally, the nepheline syenite is well layered with melanocratic nepheline syenite grading into mesocratic syenite. The melanocratic layers locally contain olivine.

At the margins of the main nepheline syenite unit are additional textural varieties of nepheline syenite. These textural varieties include a white to pink mesocratic nepheline-amphibole syenite with stubby euhedral-amphibole prisms and white to pink, mesocratic nepheline syenite with interstitial amphibole and euhedral lath to columnar feldspar.

HETEROGENEOUS AMPHIBOLE NEPHELINE SYENITE

A second phase of heterogeneous amphibole nepheline syenite intrudes the nepheline syenite described in the previous paragraph and exhibits a variety of textures. These result from brecciation and assimilation of older nepheline syenite and alkaline gabbro. Further complexity is a result of mixing with mafic magma.

COARSE-GRAINED AMPHIBOLE QUARTZ SYENITE

The coarse-grained amphibole quartz syenite occurs sporadically between Little Pic River and Red Sucker Cove. On Pic Island, amphibole quartz pegmatites, apparently derived from this unit, cut the amphibole nepheline syenite. As a result, the coarse-grained amphibole quartz syenite is considered to be part of the late stage intrusion of amphibole quartz syenites into the complex.

The coarse-grained amphibole quartz syenite is distinguished from the other syenites based on the coarse grain size with poorly aligned tabular-feldspar phenocrysts, which are up to 3 cm long with interstitial amphibole and quartz blebs. The rock is typically massive, but locally exhibits layering defined by the relative abundance of interstitial amphibole.

AMPHIBOLE QUARTZ SYENITE

Amphibole quartz syenite outcrops primarily between the west contact of the complex and Red Sucker Cove. The basaltic xenoliths, Western Gabbro, alkaline gabbro, iron-rich augite syenite, amphibole nepheline syenite and heterogeneous amphibole nepheline syenite all occur as blocks from less than 1 m to over 1 km in size at the top of the amphibole quartz syenite. The contacts of these blocks are brecciated and exhibit a range of textures from angular to very delicate serrated outlines.

The amphibole quartz syenite is typically olive-brown to pink, leucocratic and massive, with interstitial amphibole, quartz and equant string perthite. Variations appear to be a result of a succession of magma pulses during intrusion, variable cooling rates and hybridization through assimilation (Lukosius–Sanders 1988). The first phase of amphibole quartz syenite is medium grained, massive and mesocratic. This phase is intruded by a medium- to fine-grained, leucocratic amphibole quartz syenite. Both these types are then intruded by a fine-grained leucocratic quartz syenite and a series of leucocratic amphibole quartz syenite and aplitic dikes. This sequence of rock is best displayed along the northwest shore of Pic Island. A trachytic quartz syenite with tabular feldspars may be associated with the outer margin of the amphibole quartz syenite. Commonly, it defines a well-developed trachytic texture, which strikes between 3° and 49°, and dips up to 45°S.

PYROXENE-AMPHIBOLE QUARTZ-BEARING PEGMATITE

Quartz-bearing pegmatites typically occur in all the saturated to oversaturated rock types except the amphibole quartz syenite and coarse-grained amphibole quartz syenite. The pegmatites range from small irregular-shaped patches, to well-developed dikes with sharp contacts, up to 4 m wide. Acicular amphibole is commonly oriented perpendicular to the contact of the pegmatite and is intergrown with feldspar. Feldspar is the most common mineral, occurring as grains up to 25 cm long and 5 cm wide. The grain size of the pegmatites ranges from medium to very coarse. Although quartz is present in crystals up to 8 cm long, it is not an abundant mineral in most of the pegmatites.

The quartz-bearing pegmatites host niobium, yttrium, zirconium and rare earth element mineralization. Rare-metal mineralization in the quartz-bearing pegmatites is commonly associated with medium-grained granular patches rich in quartz, calcite and hematite, which are interstitial to the very coarse-grained feldspar and amphibole. Preliminary research suggests that the paragenetic sequence in the pegmatites appears to be: feldspar and clinopyroxene; quartz, zircon, columbite and pyrochlore; and bastnaesite and synchysite. The different rare metal occurrences with analyses of grab samples are summarized in Table 19.2.

AMPHIBOLE NATROLITE-BEARING PEGMATITE

The natrolite pegmatites host a diverse suite of minerals and textures. A common characteristic is the occurrence of natrolite, which usually makes up 10 to 40% of the pegmatite. Feldspars and amphibole are very coarse grained, up to 20 cm long and 10 cm wide and range in texture from stubby to acicular. A large natrolite pegmatite body, almost 2 km long and 200 m wide, occurs along Highway 17, west of Little Pic River, where it cuts Western Gabbro. Typically, pegmatites are less than 10 m wide and less than 50 m long.

Prior to the present study, there had been no documented rare metal occurrences in the amphibole-natrolite pegmatites. The elements concentrated in the natrolite pegmatites are similar to those in the quartz-bearing pegmatites and are predominantly niobium, zirconium and rare earths. The 2 occurrences (Mink Creek and Middleton) and their geochemical results are summarized in Table 19.2.

LAMPROPHYRES

Lamprophyre dikes, ranging in size from 10 cm to 3 m wide, are observed throughout the Port Coldwell alkalic complex. The most common type of lamprophyre is fine grained, black to green with calcite and locally quartz ocelli. Other types of lamprophyre were distinguished based on the presence of clinopyroxene or biotite phenocrysts. The lamprophyres cut all the rock units and appear to be less abundant east of Red Sucker Cove. Black, olivine porphyritic lamprophyre appears to be associated with the intrusion of heterogeneous amphibole nepheline syenite into amphibole nepheline syenite. The contacts of the dike are sharp, with the olivine porphyritic phase occurring within the central part of the dike, net veined by the heterogeneous amphibole nepheline syenite. Results of detailed mineralogical and chemical investigations of lamprophyres in the Port Coldwell alkalic complex were recently reported by Mitchell et al. (1991).

EMPLACEMENT OF THE PORT COLDWELL ALKALIC COMPLEX

Magmatism within the Port Coldwell alkalic complex occurred within 3 centres, referred to as Centre 1, 2 and 3 by Mitchell and Platt (1977, 1978). Basaltic xenoliths, miarolitic cavities and porphyritic rock types occur at the present erosional level, indicating that the magmas forming each of the Centres was emplaced at low pressure. In such an environment, processes such as caldera subsidence, ring-dike emplacement and stoping are important processes controlling the emplacement of magma.

The extrusion and preservation of the basaltic xenoliths may have been controlled by the process of caldera collapse. During the collapse, the Eastern and Western Gabbro intruded as ring dikes into faults around the margin of the caldera. Caldera collapse and ring-dike intrusion may also be the process controlling the intrusion of the alkaline gabbro and heterogeneous amphibole nepheline syenite. These ring dikes define the outer margin of Centre 2 magmatism and are coincident with the Red Sucker Cove and Little Pic River lineaments. Caldera subsidence and ring dikes do not appear to be related to the intrusion of Centre 3.

Table 19.2. Form, mineralogy and analyses summarized for each of the rare-metal occurrences. Analyses of grab samples by XRF and neutron activation analysis, Department of Geology, University of Western Ontario. Data from assessment files, Ministry of Northern Development and Mines, Thunder Bay.

Occurrence	Port Munro	Marathon Niobium	Ypres Point	Carden Cove		Peninsula Hill	Marathon REE	Mink Creek	Loon Lake	Middleton
Samp. #	GS91-181	GS91-230	EW91-423 and 422	EW91-414		EW91-332	EW91-321	EW91-166	EW91-304	
Description	Pegmatite 1 m wide and 900 m long, occupying a near-vertical fracture hosted in the metabasalt.	Pegmatite 1.5 m wide and 1000 m long, occupying a near-vertical fracture hosted in the metabasalt.	Pegmatite dikelet hosted in recrystallized amphibole quartz syenite.	Two pegmatites, one is a 10cm wide pegmatite occupying dip, a near-vertical fracture, and the other is a dikelet. Both are hosted in diabasic gabbro.		Pegmatite 0.5 m wide with a shallow hosted in iron-rich augite syenite.	Irregular shaped pegmatite hosted in the Eastern Gabbro.	Irregular shaped pegmatite hosted in amphibole nepheline syenite.	Massive amphibole quartz syenite, approximately 1 km by 1 km	Irregular fine-grained patch (1 m) within in a very coarse-grained natrolite pegmatite that is 200 m by 1.5 km long.
Minerals Hosting Rare Metals	pyrochlore columbite bastnaesite synchysite	pyrochlore columbite				columbite bastnaesite synchysite	bastnaesite synchysite	bastnaesite synchysite	rare earth phosphates	
Analytical Results (ppm)				Dikelet	Frac.					
Nb	3248	3575	*0.60	3476	5304	3492	1383	4697	667	1523
Zr	15610	10500		12955	8972	10485	4482	7908	1960	6929
Y	1296	173		884	1167	1685	1349	1131	256	45
La	2533	726		1515	2387	2295	2397	3081	489	139
Ce	4448	1260		2955	4169	3311	4314	5197	939	253
Nd	1364	402		1073	1399	1298	1610	1477	401	109
Sm	196	47		169	210	227	278	225	50	28
Eu	21			17	17	24	28	17	3	0.7
Tb	34	6				46		33	6	5
Yb	109	24		87	84	161	104	160	27	13
Lu	15	4		12	12	22	14	16	4	3
Ta	119	143		134	75	164	81	129	29	62
Hf	326	307		271	207	257	141	227	40	184
Th	436	101		1293	2423	2137	5404	960	126	61
U	90	134		160	299	117	145	149	24	291

Large- and small-scale block faulting, caused by the stoping of roof rocks into intrusive magma from each Centre, has resulted in extensive assimilation of the roof rocks and hybridization of the magmas near the roof. This process is important in the intrusion of Centre 1 feldspar porphyritic amphibole syenite into the basaltic xenoliths and the intrusion of the Centre 3 amphibole quartz syenite into both the Centre 1 and 2. It appears that the present erosional level corresponds to the top of Centre 3, which hosts xenoliths of Centre 1 and 2 rocks less than 1 m to over 1 km in size.

ECONOMIC GEOLOGY

Base and Precious Metal Mineralization

Base and precious metal mineralization in the Eastern Gabbro is generally located near the contact of the gabbro with Archean metavolcanic rocks. The Dunlop Copper occurrence is exposed in the Eastern Gabbro along Highway 17 approximately 100 m from the contact of the Eastern Gabbro with Archean metavolcanic and metasedimentary rocks. The occurrence is within massive gabbro, which contains numerous xenoliths of Archean rocks and rheomorphic breccia. The gabbro is coarse grained with plagioclase, clinopyroxene, olivine, magnetite, biotite and traces of apatite and up to 5% chalcopyrite. The intersection of sulphide-rich inclusions in the drill core of Noranda Exploration Limited indicates that assimilation of sulphur-rich Archean rocks is a viable mechanism for generating the mineralization.

The Marathon copper-platinum group element (PGE) occurrence of Fleck Resources Limited is located, south of Bamoos Lake in the Two Duck Lake area, within gabbroic rocks close to the east contact of the gabbro with Archean metavolcanic rocks. Copper-PGE mineralization consists of chalcopyrite, cubanite, pyrrhotite, pentlandite and pyrite and occurs in the coarse-grained Two Duck Lake gabbro (Good and Crocket 1989, 1990). PGEs are associated with the copper-rich sulphides in the gabbro (Ohnenstetter et al. 1989). Sulphides are commonly associated with biotite and with minor amphibole and chlorite in the Two Duck Lake gabbro (Good and Crocket 1989, 1990). Sulphides also occur interstitial to fresh anhydrous silicates. The close association of mineralization with gabbro occurring near the contact with Archean rocks suggests that mineralization may be related to assimilation of Archean sulphide-bearing rocks (Watkinson et al. 1983).

Base and precious metal mineralization also occurs associated with pegmatitic gabbro, south of Geordie Lake, within the central part of the complex. Grab samples of the pegmatitic gabbro assayed 0.23 and 0.17% Cu, 1100 and 2100 ppb Pd. Mineralization at Geordie Lake is distinct from the Eastern Gabbro in that the former contains high palladium relative to platinum (Pd/Pt = 19) and tellurides (Mulja and Mitchell 1991).

The Middleton copper occurrence is a chalcopyrite-rich zone with up to 0.73% Cu, hosted in the medium-grained Western Gabbro near the contact with Archean rocks. Unlike the Geordie Lake and Eastern Gabbro occurrences, the pegmatitic gabbro in the Western Gabbro does not have any base or precious metal mineralization, and the main sulphide zone does not have any significant platinum or palladium mineralization.

A 1 m wide quartz vein with sphalerite and galena was discovered during the 1991 mapping program. It is hosted in the alkaline gabbro, located along the Lake Superior shoreline at Lone Pine Point, south of Port Coldwell. The mineralization consists of massive sphalerite and galena as veinlets within a north-northwest-striking, fine-grained, granular, milky white quartz vein. A grab sample assayed 10.4% Zn and 1.55% Pb. This is the first reported occurrence of base metal mineralization in the alkaline gabbro.

Rare Metals

Based on the classification system of Černý (1991), the rare metal occurrences of the Port Coldwell alkalic complex are of the rare earth type of the niobium, yttrium and fluorine family. They are further divided into 4 subtypes: 1) niobium, zirconium rare earth pegmatites; 2) rare earth, thorium pegmatites; 3) niobium, zirconium, rare earth quartz-absent pegmatites; and 4) rare earth phosphate-bearing amphibole quartz syenite. The various occurrences with representative analyses are summarized in Table 19.2.

The Port Munroe, Marathon niobium, Carden Cove and Peninsula Hill occurrences are niobium, zirconium, rare earth pegmatites. They are located in and around the basaltic xenoliths, and associated with the intrusion of the feldspar porphyritic amphibole syenite. Rare metal mineralization is in the form of pyrochlore, columbite, bastnaesite and synchysite. The pyrochlore and columbite occur with quartz and zircon after the crystallization of perthite and aegirine. Rare earth elements are associated with a late-stage carbonate phase that crystallized bastnaesite and synchysite with pyrochlore.

The Marathon REE occurrence is a rare earth, thorium pegmatite, which intrudes the Eastern Gabbro, located along Highway 17. Typically, it consists of green feldspar, quartz, carbonate, fluorite and graphic feldspar. Rare earth elements occur in bastnaesite and synchysite, and thorium occurs in thorite. The Marathon REE occurrence was located using airborne radiometric data (Ford, Geological Survey of Canada, personal communication, 1991). Two other pegmatite dikes were located using the results from the radiometric survey. Samples of these pegmatites have been sent for analysis.

The Mink Creek and Middleton occurrence is made up of niobium, zirconium and rare earth quartz-absent pegmatites hosted in amphibole nepheline syenite. Rare metal hosting minerals identified to occur in the Mink

Creek pegmatite are pyrochlore, bastnaesite and synchysite. Unlike the other 2 subtypes of rare metal mineralization, these pegmatites may have a horizontal distribution related to the amphibole nepheline syenite, instead of being controlled by vertical structures in overlying rocks.

The fourth subtype of rare metal mineralization is hosted in massive fine-grained amphibole quartz syenite. The analyses from the Loon Lake occurrence are not as high as the other types of pegmatites; however, this unit has a much greater areal distribution than the pegmatites. The rare metals are hosted in rare earth phosphates, which crystallize after quartz. Pegmatites hosted in the amphibole quartz syenite, up to 1 m wide and 75 m long, were sampled and are being analyzed.

The majority of the rare metal occurrences are in pegmatites that are associated with the intrusion of amphibole syenite between the iron-rich augite syenite and the basaltic xenolith roof pendant. The accumulation of pegmatitic fluids within cupolas at the base of the roof pendant are considered to have high potential for a rare metal orebody in the complex.

Building Stone and Industrial Minerals

Easily accessible syenite rocks with a variety of textures and colours may be suitable for small-scale building stone projects in several of the rock units. Areas adjacent to Highway 17 and the Canadian Pacific Railroad were observed to have consistent texture and colour with limited fracturing.

The nepheline syenites within the Port Coldwell alkalic complex have been examined by Denison Mines Limited in 1960 as a potential source for nepheline. The results indicated that the nepheline had too high an iron content to be of economic value (Puskas 1967). This may be due to zeolite and hematite crystallization in the nepheline syenites during postcrystallization alteration.

Based on the results of the present study, nepheline occurs in 2 different units; amphibole nepheline syenite and heterogeneous amphibole nepheline syenite. The distribution of these rock types has been outlined, and samples of each of the different varieties have been taken by the Resident Geologist's Office in order to determine the modal abundance of nepheline in the rocks. It is anticipated that with the analytical results, it will be possible to isolate the areas that are the best targets for evaluating the potential of nepheline as an industrial mineral within the Port Coldwell alkalic complex.

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REFERENCES

Cannon, W.F., Green, A.G., Hutchinson, D.R., Myung, L., Milkereit, B., Behrendt, J.C., Halls, H.C., Green, J.C., Dickas, A.B., Morey, G.B., Sutcliffe, R.H. and Spencer, C. 1989. The North American midcontinent rift beneath Lake Superior from GLIMPCE seismic reflection profiling; Tectonics, v.8, p.305-332.

Černý, P. 1991. Rare-element granitic pegmatites. Part 1: Anatomy and internal evolution of pegmatite deposits; Geoscience Canada, v.18, p.68–81.

Good, D.J. 1992. Genesis of copper-precious metal sulphide deposits in the Port Coldwell Alkalic Complex, Ontario; unpublished PhD thesis, McMaster University, Hamilton, Ontario, 203p.

Good, D.J. and Crocket, J.H. 1989. PGE study of the Geordie Lake and Marathon Cu-Ni precious metal deposits, Coldwell Alkalic Complex; *in* Geoscience Research Grant Program, Summary of Research 1988–1989, Ontario Geological Survey, Miscellaneous Paper 143, p.186–198.

——— 1990. PGE study: The MacRae and Marathon copper-precious metal deposits, Coldwell Complex; *in* Geoscience Research Grant Program, Summary of Research 1989–1990; Ontario Geological Survey, Miscellaneous Paper 150, p.87–96.

Gupta, V.K. 1991. Shaded image of total magnetic field of Ontario, east-central sheet; Ontario Geological Survey, Map 2586, scale 1:1 000 000.

Heaman, L.M. and Machado, N. 1992. Timing and origin of midcontinent rift alkaline magmatism, North America: evidence from the Coldwell Complex; Contributions to Mineralogy and Petrology, v.110, p.289–303.

Lukosius–Sanders, J. 1988. Petrology of syenites from Centre III of the Coldwell Alkaline Complex, northwest Ontario; unpublished MSc thesis, Lakehead University, Thunder Bay, Ontario, 110p.

Milne, V.G. 1967. Geology of the Cirrus Lake–Bamoos Lake area; Ontario Department Mines, Geology Report 43, 58p.

Mitchell, R.H. and Platt, R.G. 1977. Field guide to aspects of the geology of the Coldwell alkaline complex; 23rd Annual Meeting, Institute on Lake Superior Geology, 34p.

——— 1978. Mafic mineralogy of ferroaugite syenite from the Coldwell Alkaline Complex, Ontario, Canada; Journal of Petrology, v.19, p.627–651.

Mitchell, R.H., Platt, R.G., Downey, M. and Laderoute, D.G. 1991. Petrology of alkaline lamprophyres from the Coldwell alkaline complex, northwestern Ontario; Canadian Journal of Earth Sciences, v.28, p.1653–1663.

Moroimoto, N. 1989. Nomenclature of pyroxenes; Mineralogy and Petrology, v.39, p.55–76.

Muir, T.L. 1982. Geology of the Heron Bay area, District of Thunder Bay; Ontario Geological Survey, Geoscience Report 218, 89p.

Mulja, T. and Mitchell, R.H. 1991. The Geordie Lake Intrusion, Coldwell Complex, Ontario: A palladium- and telluriium-rich disseminated sulphide occurrence from an evolved tholeiitic magma; Economic Geology, v.56, p.1050–1069.

Ohenstetter, D., Watkinson, D.H. and Dahl, R. 1989. Platinum group minerals from the Two Duck Lake intrusion, Coldwell Complex, Canada; Bulletin of the Geological Society of Finland, v.61, p.28.

Puskas, F.P. 1967. The geology of the Port Coldwell area, District of Thunder Bay; Ontario Department of Mines, Open File Report 5014, 114p.

Walker, E.C., Sutcliffe, R.H., Shaw, C.S.J. and Shore, G.T. 1991. Geology of the Coldwell Alkaline Complex; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.107–116.

Walker, J.W.R. 1967. Geology of the Jackfish–Middleton area; Ontario Department of Mines, Geology Report 50, 41p.

Watkinson, D.H., Whittaker, P.J. and Jones, P.L. 1983. Platinum group elements in the eastern gabbro, Coldwell Complex, northwestern Ontario; *in* Geoscience Research Grant Program, Summary of Research 1982–1983, Ontario Geological Survey, Miscellaneous Paper 96, p.183–191.

Wilkinson, S.J. 1983. Geology and sulphide mineralization of the margin phases of the Coldwell complex, northwestern Ontario; unpublished MSc thesis, Carleton University, Ottawa, Ontario, 125p.

Sedimentary and Environmental Geoscience Programs

20. Summary of Activities 1992, Sedimentary and Environmental Geoscience Section

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INTRODUCTION

The Sedimentary and Environmental Geoscience Section of the Geoscience Branch, Ontario Geological Survey has the mandate to investigate Phanerozoic age materials and sediments within the province. Activities undertaken include mapping of Paleozoic age rocks and Quaternary sediments; assessment of the mineral resource potential contained therein (such as sand and gravel, limestone, peat, salt, gypsum, etc.), investigation of past and current geological processes which affect the occupation and use of the land, and defining the physical properties or geochemical signature of the landscape.

The Section was formed by adding geochemical, geophysical and hydrogeological positions to the former Engineering and Terrain Geology Section. As currently structured, the Sedimentary and Environmental Geoscience Section consists of 2 subsections, Exploration and Environmental, each headed by a supervisor. In recognition of the fact that programs undertaken by either group need a range of skills, staff trained in a variety of disciplines are represented in both subsections. Staff with expertise in geochemistry, Paleozoic and Quaternary geology are present in each subsection. Hydrogeological and geophysical positions exist within the Environmental Subsection only, while industrial mineral and aggregate staff are unique to the Exploration Subsection.

It is intended that the organizational structure will allow a large degree of flexibility in the formation of multidisciplinary work groups or project teams. Should workload pressures require additional geochemical expertise on environmental projects, for example, the geochemist from the Exploration Subsection could be assigned to assist with the completion of these projects.

The relocation this year of the Geoscience Branch, Ontario Geological Survey to Sudbury from Toronto combined with its reorganization have had a major effect on the Section in that a large number of staff vacancies currently exist. The most notable effect of these vacancies was the limited number of field-based projects conducted by Section staff in 1992. This was offset to a large degree by: 1) the hiring of contract staff to assume projects formerly assigned to departed staff; and 2) the use of consultants to undertake specialized field-based surveys and research projects. The results of these actions have been the completion of several outstanding reports and maps and the creation of new geological databases.

ENVIRONMENTAL PROGRAM

The environmental program of the Section reported on in this volume is concentrated in southern Ontario, specifically the Greater Toronto Area and surrounding regions. Two field parties, each focussing on a different aspect of the surficial geology, were at work in the "greater" GTA area.

Dr. P.J. Barnett commenced work on the Oak Ridges moraine, a glacial feature that is at the centre of much public debate. The objectives of this project are 1) define the moraine through mapping; and 2) gain an understanding of how it was constructed. Results of this study will provide information that will be of value in formulating land use decisions. The surficial data base being created will allow for informed planning decisions to be made on a variety of matters currently affecting the moraine including urban development, aggregate extraction and the establishment of recreational areas.

An aggregate inventory of Haldimand and Alnwick townships, located at the eastern end of the Oak Ridges moraine south of Rice Lake, was also completed this past year. Although this project is not reported on in this volume, the results of the study have been released as Aggregate Resources Inventory Report 143. The information produced on location, quality and quantity of mineral aggregates in the townships was of significant importance in the drafting of Official Plan documents.

EXPLORATION PROGRAM

Exploration-related projects were operative in 4 areas in northern Ontario and 1 in southern Ontario. These projects were designed to provide data bases which will assist in mineral appraisal and evaluation.

A.F. Bajc began a mapping and drift sampling program in the north and east rims of the Sudbury Basin. The project, a co-operative effort with the Geological Survey of Canada, will provide a framework for mineral exploration using Quaternary sediments. In addition, the project will yield data on the geochemical behaviour of Ni-Cu-PGE in the surficial environment. The fact that the project area is situated in an area affected by decades of mining and smelting activity also allows the anthropogenic effects of this activity on the environment to be evaluated.

Quaternary mapping and drift sampling were completed by T.F. Morris in the Separation Lake area north of Kenora. This project is part of an integrated geoscience approach to assessing the geology of the local greenstone belt. The reconnaissance sampling completed this year will provide a baseline geochemical data set. Lines on which detailed sampling was conducted will serve as pilot projects for follow-up surficial sampling. The location of future detailed sampling is to be determined on the basis of Precambrian mapping in the area.

Paleozoic mapping in the area east of Lake Simcoe, southern Ontario resumed and is reported on by Armstrong and Anastas. This mapping program will provide an up-to-date geoscientific data base on the rocks in the area. Particular attention is being paid to defining the stratigraphic position and lateral extent of alkali-reactive beds. This information will allow alkali-reactive beds to be avoided in operating quarries; and future quarries to be sited with a knowledge of the position and thickness of deleterious beds. The mapping will also provide data which will contribute to reasoned and informed development and land use decisions. Planning and environmental pressures are on the rise in the area due to, among other things, the number of proposed bedrock quarries.

The Sedimentary and Environmental Geoscience Section managed 2 exploration-related projects funded under the federal-provincial Northern Ontario Development Agreement (NODA). C.A. Kaszycki began a geochemical sampling and surficial materials inventory in the Swayze greenstone belt southwest of Timmins. The project will: 1) define geochemical trends in the area, at a regional and local scale; and 2) assess the use of various fractions of the glaciogenic sediments in drift exploration. Sampling down-ice from known mineralization will provide data on the character of geochemical signatures associated with glacial dispersal in the area.

The second NODA project is an aggregate-industrial minerals inventory in the area between Blind River and Bruce Mines, east of Sault Ste. Marie. The first phase of the project will determine the distribution as well as the quality and quantity of mineral aggregates in the area. This project is been done by Dames and Moore Canada, under a contract with the OGS. Field work is reported on by Kristjansson and Kelly. As sources of aggregate in southern Ontario come under more pressure due to environmental and conflicting land use demands northern deposits may, potentially, play an important role in supplying southern markets.

APPLIED RESEARCH

Applied research projects undertaken by the Sedimentary and Environmental Geoscience Section are designed to: 1) develop methods of use in or to assist mineral resources exploration; or 2) determine geological processes which may affect occupation or use of the land base. The latter include the collecting geoscientific information on a range of environmental issues.

The radon soil gas survey conducted in 4 areas in southern Ontario was a pilot project designed to investigate geologic controls on the distribution and level of radon gas in the soil profile. Highlights of this project are reported on by Tilsley and Baker. Results in all test areas served this goal, however, the most interesting finding was the apparent relationship, in southwestern Ontario, between oil and gas fields and the radon soil gas. Initial results are currently being followed up by detailed surveys.

An investigation to define a fault along the Salmon River, east of Belleville, was completed by G.S. McFall. In order to confirm the location of the fault, which had been indicated by previous workers, a 5 hole drilling program supported by mapping was undertaken. The results will allow a better understanding of the tectonic history of the area.

Contained within the NODA section of this volume are 2 reports detailing results and observations obtained as part of the pilot project for the Geochemical Map of Ontario. Fortescue et al. present some initial results which indicate that low density sampling can define geochemical environments across the province. The field work conducted as part of this project also demonstrated the effectiveness of a Global Positioning System (GPS) unit to a well-planned field program. The details of how the GPS unit assisted helicopter-supported field work are reported on by Dyer and Fouts.

The planning and design of a mobile laboratory unit (MLU) was continued in 1992 under the direction of J.A.C. Fortescue. The MLU will add a new dimension to the geochemical capabilities of the Section, especially in the realm of water analyses. The rapid sample turnaround time provided by the MLU will be of benefit to both environmental- and exploration-type projects. Current plans call for the unit to be constructed by early 1993 with operational trials continuing in the remainder of the year.

21. Project Unit 88–36. Investigation of Faulting along the Salmon River, East-Central Ontario

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INTRODUCTION

The presence of a fault along the valley of the Salmon River in east-central Ontario has been indicated by workers such as Kay (1942), Liberty (1963) and Carson (1981a, 1981b). More recently, it has been suggested that the fault may be the northeastern extension (McFall and Allam 1990, 1991) of the seismically active (Fakundiny et al. 1978) Clarendon–Linden Fault system of western New York State and may possibly be part of a major suture zone in the North American craton (Culotta et al. 1990).

Previous investigations tended to be regional in scope and primarily concerned with delineating the stratigraphy and distribution of formations within the Black River and Trenton groups rather than on the structural geology of the area. The presence of a fault along the Salmon River valley has been brought into question as: 1) there is varying evidence for the presence or absence of stratigraphic displacement across the river valley, and 2) the actual fault plane(s) have not been documented. The Ontario Geological Survey, therefore, undertook a drilling program along the Salmon River in order to test for the presence of faulting.

The Salmon River valley is a 30 km long, almost straight surface feature that trends northeast from the village of Point Anne on the Bay of Quinte, 3 km east of Belleville, to the village of Croydon (Figure 21.1). Generally, the southeast side of the river valley is marginally higher and has a steeper slope than the northwest side which has several bedrock terraces of varying width.

PROGRAM

A total of 5 boreholes were drilled on alternating sides of the valley. Three boreholes were oriented vertically and 2 were inclined at 30° from vertical. The inclined holes were designed to: 1) intersect the steeply dipping to near vertical fractures that would constitute the fault, and 2) determine evidence for any movement. Additional information was also available from a stratigraphic test hole drilled at Melrose (D. Williams, Ministry of Transportation, personal communication, 1991) and a deep borehole drilled by Ontario Hydro at the Roblindale Quarry, near the village of Roblin (McKay 1987; McKay and Williams 1989). All of the boreholes penetrated at least 3 m into the Precambrian basement.

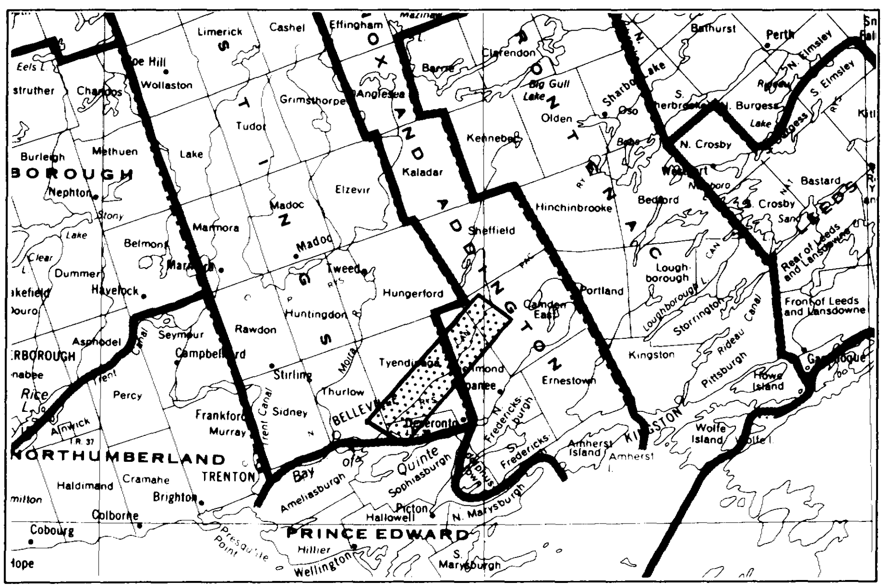

Figure 21.1. Location map of the study area, scale 1:1 584 000.

Concurrent with the drilling program, exposed Paleozoic rocks in the vicinity of the boreholes were examined; fracture orientations measured and geological observations documented.

BEDROCK GEOLOGY

The Paleozoic strata exposed in the Salmon River area of Hastings and Lennox and Addington counties are of Middle Ordovician age and consist of, in ascending order, the Shadow Lake, Gull River, Bobcaygeon and Verulam formations. These overlie the Precambrian rocks of the Sharbot Lake and the Elzevir terranes and the Robertson Lake mylonite zone of the Central Metasedimentary Belt, Grenville Province. The Robertson Lake mylonite zone is a brittle mylonite zone which separates the 2 terranes and was the locus of faulting in the Proterozoic (Easton 1988a, 1988b).

Inliers of the Precambrian basement have been identified on the northwest side of the Salmon River valley near the hamlet of Forest Mills (LeBaron and Williams 1990), near the hamlet of Kingsford and in the vicinity of the town of Shannonville near the mouth of the Salmon River. These inliers were interpreted by Kay (1942) and Liberty (1960) to be monadnocks.

The Shadow Lake Formation unconformably overlies the Precambrian basement and generally consists of a sequence of conglomerates, sandstones and shales, although it is not unusual for only part of the sequence to be present.

The Gull River Formation conformably overlies the Shadow Lake Formation although, locally, it rests directly upon the Precambrian basement. The Gull River Formation is subdivided into 2 members (Williams 1991); the lower member consists of alternating intervals of limestone and silty dolostone (grading into siltstone) with shaly partings and the upper member consists of thin-bedded limestones, commonly containing thin shale partings between the beds.

The Bobcaygeon Formation conformably overlies the Gull River Formation and is subdivided into 3 members (Liberty 1969). The primary distinction between members is the presence of numerous thin shaly partings between the limestone beds of the middle member with the lower and upper members being essentially shale free. The lower member consists of thick-bedded microcrystalline to fine-crystalline limestones intermixed with medium- to coarse-grained calcarenites and commonly contains nodules of hard, black chert. The chert nodules are rare or absent in the Salmon River area (Carson 1981a).

The Verulam Formation conformably overlies the Bobcaygeon Formation and consists of pale to dark brown and grey, medium- to coarse-grained bioclastic limestone interbedded with crystalline limestone and shale. The formation forms much of the bedrock surface south of the hamlet of Lonsdale except in the vicinity of the Salmon River valley where downcutting has exposed the underlying formations.

A variety of glacial and postglacial deposits occur in the vicinity and within the Salmon River valley (Leyland and Mihychuk 1983). Very stony till, known as "Dummer Till", occurs in discontinuous deposits along the northern segment of the river valley and on the surrounding limestone highlands. Rare glaciolacustrine deposits related to glacial Lake Iroquois also occur in this area and in the vicinity of Lonsdale, but are more extensive to the south and east. Limited glacial outwash deposits occur just south of Roblin and south of Forest Mills. Modern alluvium has been mapped within the river valley northeast of Roblin and southwest of Lonsdale.

PRELIMINARY RESULTS

In the vicinity of Roblin, the Bobcaygeon and Gull River formations are exposed in section along the township road and in the cliffs bordering the river. The strata are generally flat-lying or gently dipping at 3° to the southeast. As a result of the poor outcrop, only a small number of fractures were observed. The dominant fracture orientations are 029°/83°E and 121°/90°S with 051°/89°S being less common.

Although deformation was not noted in the exposures near the drill site, a small anticline was observed within the valley of the Salmon River just south of Roblin and both a buckle and a broad open anticline have been documented in the Roblindale Quarry (McKay 1987; McKay and Williams 1989) on the eastern bluff overlooking the river valley and Roblin.

A vertical borehole (OGS 90–16) was drilled at the Richmond Township dump site (latitude 44°22'02"N, longitude 77°01'40"W), less than 1 km southeast of Roblin and approximately on strike across the valley from the Ontario Hydro borehole. The drill hole started in the Bobcaygeon Formation at an elevation of 154.70 m above sea level (m asl), encountering the Precambrian-Paleozoic contact at 87.62 m asl, and terminating in the Precambrian at a depth of 74.6 m asl.

About 350 m to the south of the drill site, operations in a sand and gravel pit have exposed the bedrock cliff that forms the southeast side of the river valley. Slickensides, preserved by the overgrowth of calcite, were observed on the fracture surface trending 249°/76°NW. These slickensides were subhorizontal to pitching 7° toward the east and record sinistral movement.

In the Forest Mills area, the river valley walls consist of the Gull River Formation with the Shadow Lake Formation exposed at the valley wall and in the river bed. The strata are gently dipping toward the southeast and are highly fractured with 257°/76°N and 077°/81°S orientation being the most common trend and 052°/78°SE and 239°/61°NW being less common. Less than 200 m downstream, the bedding on the west side of the river valley dips 210°/09°W.

Borehole OGS 90–16C was drilled on a 70° angle toward the west and was situated within the river valley at Forest Mills (latitude 44°20'00"N, longitude 77°02'50"W). The borehole began in the Gull River Formation at 126.47 m asl and was continued to a depth of 22.2 m, terminating in the Precambrian basement. Very little Shadow Lake Formation was present, angular breccia zones were observed in the core and the Precambrian–Paleozoic contact occurred at 107.58 m asl.

Very few outcrops occur in the vicinity of Kingsford. On the southeast side of the river valley, a 500 m long roadcut, that is approximately perpendicular to the river, exposes the Bobcaygeon and Gull River formations in cross-section. The strata dip gently 2° to 3° to the southeast and the dominant fracture orientations are 276°/81°N and 228°/80°NW. Up to 18 narrow to moderately wide zones of intense fracturing striking 239°/85°NW were observed, but slickensides were very rare.

Two boreholes, OGS 90–16A and OGS 90–16B were drilled on opposite sides of the river valley at Kingsford. Located on the west side of the river, OGS 90–16A (latitude 44°17'55"N, longitude 77°05'30"W) was collared in the Bobcaygeon Formation at an elevation of 127.17 m asl and terminated at a hole depth of 62.4 m in the Precambrian. The second borehole, OGS 90–16B (latitude 44°17'23"N, longitude 77°05'15"W), was located to the east of the river. It was collared at 133.19 m asl in the Bobcaygeon Formation and terminated in the Precambrian at a depth of 77.7 m. The Precambrian–Paleozoic contact determined by these boreholes occurs at 65.61 m asl and 61.08 m asl, respectively. Small offsets of the bedding across fractures and slickensides on fracture surfaces were observed in the Paleozoic part of the cores recovered from these boreholes.

Bedrock outcrops are not common in the vicinity of the Salmon River where it is crossed by Wyman's Road just southeast of Lonsdale Station. On the southeast side of the river valley, a small roadcut exposes fractures trending 210°/90° with a 290°/89°NE trend being less common.

The second inclined borehole (OGS 90–16D) was drilled on the west side in the river valley at Wyman's Road (latitude 44°14'44"N, longitude 77°09'46"W). The borehole began at 96.61 m asl in the Gull River Formation and terminated in the Precambrian at a depth of 74.6 m. The Precambrian–Paleozoic contact in this location occurs at 26.96 m asl.

The elevation of the Precambrian–Paleozoic contact varies throughout the study area. At Kingsford, where the boreholes are located on strike on either side of the river valley, there is a 4.5 m difference in the elevation of the Precambrian surface. The dominant rock types encountered in the Precambrian were granitic gneiss and metasedimentary rocks with the amount of weathering of the Precambrian surface varying greatly.

One or more layers of an unconsolidated, pale grey material was encountered in several of the cores. This material could be gouge or thin (0.8 to 1.5 cm) layers of bentonite. Geochemical analysis to determine its composition and origin has not been undertaken.

CONCLUSION

The presence of a fault along the valley of the Salmon River was confirmed by both field mapping and drilling. In outcrop, the observation of deformation and fractures with slickensides on their surfaces indicates the presence of faulting. The presence of slickensides on fracture surfaces and zones of brecciation in the core support the field observations.

As only a cursory look at the Quaternary deposits in the vicinity of the Salmon River fault was conducted, it is uncertain whether movement has occurred on the Salmon River fault recently.

The Salmon River fault is collinear with a larger, regional fault system that cuts the Paleozoic strata (McFall and Allam 1990, 1991) and is spatially related to faulting in the Precambrian terranes (OGS 1991). This regional fault system is related to a major structural zone, or basement high, extending northeast from New York State to the Frontenac Axis (Forsyth et al. 1991; D.A. Forsyth, Geological Survey of Canada, personal communication, 1991). This zone may extend beyond these stated locations and may be part of a major suture zone (Culotta et al. 1990) in the eastern part of the North American Craton.

REFERENCES

Carson, D.M. 1981a. Paleozoic geology of the Kaladar–Tweed area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2411, Geological Series, scale 1:50 000.

——— 1981b. Paleozoic geology of the Belleville–Wellington area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2412, Geological Series, scale 1:50 000.

Culotta, R.C., Pratt, T. and Oliver, J. 1990. A tale of two sutures: COCORP's deep seismic surveys of the Grenville province in the eastern U.S. midcontinent; Geology, v.18, p.646–649.

Easton, R.M. 1988a. Geology of the Darling area, Lanark and Renfrew counties; Ontario Geological Survey, Open File Report 5693, 206p.

——— 1988b. Regional mapping and stratigraphic studies, Grenville Province with some notes on mineralization environments; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey Miscellaneous Paper 141, p.300–308.

Fakundiny, R.H., Pherd, J.W. and Pomeroy, P.W. 1978. Clarendon–Linden Fault System of western New York: longest (?) and oldest (?) active fault in eastern United States; Geological Society of America, Northwestern Section, 13th Annual Meeting, Abstracts with Programs, p.42.

Forsyth, D.A., Milkereit, B., Hinze, W.J. and Mereu, R.F. 1991. Crustal structures from the southwestern Grenville Province: features interpreted from reflection data in lakes Ontario, Erie and Huron; Geological Association of Canada–Mineralogical Association of Canada, Program with Abstracts, v.16, p.A38.

Kay, G.M. 1942. Ottawa–Bonnechere graben and Lake Ontario homocline; Geological Society of America Bulletin, v.53, p.585–646.

LeBaron, P.S. and Williams, D.A. 1990. Carbonate building stone resources of the Lake Simcoe–Kingston area, southeastern Ontario; Ontario Geological Survey, Open File Report 5730, 65p.

Leyland, J.G., and Mihychuk, M. 1983. Quaternary geology of the Tweed area, southern Ontario; Ontario Geological Survey, Map P.2651, scale 1:50 000.

Liberty, B.A. 1960. Belleville and Wellington map areas, Ontario; Geological Survey of Canada, Paper 60–31, 9p.

——— 1963. Geology of the Tweed, Kaladar and Bannockburn map-areas, Ontario; Geological Survey of Canada, Paper 63–14, 15p.

——— 1969. Paleozoic geology of the Lake Simcoe area, Ontario; Geological Survey of Canada, Memoir 355, 201p.

McFall, G.H. and Allam, A. 1990. Neotectonic investigations in southern Ontario: Prince Edward County, Phase I; Atomic Energy Control Board, Technical Report INFO 0343.

——— 1991. Neotectonic investigations in southern Ontario: Prince Edward County, Phase II; Atomic Energy Control Board, Technical Report, INFO 0343–2.

McKay, D.A. 1987. Roblindale Quarry stress measurements, preliminary evaluation, Phase I; Ontario Hydro Research Division Report 86–43–P, 143p.

McKay, D.A. and Williams, J.B. 1989. Roblindale Quarry stress measurements, preliminary evaluation, Phase II; Ontario Hydro Research Division Report 88–113–P, 90p.

Ontario Geological Survey 1991. Bedrock geology of Ontario, southern sheet, Map 2544, scale 1:1 000 000.

Williams, D.A. 1991. Paleozoic geology of the Ottawa–St. Lawrence Lowlands, Ontario; Ontario Geological Survey, Open File Report 5770, 291p.

22. Project Unit 90–25. Progress Report on the Mobile Laboratory Unit Development

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INTRODUCTION

The concept of a mobile laboratory unit (MLU), dedicated to the support of Ontario Geological Survey (OGS)–Geoscience Branch geochemical mapping, has been under development since 1989 (Fortescue 1991, 1990). This article summarizes progress with the MLU project during the past year.

CONFERENCE ATTENDANCE

To obtain up-to-date information on instruments and methodologies suitable for installation in the MLU, the author attended 2 meetings on inductively coupled plasma (ICP) spectrochemical analysis during the past year.

The first meeting was the 1992 Winter Conference on Plasma Spectrochemistry held in San Diego, California, in January 1992, and the second, a four-day ICP Spectrochemical Analysis Course held under the direction of Professor C.W. McLeod, at the Chemical Analysis Research Centre, Sheffield City Polytechnic, in Sheffield, England, in June.

In summary, at San Diego, there was general agreement among the scientists consulted that an MLU with an installed ICP designed to support geochemical mapping, on the scale envisaged, is technically feasible at this time. Critics of the MLU pointed out, however, that the installation of a large ICP mass spectrometer (ICP–MS) in a vehicle dedicated to geochemical mapping is probably not practical at this time. Consequently, serious consideration is currently being given to installing an optical emission ICP (ICP–OES) with a sixty-channel polychrometer (and a monochrometer) capable of measuring transient signals in the MLU. This instrument would be installed in the MLU initially with the option of retrofitting a later model ICP–MS instrument.

With respect to sample pre-processing, the importance of automated of "off-line" and/or "on-line" flow injection methodologies was stressed at both meetings. It was pointed out in Sheffield that the routine sample pre-processing methodologies, developed originally for an optical ICP, would be very similar to those required for an ICP–MS later on.

AN MLU DATA PROCESSING UNIT

The original OGS–MLU design included 2 components: 1) field sampling and 2) chemical processing. According to this plan, after field sampling had taken place, experienced geochemical mappers would be required for the preparation of geochemical broadsheets (and data diskettes) in Sudbury during the winter months.

In March 1992, A. Currie, Manager of the OGS Geoscience Data Centre, suggested that a small data processing unit included in the MLU could produce maps, charts, tables and diagrams required for regional geochemical map broadsheet production. This processing could be carried out as soon as the chemical data are produced by the MLU chemical laboratory at a field location. If this were done, it would: 1) reduce the number of trained staff required for the geochemical mapping program; 2) reduce the cost of production of geochemical map broadsheets; 3) substantially reduce the turnaround time for the release of geochemical broadsheets from 18 months (now) to a few weeks when the MLU is in full operation; and 4) free experienced geochemists to carry out methods research in the MLU during the winter months. For these reasons, the current plan for the MLU includes a data processing centre.

THE MLU DESIGN STUDY

In late 1991, the Ministry Relocation Project hired Equipment Planning Associates Limited (EPA), of Don Mills, Ontario to carry out a design study for the proposed MLU. This was completed in May 1992. The study included: 1) a floor layout plan; 2) provision for the installation of an ICP instrument; 3) preliminary equipment specifications; and 4) an allocation of space and power (but no equipment specifications) for the data processing centre.

A PRELIMINARY STUDY OF GOLD IN KIRKLAND LAKE WATERS

An MLU designed for modern mineral resource appraisal geochemical mapping, based on the analysis of waters, must have the capability to determine gold reliably at the parts per trillion level. Traditionally, the quantitative determination of elements at ultra-trace levels in waters requires a special clean laboratory of a type unsuitable for installation in the OGS mobile laboratory. Consequently, a search has commenced to find reliable, routine, methodologies which detect very low levels (ppt) of gold and many other elements in waters.

Recent research by Professor C.W. McLeod and his coworkers (Gomez and McLeod, in prep. a, in prep. b) has shown how small ion exchange columns can be used routinely to concentrate small amounts of gold from natural waters prior to ICP–OES and ICP–MS analysis.

The problem is: what gold levels occur within waters collected in, and around, an Ontario mining camp?

In August 1992, Professor McLeod joined an OGS geochemical field party, led by the author, in Kirkland Lake, in order to collect a small number of water samples from 1) control lakes north of the Kirkland Lake mining camp (likely to have background levels of gold); 2) stream-waters within the Kirkland Lake mining camp area, but upstream from known gold mines, or mine tailings; and 3) stream-waters known to be contaminated by gold derived from mine tailings.

The waters were collected on August 13–14, 1992, and analyzed in Sheffield a few days later. The volume of the water samples was 50 mL, with 8 to 10 mL being required for each chemical analysis. A large ICP–MS instrument was used for gold determinations using a transient signal technique following sample pre-treatment and flow injection.

Some preliminary results for gold levels in the Kirkland Lake water samples are listed in Table 22.1. These results are included to illustrate how values (at ppt levels) can vary in different waters within, and around, a mining camp. These few results are not intended to be typical of gold levels in waters of the Kirkland Lake area. They are included to demonstrate the magnitude of apparent variation of gold detected in water samples by this methodology.

These data are of interest in relation to the MLU for several reasons.

1. The methodology detected 3 different levels of gold in the Kirkland Lake waters, all at the ppt level (if accurate, this information is of considerable importance in planning gold determination methods for the MLU);
2. As expected, the gold data, presented in Table 22.1, show excellent precision obtained from the field-ion-exchange column (FIE) sample collection system as part of a FIE–FI–ICP–MS technique including a large ICP–MS instrument. (These results suggest that it may be feasible to develop a FIE–FI–OES–ICP technique to routinely determine gold at low ppt levels, and above, in the MLU);
3. From a broader perspective, the Kirkland Lake gold data illustrate the effectiveness of the FIE–FI approach for lowering determination limits for ultra-trace levels of elements in waters. (This information is important for planning geochemical mapping based on many other elements which occur at ultra-trace levels in natural waters).
4. Another important feature of the Kirkland Lake gold experiments is the small volume (8 to 10 mL) of natural waters required for gold determination at the ppt level. (If 10 mL water samples could be used for the simultaneous determination of many elements by ICP–OES, it will reduce considerably the water sample pre-treatment equipment space required in the MLU).

It was concluded from Professor McLeod's experiments that:

1. The deployment of a proven FIE–FI–ICP–OES water analysis methodology could simplify the preparation of geochemical maps in the MLU.
2. It appears that there are at least 3 levels of gold in waters of the Kirkland Lake area. Each is associated with a particular natural, or man-modified, set of landscape conditions.

Table 22.1. Levels of gold determined in waters collected from the Kirkland Lake area: 1) data from control lakes north of Kirkland Lake obtained by FI–ICP–MS; 2) data from streams within the Kirkland mining camp obtained by FIE–FI–ICP–MS; and 3) data from samples collected downstream from a mine-tailings dump obtained by FI–ICP–MS in Sheffield.

	Sample	First test	Duplicate
1) Lake-waters collected			
20+ km north of Kirkland	1	1.59 ppt	1.61 ppt
Lake (pre-concentrated on	2	1.40 ppt	2.32 ppt
on ion exchange columns	3	2.21 ppt	1.75 ppt
in the field within	5	1.46 ppt	1.56 ppt
8 hours of collection)			
2) "Control" stream-waters	10	63.09 ppt	56.64 ppt
collected upstream from	12	29.15 ppt	33.64 ppt
tailings ponds	14	37.04 ppt	37.15 ppt
(preconcentrated from	18	24.80 ppt	27.62 ppt
8 mL samples in Sheffield)			
3) Stream-waters collected	1	1010 ppt (a)	
downstream from a mine	2	950 ppt (b)	
tailings dump (without	4	3170 ppt	3030 ppt
preconcentration)	6	3377 ppt	3377 ppt

(a) and (b) duplicate sample from same field site

THE CURRENT SITUATION

The current design of the MLU allows for geochemical mapping based on water analysis only. The MLU laboratory shell is to be designed for retrofitting the equipment (e.g., dryers, furnaces, grinders) for processing other materials (e.g., lake sediments, stream sediments, soils, etc.) later on as required by the OGS.

ACKNOWLEDGMENTS

The assistance of D. Guindon, Staff Geologist, Field Services Section, Ontario Geological Survey–Information Services Branch, in Kirkland Lake, is acknowledged for organizing the sample collection schedule in Kirkland Lake. R.D. Dyer and C.R. Fouts, of the 1992 OGS geochemical field party, provided assistance during helicopter sampling of lake waters.

REFERENCES

Fortescue, J.A.C. 1990. Design considerations for a mobile laboratory unit (MLU) to support geochemical mapping in Ontario; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.185–190.

——— 1991. Progress in planning a mobile laboratory unit (MLU) to support geochemical mapping and environmental geochemistry; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.179–182.

Gomez, M.M. and McLeod, C.W. in preparation, a. Trace enrichment of gold by flow injection inductively coupled plasma spectrometry: Part I. Inductively coupled plasma emission spectrometry; (submitted to Journal of Analytical and Atomic Spectrometry).

——— in preparation, b. Trace enrichment of gold by flow injection inductively coupled plasma spectrometry: Part II. Inductively coupled plasma mass spectrometry.

23. Project Unit 90–30. Paleozoic Mapping and Alkali-Reactive Aggregate Studies in the Eastern Lake Simcoe Area

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INTRODUCTION

Middle Ordovician limestones of the Lake Simcoe area are a major source of aggregate in Ontario. Aggregate from certain beds within this sequence react with alkalis in cement causing the concrete to expand, a phenomenon termed alkali-carbonate reactivity. Detailed sampling and analysis of sections exposed in a few quarries have identified specific alkali-reactive beds (Rogers 1985). Little is known, however, about the origin and regional distribution of these beds.

The Ontario Geological Survey (OGS) has initiated a multi-year project to map the Paleozoic geology of the Lake Simcoe area at a scale of 1:50 000. This project is designed to use lithostratigraphic mapping, new depositional models and subsurface data to determine geological controls on bedrock resources, especially with respect to alkali-carbonate reactivity. Reconnaissance field investigations were undertaken in 1990 (Armstrong 1990) and acquisition of subsurface data was initiated in 1991 with the drilling and coring of a deep hole, OGS-91-1, near Manilla, southeast of Lake Simcoe (Armstrong and Byerley 1991).

In 1992, 1:50 000 scale geologic mapping was conducted in the area covered by the Orillia (31 D/11) and Fenelon Falls (31 D/10) map sheets, as well as parts of the Gravenhurst (31 D/14) and Minden (31 D/15) map sheets which are underlain by Paleozoic bedrock (Figure 23.1). At the time of writing of this report, the entire Orillia map sheet and the western third of the Fenelon Falls map sheet had been mapped.

STRATIGRAPHY

The map area is underlain by igneous and metamorphic Precambrian rocks of the Grenville Province. These rocks form the basement beneath Paleozoic strata over most of the map area and outcrop in an irregular belt along the northern part of the map area (OGS 1991a). The Precambrian basement is overlain unconformably by a succession of Middle Ordovician carbonate and clastic sedimentary rocks which are the focus of this project. The Paleozoic succession in the map area is subdivided into 4 formations, in ascending order, the Shadow Lake, Gull River, Bobcaygeon, and Verulam formations (Figure 23.2; Liberty 1969). The regional dip of these strata ranges from 3.79 to 5.68 m/km to the southwest (Liberty 1969).

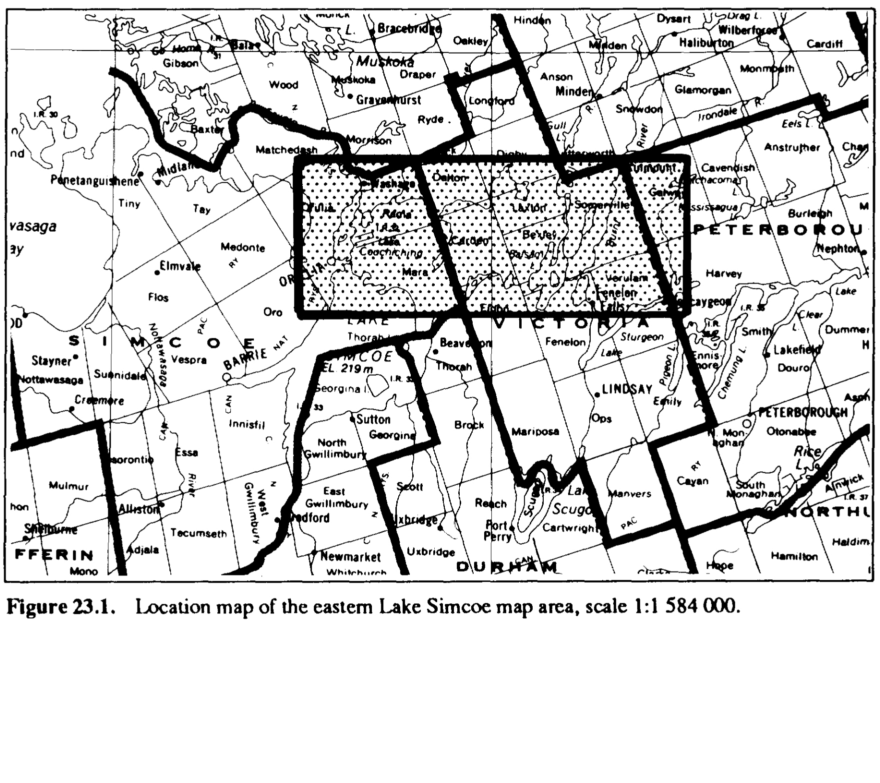

Figure 23.1. Location map of the eastern Lake Simcoe map area, scale 1:1 584 000.

Quaternary glacial sediments overlie both the Precambrian and Paleozoic bedrock and are generally thicker toward the southern boundary of the map area. Large areas of Paleozoic carbonate bedrock are covered by only thin glacial drift. The Quaternary sediments of this area were mapped by Finamore and Bajc (1983, 1984).

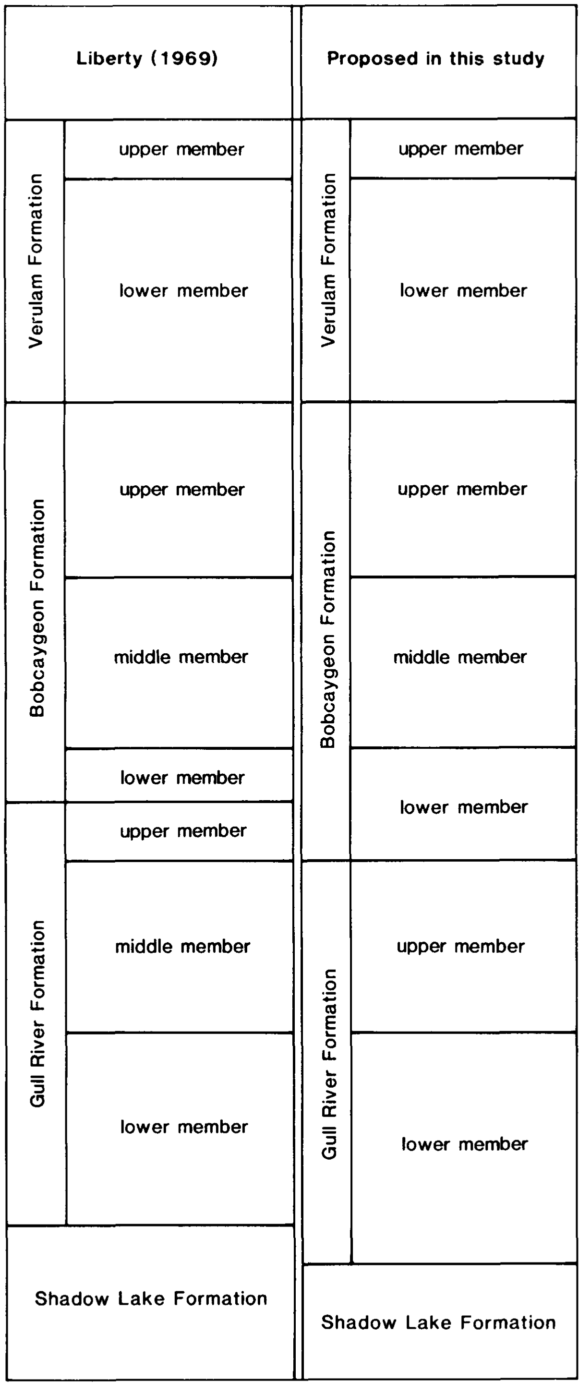

Figure 23.2. Comparison of stratigraphic nomenclature of Liberty (1969) and that proposed by this study, for the Middle Ordovician of the Lake Simcoe area.

Precambrian Geology

West of Balsam Lake and Norland, the Precambrian basement consists of intrusive igneous rocks of mainly felsic affinity and high-grade metamorphic gneisses and migmatites of sedimentary and igneous origin (OGS 1991a). These rocks are part of the Central Gneiss Belt of the Grenville Province. In the eastern part of the map area, the basement consists of metasedimentary, metavolcanic and plutonic igneous rocks of the Central Metasedimentary Belt. These 2 domains are separated by a highly sheared, deformation zone called the Central Metasedimentary Belt Boundary Zone (OGS 1991b).

The Precambrian surface upon which Paleozoic sediments were deposited appears to have been gently undulatory. Inliers of Precambrian Shield within the Paleozoic indicate that paleotopographic highs may have been up to a few tens of metres above the Middle Ordocivian sea level. Well-exposed Precambrian inliers occur 1.5 km west of Sebright and at Rohallion, just north of Canal Lake.

Paleozoic Geology

MIDDLE ORDOVICIAN

Shadow Lake Formation

The Shadow Lake Formation, the oldest Paleozoic unit in the map area, lies unconformably on Precambrian basement. It consists mainly of red and green siliciclastic shales, with lesser amounts of medium- to coarse-grained, shaly sandstones, and minor silty and argillaceous dolostones and arkosic, quartz-pebble conglomerates (Figure 23.3). The shaly, friable nature of this formation results in its generally poor outcrop exposure. No exposures of its basal contact with the Precambrian basement were found in the map area. The thickness of this formation is variable, generally ranging from 0 to 5 m. The thickest exposure (5 m) of the Shadow Lake Formation so far discovered in the map area, is located on the northwest side of Head Lake, where this unit is sharply overlain by impure carbonates of the Gull River Formation.

Some workers (e.g,. Liberty 1969) include overlying, tan-weathering, silty and argillaceous dolostones and dolomitic limestones within the Shadow Lake Formation. As these beds are dominantly carbonate, they are tentatively included within the overlying Gull River Formation in this study. The resistant nature of these beds enhances the mapability of this tentatively revised formational contact.

Gull River Formation

The Shadow Lake Formation is sharply overlain by limestones, dolomitic limestones and dolostones of the Gull River Formation. The Gull River Formation is characterized by generally tabular bedded, sparsely fossiliferous, microcrystalline, faintly laminated, limestone and dolomitic limestone, with small calcite blebs or

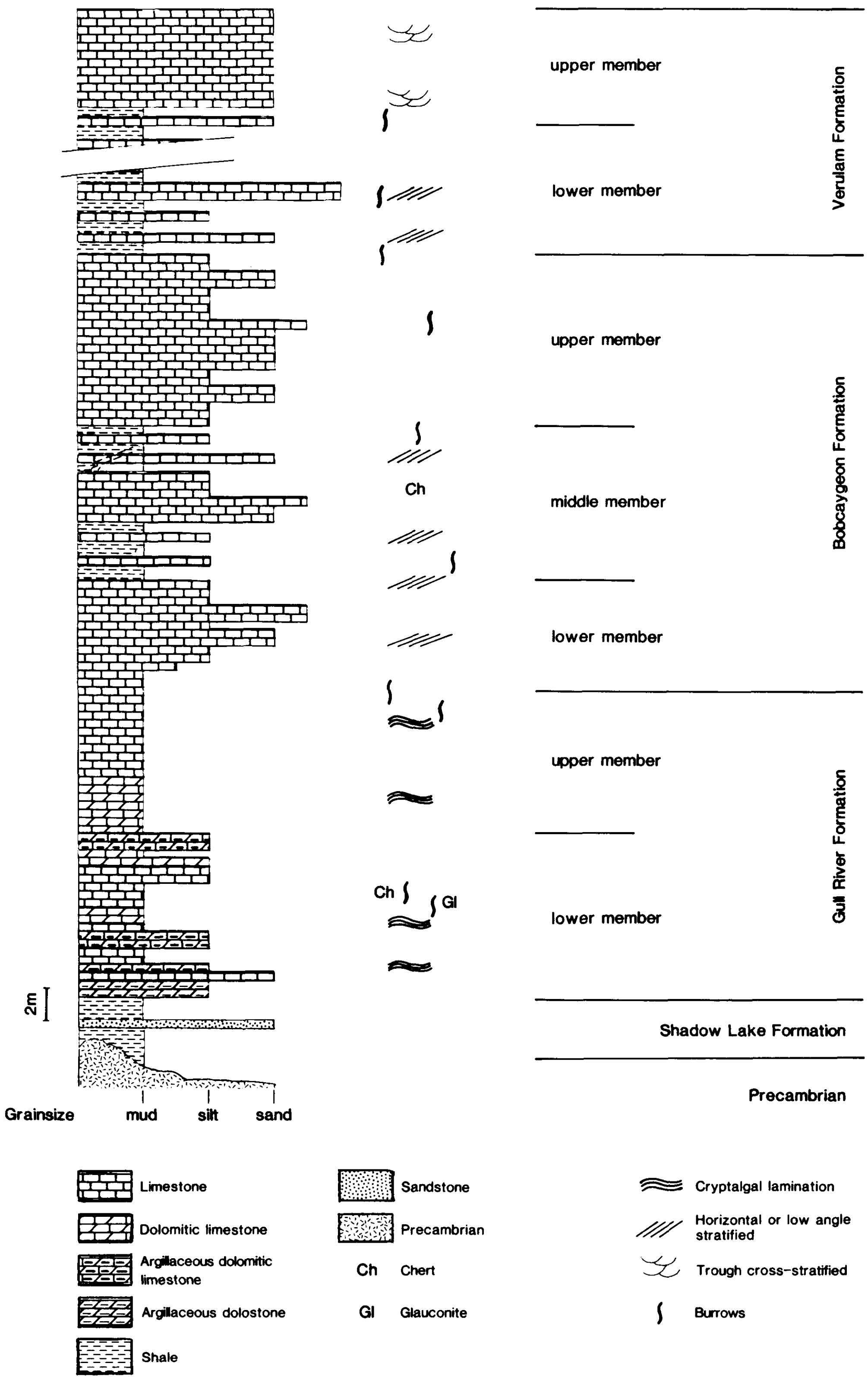

Figure 23.3. Schematic composite lithostratigraphic section of the Middle Ordovician units in Lake Simcoe map area.

"birds-eye" texture. Fossiliferous, argillaceous and coarse-grained beds are also significant, especially in the lower half of the formation (*see* Figure 23.3).

Liberty (1969) subdivided the Gull River Formation into 3 members: lower, middle and upper (*see* Figure 23.2). For reasons discussed below, much of his upper member is tentatively re-assigned to the overlying Bobcaygeon Formation. A tentative two-fold subdivision of the Gull River Formation into lower and upper members is proposed, with these units corresponding roughly to Liberty's lower and middle members, respectively (*see* Figure 23.2).

The lower member of the Gull River Formation consists of various rock types including: 1) argillaceous or silty, green-grey and grey-brown, tan-weathering, fine-grained limestones and dolostones (calcisiltites and dolosiltites); 2) laminated or mottled, microcrystalline, non- to moderately fossiliferous limestones and dolomitic limestones (lime mudstones); and 3) minor, thin calcareous siliciclastic sandstones and siltstones (*see* Figure 23.3). An interval of brown, burrow-mottled, fossiliferous, chert-bearing lime mudstones, informally termed the "brown marker bed" commonly occurs near the top of this unit. Except for the brown marker bed, fossils are generally rare in the lower member, consisting mainly of small ostracods and trilobite fragments, cephalopods, brachiopods, and gastropods.

The lower contact of the lower member of the Gull River Formation with the Shadow Lake Formation is placed at the top of the first significant shale bed (greater than 10 cm) below which there are no significant (greater than 10 cm) dolostone or limestone beds. The impure nature of the carbonates of the lower Gull River Formation and the minor, thin siliciclastic interbeds within this unit indicate that the contact with the Shadow Lake is conformable. The lower member is capped by a light green-grey argillaceous calcisiltite or dolosiltite, informally termed the "upper green marker bed" (*see* Figure 23.3). The lower member ranges between 10 to 12 m in thickness in the map area. The calcisiltites and dolosiltites appear to thicken eastward at the expense of the lime mudstones.

The upper member of the Gull River Formation consists of very light grey to light grey-brown, light grey-weathering, laminated, microcrystalline (porcelaneous), sparsely fossiliferous limestone (lime mudstone) and dolomitic limestone with minor, thin intraclastic and bioclastic beds and shaly partings. This unit ranges from 6 to 9 m in thickness. At the Uhthoff Quarry (approximately 8.5 km northwest of Orillia), the lower part of this unit has been identified as alkali-carbonate reactive (Rogers 1985). Sedimentary structures in the upper member of the Gull River Formation include widespread microbial lamination, small (less than 10 cm wide) hemispherical stromatolites, oncolites, peloids, desiccation cracks, blue mottles, calcite blebs ("birds-eye" texture) and vertical burrows. The sparse fauna of this unit is similar to that of the lower member. The tabulate coral, *Tetradium*, is present, rarely, in the uppermost beds of the upper member.

The upper contact of the upper member of the Gull River Formation is tentatively placed at the generally abrupt transition into the fossiliferous and more faunally diverse, dark brown, burrow-mottled lime mudstones and calcisiltites of the lower member of the Bobcaygeon Formation (formerly the upper member or Moore Hill beds of the Gull River Formation; Liberty 1969). This contact represents a distinct, although commonly gradational, faunal, sedimentologic and lithologic transition, which typically forms a mapable, resistant scarp. Good exposures of the upper member are present at the Uhthoff Quarry, Longford Quarry (approximately 6 km south of Washago), Sebright Quarry (2.5 km west of Sebright), and in the roadcut 2 km south of the village of Lake Dalrymple.

Bobcaygeon Formation

The Gull River Formation is conformably overlain by the generally coarser grained, more fossiliferous and darker coloured limestones of the Bobcaygeon Formation. The Bobcaygeon Formation was subdivided by Liberty (1969) into 3 members, the lower, middle and upper (*see* Figure 23.2). As discussed above, much of Liberty's (1969) upper member of the Gull River Formation is herein tentatively reassigned to be included within the lower member of the Bobcaygeon Formation. The abundant and varied fossils of the Bobcaygeon Formation include brachiopods, echinoderms, tabulate and rugose corals, stromatoporoids, gastropods, cephalopods and bryozoans. A complete section through the Bobcaygeon Formation is exposed in the Brechin Quarry (2.75 km south-southeast of Brechin). The lower member of the Bobcaygeon Formation commonly forms a scarp with the upper member of the Gull River Formation. The remainder of the Bobcaygeon Formation is exposed in a series of low scarps and vast bedding plane outcrops in the middle of the map area. The lithologic similarities of the 3 members and the typically low exposures complicate mapping of their distributions.

The lower member of the Bobcaygeon Formation (*see* Figure 23.3) typically consists of dark brown, nodular and psuedo-nodular bedded, very fine- to coarse-grained, moderately fossiliferous limestones (calcisiltites, wackestones, packstones, and grainstones). Lime mudstone occurs within the basal 2 m and as a minor component higher up in the unit. The lower member maintains a generally constant thickness of 6 to 7 m in the map area. A concentration of large stromatoporoids and tabulate corals is commonly present within approximately 2 m above the lower contact with the Gull River Formation. Hardgrounds, low-angle lamination and ripple and trough cross-bedding are common in this member. In the vicinity of Coboconk, a tan to buff, fine-grained, bioclastic grainstone is developed in the upper part of this member (and possibly the lower part of the middle member). This grainstone corresponds to the "C2 calcarenite" described by Liberty (1969). The Coboconk East Quarry offers the best exposure of the "C2" beds.

The middle member of the Bobcaygeon Formation (*see* Figure 23.3) consists of light to medium brown, tabular bedded, fine- to coarse-grained, moderately fossiliferous limestones (calcisiltites, wackestones and minor packstones and grainstones) which are commonly interbedded with grey-green shale. Black chert nodules and oncolites occur in this member. This unit contains significant intervals with characteristics similar to the lower or upper members. Sedimentary structures in the middle member include low-angle to horizontal lamination, normal grading, hardgrounds and burrows. The limestone beds commonly contain grey-green shaly burrows and the shales contain hard calcareous burrows. The middle member maintains its character throughout the study area (although shale content is difficult to assess in weathered or bedding plane outcrops) and is commonly 10 to 11 m in thickness.

The upper member of the Bobcaygeon Formation (*see* Figure 23.3) is 10 to 11 m thick in this area. This member consists of light grey-brown to blue-grey, fine- to coarse-grained, tabular to irregularly bedded, moderately fossiliferous limestones (calcisiltites, packstones and grainstones) with a minor amount of grey-green shale. Its contact with the underlying middle member is gradational and is marked by an upward decrease in shale and increase in thick, tabular grainstones and calcisiltites. The upper member is moderately to very fossiliferous, with echinoderms, brachiopods, gastropods and bryozoans (especially *Prasopora*) being the most abundant fossils. Sedimentary structures include normal grading, low-angle lamination, hardgrounds and burrows.

Verulam Formation

Conformably overlying the Bobcaygeon Formation are the interbedded limestones and shales of the Verulam Formation. Liberty (1969) subdivided the Verulam Formation into a lower and an upper member (*see* Figure 23.2). Although no complete section of this formation exists in the study area, observations from drill cores (e.g., Armstrong and Byerley 1991) suggest that it ranges from approximately 45 to 65 m in thickness.

The lower member of the Verulam Formation constitutes most of the formation and consists of interbedded dark grey to blue-grey, fossiliferous, fine- to coarse-grained limestones (grainstones, packstones and calcisiltites) and green shale (*see* Figure 23.3). Bedding is commonly irregular to nodular. The basal contact of this unit with the Bobcaygeon Formation is gradational and is marked by upward increases in shale and fossil content into the Verulam Formation. This transition is best seen in the uppermost part of the Brechin Quarry. The lower member of the Verulam Formation is very fossiliferous and contains bryozoans (both branching and domal), echinoderms, brachiopods, trilobites and gastropods. Sedimentary structures include normal grading, hardgrounds and low-angle cross-lamination. The lower member is best seen at the Gamebridge Quarry (approximately 0.5 km west of Gamebridge).

The upper member of the Verulam Formation (*see* Figure 23.3) ranges from 2 to 9 m thick and is composed of buff to tan, cross-bedded, medium- to coarse-grained bioclastic limestones (grainstones). This thin, tabular to flaggy bedded unit is readily identified by its relatively large-scale (30 to 40 cm) trough cross-stratification. More competent than the lower member due to the absence of shale, the upper member commonly forms erosion-resistant scarps 2 to 5 m high, capping many hills in the southernmost part of the map area. It can best be seen in roadcuts 5.75 and 7 km southeast of the town of Kirkfield.

REFERENCES

Armstrong, D.K. 1990. Paleozoic mapping and alkali reactive studies in the Lake Simcoe area; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.159–161.

Armstrong, D.K. and Byerley, M.C. 1991. Drilling of Paleozoic strata in Lake Simcoe area: preliminary results; *in* Summary of Field Work and Other Activities, Ontario Geological Survey, Miscellaneous Paper 157, p.155–156.

Finamore, P.F. and Bajc, A.F. 1983. Quaternary geology of the Fenelon Falls area, southern Ontario, Ontario Geological Survey, Preliminary Map P.2596, scale 1:50 000.

——— 1984. Quaternary geology of the Orillia area, southern Ontario, Ontario Geological Survey, Preliminary Map P.2697, scale 1:50 000.

Liberty, B.A. 1969. Paleozoic geology of the Lake Simcoe area, Ontario; Geological Survey of Canada, Memoir 355, 201p.

Ontario Geological Survey 1991a. Bedrock geology of Ontario, southern sheet; Ontario Geological Survey, Map 2544, scale 1:1 000 000.

———1991b. Bedrock geology of Ontario, explanatory notes and legend: Ontario Geological Survey, Map 2545.

Rogers, C.A. 1985. Alkali aggregate reactions, concrete aggregate testing and problem aggregates in Ontario — a review; Ontario Ministry of Transportation and Communications, Report EM-31, 5th ed., 44p.

24. Project Unit 91–23. Radon Soil Gas Investigations in Southern Ontario

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INTRODUCTION

The Sedimentary and Environmental Geoscience Section, Ontario Geological Survey–Geoscience Branch initiated a regional radon soil gas survey in the autumn of 1991 (Tilsley and Baker 1991). The purpose of this survey was to determine the level of naturally occurring radon soil gas in overburden. The survey was designed to examine the distribution and concentration of radon gas in a variety of geological settings. The information generated by this study is useful for many purposes, including the design of further regional radon soil gas studies, the development of site study protocols and the application of the technique to exploration for oil and gas.

TEST AREA SELECTION

In order to evaluate a number of different geological environments present in southern Ontario, 4 test areas were selected for monitoring (Figure 24.1). Radon concentrations in soil gas were studied in the Belleville–Prince Edward County, Markham–Stouffville, Wallaceburg, and Windsor areas of southern Ontario. These localities were selected to represent differing combinations of surficial and bedrock geology. The study areas are, however, characteristic of several other larger regions within southern Ontario. A brief description of the areas and their geology are as follows.

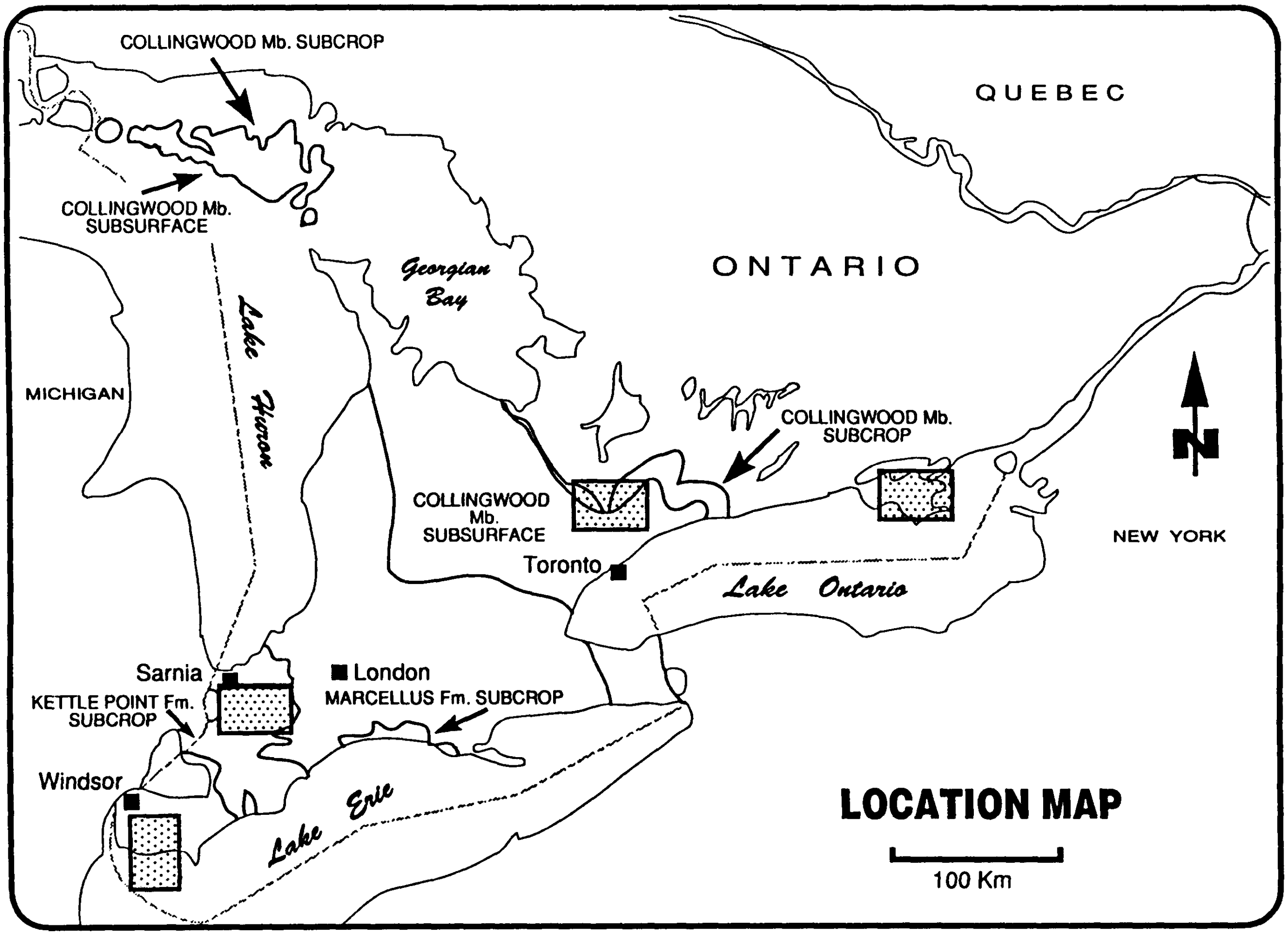

Figure 24.1. Sketch map of the test areas in southern Ontario.

1. The western Essex County–Windsor area. In this region, a moderately thick sequence of clay-silt till and glaciolacustrine sediments overlie dolostone and limestone of the Dundee Formation, in addition to the Hamilton and Detroit River groups;
2. Kent and southern Lambton counties–Wallaceburg area. Here, clayey silt till and glaciolacustrine sediments overlie shale of the Kettle Point Formation and minor Hamilton Group carbonates;
3. The Markham–Stouffville area. In this area, the surficial materials consist of a complex sequence consisting of interbedded tills, glaciofluvial and glaciolacustrine sediments. Bedrock consists of black shales belonging to the Collingwood Member of the Lindsay Formation, Blue Mountain Formation shales and Georgian Bay Formation limestones and dolostones;
4. The Belleville–Prince Edward County area. The surficial cover in this area is thin with the exception of some small, low-amplitude drumlins. Bedrock consists of Middle Ordovician limestones and dolostones of the Simcoe Group and shales, conglomerates and carbonates of the Shadow Lake Formation.

SAMPLING ENVIRONMENTS

Each of the 4 test areas was assessed with regard to radon concentration of soil gas in specific environments. The recognition of these is important, in that the movement and concentration of radon within the environments may vary markedly. To properly interpret the result patterns and the geologic controls on them, radon soil gas levels of all environments must be adequately documented. The components which define these environments are discussed under the subheadings which follow.

Bedrock Geology

Differences in bedrock lithologies were taken into account as to their radioactive content. Black shales (Kettle Point Formation and Collingwood Member of the Lindsay Formation) have very high radioactivity versus limestones and dolostones which typically have low radioactivity.

Local bedrock features, such as recognized faults or very limited, outcrop-scale lithologies, were either avoided or treated as a separate environment during the survey. The main consideration was whether the features represented a suitably sized target area.

Surficial Geology

The surficial geology, as the immediate media through which radon either passes or is generated in situ, was assessed with regard to the following:

1. composition: percentage and clast size of potentially radioactive components;
2. permeability: the less permeable the material, the longer the transit times, enabling greater radon depletion, such that there is much less radon to be measured;
3. thickness: a thicker vertical section will increase potential transit time allowing for increased radon decay and depletion, yet, at the same time, a thick section will allow much greater surface area for leaching with a potentially higher radon flux;
4. soil development: the difference in soil development over each site was noted.

Hydrogeology

An assessment was made of the rate and direction of groundwater flow. Vertical or lateral flow will displace radon from its source in either the bedrock or surficial materials. The rate of flow displacement alone can be orders of magnitude greater than upward diffusion of radon gas.

Anthropogenic Modification

The activities of humans may either enhance or decrease soil permeability thereby locally altering the radon flux. Developments such as pipelines, large-scale tile drainage areas or irrigation may greatly enhance the venting of naturally produced radon to the surface. Placement of detectors in such areas was avoided as it would bias results.

The depletion, burial or addition of organic materials to the soil profile may act as a secondary trap for uranium, which can become a local radon source.

The repeated and/or excessive use of phosphate fertilizer will contribute significant amounts of contained uranium from phosphate (apatite). This outside source would release significant radon immediately adjacent to the detector. Heavily fertilized areas were avoided.

Taking the above factors into consideration the following environments were selected within the 4 main study areas.

For the western Essex County–Windsor area, 2 environments were selected. Environment 1 consisted of clay till above dolostones and limestones, while Environment 2 comprised clay till or glaciolacustrine clays above buried sand and gravel.

In the Kent and Lambton counties–Wallaceburg area, 3 environments were chosen. Environment 1 comprised glaciolacustrine clays, silts, and sands overlying black shale rich till above Kettle Point Formation and minor Hamilton Group carbonates. Environment 2 was located where black shale rich till overlays Kettle Point Formation shales and minor Hamilton Group carbonates. Environment 3 consisted of glaciolacustrine sediments over black shale rich till, and black shale rich till over the Kettle Point Formation within the known limits of oil and natural gas fields.

Within the Markham–Stouffville area, 4 environments were selected. Environment 1 consisted of a sand and gravel veneer on Halton Till overlying Collingwood Member black shales. Environment 2 comprised Halton Till overlying black shales of the Collingwood Member. A veneer of sand and gravel on Halton Till overlying Blue Mountain Formation shales and Georgian Bay Formation limestones and dolostones characterized Environment 3. Environment 4 consisted of Halton Till overlying Blue Mountain Formation shales and Georgian Bay Formation limestones and dolostones.

Two environments were chosen within the Belleville–Prince Edward County area. Environment 1 comprised shallow till above fault zones in Middle Ordovician limestones and dolostones of the Simcoe Group and Shadow Lake Formation. Environment 2 was characterized by shallow till over unfaulted Middle Ordovician limestones and dolostones of the Simcoe Group and Shadow Lake Formation.

METHODOLOGY AND FIELD INVESTIGATION

Within well-defined geological environments, pronounced variability in radon concentrations in soil gas may occur from one sampling point to another. The variations reflect, among other factors, geology, weather changes and anthropogenic disturbances. Proper interpretation of results requires careful observation and data recording at each sample site. As glacial deposits cover most of the areas investigated, each area was inspected at the time of detector deployment. Other surficial and bedrock geology features were recorded, including the composition of tills and related glacial sediments, the nature of soils developed thereon and jointing in till and bedrock.

Inspection was made of all sample sites to avoid placing detectors where radon concentrations may be influenced by human activity, such as buried service lines, field tile drainage systems, use of phosphate fertilizer, and so on. Service burial trenches disturb the soil and are often backfilled with coarse aggregate, increasing permeability locally and resulting in greater radon flux. Field drainage tiles are good radon collectors. Elevated radon concentrations at discharges and at breaks in the tile line are common. Phosphate fertilizers usually contain 10 to greater than 100 ppm uranium.

For the requirements of this study, the Rad Elec Inc. Electret Passive Environmental Radon Monitor, or E-perm (the short form), radon measuring system was found to be most suitable. The radon detector is a charged teflon disk that carries a quasi-permanent electric charge. The static charge on the disk attracts charged ions which, one by one, reduce the charge on the disk. The surface voltage drop over a known time is a measure of time-integrated ionization during the period of exposure. The voltage drop value can be converted to radon concentration. The system includes: the charged disks; an electrically conducting, plastic housing for the disk (electret); and a voltage reader that is used to measure the voltage on the electret before and after exposure. The voltage drop is recorded and converted by calculation to average radon concentration during the period of exposure. Kotrappa et al. (1990) have described the principle and application of this technology.

The detectors are also sensitive to gamma radiation and thoron progeny. Thoron is often present in soil gas at some level of concentration. Gamma radiation measurements were made to obtain the contribution from this source to the apparent radon concentration. Special ion chambers were employed to generate the data necessary for this correction.

Field work began in late September 1991 and was completed by mid-December. During this time, 495 sampling sites were established, with approximately 40 sampling sites established for each geologic environment. Sampling density was variable from 1 per approximately 15 km^2 to 5 per approximately 1 km^2, depending upon the extent of the environment and local conditions.

The approximately 40 sampling points per environment ensured enough determinations for statistical reliability, considering the inevitable loss of detectors and data due to any number of hazards.

The detectors were placed 15 to 30 cm below the surface of the soil in small-diameter excavations. The ion chamber was protected from flooding by an inverted container or radon-transparent waterproof envelope. The excavation was sealed using the soil removed from the hole, which was placed on a plastic sheet resting on the detector container. The plastic facilitated recovery of the detectors for short-term readings and final recovery.

In agricultural areas, the sampling points were chosen, as much as was possible, in undisturbed locations along township, county and provincial highway right-of-ways. In wooded areas, near-highway locations were chosen in undisturbed soil beside a prominent tree or other easily identified feature.

Detectors were read about 7 to 10 days after placement and reset for a longer period depending on the local radon soil gas concentration. Reading of detectors must be done before the sensing device is fully discharged. "Off-scale" readings are of limited statistical value. If radon concentrations were high at a particular location and the sensor became overloaded, a new electret was installed and the measurement continued for an appropriate time.

Over the course of the survey, approximately 1350 radon and 85 thoron determinations were made within the 4 study areas. Gamma dose measurements were made at 40 of the sampling sites. Three radon concentration determinations were made at most sampling locations, excepting for a small number of stations where detector packages were vandalized, dug up by mammals, or had to be removed due to impending construction.

SURVEY RESULTS

The surveys conducted by this study and discussed herein are essentially reconnaissance in nature. Results are average concentrations of radon in the soil gas for the exposure periods. The data show that both radon concentration and flux vary with time, moisture content of the soil, atmospheric pressure and other factors. Short-term surveys lasting 30 to 60 days will be successful in identifying areas of anomalous radon concentration under most sampling conditions. Detailed site surveys will require increased sample density, but no modification of sampling technique. While annual radon concentration averages would be desirable from a research point of view, results of short-term surveys will probably be adequate for most applications.

Within the western Essex County–Windsor area, survey results showed a wider range of radon values over the sand and gravel deposits (Environment 2) than those from the clay till plain (Environment 1). Radon values for Environment 2 ranged from 73.6 pCi/L (pico Curies per litre of air, water,...) to 658.2 pCi/L, while values for Environment 1 ranged from 106.5 pCi/L to 435.9 pCi/L. Mean radon levels for Environment 2 were only slightly less than for Environment 1 (217.1 pCi/L versus 230.8 pCi/L).

The wider range of values from Environment 2 may be a reflection of enhanced groundwater flow through the more porous sediments. The groundwater serves as a transport mechanism for radium and radon and, thus, the porous nature of the sediments can permit a greater radon flux than is likely in the heavy clay soils.

Although there is not a great amount of petroleum production within the study area, the underlying formations are Paleozoic sediments in which minor accumulations of natural gas are common. It is possible that volatile hydrocarbons are being channelled along faults to surface and that these hydrocarbons are transporting small quantities of uranium and radium into the soils of the region. Such channelled volatile transport may be responsible for the apparent alignment of higher values noted in some areas.

The relationship of radon to faults in this area could be defined by several lines of samples across suspected structures. Sample spacing should be less than 50 m and extend on either side of the interpreted axis by 200 to 300 m.

Results of radon soil gas concentration measurements in the Kent and Lambton counties–Wallaceburg area showed general background in the black shale rich till to be the highest of all the areas investigated. The high levels are interpreted to be related to the presence of Kettle Point Formation black shale clasts within the till.

Results from glaciolacustrine silts and clays overlying the black shale rich till (Environment 1) showed somewhat lower radon levels when compared with the black shale rich till (Environment 2). Levels for Environment 1 ranged from 47.5 pCi/L to 689.4 pCi/L and produced a radon mean of 180.4 pCi/L. Environment 2 levels ranged from 84.86 pCi/L to 1057.9 pCi/L, with a mean of 261.4 pCi/L.

Both the tills and glaciolacustrine deposits showed local, superimposed influence from underlying deposits of oil and gas. The highest concentrations of radon in soil gas were obtained in areas of petroleum production or storage (Environment 3). Levels in this environment ranged from 26.1 pCi/L to 1539.0 pCi/L and produced a mean of 453.7 pCi/L. The greatest radon concentration recorded was 1876.85 pCi/L during an exposure time of 6.97 days.

The high levels are likely related to the presence of both radon-producing uraniferous shale clasts in the soil and an apparent petroleum volatile-related radon transport mechanism working in concert. Preliminary evidence suggests that hydrocarbon (and radon) "leakage" does not extend a great distance from the boundaries of the individual fields. There is some suggestion that highest radon values may occur toward one boundary of some fields, particularly those controlled by a regional fault. There also appear to be well-defined anomalies above petroleum-bearing reef structures as well as above fault-controlled traps. The radon anomalies related to petroleum occurrences of the Wallaceburg area were clearly defined by measurements that lasted only 6 to 7 days.

The radon concentrations indicated by survey results in the Markham–Stouffville area suggest relatively low uranium content of the soils. Most of the radon in the soil gas appears to be derived directly from the soil and parent material in the immediate vicinity of the detectors.

Direct influence of bedrock radon sources on near-surface concentrations are limited to areas of shallow drift cover. "Spot highs" may be related to channeled movement of hydrocarbon volatiles rising from the Collingwood Member black shales that subcrop in the eastern part of the area and underlie younger Ordovician shales and limestones in the west.

Radon levels for the 4 environments in the Markham–Stouffville area are as follows. Environment 1 produced a radon mean of 161.5 pCi/L and values ranging from 59.4 pCi/L to 370.3 pCi/L; Environment 2 showed values ranging from 32.3 pCi/L to 362.6 pCi/L and a mean of 149.3 pCi/L; Environment 3 had values ranging from 60.0 pCi/L to 353.3 pCi/L and a mean of 143.9 pCi/L; Environment 4 produced radon values ranging from 61.9 pCi/L to 276.8 pCi/L and a mean of 143.4 pCi/L.

In the Belleville–Prince Edward County area, radon in soil gas levels were found to be generally low in the areas of shallow overburden. The low values are thought to reflect the permeable nature of the soils, their generally porous nature and the low uranium and radium content expected of limestones.

The areas tested along the fault zone, extending from Picton Bay south to Lake Ontario (Environment 1), had some radon concentration values in excess of 400 pCi/L. This environment produced values ranging from 16.5 pCi/L to 276.8 pCi/L and a mean radon level of 144.4 pCi/L. In comparison, Environment 2 produced only a single value in excess of 330 pCi/L. This environment showed values ranging from 24.1 pCi/L to 338.2 pCi/L and a mean value of 111.8 pCi/L.

The elevated radon levels in the vicinity of the fault zone suggest movement of radon parents from depth. Small quantities of hydrocarbons can be expected in this area and there is also some possibility that "primordial methanes" may be escaping from the underlying Grenville Province (Precambrian) rocks.

There is also some possibility that groundwater circulation in the fractured rocks may provide a mechanism for bringing uranium and radium close enough to surface to permit development of elevated radon concentrations in soil.

CONCLUSIONS

The interpretation of data collected during the radon soil gas survey in southern Ontario suggests the following conclusions.

1. Radon does not migrate long distances in soils. Maximum migration is not likely to exceed 5 m even under the most favourable conditions and, in the majority of southern Ontario soils, travel distances are probably less than 2 m;
2. The concentration of radon in any soil is primarily related to the functions of: radium content of the soil; soil porosity; permeability; moisture content; and air change rate;
3. The radon concentration is variable with time in response to changes in the factors given under point 2;
4. Strong radon anomalies are observed above known oil and gas fields in southwestern Ontario;
5. Volatile hydrocarbons serve as solvents for uranium and radium, and also act as transport media to move the metals from depth into the near surface environment;
6. Release of uranium and radium from volatile hydrocarbons is probably related to oxidation of the hydrocarbons when they come into contact with oxygen in the soil above the water table;
7. Radon parents uranium and radium also move in ground- and surface waters. Some radon anomalies in soils are due to this mechanism. However, the role of volatile hydrocarbons in uranium and radium transport may be dominant along faults and in the vicinity of natural hydrocarbon accumulations;
8. Radon emanation of soil samples can be measured in the laboratory using the Electret type detectors employed in this survey. Radon emanation values can be used to estimate the radium content of soils. Since radium content is constant at any site and does not vary in response to the factors that influence radon concentration in soil gas, soil sampling and laboratory determination of radon emanation potential appears to be an attractive alternative to in situ radon concentration measurement;
9. Radon in soil gas surveys can be applied to exploration for oil and natural gas, however, soil gas surveys require relatively dry soil conditions and unfrozen ground. Soil sampling will give comparable results and can be done at a comparable cost at any time the soil is not frozen.

REFERENCES

Kotrappa, P., Dempsey, J.C., Ramsey, R.W. and Stieff, L.R. 1990. A practical E-Perm (Electret Passive Environmental Radon Monitor) system for indoor ^{222}Rn measurement; Health Physics, v.58, no.4, p.461–467.

Tilsley, J.E. and Baker, C.L. 1991. Soil radon investigations in southern Ontario; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.152–154.

25. Project Unit 92–16. Quaternary Geology of the Umfreville Lake Area, Northwestern Ontario

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INTRODUCTION

Quaternary geology mapping of the Umfreville Lake area (1:50 000 Umfreville Lake map sheet NTS 52 L/7) was initiated in the spring of 1992. This map area is bounded by longitudes 94°30'W and 95°00'W, and latitudes 50°15'N and 50°30'N (Figure 25.1). The map area lies about 60 km north of the town of Kenora and about 90 km southwest of the town of Red Lake.

A mapping program by Zoltai (1965), which included the Umfreville Lake map area, delineated surficial materials at a regional scale. Two other regional-scale mapping programs delineated surficial materials south (Minning and Sharpe 1991) and west (Nielsen 1980) of the Umfreville Lake map area. The current work will add detail to the regional work by defining the distribution and origin of surface materials and landforms within the map area.

Remotely sensed imagery (black and white aerial photographs at a scale of 1:15 840 and Landsat imagery) was initially used to define glacial landforms. Field work then determined materials related to the landforms. The origin of the materials and landforms was determined by examining their sedimentology, stratigraphy, (through man-made and natural exposures) and distribution. Laboratory analysis of materials (mineralogy, grain size, carbonate content and geochemistry) will assist in the separation and characterization of units.

PHYSIOGRAPHY

The map area lies within the Severn Uplands subdivision of the James Physiographic Region as defined by Bostock (1981). The physiography of the Severn Uplands is described as consisting of broad rolling surfaces which are underlain by crystalline Archean rock and overlain by a mantle of glacial lake deposits.

The local relief of the Umfreville Lake map area is 122 m. The highest ground is to the northeast (440 m asl) with the lowest ground to the southwest (318 m asl).

The water level in Umfreville Lake is controlled by an Ontario Hydro dam at Caribou Falls in the extreme southwest part of the map area. The lake level is maintained at about 318 m asl. Faults control the orientation of a number of lakes in the northern part of the map area; Rex and Werner lakes are examples.

BEDROCK GEOLOGY

The study area lies within the northwestern part of the Superior Province. Subprovinces present within the study area include the English River and the Winnipeg River. The English River Subprovince traverses the northern

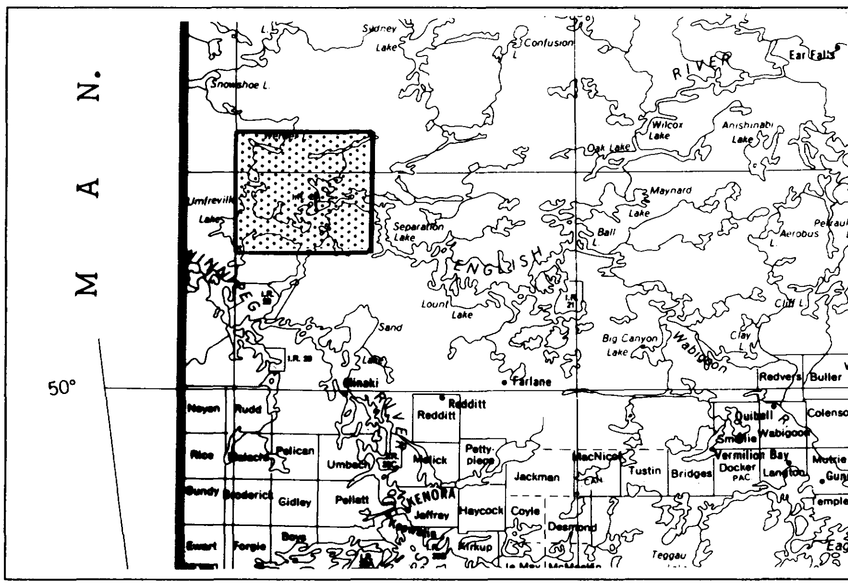

Figure 25.1. Location map of the study area, scale 1:1 584 000.

part of the map area. This subprovince is an east trending linear belt, 800 km long and 50 km wide, consisting largely of highly metamorphosed and migmatized clastic sedimentary rocks (Breaks 1991). Intermediate to felsic granitoid complexes, some of batholitic dimensions, are also a significant component of this subprovince within the study area.

The Winnipeg River Subprovince is present in the southern part of the map area. This subprovince is also an east-trending linear belt, 300 km long and 50 km wide. The Winnipeg River Subprovince consists of massive granodioritic to granitic plutons intruding highly metamorphosed and deformed tonolite to granodiorite with subordinate inclusions of metavolcanic rocks (Beakhouse 1991).

The Separation Lake greenstone belt separates the English River and Winnipeg River subprovinces in the southeastern part of the map area. Prior to the 1992 field season, geological mapping of the greenstone belt was done at a reconnaissance level (Breaks et al. 1978; Sanborn-Barrie 1988). A more detailed mapping program was initiated this summer. For further information, the reader is directed to Blackburn et al. (this volume).

The Separation Lake greenstone belt is also a west to east aligned linear belt, 45 km long with a maximum width of 5 km. The greenstone belt consists primarily of mafic metavolcanic rocks, which are overlain, in turn, by felsic metavolcanic rocks and, locally, at the eastern end of the belt, a polymictic conglomerate.

OBSERVATIONS ON THE GLACIAL GEOLOGY

The terrain topography is largely controlled by the bedrock surface. Around the perimeter of local lake basins, topography can be very flat. In these flat areas, a significant quantity of overburden exists (up to 53 m; OGS 1988). This overburden consists of glaciolacustrine materials deposited within glacial Lake Agassiz, which, at one time, covered the entire map area.

Evidence for glaciation is indicated by the presence of numerous types of glacial deposits and features. This evidence includes striae, glacial grooves and whalebacks. Striations were commonly observed on the south shores of most lakes, however, they were far less common on the north shores. Grooves and whalebacks are even less common. Striae orientations vary between 202° and 247° with a mean orientation of 228°.

Till exists as a thin veneer over bedrock, throughout much of the map area. Locally, the till thickens in bedrock depressions and on the lee side of bedrock highs. Two till types were observed. Both tills are compact, contain predominantly local clasts and are non-calcareous. The first till type was deposited by the lodgement process. This till is fissile, homogeneous and the long axis of pebbles are aligned parallel to ice flow. This till commonly occurs on the up-ice side of bedrock obstructions and flat surfaces.

The second till type was deposited by debris flows. This till is relatively less compact than the first till type, is poorly sorted and displays flow structures. This till commonly occurs on the down-ice side of bedrock obstructions and within ice-contact stratified drift deposits.

Glacial Lake Agassiz abutted the ice sheet margin as the ice retreated from the study area (Fenton et al. 1983). Some materials and features associated with the retreat of glacial ice from the study were deposited within glacial Lake Agassiz. These materials and features include ice-marginal, ice-contact stratified drift, subaqueous outwash and fine-grained glaciolacustrine deposits. Thick deposits of ice-contact stratified drift, consisting of stratified layers of sand, gravel and diamict, were observed at the proximal end of several subaqueous outwash deposits. The thickness of ice-contact stratified drift varies between 1 to 10 m.

Subaqueous outwash in the study area consists of medium- to fine-grained sand. This material is largely confined to bedrock-controlled channels although at least 2 unconstrained, broad, fan-like deposits were identified. Outwash is thought to be subaqueous on the basis of: 1) regional, glacial Lake Agassiz lake level information; and 2) a drape or blanket of laminated or varved glaciolacustrine silt and clay.

Fine-grained glaciolacustrine deposits include laminated and varved silts and clays. These deposits are commonly greater than 1 m thick and commonly overlie till and subaqueous outwash. These silts and clays are pervasive on flat ground around all lake basins.

ECONOMIC GEOLOGY

The majority of the potential aggregate resources within the study area occur within bedrock controlled channels or ice-contact stratified drift deposits. Most of the aggregate used for local road construction is derived from ice-contact stratified drift. Several bulk samples of sand and gravel were taken and will be analyzed for grain size and examined to identify clast lithologies.

Fine-grained materials (clay and silt) can be used in dam construction and as landfill site liners. Fine-grained materials are common on flat ground throughout the area below about 340 m asl.

Bulk till and pebble samples were collected on a 5 km^2 grid within the map area. The majority of bulk samples were "B" horizon soil samples which were collected at all sites defined by the grid. "C" horizon samples were collected on a much more limited basis. Geochemical analysis of these materials will provide regional background geochemical data. In addition, 3 local pilot projects will provide information on the characteristics of till dispersal patterns. The geochemical information derived from the regional and local drift sampling programs, in conjunction with the ongoing bedrock surveys (Blackburn et al. this volume), will provide information relevant to drift prospecting and environmental surveys.

REFERENCES

Beakhouse, G.P. 1991. Winnipeg River Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.279–302.

Bostock, H.S. 1981. Physiographic subdivisions of Canada; *in* Geology and economic minerals of Canada, Part A, Geological Survey of Canada, Economic Report No. 1, p.10–42.

Breaks, F.W. 1991. English River Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.239–278.

Breaks, F.W., Bond, W.D. and Stone, D. 1978. Preliminary geological synthesis of the English River Subprovince, northwestern Ontario and its bearing upon mineral exploration; Ontario Geological Survey, Miscellaneous Paper 72, 55p.

Fenton, M.M., Moran, S.R., Teller, J.T. and Clayton, L. 1983. Quaternary stratigraphy and history in the southern part of the Lake Agassiz Basin; *in* Glacial Lake Agassiz, Geological Association of Canada, Special Paper 26, p.49–74.

Minning, G.V. and Sharpe, D.R. 1991. Surficial geology, Rat Portage Bay, Ontario; Geological Survey of Canada, Map 1770A, scale 1:100 000.

Nielsen, E. 1980. Quaternary geology of a part of southeastern Manitoba; Manitoba Mineral Resources Program.

Ontario Geological Survey 1988. Werner Lake area, District of Kenora, Patricia Portion; Geological Data Inventory Folio 453, compiled by the staff of the Resident Geologist's Office, Kenora.

Sanborn-Barrie, M. 1988. Geology of the tectonic boundary zone between the English River and Winnipeg River subprovinces, northwestern Ontario; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.98–106.

Zoltai, S.C. 1965. Kenora-Rainy River surficial geology; Ontario Department of Lands and Forests, Map S165, scale 1:506 880.

26. Project Unit 92–19. Geological Investigations Within the Oak Ridges Moraine Area, Whitchurch–Stouffville and Uxbridge Township Municipalities, Ontario

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INTRODUCTION

Investigations into the sediments composing the Oak Ridges moraine and their distribution began this past summer in the township municipalities of Whitchurch–Stouffville and Uxbridge (Figure 26.1). These investigations are part of a three-year project to study the origin, sediment distribution and limits of the eastern half of the Oak Ridges moraine. The project is designed to provide information which will form the basis of wise planning decisions within the Oak Ridges moraine area. The project was, in part, undertaken in response to requests from the Oak Ridges Moraine Technical Working Committee, the Greater Toronto Area and the Ministry of Natural Resources.

This past summer's work included the examination of numerous sand and gravel pit excavations, natural exposures and soil probe and auger samples in areas with little natural exposure. This work helped to define the nature of the task and the methods needed to complete it. The author was ably assisted in the field by K.M. McCrae, who made independent geological observations in the Whitchurch–Stouffville area, S. Hynes and A. Robitaille. I would also like to thank area residents for kindly allowing access to their lands.

OAK RIDGES MORAINE AREA

The "Oak Ridges moraine area" is the term used in *Space for all — options for a Greater Toronto Area greenlands strategy* (Kanter 1990) for a physiographic region which includes the Oak Ridges moraine and

> the north and south slopes, where many water courses have their sources. More specifically, the southern boundary is defined by the 244-metre (800-foot) topographic contour that is physiogra-phically part of the south slope. The northern limit is defined as the extent of ice-contact stratified drift on the north slope of the Moraine ... Ice-contact stratified drift is the term given to materials deposited in contact with the melting glacial ice (Kanter 1990, p.42).

The Oak Ridges moraine proper has been defined in several different ways in the past, based primarily on geomorphology and/or surficial sediment distribution (Taylor 1913; Chapman and Putnam 1943, 1951, 1966, 1984; Gwyn and DiLabio 1973; Duckworth 1975; White 1975; Gwyn and Cowan 1978).

The wide use of Chapman and Putnam's *Physiogra-*

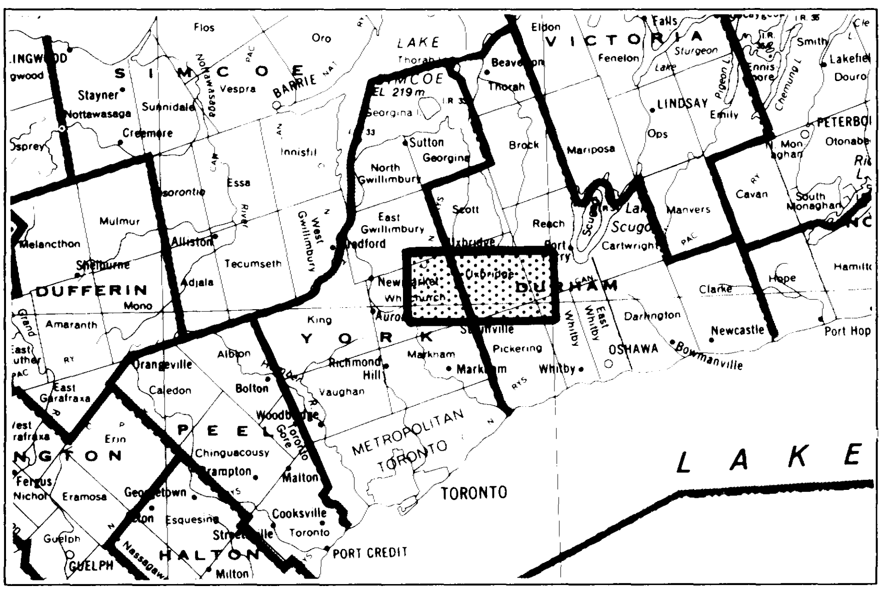

Figure 26.1. Location map of the study area, scale 1:1 584 000.

phy of Southern Ontario (1951, 1966, 1984) has led to the equally wide use of their definition of the Oak Ridges moraine.

Chapman and Putnam (1943) modified Taylor's (1913) original definition of the Oak Ridges moraine. They included several of the other moraines defined by Taylor and, in so doing, extended the moraine westward to the Niagara Escarpment as was previously done by Logan (1863). The eastern end was placed near Morganstown, however, Chapman and Putnam suggested, as did Logan, that the moraine may be extended to include the ridge of high land at Oak Lake (Chapman and Putnam 1984, p.53).

FINDINGS

The Oak Ridges moraine, as defined by Chapman and Putnam (1984), can be considered a complex of smaller landforms. Some of the smaller component landforms were previously identified by Taylor (1913); others appear not to have been recognized before. From the type and distribution of the landforms making up the moraine, several sequential ice-marginal positions can be determined. As well, for the most part, the moraine was deposited in standing water. An ice-contact glacier-fed lake supported on at least 2 sides by glaciers must have existed during deposition of the Oak Ridges moraine; hence, the interlobate nature of the morainic sediments.

In the area investigated, the oldest features observed are coalescing subaqueous fan-deltas fed from the north and ice-supported on their northern side. These features, in part, form the prominent ridge northeast of Bloomington. The fan-deltas were subsequently overridden by a glacial advance flowing toward the north as indicated by the occurrence of unidirectional-overturned strata beneath diamicton and shear planes and the lithology of clasts within the diamicton (Halton Till). Incorporation of subsole sediments into the base of the till was also noted.

Glaciolacustrine sediments are associated with the till indicating that the overriding ice advanced into and terminated in a lake. The limit of this advance is marked by a narrow zone of hummocky topography, extensive kettle lakes and kettle holes and by the surface distribution of the Halton Till. This was the ridge originally defined as the Oak Ridges moraine by Taylor (1913).

Sand and gravel deposits buried beneath Halton Till northeast of Gormley may be related to the fan-delta sediments near Bloomington. Paleoflow direction, as determined from sedimentary structures within these sediments, was toward the southwest. In the deposits northeast of Gormley, deposition may have occurred subglacially in a large cavity beneath the glacier prior to lobation, in a large cavity beneath the northward-advancing ice margin, or proglacially along the ice margin.

Between the margin of the southern ice (Ontario lobe) and the northern ice margin (sometimes referred to as the Simcoe lobe), extensive sedimentation was occurring within a large proglacial lake. Subaqueous fans developing along the ice margins coalesced; forming the large sand plain in the Ballantrae area. Paleoflow directions were predominantly westward between the 2 glacier margins. The slope along the western edge of this plain is interpreted as a depositional slope of the coalescing fans. The slope and the plain have both been subsequently altered extensively by gullying and modified by the deposition of eolian sands.

A large subaqueous fan southwest of Holt marks a later position of the northern ice margin. It roughly corresponds to the northern boundary of Chapman and Putnam's Oak Ridges moraine.

At Goodwood and particularly southeast of Uxbridge, the component landforms of the moraine are more difficult to separate. Buried conduit or fan gravels, marking former positions of the northern and southern ice margins have been recognized within some sand and gravel pit exposures. However, they are commonly buried by glaciolacustrine sediments, similar to the sediments that occur in the Ballantrae area. The water level of the ice-contact lake may have fluctuated greatly during the deposition of these stratified sediments. Sedimentation was also occurring around numerous ice blocks resulting in the hummocky nature of the moraine here.

No direct link between the sediments of the Oak Ridges moraine and the tunnel valleys to the north of the moraine was established this summer, contrary to Barnett (1990). Some evidence exists, however, that suggests the tunnel valleys may extend in the subsurface south of the moraine. One such valley occurs between Claremont and Balsam and appears to be filled with at least 2 layers of fine-grained till and glaciolacustrine sediments.

REFERENCES

Barnett, P.J. 1990. Tunnel valleys: evidence of catastrophic release of subglacial meltwater, central-southern Ontario, Canada; Geological Society of America, Northeastern Section, Syracuse, New York, Abstracts with Programs, p.3.

Chapman, L.J. and Putnam, D.F. 1943. The moraines of southern Ontario; Royal Society of Canada, Transactions, 3rd ser., v.37, sec.4, p.33–41.

——— 1951. The physiography of southern Ontario; University of Toronto Press, Toronto, Ontario, 284p.

——— 1966. The physiography of southern Ontario; University of Toronto Press, 2nd ed., Toronto, Ontario, 386p.

——— 1984. The physiography of southern Ontario; Ontario Geological Survey, Special Volume 2, 270p.

Duckworth, P.B. 1975. Paleocurrent trends in the latest outwash at the western end of the Oak Ridges moraine, Ontario; unpublished PhD thesis, University of Toronto, Toronto, Ontario, 274p.

Gwyn, Q.H.J. and Cowan, W.R. 1978. The origin of the Oak Ridges and Orangeville moraines of southern Ontario; Canadian Geographer, v.XXII, no.4, p.345–352.

Gwyn, Q.H.J. and DiLabio, R.N.W. 1973. Quaternary geology of the Newmarket area, southern Ontario; Ontario Division of Mines, Preliminary Map P.836, scale 1:50 000.

Kanter, R. 1990. Space for all — options for a Greater Toronto area greenlands strategy; Ontario Provincial Government, 164p.

Logan, Sir W. 1863. Geology of Canada, Geological Survey of Canada, Summary Report, p.886–930.

Taylor, F.B. 1913. The moraine systems of southwestern Ontario; Canadian Institute Transactions, v.10, p.57–79.

White, O.L. 1975. Quaternary geology of the Bolton area, southern Ontario; Ontario Division of Mines, Geological Report 117, 118p.

27. Project Unit 92–20. Geochemical Response of Surficial Media, North and East Ranges, Sudbury Basin, Sudbury, Ontario

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INTRODUCTION

A multi-year study along the North and East ranges of the Sudbury Basin was initiated during the summer of 1992 to evaluate the effectiveness of overburden geochemistry for mineral exploration in the Sudbury mining camp and to provide practical information on the geochemical behaviour of Ni-Cu-PGE, Zn-Cu-Pb and associated elements in the surficial environment.

The project is being undertaken co-operatively with the Mineral Resources Division of the Geological Survey of Canada. The federal portion of the project is funded under the Canada–Ontario Northern Ontario Development Agreement (NODA).

The study area (Figure 27.1) includes: all of the Sudbury Igneous Complex on the North and East ranges of the Sudbury Basin; a portion of the Archean footwall gneisses north of the basin; and a portion of the Huronian, Whitewater Group (Onaping, Onwatin and Chelmsford formations) within the basin. The study area occupies approximately 1300 km² and consists of the following townships: Foy, Bowell, Wisner, Norman, Levack, Morgan, Lumsden, Hanmer, Capreol, Maclennan, Cascaden, Dowling and Trill.

Extensive road networks pass through the townships of Maclennan, Capreol, Hanmer, Levack and Dowling allowing easy access to most areas. Access within the remaining townships is limited.

Previous studies of Quaternary geology within the Sudbury region include those of Boissonneau (1965, 1968), Burwasser (1979), Gartner (1980a, 1980b) and the Ontario Geological Survey (1987). These studies deal primarily with Quaternary deposits and history as well as terrain and aggregate resource evaluation.

Few studies emphasizing surficial geochemistry and its application to mineral exploration have been published for the Sudbury region. A recent paper by Coker et al. (1991) summarizes the dispersion and behaviour of platinum group elements in the surficial environment at Ferguson Lake, NWT, Rottenstone Lake, Saskatchewan and Sudbury, Ontario.

OBJECTIVES

This project was motivated by a renewed interest in exploration for nickel in Canada and a developing interest in exploration for Zn-Cu-Pb massive sulphide deposits in the Sudbury Basin. This study will: document the

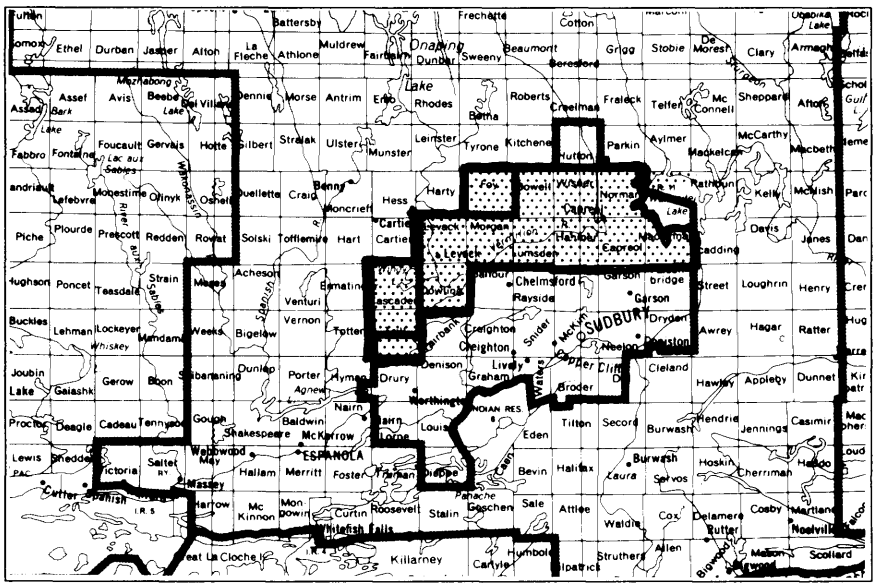

Figure 27.1. Location map of the study area, scale 1:1 584 000.

response of surficial media (water, vegetation, humus, soil and till) to known Ni-Cu-PGE and Zn-Cu-Pb mineralization; evaluate the usefulness of these media for mineral exploration; and define patterns of glacial dispersion within the basin. The nature of mobilization and redistribution of Ni-Cu-PGE and Zn-Cu-Pb and associated elements within the zone of weathering, as well as the residence sites of these metals within the various media, will be established. This will be accomplished in part by the use of selective sequential extraction procedures. These procedures may also aid in the differentiation of natural versus anthropogenic geochemical signatures for the various media sampled.

METHODOLOGY

The field portion of the project consists of 3 basic components: 1) detailed Quaternary mapping; 2) regional sampling of surficial media; and 3) property-scale sampling of surficial media.

Detailed Quaternary mapping at a scale of 1:20 000 was undertaken to establish a framework of Quaternary geology for mineral exploration. Aside from providing a detailed map showing the distribution of surficial materials within the study area, the Quaternary mapping is intended to provide: 1) a detailed analysis of ice flow across the region; 2) document the sediment stratigraphy preserved within the study area; and 3) provide information critical for the evaluation of these units and the soils developed upon them for programs of surface geochemistry.

The Quaternary mapping program is also aimed at facilitating the interpretation of both regional and property-scale humus, soil and till sampling programs which were initiated during this past field season.

BEDROCK GEOLOGY

The elliptically shaped Sudbury Structure, which is famous for its nickel-copper sulphide ores, is situated northwest of the Grenville Front along the boundary of the Superior and Southern provinces. It measures approximately 60 km long and 23 km wide with its long axis oriented to the northeast. Archean granites, granitic gneisses and metavolcanic rocks of the Superior Province lie to the northwest of the Sudbury Structure, whereas a predominantly clastic Huronian succession with some metavolcanic rocks of the Southern Province surrounds the remaining portions of the basin (Dressler 1984).

The Sudbury Structure consists of: 1) the Sudbury Igneous Complex, a funnel-shaped, mafic to felsic intrusion; 2) the overlying Sudbury basin assemblage which contains heterolithic breccias, mudstones and wackes of the Whitewater Group; and 3) brecciated footwall rocks which occur along the outer edges of the Sudbury Igneous Complex. Ni-Cu-PGE mineralization occurs primarily along the contact of the Sudbury Igneous Complex and the surrounding footwall rocks as well as in offset dikes that both radiate out from and trend parallel to the outer edges of the Sudbury Igneous Complex. Zn-Cu-Pb mineralization occurs both within the Onaping Formation and the lower portions of the Onwatin Formation (Vermillion Member) (Dressler 1984).

PHYSIOGRAPHY

The study area can be subdivided into 2 distinct physiographic regions. These regions, informally referred to as the "north range" and the "valley" display distinct topographic signatures. The "valley", which is underlain by the relatively flat-lying, Onwatin and Chelmsford formations, is a flat to gently undulating glaciolacustrine plain with local relief generally less than 15 m. Most of the relief is attributable to the outcrop pattern caused by broad warpings of the Chelmsford Formation as well as downcutting of the Vermillion River through glaciofluvial and glaciolacustrine deposits.

The contact between the "valley" and the "north range" falls along the north edge of the Vermillion River valley at the geologic contact between the Onaping and Onwatin formations. The resistant rocks of the Onaping Formation, the Sudbury Igneous Complex and the footwall granites and granite gneisses form the rugged uplands of the "north range". Major north-northwest-trending faults, now occupied by southward-flowing rivers, crosscut the north range. Local relief along these valleys can exceed 100 m. Additional relief within this region is attributed to differences in competence among those rocks exposed along the north range.

QUATERNARY GEOLOGY

The Quaternary deposits observed within the study area appear to be the product of the Late Wisconsinan glaciation and postglacial processes. There is no direct evidence for the presence of deposits older than those of the last ice advance. Older deposits may exist in the subsurface within certain parts of the valley where up to 100 m of overburden has been documented (Burwasser 1979). Older deposits may also be preserved in protected, topographic depressions within the north and east ranges.

Ice Flow Record

Ice flow indicators, consisting of glacial grooves and striae, chatter marks, crag and tail features and roches moutonnées, suggest a fairly consistent ice flow pattern across the North and East ranges. Ice flow across the North range was to the south at 170° to 210°. Ice flow across the East range was towards the southwest, out of the Wanapitei Lake basin, at 220° to 245°. Crossing striae within the Sudbury Basin consistently indicate an early southwesterly ice flow crosscut by a later west-southwesterly ice flow. This crosscutting relationship is probably attributable to a shift in ice flow to parallel to the axis of the Sudbury Basin as the main ice mass thinned during deglaciation.

Sediment Record

The sediment record preserved within the study area appears to be a product of ice wasting during deglaciation. A thin, discontinuous veneer of variably textured till was deposited upon the flanks of bedrock knobs and in topographic depresssions oriented transverse to ice flow. Thicker accumulations of till are found within the Cartier I Moraine. The moraine is a continuous geomorphic feature which extends along the edge of the North and East ranges of the basin from the Sudbury airport northwest to Capreol to due west through the northern portions of Hanmer, Lumsden, Morgan and Levack townships. The moraine, which in places attains a width of approximately 1 km, is probably a recessional feature. It is composed of both till and ice-contact, glaciofluvial deposits.

Other areas of ice-contact stratified drift, consisting of esker and kame complexes, ice-walled channel deposits and ice-contact deltas have been identified throughout the study area. A large, kettled, ice-walled channel deposit is situated in the vicinity of the Sudbury airport in Maclennan Township. Large, esker-kame complexes are situated in the northwest corner of Capreol Township and along a fairly extensive glaciofluvial system which begins near the town of Onaping and extends southwestward through Windy Lake toward West Cameron Lake. Ice-contact deltas grading to low levels of glacial Lake Algonquin have been identified at the town of Capreol and at the mouth of the Nelson River in Lumsden Township.

Extensive, terraced glaciofluvial systems have been identified along most of the river valleys which flow into the Sudbury Basin off the north range. The most notable of these are situated along the Vermillion River valley north of Capreol, along the Rapid River valley in Wisner Township, along the Nelson River valley in Bowell and Lumsden townships, along the Sandcherry Creek valley in Foy and Morgan townships and along the Onaping River valley in Levack and Dowling townships. As many as 5 or 6 distinct terraces have been identified along any 1 of these valleys. The terraces were formed in response to lowering base levels as the levels of glacial Lake Algonquin declined.

Laminated, glaciolacustrine sand and silt deposits of glacial Lake Algonquin are found primarily within the Sudbury Basin. These deposits have been, in places, reworked by eolian processes. Thin, eolian sheet sands have been observed over large areas of Hanmer and Capreol townships.

Downcutting along the Vermillion River valley following the drainage of glacial Lake Algonquin resulted in the formation of several low terraces along which alluvial sands were transported and redeposited. The river is currently an active, mature fluvial system. It meanders its way westward, constantly eroding older glaciolacustrine and alluvial deposits, abandoning cut-off channels. The abandoned channels form oxbow lakes, which, in time, become vegetated wetlands.

Extensive peatlands are situated in poorly drained lowlands within Hanmer and Capreol townships. Less extensive peatlands are situated in restricted, bedrock-controlled, topographic hollows within the north and east ranges.

GEOCHEMICAL SAMPLING

Humus, soil and till samples were collected regionally throughout the study area in an attempt to: 1) obtain background geochemical signatures for the major bedrock units present; and 2) evaluate regional dispersal patterns across the study area. The regional till sampling program was conducted primarily within areas accessible by roads, bush trails and hydro lines. Samples will be collected in less accessible areas during the next field season with the ultimate goal of obtaining 20 to 25 sample sites per township. Approximately 12 to 13 sample sites per township have been collected to date.

Detailed, property-scale sampling was conducted at 3 sites known to contain Ni-Cu-PGE mineralization along the North Range. Two of the 3 properties are situated in radial offset dikes which traverse the Archean granitic gneisses north of the Sudbury Igneous Complex. The third property is situated within the Archean gneisses, about 1 km from the edge of the Sudbury Igneous Complex. A sample spacing of approximately 100 to 200 m was obtained from these properties.

At each sample site, several media were collected for geochemical analysis. These include: 1) humus; 2) B-horizon soil; and 3) C-horizon of till. The silt and clay fraction (-230 mesh) of the B and C-horizons will be analyzed. A large (8 to 10 kg) sample of C-horizon till was collected at each site for heavy mineral separations and subsequent mineral identifications and geochemical analysis. C-horizon till samples were in most cases collected from a minimum depth of 1 m. They were sieved in the field on a 5 mm screen to remove the pebble fraction. The pebbles were retained for future lithologic identification.

Humus

Humus samples were collected at each site for geochemical analysis. Along the East Range, a sparse vegetation cover has resulted in the contamination of humus samples by wind-blown silt and very fine sand. Care was taken to avoid including this mineral matter with the organic humus.

Much of the study area has been affected by forest fire activity as well. As a result, the humus is usually thin, rooty, discontinuous and contains moderate amounts of charcoal.

Soil

B-horizon samples were collected from each site as well. In most cases, the B-horizon was developed in till, however, there were instances where a thin cover of eolian or glaciofluvial sand was present. In these cases, the B-horizon was developed in sand and sampled accordingly. Samples were collected from the most oxidized material immediately below the leached A_e horizon of the soil profile.

Till

Most C-horizon till samples collected as part of this study were obtained from roadcut exposures and shallow (approximately 1 m) testpits. The tills were generally moderately oxidized and had a buff grey to dark, olive brown colour. Reddish coloured tills were encountered in the Levack area. The reddish colour is attributed to the incorporation and comminution of reddish, Huronian siltstones which outcrop to the northeast.

Till collected from the study area was generally coarse textured (i.e., deficient in silt and clay), stony and carbonate poor. Finer grained facies were observed in Maclennan Township down ice from Wanapitei Lake. The fine texture of these tills is attributed to the incorporation of fine-grained glaciolacustrine sediments from within the lake basin as well as Huronian argillites and wackes which underlie and outcrop northeast of the lake.

Several till facies were recognized across the study area. Till samples collected from the Cartier I Moraine were generally sandy, stony and contained interbeds of stratified sands and gravels. These tills are interpreted as the deposits of ice-marginal debris flows. Dense, fissile, silty sand tills containing faceted and striated clasts were collected from the stoss sides of many bedrock outcrops. These tills are interpreted as subglacial lodgement deposits. Looser, silty sand facies containing glacially abraded clasts and lenses of stratified sand and silt were collected from the lee sides of most rock knobs. These tills are interpreted as subglacial meltout deposits. Stony, sandy facies containing abundant angular rock fragments were found throughout large portions of Cascaden Township. This facies probably represents debris which accumulated on and adjacent to stagnating blocks of ice. The lodgement and subglacial meltout facies are the preferred sampling media for programs of drift prospecting.

Few till samples were collected from within the basin where thick sequences of glaciolacustrine sediments conceal most till and bedrock. In a few cases, till was collected from the stoss edges of bedrock outcrops. The upper portions of these tills appeared to be reworked by glaciolacustrine processes. Till was also difficult to find within the valleys of the major glaciofluvial systems which traverse the North and East ranges. In these areas, till samples were collected from the flanks of steep bedrock knobs that protrude up through and fringe the glaciofluvial deposits.

FUTURE WORK

Humus, soil and till sampling will continue in less accessible areas of the North and East ranges during the 1993 field season. Additional sampling will be undertaken on the properties visited during the 1992 field season. Several additional property-scale case studies will be undertaken as well. Water and vegetation sampling programs will be undertaken during the latter stages of this project.

ACKNOWLEDGMENTS

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REFERENCES

Boissonneau, A.N. 1965. Surficial Geology, Algoma, Sudbury, Timiskaming and Nipissing; Ontario Department of Lands and Forest, Map S465, scale 1:506 880.

——— 1968. Glacial history of northeastern Ontario, 2: the Timiskaming–Algoma area; Canadian Journal of Earth Sciences, v.5, p.97–109.

Burwasser, G.J. 1979. Quaternary geology of the Sudbury Basin, District of Sudbury; Ontario Geological Survey, Report 181, 103p.

Coker, W.B., Dunn, C.E., Hall, G.E.M., Rencz, A.N., Dilabio, R.N.W., Spirito, W.A. and Campbell, J.E. 1991. The behaviour of platinum group elements in the surficial environment at Ferguson Lake, N.W.T., Rottenstone Lake, Sask. and Sudbury, Ont., Canada; Journal of Geochemical Exploration, v.40, p.165–192.

Dressler, B.O. 1984. General geology of the Sudbury structure; *in* The geology and ore deposits of the Sudbury Structure, Ontario Geological Survey, Special Volume 1, p.57–82.

Gartner, J.F. 1980a. Capreol area (NTS 41 I/NE) districts of Nipissing and Sudbury; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 95, 16p.

——— 1980b. Cartier area (NTS 41 I/NW) districts of Algoma and Sudbury; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 94, 18p.

Ontario Geological Survey 1987. Aggregate resources inventory, west of Sudbury, Regional Municipality of Sudbury and District of Sudbury; Ontario Geological Survey, Aggregate Resources Inventory Paper 140, 152p.

Geoscience Laboratories Programs

28. Summary of Activities, 1992 Geoscience Laboratories Section

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The Geoscience Laboratories serve the other OGS–Geoscience Branch sections, resident geologists, and other outside clients by analyzing samples for mineralogy, major, minor and trace element chemistry. P.C. Lightfoot deserves credit for having directed the Laboratories during most of this past year.

QUALITY ASSURANCE

Many staff members have been involved in extensively studying our quality assurance programs. In addition to routine quality assurance through the standard reference materials and international reference standards analyses programs, interlaboratory comparison programs, internal reagent blank and "unknown" tests programs, several staff members have been studying specific problems, such as those reported herein by S.B. Beneteau, G. Henri, A. Martin, J.M. Richardson, and J. Tait.

RELOCATION

Much of this year's activity has been devoted to preparing for and actually moving the Geoscience Laboratories from 77 Grenville Street to the Willet Green Miller Centre in Sudbury. Unlike the other sections, this process for the laboratories did not just mean packing a few boxes and moving in one weekend. As a part of decommissioning, complex agendas for bringing major equipment offline, packing hazardous materials safely for disposal and for the move, and dealing with how to dismantle the old laboratories all had to be addressed. In addition, the staff had to also juggle issues arising from the new laboratories commissioning, including identifying equipment needs, specifying service requirements, consulting with relocation consultants about the new building, and preparing for major equipment commissioning, knowing that all chemicals and samples had to be prepared in Toronto prior to the move, since our facilities would not be finished before some major equipment was recommissioned. P.C. Lightfoot, then Acting Chief of the Laboratories, spearheaded this massive job, with assistance from all the staff, but from D. Crabtree, in particular. I must congratulate them and the whole staff on the wonderful job they have done. Clearly, their preparation will ensure a smooth transition to operation, once the commissioning phase really begins.

TECHNOLOGY DEVELOPMENT

In order to select new equipment for the laboratories, and implement its use into our routine operations, all staff have extensively planned new analytical procedures. Reports on these activities will be deferred until next year, because these remain to be validated through normal operations.

LOOKING TO THE FUTURE

Developing long-term plans by completing a needs assessment for the laboratories has also been a priority. As a result, staff has been surveying client groups, researching new techniques which could be used to improve client services, investigating improvements in our current services, and prioritizing plans for future improvements. The article by Martin and Richardson reports on one such study. Such planning will serve to maintain our laboratories as the premier analytical centre of its type in Ontario.

TECHNOLOGY TRANSFER

In order to automate the method for determining ferrous iron and to initiate technology transfer to industry, Tait and Richardson, in collaboration with Brinkman Instruments, developed a more precise, more easily used analysis involving potentiometric titration. Several private Ontario geoanalytical companies are evaluating this new system with a view to using it in the future. Richardson continues to have numerous requests for her triangular plotting package for Lotus®, and for the paper by Richardson and Riddle describing the laboratories' purchasing strategy for major equipment.

29. Quality Control for Inductively Coupled Plasma–Mass Spectrometric Data in the Geoscience Laboratories

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INTRODUCTION

The inductively coupled plasma mass spectrometer (ICP–MS) in the Geoscience Laboratories provides analyses for 2 distinct suites of elements. The T4 package is comprised of Y, La, and the rare earth elements (Ce, Pr, Nd, Sm, Eu, Gd, Tb ,Dy, Ho, Er, Tm, Yb, and Lu). The T5 package consists of Hf, Ta and other elements, such as Cs and Nb, which traditionally have been difficult to determine in geological material due to the refractory nature of the host minerals. In the Toronto facility, the additional elements were analyzed via ICP–MS on a "special request" basis. In all, 17 elements are routinely analyzed by ICP–MS.

Due to such a large number of elements being reported for geological samples, a stringent quality-control process must be used to ensure that our clients receive high-quality data. The Geoscience Laboratories has established a thorough quality-control process that monitors the method from sample digestion to final analysis, to ensure data quality. The quality-control standards that are used with each sample batch before data release are outlined below. As well, this paper summarizes ICP–MS data acquired over the final six-month period in the Toronto facility, to provide a database benchmark to aid in bringing the ICP–MS instrumentation on-line at the Willet Green Miller Centre in Sudbury.

QUALITY CONTROL STANDARDS

The goal of the Geoscience Laboratories is to provide ICP–MS data that yields long-term (greater than five-year) precision and accuracy at ± 10%. To achieve this, a goal of ± 5% is set and obtained on a "per batch" basis. A batch is comprised of numerous jobs analyzed over a period of time (usually 1 day). To maintain high-quality ICP–MS data throughout a batch, as well as over a period of years, 4 types of control materials are utilized. The T4 and T5 quality-control procedures ensure that reference materials for sample digestion (e.g., in-house reference material MRB 29) and instrument operation (e.g., CHK3) are appropriate and that the precision and accuracy (e.g., standard reference materials MRG–1, SY–2, BHVO–1 and AC–E) are suitable and that procedure monitoring and sample homogeneity checks (e.g., client duplicates) are in place.

First, digestion control material MRB 29 (in-house basalt) and client duplicates are used to monitor contamination in T4 or T5 inorganic acid digestion process (Procedure EA19, OGS 1990). Within an individual job, MRB 29 is digested separately in every 14th beaker and an acid blank is digested separately in every 15th beaker. Second, at least 1 duplicate sample is also included within each job. Larger jobs require more duplicate samples, which are inserted into the digestion/analysis circuit at an approximate frequency of 1 set of duplicates per 15 client samples analyzed.

Third, a reagent blank (BLK–1) is also included during the T4 or T5 digestion procedure. Contamination derived from reagents or the digestion procedure will be evident in the analysis of the blank. If contaminants are introduced during crushing or splitting of client's samples, these are identified by the analyses of blind samples introduced into the analysis circuit by the Chief Analyst.

Fourth, the instrument control material "CHK3" is an in-house composite material comprised of typical samples analyzed. The advantages of using such control material are that large quantities (typically 20 L) can be composed, the control sample is in the same state (i.e., liquid) as client samples when analyzed, the control is in a liquid state. As a result, having large quantities of control material in a liquid state provides a homogeneous material available for analyses over a lengthy time period (approximately 2 years). Similarly, since CHK3 is prepared in the same fashion as all client samples, the CHK3 material will be matrix-matched to these samples. Accordingly, the CHK3 quality-control material monitors only the instrument parameters during operation. The only disadvantages of using CHK3 material is that it is finite in amount and that it only monitors 1 part of the T4 or T5 analyses process (i.e., the instrument operating conditions).

Fifth, specific standard reference materials (SRMs) are used to determine precision and accuracy. SRMs are chosen to closely match the predominant rock-types submitted in a job. Such a procedure minimizes the importance of non-spectroscopic interferences due to the composition of the client's samples. The 4 SRMs typically reported with T4 or T5 data released to clients are MRG–1, SY–2, BHVO–1 and AC–E. These 4 SRMs where chosen because 1) these reference materials represent the types of materials usually analyzed, 2) they are readily available, 3) they represent a wide range of concentrations, and 4) they have well-documented and well-determined values.

QUALITY CONTROL OF ANALYSES

A typical ICP–MS run consists of analyzing digestion controls (MRB 29, client duplicates), instrument control (CHK3), and precision and accuracy control (MRG–1, SY–2, BHVO–1, AC–E) samples. The first and most important quality-control check investigates whether or not the ICP–MS is in control. To do this, the results for CHK3 are compared with the expected values (Tables 29.1 and 29.2). If all elements are within ±5% (1σ) of the expected values, the instrument is deemed to be "in statistical control". Statistical control results when all critical variables are controlled to the extent necessary and possible, resulting in stability of the process and reproducibility of the data within defined limits (Taylor 1987).

Once the instrument operating conditions are proven to be in statistical control, the composition of determined MRB 29 is checked to monitor the digestion procedure. The concentrations are expected to be within ±5% (1σ) of reported values (*see* Tables 29.1 and 29.2). As well, verification that the client duplicate samples agree to within ±5% (1σ) is the final check to indicate that the digestion procedure has been uncorrupted. Finally, the SRMs (MRG–1, SY–2, BHVO–1, AC–E) are examined. If this data are within ±5% (1σ) of those expected (Tables 29.3 and 29.4), this last test is considered complete. When the data from a job meets these criteria, the samples are given technician approval. If any of the above quality-control checks fail (i.e., precision worse than ± 5%), samples are either redigested and re-analyzed if digestion control samples are poor, or only re-analyzed, if the instrument check or SRMs are poor.

When required, reported data is accompanied by a written quality-control document. This document contains a QC note that alerts clients to any aberrations that were observed during T4 or T5 analyses. Such QC notes may contain information pertaining to undigested material in beakers (Richardson et al. 1990), samples requiring dilutions, elements occurring at concentration levels below the determination limits (OGS 1989), etc.

RESULTS

Data produced by ICP–MS in the Geoscience Laboratories yields long-term (i.e., two-year) precision and accuracy of about ±5% for all elements in the T4 and T5 packages (Doherty et al. 1990). Typically, batch precision is approximately ±3%. Composition values acquired over a six-month period, from January 1, 1992 to July 1, 1992, are illustrated in Tables 29.1 to 29.4. This data is based on an average population of 100 T4 analyses and 75 T5 analyses per control material. The data in these tables provide clients a reference with which to verify the quality-control data received with their individual jobs.

Elemental contents for instrument control material (CHK3) and digestion control material (MRB 29) for T4 elements (*see* Table 29.1) and T5 elements (*see* Table 29.2) are also accompanied by the absolute uncertainty (standard deviation, 1σ) and relative standard deviation (RSD). In addition, elemental contents for standard reference materials, MRG–1, SY–2, BHVO–1, and AC–E, for T4 elements (*see* Table 29.3) and T5 elements (*see* Table 29.4) are accompanied by accepted value for elemental contents (Govindaraju 1989) and the accuracy associated with this compilation. In many cases (e.g., La in MRG–1), the value obtained from Govindaraju (1989) is only a "proposed" or "informative" value, not a recommended value. Accordingly, recommended values are underlined in the tables. As a result, average elemental accuracy for each SRM is reported using only those accuracy values which are based on recommended (underlined) elemental values.

PRECISION

The average T4 element relative precision of all control materials in Tables 29.1 and 29.3 ranges from ±3.2% (SY–2, AC–E; *see* Table 29.3) to ±4.5% (MRG–1; *see* Table 29.3), with an average of ±3.6% (n=6). The T5 average element precision of all control material ranges from ±4.4% (CHK3; *see* Table 29.2) to ±7.4% (AC–E; *see* Table 29.4), with an average of ±5.6% (n=6). Accordingly, this data indicates that the over-all precision of the T4 package is ±3.6% and is ±5.6% for the T5 package. The relative precision (RSD) for both instrument and digestion control materials for T4 analyses is ±3.5% and ±3.6%, respectively, for the period in question. Similarly, instrument and digestion control materials for T5 analyses have a relative precision (RSD) of ±4.4% and ±4.8%, respectively. These values for instrument and digestion control material are within expected quality-control guidelines for the Geoscience Laboratory. Data presented in this fashion illustrates how Laboratories' quality-control goals are reached from many points of view. Subjecting data to such a strong statistical tracking program aids in delineating inconsistencies in any aspect of the T4 or T5 analysis process.

Accuracy

The elemental accuracy for T4 package ranges from 1.6% (Ce, Yb) to 7.9% (Y), with an average of 3.9% overall for T4 elements (*see* Table 29.3) and ranges from 3.7% (Ta) to 9.0% (Cs), with an average of 6.6% overall for T5 elements (*see* Table 29.4) for all SRM tested. In cases where elemental contents in the SRM approaches or is below the determination limit (i.e., Cs contents in SY–2 and BHVO–1), the accuracy deteriorates. The data outlined in Tables 29.3 and 29.4 illustrate that, on a routine basis, elemental contents from a wide sample composition range (delineated by the SRMs illustrated) have a well-determined average accuracy of about ± 5% (1σ).

Table 29.1. T4 elemental contents for instrument and digestion control material for quality control purposes. All contents in parts per million (ppm). Absolute uncertainty and relative standard deviation at 1σ.

	CHK3 (n=191)			MRB 29 (n=154)		
ELEMENT	Conc.	Abs. Unc.	RSD (%)	Conc.	Abs. Unc.	RSD (%)
Y	24.0	0.8	3.4	25.3	0.8	3.1
La	20.8	0.5	2.4	21.3	0.6	2.8
Ce	45	1	2.4	49	2	3.0
Pr	5.2	0.1	2.7	6.2	0.2	3.3
Nd	21.3	0.6	2.8	27.3	0.9	3.2
Sm	4.8	0.2	3.6	6.2	0.2	3.8
Eu	1.21	0.04	3.5	1.91	0.06	3.4
Gd	4.5	0.2	3.9	5.7	0.2	4.0
Tb	0.71	0.03	3.8	0.84	0.03	3.9
Dy	4.5	0.2	3.5	5.1	0.2	3.9
Ho	0.90	0.03	3.8	0.99	0.04	3.8
Er	2.45	0.10	3.9	2.9	0.1	4.1
Tm	0.36	0.02	4.6	0.36	0.02	4.3
Yb	2.42	0.09	3.9	2.38	0.08	3.5
Lu	0.35	0.02	4.9	0.34	0.02	4.6
Avg.			3.5			3.6

Conc. - Average concentration of element in ppm
Abs. Unc. - Absolute uncertainty
RSD - Relative standard deviation

Table 29.2. T5 elemental contents in instrument and digestion control material. All contents are in parts per million (ppm). Absolute uncertainty and relative standard deviation are 1σ.

	CHK3 (n=112)			MRB 29 (n=67)		
ELEMENT	Conc.	Abs. Unc.	STD (%)	Conc.	Abs. Unc.	STD (%)
Hf	3.5	0.2	4.7	4.6	0.2	4.5
Ta	1.36	0.06	4.4	0.86	0.02	3.1
Nb	16.2	0.8	5.1	14.3	0.8	5.3
Cs	1.85	0.06	3.2	0.23	0.01	5.6
Avg.			4.4			4.8

Conc.- Average concentration of element in ppm
Abs. Unc.- Absolute uncertainty
RSD- Relative standard deviation

Table 29.3. T4 elemental contents in various standard reference materials. All contents in parts per million (ppm). Absolute uncertainty and relative standard deviation at 1σ.

	MRG-1 (n=117)					SY-2 (n=93)					BHVO-1 (n=89)					AC-E (n=107)					#
ELEMENT	Conc. Unc.	Abs. (%)	RSD	Value* (%)	Acc.	Conc. Unc	Abs (%)	RSD	Value* (%)	Acc.	Conc. Unc	Abs (%)	RSD	Value* (%)	Acc.	Conc. Unc	Abs (%)	RSD	Value* (%)	Acc.	
Y	12.2	0.4	3.5	14	12.9	123	4	3.1	128	3.9	24.5	0.9	3.5	27.6	11.2	168	6	3.8	184	8.7	7.9
La	9.0	0.3	2.9	9.8	8.2	69	2	2.7	75	8.0	15.4	0.4	2.3	15.8	2.5	58	1	2.5	59	1.7	5.1
Ce	26.1	0.8	3.0	26	0.4	165	5	3.0	175	5.7	39	1	2.5	39	0	159	4	2.3	154	3.2	1.6
Pr	3.7	0.1	3.5	3.4	8.8	19.5	0.6	3.2	18.8	3.7	5.3	0.2	3.3	5.7	7.0	21.1	0.6	2.8	22.2	5.0	5.2
Nd	18.3	0.7	3.7	19.2	4.7	76	2	3.0	73	4.1	25.0	0.8	3.2	25.2	0.8	92	3	3.1	92	0	1.8
Sm	4.6	0.2	4.4	4.5	2.2	16.3	0.5	3.3	16.1	1.2	6.3	0.2	3.6	6.2	1.6	24.9	0.8	3.2	24.2	2.9	2.0
Eu	1.48	0.06	3.9	1.39	6.5	2.52	0.08	3.3	2.42	4.1	2.13	0.07	3.5	2.06	3.4	1.98	0.07	3.3	2	1.0	3.6
Gd	4.1	0.2	3.9	4	2.5	16.3	0.5	3.4	17	4.1	6.1	0.2	3.7	6.4	4.7	25.7	0.9	3.4	26	1.2	3.3
Tb	0.54	0.02	4.2	0.51	5.9	2.86	0.09	3.0	2.5	14.4	0.89	0.03	3.6	0.96	7.3	4.5	0.2	3.6	4.8	6.3	6.5
Dy	3.0	0.1	4.2	2.9	3.3	19.9	0.7	3.4	18	10.6	5.3	0.2	3.9	5.2	1.9	30	1	3.4	29	3.4	2.7
Ho	0.50	0.02	4.2	0.49	2.0	4.6	0.1	3.1	3.8	21.1	0.98	0.04	4.0	0.99	1.0	6.2	0.2	3.6	6.5	4.6	3.3
Er	1.15	0.05	4.8	1.12	2.7	14.2	0.5	3.3	12.4	14.5	2.41	0.09	3.8	2.4	0.4	17.0	0.7	3.9	17.7	4.0	2.2
Tm	0.13	0.01	7.4	0.11	18.2	2.42	0.06	2.7	2.1	15.2	0.32	0.02	5.4	0.33	3.0	2.65	0.09	3.5	2.6	1.9	6.7
Yb	0.83	0.04	4.7	0.6	38.3	17.6	0.5	2.9	17	3.5	1.99	0.07	3.6	2.02	1.5	17.1	0.5	3.2	17.4	1.7	1.6
Lu	0.11	0.01	9.5	0.12	8.3	2.9	0.1	4.7	2.7	7.4	0.27	0.01	5.3	0.291	7.2	2.40	0.07	3.0	2.45	2.0	4.6
Avg.			4.5		8.3			3.2		8.1			3.7		3.6			3.2		3.2	3.9
$Avg._{Rec}$					4.9					6.0					3.8					3.2	

Conc.- Average concentration of element in ppm
Abs. Unc.- Absolute uncertainty
RSD- Relative standard deviation
Value*- Value from Govindaraju (1989)
Underlined values - Recommended value from Govindaraju (1989)
- Average elemental accuracy (average accuracy determined only on elements with recommended values)
Avg.- average
$Avg._{Rec}$- average based on element accuracies determined only on elements with recommended values (i.e., underlined)

Table 29.4. T5 elemental contents for standard reference materials. All contents in parts per million (ppm). Absolute uncertainty and standard deviation are 1σ.

	MRG-1 (n=52)					SY-2 (n=60)					BHVO-1 (n=69)					AC-E n=82					#
ELEMENT	Conc	Abs Unc	RSD (%)	Val.*	Acc. (%)	Conc.	Abs Unc	RSD (%)	Val.*	Acc. (%)	Conc.	Abs Unc	STD (%)	Val.*	Acc (%)	Conc	Abs Unc	RSD (%)	Val. *	Acc (%)	
Hf	3.9	0.2	4.8	3.76	3.7	9.2	0.4	4.5	7.7	19.5	5.0	0.2	4.2	4.38	14.2	30	1	3.5	27. 9	7.5	8.5
Ta	0.85	0.03	3.8	0.8	6.3	1.97	0.08	4.2	2.01	2.0	1.23	0.05	3.8	1.23	0	6.8	0.2	3.4	6.4	6.3	3.7
Nb	21	1	4.9	20	5.0	32	2	5.2	29	10.3	18.7	0.8	4.4	19	1.6	120	6	4.9	110	9.0	5.3
Cs	0.59	0.03	4.5	0.57	3.5	2.67	0.06	2.2	2.4	11.3	0.079	0.00 9	11.0	0.13	39.2	2.80	0.07	2.6	3	6.7	9.0
Avg.			4.5		4.6			4.0		10.8			5.8		18.3			3.8		7.4	6.6
$Avg._{Rec}$					5.0					6.7					5.3					7.4	

Conc.- Average concentration of element in ppm
Abs. Unc.- Absolute uncertainty
RSD - Relative standard deviation
Val.* - Value from Govindaraju (1989)
Underlined values - Recommended value from Govindaraju (1989)
- Average elemental accuracy (average accuracy determined only on elements with recommended values)
Avg.- average
$Avg._{Rec}$- average based on element accuracies determined only on elements with recommended values (i.e., underlined)

The average accuracy data for each SRM is reported using only those values which are based on "recommended" (Govindaraju 1989) elemental values. The average accuracy, based on recommended values, ranges from 3.2% (AC–E, *see* Table 29.3) to 6.0% (SY–2, *see* Table 29.3) for T4 elements and from 5.0% (MRG–1, *see* Table 29.4) to 7.4% (AC–E, *see* Table 29.4). Accordingly, this data illustrates that, on a routine basis, average accuracy for samples comprising a wide compositional range (delineated by the SRMs illustrated), have an average accuracy of about ±5% (1).

SUMMARY AND CONCLUSIONS

In the Geoscience Laboratories, samples requiring T4 or T5 analyses via ICP–MS undergo an extensive quality-control checking program to ensure that all aspects of the analysis process from sample digestion to instrument determination are coherent. The client receives ICP–MS data that has undergone a thorough quality-control investigation. Geological material is used to monitor sample digestion, instrument operation, and the entire T4 or T5 analysis procedure as a whole. Each level of quality control must lie within a ±5% window of the expected value before the client sample data is released. As well, quality-control notes are also submitted, if aberrations occur during sample analyses. Data for a six-month period indicates an average precision for T4 and T5 elements from samples of wide geological composition of ±3.6% and ±5.6%, respectively. The average accuracy for T4 elements is 3.9% and for T5 elements, 6.6% across a wide sample composition range. Accordingly, ICP–MS data released by the Geoscience Laboratories yields long-term precision and accuracy of about ±5% RSD for T4 and T5 packages.

ACKNOWLEDGMENTS

I thank W. Doherty for his extensive ICP knowledge and experience. Without his research and method development on the T4–T5 packages in the Geoscience Laboratory, such high-quality data would not be available.

REFERENCES

Doherty, W., Wong, P. and Hodges, A.E. 1990. Determination of 22 trace elements in geological materials by inductively coupled plasma mass spectrometry; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.235–238.

Govindaraju, K. 1989. Compilation of working values and sample descriptions for 272 geostandards; Geostandards Newsletter, v.13, p.1–113.

Ontario Geological Survey 1989. Analytical capabilities and services; Geoscience Laboratories, Ontario Geological Survey.

——— 1990. The analysis of geological materials, volume II: a manual of methods; Ontario Geological Survey, Miscellaneous Paper 149. p.EA19–1—EA19–19.

Richardson, J.M., Doherty, W. and Tsigaris, J. 1990. Quality control for rare earth elements in geological materials: Comparison of XRF and ICP–MS zirconium determinations; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.228–234.

Taylor, J.K. 1987. Quality assurance of chemical measurements; Lewis Publishers, Chelsea, Michigan, p.13–14.

30. Quality Control in Geoanalytical Inductively Coupled Plasma–Optical Emission Spectrometry

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INTRODUCTION

In Toronto, the Geoscience Laboratories of the Ontario Geological Survey (GLOGS) utilized a Jobin Yvon 48P (JY48P) Inductively Coupled Plasma–Optical Emission Spectrometer (ICP–OES) to simultaneously determine Be, Co, Cu, Ni, Sc, V, Y and Zn (Trace 2 or T2 package) in geological materials.

The procedure for T2 sample analysis and quality control (QC) for the JY48P is detailed in the OGS Miscellaneous Paper 149, procedure EA18 (OGS 1990). Routine maintenance of the spectrometer and the established quality-control protocols assured optimal operation. Applied research into the development of geoanalytical methods which rely on ICP–OES has focussed on optimizing the instrument operation and analytical protocols (Doherty and Wong 1991). Factors which influence precision and accuracy are the instrument operating parameters, including forward power and gas flows. These were optimized to minimize determinate (or non-random) error associated with spectroscopic and non-spectroscopic interferences.

At the GLOGS, the quality-control (QC) program for the T2 package ensures that the accuracy and precision of the data generated for this package is within the Laboratories general goal of ±10% over a five-year period. Precision and accuracy can be monitored by following a strict quality-control protocol which requires the close scrutiny of all reported data using Standard Reference Material samples (SRMs), instrument control check solution (CHK), and sample digestion controls such as in-house reference materials (MRBs), sample duplicates and blanks. The instrument control check solution (CHK) is a compilation of MRB–29 digestion control solutions which were collected over time. MRB–29, a basalt, was selected since a large percentage samples submitted to the GLOGS are of this composition.

Statistically, the instrument control data differs from the digestion control data by less than 2% RSD (relative standard deviation) and indicates that the variations in the sample preparation step introduces minimal uncertainty and thus does not degrade the quality of the T2 data (Table 30.1 and Figure 30.1). The overall precision for the T2 method calculated from data obtained from the instrument control CHK sample ranges between 2 to 5% RSD (Table 30.2).

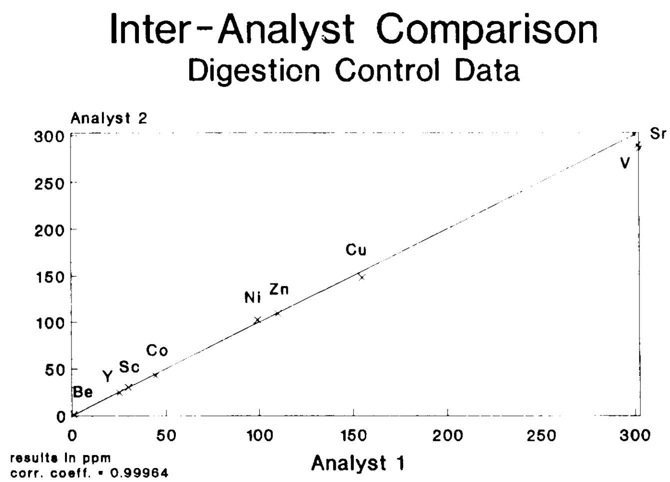

Figure 30.1. Results from Table 30.1 are plotted and indicate the high level of agreement between different analysts. The good correlation coefficient of 0.99964 confirms this.

EXPERIMENTAL

The rock to be analyzed is ground to a fine powder (-200 mesh) and a portion is dissolved in an acid mixture. The liquid sample is then introduced into the plasma by nebulization. The nebulizer produces an aerosol from the liquid sample. About 3% of this aerosol is subsequently injected into the central channel of the plasma. The sample droplets which enter the plasma reaction cell are desolvated, atomized and ionized. The radiation emitted from the plasma is selectively measured, in terms of elements of interest either qualitatively and/or quantitatively by the optical emission spectrometer (OGS 1990). A photomultiplier tube measures the amount of energy emitted from the plasma for each specific wavelength (or line) for each element by producing an electrical signal which is calibrated to quantitatively determine the concentration of the analytes (elements) of interest. It is assumed that the emitted energy is proportional to the concentration of atoms and ions.

QUALITY CONTROL

The quality-control procedures for the T2 package were established to track instrument performance and sample preparation, which are independent of each other. Thus, the quality-control data permits quick identification of the source of the problem(s) when the QC data falls outside established and acceptable limits. Poor QC data for instrument control samples such as CHK and SRMs quickly indicate instrument problems (e.g., mechanical, electrical or otherwise). The quality of data produced by digestion control samples such as MRBs, duplicates and blanks can indicate problems in sample preparation. "Blind" duplicates are inserted into every job by the Chief Analyst, unknown to the lab technician (hence "blind") to indicate the quality of data (precision) reported. SRMs reported with every job indicate the level of accuracy for that data produced.

Instrument Control

An instrument check solution (CHK) and geological reference materials (SRMs) are used to monitor the instrument performance and thus ascertain that the system is "in control". These samples are run prior to and after any batch of submitted samples. Periodic CHK samples are analyzed after every 10 submitted samples.

During method development, means and standard deviations were established for all of the T2 elements present in the CHK solution (*see* Table 30.1 for such values). For each batch of samples, the SRM and CHK solution results are compared to the established values using a control chart (or a numerical equivalent) (Figure 30.2). If the measured value is within 2 standard deviations of the expected mean value (i.e., within the warning limits) the measurement process is considered to be in statistical control. When data falls outside the warning limits, the instrument is inspected for possible mechanical or electrical problems and the subsequent data is closely monitored. Figure 30.2 indicates that, except for 2 outliers, all of the Be data for SY–2 is within the warning limits over the period of January to July, 1991. This indicates that these data points are precise. Comparison of the mean of 21.33 ppm to the certified value of 22 ppm for Be in SY–2 (Govindaraju 1989), indicates that the system is accurate to ±3%.

Data for standard reference materials is treated in a manner similar to the instrument CHK solution. The SRM data indicates the accuracy of the results (Figures 30.3a,b,c). These plots exhibit high correlation coefficients (close to 1) and intercepts close to or at 0, indicating high accuracy with no bias in the data. Comparison between the OGS ICP–OES T2 results and the accepted values for the reference materials indicates an accuracy of ±10% and typically to within 5%, depending on the analytes (elements of interest) and their concentrations relative to the instrument detection limits. Results for SY–2 are listed in Table 30.3.

Digestion Control

Digestion control samples are prepared with every batch of submitted samples. These include a suite of in-house reference materials (MRBs), 1 duplicate for every 10 submitted samples, as well as sample blanks. Results from the digestion control samples are inspected to verify that no sample mix-up has occurred (duplicates), and that contamination levels are negligible (from acid mixture in blanks or fumehood in all digestion samples). Data from these determinations can be plotted using control charts (*see* Figure 30.2). These charts are used to detect problems in the solution preparation procedures. Results from sample duplicates and MRBs are used to determine the level of precision in the method.

Statistically, the precision of the instrument control CHK data differs from the digestion control MRB–29 data by less than 2% RSD (*see* Table 30.3) which indicates the sample preparation step has a minimal effect on the overall reproducibility of the T2 data. Therefore, inter-analyst data (*see* Table 30.1 and Figure 30.2) indicates the ruggedness of T2 method in terms of

Table 30.1. Quality-control data collected in 1989 and 1991 by 2 different analysts using the same CHK solution. Results indicate ruggedness of method in terms of instrument control. Quoted precision is ±1 standard deviation. All results are in ppm.

ELEMENT	QUALITY CONTROL DATA FOR CHK SOLUTION	
	Analyst 1	Analyst 2
Be	0.81± 0.04	0.98 ± 0.16
Co	44.5 ± 4.9	42.4 ± 1.5
Cu	155 ± 5	148 ± 7
Ni	99 ± 1.3	102 ± 2.5
Sc	30.2 ± 0.6	29.8 ± 1.3
V	302 ± 6	289 ± 8
Y	25.4 +/- 0.4	24.2 +/- 0.8
Zn	110 +/- 1.4	109 +/- 3

Table 30.2. Long-term instrument precision data extracted from the quality control CHK data collected in 1990 and 1991. Analyst 2 data is listed in Table 1 (Doherty and Wong 1991).

ELEMENT	INSTRUMENT PRECISION	
	ANALYST 1	ANALYST 2
	%RSD	%RSD
Be	7.5	14.5
Co	2.0	3.7
Cu	1.7	2.8
Ni	2.6	5.3
Sc	1.6	3.3
V	1.9	2.4
Y	1.8	2.8
Zn	1.5	3.3

instrument control. The overall precision of the T2 method can be calculated to be between 2 and 5% RSD using the long-term data extracted from the quality-control CHK data collected between 1990 and 1991 (*see* Table 30.2).

COMPILED RESULTS

Table 30.3 shows the results of a compilation of data collected from November 1990 to April 1992 using the JY48P ICP-OES in Toronto for several OGS in-house reference materials ("MRB-7","MRB-8", "MRB-9" and "MRB-29"), the instrument check solution ('CHK') and a SRM ("SY-2"). Instrument detection limits are also specified (OGS 1989). The overall precision for the T2 method for a wide range of geological compositions is ±8% RSD over this two-year period. However, this precision incorporates elemental concentrations which are at or near the detection limit. These values inherently have a higher %RSD because of instrument signal instability at that level, (i.e., 1 ppm Be in MRB-29, instrument determination limit for Be is 1 ppm, therefore RSD=16.3%), and therefore cannot be measured as precisely. This is recognized in OGS (1989). The overall average precision for the T2 method, taking this fact into account, results in a RSD of ±5%.

Based on the QC consideration developed here and the extensive data base presented in Table 30.3, there are new preferred values for the OGS in-house reference materials (MRBs). Because it is unclear what QC was in place for the values in the Lightfoot et al. (1991) compilation, it is recommended that the data in Table 30.3 be used instead.

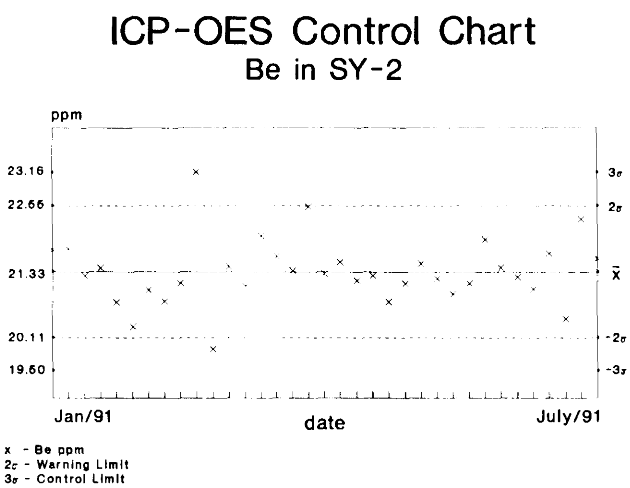

Figure 30.2. Control chart which measures instrument performance in terms of precision. The expected value (x), warning limit (2), and control limits (3) are displayed. When the measured data points fall within the warning limits, the system is in statistical control. Accuracy can also be calculated when using SRMs by comparing the mean (x) to the certified value, in this case, 22 ppm for Be in SY-2 (Govindaraju 1989). SY-2 is a SRM collected from a syenite in the Bancroft, Ontario, area.

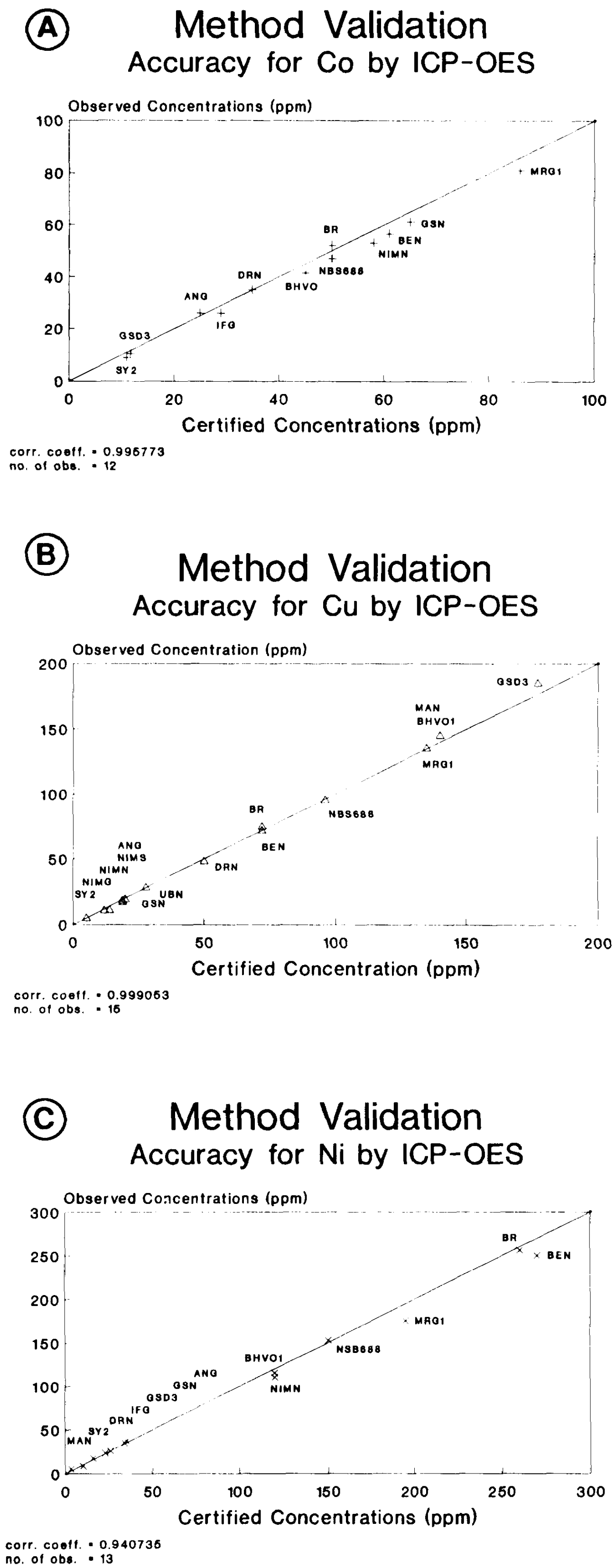

Figure 30.3. (a,b,c) The method validation graphs indicate the level of accuracy in ICP–OES determinations. Samples are SRMs chosen to represent a wide range of rock types and analyte concentration. Certified values are *from* Govindaraju (1989).

Table 30.3. Elemental concentrations (ppm in rock) which have been collected on the JY48P in Toronto between November 1990 and April 1992. Overall precision is based on MRB, SRM and CHK results and is dependant on instrument detection limits.

	Be	Co	Cu	Ni	Sc	V	Y	Zn
MRB-7								
mean	0.42	45.5	80.8	208.6	25.0	171.3	14.5	87.0
n	49	49	49	49	49	49	49	49
sd	0.1	1.5	3.3	6.5	2.1	6.2	0.8	3.4
%rsd	21.9	3.3	4.1	3.1	8.4	3.6	5.2	3.9
MRB-8								
mean	3.0	2.9	5.5	7.5	2.3	5.1	74.1	22.6
n	37	37	37	37	36	36	36	36
sd	0.1	0.5	1.1	1.2	0.3	0.5	12.9	1.9
%rsd	4.3	16.2	19.7	16.5	11.6	10.5	17.3	8.3
MRB-9								
mean	0.7	3.7	6.6	10.3	2.4	6.5	7.2	34.3
n	40	40	40	40	40	40	40	40
sd	0.04	0.5	1.0	1.5	0.3	0.6	0.4	2.5
%rsd	5.1	13.0	15.3	14.3	11.2	9.0	5.6	7.4
MRB-29								
mean	1.0	42.7	147.1	101.8	29.9	287.1	24.2	108.0
n	55	55	55	55	55	55	55	55
sd	0.2	1.5	6.9	2.7	1.3	10.0	0.8	3.8
%rsd	16.3	3.5	4.7	2.6	4.2	3.5	3.4	3.5
CHK								
mean	1.0	43.7	151.2	103.8	30.9	295.4	24.9	112.5
n	343	343	343	343	343	343	343	343
sd	0.1	1.6	4.3	5.5	1.0	7.2	0.7	3.8
%rsd	14.5	3.7	2.8	5.3	3.3	2.4	2.8	3.3
SY-2								
mean	21.2	9.5	6.7	8.6	7.3	47.5	120.5	254.7
n	52	52	52	52	52	52	52	52
sd	0.7	0.9	1.2	1.0	0.5	1.7	2.1	8.4
%rsd	3.2	10.0	18.2	11.3	6.5	3.6	1.8	3.3
Detection Limits	1	5	5	5	2	5	5	5

FUTURE APPLICATIONS

The Geoscience Laboratories at the new Willet Green Miller Centre in Sudbury will be equipped with a new Thermo Jarrell Ash ICAP61E sequential/simultaneous ICP-OES and an upgraded high-resolution LECO Plasmarray (ICP 2000). These instruments will be more than capable of providing the quality assurance data, in terms of accuracy and precision, which satisfies the OGS's program requirements. Results outlined in this paper will provide the acceptable baseline required for commissioning and routine operation of these new ICPs.

CONCLUSIONS

The ICP–OES method for the determination of Be, Co, Cu, Ni, Sc, V, Y and Zn in geological materials of wide-ranging composition is precise to ±2% to ±5% RSD, and accurate to within ±5%. The quality-control program for the T2 package assures accurate and precise results by following a strict quality-control protocol which requires the use of instrument control samples (CHK and SRMs), and sample digestion controls such as in-house reference materials (MRBs), sample duplicates and blanks. A control chart is a valuable tool in determining whether a measurement process is in statistical control. Inter-analyst data indicate that the written documented bench level procedures for the ICP–OES method are adequate to ensure continuity of service and change of personnel. New values for the OGS in-house reference materials (MRBs) for T2 elements are recommended.

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REFERENCES

Doherty, W. and Wong, P. 1991. Developments in geoanalytical inductively coupled plasma optical emission spectrometry; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.220–222.

Govindaraju, K. 1989. Compilation of working values and sample descriptions for 272 geostandards; Geostandards Newsletter, v.13, p.1–113.

Lightfoot, P.C., Chai, G., Hodges, A.E. and Rowell, D. 1991. An update on the certification of the OGS in-house MRB standard reference materials; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.231–236.

Ontario Geological Survey 1989. Analytical capabilities and services; Geoscience Laboratories, Ontario Geological Survey.

——— 1990. The analysis of geological materials, volume II: a manual of methods; Ontario Geological Survey, Miscellaneous Paper 149, p.EA18–1—EA18–29.

31. Proposed Upgrade of Sample Preparation Procedures for Major Element Analysis at the Geoscience Laboratories

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INTRODUCTION

The X-ray fluorescence (XRF) method for the analysis of major constituents in geological materials has been utilized since 1945. The Ontario Geological Survey (OGS) has developed this method to form several analytical packages, which include not only the major elements (Si, Al, Ca, Mg, Na, K, Fe, Mn, P, Ti), but also loss on ignition (LOI), FeO (by titration), carbon, sulphur and H_2O (+ and -) (by infrared combustion). To improve the data quality, the OGS is in the process of modernizing the instrumentation and methods associated with each element. The results of this programme thus far has been shown in the success of the Leco Instruments Canada FX200 (Richardson and Vijan 1991) and the Metrohm AG FeO titroprocessor (Tait and Richardson this volume). Both improvements show a marked increase in data quality, daily output and cost effectiveness. Based on these achievements, the next step is to investigate and test other possible upgrades to the major element packages, to improve sample flow and revise methods in sample handling and sample preparation further reduce cost and improve time efficiency factors.

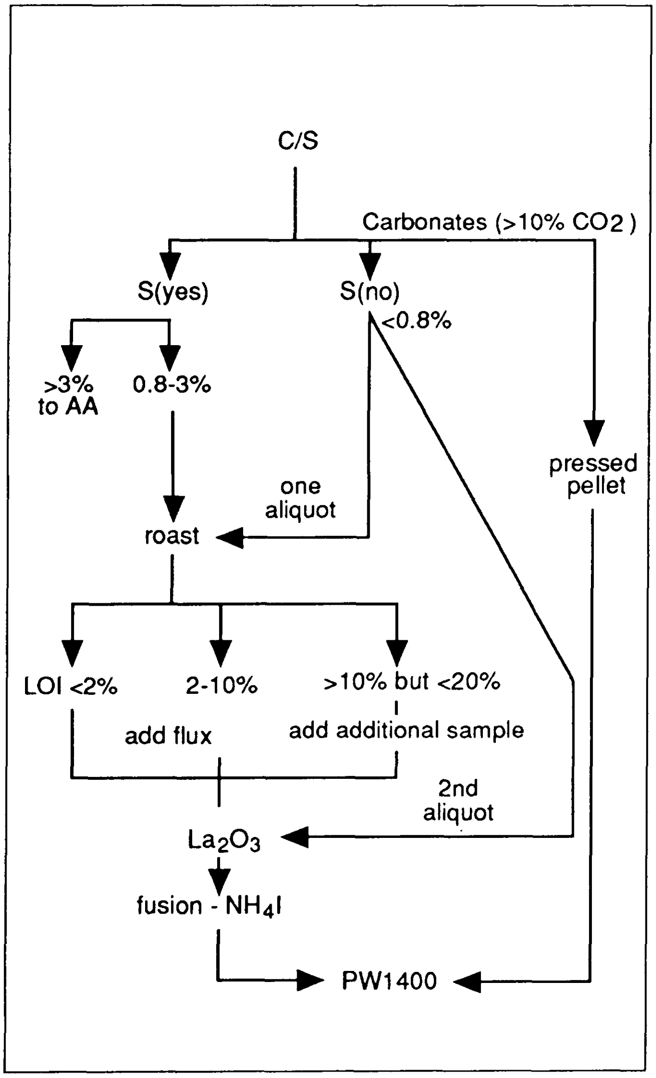

Figure 31.1. Schematic flow chart of present sample preparation procedures.

ASSESSMENT OF CURRENT MAJOR ELEMENT PREPARATION PROCEDURE

The current methods used at the Geoscience Laboratories are documented as procedures EA6 (XRF Majors), EA12 (H_2O +/-) and EA13 (C/S) in OGS 1990. Figure 31.1 shows the present flow of samples and the various instruments necessary to produce the analyses.

All samples are first evaluated on the basis of their carbon and sulphur content. This originally was done in the Toronto laboratories on the Leco Instruments Limited SC–44 and will now be done in Sudbury using the newly acquired Leco Instruments Limited SC–444. The carbon content will determine the subsequent method of analysis (pressed pellet or fused disc). If a high carbonate content is determined (greater than 10% CO_2), the major element XRF analysis will proceed using a pressed pellet sample. This choice is predicted by the small sample size that remains after roasting has driven off all the volatiles including CO_2. [Roasting requires a certain amount of sample to be placed in a furnace and heated for a predetermined time at a set temperature. This will eliminate volatile elements in the sample.]

Concurrently with carbon, sulphur is also determined. Samples containing less than 0.8% sulphur are split. One aliquot is fused for XRF analysis, the other aliquot is roasted to determine the LOI. If the sample is found to contain between 0.8% to 1.5% sulphur, the sample can proceed to the fusion process only after roasting. Samples containing between 1.5% S to 3% S can possibly be roasted and fused if monitored very carefully. If sulphur is greater than 3%, the sample is immediately transferred to the atomic absorption spectrometry (AAS) suite for analysis. The roasting process may not burn off all the S (as SO_4) or convert all the sulphur complexes to sulphates. The high sulphur content in the sample may be present as sulphide minerals. These will attack and possibly destroy the platinum crucibles during fusion.

Presently to roast a sample, an analyst weighs 1.25 g of sample into a porcelain crucible. The crucible is then placed into a muffle furnace for 2 hours. During this interval, the temperature is raised from 800°C to 1200°C. After roasting, the sample is cooled in a desiccator and then reweighed to determine the LOI. The LOI determination indicates additional steps that may be required prior to fusion. If an LOI of greater than 10%, but less than 20% is acquired by the sulphur and carbon results, additional amounts of sample must be roasted (i.e., up to 2 g) so that a total 1.25 g of dehydrated, roasted material is available for fusion. If the LOI is greater than 2%, but less than 10%, additional flux must be added to the fusion mixture so that a constant-fusion starting-weight of 1.25 g is maintained. For samples with less than 0.8% sulphur, the sample to be fused does not require roasting, so long as the total calculated LOI (S + C + H_2O [if available]) is less than 2%.

To prepare glass discs for XRF analysis, the roasted or unroasted material is added to a weighed amount of lithium tetraborate ($Li_2B_4O_7$) and lanthanum oxide (La_2O_3). This combination is mixed and poured into a platinum crucible which contains a few grains of ammonium iodide. The platinum crucible is then placed in the fluxer for fusion.

Using the present fusion reagents, the sample and flux are essentially diluted with La_2O_3 (used as a heavy absorber) in an attempt to ensure that all samples have a similar composition. $Li_2B_4O_7$ is considered one of the better choices of flux for geological materials when all major elements are required. Some fluxes contain elements of interest (e.g., sodium) and are thus unsuitable. Ammonium iodide is the preferred non-wetting agent for platinum fusions. The alternative, lithium bromide, will cause spectral interference on some commonly analyzed elements (e.g., Rb, Al) (Willis and Duncan 1992).

DISADVANTAGES OF CURRENT METHOD

Disadvantages of the present sample handling and preparation procedures include suppression of element intensity during instrumental analysis, cost for expensive reagents and time effectiveness in terms of work flow.

First, flux addition to samples with roasted weights from 2 to 10% is used to ensure a constant weight at time of fusion. However, this process has not been proven to be relevant to data generated. Furthermore, it may also introduce additional errors due to weighing.

Second, carbonate rock types are presently prepared using a pressed pellet procedure. This is because, after roasting, only a small amount of sample remains, as the majority was released as CO_2. This small sample, when combined with the reagents and fused, produces a thinner than normal button. The thin button combined with the light matrix present in a carbonate material will allow the X-rays to penetrate the disc much further than normal; possibly to the point where the X-rays will pass through the disc. If this happens, the detector will receive only a weak signal and thus yield incorrect results. This parameter is referred to as the infinite thickness of a sample. Unfortunately, the alternate pressed pellet method, which is also used, has drawbacks due to grain size effects, infinite thickness, possible lack of homogeneity and undiluted matrices which could be eliminated or reduced by the use of the fusion process.

Third, although the addition of La_2O_3 does assist in matrix-matching samples of a variety of rock types, it can usually be deleted from preparation methods due to the advancement of the modern software packages. Traditionally, La_2O_3 was used to flatten or smooth the spectral response resulting from XRF analysis. Matrix effects were minimized point where most matrices became essentially homogeneous with the addition of La_2O_3. While this method is beneficial when variations in composition occur in the sample, it also suppresses the element of interest response. This signal loss makes the determination of low concentrations or light elements (e.g., Na or Mg) extremely difficult.

PROPOSALS FOR UPGRADE OF SAMPLE PREPARATION PROCEDURES AND POSSIBLE BENEFITS

A series of tests is proposed to determine the benefit of different reagents and alternate procedures to assist with the sample preparation and optimize flow. The alteration of the flux and other reagents could result in the reduction of the total fusion time on the FX200. This would be more cost effective in terms of reagents and also analyst time. A revised procedure could result in the elimination and/or replacement of some of the preparation steps and an even, steady work flow through the XRF lab.

Flux Test

While $Li_2B_4O_7$ is a good choice of flux for fused glass disc analysis, there are other fluxes available that should be examined, namely lithium metaborate ($LiBO_2$). While this flux alone is not the most ideal choice, a combination of $Li_2B_4O_7$ and $LiBO_2$ may be of benefit. The combination of $Li_2B_4O_7$ and $LiBO_2$ in various ratios could reduce the melting point of the present, single-component flux. Potentially, this could rapidly dissolve geological material. The mixture is also known to assist in the dissolution of silica-rich samples (Willis and Duncan 1992).

Additive Test

Other additives besides the present reagents could be tested. Lithium nitrate ($LiNO_3$), an oxidizing agent, could increase the rate of reaction, prevent reduction to metals during fusion, oxidize sulphide minerals and help in the elimination of carbon (Willis and Duncan 1992). Another reagent of interest, lithium fluoride (LiF), is a "fluidizer" which assists in the complete transfer of fusion melt from the crucible to mold. It also helps to render felsic and mafic samples more soluble (Willis and Duncan 1992; Bertin 1984, p.753). Finally, lithium carbonate (Li_2CO_3) assists in the agitation and dissolution of the sample by promoting the escape of CO_2 through the melt (Bertin 1978, p.412).

The fusion of a rock sample can be termed "easy" or "difficult" depending on the elemental composition of the sample. Some re-occurring problems with the fusion process are the presence of elements in the sample which will damage the platinum crucibles (e.g., S as sulphides, As, F, C, base metals) or the viscosity of the melt to be poured. High iron concentrations result in a viscous fusion melt that is more difficult to pour. A small percent of partially oxidized base metals, sulphide minerals, carbon or fluorine may damage the platinumware by combining with the platinum and destroying the purity or integrity of the crucible. Finally there is the consideration of fusion time, samples containing high amounts of Si (greater than 70%) require additional fusion time to properly dissolve. In general, "difficult" samples take longer to fuse and require more attention. The different reagents proposed could benefit the fusion, possibly expand the range of "easy fusion" type samples and reduce our overall fusion time. The cost of and problems associated with La_2O_3 could be eliminated and replaced with fusion-assisting reagents.

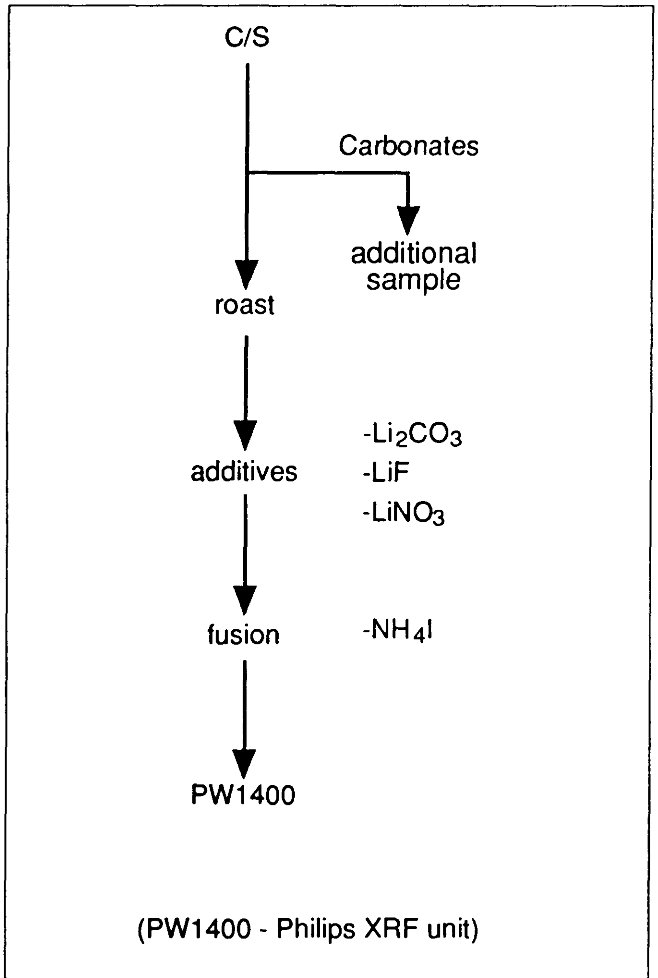

Figure 31.2. Schematic flow chart of proposed sample preparation system.

INTEGRATION OF THE LECO TJA500 LOSS ON IGNITION (LOI) DETERMINATOR INTO THE MAJOR ELEMENT PACKAGE

Samples roasted prior to fusion have reduced S, C, F and moisture contents. S, C, and F may result in damage to the platinumware. Acquisition of the Leco automated LOI unit has made it possible to consider using exclusively roasted material for fusions.

The Leco Instruments Limited TJA500 LOI determinator is a programable loss/gain-on-ignition instrument, which can ramp the temperature to pre-designated levels and measure the sample-weight loss and gain at each increment. The sample is loaded into the crucible at an indicated mark on the inside. The LOI unit automatically weighs the crucible and waits for the sample to be added. The crucible is then weighed again and the sample weight recorded. Up to 19 samples per rack can be determined. Two racks are available, thereby giving a total capacity of 38 samples. The temperature increase can then be programmed by the user to desired levels and the loss or gain of weight calculated at each step.

A POTENTIAL PROCEDURE BASED ON THE FUTURE ACCEPTANCE OF DISCUSSED REAGENTS

Should the discussed reagents prove beneficial, the present procedure could be revised to suit the new fusion additions and newly acquired instrumentation (Figure 31.2). Ideally, all samples will be analyzed for S and C first. Based on those results, the sample will be subject to a pre-fusion roast. If a carbonate rock is noted, either by C result or geologist identification, then enough sample will be roasted to generate enough dehydrated material for fusion. The fusion reagents will be added to the flux into which the roasted sample is mixed. It is speculated that the reagents should act in the following manner during fusion.

As the mixture is heated in the crucible over a low flame, with no agitation, it will begin to melt. As this occurs, the lithium nitrate will begin to bind to elements requiring further oxidation, reducing them to a neutral oxide state. The lithium fluoride will combine with the silicates resulting in easily decomposed silicon tetrafluoride. As the mixture becomes more fluid, the lithium carbonate will assist in the agitation of the melt by the release of CO_2 bubbles. The amount of carbonate should be very small so that this reaction would be completed before the end of the fusion. The remaining "bubbles" will be removed by the nitrate. Also to note the solubility of felsic and mafic samples is assisted when lithium carbonate and lithium fluoride are added to lithium tetraborate. Ammonium iodide is added to the mix at the beginning of the fusion process to assist in keeping the melt fluid and not adhering to the crucible walls. It may have been completely volatized by the end. At this point, just before casting begins, a few grains should be added by the analyst to renew the non-wetting state and facilitate the pour. The lithium fluoride will also assist with the complete pour of sample from crucible to mould and with the production of clear glass discs.

The types of samples which would be considered for alternate sample preparation methods would be those high in sulphide minerals or those with extremely high trace element compositions (e.g., zirconium, rare earths, base metals or Mn, P and Ti). Except for the massive sulphide samples, which would go to AAS for analysis, most other conditions could be attempted by XRF using alternate preparation and calibration methods.

SUMMARY

The relocation of the Ontario Geological Survey–Geoscience Branch to Sudbury in the summer of 1992 has initiated the long and arduous process of re-instituting the total workings of a major laboratory. The Spectroscopy Subsection alone has had over 10 relocated or new pieces of major equipment installed. The estimated date for production start-up should be early in 1993. The considerations of different reagents and possible procedural changes could be worked into the lab after all instruments are on-line. Once the on-line status has been reached, investigations can begin to test various flux/sample/reagent combinations, set optimal conditions for sample types and determine exact procedures.

Integrating the LOI determinator, the fluxer units, carbon and sulphur determinator and the automated sample changers on the XRF instruments will result in a high level of modernization for the major element package. Each procedure will be tested and developed to compliment and enhance the function of each instrument. The success of the above proposal should lead to improved data quality (through the absence of La_2O_3 as a suppressor), more efficient sample throughput, cost-effective operations and a satisfied client base.

ACKNOWLEDGMENTS

Conversations and instructions from Dr. C. Wu, Dr. J. Willis and Dr. A. Duncan at the University of Western Ontario were of immeasurable help in confirming ideas and thoughts.

Support and sevice from Leco Instruments was as beneficial as always.

REFERENCES

Bertin, E.P. 1978. Introduction to X-ray spectrometric analysis; Plenum Press, New York, 485p.

Bertin, E.P. 1984. Principals and practices of X-ray spectrometric analysis; Plenum Press, New York, 1079p.

Ontario Geological Survey 1990. The analysis of geological materials, volume II: a manual of methods; Ontario Geological Survey, Miscellaneous Paper 149.

Richardson, J.M. and Vijan, S. 1991. Automated sample preparation for X-ray fluorescence analysis; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.252–256.

Willis, J. and Duncan, A. 1992. Introductory course on XRF spectrometry, course notes; University of Western Ontario, Department of Geology, p.13a-3—13a-5, p.13a-10.

32. Method Validation in the Spectroscopy Subsection, Geoscience Laboratories

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INTRODUCTION

Method validation is the process used to ensure that a particular analytical methodology using a specific combination of techniques (sample decomposition procedure and instrumental procedure) will yield a particular analytical result which has been proven to be correct (Taylor 1987). As such, method validation is a form of certification. Such an exercise ensures that the specified combination of procedures will yield a precise and accurate analytical value for certain sample types during routine, specified analytical conditions. Preferred procedures are "robust" or "rugged," as they are more independent of human (i.e., analyst performing the test) and support (i.e., reagent blanks and mechanical service) conditions. Reputable laboratories have documented, validated methodologies (standard operating procedures: SOP) that are in place to assure that specific tests are performed correctly and thus to ensure client satisfaction with data quality. It is critical to perform method validation exercises when procedures are instituted or changed, new equipment procured or new staff hired to ensure continuity of quality control (QC) for clients and thus the preservation of the lab's standards.

To meet client demand, the Geoscience Laboratories continually strives to achieve lower determination limits. In 1992, with the move to the Willet Green Miller Centre in Sudbury and the resultant acquisition of new equipment and staff, there is the need to outline the procedures used for method validation in spectroscopy to document analytical expectations and to ensure analytical consistency. Overall, the new or relocated equipment must be proven to produce similar or better quality determinations (i.e., similar or higher figures of merit) in the Sudbury facility, while generating a wide variety of elements in exceedingly varied and often complex sample matrices. The new instrumentation in the Laboratories must be proven to be compatible with old procedures (i.e., OGS 1990) to ensure that differences required by patent law, technological innovation or new analytical requirements do not negate existing protocols. Variables such as staff turnover or new instrument operating conditions can also result in an erosion of SOP unless an established and written method validation program and documentation is in place, used and the results readily available for comparison.

Therefore, the Spectroscopy Subsection of the Geoscience Laboratories, Ontario Geological Survey–Geoscience Branch is documenting the steps which comprise the method validation exercise traditionally used to certify methods within this group. This document outlines the steps which are followed to determine the expected precision and accuracy of a given method (sample preparation and instrumentation technique), the upper and lower determination limits, the limit of quantification and the limit of detection, optimal working range, inherent bias, blank levels and sensitivity. This method validation procedure, when successful, proves the applicability of a given method to geological materials. Within this exercise, speed and cost of analysis, ease of operation, ruggedness, and a comparison to other methods can be assessed and optimized. The outlined exercise ensures that instruments, procedures and reagents are applicable and appropriate to geoanalysis and that QC is maintained throughout the Subsection. This documentation is the first such written baseline available for perusal. Revisions are possible and expected — thus, the requirements to discuss several key steps thoroughly (as indicated). A final version will be compiled in the OGS quality-control manual (OGS in prep.).

PROCEDURAL INFORMATION

Method validation exercises can be undertaken using 4 different types of procedures. Acceptable results can be obtained by 1) the analysis of synthetic formulations, 2) analysis of spiked samples (standards additions), 3) comparison of obtained results with those obtained by a official or standard methods (i.e., ASTM testing), or 4) by the analysis of certified reference materials of known concentrations (Garfield 1991). The usefulness of any of these approaches is dependant upon the sample types expected and the availability of methods or standards.

Unlike other fields of analysis, there is a wide range of rock, ore and related materials of certififed composition that are known as standard reference materials (SRM) and are available to geoanalysts. These SRMs are produced and certified by several international organizations (cf. Govindaraju 1989). This availability, coupled with the difficulty in matrix matching the complex composition of rocks and the resulting spectral complexity, means that option 4, analysis of certified material, is perhaps the most appropriate way to develop a method validation exercise for geological samples. It is used almost exclusively for elemental analysis in the Spectroscopy Subsection.

SETTING ANALYTICAL STANDARDS

Every laboratory has a set of general benchmark figures of merit or analytical goals which each method and analyst must meet. At the Geoscience Laboratories, the expectation is that over a five-year period, precision and accuracy will not exceed ±10% (2σ) for a given element when that element's concentration is more than 10 times the detection limit of the method in question (OGS 1989). The long time-frame is required because data from any given year is typically integrated into larger projects that last up to five years. Thus, precision is typically quoted in either parts per million or percent (i.e., absolute) at the 95% confidence limit (twice the standard deviation) for a value at 10 times the determination limit of the method (OGS 1989). For some tests (e.g., T4), when the data are 100 to 300 times the determination limit, the relative standard deviation is less than 5% (OGS 1989).

To achieve the five-year benchmark figure, precision and accuracy of about 5% is demanded on a per batch or job basis. Typically, a batch or job would consist of 20 to 70 samples submitted by 1 geologist. Such stringent requirements means that there is a 5% cushion over the long term. Thus, variables, such as reagent, personnel, technique, instrumentation or lab-setting changes, can be absorbed and the data still be acceptable to the Ministry's long-term program objectives. Thus, any method validation exercise must certify that the method in question can indeed generate data of suitable high quality to meet the short-term Laboratories' standards. This ensures that long-term figures of merit are not compromised.

STEPS IN METHOD VALIDATION: GUIDELINES

Method validation consists of several steps which should be undertaken in a well-constrained order. Much of the exercise can be completed in a relatively short time frame (i.e., several days to 1 week). The second part of the process (operational compilation) requires a longer time frame (e.g., 6 months to 1 year) and results in a larger data base. At the end of that time period, a statistically coherent body of data should have been gathered under a normal range of operating conditions. This data will be for a variety of reference sample types and the elemental contents will be well determined. At this point, factors contributing to ruggedness can also be evaluated.

To avoid the possible wastage of SRMs, it is appropriate to first determine precision using internal reference materials and samples of varied composition which span the advertised analytical range of the instrument. Twelve to 15 samples is a minimum number to ensure that the range is properly tested. At least 7 blanks should be determined at this stage as well.

When the precision is established, the accuracy should be determined using SRMs (Taylor 1987). Depending on sample size and SRM availability, approximately 7 determinations should be undertaken of a minimum of each of 5 SRMs with diverse compositions. More should be used, if more are available that meet all criteria. If in-house reference materials are analyzed during this part of the exercise, their composition can be determined by fiat. Such informal certification can be useful. A minimum of 7 blanks should be included again.

From the data derived from this analytical work, the figures of merit for the method can be determined. It is important to reiterate that the procedure outlined above is meant to be used as a guideline. If the number of replicates can be easily increased, this is preferable. If the number of SRMs must be diminished, this is unfortunate, but there are times when circumstances may warrant use. Any deviations from the procedures set forth here should be thoroughly discussed by all involved before the method validation exercise begins to minimize the impact of compromises.

TRAINING/DETERMINING OPERATOR REPRODUCIBILITY

Any method validation exercise has as a fundamental tenet that the operator be fully trained, competent with the procedures and comfortable performing them routinely. Secondly, the instrument and/or equipment used must be fully functional to vendor specifications. To ensure this, the analyst in question should repeatedly analyze a small suite of samples of unknown compositions which are both within the middle of the advertised instrument analytical range and available in great quantity. Typical "fodder" could be the remnants of previously submitted samples. This will ensure that the analyst is comfortable with instrument operation and the performance of the samples while they are analyzed. If is difficult to exactly say how many samples should be analyzed before the validation exercise begins: it depends greatly on the experience and capabilities of the analyst. Given the importance of the method validation exercise, it is best if the analyst determines, in consultation with other staff, how soon after training the method validation can begin.

SELECTION AND USE OF REFERENCE MATERIALS

Reference materials to be used during a method validation exercise should be selected on the basis of similarity in composition to typical sample material. This equivalence should encompass concentration range, analytes of interest, matrix effects, possible spectral interferences and sources of determinate and indeterminate error. If these criteria are not fulfilled, then the method will not be validated for the sample type. The elemental range in the suite of reference materials should span both the analytical range of the instrument and the range of geological compositions found in nature (or commonly submitted samples) if possible. Obviously, other parameters to be considered include the degree and confidence with which the certified values of the reference materials are known and the availability of SRM based on the amount(s) required to complete the validation exercise.

The OGS has both in-house reference materials (known as "MRB samples") and SRMs. These serve several quality-control purposes. Only SRMs can provide an authoritative measure of accuracy. The composition of these samples is known and well documented (e.g., Abbey 1983; Govindaraju 1989). SRMs must be used sparingly. Care must be taken not to waste them either accidentally or as a result of poorly considered activities, to ensure a long-term supply. Typically, 6 to 10 SRMs covering a wide compositional range should be used in a method validation exercise. They should not be analyzed until the analyst is highly confident in his ability to perform the procedure correctly.

It is important that reference materials held in high regard and known to be well determined are selected. Unfortunately, such materials are scarce and treasured. However, given the analytical difficulties that can arise if the compiled analytical values of the SRMs are in error, it is imperative to make the best compromises. For instance, inhomogeneities in the GXR series of SRM (Kane et al. 1992) have resulted in poor accuracy and bad calibrations. Overall, it is better to use a limited number of SRM that have well-determined compositions than a wide variety of SRM that are less well determined.

A suite of approximately 30 in-house reference materials comprise the MRB samples. These were generated to support 4 important Geoscience Laboratories' functions. First, they provide a good quantity of well-characterized materials for in-house method development. Second, they are used to routinely monitor analytical performance. Third, the analysis of these materials provides data for the long-term quality-control program within the Laboratories. Fourth, they provide a means for the Laboratories to monitor external analytical work done by contract agencies (Lightfoot et al. 1991). These materials are known as the MRB samples because the first group (MRB 1–7) were developed when the Laboratories were part of the Minerals Research Branch of the Ontario Ministry of Natural Resources.

The composition of MRB samples is documented in house either by association or by fiat (in association with SRM) or analytically using several independent analytical methods. They are used extensively to determine precision or as digestion and instrument control samples as they are available in reasonably great quantity (hundred kilograms prepared at once). They have been collected from Ontario rock units to represent the various types of incoming samples (Lightfoot et al. 1991). In contrast to SRMs, MRB samples are used more generously to monitor routine analytical work on a daily basis.

In the FeO validation exercise conducted by Tait and Richardson (this volume), 13 MRB samples were analyzed with 5 SRM (Tait and Richardson, this volume, Table 33.1). Combined, this suite had a FeO content ranging from 0.13 to 15.15% FeO which represented a wide range of geological compositions (intrusive and extrusive rocks, felsic and mafic rocks, altered and fresh rocks and iron formations). Alone, the SRMs had a compositional range from about 3.5 to 15% FeO and consisted of gabbro, syenite and iron formation. The MRB samples were certified by fiat during this exercise.

DETERMINATION OF BLANK

The term "blank" is used to refer to any contamination that is added from all sources external to a sample. Such contaminants may be environmental (i.e., the result of poor housekeeping, old equipment, equipment reacting with reagents) or due to contamination in reagents (purchased chemicals or even water). Such contaminations can introduce measurable amounts of elements of interest to the analytical process. Thus, "high blanks" can seriously effect the accuracy of low or trace level determinations (Taylor 1987). The 3 main ways to minimize the blank contribution to an analysis are to reduce the size of the blank contribution as much as possible by using minimal amounts of pure chemicals, to vigilantly keep records of chemicals and vessels and isolating usage of same to clean, conditioned areas, and by closely monitoring the level of blank determinations.

Blanks should be analyzed with each batch of samples, when new reagents are opened for use and when operation conditions change (i.e., fumehood supply air turned off and on). The results can be plotted on control charts (concentration versus time, cf. Taylor 1987) or treated statistically (Taylor 1987) to allow the determination of systematic trends or outliers. Abnormalities can then be correlated with operational causes and corrective measures taken. Obviously, contamination can generate a discrepancy in the final data.

The level of the blank value is determined by measuring a sample which has been subjected to all the analytical conditions and procedures that normal samples are except for the addition of the actual sample powder or liquid to the vial or dish. The measured value derived from this is said to be the "reagent" blank. If high blanks are determined, probable causes should be evaluated and minimized as much as possible. A final, but not optimal, way to combat a high reagent blank is to determined the reagent blank and subtract it from the measured result for a sample, thus getting a "true" value. Such determinations are most critical when the measurements are close to the limit of detection of the method used.

DETERMINATION OF PRECISION (RELATIVE STANDARD DEVIATION)

Precision is a measure of how closely a single measurement agrees with another measurement of the same substance. The measurements must be generated by repeated application of the same process under specified conditions (Taylor 1987). Precision is quantified by the standard deviation of the mean. Precision can be expressed in a absolute sense (Table 32.1, Equation 1) and in a relative or proportional sense (see Table 32.1, Equation 2). The relative precision is also known as the relative standard deviation, standard error or RSD. Doubling the value obtained from Equation 1 (which generates a precision value at the 1s level) will yield the absolute uncertainty at 2s or the 95% confidence limit. Either the 1s or 2s values can then be divided by the mean to get the RSD at either 1s or 2s level, respectively. Final figures of merit for methods should be expressed at the 2s level.

In any situation, the body of data can either be from a small subset of all the true values (the sample) or can reflect the entire set of data available (the population). If the mean is derived from some components of a population (i.e., a sampling), it is denoted as μ. If it reflects all components of a population, the mean is denoted as X. Thus, X represents the average of some individual measurements, but not the average composition of the universe of those values. Following through, the absolute standard deviation derived from a sample measurement is denoted "s", that of a population as σ (Taylor 1987). When population statistics are being calculated, the denominator of the equation is n, the number of measurements. In contrast, when using sample statistics, the denominator is (n-1). (n-1) represents the degrees of freedom or independent deviation calculations that are possible within the sample after X has been calculated. This difference can result in separate values for "s" and σ, particularly when n is very small or X is very low (close to the determination limit). With either increasing numbers of replicates or larger elemental abundances, the difference between "s" and "σ" decreases.

Table 32.1. Equations.

Equation 1. Absolute Standard Deviation

$$ASD = \sigma = \sqrt{\frac{\Sigma(X_i - \mu)^2}{n}} \approx "s" = \sqrt{\frac{\Sigma(X_i - X)^2}{n-1}}$$

where σ = population standard deviation (used with μ)
"s" = sample standard deviation (used with X)
X_i = individual analytical measurement
X = mean or average measurement (used with s)
μ = mean or average measurement (used with σ)
n = number of measurements

Equation 2. Relative Standard Deviation

$$RSD = \frac{s}{X} \times 100 \text{ (in percent)} \approx RSD = \frac{\sigma}{X} \times 100$$

Equation 3. Accuracy

$$\left(\frac{\text{measured value - certified value}}{\text{measured value}}\right) \times 100 \text{ (result in percent)}$$

Equation 4. Percent difference

$$\left(\frac{\text{measured value - "by fiat" value}}{\text{measured value}}\right) \times 100 \text{ (result in percent)}$$

where certified value: "known" value, based on Govindaraju (1987)
measured value: analytical result determined experimentally or mean of several such results
"by fiat value": "best value", *see* next section

In a typical method validation exercise, approximately 7 replicates of each MRB sample, SRM and blank are generated, thus, statistics which reflect sample testing should be used (i.e., "s" and X). Population statistics should be used for large groups of data, particularly if the data are determined on many aliquots of a relatively small source (e.g., the 10 L CHK control solutions prepared to monitor ICP analysis). In their reports on long-term ICP-MS and ICP-OES quality control, Beneteau (this volume) and Henri (this volume) report data compilations based on 100 or 340 determinations of control solutions. In these cases, population measures were used (σ). In contrast, the statistical measures reported for SRM in these papers and all measures in Tait and Richardson (this volume) should be reported as sample statistics ("s"). It is difficult to determine σ (as opposed to "s") for a SRM, as this would involve analyzing a significant portion of the entire supply of the material. A possible exception might be statistical values determined from the compilation of analytical values for BCR-1 (Gladney et al. 1990), a famous and now nearly depleted SRM.

The absolute standard deviation (ASD) and the relative standard deviation (RSD) both express the degree of uncertainty associated with a particular measurement either absolutely or relatively. The ASD is most useful to the end user of a data set, as it indicates the total amount of uncertainty associated with a single measurement expressed in the same units as the measurement. For instance, if a validation exercise was evaluating the determination of Rb and CaO by XRF, the ASD would be expressed in ppm Rb and wt % CaO. Percent in a proportional sense would not figure into the expression. In the case of MRB 7 in Table 33.1 of Tait and Richardson (this volume), the measured FeO content of 9.00% FeO has a ASD of ±0.1% FeO. This means that the "error bars" associated with the measurement are ±0.10% FeO "wide" and that the true value lies between 8.9 and 9.1% FeO. There are not actually any errors per se in the measurement, the ASD simply provides a quantification of the absolute uncertainty inherent in the measurement processes.

However, when assessing the validity of a method and during method comparison, the ASD is not as useful as the RSD. The RSD allows a better comparison of the degree of uncertainty because it is a proportional measure. Since the RSD is proportional, it is determined in percent, not as a unit related to the analyte composition (i.e., % as opposed to ppm Rb or wt % CaO). The RSD provides a more meaningful measure of differences in precision across a wide compositional range. For example, in Tait and Richardson (this volume), both MRB16 (0.52% FeO) and MRB 17 (0.13% FeO) have ASD of ±0.01% FeO (Tait and Richardson, this volume, Table 33.1). However, the RSD for these samples are different, 2.25% versus 9.11%. Such a difference in RSD is the result of the small amount of FeO present in MRB17. Typically, precision degrades near the determination limit as the analytical signal measured is small (cf. data for Be vs that for Ni in MRB–29 in Henri, this volume; Table 30.3). Accuracy is also effected (cf. Cs in BHVO–1, Beneteau, this volume, Table 29.4). The RSD highlights these differences in a way that the ASD cannot and, thus, is a more useful tool in method validation or quality-control exercises.

DETECTION LIMIT, LIMIT OF QUANTIFICATION, DETERMINATION LIMIT, LIMIT OF LINEARITY

The detection limit of a method is the point at which a measured value is larger that the uncertainty associated with it (Taylor 1987). Colloquially, the limit of detection is equated with the point at which a peak can be distinguished from a background. It is defined statistically as 3 times the value of the standard deviation as the concentration approaches 0 (s_o)(Taylor 1987). Quantitative measurements are not possible at the detection limit. The lower limit at which measurements become quantitative is the limit of quantification (LOQ) or determination limit. This is defined as 10 times the value of the standard deviation as the concentration approaches 0 (Taylor 1987). However, at the limit of quantitation, the relative confidence in the measured value is about ±30% (2σ) at the 95% probability level (Taylor 1987), which is outside the normal quality-control specifications of the Geoscience Laboratories. The parameter s_o or the standard deviation at 0 concentration cannot be readily measured. However, it can be easily calculated. This parameter is the intercept of that line regressed through the absolute standard deviation data generated by the replicates of samples analyzed to determine precision. Thus, it is expressed graphically on a plot of ASD versus concentration (Figure 32.1).

As the analyte concentration increases, the signal intensity increases and measurements taken become statistically more sound. The upper limit of reliable measurement is the point at which the relationship of concentration to intensity is no longer linear and, thus, calibrations cannot be carried out. These parameters delineate the dynamic range of an analytical method. The definition of the analytical working range varies depending upon the required precision and accuracy benchmarks. Typically, the effective working range of the instrument in the Geoscience Laboratories setting is narrower than documented by the vendor due to the stringent quality-control requirements.

ERROR MAGNIFICATION CURVE

The relationship between RSD and concentration can be portrayed graphically (Figure 32.2) using an error magnification curve. During method validation exercises, each sample used to determine precision (typically, but not restricted to, the MRB samples and SRMs) is plotted to yield the curve. The curve generated from such data is typically very steep at lower concentrations. The theoretical detection limit and the limit of quantitiation cannot be distinguished. The overall working range is represented by a flattening of the curve. As the limit of linearity is approached, the curve gently inclines up as higher RSDs are generated (Figure 32.3). Using such a curve and the general laboratory precision benchmark points, the upper and lower limits of the effective working range can be determined and concentrations assigned to these endpoints. If required, the uncertainty associated with measurements outside the normal work-

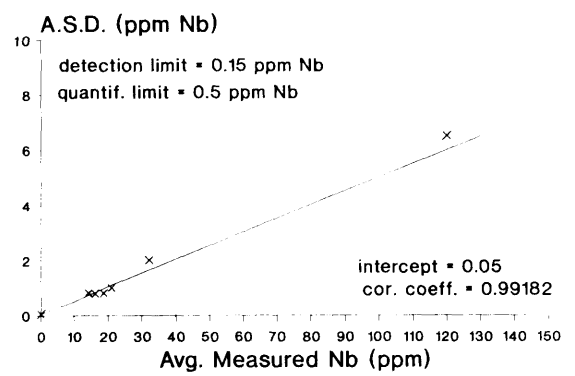

Figure 32.1. Graphical representation of detection limit and quantification limit (data *from* Beneteau, this volume).

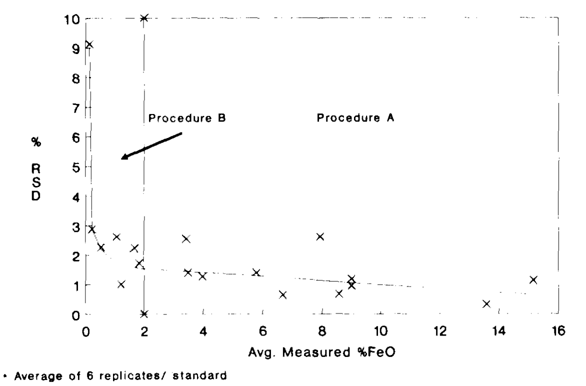

Figure 32.2. Error magnification curve for ferrous iron determinations (*from* Tait and Richardson, this volume).

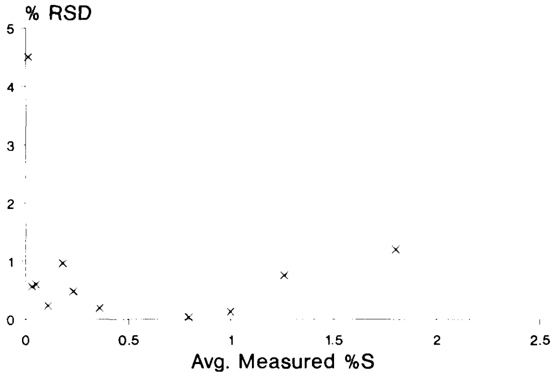

Figure 32.3. Error magnification curve for sulfur (Sonnylal and Richardson 1991).

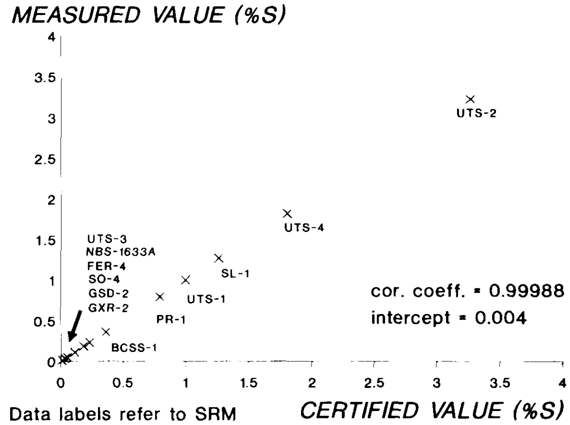

Figure 32.4. Graphical representation of accuracy (Sonnylal and Richardson 1991).

ing range can also be predicted with some confidence.

For example, the lower limit of the Geoscience Laboratories working range of the overall potentiometric titration method (i.e., both procedures A and B) is 0.2% FeO (i.e., inflection point on Figure 32.2). At these iron contents, the RSD of the procedure is ±3% (1s), which is near the general Geoscience Laboratories' benchmark figure of merit (about ±5% 2s) for single batches of samples. The data also indicates that, although samples containing up to 15% FeO were analyzed, the upper limit of the working range has not yet been determined (i.e., the RSD has not yet begun to increase). Thus, the true working range of the potentiometric titration procedure has not yet been established.

DETERMINATION OF ACCURACY

Accuracy is an absolute measurement of how closely a determined value approaches a known or certified value (*see* Table 32.1, Equation 3). At the Geoscience Laboratories, SRMs with well-determined "recommended" certified values (cf. classification of Abbey 1983; Govindaraju 1989) are used to determine accuracy. A related quantity is the "percent difference" which documents how closely a determined value approaches another value thought to be correct (e.g., an analytical value determined by fiat during a method validation exercise) (*see* Table 32.1, Equation 4). The degree of accuracy can be expressed in 2 ways. Using Equation 3, accuracy can be expressed as a positive or negative quantity for each SRM. These data can be averaged for a suite and expressed as ± the mean of the procedure. For example, the accuracy determined in the FeO method validation exercise done by Tait and Richardson was -1.86% FeO (their Table 33.1, this volume). Alternatively, measured values can be plotted against the certified values for all SRM and a linear regression fitted to the data (Figure 32.4).

Bias is an incorrect result that arises due to a systematic error inherent in a method or that is caused by an artifact or idiosyncrasy in or of the measurement system. These can include temperature effects, contamination errors or calibration errors. Bias to the data can be either positive or negative and influences the accuracy. Bias is documented statistically by the parameters derived from the linear regression of the measured and certified values of the SRM used in the accuracy exercise. After linear regression, the slope of the line on a plot such as Figure 32.4 should be 1, the intercept approach 0 and the correlation coefficient approach 1. If not, there is bias in the data (Taylor 1987). For instance, a positive intercept could be generated by consistent contamination of the samples. This would also be observed in the blank determinations. If the correlation coefficient is low, this indicates unacceptable scatter in the data, perhaps resulting from either the measured determinations or poorly determined SRM were used.

DETERMINATION OF THE COMPOSITION OF IN-HOUSE REFERENCE MATERIALS BY FIAT

Although the correct determination of the elemental composition of the MRB samples is of prime importance to the Laboratories, much of the analytical work for these samples is based on in-house characterization. Analyzing the MRB samples concurrently with the SRMs as part of a method validation exercise allows a statistically representative compiled value to be determined for the MRB samples and, thus, a strong foundation for a "best value". If the determinations on the SRMs are accurate within the Laboratories' standards, then, it follows that, if the MRB samples were analyzed at the same time, by the sample procedures, that the determined value represents the true value for the MRB sample. Thus, the MRB composition is determined by association or by fiat. In no way do these values represent truly certified values: such determinations are only "best values".

TESTING IN UNUSUAL CIRCUMSTANCES

In some instances, the Geoscience Laboratories is asked to analyze unusual samples for which the elemental constituents are expected to be outside the normal working range of a particular methodology. In such special circumstances, the method validation exercise allows some estimation of the potential analytical uncertainties. For example, if a sample is thought to contain a very low amount of FeO and analysis is requested, using the error magnification curve, the potential RSD can assessed. Samples having about 0.1% FeO will have a RSD of about 9% and, thus, an ASD of 0.01% (cf. Figure 32.1 and Table 32.1, Tait and Richardson, this volume).

RUGGEDNESS AND OPERATIONAL FOLLOW-UP

During the development of a method, the "ruggedness" or tolerance of critical operational parameters must to be determined. Such factors could include variations in environmental considerations (humidity, temperature, pressure), or chemical factors (reagent concentration, pH control, voltage). Such parameters should be determined functionally (i.e., during application of the procedures), so that their relative effects on the measured analytical values be determined. If possible, these parameters should be optimized (Taylor 1987) and as much as possible, tested, before a method is validated (cf. Youden 1989).

Unfortunately, in practise it is not possible to test all possible parameters before a method is validated and used. Weaknesses or problems with a method may only arise with the analysis of an unusual sample type or acquisition of new supporting apparatus (i.e., new crucibles). Thus, a "compilation period" of 10 to 12 months is required after every method validation exercise during which blanks, standards and duplicates are analyzed assiduously, the data carefully charted and the results closely monitored. The assessment of the resultant data will illustrate how rugged the method is and if redefinition of the method is required.

After obtaining the method validation data outlined in Tait and Richardson (this volume), the method was put into routine use and monitored. After operation for 10 months in the Toronto facility, the results in their Table 33.2 were obtained. Based on several SRM determinations, it appeared that the accuracy of the method was improving for some reason. Furthermore, compiled values for MRB29 also appeared to contain more FeO than was determined in the validation exercise. This correlated with the use of new crucibles with tightly fitting lids. Follow-up work in Sudbury may confirm this when the method is revalidated.

The T2 and T4 are 2 extremely well-documented and rugged methods in the Spectroscopy Subsection that have been used for several years. In both cases, there is a large integrated statistical database (documented in Henri (this volume) and Beneteau (this volume), respectively) which have resulted from using a well-tested, rugged method. These methods are subjected to several levels of quality control to ensure data quality. The sample digestion procedures and instrument operation are monitored in both cases. Inconsistencies, if present, could be easily observed due to the statistical tracking of all procedures that are part of the method. Also, due to staffing changes, it was also possible to compare the impact of 2 fully trained analysts in different years for the T2 package. The high correlation coefficient in Henri's (this volume) Figure 30.1 (0.99964) indicates that the method is exceedingly robust. Long-term data collection such as this further supports the method validation exercise and ensures that quality-control benchmarks are met.

BENEFITS OF THE METHOD VALIDATION EXERCISE

Overall, the method validation exercise outlined here has many advantages. First, it provides a standardized means to determine the figures of merit, especially precision and accuracy, that are vital cornerstones of a client's confidence in, and satisfaction with, a laboratory. Second, it convinces laboratory staff that an appropriate level of expertise is achieved, maintained and that the method is functioning in an appropriate manner. Third, it allows an analyst to demonstrate his/her ability to do a analytical procedure correctly and allows the analyst to prove the quality of his/her work. Fourth, it provides a clear perspective on the use of a specific instrumentation or certain sample types, which can then be used to compare with previous or other methods in terms of cost or time effectiveness (cf. Tait and Richardson, this volume). Such an exercise is a building block in the quality control program of a reputable laboratory.

CONCLUSIONS

A method validation exercise is documented that can be used to determine the figures of merit (precision, accuracy, sensitivity, working range, detection limits, blanks) for data generated using a specific analytical method for a variety of expected sample types. It provides a framework which can be used to compare with other methods in analytical figures of merit and allows a baseline against which cost, time effectiveness and other parameters can be assessed. Finally, it will convince all concerned (operator, supervisory staff and clients) that the level of expertise is achieved, maintained and that the instrument is capable of functioning in an appropriate manner.

ACKNOWLEDGMENTS

The staff of the Spectroscopy Subsection has encouraged me to clarify and document these concepts which we use regularly. It is because of their analytical skill and good humour that Geoscience Laboratories can consistently provide the high-quality analytical data that is available to Ministry staff in the M1, M2, M3, T2, T3, T4 and T5 analytical packages.

REFERENCES

Abbey, S. 1983. Studies in standard samples of silicate rocks and minerals 1969–1982; Geological Survey of Canada, Paper 83–15.

Garfield, F.M. 1991. Quality assurance principles for analytical laboratories; Associations of Official Chemists. 192p.

Gladney, E.S., Jones, E.A. Nickell, E.J. and Roelandts, I. 1990. 1988 Compilation of elemental concentration data for USGS Basalt BCR–1; Geostandards Newsletter, v.14, p.200–359.

Govindaraju, K. 1989. Compilation of working values and sample descriptions for 272 Geostandards; Geostandards Newsletter, v.13, p.1–113.

Kane, J.S., Seims, D.F. and Arbogast, B.F. 1992. Geochemical exploration reference samples GXR–1 to GXR–4 and GXR–6: Evaluation of homogeneity based on high precision analyses. Geostandards Newsletter, v.16, p.45–54.

Lightfoot, P.C., Chai, G. Hodges, A.E. and Rowell, D. 1991. An update report on the certification of the OGS in-house MRB standard reference materials; *in* Summary of Field Work and other Activities 1991, Ontario Geological Survey, Miscellancous Paper 157, p.231–236.

Ontario Geological Survey 1989. Analytical capabilities and services; Geoscience Laboratories, Ontario Geological Survey.

——— 1990. The analysis of geological materials, volume II: a manual of methods; Ontario Geological Survey, Miscellaneous Paper 149.

——— in preparation. The analysis of geological materials, volume III: quality-control procedures.

Sonnylal, S. and Richardson, J.M. 1992. Carbon, sulfur and water determinations by combustion/infrared absorption (via induction furnace); *in* Abstracts, Ontario Mines and Minerals Symposium 1991, p.52.

Taylor, J.K. 1987. Quality assurance of chemical measurements; Lewis Publishers, Chelsea, Michigan, p.13–14.

Youden, W.J. 1989. Statistical techniques for colloborative tests; Association of Official Chemists, Arlington, Virginia.

33. Determination of Ferrous Iron by Automated Potentiometric Analysis

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INTRODUCTION

Iron is a major constituent of geological materials: the average composition of the Earth's crust is approximately 6.2% Fe (Fyfe, 1974). Accordingly, as part of the Geoscience Laboratories' major element packages, ferrous (Fe^{2+}), ferric (Fe^{3+}) and total iron are determined. In the M1 package, total iron is reported as determined by X-ray fluorescence (XRF). For the M2 package, total iron is determined by XRF, ferrous iron by titration and ferric iron by difference (Procedure EA15, OGS 1990). Both ferric iron and total iron can also be determined by wet chemical means by special request (Procedure EA14, OGS 1990). Traditionally, the ferrous iron procedure has involved a manual volumetric titration. As part of a modernizing initiative, a new automated potentiometric method has been acquired by the Spectroscopy Subsection. It utilizes the classical procedures of sample decomposition, but substitutes an automated potentiometric titration for a manual volumetric one.

Changing the titration procedures has advantages such as increased productivity, better accuracy and precision, reproducible determination of the endpoint with no wastage of reagents, and the elimination of human error in the transfer and calculation of data. Operator bias is also minimized during titration, thus consistently providing more reproducible data. Preliminary data based on 10 months operation in the Ministry's Toronto laboratory has indicated an accuracy of ±1.86% FeO, a relative standard deviation (measure of precision) of ±1.48% FeO within the working range of 0.2 to 16% FeO and increase in productivity of 100%.

METHODOLOGY

Most modern instrumental analytical techniques provide the elemental composition of the sample, but do not readily provide information about the oxidation state of its constituents. Mössbauer spectroscopy can provide such information, but the complex spectra produced for multicomponent mixtures such as rocks mean that this technique is of limited use for routine geoanalysis. Classical volumetric methods (i.e., titration) have been used to reliably determine the FeO content of rocks. Potentiometric titration is routinely used now at the Geoscience Laboratories. The full analytical procedure currently used is available upon request from the Geoscience Laboratories Section in Sudbury.

Sample Preparation

In summary, the sample is decomposed by heating 0.5 g of the rock powder in sulphuric and hydrofluoric acids contained in a covered platinum crucible. The crucible lid and contents are then placed in a mixture of saturated boric and sulphuric acids. The resulting solution is titrated against standardized potassium permanganate which oxidizes the ferrous iron to ferric iron (Equations 1, 2 and 3). The saturated boric acid solution is used to remove excess fluoride ions (Equations 4 and 5):

$$5Fe^{2+} \xrightarrow[77V]{} 5Fe^{3+} + 5e^- \quad (1)$$

$$5e^- + MnO_4^- + 8H^+ \xrightarrow[1.51V]{} Mn^{2+} + 4H_2O \quad (2)$$

$$MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O \quad (3)$$

$$H_3BO_3 + 2H_2O \rightarrow H_4BO_4^- + H_4O^+ \quad (4)$$

$$H_4BO_4^- + 4HF \rightarrow BF_4^- + 4H_2O \quad (5)$$

There are 3 main problems associated with this procedure. Foremost is oxidation of the sample during decomposition, but prior to titration. This is minimized by ensuring that decomposition vessels are fitted with tight lids and that the sample is titrated as soon as decomposition is completed. Secondly, when excess sulphur is present in the sample (i.e., sample contains greater than 8% sulphide minerals) Fe^{3+} is reduced to Fe^{2+} by S during the analytical procedure and, thus, a falsely high FeO content can be reported. In these cases, a quality-control (QC) note to the client is in order. Most rocks samples submitted to the Geoscience Laboratories in the past do not exceed these sulphur levels. Finally, although most iron-bearing minerals form soluble ferrous and ferric sulphates and are thus decomposed by the above procedure, some minerals such as tourmaline, staurolite, ilmenite, magnetite and pyrite are incompletely dissolved. In these cases, there will be residue remaining in the digestion vessel and the client notified via a QC note. Upon request, X-ray diffraction is available within the Geoscience Laboratories to identify such residue.

TITRATION

Theory

Titration is the process by which the quantity of an analyte in a solution is determined by the amount of a standard reagent it consumes to achieve a certain pH or electrical potential. The goal of every titration is to achieve an such end point, i.e., to add a suitable amount of standard (or exactly known) solution to the test solution so that the test solution is chemically equivalent to the known substance with which it is reacting. This happens at the "equivalence point", but this point can only be estimated by observing physical changes associated with the chemical state (Skoog and West 1982). Traditionally, a physical change is used (colour difference). In these cases, a chemical compound or indicator is added to the reaction so that the solution changes colour at the equivalence point.

To determine the concentration of the analyte in the solution made from the submitted sample, the volume of the standard solution or titrant added before the end point is reached is noted. Since 1 solution has a known concentration (the titrant), that of the other (submitted sample) can be calculated. This is done mathematically after recording the volumes of the solutions used (in mL) and, thus, is considered to be volumetric in nature. Alternatively, identical results can be obtained potentiometrically. In this case, the end point is found by measuring the potential on an electrode immersed in the reaction mixture. In both cases, stoichiometry is assumed during the reaction.

Measurement of the electrical potential across a suitable indicator electrode (in the case of FeO, massive Pt) also permits the establishment of the equivalence point. Such a titration involves measuring and recording the cell potential in (mV or pH) after each addition of reagent. At the start, the titrant is added in large doses, however, as the end point is reached, the increments are decreased in size. Controlling factors include the ensuring time to reach equilibration (i.e., drift in measured potential should be less than 1 to 2 mV/minute) and thorough stirring. End points are recognized by the midpoint of a steeply rising curve of potential versus reagent volume. Alternatively, the first or second derivatives of this curve can be used. Potientiometric titrations provides inherently more accurate data than volumetric titrations, as the former are based on colour changes that are determined visually. Potentiometric titration is particularly useful when titrating coloured or turbid solutions.

Instrumentation

The Metrohm AG 670 Titroprocessor is a fully programmable automatic titrator which offers sophisticated flexibility and control over potentiometric titrations. It has sufficient memory to store up to 68 complete procedures, for a variety of applications, using 3 different types of titrations. The unit also has an automatic burette, pump, and a ten-position sample changer (Photo 33.1). Programming parameters are easily selected and a record of the titration curve, data and calculated concentrations are printed out by an internal printer. The titroprocessor can accommodate external devices such as an external data system and a balance. The OGS Laboratory Information Management System (LIMS) can be linked, via an RS232 port, to the titroprocessor. These connections virtually eliminate the possibility of human transcription errors. All mathematical and statistical calculations are incorporated in the procedures, thus eliminating mathematical errors. Up to 68 complete methods, including all parameters, calculations and sample changer commands, as well as instructions for data output, can be stored in the titroprocessor memory. Three titration styles are accommodated.

Dynamic titration is characterized by incremental titrating with variable volume steps. The volume increments are large in the flat part of the curve, i.e., the titration is relatively fast and the equivalence point is not approached. In the steep part of the curve, the small-volume increments are dispensed as the equivalence point is close. This mode of titration has the advantage of accumulating many data points near the equivalence point and, thus, the point can be interpolated exactly and a rapid, precise titration is possible. The OGS method uses this mode as a default procedure (known as Procedure A) for first-pass FeO determinations because most samples submitted to the Laboratories contain greater than 2% FeO.

In the monotonic titration mode, the volume increments are independent of the region of the titration curve. The monotonic titration is used to maintain precision when small titrant volume increments are needed. This style of titration is used regularly within the Laboratories for blank determinations and geological materials with low FeO content (less than 2% FeO) after dynamic titration and is known as Procedure B.

End-point titrations are titrations which are carried out to a preset end point. End-point titrations are generally used when 1) a determination must be carried out

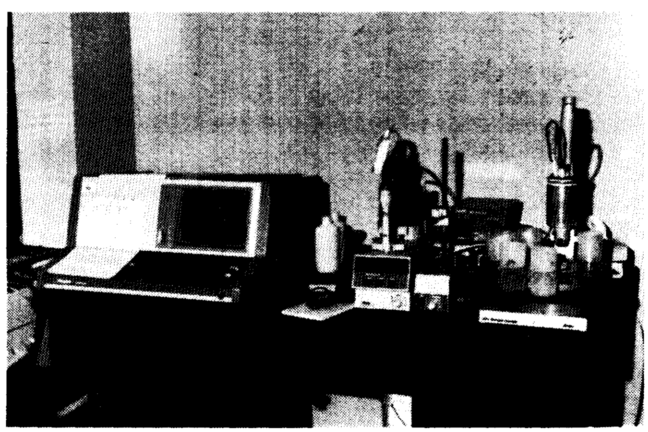


Photo 33.1. Metrohm AG titroprocessor as configured at the Geoscience Laboratories Toronto facility. Titroprocessor (left), dosimat (central) and sample changer (right), keyboard of LIMs computer just seen on far left.

Table 33.1. Accuracy and precision data generated using in-house reference materials (MRB 7 to 18) and standard reference materials. Figures of merit were calculated on the basis of an average of 6 replicates per reference material. Certified values from Govindaraju (1989). ASD, absolute standard deviation; RSD, relative standard deviation.

REFERENCE MATERIAL	ROCK TYPE	CERT. VALUE (%FeO)	MEAS. VALUE (%FeO)	# RUNS	PRECISION ASD ±(%FeO)	PRECISION RSD ±(%)	ACCURACY (%)
MRB–7	Basalt		9.00	8	0.10	1.17	
MRB–8	Rhyolite		1.05	5	0.03	2.61	
MRB–9	Felsic Volcanic		1.21	5	0.01	1.00	
MRB–10	Peridotite		1.67	5	0.04	2.22	
MRB–11	Ultramafic		7.92	7	0.21	2.60	
MRB–12	Diabase		6.66	5	0.04	0.63	
MRB–13	Iron Formation		9.02	5	0.09	0.95	
MRB–14	Andesite		3.97	5	0.05	1.26	
MRB–15	Rhyolite		1.83	5	0.03	1.71	
MRB–16	Pegmatite		0.52	5	0.01	2.25	
MRB–17	Pegmatite		0.13	5	0.01	9.11	
MRB–18	Pegmatite		0.22	5	0.01	2.87	
MRB–29	Basalt		5.78	5	0.08	1.39	
MRG–1	Gabbro	8.66	8.57	12	0.06	0.66	–1.10
SY–2	Syenite	3.56	3.48	13	0.05	1.38	–2.18
SY–3	Syenite	3.59	3.41	6	0.09	2.53	–5.01
FER–2	Iron Formation	15.24	15.15	3	0.17	1.12	–0.59
FER–3	Iron Formation	13.63	13.57	3	0.04	0.31	–0.42
AVERAGE (in working range)				6	±0.06%FeO	±1.48%	–1.86

Table 33.2. Accuracy and precision data generated using in-house reference materials (MRB 7 to 18) and standard reference materials. Data was collected over a ten-month period in the Toronto facility by 1 operator. Figures of merit were calculated on the basis of an average of 6 replicates per reference material.

REFERENCE MATERIAL	CERT. VALUE (%FeO)[1]	MEAS. VALUE (%FeO)[2]	COMPILED VALUE (%FeO)[3]	% DIFF.	# RUNS	PRECISION (COMPILED VALUE) ASD ±(%FeO)	PRECISION (COMPILED VALUE) RSD ±(%)	ACCURACY (%)
MRB–11		7.92	7.94	0.25	4	0.21	2.05	
MRB–12		6.66	6.73	1.05	5	0.04	0.66	
MRB–14		3.97	3.99	0.50	7	0.07	1.70	
MRB-15		1.83	1.85	1.09	5	0.04	2.20	
MRB–29		5.78	5.87	1.56	16	0.08	0.99	
SY–3	3.59	3.41	3.46	1.47	3	0.06	2.17	–3.62
AVERAGE				0.99		±0.07%FeO	±1.64%	

[1] Govindaraju (1989)
[2] Measured value from Table 33.1
[3] Compiled value determined over ten-month period; mean of number of runs reported

$$\% \text{ Diff} = \left(\frac{\text{comp.} - \text{meas.}}{\text{meas.}}\right) \times 100$$

ASD: Absolute standard deviation = sample standard deviation (X σn–1) at 1 σ level

$$\text{RSD: Relative standard deviation} = \frac{\text{ASD}}{\text{mean}} \times 100\%$$

$$\text{Accuracy: } \frac{[\text{compiled} - \text{certified}]}{\text{certified}} \times 100$$

extremely rapidly, 2) a standard method stipulates an endpoint titration, or 3) an excess of titrant must be avoided. This style of titration is not used regularly at the Geoscience Laboratories.

ANALYTICAL RESULTS

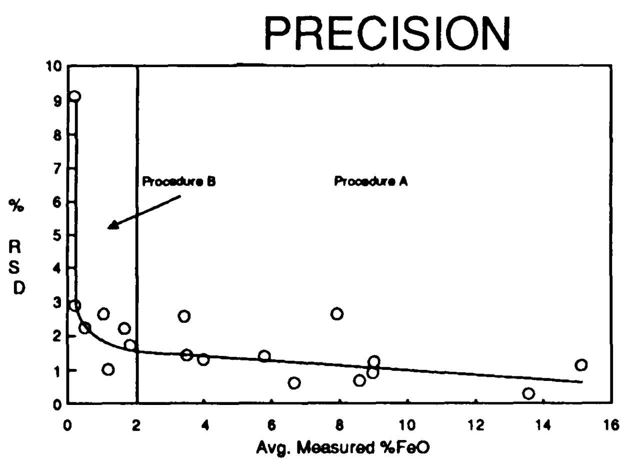
Ontario Geological Survey in-house reference materials (MRB 7 to 18) and international standard reference materials (SRMs) were analyzed using the automated procedures listed here and in OGS (1990) for method validation purposes. Accuracy and precision data generated during this exercise are listed in Tables 33.1 and 33.2. In all cases, data were based on an average of 6 replicates per reference material. A dynamic titration (Procedure A) was used for all samples. Those that contained less than 2% FeO were re-analyzed using a monotonic titration (Procedure B).

The suite of test materials used has a FeO content ranging from 0.13 to 15.15% FeO (*see* Table 33.1). The constituents were chosen to represent a wide range of geological compositions (intrusive and extrusive, felsic and mafic, altered and fresh rocks, and iron formations). The average absolute standard deviation (ASD) generated by the analysis of this test set is ±0.06% FeO: the average relative standard deviation (RSD) of the method is ±1.48% FeO (*see* Table 33.1).

The ASD and the RSD are both measures of precision. In both cases, they express the degree of uncertainty associated with a particular measurement either in an absolute sense or a relative sense. The ASD is most useful to the end user of a data set as it indicates the total amount of uncertainty associated with a measurement in the same units as the measurement. If this validation exercise was evaluating the determination of Rb by XRF, the ASD would be expressed in ppm Rb: percent would not figure into the term. In the case of MRB 7 in Table 33.1, the measured value of 9.00% FeO has "error bars" associated with it that are 0.10% FeO wide. These ranges do not represent "errors", but uncertainties in the digestion and analytical measurement processes.

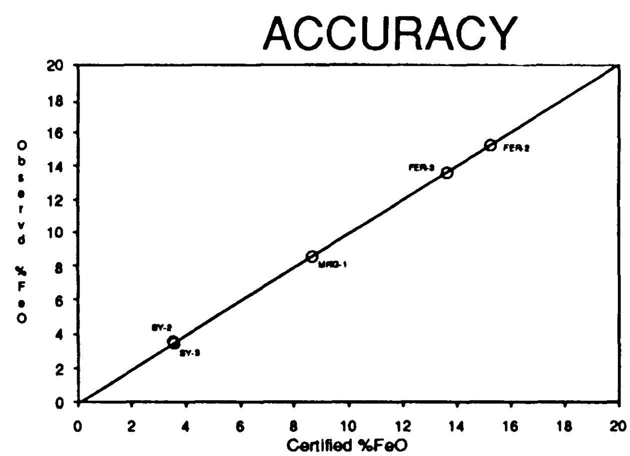
When assessing the usefulness of a method, the ASD is not as useful as the RSD as the latter allows better comparison of the degree of uncertainty associated with a measurement. It represents the amount of uncertainty relative to the measured value. Since it is a proportional value, it is in %, not %FeO. It provides a more meaningful measure of difference across a wide compositional range. For example, both MRB16 and MRB 17 have ASD of 0.01% FeO (*see* Table 33.1). In contrast, the RSD are different, 2.25% versus 9.11%. This difference in precision is the result of the small amount of FeO present in MRB17. Precision is always poorer near the determination limit of a method. Thus, the RSD is a useful tool to evaluate a method as it provides meaningful average of the uncertainty over a wide compositional range.

By plotting RSD against the average measured FeO determined for each reference material, a error magnification curve can be generated (Figure 33.1). From this, the determination limit of the method, the upper and lower limits of the working range can be determined. The determination limit of the automated titroprocessor procedures (using Procedures A and B) is 0.2% FeO (i.e., inflection point on Figure 33.1). At these iron contents, the precision (relative standard deviation or RSD) of the procedure is ±3%, which is the general Geoscience Laboratories benchmark figure of merit (±3%) for single batches of samples. The data also indicates that, although samples containing up to 15% FeO were analyzed, the upper limit of the working range has not yet been determined (i.e., the RSD has not yet begun to increase). Thus, the true working range of the titroprocessor has not yet been established. However, for the analysis of most rocks received by the Geoscience Laboratories, such a range is sufficient. When the Geoscience Laboratories are re-established in Sudbury, the true working range will be determined if merited based on submitted samples.



* Average of 6 replicates / standard

Figure 33.1. Error magnification curve for ferrous iron determinations using titroprocessor.



* 5 Standard Reference Materials used.

Figure 33.2. Graphical representation of accuracy data.

Table 33.3. Comparison of the automated and manual titration procedures in terms of productivity, quality of data and expandability.

PARAMETER	MANUAL	AUTOMATED
Dynamic Range	2.0–10% FeO	0.2–>16% FeO
Minimum Readable Volume Titrant	0.02 mL	0.001 mL
Detection Limit	0.03% FeO	0.015% FeO
Productivity	4/hr	8/hr
Accuracy	±8%	±1.86%
Relative Precision	±2.0%	±1.48%
Computer Interface Capability (LIMS)	No	Yes
Balance Interface Capability	No	Yes
Arithmetic Calculations	No	Yes
Titrant Waste	Possible	Nil
Mineral Analysis	Difficult	Easier

International rock reference materials spanning a compositional range from 3.41 to 15.15% FeO were used to assess accuracy. Those chosen represent common Ontario rock types (i.e., syenites, gabbros and iron formations). Calculated accuracy of the method is - 1.86%. Graphically, this is expressed in Figure 33.2. There is no significant bias in either the slope (m=1.0) or intercept (b=-0.14) of the line which is constrained by the data. Thus, the automated OGS titrometric FeO produces accurate determinations within the range of FeO content spanned by the reference materials used.

After obtaining the above data during the method validation exercise, the instrument system was put into routine use. In-house reference materials (samples prefixed as MRB) were analyzed every 10 to 15 samples to ensure the results for a given set of samples were within laboratory expectations. This forms the compiled precision quality-control database tabulated in Table 33.2. The subset of reference materials is smaller (*see* Table 33.2) as the reference materials that were analyzed were chosen based on the composition of the samples in the submitted jobs. The preponderance of MRB-29 indicates the large amount of basalt submitted during this period.

The compiled ten-month average of the compiled suite of reference materials is listed in Table 33.2. Comparison of the averaged results obtained during the method validation study with those from the compiled average indicate that the data is identical within the precision of the measurements. The average ASD ±0.07% FeO, compared to ±0.06% FeO. The compiled RSD is only slightly higher than the validation RSD: ±1.64 versus ±1.48%.

The accuracy data generated during the compilation period is not as extensive as as that formulated duirng the method validation exercise as the purpose of the exercise was to reduce the need to physically consume SRM. SY-3 was analyzed 3 times during the compilation period. From such a limited data base, it can only be said that the accuracy improved slightly during this period. Strictly speaking, MRB samples cannot be used to determine accuracy as their true values are not certified. However, during the method validation exercise, their values were determined by fiat or by association. If the MRB samples are interspersed with SRM and analyzed under identical conditions, and the results for the SRM are accurate, it follows that the determined values for the MRB are correct. The percent difference parameter in Table 33.2 indicates how closely the compiled MRB determinations correspond to the data determined during the validation exercise, indicating that the compiled data are accurate too, by fiat.

The careful statistical tracking carried out during this study and the high-precision data obtained suggested that there is a slight, but real, difference in the 2 data sets. During the ten-month compilation period, new decomposition crucibles with tighter fitting lids were obtained to replace those that had been in use for many years. The improved accuracy in the determination of SY-3 may be due to this factor. Future work in the Sudbury facility will attempt to confirm this.

COMPARISON OF MANUAL AND AUTOMATED TECHNIQUES

Where possible, the Geoscience Laboratories has moved toward automated sample preparation and instrumentation in an attempt to increase safety, time efficiency, reproducibility and productivity while improving the cost effectiveness of a procedure. Comparison of the manual and automated titration style (Table 33.3) indicates that the new procedures are preferable to the manual techniques. For instance, the throughput of samples has increased by 100%, while the possibility for transcription and mathematical errors has diminished significantly. Finally, as the titration is controlled electronically, the end point is not overshot. This means that there is no wastage of either the titrant or the chemicals required for sample decomposition. Operationally, this automated procedure is a worthwhile improvement on previous practice.

Additionally, as part of the Laboratories' mandate, methods are constantly being evaluated to improve precision, accuracy and lower determinations limits. In this case, using the automated techniques, accuracy improved from ±8% to ±1.86%, precision from ±2% to

±1.48% and the determination limit decreased by half. The dynamic working range of the system was 2 to 10% FeO and is now significantly extended from 0.2 to greater than 16% FeO. Thus, the analytical objectives are also fulfilled.

CONCLUSIONS

The introduction of the Metrohm AG Titroprocessor into the Geoscience Laboratories has resulted in both significant improvements in data quality and a more cost- and time-effective operation, when compared with the manual techniques used previously. Accuracy has been improved from ±8% to better than ±2%. Average precision has been improved slightly from ±2% to ±1.5%. The dynamic range has been extended at both the lower and upper ends. Better precision can be maintained at FeO contents less than 2% as a monotonic titration is performed which allows more precisely determination of the titration equivalence points. By automating the titration as opposed to performing it manually, operator-based differences are eliminated. Overall, the titroprocessor's capability to perform mathematical calculations and interface with a balance and the OGS Laboratory Information Management System (LIMS) has resulted in an increase in productivity of 100%.

ACKNOWLEDGMENTS

R. LeBlanc and C. Pollard from Brinkmann Instruments (Canada) Ltd., the Canadian distributor of Metrohm AG products, provided expert assistance with the initial set-up, training and operation of the titroprocessor. G. Henri kindly revised the equations. J. Foucault contributed to this project in the early stages of the implementation of the instrument in the Geoscience Laboratories.

REFERENCES

Fyfe, W.S. 1974. Geochemistry, Oxford University Press.

Goldich, S.S. 1984. Determination of ferrous iron in silicate rocks; Chemical Geology, v.42, p.343–347.

Govindaraju, K. 1989. Compilation of working values and sample descriptions for 272 Geostandards; Geostandards Newsletter, v.13, p.1–113.

Langmhyr, F.J. and Graff, P.R. 1965. A contribution to the analytical chemistry of silicate rocks: a scheme of analysis for eleven main constituents based on decomposition by hydrofluoric acid; Norges Geologiske Undersokelese No. 230, Universitetsforlaget, Oslo.

Langmhyr, F.J. and Kringstad, K. 1966. An investigation of the composition of the precipitates formed by the decomposition of silicate rocks in 38%–40% hydrofluoric acid; Analytica Chimica Acta, v.35, p.131–135.

Ontario Geological Survey 1990. Analysis of geological materials, volume II: manual of methods; Ontario Geological Survey, Miscellaneous Paper 149.

Potts, P. 1987. Handbook of silicate rock analysis; Blackie, Glasgow.

Skoog, D.A. and West, D.M. 1982. Fundamentals of analytical chemistry, 4th ed.; Sanders College Publications, Toronto, 859p.

Sulcek, Z. and Povondra, P. 1989. Methods of decomposition in inorganic analysis; CRC Press, Boca Raton, Florida.

Wilson, A.D. 1955. Determination of ferrous iron in rocks and minerals; Geological Survey of Great Britain, Bulletin, v.9, p.56–58.

Canada–Ontario Northern Ontario Development Agreement

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34. The Design and Evaluation of a Cushioned Rock-Drill Handle

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INTRODUCTION

Jack-leg rock drills can produce vibration white finger disease in their operations, which can cause varying levels of arm and/or hand discomfort and, in severe cases, impairment. In addition, there are significant economic repercussions for the mining industry, including reduced operator efficiency, lost time through increased absenteeism, and increasing compensation awards.

The Mining Industry Research Organization of Canada (MIROC) is a non-profit organization sponsored by 8 member-companies within the Canadian mining industry. "The Design and Evaluation of a Cushioned Rock-Drill Handle" project is a joint Northern Ontario Development Agreement (NODA)–MIROC undertaking.

MIROC and Teledyne Canada Mining Products have previously undertaken a three-phase program to develop, test and evaluate the feasibility and durability of a modified handle design and its effect on reducing hand-transmitted vibration under different underground conditions.

The first and second phase demonstrated that, for the Joy AL 60 jack-leg drill, cushioned handle designs could significantly reduce hand-transmitted vibration, particularly for frequencies above 500 Hz. In this range, reductions in overall vibration level by a factor of 3, relative to the standard steel handle, were consistently observed.

The third phase evaluated the long-term durability and effectiveness of the prototype cushioned handle under different conditions underground. The performance of the cushioned handle was found to be unaffected by exposure to typical mining environments and the operators indicated some degree of preference for the cushioned handle, if certain design modifications could be achieved.

The recommended modifications included: 1) a reduction in handle length, 2) incorporating an anti-slip surface on the handle, 3) reduction in size of the handle's large end to allow easy and safe collaring of a hole, and 4) modification of the air release port to redirect the exhaust air away from the operator.

To date, MIROC has contributed a total of $68 000 to the project, with Teledyne Canada Mining Products contributing a similar amount in materials and in kind.

This project is designed to design, fabricate, test and evaluate a suitable and marketable cushioned handle for both the Joy and Secan rock drills. The project is to be carried out at a total cost of $100 000 which includes $50 000 from NODA, $10 000 from MIROC and $40 000 from Teledyne. The Teledyne support will be through a direct contract with Queen's University. The work will be conducted by the Department of Mechanical Engineering, Queen's University, between September 1, 1992 and February 28, 1994.

PROJECT PROPOSAL

This proposal calls for the design and fabrication of an improved cushioned handle and evaluation of its effectiveness under controlled laboratory conditions and at typical underground sites. Handles would be developed for the Joy and Secan jack-leg drill and be designed as replacement handles for these drills.

The proposed program calls for design modifications to be implemented on the cushioned handle so as to conform with the recommendations of the phase 2 report, noted earlier. In addition, modifications of the cushioning material's effective compliance will be undertaken in an effort to improve low-frequency vibration isolation performance. The new handle would then be tested under controlled laboratory conditions to qualify the reduction in hand-transmitted vibration achieved. Field testing of the handle will be conducted in different underground mines to: investigate the overall effectiveness and performance of the cushioned handle in the field; verify the level of reduction of hand-transmitted vibration achieved relative to the standard steel handle; evaluate the durability of the new cushioned handle under production conditions; and investigate operator acceptance of the cushioned handle.

The project will be conducted at Queen's University, within the Departments of Mechanical Engineering and Mining Engineering, at Teledyne Canada Mining Products' Thornbury plant and at member-company underground mines.

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BENEFITS

Teledyne foresees a significant market for the proposed cushioned handles and expects to recoup its investment relatively quickly through sales to jack-leg drill users. In addition, Teledyne expects to be able to apply the knowledge gained in this project to other types of hand-held equipment, both in the mining and construction industries.

The mining industry, as a whole, can expect to benefit from the development of the proposed cushioned handles through improved operator health and safety, increased operator efficiency, and reduced compensation costs.

OBJECTIVES

1. To design and fabricate improved cushioned handles for the Joy and Secan drills.
2. To test the handle under laboratory conditions to quantify the reduction in hand-transmitted vibration achieved relative to the standard steel handle.
3. To evaluate the durability of the cushioned handle when used underground under production conditions.
4. To investigate operator acceptance of the cushioned handle.
5. To provide the final design characteristics for a marketable cushioned handle for both the Joy and Secan jack-leg drills.

DELIVERABLES

Progress reports will be issued to all the funding agencies at the end of the sixth and twelfth months of the contract.

An open file report providing complete details of the new handle designs, the vibration test procedures utilized, and a complete summary of the results, including a quantitative and qualitative evaluation of the effectiveness of the cushioned handle, will be issued in the eighteenth, and final, month of the contract.

A demonstration of the handle will be conducted at major mining companies in northern Ontario.

PRINCIPAL INVESTIGATORS

The study will be carried out at underground mines and within the Departments of Mechanical Engineering and Mining Engineering, Queen's University, Kingston, under the direction of Dr. T.N. Moore, Department of Mechanical Engineering and Dr. E.M. DeSouza, Department of Mining Engineering. Teledyne Canada Mining Products will provide the necessary engineering/manufacturing/marketing liaison.

TIMETABLE

The study will be carried out over an eighteen-month period beginning on September 1, 1992.

35. A Geochemical Mapping Traverse Along the 80th Meridian West

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INTRODUCTION

Large areas of high mineral potential in Ontario have not, as yet, been mapped geochemically. The principal reason is that, until recently, geochemical mapping has been considered ineffective in most of northern Ontario owing to the complexity of the landscapes which occur there. However, to date, no systematic test of this hypothesis has been made by the Ontario Geological Survey (OGS).

The idea of a Geochemical Map of Ontario, similar to province-wide geological and geophysical maps, was suggested by the writer in 1983 (Fortescue 1983). At that time it was considered impractical for 2 reasons, 1 was the supposed ineffectiveness of the geochemical mapping techniques then in use and the other was the large logistical problem involved in obtaining geochemical samples on the scale required.

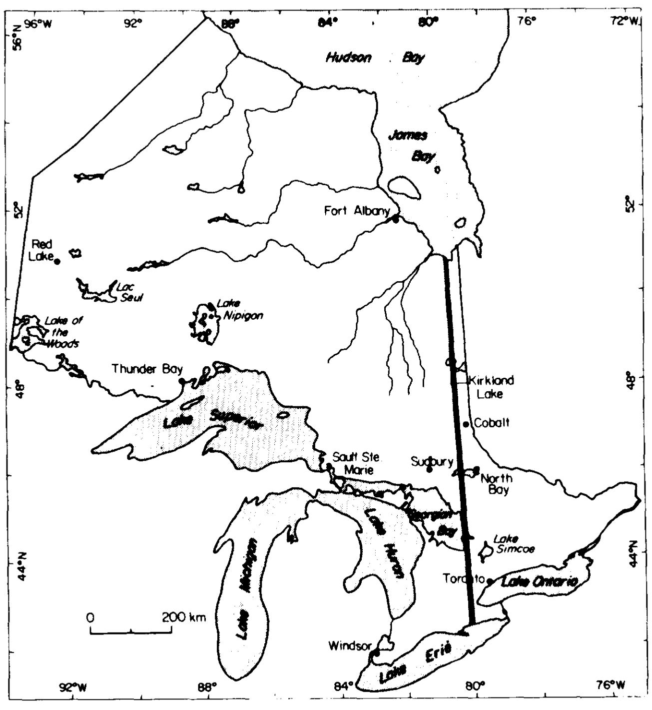

Figure 35.1. Location map of the 80th meridian.

During the past 5 years, this picture has changed. For example, it has been shown by several Scandinavian workers that large geochemical patterns (associated with metallogenic provinces on a continental scale) can be delineated by geochemical mapping. In Norway, patterns of this type, discovered by low-density geochemical mapping, led to the modification of existing geologic maps in some areas (Bolviken et al. 1990). Another development has been the demonstration that, under favourable conditions, low-density geochemical sampling may delineate continental-scale natural and anthropogenic geochemical patterns of various kinds (Ottesen et al. 1989; Koljonen et al. 1989; Bolviken et al. 1990).

These developments, and others like them described in the literature (e.g., Darnley 1990, 1992), led directly to the design of the OGS Meridian Project.

The Meridian Project is part of the Canada–Ontario Northern Ontario Development Agreement (NODA). The project was designed as a pilot project leading to the future preparation of a Geochemical Map of Ontario.

Once completed, a Geochemical Map of Ontario would have many uses, including the ranking of greenstone belts in order of importance for mineral resource appraisal. From the environmental viewpoint, a Geochemical Map of Ontario would be of considerable importance in the delineation of areas of anthropogenic fallout. For example, the province-wide extent of nonpoint-source lead patterns.

OBJECTIVE

The objective of the Meridian Project is to examine the feasibility of geochemical mapping on a province-wide scale in Ontario. Mapping will be based on samples collected at regular intervals along the 80°W meridian from the south to the north of the province.

CHOICE OF LOCATION

The 80th meridian was chosen for a province-wide geochemical traverse for several reasons. Among these were landscape complexity due to significant changes along the meridian in: 1) bedrock geology; 2) Quaternary cover; 3) soil and forest cover; 4) landscape type; and 5) anthropogenic influences of various kinds typical of Ontario.

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A line traverse was chosen to provide experience in: 1) planning; 2) sampling; 3) sample processing (including pretreatment and chemical analysis); 3) data processing; 4) data presentation; and 5) interpretation of geochemical patterns obtained from province-wide geochemical mapping.

GEOLOGY

The 80th meridian traverses the 3 major bedrock assemblages found in the province. These are: 1) Paleozoic carbonates (in southern Ontario and near the shore of James Bay); 2) Proterozoic rocks (Grenville Province) in the central part of the traverse (north from Midland to just north of North Bay); and 3) Archean rocks (from north of North Bay nearly to James Bay). Most of these rocks strike at a high angle to the 80th meridian.

QUATERNARY GEOLOGY

The overburden along the meridian from Lake Erie to Hamilton is composed largely of glaciolacustrine sediments. Farther north, between Hamilton and Midland, the Quaternary materials that underlie the meridian are complex and varied. They include tills, glaciofluvial deposits and organic terrain. From Midland north, to south of Kirkland Lake, the Quaternary cover is commonly a thin continuous layer of till with scattered patches of glaciolacustrine deposits. From just south of Kirkland Lake, northward to Lake Abitibi, the sampled line crosses extensive areas of thick, varved glaciolacustrine clays. North of Lake Abitibi, the meridian traverses the clay-rich Cochrane Till, which is overlain by continuous organic terrain as James Bay is approached.

ENVIRONMENTAL GEOCHEMISTRY

Anthropogenic influences on the geochemistry of landscapes along the traverse may be significant in southern Ontario, especially around Hamilton and Toronto, and probably decrease northwards. The Sudbury smelters provide a significant point source of atmospheric copper and nickel pollution, which has been detected at the surface of lake sediments collected tens of kilometres to the northeast — almost as far east as the 80th meridian.

Detectable levels of lead, due to nonpoint-source atmospheric fallout, are expected to contaminate all the lake bottoms sampled along the meridian traverse in Ontario. In regions of northern Ontario, this was measured by a method described by Fortescue (in press) based in a comparison of the geochemistry of pre- and post-Ambrosia lake sediment core samples.

METHODOLOGY

The 80°W meridian sampling plan called for the collection of composites (4 sample) of sediment and water each representing adjacent 10 by 10 km areas (micromodules) along a 930 km meridian traverse from Lake Erie to James Bay (Figures 35.1 and 35.2). The micromodule sampling plan was chosen to ensure the detection of significant geochemical patterns along the meridian.

The purpose of the 4 sample composites was to: 1) obtain a representative sample from each micromodule; 2) reduce noise in the geochemical data; 3) minimize helicopter time; and 4) simplify the display of geochemical data on a province-wide scale. The choice of 1 sample station at random in each micromodule quarter was a practical compromise between all the above considerations.

Stream sediments, lake sediments and waters were chosen as meridian sample media because they were known to provide reliable geochemical map data in southern, central and, possibly, northern Ontario. In addition, mineral soil samples were collected from the 22 micromodules in southern Ontario.

Field work along the meridian was completed in June, July and August 1992. The laboratory work is expected to be completed by the end of November 1992. The project report should be released in the early summer of 1993.

SAMPLING PROCEDURE

Southern Ontario: Lake Erie to Midland

The extensive road network in southern Ontario facilitated the collection of stream waters, stream sediments and mineral soil samples. The sampling plan called for the random collection of 4 samples of each type within each of the 22 adjacent micromodules (10 by 10 km UTM grid areas). Wherever possible, 1 sample station was located in each of the 4, 5 by 5 km quarters of each micromodule. Sample stations were always established approximately 25 to 50 m upstream of road bridges or culverts.

Water sampling involved mixing four 250 mL water samples, (1 derived from each micromodule quarter) in a 1 L high-density polyethylene bottle creating a composite sample. These bottles were stored in a refrigerator at the end of each day prior to pH determinations and acidification. Stream sediments and mineral soils were collected in wet strength 4 by 6 inch Kraft paper bags.

Sample locations were recorded on customized 1:50 000 scale plastic laminated topographic maps. A video camera was used to visually record all sample stations in southern Ontario. This was to test the feasibility of investigating general relationships between landscapes sampled and geochemical results obtained.

Northern Ontario: Midland to James Bay

The lack of extensive road access in much of northern Ontario precluded the use of surface vehicles for sample collection. The most practical and efficient method for the collection of lake waters and lake sediments is by float-equipped helicopter. Consequently, a Bell 206B,

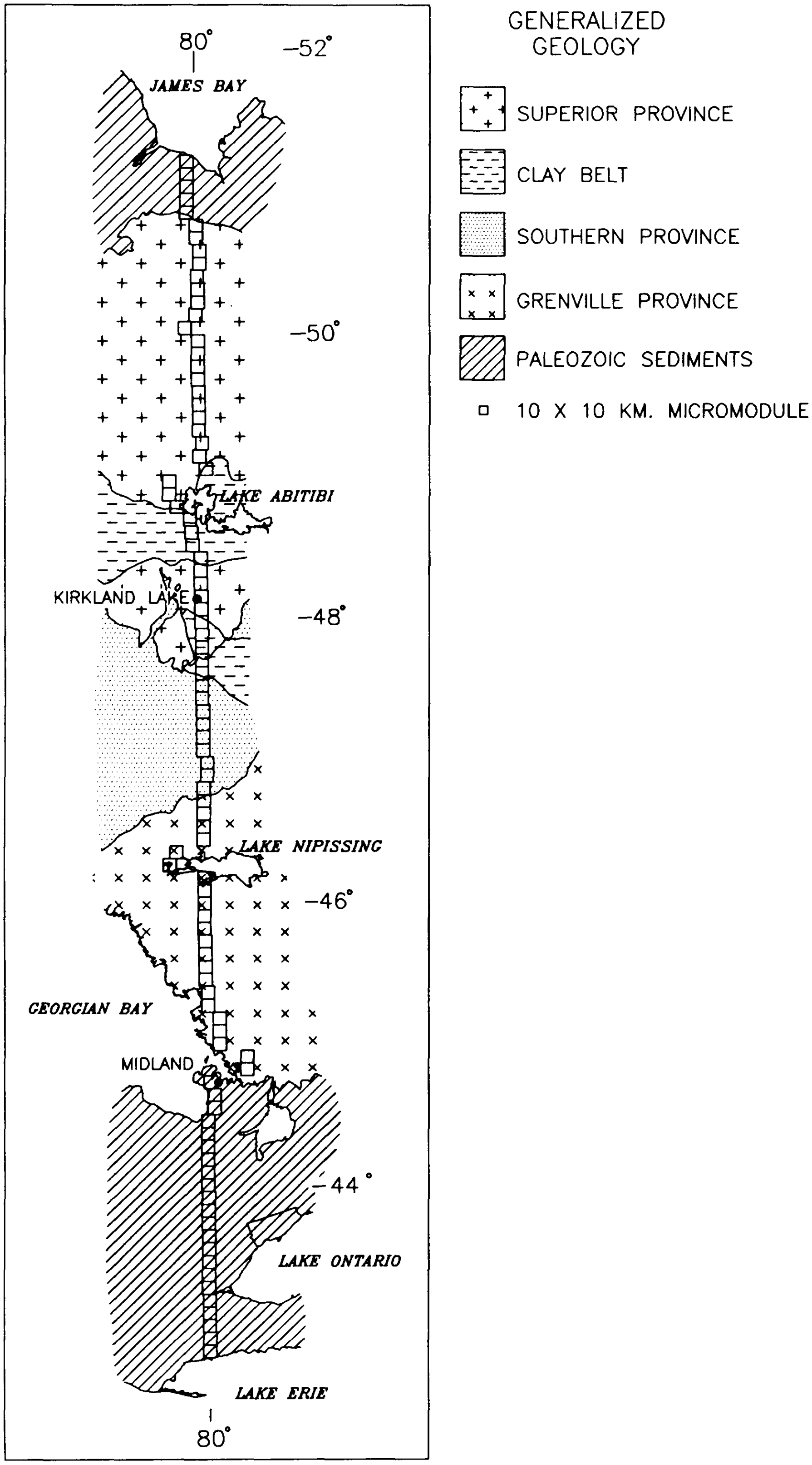

Figure 35.2. Micromodules sampled along the 80th meridian from Lake Erie to James Bay.

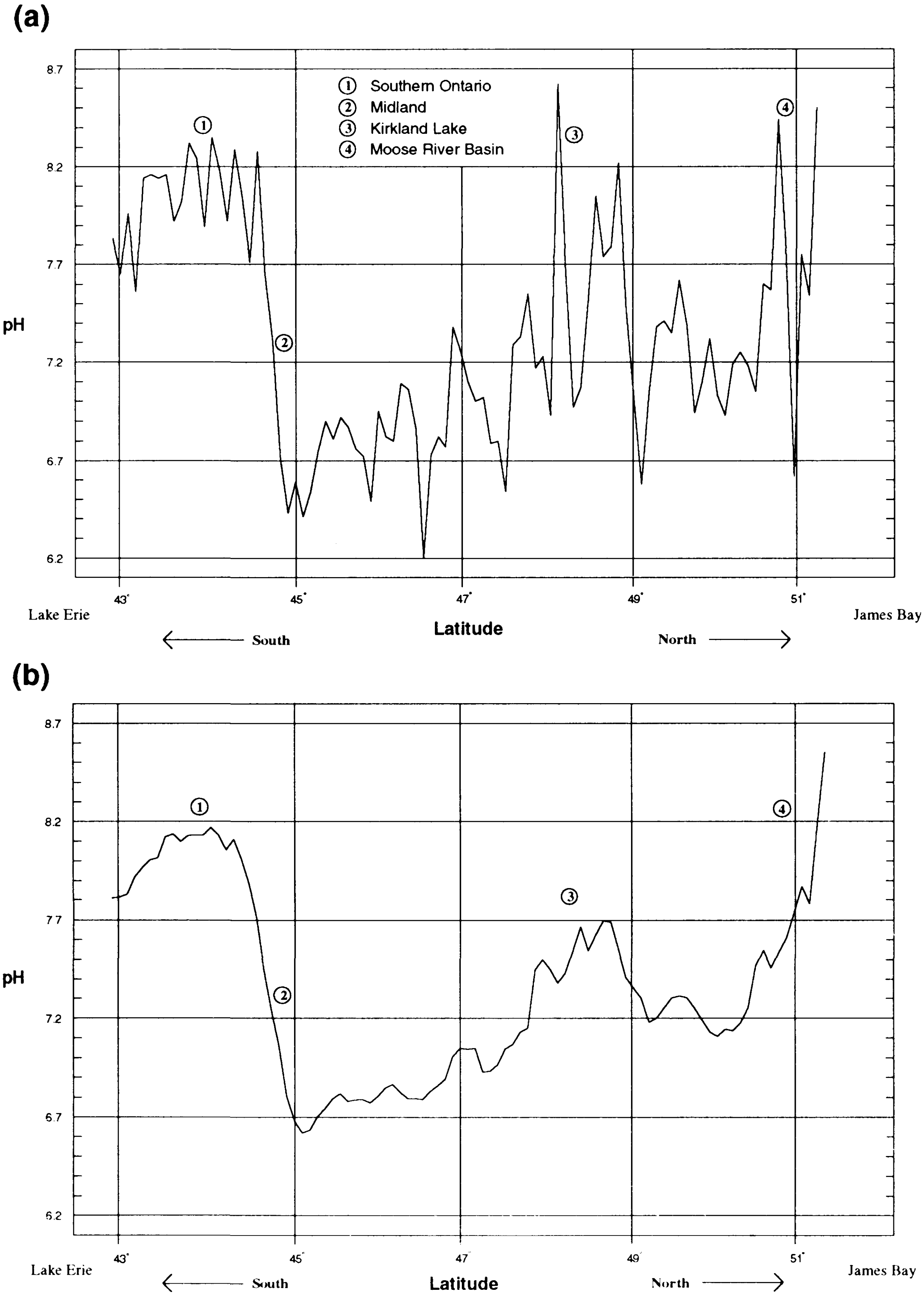

Figure 35.3. Meridian Project stream and lake water pH from Lake Erie to James Bay. (a) Raw data; (b) data smoothed using a seven-point moving average.

equipped with the OGS lake sediment sampling gear (Fortescue 1988), was used.

In most of the 72 lake micromodules, both pre- and post-Ambrosia lake sediment samples were collected using a simple gravity sampler as described by Fortescue (1988). As before, where possible, 1 sample was taken from each micromodule quarter. The lake sediment cores were extruded on the helicopter float and the samples placed in Whirl-Pak plastic bags for transport to the laboratory. Lake waters were collected and added together to create a composite sample for each micromodule as described previously for stream waters. Deep lake water samples (+5 m) were taken using a 3/4-inch Tygon tube sampler.

During helicopter sampling, a Trimble Pathfinder Basic Global Positioning System (GPS) receiver was used to record exact UTM coordinates of lake sample sites and facilitate helicopter navigation between sample sites. The use of this instrument reduced the helicopter time required between lake sample sites and expedited the transfer of sample station UTM coordinates to a computer data base (*see* Dyer and Fouts, this volume).

In the helicopter, sample station positions were also recorded manually on customized 1:50 000 scale laminated topographic maps. During sampling, a video camera was used to obtain a visual record of landscapes in selected lake basins.

Preprocessing and Chemical Analysis of Samples

The pH of cooled, composite, water samples was measured soon after collection. The 1 L water samples were then acidified with 10 mL of concentrated nitric acid (HNO_3) to prevent the growth of microorganisms and the precipitation of metals on the container walls.

In the laboratory, the water samples will be filtered (-45 micron) prior to the determination of 30+ major, trace and ultratrace elements. The methodology for chemical analysis of all the meridian samples will include stringent quality control procedures based on replicated analyses of international reference materials.

Stream sediment, soil and lake sediment samples will require preprocessing before chemical analysis. This includes oven drying and sieving of mineral samples and grinding of dry lake sediment material. Micromodule composites for each of the prepared dry samples will be created by mixing together 5 g portions of samples representing the 4 micromodule quarters in each micromodule. Loss on ignition and levels of elements will be determined in each composite sample. In the event of any interesting, or unusual, results from analysis of the composites, micromodule quarter samples may be later analyzed individually.

DATA PROCESSING

The element data will be processed using the Clarke Index–I transform to facilitate visual comparisons among element and sample media patterns along the meridian.

Preliminary visual interpretation of the meridian element patterns will be completed in relation to geophysical, geological and Quaternary maps.

Geochemical sections generated for this project will be created using the computer-aided drafting software, AutoCAD™. The analytical results will be linked to the AutoCAD™ drawings via a relational data base allowing greater flexibility in the generation of geochemical anomaly and province-wide maps, graphs, etc.

Statistical analysis and image processing of the meridian geochemical data will be completed in an effort to determine base line geochemistry in each of the sampled materials over the major rock types and to investigate interelement effects.

RESULTS OF THE pH DETERMINATIONS

Figures 35.3a and 35.3b illustrate the variation in pH from south to north along the meridian from Lake Erie to James Bay. After smoothing this data with a seven-point rolling average (*see* Figure 35.3b), the noise in the data is reduced considerably, and clear pH trends along the meridian are evident.

For example, a natural buffering effect of a carbonate terrain occurs in southern Ontario and near James Bay. Similarly, the extensive carbonate-rich clay belt in the vicinity of Kirkland Lake is associated with a well-defined increase in pH along the meridian in the area. Further examination of these data is proceeding at the time of writing this paper.

DISCUSSION

The pH patterns discussed above suggest that the approach described here may also detect valid, large-scale, geochemical element patterns across Ontario. If this is so, a Geochemical Map of Ontario, based on meridian mapping, could be feasible.

The 80°W meridian project was originally designed to be carried out in Ontario by the OGS. More recently, it has been suggested that the project could also be of interest internationally. For example, using the same geochemical sampling plan, the meridian traverse might be extended for 1000 km south to the Atlantic coast near Charleston, North Carolina. Meridian mapping on this scale might provide data of interest in the development of global geochemical mapping, as described recently by Darnley (1992).

REFERENCES

Bolviken, B., Kellerud, G. and Loucks, A. 1990. Geochemical and metallogenic provinces; A discussion initiated by results from geochemical mapping across Fennoscandia; Journal of Geochemical Exploration, v.39, p.49–90.

Darnley, A.G. 1990. International Geochemical Mapping Project — A contribution to environmental studies; in Chemistry and the Environment, Proceedings of a Regional Symposium, Brisbane 1989, Commonwealth Science Council.

——— 1992. Update on the International Geochemical Mapping Project; Explore, no.76, July 1992, p.11–14.

Fortescue, J.A.C. 1983. A phased approach to the presentation of regional geochemical survey data from southwest Ontario; *in* Summary of Field Work and Other Activities 1983, Ontario Geological Survey, Miscellaneous Paper 116, p.151–155.

——— 1988. A regional geochemical survey of part of the Batchawana Greenstone Belt, District of Algoma; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.482–488.

——— in press. Regional geochemical mapping; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.1349–1393.

Koljonen, T., Gustavsson, N., Noras, P. and Tanskenen, H. 1989. Geochemical atlas of Finland: Preliminary aspects; Journal of Geochemical Exploration, v.32, p.231–242.

Ottesen, R.T., Bogen, J., Bolviken, B. and Volden, T. 1989. Overbank sediment; A representative sample medium for regional geochemical mapping; Journal of Geochemical Exploration, v.32, p.257–277.

36. Global Positioning System as an Aid to Geochemical Mapping

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INTRODUCTION

A Global Positioning System (GPS) receiver was used during the helicopter-supported part of the Meridian Project field work (*see* Fortescue et al., this volume). Improvements in GPS receiver design and worldwide satellite coverage have made the use of a GPS a reliable and routine method for collection of digital positional data. The possibility of using a GPS in a helicopter for positioning of lake sediment sampling sites was first considered during the 1991 regional geochemical mapping program (Fortescue et al. 1991).

The rationale for using a GPS on the Meridian Project was twofold. Firstly, for the collection and storage of accurate digital positional data, which can be converted to various computer file formats for use in a Geographic Information System (GIS) and for use with image processing software such as AutoCAD™. Secondly, as a navigational aid for the helicopter between sample sites along the 80th meridian from Parry Sound to James Bay.

This paper was written to describe one of the Ontario Geological Survey's initial field experiences with a GPS system on a helicopter-supported project.

AN INTRODUCTION TO GPS

The Global Positioning System was developed by the United States Department of Defence during the last decade. Quite simply, a constellation of satellites in the Earth's orbit, through the emission of low power radio signals timed by accurate clocks, provide very accurate positional coordinates through the concept of triangulation. Presently, the constellation consists of 18 healthy satellites out of a planned complement of 24 (including 3 spares). A GPS receiver receives the signals from 3 or more satellites, which are located in different parts of the sky, and computes a position. A minimum of 3 satellites is required in order to compute a 2 dimensional position (2D), which for navigational purposes is acceptable. For accurate positioning in 3 dimensions (3D), a minimum of 4 satellites is necessary. A direct line of sight between the satellites and the GPS receiver antenna is required. The signal is effected only slightly by atmospheric effects such as weather (i.e., rain droplets). Essentially, the Global Positioning System is a 24 hour, all weather positional and navigational aid.

The satellites emit 2 distinct codes, 1 intended for military use and the other for civilian use. The GPS receivers available to the public can only receive the civilian band. This is subject to intentional degradation (known as Selective Availability) by the United States Department of Defence in order to thwart the use of GPS by "unfriendly powers." For this reason, even under ideal conditions of satellite visibility and geometry, a GPS receiver would likely not exceed a positional accuracy of better than 50 m. Greater accuracy can be achieved by utilizing a base station GPS unit that is located at a known position and is continuously recording its position. The magnitude of GPS positional errors at the base station are therefore known, and this information can be applied to data collected by a remote GPS unit used in the field. This process is known as differential correction and can result in positional accuracies to within 3 to 5 m.

GPS AND THE MERIDIAN PROJECT

Because the Meridian Project was to involve low density lake sediment sampling (sample sites 5 to 10 km apart), the accuracy provided by a GPS's autonomous operation (50 to 100 m) was considered sufficient.

As a navigational aid, the GPS was expected to be an important part of this project. With sample stations widely spaced (3 to 5 km), conventional visual navigation by a map is slow, cumbersome and subject to human error, especially when flying at a low level over monotonous terrain, such as the James Bay Lowland. This results in the inefficient use of helicopter flight time.

With a GPS system, sample site waypoints (the approximate UTM coordinates are derived from topographic maps) are entered into the GPS receiver prior to each days work. Navigation from sample site to sample site would rely largely on bearing and range data obtained from the GPS. Once at a sample station, its position fix is obtained and stored. Should the need arise to return to a site in the future, the GPS can be used to navigate back to the same spot (subject to the accuracies outlined above). This procedure optimizes helicopter flight time and, as a consequence, results in fewer flight hours required for a project.

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CHOICE OF A GPS UNIT

There were several criteria to consider in the determination of a suitable GPS unit for use in a helicopter with the Meridian Project. These were:

1. The GPS receiver must be operable within a helicopter, preferably with an internal antenna, allowing for ease of installation and portability. (Note: while external GPS antennas designed for use with aircraft do exist, such an installation is permanent and requires Federal Department of Transport certification. Most helicopter companies have not yet installed GPS receivers or antennas on their helicopters.)
2. The unit must allow the input and storage of waypoints (minimum 300) that can be labelled with an attribute such as a sample station number.
3. The unit must be able to connect to an external computer for the downloading of positional data and have software for output or conversion of the data to various computer formats, including ASCII, AutoCAD™ DXF and dBaseIV™.
4. The unit must be rugged and have a reliable power source independent of the helicopter.

It was determined that the Trimble Pathfinder Basic satisfied the above requirements.

MISSION PLANNING AND PREPARATION

Prior to the start of the helicopter-supported field work, the mission-planning software included with the GPS receiver was used to determine satellite availability along the 80th meridian during the time frame in which the work was to be completed. While an internal antenna on the GPS receiver greatly simplifies installation and portability of the unit, it also means the line of sight to the antenna is dependant on the window area of the helicopter and the direction of flight. The restricted field of view expected with the GPS receiver mounted on the instrument panel was simulated with the mission-planning software. Satellite availability was determined between the hours of 8:00 a.m.to 6:00 p.m. for 3 scenarios: 1) satellites available to the receiver in a northward flight direction; 2) satellites available in a southward flight direction; and 3) total satellites 10° above the entire horizon. Figure 36.1 is a graphical representation of the typical satellite availability along the 80th meridian in the Lake Temagami area. After simulating these conditions along the meridian from Parry Sound to James Bay, it was apparent that:

1. A northward flight direction would be preferable because more satellites, with better geometry, were available in the northern part of the horizon.
2. A consistent gap in satellite coverage would occur between approximately 11:30 a.m. and 1:00 p.m.

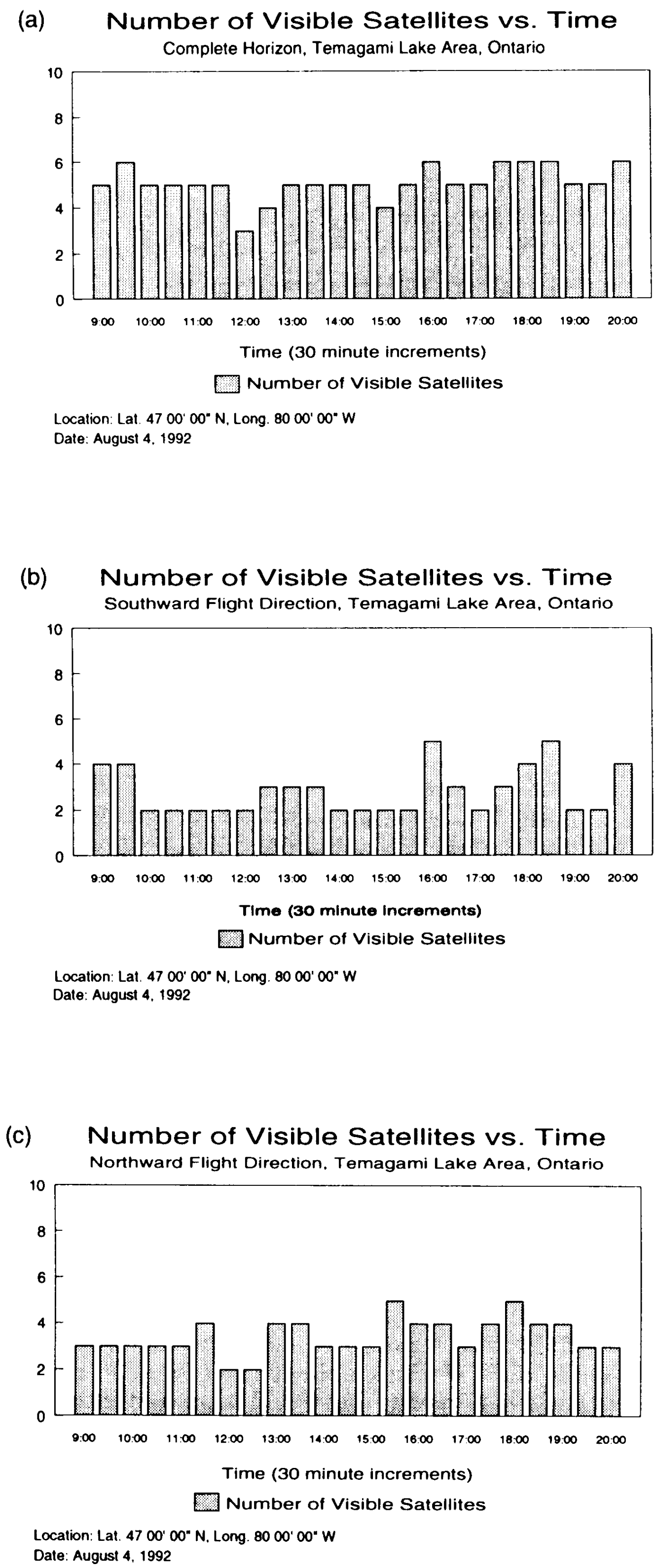

Figure 36.1. Number of visible satellites plotted against time of day along the 80th meridian in the Temagami Lake area for (a) complete unobstructed horizon, (b) southward helicopter flight direction with internal GPS antenna and (c) northward helicopter flight direction with internal GPS antenna. (Data from Trimble TrimPlan™ software using almanac file collected on July 24, 1992.)

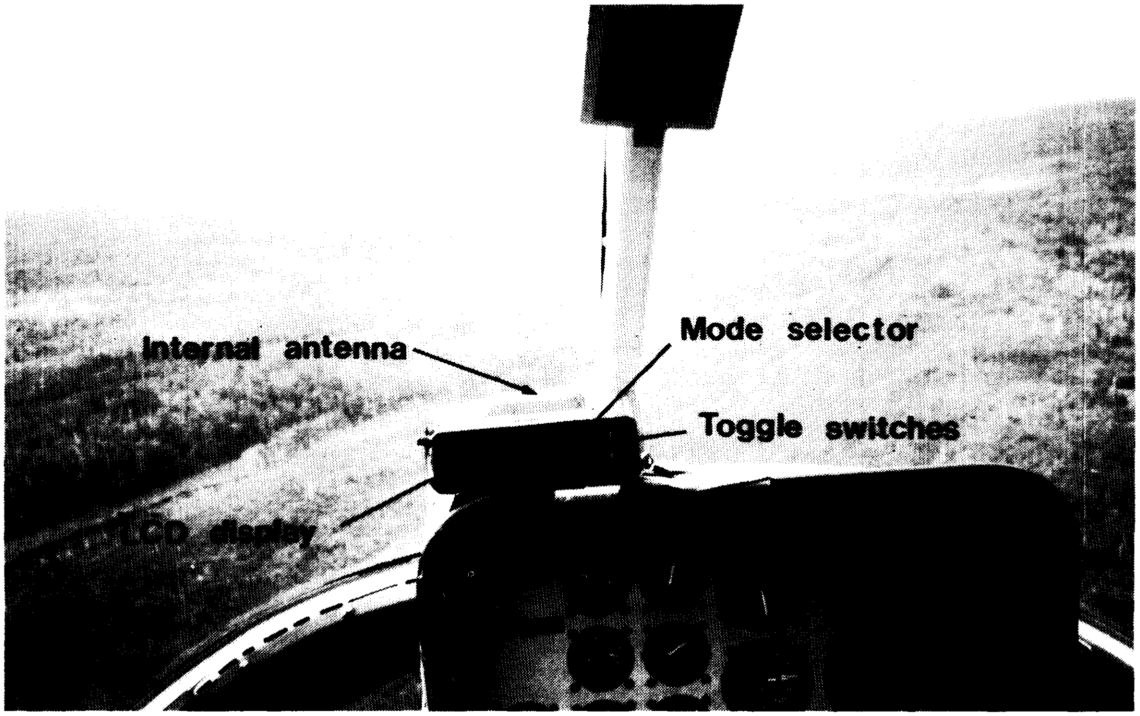

Photo 36.1. GPS receiver mounted on the helicopter instrument panel.

3. With the exception of the gap mentioned above, 5 or 6 satellites would be above the horizon all day.

It was concluded that 2D navigation with the GPS would be feasible for most of the day, but 3D positioning of sample stations would be hampered by the restricted antenna field of view and poor satellite availability at midday.

GPS IN THE FIELD

Preparation for each days flight involved inputting rough UTM sample station coordinates and sample numbers into a portable computer for uploading to the GPS unit via the Trimble GPS software and a RS–232 serial port connection. A removable nickel-cadmium battery pack was recharged each night and proved to be sufficient for 8 to 10 hours of continuous operation.

The GPS receiver was mounted on the navigator's side of the helicopter instrument panel with velcro tabs, which allowed for easy removal after each days work (Photo 36.1). During long ferry flights, the GPS receiver was oriented towards the pilot to more efficiently monitor course corrections.

Normal use of the unit between sample stations (3 to 5 minutes flight time) involved telling the pilot the bearing and distance to the next sample station. The navigator would then be free to prepare for the next sample site, take notes etc., while updating the pilot on the bearing and distance as required. This procedure proved very efficient because, upon lifting off from a sample station, the pilot could immediately get on track to the next station.

This procedure was utilized from Parry Sound to James Bay from July 28 to August 14, 1992. The following points summarize the most significant findings of GPS use during this project:

1. Navigation with the GPS proved very successful with the receiver often tracking 4 satellites between sample stations. The exception to this was during midday (11 a.m. to 1:00 p.m.) when, depending on the flight direction, less than 3 satellites or 3 satellites with very poor geometry could be tracked.
2. Recording a position involved toggling 1 switch upon landing at the sample station, providing at least 3 satellites were available. If not, the pilot would rotate the helicopter slowly until a third satellite was tracked. If a third satellite could not be contacted (usually during midday, 11 a.m. to 1:00 p.m.), another attempt would be made during lift-off from the lake. Only at a few sample stations was there no GPS position possible. According to the GPS receiver, the best accuracy obtained was in the range of plus or minus 100 m.
3. The effect of topography and tree canopy proved to be an important factor. On average, 5 satellites were above the entire horizon at any given time; however, 1 of these satellites would be blocked due to the restricted antenna view. Of the remaining 4 satellites, at least 1 would be low on the horizon. Often the GPS would be receiving from 4 satellites (3D positioning) but lose the satellite located low on the horizon during the last 5 to 10 m. of descent onto a lake. A less accurate 2D position was recorded, and

the elevation component of the position would be that of the last computed elevation (i.e., the last computed elevation during the descent onto the lake).

DATA PROCESSING

The positional data including sample numbers were downloaded from the GPS receiver to a portable computer each evening. Once the field work was completed, the sample positions were stored in ASCII format using the software supplied with the GPS unit. The data was then imported into the Ontario Geological Survey's Fieldlog data base program from which a sample location map was created for use with AutoCAD™.

CONCLUSION

Conclusions reached this summer are as follows:

1. As a navigational aid, the GPS proved extremely useful and convenient, even with the restricted field of view due to the internal antenna. Once the full satellite constellation is in place, the gaps in satellite coverage will be filled making navigation with a GPS (with internal or external antenna) a very reliable method. The saving in flight time during this project, although difficult to estimate, was certainly significant.

2. The accuracy of positioning was adequate for the Meridian Project; however, the consistent collection of 3D positional data was hampered by the antenna's restricted field of view, incomplete satellite coverage and topography and/or tree canopy obstructions. The use of an external antenna and the future implementation of a full satellite constellation will probably result in consistent 3D positional measurements with an accuracy of plus or minus 100 m.

3. The suitability of GPS for any project depends on the particular requirements of the project. For the Meridian Project, navigation and positioning to an accuracy of 100 to 200 m was acceptable. Other projects that require more precise positional accuracies, such as high density geochemical mapping, should utilize base station differential correction. The effects of the topography and the tree canopy varies from project to project and should be considered prior to the selection and use of any GPS system.

4. At present, especially without a complete satellite constellation in orbit, the ability to do mission planning prior to going into the field is an integral part of the use of the Global Positioning System.

REFERENCES

Fortescue, J.A.C., Vida, E.A. and Wadge, D.R. 1991. Regional Geochemical mapping in the Batchawana Greenstone Belt: The Cow River Project; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.169–174.

37. Geology of Keith and Muskego Townships, Northern Swayze Greenstone Belt

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INTRODUCTION

Keith and Muskego townships were mapped during the 1992 field season in a continuing project to update the geological database of the northern Swayze greenstone belt. Mapping commenced in 1991 in Foleyet and Ivanhoe townships immediately west of the current map area (Ayer and Puumala 1991). Keith and Muskego townships are bounded by latitudes 48°03'N and 48°19'N and longitudes 82°12'W and 82°24'W (Figure 37.1). Previous geological mapping covering parts of the map area included work by Harding (1937), Prest (1951) and Breaks (1978) and a regional reconnaissance mapping project by Thurston et al. (1977) which included all of the map area. The current mapping project is at a scale of 1:15 840 and focusses on updating our understanding of the stratigraphy, structure and mineral potential in an area with possible lithological and structural continuity to the economically fertile Timmins area about 100 km to the northeast.

Outcrop density is variable from very low in much of Muskego Township to relatively high in the vicinity of the Joburbe Mine in Keith Township. Interpretative correlation of map units and structures was aided by airborne magnetic and electromagnetic data (ODM-GSC 1963a, 1963b; OGS 1990a–f).

MINERAL EXPLORATION

The map area has undergone a considerable amount of mineral exploration, although much of this effort was concentrated in the northern half of Keith Township and the southern part of Muskego Township (Figure 37.2). In the early period, iron and gold were the commodities of principal interest (Harding 1937). The discovery of gold mineralization, leading to the Joburke Mine in Keith Township in 1946, resulted in an intensification of gold exploration (Prest 1951), which has continued to the present. Since the 1960s, various mineral exploration companies have explored parts of the map area for copper, zinc, nickel and asbestos utilizing airborne and ground electromagnetic surveys with follow-up diamond drilling programs.

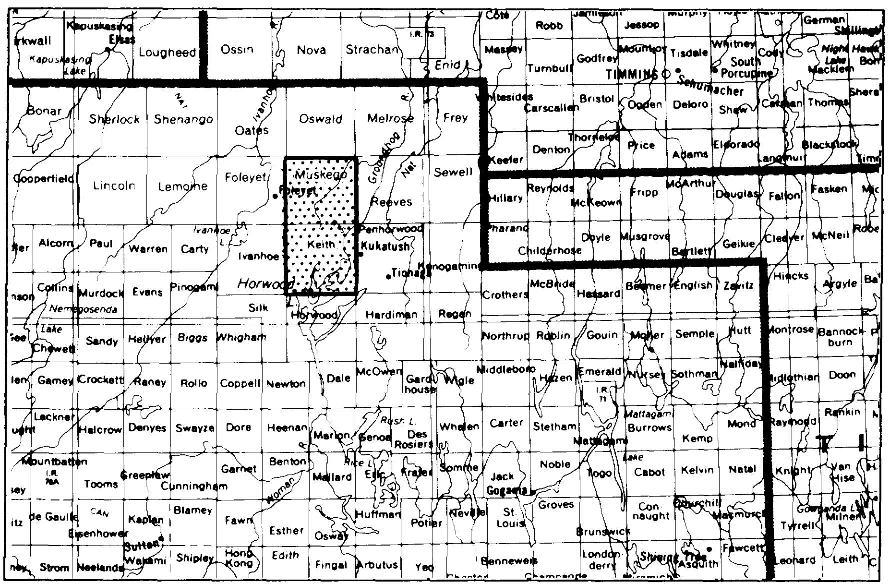

Figure 37.1. Location of Keith and Muskego townships, scale 1:1 584 000.

NODA • EDNO
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This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

Exploration work filed for assessment credit is summarized in Geological Data Inventory Folios (GDIF) for the 2 townships on file at the Resident Geologist's Office in Timmins. The Joburke Mine produced a total of 474 085 tons with an average grade of 0.106 ounces Au per ton during the periods of 1973–75 and 1979–81 (unpublished report, Mining Corporation of Canada Limited 1981). The most recent exploration, by Noranda Exploration Company, Limited and Tarzan Gold Incorporated, on the property consisted of stripping, trenching and sampling, ground electromagnetic, induced polarization surveys, geochemical and geological surveys and diamond drilling continuing to 1989. An extensive exploration program of stripping, trenching and sampling, geophysical and geological surveys and diamond drilling was conducted by Marshall Minerals Corporation up to 1989 on a large claim block surrounding the Joburke claims to the north, east and south. A considerable amount of this work was focussed on the Hoodoo-Patricia prospect located about 1.5 km southeast of the Joburke Mine (Siragusa 1990a, 1990b). Anomalous gold values have also been obtained within the Slate Rock Lake deformation zone in the southern part of Muskego Township. In the late 1980s, Utah Mines Limited, Unigold Resources Limited and BP Resources Canada Limited conducted exploration programs within this area.

Diamond drilling in 1972–73 by Dome Exploration (Canada) Limited intersected anomalous zones of zinc and copper associated with sulphidic and graphitic iron formation in 3 separate areas in the northern half of Keith Township. These zones include assay values of up to 1.4% Zn and 1.5% Zn over two 15 feet (4.6 m) intervals in a diamond drill hole west of the Groundhog River; a 73 feet (22.2 m) intersection with 0.5 to 0.75% Zn south of Slate Rock Lake and 0.37% Cu over 6.7 feet (2.0 m) south of the Hoodoo–Patricia prospect. Copper mineralization was explored by United Macfie Mines Limited in south-central Muskego Township in 1970–71. The occurrence is associated with an enclave of iron formation

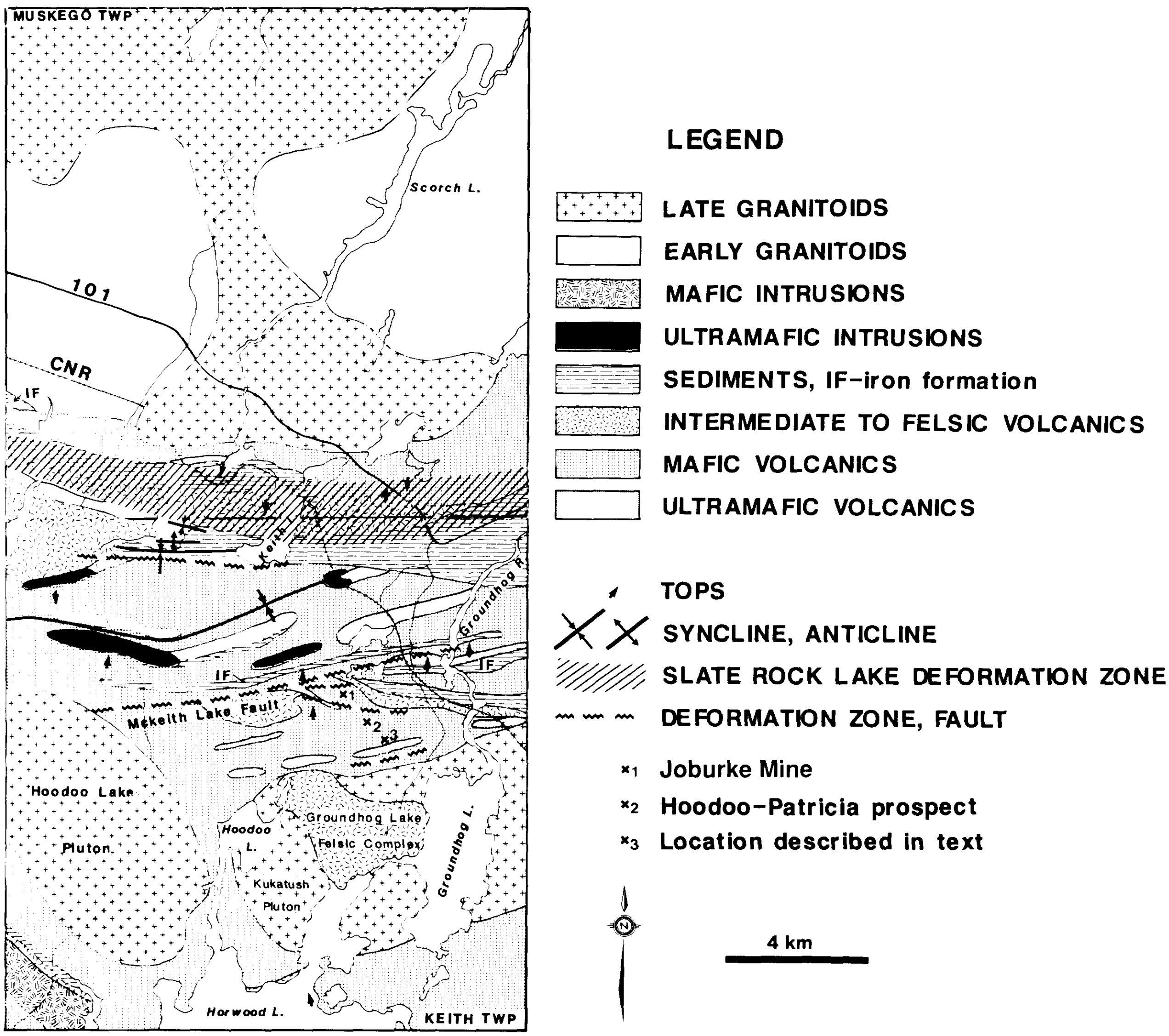

Figure 37.2. General geology of Keith and Muskego townships.

within the northern granitoid complex about 1 km north of Highway 101, east of Scorch Creek. The exploration program consisted of trenching and sampling, ground electromagnetic and magnetic surveys and diamond drilling. Surface sampling indicated assay values of up to 0.30% Cu over 27 feet (Thurston et al. 1977).

GENERAL GEOLOGY

With the exception of Proterozic diabase dikes, all rocks are of Archean age and occur within the Abitibi Subprovince. Structural features and stratigraphy are steeply dipping and generally trend easterly. The supracrustal rocks are broadly subdivided into 2 assemblages. These are identified as the Muskego–Reeves assemblage (MRA) and the Horwood assemblage (HA) lying to the north and to the south of the Hoodoo Lake and Kukatush plutons, respectively. The distribution of these assemblages are slightly modified after Jackson and Fyon (1991). The 2 assemblages are discriminated on the basis of the relative diversity of supracrustal rock types. The differences include a much wider variety of volcanic compositions and a greater abundance of proximal sedimentary and volcanic rock types in the MRA, in contrast with the monotonous mafic flows of the HA. These differences suggest differing magma sources and a more proximal depositional environment for the MRA. The contact between the 2 assemblages occurs in an unexposed area between the Hoodoo and Kukatush plutons. In Ivanhoe Township, west of the map area, the assemblages are bounded by the Muskego River fault along which the HA appears to be uplifted with respect to the MRA (Ayer and Puumala 1991).

Metavolcanic rocks

Komatiitic ultramafic volcanic rocks represent an estimated 5 to 10% of the MRA. These rocks are typically talcose with a wide variety of weathered surface colours ranging from dark green to orange-brown to white. These units texturally range from massive and polysutured to spinifex textured. Massive flows range from aphyric to porphyritic. In deformation zones, the ultramafic rocks are altered to chlorite-talc-carbonate schists with or without a bright green fuchsitic mica. Based on a combination of outcrop and aeromagnetic information, the ultramafic flows appear to form as lenticular units up to several hundred metres thick and 5 km long. At least some of these lenticular flow units appear to have formed along specific stratigraphic horizons, which suggest the lenticular flow units might have represented basinal areas of komatiite accumulation separated by higher areas of non-deposition. This observation is supported by their common association with sulphidic iron formation and fine turbidites which also imply deep water deposition. The close spatial relationship of the komatiite flows with massive, medium-grained serpentinite sills of more enigmatic origin (described below) suggests a cogenetic relationship which is not as yet fully understood.

Mafic volcanic rocks of mixed magnesium and iron tholeiitic composition represent the dominant supracrustal rock type constituting about 90% of the HA and 60% of the MRA. The mafic volcanics are dark green to grey and are predominantly aphyric. Rare plagioclase megaphyric mafic flows were only observed adjacent to the northern granitoid complex in southeastern Muskego Township. Fine-grained massive and pillowed flows are most common mafic flow type within the map area, along with less abundant amygdaloidal flows, variolitic flows and flow breccias. Massive mafic flows containing pyroxene spinifex textures occur rarely in northern Keith Township in flows of possible basaltic komatiite composition. Typically, the thick massive flow units are medium grained and gabbroic textured in all but the more quickly cooled thin upper and lower margins of the flow units. Previously, many of these gabbroic units were identified as mafic intrusions (Prest 1951), but the intimate association of pillowed flows and interflow sedimentary rocks indicates an extrusive origin. Mafic pyroclastic units consisting of tuff and lapilli tuff were only identified in a few isolated localities.

Intermediate to felsic calc-alkalic metavolcanic rocks constitute about 20% of the MRA and less than 5% of the HA. The intermediate volcanic rocks are medium to light green-gray. Aphyric, pillowed, amygdaloidal flows are common. Flow breccias, tuff and lapilli-tuff are relatively common. Felsic metavolcanic units are light gray and are typically quartz and/or feldspar phyric. The felsic units are massive to brecciated. In many localities, it is uncertain if the brecciation is autoclastic or tectonically induced. It is possible that many of these felsic units are complexes of intrusive and extrusive origin possibly in volcanic dome-like settings.

The Groundhog Lake felsic complex (GLFC) is located in southeastern Keith Township, occurring as a large enclave (3 by 5 km) within the Kukatush pluton. The complex consists for the most part of a weakly foliated, homogeneous, porphyritic, very fine-grained, massive felsic rock, with subordinate felsic pyroclastic rocks and wacke occurring along the southern margin of the body. The massive rock is typically composed of 1 to 2% feldspar phenocrysts (3 mm), and 2 to 3% fine-grained, aligned biotite crystals, set in an aphanitic felsic groundmass. Irregular patches of coarser grained granitic material were locally observed, likely produced by the escape of a related, volatile-rich phase. Miarolitic cavities were observed within the porphyritic rock along the west shore of Groundhog Lake. The lenticular-shaped cavities average 3 cm in length, and are often partly filled with quartz and garnetiferous/chloritic material. Based on its porphyritic and homogeneous nature, the presence of miarolitic cavities, and the development of a coarser grained phase, the GLFC is interpreted as a subvolcanic felsic unit. The injection of numerous dikes of monzonite originating from the Kukatush pluton, and close association with felsic pyroclastic and sedimentary rocks to the south, clearly support a synvolcanic emplacement origin. It is possible that the GLFC may have represented a high level magma chamber for the felsic metavolcanic units and as a heat source to drive convective hydrothermal systems in the overlying supracrustal succession (*see* Economic Geology).

Metasedimentary Rocks

Clastic and chemical sedimentary rocks represent about 20% of the Muskego–Reeves assemblage (MRA) and less than 5% of the Horwood assemblage (HA). The sedimentary rocks are common throughout the MRA both as the more extensive units indicated on Figure 37.2 and as intercalations within volcanic units which are too thin to be represented on the figure. A wide variety of sedimentary types are present. Clastic sedimentary rocks consisting of conglomerate, sandstone, siltstone and mudstone occur in a unit up to 2 km thick extending across the central part of the map area. The conglomerates are heterolithic and composed of well-rounded clasts of quartz-feldspar porphyry, intermediate volcanic, sandstone and up to 5% of a fine-grained, sugary-textured quartzose clast which could represent either recrystallized chert or vein quartz. Conglomerate beds are up to 1 m thick and have abrupt contacts with interbedded sandstones up to 50 cm thick. Rare normal grading and interbedded siltstone and mudstone units are locally present.

A second clastic unit up to about 1 km thick lies about 1 km north of the main unit. It is not well exposed and lies within the Slate Rock Lake deformation zone. Where it is relatively undeformed and unaltered, it consists of turbiditic sandstone, siltstone and mudstones with considerable intermixture of intermediate volcanic rocks.

The other thinner, sedimentary units indicated on Figure 37.2 consist of thinly to thickly bedded turbidites and a wide variety of chemical sediments. The chemical sediments consist of magnetite, hematite, sulphide and graphite facies ironstone typically interbedded with chert. The most extensive ironstone unit, lying north of the McKeith Lake fault (*see* Figure 37.2), consists of magnetite-chert (locally amphibole-rich) banded ironstone throughout a strike length of about 10 km. Other units change from magnetite-facies to hematite-facies ironstone along strike. Sulphide ironstone occurs in discrete units separated from the oxide facies ironstones. They consist of fine-grained laminated pyrite or beds of concretionary pyrite nodules interbedded with graphitic mudstones and/or chert. The sulphide and graphitic ironstones locally contain significant amounts of zinc and copper (*see* Mineral Exploration). They were most likely deposited from seawater enriched in metals from hydrothermal vents during hiatuses in volcanism.

Mafic to Ultramafic Intrusive Rocks

Mafic to ultramafic intrusive rocks occur within Keith Township, intruding both the MRA and HA supracrustal sequences. The intrusions mainly consist of isolated sill-like bodies of gabbro and serpentinite interpreted to be consanguineous with the volcanic succession. Some appear to be differentiated layered sills of peridotite, pyroxenite, and gabbro. Some of these bodies may be thick massive flows, as disequilibrium crystal morphologies (i.e., acicular and/or dendritic) indicative of rapid cooling are widespread.

An elliptically shaped body, the Cornice Creek gabbro, occurs in the southwestern corner of the map. The intrusion is well foliated along its margin, and locally contains felsic to mafic volcanic xenoliths, implying a pretectonic emplacement during or shortly following volcanic activity in the area. The rock is characterized by large clusters (5 to 10 mm) of hornblende crystals set in a finer grained matrix dominated by plagioclase. Such texture is typical of many other smaller gabbroic bodies in Keith Township.

Sill-like ultramafic bodies of peridotite to dunite composition consist of uniform, fine- to medium-grained, polyhedral-jointed, serpentinized, olivine-rich orthocumulates. These bodies commonly grade laterally into unequivocal spinifex-textured komatiite flows and, thus, could possibly represent feeders or proximal channel facies ultramafic flows, similar to those associated with komatiite-hosted nickel deposits in Archean sequences (Lesher 1989).

Early Felsic to Intermediate Intrusive Rocks

Most of Muskego Township is underlain by foliated felsic to intermediate intrusive rocks intruded from the north by a late granitic intrusion. The early intrusive rocks consist of moderately foliated, equigranular hornblende-biotite granodiorite and hornblende diorite. Both phases are likely co-magmatic in origin. As outcrop is very scarce in the northern part of map area, intrusive contacts with the late granitoids have been interpreted mostly on the basis of aeromagnetic data. Early porphyritic intrusions (quartz and/or feldspar porphyry) are found throughout the map area, occurring as small lenticular bodies or dikes.

Late Felsic Intrusive Rocks

Three large massive to weakly foliated felsic intrusions are found in the map area: 1) the Hoodoo Lake pluton in southwestern Keith Township; 2) the Kukatush pluton in southeastern Keith Township; and 3) a granitic batholith occupying much of Muskego Township.

The Hoodoo Lake pluton is an oval-shaped body measuring approximately 10 km in length and up to 5 km in width, extending to the northwest partly into Foleyet Township. It is a massive, homogeneous, porphyritic biotite granodiorite characterized by large alkali feldspar phenocrysts (1 to 3 cm) set in a medium-grained groundmass dominated by plagioclase and quartz. The intrusion is leucocratic, as biotite amounts to only 5% of the rock. The surrounding mafic volcanic rocks have been amphibolitized by contact metamorphism, and show foliations which parallel the intrusive contact. Such features are also observed adjacent to the Kukatush pluton. Although exposures are restricted to the southeastern margin of the pluton, intrusive contacts were nonetheless interpreted fairly accurately, as the body exhibits a distinct negative aeromagnetic anomaly.

The Kukatush pluton is an east-trending body approximately 5 km in width that extends well into Penhorwood Township to the east. It consists of a massive, equigranular, medium-grained hornblende monzonite containing a significant proportion of mafic volcanic xenoliths (5 to 10%). Few inclusions of fine-grained felsic volcanic rock, likely derived from the Groundhog Lake felsic complex, were also observed. A more differentiated quartz monzonite, containing 10% alkali feldspar phenocrysts (1 cm), occurs locally as a marginal phase. In contrast to the low magnetic susceptibilities of the Hoodoo Lake pluton and the large felsic enclave identified as the Groundhog Lake felsic complex, the Kukatush pluton exhibits a positive aeromagnetic anomaly, which, in conjunction with limited outcrop, indicates a more extensive distribution to the west than was indicated by Breaks (1978).

The large felsic intrusion intruding the foliated granodiorite and diorite in Muskego Township consist of a massive to weakly foliated, equigranular to porphyritic, medium-grained biotite-muscovite granite. It is distinguished from the surrounding early granitoids by its higher potassium content, significant differences in mafic mineral composition, and common porphyritic nature. The rock becomes weakly foliated to the south, near the contact with the supracrustal rocks, suggesting a late syntectonic emplacement. The granite has undergone significant epidotization in the northwestern part of the township, probably as a result of the intrusion of abundant granitic pegmatite dikes in the area. Similar dikes containing minor quantities of chalcopyrite and molybdenite were found in one locality within the foliated granodiorite.

STRUCTURE AND METAMORPHISM

Three separate tectonically induced fabrics were observed in parts of the map area. These observations indicate that a number of distinct phases of deformation have affected the supracrustal rocks in a complex interplay of folding and faulting. An easterly trending S_1 fabric is evident in most supracrustal rocks. Dips are uniformly steep to the north with the exception of a zone of steep southerly dipping fabric in a contact strain aureole extending up to 1 km south of the northern granitoids in Muskego Township.

Folding

Although sparsely distributed, top indicators uniformly indicate a southerly facing direction from the northern granitoid contact in Muskego Township to the central axis of the sedimentary unit extending across northern Keith Township. South of this sedimentary unit, facings are generally to the north, indicating the unit lies in the keel of a synclinorial fold. This is also supported by east-plunging minor folds and a number of reversals of facing direction observed within the sedimentary unit in the vicinity of the southern part of Slate Rock Lake (*see* Figure 37.2). Coaxially refolded thinly bedded sandstones in this area indicate at least 2 fold episodes have affected these rocks.

Facing reversals several kilometres south of Slate Rock Lake indicate a second synclinal structure south of the main sedimentary unit (*see* Figure 37.2).

Faulting

The Slate Rock Lake deformation zone (SRDZ) is an extensive zone of ductile deformation up to 1.5 km wide extending easterly across the southern part of Muskego Township. Much of the rock within this deformation zone is highly schistose and carbonatized. Three separate fabrics are evident in the schistose rocks throughout much of this zone. They consist of an subvertical east-trending S_1 schistosity overprinted by a gently dipping pervasive S_2 crenulation or kink cleavage with highly variable strike which is axial planar to gently plunging open folds to locally tight chevron folds. S_3 consists of a poorly developed, steep northeasterly trending cleavage possibly associated with northeast-trending Z-shaped kink bands.

A number of less extensive deformation zones are evident in Keith Township. They consist of strata-parallel zones of highly schistose and carbonatized rock 10 to 100 m thick. Some of these zones also host auriferous quartz veins such as at the Joburke Mine and Hoodoo–Patricia prospect. Three separate fabrics are also evident in the shear zones associated with the Joburke Mine, but, in contrast to the SRDZ, the flat S_2 crenulation cleavage is only locally developed, while the steep dipping S_3 fabric is a pervasive axial planar cleavage to northeast-trending Z folds.

The McKeith Lake fault appears to represent a later generation of brittle-ductile faulting. The fault trends east northeast across much of Keith Township (*see* Figure 37.2). Where the fault is well exposed, in the vicinity of the Joburke Mine, it consists of schistose, brecciated and hematitized rock in a zone up to 50 m wide which clearly truncates a number of distinctive supracrustal units. The western extension of the fault is more speculative, but based on airborne geophysical evidence (OGS 1990c, 1990d) it appears to be truncated by the Hoodoo Lake pluton and may in fact have originally been continuous with the Muskego River Fault which is truncated by the pluton in Ivanhoe Township (Ayer and Puumala 1991).

Metamorphism

Most of the supracrustal rocks have attained greenschist-facies metamorphism. Contact metamorphism of amphibolite facies is achieved within 2 km of the contact with the northern granitoid complex and within 1 km of the contact of the Kukatush and Hoodoo Lake plutons. This metamorphic upgrading corresponds with a colour change from dark green to black, and localized development of medium-grained, feathery amphiboles and/or garnet porphyroblasts in mafic volcanic rocks.

ECONOMIC GEOLOGY

Gold

Gold occurs in sufficient quantities and grade at the Joburke Mine in Keith Township to have supported the production of almost 1/2 million tons of ore which was trucked to Timmins for processing in the 1970s and early 1980s (unpublished report, Mining Corporation of Canada Limited 1981). At the Joburke Mine, the gold mineralization occurs in 2 structural settings. Widespread mineralization with relatively low grades occurs in thin quartz-carbonate veins which parallel the foliation in highly schistose and carbonatized basalts within the Joburke deformation zones. These early veins are folded in conjunction with the S_1 foliation, into westerly plunging Z folds with a steeply dipping northeast-trending axial planar cleavage. Four ore zones in 2 east-trending deformation zones have received varying amounts of production. The ore zones consist of an intricate network of quartz stringers and veins which are typically folded into steep easterly plunging S-shaped patterns (Prest 1951). Minor pyrite and chalcopyrite are commonly present in the higher grade veins. The McKeith Lake fault apparently truncates the Joburke deformation zones west of the mine (*see* Figure 37.2), but does not appear to host any significant gold mineralization.

Gold also occurs in a less extensive deformation zone of carbonatized and quartz-veined basalts at the Hoodoo–Patricia prospect and a number of smaller shear zone hosted occurrences east and south of the Joburke

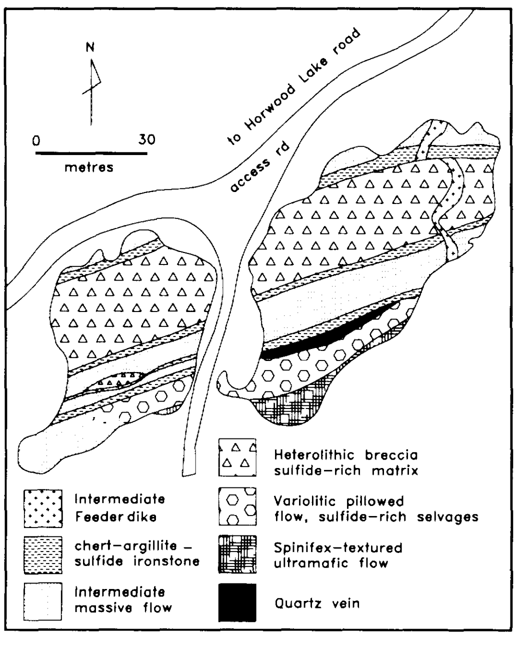

Figure 37.3. Geology of a mineralized outcrop area in Keith Township (*see* Economic Geology for description).

Mine (Siragusa 1990a, 1990b).

Gold is locally present in the more extensive Slate Rock Lake deformation zone in southern Muskego Township. A number of mineral exploration programs in this area have detected anomalous gold values (*see* Mineral Exploration), but not in economic concentrations. Mineralization in this area is typically associated with quartz-carbonate veining and disseminated sulphides including pyrite, pyrrhotite, chalcopyrite and arsenopyrite in highly schistose and carbonatized rock.

Base Metals

Zinc and copper occurrences are scattered throughout the map area. The more significant zinc assays are from diamond drilling of banded chert-sulphide facies iron formation and graphitic mudstones. Some of these sulphide iron formations are closely associated with unusual breccias which may have resulted from hydrothermal activity. A stripped outcrop about 500 m southeast of the Hoodoo–Patricia prospect (see location 3, Figure 37.2) illustrates this geological setting. Three separate iron formation units are intercalated with spinifex-textured komatiites, massive and pillowed intermediate to mafic flows and an unusual breccia about 30 m thick (Figure 37.3). The breccia consists of extremely poorly sorted and angular clasts of chert, sulphide iron formation and massive flow up to 3 m in diameter supported in a finely comminuted matrix. Thin siliceous rinds around some of the clasts indicate silicification and locally the breccia matrix and the interpillow margins of underlying flows contains concentrations of pyrrhotite with minor chalcopyrite. Diamond drilling, done by Dome Exploration (Canada) Limited in this area, indicated assay values of up to 0.37% Cu over 6.7 feet (2.0 m) (see Mineral Exploration). Many other minor occurrences of pyrrhotite and chalcopyrite were observed by the field party in the immediate area. Sulphide occurrences are also indicated in this area by Prest (1951) and in a stratigraphically equivalent area along strike about 2 km to the east. It is interesting to speculate about the close spatial association with the synvolcanic Groundhog Lake felsic complex which underlies these occurrences about 2 km to the south. It is possible that the complex may have acted as a heat source for hydrothermal solutions which ultimately resulted in deposition of the sulphidic ironstone units.

Possible hydrothermal breccias similar to the above described unit were also observed in core drilled by Dome Exploration (Canada) Limited associated with thick pyritic and graphitic iron formation units with assay values of up to 1.5% Zn over 15 feet (4.6 m) about 2.5 km to the north west of the Groundhog River (see Mineral Exploration).

An extensive zone of chloritoid alteration up to about 500 m wide with an apparent strike length of 4 km occurs within the Slate Rock Lake deformation zone. Fine feathery chloritoid is visible on cleavage surfaces in a plagioclase phyric felsic schist north of Keith Lake

(Prest 1951) and as medium-grained black tabular porphyroblasts of probable chloritoid in felsic and mafic carbonatized schists in diamond drill core along strike to the east and west. As chloritoid in greenschist facies metavolcanic rocks has been documented to be the result of hydrothermal alteration (Franklin et al. 1975; Lockwood 1986), it is assumed that this zone represents a zone of conformable hydrothermal alteration which could be associated with sulphide mineralization. The association of chloritoid alteration with stratabound sulphides was also documented to the west in Foleyet Township (Ayer and Puumala 1991).

The map area may have potential for komatiite-hosted nickel mineralization. The close association of sulphidic iron formations with a wide variety of komatiite flow types and compositions indicates a geological similarity to that of nickel mineralization in the Kambalda area of Australia and at the Langmuir and Redstone deposits in the Timmins area (Lesher 1989).

ACKNOWLEDGMENTS

Close co-operation with exploration company individuals by access to information and core not in the public domain and guided property tours has resulted in a much improved understanding of the geology of the map area. Appreciation is therefore extended to B. Jeffery and J. Aultman of Falconbridge Exploration; J. Wakeford and R. Dahn of Noranada Exploration Company, Limited; P. Burchell of Placer Dome Incorporated; and J. Sanford of Marshall Minerals Corporation for all their help.

REFERENCES

Ayer, J.A. and Puumala, M.A. 1991. Geology of Foleyet and Ivanhoe Townships, Northern Swayze greenstone belt; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.263–267.

Breaks, F.W. 1978. Geology of the Horwood Lake area, District of Sudbury; Ontario Geological Survey, Report 169, 67p.

Franklin, J.M., Kasarda, J. and Poulsen, K.H. 1975. Petrology and chemistry of the alteration zone of the Mattabi massive sulphide deposit; Economic Geology, v.20, p.63–79.

Jackson, S.L. and Fyon, A.J. 1991. The western Abitibi Subprovince in Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.404–482.

Harding, W.D. 1937. Geology of the Horwood Lake area; Ontario Department of Mines, v.46, 42p.

Lesher, C.M. 1989. Komatiite-associated nickel sulfide deposits; *in* Ore deposition associated with magmas; Reviews in Economic Geology, v.4, p.45–101.

Lockwood, M.B. 1986. The petrographic and economic significance of chloritoid in the Wawa Greenstone Belt; unpublished MSc thesis, Carleton University, Ottawa, Ontario.

Ontario Department of Mines–Geological Survey of Canada 1963a. Groundhog Lake, Ontario Department of Mines–Geological Survey of Canada Map 2263G, scale 1:63 360.

——— 1963b. Oswald Lake, Ontario Department of Mines–Geological Survey of Canada Map 2264G, scale 1:63 360.

Ontario Geological Survey 1990a. Airborne electromagnetic and total intensity magnetic survey, north Swayze–Montcalm area; Ontario Geological Survey, Map 81368, scale 1:20 000.

——— 1990b. Airborne electromagnetic and total intensity magnetic survey, north Swayze–Montcalm area; Ontario Geological Survey, Map 81369, scale 1:20 000.

——— 1990c. Airborne electromagnetic and total intensity magnetic survey, north Swayze–Montcalm area; Ontario Geological Survey, Map 81375, scale 1:20 000.

——— 1990d. Airborne electromagnetic and total intensity magnetic survey, north Swayze–Montcalm area; Ontario Geological Survey, Map 81376, scale 1:20 000.

——— 1990e. Airborne electromagnetic and total intensity magnetic survey, north Swayze–Montcalm area; Ontario Geological Survey, Map 81382, scale 1:20 000.

——— 1990f. Airborne electromagnetic and total intensity magnetic survey, north Swayze–Montcalm area; Ontario Geological Survey, Map 81383, scale 1:20 000.

Prest, V.K. 1951. Geology of the Keith–Muskego townships area; Ontario Department of Mines, Annual Report, v.59, pt.7.

Siragusa, G.M. 1990a. Deformation and associated auriferous quartz veining in Keith Township, northern Swayze belt; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.86–90.

——— 1990b. Geology of the Patricia showing (1987)–Hoodoo prospect, Keith Township; Ontario Geological Survey, Open File Map 145, scale 1:250.

Thurston, P.C., Siragusa, G.M., and Sage, R.P. 1977. Geology of the Chapleau area, districts of Algoma, Sudbury and Cochrane; Ontario Division of Mines, Geological Report 157, 293p.

38. Quaternary Geology of the Foleyet Area, Northern Ontario

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INTRODUCTION

The field work begun this summer in the Foleyet area (NTS 42 B/1) was carried out as part of a four-year regional till sampling and surficial geologic mapping program covering the Swayze greenstone belt. The project area encompasses 5 NTS 1:50 000 map sheets (Figure 38.1) 42B/1, 41O/9, 41O/10, 41O/15 and 41O/16, bounded by latitudes 47°30′N and 48°15′N, and by longitudes 83°00′W and 82°00′W. The overall objective of this program is to provide the regional Quaternary framework for mineral exploration using glacial drift. This is to be accomplished: 1) by determining the nature and distribution of various types of surficial deposits; 2) deciphering regional ice flow history both erosional (striation record) and depositional (stratigraphic record); and 3) identifying regional variations in the lithologic and geochemical composition of till that may be used as an aid to mineral exploration within the region.

The Foleyet map sheet (42B/1) comprises the northeastern-most part of the study area. The town of Foleyet is located approximately 100 km west of Timmins along Highway 101. Numerous secondary and logging roads provide good access throughout most of the region. Surficial geology of the study area was mapped by Boissonneau (1966, 1968) at a scale of 1:506 880, and engineering and terrain geology maps were compiled by Lee and Scott (1980) and Roed and Hallett (1979) at a scale of 1:100 000. In this study, detailed mapping was carried out at scales of 1:15 840 and 1:20 000 and will be compiled at a scale of 1:50 000.

GENERAL BEDROCK GEOLOGY

The northern Swayze greenstone belt is part of the Abitibi Subprovince. East of the study area, the belt is largely truncated by granitic batholiths, but it appears to be continuous with the Timmins portion of the Abitibi belt to the east (Ayer and Puumala 1991). Bedrock within this region has been mapped at a variety of scales by Harding (1937), Prest (1951), Milne (1972), Thurston et al. (1977), Breaks (1978), Ayer and Puumala (1991). An overview of the bedrock geology is presented by Jackson and Fyon (1991). In the Foleyet area, supracrustal rocks of the Swayze belt have been subdivided into 2

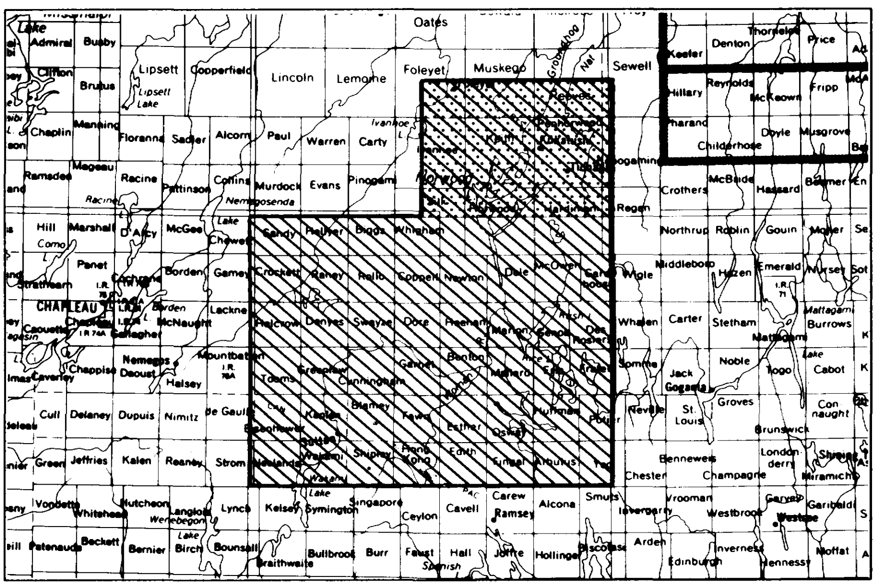

Figure 38.1. Location of project area (stippled), including area mapped during 1992 field season (shaded), scale 1:1 584 000.

This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

lithological groups, the Muskego–Reeves assemblage and the Horwood assemblage. The Muskego–Reeves assemblage, underlying the northern part of the area, comprises a diverse lithologic assemblage composed of ultramafic, mafic and felsic flows and pyroclastic rocks. Sedimentary units are composed of conglomerates, wackes, mudstones and banded ironstone. The Horwood Lake assemblage underlies the southern part of the map area, separated from the Muskego–Reeves assemblage by the Muskego River fault. This assemblage comprises a lithologically monotonous series of mafic flows and synvolcanic mafic sills (Ayer and Puumala 1991).

Gold mineralization within this region is genetically associated with east-west trending carbonatized shear zones such as the Muskego River fault and the Keith–Penhorwood deformation zone, which hosts the Joburke Mine, the Patricia showing and the Hoodoo prospect (Siragusa 1991, 1990a, 1990b, 1989). Elsewhere, several gold occurrences including a past producer (Tionaga Mine) also cluster around the intersection of 2 major regional faults: the north-trending Horwood Lake fault (Breaks 1978) and the northeast-trending Hardiman Bay fault (Breaks 1978). However, the direct association between these late brittle faults and Au mineralization is tenuous (Siragusa 1989).

Parts of the Muskego–Reeves assemblage are considered to have good potential for volcanogenic massive sulphide deposits. In the northeastern part of the map area, hydrothermal alteration, including silicification and chloritoid-bearing mafic volcanic rocks, has been observed in association with stratabound massive sulphides (Ayer and Puumala 1991).

Talc, presently being mined, and asbestos, previously mined, have been extracted from bodies of serpentinized and carbonatized ultramafic rock (Milne 1972).

PHYSIOGRAPHY

The project area lies wholly within the Abitibi upland of the James Region as defined by Bostock (1970). This Abitibi upland straddles the continental divide, exhibiting moderately rolling relief, with elevations averaging between 300 and 400 m. The mapped area is located north of the drainage divide and all modern surface drainage is channelled northward into Hudson Bay via the Ivanhoe and Groundhog rivers and their tributaries. Major rivers are bedrock controlled and trend to the northeast, parallel to major bedrock structures.

The map area is extensively drift covered. The northern region is characterized by a gently rolling and fluted till plain. Bedrock outcrop in this area is rare, and drift thickness is variable ranging up to 35 m. Two large esker systems are observed in the map area, the Ivanhoe esker (Richard 1984) and associated tributaries in the west, and the Penhorwood esker (Richard 1984) in the east. In the vicinity of these eskers, local relief ranges up to 65 m, and associated subaqueous fan and eolian deposits obscure bedrock topography for several kilometres adjacent to glaciofluvial systems. The southeastern part of the map area is characterized by thin discontinuous drift cover and gently to moderately rolling bedrock-controlled topography.

GLACIAL GEOLOGY

Ice Flow History

Striations observed throughout the map area indicate that the main direction of ice flow was to the southwest at 190° to 200°. At numerous sites, however, crossing striae record a sequence of ice flow events both predating and post-dating the main 190° to 200° flow event. Age relationships were determined on faceted stoss/lee surfaces and also by superposition (younger striae located in grooves associated with older flow directions). At several sites along Highway 101, striations younger (more recent) than the regional 190° to 200° direction were observed. Two distinct younger ice flow directions have been recorded, one trending to the southwest at approximately 230° to 240°, and another trending to the southeast ranging from 170° to 150°. At the Patricia showing, an area of stripped outcrop extending 400 m by 140 m reveals a complex sequence of ice flow events. At this site, the orientation of striae associated with these younger flow events is variable, being significantly influenced by bedrock topography. This may suggest that these striae were formed under thin ice during deglaciation. The regional significance of these younger ice flow directions has as yet to be determined. They may reflect local reorientation of ice flow associated with the development of large esker systems and/or local ice marginal fluctuations.

Striations pre-dating the regional 190° to 200° flow event have also been observed at several sites. At the Patricia showing, striae protected within bedrock swales record 2 different older ice flow directions, one trending west at approximately 270° and a second trending southeast at approximately 140°. Faceted outcrops indicating an older southwest flow event at 230° have also been observed in trenches exposing bedrock at the Joburke mine site. This corresponds, at least in part, with the striation record in the eastern Abitibi, west of the Harricanna moraine (Veillette 1986, 1989; Veillette and Pomares 1991), where ice flow during the last glacial maximum is thought to have shifted from westerly (230° to 270°) to southerly (180° to 220°) to southeasterly (170° to 160°). Older southeast-trending striae may reflect a pre-Wisconsinan glaciation as suggested for older tills in the Timmins area (Bird and Coker 1987; Alcock, personal communication, 1987 as referenced *in* Steele et al. 1989).

Surficial Deposits and Landforms

Much of the northern and central parts of the mapped area are characterized by extensive till cover. In these regions, thick deposits of till and associated debris flow sediments mask underlying bedrock topography forming fluted till plains or till plateaux. Fluting trends to the southwest at 190° to 200°. Till composition is variable. In areas of thick till cover, wherever exposure permitted (roadcuts, trenches, etc.), a dense and compact till with a sandy silty matrix was commonly observed at depth (3 to 4 m). This till facies is calcareous, containing a noticeable proportion of carbonate casts. In hand-dug pits (approximately 1 m depth), till was commonly loose and sandy containing abundant pockets and stringers of sand, likely reflecting meltout or sediment flow processes. Carbonate content is variable, a function of leaching in the near surface environment.

In the southeastern part of the region till cover is thin and discontinuous. Till matrix is commonly very sandy, containing abundant pockets and stringers of sorted sand. Thick sequences (2 to 3 m) of till and interbedded sand to gravelly sand have been observed on the down-ice (lee) side of bedrock structures suggesting deposition in subglacial cavities. Again, carbonate content is variable reflecting near surface weathering processes.

Eskers throughout the region trend to the southwest, subparallel to fluting. Eskers within the western part of the map area form tributaries to the much larger Ivanhoe esker (Richard 1984) that extends just beyond the western margin of the map sheet. Tributary eskers are well developed with single crested ridges extending over several kilometres. In the vicinity of the trunk esker, these tributaries swing to the west and exhibit more southwesterly trends. In the eastern part of the map area, the Penhorwood esker (Richard 1984) extends for several tens of kilometres across the region, becoming indistinct and unmappable near the southern margin of the map sheet. This esker exhibits a sharp and well-defined crest over much of its length with local relief ranging up to 50 m. Kettle lakes are well developed along the entire length of this system. Unlike the Ivanhoe esker, smaller tributary eskers have not been developed.

Materials associated with these large eskers systems are variable. Esker core sediments commonly comprise moderately well-sorted cobble gravel, with maximum clast size achieving 1 m in diameter. The margins of esker ridges are commonly flanked by much finer grained medium to fine and silty fine sand, forming ripple drift sequences associated with deposition on subaqueous fans. Much of this material has been reworked by eolian processes to form large parabolic to transverse dunes. Dune orientation indicates paleowind direction from the west/northwest.

Laminated silt and clay has been observed in topographic lows throughout the region. The most extensive deposits occur within river valleys in the northern part of the map area (Nat River and Ivanhoe River), and along the shore of Horwood Lake (Breaks 1978).

Stratigraphy

Stratigraphy in the Foleyet area is related primarily to late glacial and deglacial events. Pebble fabrics measured in surface till indicate deposition by ice flowing to the south/southwest. At the Luzenac Talc Mine, exposure in an open pit revealed approximately 4 m of sandy till overlain by approximately 2 m of slightly clayey sandy till, which, in turn, is overlain by approximately 2 m of laminated silt and clay. The contact between tills is marked by a zone of interbedded stratified sand, silty fine sand and diamicton that, in places, is capped by thin and discontinuous clay laminae interbedded with layers of sand. At 2 sites along section, reworked organics were observed within sand layers at this contact. At present, the age of these organics is unknown, but they may represent recycling of older deposits. Similar reworked organics have been observed at the base of Barlow/Ojibway sediments in areas further north and east (J.J. Veillette, Geological Survey of Canada, personal communication, 1992). This entire sequence likely reflects retreat and local re-advance of the ice margin.

At one site, exposure in a stream cut revealed an extremely compact and blocky till at surface. This till differs from the regional surface till in that it is highly jointed and oxidized along fractures. Individual blocks are extremely dense and this till contains an a larger concentration of carbonate pebbles than is found in the regional till. Pebble fabrics indicate deposition by ice flowing southeast. It is possible that this till represents an older ice flow event, but further work is required to evaluate this interpretation.

DRIFT PROSPECTING

Samples of surface till were collected at both regional and detailed scales. Regional sampling was carried out in an effort to identify geochemical and lithological trends that may act as an aid to mineral exploration within the region. At a regional scale, the geochemical and lithological composition of till may outline: 1) trends that are useful in identifying the lateral extent of bedrock units obscured by drift cover; 2) large-scale geochemical anomalies that may indicate favourable sites for mineralization; and 3) mineralogy associated with alteration zones related to mineralization. Detailed sampling will be carried out over various types of mineralization found within the region in an effort to characterize the geochemical and lithological signature of mineralization within the till, and to map the scale and form of glacial dispersal associated with various types of deposits.

At the regional scale, a total of 135 sites were sampled across the map sheet. Sampling density averaged approximately 1 per 7 km², with a sample spacing of approximately 2 km along roads and lakeshores. Sampling spacing decreases in areas of limited access or extensive glaciofluvial or glaciolacustrine sedimentation. Samples were collected from roadcuts, borrow pits and metre deep hand-dug pits. Detailed sampling was carried out at the site of the Joburke gold mine. A total of 55 sites were sampled extending approximately 1 km down-ice and 400 m up-ice from the ore zone. Additional detailed studies are planned in the vicinity of base metal and nickle sulphide deposits. At each site, samples of C-horizon till, B-horizon till and humus were collected in order to evaluate the sampling media most effective for geochemical exploration for various types of deposits within the region.

REFERENCES

Ayer, J.A. and Puumala, M.A. 1991. Geology of Foleyet and Ivanhoe townships, Northern Swayze greenstone belt; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Report 157, p.263–267.

Bird, D.J. and Coker, W.B. 1987. Quaternary stratigraphy and geochemistry at the Owl Creek Gold Mine, Timmins, Ontario, Canada; Journal of Geochemical Exploration, v. 28, p.267–284.

Bostock, H.S. 1970. Physiographic subdivisions of Canada; *in* Geology and economic minerals of Canada, Geological Survey of Canada, Economic Geology Report, no.1, p.9–30.

Breaks, F.W.. 1978. Geology of the Horwood Lake area, District of Sudbury; Ontario Geological Survey, Report 169, 67p.

Boissonneau, A.N. 1966. Glacial history of northeastern Ontario I. The Cochrane–Hearst Area; Canadian Journal of Earth Sciences, v.3, p.559–578.

——— 1968. Glacial history of northeastern Ontario II. The Timiskaming–Algoma area; Canadian Journal of Earth Sciences, v.5, p.97–109.

Harding, W.D. 1937. Geology of the Horwood Lake area; Ontario Department of Mines, v.46, 42p.

Jackson, S.L. and Fyon, A.J. 1991. The western Abitibi Subprovince in Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, p.405–482.

Lee, H.A. and Scott S.A. 1980. Northern Ontario engineering geology terrain study, data base map, Foleyet; Ontario Geological Survey, Map 5102, scale 1:100 000.

Milne, V.G. 1972. Geology of the Kukatush–Sewell Lake area, District of Sudbury; Ontario Division of Mines, Geological Report 97, 109p.

Prest, V.K. 1951. Geology of the Keith–Muskego townships area; Ontario Department of Mines, Annual Report, 1950, v.59, pt.7, 44p.

Richard, J.A. 1984. Geochemistry of Swayze belt esker, Northern Ontario; Geological Survey of Canada, Open File 1088, 22p.

Roed, M.A. and Hallett, D.R. 1979. Northern Ontario engineering geology terrain study, data base map, Ridout; Ontario Geological Survey, Map 5015, scale 1:100 000.

Siragusa, G.M. 1989. The geological setting of gold mineralization in the Horwood lake area of the Swayze belt; *in* Summary of Field Work and Other Activities 1989, Ontario Geological Survey, Miscellaneous Paper 146, p.132–135.

——— 1990a. Geology of the Patricia showing (1987) – Hoodoo prospect, Keith Township; Ontario Geological Survey, Open File Map 145, scale 1:250.

——— 1990b. Deformation and associated auriferous quartz veining in Keith Township, northern Swayze belt; *in* Summary of Field Work and Other Activities 1990, Ontario Geological Survey, Miscellaneous Paper 151, p.86–90.

——— 1991. Eastward tracing of the Patricia showing - Hoodoo prospect deformation zone, northern Swayze belt; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.73–75.

Steele, K.G., Baker, C.L. and McClenaghan, M.B. 1989. Models of glacial stratigraphy determined from drill core, Matheson area, northeastern Ontario; *in* Drift prospecting; Geological Survey of Canada, Paper 89–20, p.127–138.

Thurston, P.C., Siragusa, G.M. and Sage, R.P. 1977. Geology of the Chapleau area, districts of Algoma, Sudbury, and Cochrane; Ontario Division of Mines, Geological Report 157, 293p.

Veillette, J.J. 1986. Former southwesterly flows in Abitibi-Temiscamingue: implications for the configuration of the Late Wisconsinan ice sheet; Canadian Journal of Earth Sciences, v.23, p.1724–1741.

——— 1989. Ice movements, till sheets and glacial transport in Abitibi–Timiskaming, Quebec and Ontario; *in* Drift Prospecting; Geological Survey of Canada, Paper 89–20, p.139–154.

Veillette, J.J. and Pomares, J.–S. 1991. Older ice flows in the Matagami–Chapais area, Quebec; *in* Current Research, Part C, Geological Survey of Canada, Paper 91–1C, p. 143–148.

39. Western Abitibi Mineral Deposit Study

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INTRODUCTION

The Western Abitibi Mineral Deposit Study is a 3 year project to document in detail all known mineral occurrences in the Swayze greenstone belt and surrounding areas. This study area encompasses 78 townships southwest of Timmins (Figure 39.1) and contains the Swayze greenstone belt within the Abitibi Subprovince and part of the adjacent Kapuskasing Structural Zone west of the Ivanhoe Fault (Figures 39.2 and 39.3). There are several parts to the study, the first part is to: 1) research; 2) locate; 3) resample; and 4) describe all mineral occurrences in the study area. The second part is to document these observations in an open, relational, computerized data base so as to provide an "in depth" mineral deposit inventory that can be incorporated in any forthcoming

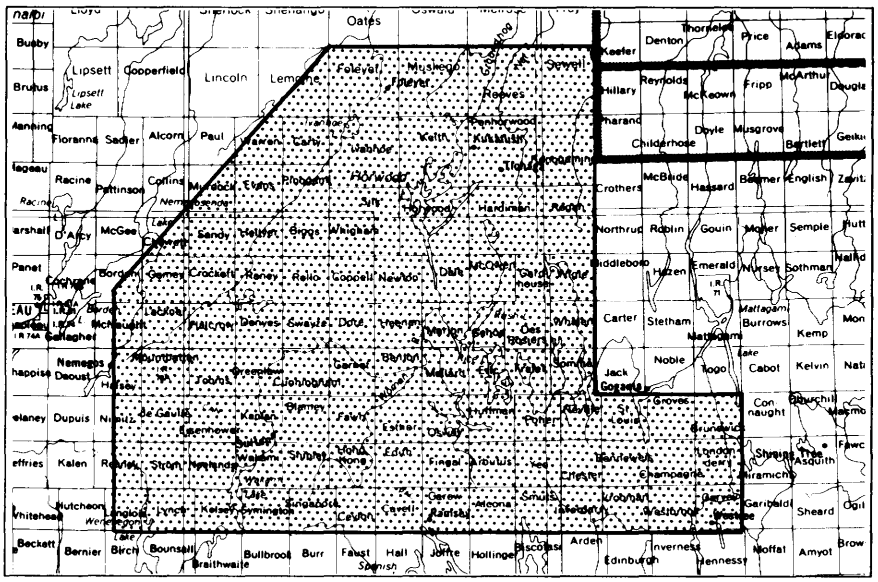

Figure 39.1. Location of the Western Abitibi Mineral Deposit Study, scale 1:1 584 000.

NODA • EDNO
CANADA ONTARIO
Minerals • Minéraux

This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

provincial Geographic Information System (GIS). The study is also to complement other NODA studies presently under way in the Swayze greenstone belt. These include the regional geologic mapping program (K. Heather, Geological Survey of Canada), the regional Pleistocene glacial study (C.A. Kaszycki, Ontario Geological Survey) and the detailed mapping program (J.A. Ayer, Ontario Geological Survey). Additional objectives of this study are to liaise with companies and prospectors working in the area, in order to be up to date on all new developments in the area and to be of assistance in any developments. The final objective of the study is to map those important mineral occurrences for which no maps exist.

The mineral occurrences that have been documented to date include precious metal, base metal and industrial mineral occurrences. So far no attempt has been made to include any of the known peat occurrences in the area. Even so, there are 313 mineral occurrences within the study area listed in the recent Mineral Deposit Inventory (MDI) (Ernsting et al. 1992).

In this, the first year of the project, work has been concentrated on the northern part of the Swayze greenstone belt.

COMPUTER DATA BASE

Initially a review of previous mineral evaluations and inventories in the province was made, especially those entered into computer data bases; for example, the Atikokan inventory (Schnieders and Dutka 1985), the Red Lake inventory (Durocher et al. 1987), the Wawa inventory (Frey and Stewart 1992), the Black River-Matheson inventory (Bath 1990) and the recent Ontario Mineral Deposits Inventory (Staff Geoscience Data Centre 1990). It was concluded that the Ontario MDI software program could not meet the requirements of documenting, in detail, the mineral deposits. The other provincial computerized studies vary from writing up descriptions in the traditional way, using either word-processing software or keywords plus very brief descriptions in data base software. The most comprehensive approach encountered has been assembled by the B.C. Geological Survey Branch in their MINFILE software (Jones and McPeek 1991; Geological Survey Branch 1991). Though the strong need for standardization is recognized, none of the data base systems previously used in Ontario have the depth proposed for the present field-orientated study. Consequently, an open data entry platform has been set up in dBASE to mimic the B.C. MINFILE system with some additional fields that were found to be particularly useful in other mineral deposit studies. This platform had to be implemented rapidly with its various flaws in order to document the results of the present field season. At the moment, all the various levels in the platform have not been integrated into a one window approach for each mineral occurrence. However, it is hoped that the data entered with this platform can be readily incorporated into a standard system when such a system is implemented. The envisaged structure of the data base is given in Table 39.1.

The Master Deposit file is illustrated in detail with the included sample, and the entry templates for the other files are given in Table 39.2. Beyond these examples, several points need some amplification:

Master Deposit File

1. The mineral occurrence number is an extension of the NTS system and, consequently, indicates a rough location for the mineral occurrence. This numbering method is essentially the same as other systems.

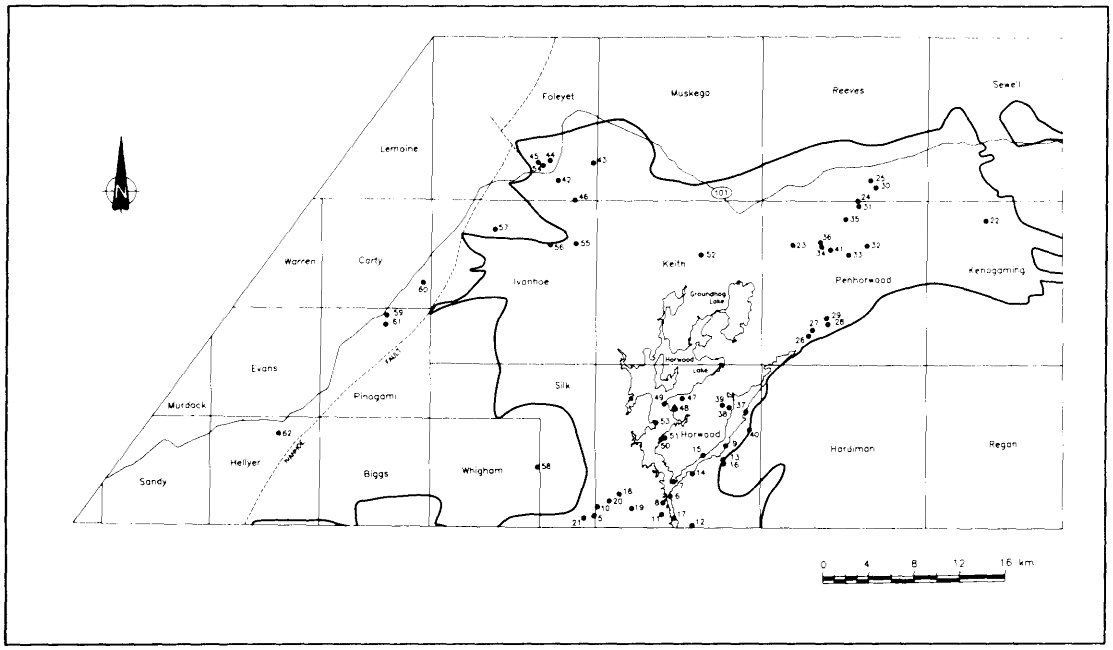

Figure 39.2. The northern part of the study area showing the Swayze greenstone belt in outline. The numbered dots are the mineral occurrences that have been documented and listed in Table 39.3.

2. The method of locating the occurrence is given as either a global positioning system (GPS) or a digitizing system. With the GPS method, readings were averaged over 10 minutes or until the "stated precision" was less than 10 m. Such readings under various weather conditions on different days were found to be reproducible to within 50 m. Where digitizing has been employed, the steps involved have been listed, and the final map used has usually been the Ontario Base Maps (OBM) at a scale of 1:20 000. It has been found that some occurrences previously listed as precisely located, have co-ordinates up to 1.2 km from the true location. More typical errors are between 100 and 400 m.

3. The status of the occurrence, that is, showing versus occurrence versus prospect versus deposit, has proved to be a problematic parameter, as a number of "occurrences" have been included in previous inventories that are not valid occurrences. Rather than omitting such "occurrences" from the data base they have been included, but it is felt that nondiscretionary parameters, for example, the tested size (i.e., strike length, thickness, tested depth and grade) would be more valid. The greater the number of these parameters that have been defined and their magnitude, the more significant is the occurrence. Furthermore, such parameters may prove more useful when the data base is linked to computer-automated drafting software. Consequently, these parameters have been added to the data base, and it is noteworthy that the grade of the occurrences tends to drop with more extensive exploration.

4. The common grade is a nonrigorous average of the assay data. Such a parameter may be more meaningful than the best assay listed together with the reserve information, as in the B.C. MINFILE system.

5. The geologic assemblages have been taken from the work of Jackson and Fyon (1991).

6. Codes have not been used for rock types or minerals. The reason for this is the discrepancy in codes used across Canada and the consequent confusion and restrictions. A specific example is komatiite, which has no approved code in any of the data base systems reviewed. The push for computer efficiency can come at a later date using code translation software.

Production

1. This file has not been modified from the B.C. MINFILE structure, but it has proved difficult to obtain annual production figures since the old Ontario Department of Mines annual reports were discontinued. More recent figures tend to be totals for several mines, or different phases in the mining cycle, or rough unofficial estimates. Between the old annual report statistics and the more recent statistics, there is a ten-year gap where there is an absence of any official figures on file.

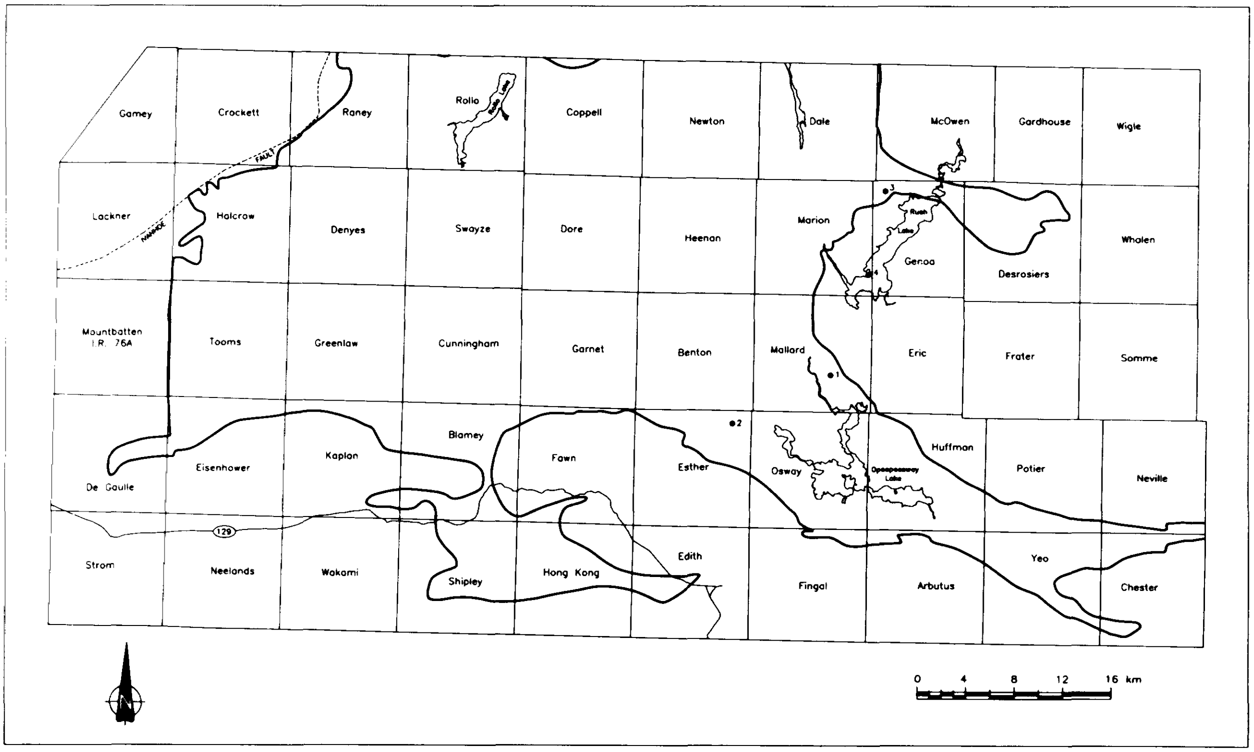

Figure 39.3. The southern part of the study area showing the Swayze greenstone belt in outline. The numbered dots are the mineral occurrences that have been documented and listed in Table 39.3.

Check Assaying

1. During the property visits, the mineralization has been resampled selectively. The samples collected are typically grab samples of the best apparent mineralization exposed, or duplicates of previously reported assays. In addition to samples collected this past year, all assay data on samples collected by government geologists over the years have been incorporated into the file.

Whole Rock

1. Some samples for whole rock analyses have been collected in order to characterize the geochemical affinity of some of the metavolcanic rocks. Samples have also been collected in certain areas of extensive alteration. It is the intent of this project to combine these data with the Petroch data file.

Assessment Files

1. Reports within individual assessment files have been catalogued by the year, company, amount and type of work, similar to the B.C. MINFILE system. Such an index is an intermediate step between the map index showing the area covered by the assessment files, which is available commercially in digital form, and the pending Assessment File Raster Imaging (AFRI) project.

MINERAL OCCURRENCES

As of the end of August, 62 mineral occurrences had been documented of which 53 had been field checked (Table 39.3, *see* Figures 39.2 and 39.3). Most are small vein hosted, mesothermal gold occurrences. In addition to these gold occurrences, several stratiform base metal occurrences associated with iron formations have been documented, together with banded iron deposits, magmatic nickel-copper occurrences and a variety of industrial mineral deposits. In order to illustrate the type of data being recorded, 1 record in the Master Deposit File is highlighted, on pages 212–214, as an example.

ACKNOWLEDGMENTS

Both M. Leroux and M. Nuss provided very able and cheerful assistance during the past summer. Also the assistance and support of all the staff at the Resident Geologist's, Claim Inspector's, and MNR Offices in Timmins in expediting and loaning equipment was a considerable help in implementing the field work. In addition the hospitality, co-operation, and assistance of Falconbridge Exploration, Noranda Exploration, Placer Dome Inc Exploration, Luzenac Talc, plus others is greatly appreciated. Finally, the author would like to acknowledge the many discussions with other geologists and explorationists working in the area including K. Heather, J. Ayer, and G. Ross.

Table 39.1. Envisaged structure of Swayze Minfile Data Base.

1. Master Deposit File	a) Names, Location, etc.	2. Sketches	a) Sketches and Maps
	b) Commodities and Grade Any Production ? Any Reserves ?	3. Visits	a) General Comments
		4. Production	a) Year
	c) Access		b) Tonnes Mined and Method
	d) Exploration History		c) Products and Amount
	e) Geology Era and/or Subprovince Host Rocks Associated Rocks Setting	5. Reserves	a) Date and Reference
			b) Tonnes, Grade, Category
		6. Check Assaying	a) Location
	f) Structure Associated Structures Setting		b) Description
			c) Results
	g) Economic Mineralogy Principle Minerals Associated Minerals Alteration Minerals Alteration Type Deposit Character Deposit Classification Tested Size Orientation Description	7. Whole Rock	a) Location
			b) Description
			c) Results
		8. Drill Core	a) List of Pertinent Holes from Drill Core Library
		9. Master Reference	a) All Pertinent References
		10. Assessment Files	a) Year and Company
	h) Analytical Work and References		b) Amount and Type of Work

Table 39.2. Data entry templates.

Visits File

Report on Property Visit
Local No. *42B/01E/005*

Date *21/11/85* Geologist *Ireland, J.*

Comments Memo

In the company of Mr Reg Veil, foreman with Extender Minerals, the underground workings were visited...

Production File

Production Statistics

Local No. *42B/01E/004*

Year *1964*
Metric Tonnes of Ore Mined *800*
Mining Method *Quarry*

Commodity

1 *Silica* Amount ___ (in grams if precious

2 ______ Amount ___ metal otherwise in

3 ______ Amount ___ kilograms)

4 ______ Amount ___

Other Credits ___________

Maximum Depth of Workings 5 m
Daily Mill Capacity ___ tonnes

Comments Memo
Official production figures are not available...

Reserves File

Reserves Data
Local No. *42A/05E/001*

Ore Zone *Fockler*

Category of Reserves *Inferred*

Year *1989* Metric Tonnes *258 600*

Commodity *Au* Grade *5.0* (in g/t

_____ Grade ___ for precious

_____ Grade ___ metals, in %
otherwise)

Comments Memo
Fumerton S. 1989
Report on work...

Check Assaying File

Assay Data

Local No. *42B/01E/018* Source *Fumerton*
Sample No. *9542* Type *GRAB* UTM *17*
Lab *Timiskaming* E *408627*
Description Memo N *5317733*
Sample taken from the top of the trench...

Au *0.020* g/t Ag *0.00* g/t
Pt _____ g/t Pd ____ g/t

As ____ % Cd ____ % Co ____ % Cr ____ %
Cu *0.144*% Mo ____ % Ni *0.014* % Pb *0.015*%
Sb ____ % U ____ % Zn *1.300*%

Whole Rock File

Whole Rock Data

Local No. __________ Source ________
Sample No. ____ Type ____ UTM __
Lab __________ E ______
Description Memo N _______
Sample taken from...

SiO_2 ___ % TiO_2 ___ % Al_2O_3 ___ %
Fe_2O_3 ___ % FeO ___ %

Assessment File

Assessment Work

File No. *T 890* Company *Keevil Mining* Year *1964*
Type of Work

Geological *GEOL* Amount *30* hectares

Geophysical *EMGR* Amount *23* kilometres
Geochemical Amount No. of samples

Drilling *DIAD* Amount *696m /6* holes

Prospecting Amount ___ hectares

Physical Amount ___ hectares

Swayze MINFILE Master Deposit File Example

LOCATION

Local No.41O/16E/001	Name	Jefferson
MDI No. S 462		
NTS 41 O/16E	Other Names	Smith
Lat. 47°50.12 N	Status	Prospect
Long. 82°12.08 W	Owner	Falconbridge
UTM 17	Twp	Genoa
East 410100	Mining Div	Porcupine
North 5298480	Claim Map	M 833
Located by	Date entered	02 Sept. 92
Digitizing	Date revised	
	Revising Geologist	
	Core in library	No
	Visited	Yes

Description of Point Located

A pit is within a 50 m long trench on a southern crest of a ridge. The position was taken from an OBM 1:20 000 plan modified by a company to show the grid (1992). The base line of the grid has been fixed using a GPS unit.

COMMODITIES

Commodities	Common Grade	
Principle 1	Pb	3.30%
2	Zn	4.60%
Minor	1 ________	
	2 ________	
Any Production	No ___	
Any Reserves	Yes ___	

ACCESS

Access to the occurrence is difficult and involves a circuitous road trip. Initially use the Sultan access road from Highway 144, then drive along the Mallard forest access road to the old road to Rush Lake. This last road is a 4 by 4 trail, and it is 7 km to the landing at Rush Lake. From the landing, a boat must be taken to a bay on the northwest shore. Then from this point, the showing is a 2 km traverse along a well-marked trail and down a grid line marked on the sketch.

EXPLORATION HISTORY

1908

Mr. Smith discovered a sulphide-, oxide- and silicate-facies iron formation while exploring for iron in an area subsequently staked and then held by Jefferson Mining Corporation. Follow up diamond drilling of the iron formation in 1910 intersected a number of sphalerite, galena and chalcopyrite occurrences within the sulphide-facies iron formation. This drilling was done in conjunction with an extensive trenching program. Prospecting for lead in the vicinity of the discovery drill hole located a showing 100 m to the east. After another 2 years, a test pit was sunk on the showing and exposed variable galena, sphalerite and chalcopyrite concentrations. A high grade sample assayed 73% Pb and 6% Zn.

1928

Century Zinc drilled 10 short holes on the lead-zinc showing and estimated 91 000 tonnes grading 4.6% Zn and 3.3% Pb existed in 2 closely spaced bodies.

1929

Canam Metals drilled 4 additional diamond-drill holes into the lead-zinc deposit.

Oliver Iron Mining Company explored the whole iron range including the lead-zinc deposit, but the results of this work are unknown.

1950

Sudbury Lead-Zinc Mines Ltd drilled 23 short holes in the main lead-zinc showing, which confirmed the general tenor of the massive sulphide mineralization previously reported.

1957

Stackpool Mining carried out an electromagnetic survey over the whole iron formation and then drilled 1063 m in 13 holes to test the iron ore potential.

1978

Texasgulf Canada carried out horizontal loop electromagnetic (HLEM) and very low frequency electromagnetic (VLF–EM) surveys combined with a magnetic survey over a small claim block, which included the main showing.

Noranda Exploration geologically mapped a large area, which included the Jefferson and Burton showings and then carried out magnetic and HLEM surveys over the area.

1980

Falconbridge Exploration started a large gold exploration program centred on the iron formations, though most of the work was performed to the southwest of the lead-zinc showing. The work consisted of VLF–EM, magnetic, whole rock plus trace element lithogeochemical surveys combined with outcrop stripping and geologic mapping. A strong lithogeochemical anomaly is associated with the lead-zinc showing.

1992

Falconbridge Exploration resumed development in the area, but this time they searched for base metals in the felsic pile underlying the iron formation. The work consisted of geologic mapping and geophysical surveys.

GEOLOGY

Era	Archean
Province	Superior
Subprovince	Abitibi
Assemblage	Marion
Host Rocks	1 Iron Formation 2
Associated Rocks	1 Rhyolite, Pyroclastic 2 Basalt, Tholeiite 3 ______ 4 ______
Related Structure	1 ______ 2 ______

Geological Setting

The mineralization is hosted in the Woman River banded iron formation. Regionally, the iron formation is composed of varying proportions of chert, jasper, magnetite, hematite, sulphide, silicate and carbonate. The sulphide facies are more dominant in the northeast in the vicinity of the lead-zinc showing, especially where sulphides occur in the underlying felsic metavolcanic rocks. Locally, garnet porphyroblasts occur in the amphibole-rich beds.

Underlying the iron formation is a sequence of felsic metavolcanic rocks primarily composed of flow breccias, pyroclastic rocks and minor massive flows. These rocks have been subjected to chlorite and sericite alteration. Immediately underlying the sulphide-facies iron formation and about 100 m northeast of the showing is a wedge of felsic debris breccias.

Overlying the iron formation is an altered tholeiitic sequence of pillowed and massive basaltic flows. Alteration in this sequence is typically carbonate with some sericite and/or biotite.

Feldspar porphyry dykes have been intersected in drill core in the vicinity of the showing. Thin, fine-grained felsic veinlets with disseminated pyrite cut the iron formation at a shallow angle.

Structural Setting

No structural features are documented.

ECONOMIC MINERALOGY

Minerals

Principle Minerals	1 Galena 2 Sphalerite 3 ______ 4 ______
Associated Minerals	1 Chalcopyrite 2 Pyrite 3 Pyrrhotite 4 ______
Alteration	1 Chlorite 2 Sericite 3 ______ 4 ______
Alteration Type	1 ______ 2 ______ 3 ______

Characteristics

Deposit Character	Stratiform
Deposit Classification	Exhalative

Tested Size

Strike Length	100 m
Thickness	12.0 m
Depth	30 m
Open ?	Yes
Strike	085°
Dip	80°S
Plunge	______
Azimuth	______

Description

Mineralization varies between nearly pure sections of massive galena in the centre of the main trench and the margins, which have higher proportions of sphalerite relative to the centre. Chalcopyrite occurs together with sphalerite and galena in bands within the iron formation 15 m east the main pit.

Fine disseminated sphalerite has been observed in the chert horizons within the iron formation. This sphalerite is not associated with other sulphides and locally forms discontinuous trails partially concentrated along 1 contact. Similarly in the amphibole-rich beds, fine-grained pyrite is concentrated along 1 contact.

Within the feldspar porphyry there are trace amounts of very fine-grained galena disseminated in the matrix.

ANALYTICAL WORK AND REFERENCES

Check Assays Available ?	Yes	
Whole Rock Analyses ?	No	
Specific Published References	1	AGM CIM 1926
	2	ODM AR 35–2
	3	ODM GR 38
	4	____________
Timmins' Assessment Files	1	T1888
	2	T1908
	3	T2083
	4	T2158
	5	T2345
	6	____________

Table 39.3. List of mineral occurrences documented in the summer of 1992. For locations of minerals *see* Figures 39.2 and 39.3.

Fig No.	Local No.	Name Alternative	Township Status	MDI No.	Commodities	Visited
1	41O/09W/002	Maltby Ross	Mallard Occurrence	S 2693	Au	Yes
2	41O/09W/001	Northern Aerial Burton	Esther Occurrence	S 384	Au	Yes
3	41O/16E/001	Jefferson Smith	Genoa Prospect	S 462	Pb, Zn	Yes
4	41O/16E/002	Rush Lake Copper Parr Ivanov	Marion Anomaly	S 2669	Cu	Yes
5	41O/16W/001	Orofino Swayze Mine Thorne – Doré	Silk Prospect	S 429	Au	Yes
6	41O/16W/003	Smith – Thorne Tionaga Mine	Horwood Past Producer	S 441	Au	Yes
7	41O/16W/004	Thorne	Horwood Occurrence		Au	Yes
8	41O/16W/005	Gilbert	Horwood Anomaly	S 2632	Au	Yes
9	41O/16W/006	Smith	Horwood Anomaly	S 2625	Au	Yes
10	41O/16W/007	Radiant	Horwood Anomaly	S 2646	Au	No
11	41O/16W/008	Gifford Donalda	Horwood Prospect	S 448	Au	Yes
12	41O/16W/009	Cambach Bachman Campbell and Reany	Horwood Occurrence	S 2631	Au	No

Table 39.3. continued.

Fig No.	Local No.	Name Alternative	Township Status	MDI No.	Commodities	Visited
13	41O/16W/010	Jacobs Horwood Syndicate	Horwood Anomaly	S 2634	Au	Yes
14	41O/16W/011	Silams	Horwood Anomaly	S 585	Au	Yes
15	41O/16W/012	Gould Dunn Deburmac	Horwood Anomaly	S 2633	Au	Yes
16	41O/16W/013	Ajax	Horwood Anomaly		Au	Yes
17	41O/16W/014	Golden Dragon	Horwood Anomaly		Cu	Yes
18	41O/16W/015	Wdowczyk Wdowczyk–Landers	Horwood Anomaly	S 2645	Au	Yes
19	41O/16W/016	Landry Hardiman Bay	Horwood Anomaly	S 442	Au	Yes
20	41O/16W/017	Landers	Horwood Anomaly	S 2644	Au	Yes
21	41O/16W/018	McVittie McVittie–Cryderman	Silk Anomaly	S 2788	Au	Yes
22	42A/04W/001	Ireland Crawford River	Kenogaming Anomaly		Ni, Pt, Cu, Pd	Yes
23	42B/01E/001	Radio Hill Groundhog	Penhorwood Developed Prospect	S 458	Fe	Yes
24	42B/01E/002	Penhorwood Mine Steetly Talc	Penhorwood Producer	S 558	Talc	Yes
25	42B/01E/003	Reeves Mine	Reeves Past Producer	S 451	Asbestos	Yes
26	42B/01E/004	Horwood Mine Tionaga Site Roseval #1	Penhorwood Past Producer	S 2764	Silica	Yes
27	42B/01E/005	Cryderman Ravena Extender	Penhorwood Past Producer	S 596	Barite	Yes
28	42B/01E/006	Roseval #2	Penhorwood Past Producer		Silica	Yes
29	42B/01E/007	Roseval #3	Penhorwood Past Producer		Silica	Yes
30	42B/01E/008	75 Zone	Reeves Prospect		Asbestos	Yes
31	42B/01E/009	Jehann Fibre	Penhorwood Occurrence	S 2625	Asbestos	Yes
32	42B/01E/010	Nat River Fibre	Penhorwood Occurrence	S 452	Asbestos	No
33	42B/01E/011	Dupont Fibre	Penhorwood Occurrence	S 2624	Asbestos	No
34	42B/01E/012	Bromley Bragagnola No. 1 Zone	Penhorwood Occurrence	S 2622	Au Ag	Yes

Table 39.3. continued.

Fig No.	Local No.	Name Alternative	Township Status	MDI No.	Commodities	Visited
35	42B/01E/013	Nib Yellowknife Bromley–Lafortune North Jehann	Penhorwood Occurrence	S 453	Au	Yes
36	42B/01E/014	RF Zone Utah	Penhorwood Occurrence	S 2630	Au Ag	Yes
37	42B/01E/015	Monte Carlo Newman Feld	Horwood Anomaly	S 440	Mo Au	Yes
38	42B/01E/016	Labbé #1 and #2 Queensway	Horwood Occurrence	S 443	Au	Yes
39	42B/01E/017	Labbé #3	Horwood Anomaly		Au	N0
40	42B/01E/018	Asarco Ross–Morin	Horwood Prospect	S 2798	Cu Zn	Yes
41	42B/01E/019	Barrick American Barrick	Horwood Anomaly	S 2627	Au	No
42	42B/01W/001	Hudbay Road Group	Foleyet Occurrence	S 2799	Zn	Yes
43	42B/01W/002	Inco Inco 26699	Foleyet Anomaly		Fe	No
44	42B/01W/003	Keevil–Highway	Foleyet Anomaly		Zn	No
45	42B/01W/004	Keevil–Ivanhoe River Keevil Group 34	Foleyet Anomaly	S 2628	Zn	Yes
46	42B/01W/005	Keevil Group 15 Keevil South Hudbay F82-2	Foleyet Anomaly	S 2800	Cu	Yes
47	42B/01W/006	Stack Vein Lefever Silams	Horwood Occurrence	S 444	Au	Yes
48	42B/01W/007	Lefever Silams and Desourdy Inlet	Horwood Occurrence	S 445	Au	Yes
49	42B/01W/008	Kerr Addison Main Lefever	Horwood Occurrence	S 446	Au	Yes
50	42B/01W/009	Groundhog Jessop Jessop–Seery	Horwood Occurrence	S 447	Au	Yes
51	42B/01W/010	Ultrex	Horwood Anomaly		Cu	Yes
52	42B/01W/011	Joburke Gold Mine New Joburke	Keith Past Producer	S 430	Au	Yes
53	42B/01W/012	O'Neil Pinecone	Horwood Anomaly	S 424	Au	Yes
54	42B/01W/013	Hudbay F82–6	Foleyet Occurrence		Cu	Yes

Table 39.3. continued.

Fig No.	Local No.	Name Alternative	Township Status	MDI No.	Commodities	Visited
55	42B/01W/014	Keevil Group 17 Muskego River	Ivanhoe Anomaly	S 2629	Zn	Yes
56	42B/01W/015	Ayer	Ivanhoe Occurrence		Cu Zn	Yes
57	42B/01W/016	Ivanhoe Lake	Ivanhoe Anomaly		Cu	No
58	42B/01W/017	Marl Lake	Whigham Occurrence	S 3207	Marl	No
59	42B/02E/001	Keevil Group 23 Keevil 65–8	Pinogami Anomaly	S 556	Cu	Yes
60	42B/02E/002	Keevil Group 31	Carty Anomaly		Cu	Yes
61	42B/02E/003	Keevil Group 23 Keevil 65–9	Pinogami Anomaly	S 556	Ni	No
62	42B/02W/001	Keevil Group 38	Hellyer Anomaly		Cu	Yes

REFERENCES

Bath, A.C. 1990. Mineral occurrences, deposits, and mines of the Black River–Matheson area; Ontario Geological Survey, Open File Report 5735, 1883p.

Durocher, M.E, Burchell, P. and Andrews, A.J. 1987. Gold occurrences, prospects, and deposits of the Red Lake area; Ontario Geological Survey, Open File Report 5558, 704p.

Ernsting. J., van Haaften, S., Hoffer, D., Pauk, T. and Lee, C. 1992. Mineral deposit inventory database (MDI) — ASCII data release: An Ontario wide index database to mineral deposits; Ontario Geological Survey, 83p.

Frey, E.D. and Stewart, R.C. 1992. Wawa mineral deposits data base; Ontario Geological Survey, Open File Report 5775, 420p.

Geological Survey Branch 1991. MINFILE, coding manual, version 3.31; B.C. Ministry of Energy, Mines and Petroleum Resources, Information Circular 1991-3, 28p.

Jackson, S.L. and Fyon, J.A. 1991. The western Abitibi Subprovince in Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.405–482.

Jones, L.D. and McPeek, C.B. 1991. MINFILE — A mineral deposit information system for British Columbia, Canada; B.C. Ministry of Energy, Mines and Petroleum Resources, 26p.

Schnieders, B.R. and Dutka, R.J. 1985. Property visits and reports of the Atikokan economic geologist, 1979-1983, Atikokan Geological Survey; Ontario Geological Survey, Open File Report 5539, 512p.

Staff of the Geoscience Data Centre 1990. Mineral deposit inventory database; Ontario Geological Survey, Input Manual Version 1.0, 129p.

40. Geology of Western Greenwater Lake Area, District of Thunder Bay, Ontario

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INTRODUCTION

This is the second year of a three-year mapping project of the west-central Shebandowan greenstone belt, an area of Archean supracrustal rocks that form part of the Wawa Subprovince in northwestern Ontario. The purpose of the project is to update and expand the geologic data base and evaluate mineral potential of the west-central Shebandowan greenstone belt.

The bedrock mapping in 1991, the first year of the project, was conducted in Moss Township, which adjoins the 1992 map area to the east. The results of the 1991 survey have been reported by Osmani et al. (1991). The 1992 map area (Figure 40.1), which covers approximately 250 km², is situated 120 km west of Thunder Bay. It is bounded by longitudes 90°39'29"W and 90°25'W and latitudes 48°30'N and 48°36'46"N.

Access to the map area is by Highway 11 west from Thunder Bay to the village of Kashabowie and from there to Highway 802 south to where a major logging road (Camp 517 Road) leads into the map area. Alternative means of access would be by float- or ski-equipped aircraft to Upper Shebandowan, Greenwater, Burchell and Fountain lakes.

Preliminary findings of the 1992 survey are summarized in this report, and a subsequent preliminary map based on this survey will be released early in 1993.

MINERAL EXPLORATION HISTORY

The following selected information is derived from the assessment files of the Resident Geologist's Office, Thunder Bay and the Assessment Files Research Office, Ontario Geological Survey, Sudbury.

The map area contains 1 past-producing copper-gold-silver mine, the North Coldstream Mines Limited (NCML). The earliest exploration activity, which led to the discovery of the mine, dates back to 1871. At that time, copper was discovered at the present mine site, and soon after that, several claims adjoining the discovery

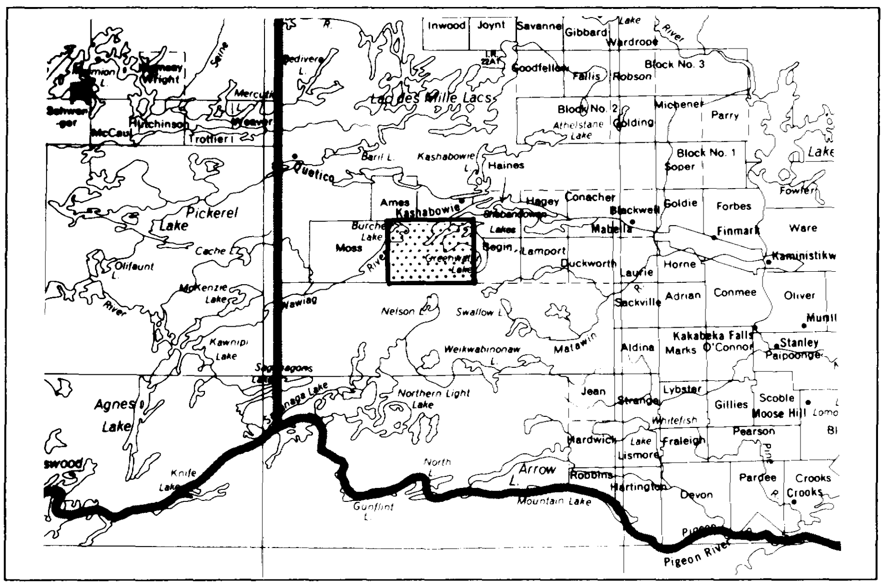

Figure 40.1. Location map of the study area, scale 1:1 584 000.

NODA • EDNO
CANADA ONTARIO
Northern Ontario Development Agreement
Entente de développement du nord de l'Ontario
Minerals • Minéraux

This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

site were staked and patented. The New York and Canadian Copper Company, which was incorporated in 1902, acquired the occurrence which was then known as the Tip Top Mine. Approximately, 1 312 979 pounds of Cu was produced from the mine site in 1903, 1906 and 1916 to 1917.

The Coldstream Copper Mines Limited acquired the property in 1951. The mine was prepared for production, complete with a new vertical three-compartment shaft and mill facilities. Production began in June 1957 and ended in February 1958. Shortly after the company was reorganized, the name was changed to North Coldstream Mines Limited, and production commenced in February 1960. Total production from the years 1906 until 1967, included: 102 million pounds of Cu, 440 000 ounces of Ag and 22 000 ounces of Au from a total of 2.7 million tons of ore mined (2% Cu, 0.22 ounce Ag per ton and 0.012 ounce Au per ton).

The present map area underwent 2 main periods of exploration activity during the late 1950s to early 1960s and from the early 1980s to the present day. Between 1950–1970 much of the exploration was focussed on base metal sulphide deposits. It was not until the 1980s that gold became the major target for most of the exploration activity in the map area. This trend still continues.

During the 1950s and 1960s, exploration and mining activities were dominated by the Coldstream Mines Limited (presently known as North Coldstream Mines Limited) in the Burchell Lake area. In the 1950s, Jellico Mines (1939) Limited explored the Upper Shebandowan Lake area. The company carried out geologic and geophysical surveys and diamond drilling on the islands and the mainland to the west of Upper Shebandowan Lake and discovered copper mineralization (up to 5.1% Cu) on Copper Island.

Exploration activities, including geologic and geophysical surveys, in the northern and central parts of the map area were carried out by many individuals and exploration companies. These include surveys by Minnova Limited, Noranda Exploration Company Limited and Corona Corporation. Diamond drilling in these locations has been carried out by Wing–Wallace–Calvert Limited, Newmont Exploration Company Limited and Freeport McMoran Gold Company. The southeastern part of the map area did not undergo much, if any, exploration activity.

In September 1987, Noranda Exploration Company Limited acquired the North Coldstream Mines property from Conwest Exploration Company Limited. A significant discovery of gold was made by Noranda Exploration Company Limited on the eastern half of the property. Between 1987–1991, Noranda Exploration Company Limited carried out prospecting and geologic and geophysical surveys, humus and soil sampling, trenching, channel sampling, and diamond drilling. A total of 6138 m of diamond drilling was carried out between 1988–1991. As a result of these activities, the company delineated 3 gold-bearing zones on the property. As of February 1991, the estimated reserve combining all 3 zones is over 5 million tonnes grading 1.43 g/t.

The following information, including estimated tonnage and grade from those gold-bearing zones, is provided by Conwest Exploration Company Limited.

	Tonnes (metric)	Au Grade (g/t)	Au (g)
East Zone	637 766	1.25	759 900
North Zone	1 575 475	1.07	1 685 079
Main Zone	2 053 645	1.72	3 535 626
Deep Reserves–below 200 m (Main and South zones combined)	840 304	1.50	1 262 157
TOTAL	5 107 190	1.43	7 278 762

In September 1991, Noranda Exploration Company Limited dropped the option on the property and no further work is planned (Personal communication, M. Zurowski, Vice President, Conwest Exploration Company Limited, Toronto, September 8, 1992).

Several gold and copper occurrences are found within the map area (Figure 40.2), and assessment work information on them is recorded in the Resident Geologist's Office in Thunder Bay, Ontario.

PREVIOUS WORK

The western part of the map area was mapped by Giblin (1964) and the eastern half by Hodgkinson (1968) at a scale of 1:15 840. A structural study of the central Shebandowan greenstone belt detailing the overall pattern of tectonic strain was carried out by Stott (1985). Recently, an airborne electromagnetic and total intensity magnetic survey was flown over the entire length of the Shebandowan greenstone belt. Maps based on this survey have been published (OGS 1991a).

GENERAL GEOLOGY

With the exception of Proterozoic diabase dikes (Osmani 1991), all rocks in the study area are Archean in age (Corfu and Stott 1986). The map area includes part of the western Shebandowan greenstone belt of the Wawa Subprovince. The Shebandowan greenstone belt is bounded to the north by the metasedimentary rocks and associated granitic intrusions of the Quetico Subprovince, and to the south by a granitoid batholithic complex (OGS 1991b). To the north, the contact with the Quetico Subprovince metasedimentary rocks is both conformable and fault bounded (Giblin 1964; Hodgkinson 1968; Stott 1985). The Quetico Subprovince metasedimentary rocks are not exposed in the present map area. The Shebandowan greenstone belt, within the study area, is chiefly composed of mafic to felsic metavolcanic units, which have been intruded by numerous syn- to posttectonic mafic to felsic intrusive rocks.

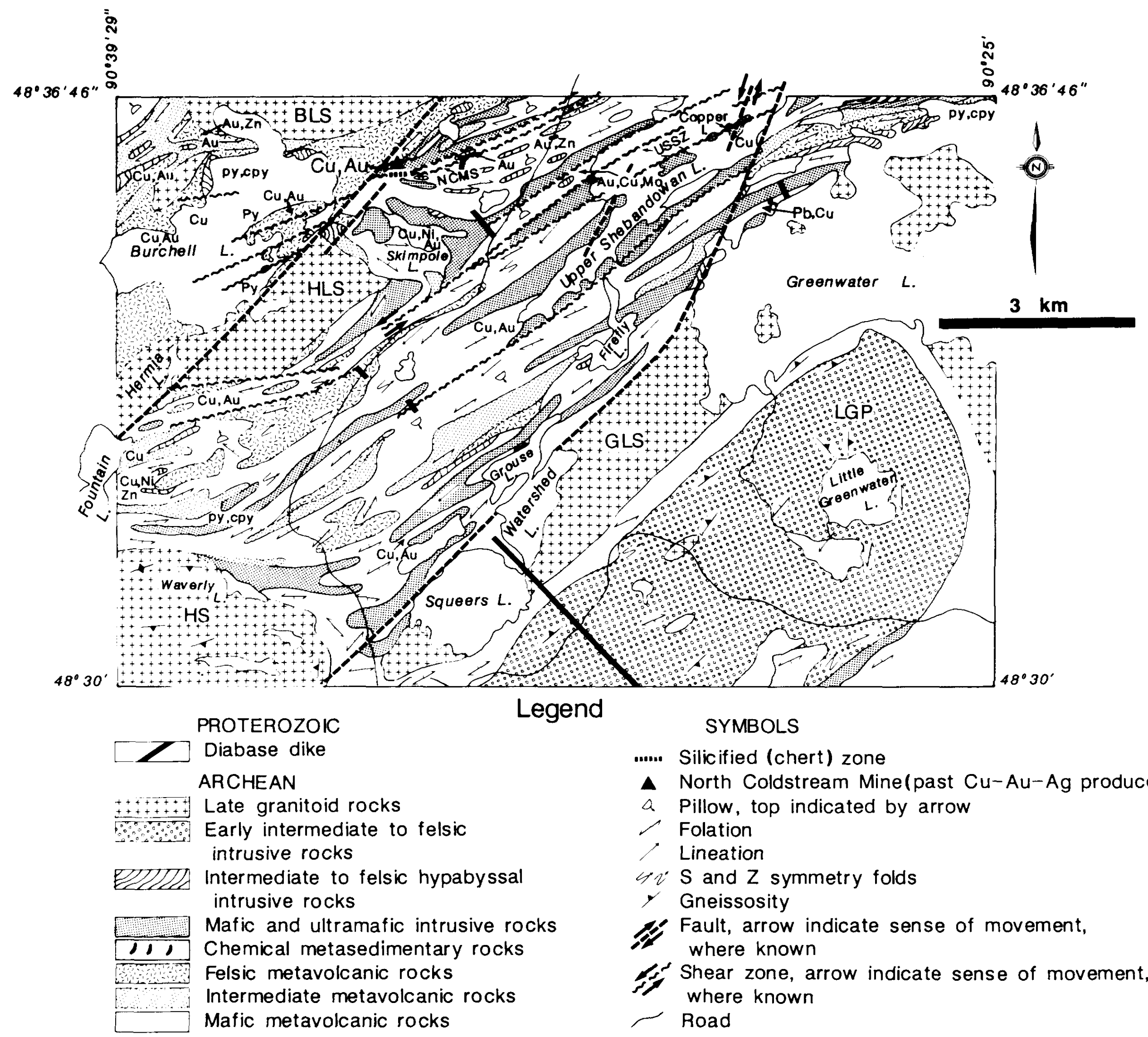

Figure 40.2. General bedrock and structural geology of western Greenwater Lake area. The distribution of mineral occurrences is also shown. The abbreviations are: BLS=Burchell Lake stock; HLS=Hermia Lake stock; HS=Hood Lake stock; GLS=Greenwater Lake stock; LGP=Little Greenwater Lake pluton; NCMS=North Coldstream Mine Shear Zone; USSZ=Upper Shebandowan Lake Shear Zone; py=pyrite; and cpy=chalcopyrite.

The supracrustal rocks of the map area have been subdivided by Williams et al. (1991) into 2 assemblages: 1) the Burchell assemblage characterized by 3 northward-younging volcanic cycles; and 2) the Greenwater assemblage, consisting of 3 southward-younging volcanic cycles. The contact between the Burchell and Greenwater assemblages is placed immediately south of the south shore of Shebandowan Lake by Williams et al. (1991). The present study area supports the general disposition of these assemblages within the map area.

Metavolcanic and Metasedimentary Rocks

The supracrustal rocks consist of mafic, intermediate and felsic metavolcanic rocks and subordinate volcanic-derived interflow wacke and mudstone. The mafic metavolcanic rocks are the most abundant rock type among the supracrustal rocks. They are chiefly composed of massive, plagioclase-phyric and pillowed flows and associated pillow breccia. Chlorite schist of mafic metavolcanic protolith is abundant in high strain zones. Amphibolite, amphibole-schist and gneiss are found proximal to large granitoid bodies. Garnet-bearing amphibolite and amphibole-schist are common north of the Hood Lake stock and south of the Hermia Lake stock. These garnet-bearing amphibolites reflect the amphibolite-grade contact metamorphic aureole imposed during the emplacement of the granitoid stocks.

Pillowed flow units are relatively abundant to the northwest and southwest of the Upper Shebandowan Lake. A discontinuous plagioclase-phyric flow unit can be traced from the north shore of Greenwater Lake to the west of Squeers Lake. Mafic tuff and derived metasedimentary rocks are abundant in the southwestern part of the map area. A few exposures of lapilli tuff and tuff-breccia occur north and southwest of Upper Shebandowan Lake.

Thick deposits of felsic metavolcanic rocks occur in the Burchell Lake area, south of Hermia Lake and the north shore of Greenwater Lake. Elsewhere, they generally occur as narrow lenses, measuring from a few meters to hundreds of metres in strike length. The felsic metavolcanic rocks are composed of tuff, lapilli tuff, tuff breccia and massive and porphyritic flows. Felsic to intermediate sericite schist is an abundant rock unit within high strain zone areas. The felsic metavolcanic rocks in the Burchell Lake area are predominantly composed of massive and porphyritic flows and sericite schist. Some of these sericite schists represent felsic fragmental rocks of undetermined origin. South of Hermia Lake, pyroclastic rocks are chiefly composed of tuff, lapilli tuff, tuff breccia and minor massive flows. The felsic clasts measuring lapilli to block size (up to 35 cm by 7 cm) occur in a sericitized, quartz-phyric (0.05 mm) tuffaceous matrix. Block- and lapilli-size clasts make up 60% to 70% of the rock volume. The majority of clasts in the lapilli tuff and tuff breccia are felsic and contain quartz phenocrysts, but minor aphanitic, wispy-looking mafic, lapilli-size clasts were also noted.

North of Greenwater Lake, a felsic pyroclastic pile, measuring up to 450 m thick and 5 km in strike length, consists of coarse pyroclastic units with block- to lapilli-size clasts in the centre of the pile, which fines to ash tuff both to the east and west. The felsic clasts, some of which are pumiceous, occur within a felsic matrix. These felsic metavolcanic rocks grade north into intermediate tuff to lapilli tuff, which in turn passes into the mafic flows. Gabbro and feldspar porphyry dikes and sills intrude the felsic metavolcanic pile.

This mafic to felsic metavolcanic sequence probably represents a complete volcanic cycle, where a volcanic pile progressively grew from a mafic base to a felsic top. Large gossan zones containing pyrite, chalcopyrite, malachite and arsenopyrite occur in the felsic tuff horizons in the felsic metavolcanic pile.

Thick deposits of intermediate metavolcanic rocks occur northwest of Burchell and west of Grouse and Squeers lakes areas. Elsewhere, they occur subordinate to the mafic and felsic metavolcanic rocks. The intermediate metavolcanic rocks are composed of tuff, lapilli tuff, tuff breccia and minor massive flow units. Intermediate metavolcanic rocks are also found in association with the mafic metavolcanic flow units.

Chemical Metasedimentary Rocks

The chemical metasedimentary rocks including chert-magnetite banded iron formation, chert, chert with pyrite ± pyrrhotite and minor silicate-facies iron formation units occur as a minor component throughout the map area. They range in thickness from less than a meter to up to 10 m. The most abundant and thickest of chemical sedimentary rocks is a chert-magnetite banded iron formation found along the north shore of Greenwater Lake.

Mafic and Ultramafic Intrusive Rocks

Mafic intrusive rocks including gabbro, a differentiated gabbro-anorthosite assemblage, amphibolite and diorite occur as large and small sill and stock-like bodies throughout the map area. The majority of these sills are concordant with the regional schistosity, and on a regional scale, these bodies are folded, sheared and share the same alteration as their coeval mafic metavolcanic rocks.

The most predominant of all these mafic to ultramafic intrusive rocks is gabbro and its chlorite ± actinolite schist equivalent. Grain size in the gabbro varies from medium to coarse, but fine- to medium-grained varieties are not uncommon. Large differentiated sill-like intrusions, which include gabbro-anorthositic gabbro-anorthosite assemblages, occur on the north shore and on islands of Upper Shebandowan Lake. Gabbro to anorthositic gabbro also occur north of the North Coldstream Mine site. At both locations, these bodies are often accompanied by a plagioclase-phyric phase in which the plagioclase grains can measure up to 5 cm across. In a few outcrops on the islands of Upper Shebandowan Lake, the compositional layering was noted but was not distinct enough to indicate the structure of the mass.

The ultramafic rocks include sills and dikes of peridotite and minor pyroxenitic phases within the peridotite mass. The derived serpentine ± tremolite ± talc ± magnetite schist was seen north of Greenwater Lake and 2.7 km northeast of Waverly Lake. Peridotite commonly occurs as massive bodies, but a polysutured variety was observed at 2 locations, 1 north of Greenwater Lake and the other on the south-central shore of Grouse Lake. The massive and polysutured (possible flow?) varieties are commonly associated with the gabbros, but no evidence of transition from one rock to the other was observed. The peridotite contains up to 40% magnetite. The high magnetite content in peridotite is thought by the authors to be derived from the alteration of olivine. Peridotite weathers rusty brown, and on a fresh surface it is bluish green to black. Minor sulphide mineralization is generally restricted to quartz ± carbonate veinlets which occur in or near to shear fractures. The gabbro and derived schists at the North Coldstream Mine and the differentiated gabbro to anorthosite bodies and their derived schists on Copper Island of Upper Shebandowan Lake are host rock to the copper mineralization (*see* Economic Geology).

Intermediate to Felsic Hypabyssal Rocks

Hypabyssal intrusive rocks, including feldspar, quartz-feldspar, quartz and minor hornblende ± quartz-feldspar porphyries and fine-grained equigranular intrusive rocks, occur throughout the map area mainly as steeply dipping dikes or sills and local small stock-like bodies. The porphyries are generally characterized by 20% to 50% phenocrysts of feldspar and quartz, ranging from 2 mm to 0.5 cm and occasionally to 1 cm in size, set in a fine-grained to aphanitic matrix of intermediate to felsic composition. In the quartz-feldspar porphyries, the quartz phenocrysts are generally smaller and subordinate to feldspar but vary in proportion from 1 intrusion to another. More than 1 generation of porphyries and their fine-grained equivalents occur within the map area, but age relationship cannot be determined, since no cross-cutting relationships among them were observed. They intrude all major rock types and were not seen to be cut by late granitoid rocks. Unlike their host rock, many porphyries are variably deformed and affected by hematization, silicification and carbonitization including iron carbonate alteration. They can contain 2% to 5% magnetite and sulphides (pyrite ± chalcopyrite). Some of the porphyries host gold mineralization (e.g., porphyry system on the property of Conwest Exploration Company Limited).

Early Intermediate to Felsic Intrusive Rocks

The early intermediate to felsic intrusive rocks are represented by the Little Greenwater Lake pluton (LGP), which occupies the southeast part of the map area. It is separated from a crescentic-shaped (Stott 1985), late granitoid stock to the north by an arcuate narrow band of amphibolitized mafic metavolcanic rocks.

The LGP is poorly exposed through much of the southeast part of the map area. The predominant rock type within the LGP is foliated to gneissic tonalite and granodiorite. Minor phases of foliated to massive tonalite, trondhjemite and granite are also present. The tonalite to granodiorite weathers white to pink, and it is grey on fresh surfaces. The gneissosity in the tonalite is defined by quartz and plagioclase and biotite ± hornblende bandings.

Late Granitoid Stocks

Four late Archean composite stocks (the Hood Lake, Greenwater Lake, Burchell Lake and Hermia Lake stocks) occur in the map area. The heart-shaped Hood Lake stock is located west of Squeers Lake, and only the northeast part of the stock is within the map area. The stock is chiefly composed of hornblende ± pyroxene monzonite and syenite and is characteristically porphyritic. The feldspar phenocrysts (up to 5 cm long) are grey to pinkish grey and range in shape and form from lath shaped to square and rarely hexagonal. The phenocrysts make up 10% to 15% of the rock volume. Twinning is well developed in lath-shaped phenocrysts, and some phenocrysts show zoning. Disseminated magnetite and minor pyrite are always present. The margin of the stock is mafic and shows a broad gradational change from syenite to monzonite in the core to a syenodiorite to monzogabbro phase along the margin of the stock. Gneissosity is observed in several locations.

The crescentic-shaped (Stott 1985) Greenwater Lake stock (GLS) is located under and along the shores of Greenwater Lake. A poorly exposed southwestern extension of this stock also underlies much of Watershed and Squeers lakes. It is predominantly a feldspar porphyritic (3 cm long) hornblende granite. The rim of the stock is quartz syenitic or monzonitic in composition.

The Burchell Lake stock (BLS) is located north of Burchell Lake. Only the southern-most part of the stock is exposed in the map area. The stock chiefly consists of feldspar-porphyritic hornblende granite. The biotite-rich phase was also noted along the shore of Burchell Lake. At 1 location on the northeast shore of Burchell Lake, a biotite-rich phase may possibly represent a lamprophyre (Giblin 1964).

The Hermia Lake stock (HLS) is situated between Hermia Lake and south of Burchell Lake. It is predominantly a feldspar porphyritic hornblende syenite to monzonite with a hornblende granite phase to the east. The feldspar phenocrysts are zoned and vary in shape from being square to hexagonal. The phenocrysts make up less than 10% of the rock volume, except in 1 location where the rock is made up entirely of phenocrysts.

Diabase Dikes

Diabase dikes are the youngest intrusive rocks in the map area. The dominant trend of these dikes is northwest, but northeast-striking dikes also occur. Two varieties of dikes are present in the map area: 1) the northwest-trending, fine-grained to aphanitic dikes; and 2) the northeast-trending, plagioclase porphyritic dikes. These dikes are reddish brown on the weathered surface and dark grey to black on the fresh surface. Dikes are unfoliated and show little or no alteration. The texture is generally diabasic with plagioclase laths less than 1 mm in size in aphyric dikes, but in porphyritic varieties, the plagioclase is up to 5 mm across. Widths of the dikes range from less than 1 to 10 m.

METAMORPHISM

Metamorphic grade ranges from lower greenschist to amphibolite. Greenschist grade is found throughout the map area, except in areas proximal to granitoid stocks where metamorphic grade is increased to amphibolite grade. Mafic metavolcanic and gabbroic rocks proximal to these stocks contain dark green to black hornblende and plagioclase. Mafic to intermediate metavolcanic rocks north of the Hood Lake stock are banded and contain abundant red-brown, garnet-rich layers. Garnet was also noted proximal to the Hermia Lake stock.

STRUCTURAL GEOLOGY

Tectonic foliation in pyroclastic and interflow metasedimentary units conform to the bedding throughout the map area. Pervasive foliation and lineation are present proximal to the major shear zones and topographic lineaments. Outside the high strain zones, the foliation is moderately to weakly developed and the lineation disappears. Generally, bedding and foliation strikes northeast to east-northeast, but deflection of these regional strikes are evident proximal to the late granitoid bodies. Regional mineral and clast-stretching lineations show moderate to shallow plunges (55° to 20°) to the southwest. Local reversals in lineation trends are not uncommon.

Well-preserved pillows, graded pyroclastic units and the architecture of individual flow units north and northwest of Upper Shebandowan Lake suggest stratigraphic younging direction is to the north. A few pillows southwest of Upper Shebandowan Lake face southwards suggesting stratigraphic younging direction is to the south.

Isoclinal folding on an outcrop scale, displaying S and Z symmetry, was observed throughout the map area. Kink folds of S and Z symmetry with steeply plunging axes occur throughout the map area. However, the kink folds are more abundant in the northern rather than the southern part of the map area.

Significant structural features in the map area are the widespread presence of northeast- to east-northeast-striking, steeply dipping ductile to brittle shear zones. These structures are most abundant in the northwestern half of the map area. Movement along these shear zones is predominantly sinistral as shown by tails of rotated clasts in pyroclastic units and deflection of foliation trends in outcrop-scale shear zones. Two prominent regional shear zones of economic significance occur in the northern part of the map area.

The east-northeast-trending North Coldstream Mine Shear Zone (NCMS) is an up to 300 m wide zone which extends from North Coldstream Mine for about 5 km to the northeastern limit of the map area. The NCMS is characterized along its strike length by penetrative schistosity, outcrop-scale shear zones, topographic lows, silicification, carbonitization and locally intense iron-carbonate alteration.

The northeast-trending Upper Shebandowan Lake Shear Zone System (USSZ), which underlies and passes through the islands in Upper Shebandowan Lake, is another prominent structure. This structure appears to be composed of sets of subparallel shear zones that extend southwestward from the Three Miles Bay area (Hodgkinson 1968) into the present study area. At Copper Island, it is characterized by intense chloritization, silicification and abundant quartz veining. Rusty patches containing up to 1% sulphide (chalcopyrite, pyrite) mineralization were observed in places along the shorelines of Copper Island and the other islands. Up to 5.1% Cu has been reported by Jellico Mines (1939) Limited from the Copper Island showing (Assessment Files, Resident Geologist Office, Thunder Bay). A shear zone, which runs southwestward along the southern shore of the Upper Shebandowan Lake, is roughly coincident with the contact of the Burchell and Greenwater assemblages of Williams et al. (1991) and may represent a tectonic juxtaposition of unrelated sequences along the faulted contact.

ECONOMIC GEOLOGY

The regional distribution of known base metal occurrences (Giblin 1964) and field observations made by the present survey suggest that many of these occurrences are located at or near the intermediate to felsic metavolcanic contacts (Table 40.1). These contacts, in many cases, are sheared or fractured, and sulphide mineralization appears to be associated with them. Pyrite and chalcopyrite occur both as disseminations and massive fillings. Copper is usually the most significant base metal in the map area. Anomalous zinc and nickel often accompany the copper mineralization. Examples of this type of sulphide mineralization are observed in many parts of the map area, but most significantly to the east of Fountain Lake and southeast of Hermia Lake (*see* Table 40.1, samples I5–4a, I5–4b, I5–5a, SWC 15A–6a, SWC15A–6b, J1–1a, J2–5a, J2–9a and J2–10).

Copper mineralization also occurs in the sheared mafic to intermediate pyroclastic units west of Upper Shebandowan Lake (sample H5-4a) and the plagioclase-phyric mafic flow on the northwest shore of Watershed Lake (sample SWD20–3). Significant copper mineralization also occurs east of Hermia Lake, where a mineralized zone has been traced for a length of 400 m (Giblin 1964) using several trenches. Chalcopyrite, pyrite and bornite occur both as disseminations and massive fillings along the east- and northeast-trending shear zones and along the associated fractures within the felsic and mafic metavolcanic rocks. Sulphide mineralization also occurs in the schistosity planes of an iron formation unit and in quartz-feldspar porphyry. Giblin (1964) also reported the presence of sulphides in a diorite, which contained up to 1.09% Cu. All rock types exposed in the trenches are cut by northeast- and east-striking shear zones and are variably altered by silicification and minor carbonitization. Minor quartz-carbonate veins are also present within or adjacent to the shear zones. The brecciated felsic metavolcanic rock, which has been reported to contain up to 1.10% Cu (*see* Table 40.1, Hermia Lake copper showing), is thought by Giblin (1964) to be the most favourable host rock. Grab samples of all exposed rock units in trenches were taken by the present field party and have been submitted for analysis. Results from these samples are pending.

Pyrite, chalcopyrite and bornite were observed in a highly oxidized chert unit (sulphide-facies iron formation?), approximately 1.5 km north of Waverly Lake on the property of International Geoventure Incorporated. The chert unit, which occurs within or between mafic and intermediate tuff units, is approximately 4 m wide and 45 m long. It is massive to brecciated, and massive sulphides occur mainly within the matrix of the brecciated part of the chert bed.

Significant copper mineralization, which is hosted by mafic intrusions, is known to occur at 2 locations within the map area: 1) the Copper Island occurrence at Copper Island in the Upper Shebandowan Lake; and 2) the North Coldstream Mine deposit just east of Burchell

Table 40.1. Assay results from some of the samples collected by the field party. All analyses by Timiskaming Testing Laboratory, Cobalt, Ontario.

Sample	Au	Ag	Cu	Ni	Co	Pb	Zn	Cr	Sb	As	Mo	Remarks
G2–3a	0.154	N	25	26	41	<10	12	11	<10	<10	–	Quartz-feldspar porphyry, highly silicified, oxidized, iron carbonate, py and cpy (NCMS)
G3–5	0.017	N	24	55	62	<10	63	15	<10	<10	–	Quartz-feldspar porphyry – sheared, carbonate, py and cpy (NCMS)
G3–7	0.031	N	921	42	45	<10	41	55	<10	<10	–	Quartz ± feldspar porphyry – oxidized, cpy and py (NCMS)
H5–4b	0.011	N	17	45	75	<10	27	22	<10	<10	18	Feldspar ± quartz porphyry – shearing, q.c. veinlets, hematization, py and cpy – approximately 460 m west of Upper Shebondowan Lake (USSZ)
H5–4a	0.031	N	2540	222	152	<10	73	58	<10	<10	–	Mafic tuff-tuff breccia – shearing and folding, q.c. veins, iron carbonate, cpy-py – approximately 460 m west of Upper Shebondowan Lake (USSZ)
H5–3	0.021	N	36	39	21	<10	46	42	30	<10	–	Mafic tuff-lapilli tuff – shearing, py and cpy approximately 430 m west of Upper Shebondowan Lake (USSZ?)
SWB24–1	N	N	194	38	45	<10	37	<3	<10	<10	–	Plagioclase-phyric mafic flow and iron formation? - py and cpy dissemi nated in magnetite layers-north shore Greenwater Lake
SWB25–3	N	N	156	20	7	<10	202	40	<10	<10	–	Plagioclase-phyric mafic flow – rust zone, no sulphide mineralization visible – north shore Greenwater Lake
15–4a	T	N	462	323	69	<10	181	260	38	<10	–	Chlorite schist (diorite intrudes contact between chlorite schist and felsic to intermediate-sericite schist) – cpy and py-southeast of Hermia Lake
15–4b	N	N	328	310	64	<10	218	365	41	<10	–	Same as I5-4a
15–5a	N	N	201	8	7	<10	19	19	<10	<10	–	Felsic to intermediale sericite schist (~190 m south of chlorite schist – I5-4a & b) undetermined fine-grained sulphide-southeast of Hermia Lake
SWC15A–6a	N	N	76	33	7	<10	330	32	<10	<10	–	Silicified mafic or intermediate metavolcanic (intercalated with felsic metavolcanic) – cpy and py - southeast of Hermia Lake
SWC15A–6b	T	N	227	25	18	<10	43	47	<10	<10	–	Same as SWC15A-6a
J1–1a	T	N	351	14	35	<10	47	41	35	<10	–	Intermediate tuff - lapilli tuff (in contact with felsic metavolcanic) – cpy and cp – east of Fountain Lake
J2–5a	0.007	N	351	14	35	<10	47	41	35	<10	–	Mafic metavolcanic – py – east of Fountain Lake
J2–6a	T	N	57	28	8	<10	111	177	17	<10	–	Graphitic schist within mafic and intermediate metavolcanic horizon – silicification, carbonitization, sulphides – east of Fountain Lake
J2–9a	N	N	67	26	24	<10	155	39	36	<10	–	Intermediate flow and/or tuff (near contact with the mafic metavolcanic rock) – py and po – east of Fountain Lake
J2–10	T	N	243	39	10	<10	137	55	38	<10	–	Intermediate tuff with felsic flow – rusty, silicification –cpy, py – east of Fountain Lake
H1–5	0.006	N	102	85	19	<10	62	162	<10	<10	–	Intermediate flow – py, cpy and chl – north of Burchell Lake

Table 40.1. continued.

Sample	Au	Ag	Cu	Ni	Co	Pb	Zn	Cr	Sb	As	Mo	Remarks
H1–4	0.027	N	30	23	7	<10	56	21	<10	<10	–	Intermediate or felsic metavolcanic – silicification, py, cpy and bo – north of Burchell Lake
H13	T	N	124	28	3	<10	20	42	<10	<10	–	Felsic flow – py and cpy as veinlets in fractures–north shore Burchell Lake
SWD19–7a	N	N	99	24	14	<10	188	30	<10	<10	–	Intermediate tuff – py, cpy and bo along bedding and/or foliation (adjacent to plagioclase-phyric mafic flow) – south of Grouse Lake
SWD20–3	N	N	1020	141	28	<10	115	36	<10	<10	–	Plagiclase - phyric mafic flow or gabbro – 15 cm x 3 m rusty shear zone, cpy and py – northwest shore of Watershed
Hermia Lake	0.03	–	1.10%	–	–	–	–	–	–	–	–	Felsic metavolcanic – py and cpy (Giblin 1964)
Copper Showing	–	–	–	–	–	–	–	–	–	–	–	Diorite - py and cpy (Giblin 1964)
	0.03	–	1.09%	–	–	–	–	–	–	–	–	Other observations : a) Chlorite schist – silicification b) Felsic flow and tuff c) quartz – feldspar porphyry. d) Iron formation a, b, c and d rock units are sheared (northeast and eastwest trends) and contain py, cpy, bo, mal, q.c. veins (a, b, c trends) d observations are made by the present field party – assay results are pending)
Copper Island	–	–	up to 5.1%	–	–	–	–	–	–	–	–	Gabbroic sill complex – shearing, quartz veins, cpy (Assessment Files Resident Geoogists Office, Thunder Bay)
Upper Shebandowan Lake												

ABBREVIATIONS

Bornite	–	bo
Chalcopyrite	–	cpy
Chlorite	–	chl
Malachite	–	mal
Pyrite	–	py
Pyrrhotite	–	po
Quartz Carbonate veins and/or veinlets	–	q.c.

Nil	–	N (<25 ppb)
Trace	–	T (25-34 ppb)
NCMS	–	North Coldstream Mine Shear Zone
USSZ	–	Upper Shebandowan Lake Shear Zone

Note: Assay values for Au are given as ounce per ton. Unless otherwise indicated, values for other elements are in ppm.

Lake. The gabbro-anorthosite sill complex, which is exposed at Copper Island, is part of a much larger differentiated intrusive sill complex which underlies much of the Upper Shebandowan Lake and is exposed on the islands, the north shore and west of the lake. This gabbroic-sill complex is intrusive into the metavolcanic rocks. At Copper Island, the chalcopyrite and pyrite mineralization is reported to occur within this gabbroic-sill complex and appears to be related to the northeasterly striking shear zone (USSZ) (Hodgkinson 1968). The USSZ is characterized by outcrop-scale shear zones, pervasive schistosity and chloritization. Abundant quartz veining within the intrusion is associated with the shearing. Chalcopyrite is reported to occur both in sheared gabbroic rocks and in quartz veins (Assessment Files, Resident Geologist's Office, Thunder Bay). Samples of sheared gabbroic rocks containing 5.1% and 3.9% Cu over 0.9 and 1.2 m, respectively, have been reported.

Another example of copper mineralization associated with a mafic intrusion is the North Coldstream Mine deposit which will be discussed later in some detail under a separate heading.

Minor gold, in the map area, is commonly associated with the copper mineralization (e.g., North Coldstream Mine and the Hermia Lake copper occurrence). However, significant gold mineralization is known to occur in areas of intense ductile shearing. Examples of this mineralization style are documented by the authors, most notably, in the northern part of the map area, where numerous northeast-striking, small- and large-scale shear zones cut across all major rock types. Sulphide mineralization (pyrite, chalcopyrite and minor arsenopyrite) occur as disseminations and seams along the schistosity planes within or adjacent to these shear zones. Quartz-carbonate veining, silicification, carbonitization and most importantly iron-carbonate alteration are characteristic features related to the gold mineralization in these shear zones. An example of shear zone related mineralization was observed at North Coldstream Mine property (eastern half) of Conwest Exploration Company Limited. Quartz-feldspar and quartz porphyries, which are known to host gold mineralization (Conwest Exploration Company Limited, unpublished data), are emplaced within mafic to intermediate metavolcanic rocks. The porphyries and metavolcanic rocks are cut by numerous, east-northeast-striking ductile to brittle shear zones (NCMS). The porphyries and metavolcanic rocks within or adjacent to these shear zones are variably schistose, silicified, carbonitized, oxidized and locally display intense iron-carbonate alteration. Sulphide mineralization was noted both in porphyries and in sheared metavolcanic rocks. Three grab samples of porphyry and 2 of mafic to intermediate metavolcanic rock were collected for analysis. Three samples of porphyry have assayed 0.154, 0.017 and 0.031 ounces Au per ton (*see* Table 40.1, samples G2–3a, G3–5 and G3–7), and results from samples of mafic metavolcanic rocks are still pending. Significant rediscovery of gold mineralization by Noranda Exploration Company Limited, on the North Coldstream Mine property of Conwest Exploration Company Limited, is discussed in the "Mineral Exploration History" section.

Two other examples of shear zone related gold mineralization are found west of Upper Shebandowan Lake (*see* Table 40.1, samples H5–3, H5–4a and H5–4b). In the first example, approximately 460 m west of Upper Shebandowan Lake, gold mineralization occurs in a sheared mafic to intermediate pyroclastic unit (tuff-tuff breccia) and in a quartz-feldspar porphyry. The porphyry is intrusive into the mafic-intermediate pyroclastic rock. Shearing and strong schistosity developed in the porphyry and pyroclastic unit are interpreted to be associated with the USSZ. Abundant quartz veining, silicification, hematization and iron-carbonate alteration (ankerite) are noted in porphyry and pyroclastic rocks. Massive and disseminated chalcopyrite and pyrite occur along schistosity planes, shear fractures and quartz veins and pods. A grab sample of porphyry and a pyroclastic rock, taken by the present field party, assayed, respectively, 0.011 and 0.031 ounces Au per ton (samples H5–4b and H5–4a). Anomalous molybdenite (18 ppm) is also associated with the gold mineralization in the porphyry. In the second example, which is located 430 m west of the Upper Shebandowan Lake, a highly anomalous gold (0.021 ounces Au per ton) value is from a sheared pyroclastic rock (mafic tuff-lapilli tuff; sample H5–3).

Potential shear-zone-hosted gold mineralization also exists in the Burchell-Skimpole lakes areas. In these areas, shearing and associated zones of silicification, carbonate and/or iron-carbonate alteration were noted in felsic and intermediate metavolcanic rocks and quartz-feldspar and feldspar porphyries. Significant sulphide mineralization (pyrite, chalcopyrite) was noted in these rocks.

The NCMS and USSZ should be explored thoroughly along their entire strike lengths (*see* Figure 40.2) for possible new gold horizons and extensions of known gold zones.

North Coldstream Mine Deposit

The North Coldstream Mine copper-gold-silver deposit was discovered in early 1870. Between 1906–1967, 102 million pounds of Cu, 440 000 ounces of Ag and 22 000 ounces of Au were produced from a total of 2.7 million tons of ore mined.

A gabbroic (gabbro, plagioclase-phyric gabbro to anorthositic gabbro) sill-like body at the North Coldstream Mine was intruded along the contact between felsic and mafic metavolcanic rocks. The orebody, hosted by a siliceous zone (300 by 120 m), is situated between the gabbro and the mafic metavolcanic rocks. The chlorite ± epidote-actinolite schist of gabbroic and mafic metavolcanic protoliths and minor quartz-carbonate-sericite schist of felsic metavolcanic protolith occur north, south and east of the siliceous zone. Quartz-feldspar and feldspar porphyry occur as minor intrusions within and adjacent to the siliceous zone. At 1 location along the north margin of the siliceous zone, progressive silicification of epidote-chlorite-actinolite schist of gabbroic protolith was noted. The intensity of silicification at this location progressed from hairline silicification to patchy in distribution, then to total conversion of schist into the siliceous rock. Based on this observation, we suggest that the protolith of the siliceous rock, in part, is gabbro. However, silicification of mafic and felsic metavolcanic rocks cannot be completely ruled out, since they are also present adjacent to the siliceous zone. The east-northeast-striking shear zone (NCMS) is interpreted to occur between the gabbro and the mafic metavolcanic rocks.

An east-striking shear zone is also interpreted to occur along the contact between the gabbro and the felsic metavolcanic rocks to the north of the mine. This shear zone is characterized by several outcrop-scale shear zones along the northern margin of the gabbro. Minor amounts of sulphide minerals (pyrite, pyrrhotite, chalcopyrite) and quartz-carbonate veins occur within the shear zones.

Numerous relatively late fractures and faults of both northeast and northwest trends, displaying sinistral and dextral displacements, respectively, occur in outcrops at the mine site and in adjacent areas.

The mineralization at the North Coldstream Mine deposit consists of chalcopyrite and pyrite, with minor malachite, pyrrhotite and azurite. The sulphide minerals occur in sheared and fractured host rocks. The siliceous host rock, which is also known as chert (Giblin 1964), contains several sulphide lenses comprising a high density network of chalcopyrite and pyrite veinlets, as massive and disseminated mineralization. The mineralized lenses are interconnected by zones of lower grade mineralization and have a maximum horizontal dimension of 70 by 70 m and a plunge of 50°E.

The siliceous host, where unmineralized and unsheared, is massive, aphanitic, buff and mauve in colour and textureless. It consists of mainly quartz with minor amounts of carbonate, albite, sericite, chlorite, leucoxene and magnetite (Giblin 1964). Chemical analyses of 14 samples of the siliceous host range from 92% to 95% SiO_2, 1.90% to 3.89% TiO_2, 1.42% to 2.25% Al_2O_3 and 0.17% to 2.01% Fe_2O_3 (total iron). Selenium and bismuth are the only other elements that are strongly anomalous (e.g., 52 ppm Se and 28 ppm Bi). These high concentrations of selenium and bismuth are not necessarily indigenous to the siliceous host rock. They most likely were introduced during the mineralizing event, which is superimposed on the siliceous host rock.

One part of the siliceous host rock contains 5.67% to 8.48% TiO_2, and SiO_2 ranges from 40% to 85%. This titanium-rich part of the host rock is transitional into the epidote-chlorite-actinolite schist, which represents the sheared contact between the siliceous rock and a gabbro body to the north.

Based on field evidence, geochemical data and the metal association of the deposit, we outline the following implications regarding the source and origin of the North Coldstream Mine deposit.

1. The epidote-chlorite-actinolite schist is derived from gabbroic and mafic volcanic rocks.
2. The schist is progressively silicified and grades into the massive siliceous (chert) zone.
3. The presence of euhedral titano-magnetite needles in partly silicified gabbroic rocks and within the siliceous zone suggest that the needles are probably contemporaneous with the silicification.
4. The high titanium content in the siliceous zone suggests that the siliceous rock is either derived from titanium-rich mafic rock (gabbroic or mafic metavolcanic rocks) or that the titanium was added during the alteration process.
5. The deposit lies at the same stratigraphic position as numerous metal occurrences of the area, some of which are likely volcanic-associated massive sulphide (VMS) types. The metal association of copper, cobalt, nickel, bismuth and gold at the North Coldstream Mine deposit is, in part, VMS type (Hannington et al. 1991). However, high TiO_2 (1.42% to 8.48%), Co (0.4%), Ni (5790 ppm) and Bi (28 ppm) at the North Coldstream Mine deposit may indicate derivation of metals from a mafic intrusive source. Although the gold abundance is consistent with either the VMS or mafic intrusive-related sulphide mineralization, the anomalous gold may also represent superimposition of gold upon the pre-existing sulphide deposit during the late ductile shearing event. For example, the North Coldstream Mine deposit lies at the NCMS, which is anomalous in gold. Therefore, some or all gold may be related to this shearing event.

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REFERENCES

Corfu, F. and Stott, G.M. 1986. U-Pb ages for late magmatism and regional deformation in the Shebandowan Belt, Superior Province, Canada; Canadian Journal of Earth Sciences, v.23, p.1075–1082.

Giblin, P.E. 1964. Geology of the Burchell Lake area, District of Thunder Bay; Ontario Department of Mines, Geological Report 19, 39p.

Hannington, M. Herzig, P., Scott, S., Thomposon, G. and Rona, P., 1991. Comparative mineralogy and geochemistry of gold-bearing sulfide deposits on the mid-ocean ridges; Marine Geology, v.101, p.217–248.

Hodgkinson, J.M. 1968. Geology of the Kashabowie area, District of Thunder Bay; Ontario Department of Mines, Geological Report 53, 35p.

Ontario Geological Survey 1991a. Airborne electromagnetic and total intensity magnetic survey, Shebandowan area; Ontario Geological Survey, Maps 81 551 to 81 594 (inclusive), scale 1: 20 000.

Ontario Geological Survey 1991b. Bedrock Geology of Ontario, west-central sheet; Ontario Geological Survey, Map 2542, scale 1:1 000 000.

Osmani, I.A. 1991. Proterozoic mafic dike swarms in the Superior Province of Ontario; *in* Geology of Ontario; Ontario Geological Survey, Special Volume 4, Part 1, p.661–681.

Osmani, I.A., Anthony, E.G. and Payne, J. 1991. Geology and mineral potential of Moss Township, Shebandowan Greenstone Belt, District of Thunder Bay, Ontario; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.268–275.

Stott, G.M. 1985. A structural analysis of the central part of the Archean Shebandowan Greenstone Belt and a crescent -shaped granitoid pluton, northwestern Ontario; unpublished PhD thesis, University of Toronto, Toronto, Ontario, 285p.

Williams, H.R., Stott, G.M., Heather, K.B., Muir, T.L. and Sage, R.P. 1991. Wawa Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.485–539.

41. Geology of Marks and Adrian Townships, District of Thunder Bay

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INTRODUCTION

Marks and Adrian townships are located between latitudes 48°18'41"N and 48°59'55"N and between longitudes 89°46'W and 89°53'50"W (Figure 41.1). The map area is centred approximately 45 km west of Thunder Bay and is easily reached via Highway 590 from Kakabeka Falls. Major logging roads referred to locally as "the Boreal road" and "the Adrian Lake road" provide access to the northern part of Marks Township and Adrian Township, respectively. Numerous minor logging roads, concession roads and sideroads provide access to most of the map area. The northeastern part of Adrian Township was accessed by helicopter.

MINERAL EXPLORATION

Tanton (1931) reported that amethyst and quartz crystals occurred in granite in Lot 4, Concession VI, Marks Township, and that an amethyst vein was reported to occur in Lot 12, Concession I of Marks Township. There was no report of further exploration activity until 1958. At this time, the Hanna Mining Company carried out exploration for iron on 2 properties in northern Marks Township. No economic orebodies were discovered.

In the late 1960s and 1970s exploration for base metals was carried out by Noranda Exploration Company Limited and the Canadian Nickel Company Limited mainly in Adrian Township. No significant mineralization was discovered.

A number of mining claims were in good standing at the time of writing this paper. These claims covered areas underlain by airborne electromagnetic conductors detected by the recently released Ontario Geological Survey total intensity magnetic and electromagnetic surveys (OGS 1991a–d).

GENERAL GEOLOGY

The map area is underlain by Neoarchean rocks composed of ultramafic, mafic, intermediate and felsic metavolcanic rocks; related intrusive rocks; and clastic and chemical metasedimentary rocks. These rocks have been intruded by Neoarchean plutons and batholiths composed of diorite, tonalite, granodiorite and granite.

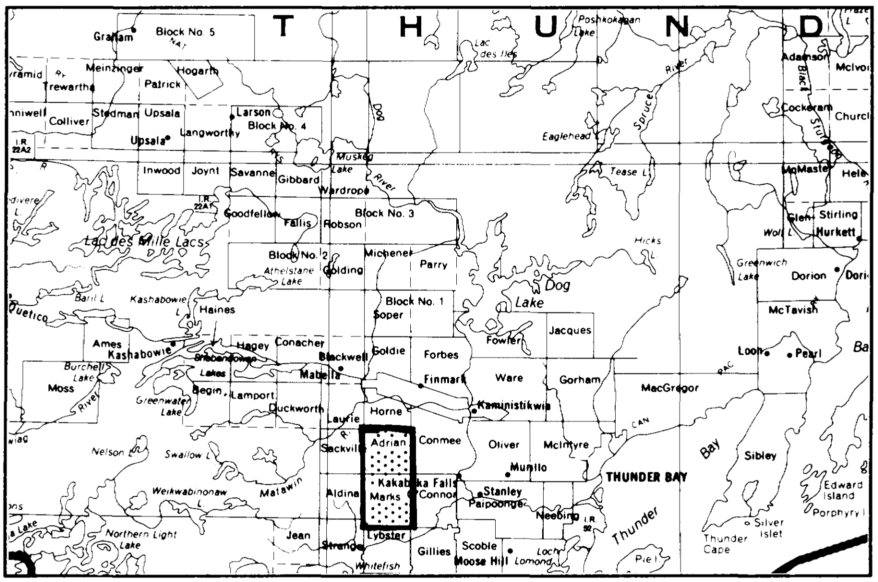

Figure 41.1. Location map of Marks and Adrian townships, scale 1:1 584 000.

This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

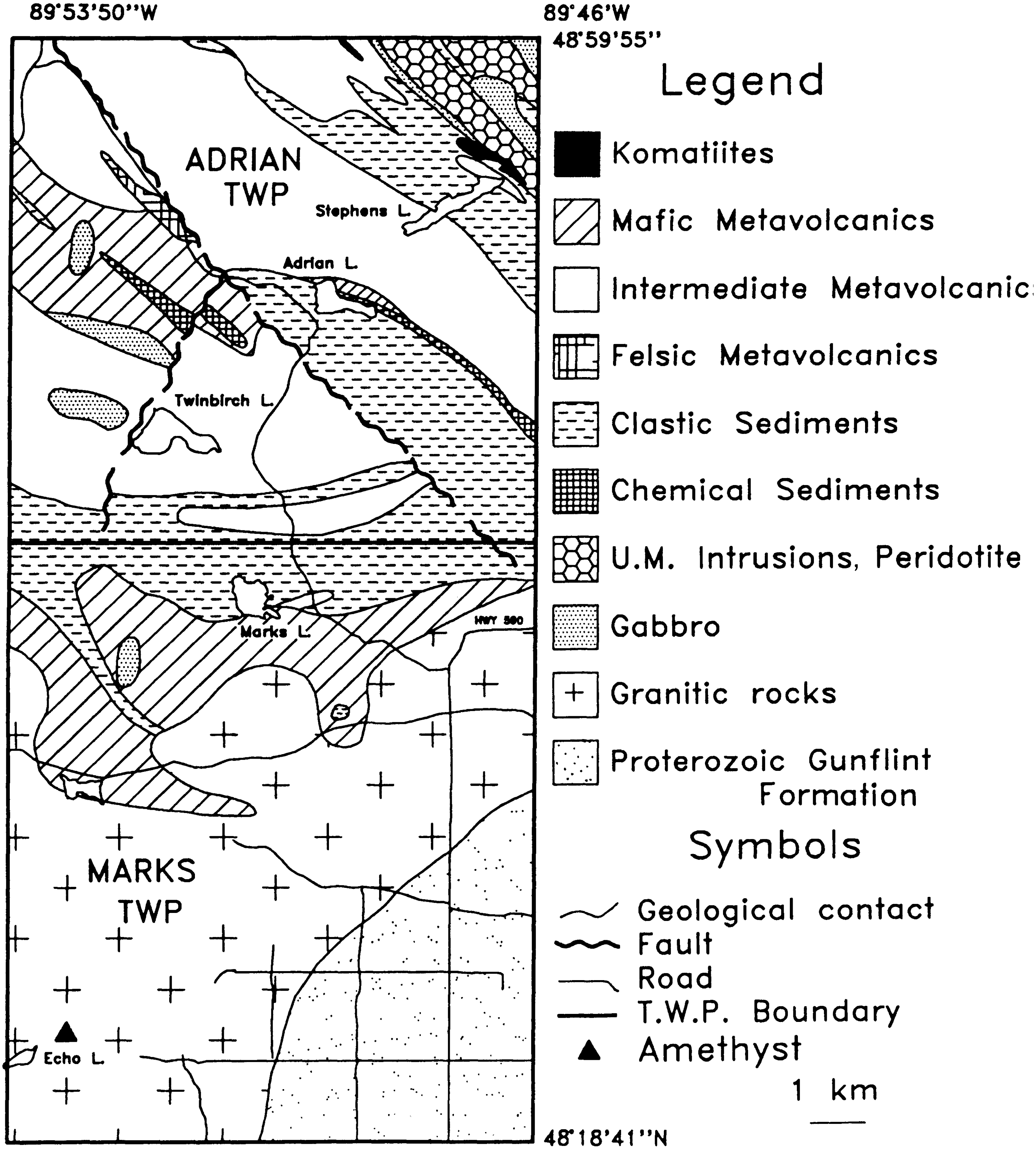

Figure 41.2. General geology of Marks and Adrian townships.

Paleoproterozoic metasedimentary rocks composed of taconite, conglomerate, stromatolitic and algal mat chert belonging to the Gunflint Formation of the Animikie Group unconformably overlie the Archean rocks.

Previous mapping by Tanton (1931) covered the area at reconnaissance scale. Carter (1985, 1986) mapped the areas north and east of Adrian Township, and every effort has been made to correlate the geology in the map area with these earlier maps.

Ultramafic and mafic metavolcanic rocks that contain spinifex, polysutured and, locally, flow-brecciated textures are inferred to be komatiites (Carter 1985, 1986) and occur as narrow flows in the northeastern part of Adrian Township (Figure 41.2). Most of these rocks are grey-green, nonmagnetic, basaltic flows; however, polysutured peridotitic flows are locally present.

Mafic metavolcanic rocks occur as 2 major units and as many minor units in the map area. Amphibolitic mafic metavolcanic rocks form an east-trending band adjacent to the granitic contact in the northern part of Marks Township. These rocks are black to dark green, foliated to gneissic and commonly lineated. For the most part they are massive, and only locally pillowed flows and mafic lapilli tuff were observed. Reliable stratigraphic indicators were observed in 1 place only where pillowed flows indicated tops to the east.

Massive mafic metavolcanic rocks form a major northwest-trending unit that extends from the central part of Adrian Township to its northwest boundary. These rocks are predominantly composed of dark green, massive flows with minor pillowed and flow-top brecciated flows. Variolites occur locally. This unit appears to be fault and shear terminated southwest of Adrian Lake. Pillow shapes indicate stratigraphy younging to the west and southwest.

Many discontinuous or narrow mafic units are interlayered with metasedimentary and intermediate metavolcanic rocks east of Adrian Lake. For the most part, these units are similar to the previously described rocks; however, in a few places between Adrian and Stephens lakes, the mafic flows are hornblende phyric, which is inferred by the author to represent a calc-alkalic geochemical affinity.

Intermediate metavolcanic rocks underlie much of Adrian Township. Tuff, crystal tuff, lapilli tuff and crystal lapilli tuff occur in an easterly trending band in the southern part of Adrian Township. These rocks weather grey to dark grey and commonly contain biotite in the matrix, which is interpreted to result from upper greenschist-grade metamorphism. Intermediate rocks in the easterly trending band are uniformly feldspathic with grain size varying between 1 and 7 mm. For the most part, these deposits are massive, moderately sorted, ungraded and poorly stratified. Intermediate metavolcanic rocks are also interbedded with wacke and mudstone in southern Adrian Township and in the northern part of Marks Township. These rocks are similar in composition to the intermediate rocks described above but are commonly well bedded, well sorted and are massive to graded. Reversals in stratigraphic tops indicate these units are isoclinally folded.

Intermediate flows and pyroclastic rocks form a distinctive unit in the central and northwestern part of Adrian Township. These rocks contain plagioclase and hornblende phenocrysts and generally weather grey, green and light yellow. Locally, some of the fragments in the pyroclastic rocks are pink or pale green. Massive dacite flows and autoclastic breccias are common east of the Adrian Lake road near the northern boundary of Adrian Township. These rocks weather chalky white and, for the most part, are aphanitic with wispy fragments that are of the same composition as the groundmass. Locally, plagioclase and hornblende phenocrysts were observed. Plagioclase- and hornblende-phyric flows were also observed east of Stephens Lake.

Grey to green, heterolithic lapilli tuff (4 mm to 5 cm) is the most common rock type of this intermediate flow and pyroclastic rock unit and is most abundant between Stephens Lake and the Adrian Lake road. These lapilli tuff units are typically ungraded, unsorted, crudely to nonstratified and, for the most part, are clast supported. Intermediate fragments are most common with mafic and felsic fragments less abundant. Rarely, jasper and laminated mudstone fragments were observed. In 1 outcrop on an old logging road north of Adrian Lake reaction rims were observed on some of the fragments, which indicates the fragments were either hot when deposited or they reacted with hot fluids after deposition. Lapilli tuff from this outcrop is very similar to grey, dacitic lapilli tuff correlated with the Shebandowan assemblage, a post-Keewatin greenstone (Williams et al. 1992) observed by the author on the Shebandowan mine road approximately 26 km to the northwest.

Intermediate tuff breccia is most common in the area west of Stephens Lake and is well exposed in a series of outcrops approximately 2 km northwest of Adrian Lake at the end of a logging road. Here, heterolithic fragments up to 1 m in size are composed of flow-laminated, intermediate to felsic flows; feldspar and hornblende porphyry; mafic trachytic-textured flows; intermediate pumice; previously brecciated clasts; jasper fragments; and rare, red trachytic-textured flows. Fragments are angular to subrounded. These rocks are interpreted to be primary block and ash pyroclastic deposits, which are indicative of explosive volcanism. The presence of plagioclase and hornblende phenocrysts is inferred by the author to indicate that the rocks are calc-alkalic.

Tuff is uncommon in the intermediate unit in the central part of Adrian Township and where present occurs as narrow units interlayered with coarser-grained pyroclastic deposits. This tuff is commonly green with green, grey and less commonly pink lithic and feldspathic grains. Hornblende grains and crystals are locally present.

Reliable stratigraphic indicators are very rare in this unit, and those that are present indicate "tops" are west to southwest. Contacts of this intermediate unit with the underlying and overlying units were not observed. Intermediate tuff and lapilli tuff of similar composition were observed interbedded with metasedimentary rocks to the northeast, which suggests a gradational transition from a metasedimentary to a metavolcanic environment. The plagioclase- and hornblende-phyric intermediate metavolcanic rocks appear to overlie the feldspathic intermediate rocks described above; however, locally, the 2 rock types appear to be intercalated. The western contact with felsic and mafic metavolcanic rocks is faulted and sheared, which precludes an accurate determination of the nature of the contact.

Felsic metavolcanic rocks form a narrow unit exposed along and west of the Adrian Lake road approximately 3 km northwest of Adrian Lake. Massive, coarse-grained quartz porphyritic flows, tuff and lapilli tuff occur in fault contact with the plagioclase- and hornblende-phyric intermediate unit to the northeast and appears to underlie mafic metavolcanic rocks to the southwest. The felsic rocks weather white to grey, are quartz bearing and are generally very hard. Disseminated pyrite occurs throughout the flows and locally as clasts and disseminations in the pyroclastic rocks.

Felsic quartz porphyry and crystal tuff occur interlayered with mafic amphibolite and amphibolitic metasedimentary rocks in the vicinity of a magnetite-chert unit in northwestern Marks Township. These rocks weather white and are dark grey on a fresh surface, commonly with an aphanitic texture. The felsic quartz porphyry appears to be discontinuous along strike, and it is possible that it represents a subvolcanic intrusion.

Felsic rocks also occur interlayered with intermediate rocks west and east of the Adrian Lake road, but the felsic rocks appear to be discontinuous.

Clastic metasedimentary rocks form 2 major bands in the map area and are composed of wacke, siltstone, mudstone, conglomerate, derived schist and gneiss. One major band extends from the northwestern boundary of Marks Township to the eastern boundary of the map area. Wacke derived from intermediate tuff and mudstone is the major rock type in this band. Schist, gneiss and a distinctive quartz-bearing pebble conglomerate are minor rock types. Wacke is thickly to thinly bedded and is predominantly massive but locally displays grain gradation. Biotite and less commonly garnet occur, which indicates middle to upper greenschist-grade metamorphism. Mudstone and siltstone are commonly black, laminated to thinly bedded and in a few places are graphitic. Mudstone and siltstone commonly occur at the top of wacke beds and also occur as thick units especially north of Marks Lake. Intermediate tuff and crystal lapilli tuff are commonly interbedded with the wacke and mudstone, and where these tuffs were reworked, they are very difficult to distinguish from the metasedimentary rocks. Reversals in stratigraphic facings indicate this metasedimentary unit is complexly folded.

Within this band of metasedimentary rocks there occurs a distinctive quartz-bearing pebble conglomerate, which can be used as a marker unit. This conglomerate is predominantly composed of rounded to angular, sugary-textured quartz pebbles up to 5 cm in size with subordinate mudstone, intermediate and mafic metavolcanic pebbles of comparable size. For the most part, the pebbles are matrix supported in a recrystallized biotitic and hornblendic matrix that commonly contains up to 5% disseminated pyrrhotite. The quartz pebbles commonly display laminations, and this fact indicates that they may have orginally been resedimented chert.

The second major band of metasedimentary rocks extends northwest through the map area from the southeast corner of Adrian Township to the north central part of the township. Wacke and mudstone are the predominant rock types, and they are commonly organized into laminated to thinly bedded (1 mm to 5 cm) couplets interpreted to be turbidites. Chert, intermediate tuff and lapilli tuff and magnetite-jasper iron formation compose distinct units within the turbidites and, locally, form thick mappable units (see section on chemical metasedimentary rocks). Conglomerate is well developed within the sequence, and 2 distinct types were recognized. Pebble conglomerate is composed of small rounded to angular quartz, intermediate and mafic metavolcanic and mud chip fragments, from 4 to 9 mm in size, in a sand to grit matrix. The pebbles are most commonly clast supported and densely packed; however, matrix-supported mud chip conglomerate is common. Pebble conglomerate generally forms discontinuous units interbedded with wacke and mudstone near the top of the sequence.

Chert and jasper cobble conglomerate forms a narrow (less than 50 m thick) unit that was followed more or less continuously for 6 km along strike. The unit is best exposed northwest of Stephens Lake, where over 90% of the cobbles and blocks are composed of angular to rounded jasper-magnetite (5 to 75 cm) and laminated mudstone. The remaining 10% of the clasts are composed of intermediate and mafic metavolcanic cobbles. The conglomerate is clast to matrix supported in a sand matrix, and 1 large jasper clast and a few smaller clasts contain contorted bedding and quartz veins that do not extend into the matrix. Farther north jasper cobbles are less common, and white- to yellow-banded chert cobbles occur. This conglomerate unit represents a resedimented deposit and implies that the mudstone and jasper-magnetite iron formation were contorted, quartz veined and uplifted prior to resedimentation. It is inferred that a pre-Kenoran orogeny affected the Neoarchean rocks in the map area, and this orogeny is most likely equivalent to the one inferred to have formed the Shebandowan assemblage (Williams et al. 1992).

Chemical metasedimentary rocks are composed of chert, jasper-magnetite iron formation and sulphide-facies iron formation. Chert commonly occurs as narrow (1 to 3 cm thick) interbeds within the clastic metasedimentary bands and rarely forms mappable units. However, interbedded chert, mudstone and graphitic-sulphiditic mudstone form thick units southeast of Adrian

Lake, in the southern part of Adrian Township and, locally, northeast of Stephens Lake. These rock types are coincident with trains of airborne electromagnetic conductors, which effectively map the location of these units (OGS 1991a-d).

Thick, folded sequences of interlaminated chert and magnetite occur in the northeast part of Marks Township and are inferred from airborne geophysics (OGS 1991d) to underlie the north central part of Marks Township. These deposits were explored by the Hanna Mining Company and were determined to be too lean to be economic.

Jasper-magnetite iron formation occurs most commonly in the band of metasedimentary rocks southeast and northwest of Stephens Lake. Here, laminated jasper and magnetite form units up to 20 m thick, which can be followed more or less continuously along strike. It is inferred by the author that these units were the source of some of the jasper-magnetite clasts in the chert and jasper cobble conglomerate described above. Jasper-magnetite iron formation also forms a mappable unit west of the Adrian Lake road approximately 1700 m north of Twinbirch Lake. Here the iron formation is interlayered with mudstone, intermediate tuff and mafic flows. The iron formation appears to pass gradationally into chert and graphitic mudstone along strike to the northwest. Thin bands of iron formation interbedded with wacke and mudstone were observed in several places in northwestern and southeastern Adrian Township, but these units are generally not mappable.

Ultramafic intrusive rocks occur in the northeastern part of Adrian Township and are composed predominantly of massive peridotite with minor amounts of pyroxenite. Northwest-trending peridotite dikes and sills intruded metasedimentary and intermediate metavolcanic rocks between the east end of Stephens Lake and Thunder Lake. The peridotite is massive and is fine grained to coarse grained with no detectable variation in grain size across the intrusion. Rarely, polygonal cooling joints were observed and in some of these joints asbestos fibers occur up to 1.5 mm in size. At a small lake approximately 900 m south of Thunder Lake, the contact of a peridotite dike was observed to cut across the bedding of cherty metasedimentary rocks at a 30o angle, which indicates these peridotite dikes are intrusions and not thickly ponded ultramafic flows. Dark green, nonmagnetic pyroxenite was observed in the Thunder Lake area as part of an ultramafic intrusion.

Mafic intrusive rocks are composed of gabbroic dikes, sills and small plutons. Massive, medium-grained gabbro and leucogabbro are the predominant rock types. Leucogabbro with lesser amounts of gabbro and rarely anorthositic gabbro occurs in the northwest part of Adrian Township, both as part of the ultramafic dikes and sills and as separate intrusions. The absence of good exposures makes the separation of the various intrusive phases difficult in this area.

Medium-grained, dark green gabbroic rocks and hornblende-phyric gabbroic rocks occur within the mafic metavolcanic units, and it is possible that here the gabbroic rocks are thick-ponded mafic flows. In 1 area along the northwest boundary, gabbroic-textured dikes were observed to have intruded pillowed mafic flows, and the author favours calling all similarly textured rocks gabbro.

Neoarchean granitic rocks occur in central and southwestern Marks Township and are composed of, in order of decreasing abundance: granodiorite to quartz monzonite, potassium feldspar porphyritic to equigranular granite, tonalite, quartz diorite to diorite and migmatite. Pink, equigranular, biotite-hornblende-bearing granodiorite to quartz monzonite is volumetrically the most abundant granitic rock in the map area and underlies most of the southwestern part of Marks Township. This rock commonly contains a northwest-trending foliation and, locally, contains amphibolitic xenoliths and gneissic patches. Biotite content is generally greater than hornblende, and commonly total mafic content is less than 25% although rarely it may up to 45%.

Potassium feldspar porphyritic and equigranular granite most commonly occur adjacent to the contact with the supracrustal rocks in the northwestern part of Marks Township. These rocks weather red to grey and may contain pink to white, euhedral feldspar phenocrysts up to 3 cm in size. The granite is most commonly foliated parallel to the contact with the supracrustal rocks and appears to be gradational with the granodiorite farther to the south.

Tonalite, quartz diorite and diorite occur only locally and weather white to grey. Hornblende content is greater than that of biotite, and these rocks are gradational with the more abundant granodiorite. Granitic migmatite is locally developed and is best exposed along Highway 590 in the northeastern part of Marks Township. Here, white aplitic and tonalitic dikes envelope dark green to black mafic amphibolite and biotite-bearing lamprophyre xenoliths.

Late Neoarchean mafic intrusions are composed of diabase and lamprophyre. Narrow (less than 25 m wide) diabase dikes, which can be followed along strike for only a few meters, intrude the intermediate metavolcanic rocks in central and northwestern Adrian Township. The diabase is medium grained, weathers brown and is granular textured. On a fresh surface, brown translucent hornblende and opaque plagioclase form an equigranular, subophitic texture.

Dark green- to black-weathering lamprophyre was observed in several places in the supracrustal and granitic rocks. Lamprophyre contains from 10 to 50% dark brown to black biotite in a green hornblende and plagioclase groundmass. The lamprophyre is commonly equigranular; however, porphyritic dikes have large biotite phenocrysts up to 7 mm in size. In a few places within the supracrustal rocks, lamprophyre is accompanied by iron carbonate alteration. The southeastern part of Marks Township is underlain by members of the Gunflint Formation of the Paleoproterozoic Animikie Group. Taconite, black and red algal chert and conglomerate are only locally exposed, as these rocks are flat lying and mostly covered by overburden. Hematitic and, locally, magnetitic taconite is composed of medium to coarse sand and grit; oolitic and pisolitic development is common. The sand grains composed of quartz and lithic fragments are silica cemented, and in many places green silicate minerals, possibly greenalite and/or minnesotaite, occur. Red, green and brown varieties of taconite were observed.

Black and red algal chert is commonly closely associated with the taconite. Thinly laminated algal chert is most common; however, hemispherical algal mounds were observed along the second sideroad between Concession I and II, Marks Township. Black laminated algal chert and brown taconite occur at the unconformity with Neoarchean quartz diorite on the Concession IV road, Marks Township.

Quartz pebble-bearing conglomerate was observed in only 1 location as an outlier surrounded by quartz diorite and granodiorite on the second sideroad in Concession IV, Marks Township. The conglomerate is exposed over 1 m^2 and consists of quartz pebbles in a coarse quartz-rich sand matrix.

STRUCTURE AND METAMORPHISM

The Neoarchean supracrustal rocks are complexly folded and faulted. Three major structural domains were recognized: 1 in northern Marks and southern Adrian townships adjacent to the contact with the granitic rocks; 1 in the northeastern part of the map area; and 1 domain in the northwestern part of the map area. The structural domain in the northern part of Marks and the southern part of Adrian townships is characterized by foliations that are generally parallel to the inferred contact with the granitic rocks, and this foliation is consistently cut by a northeast-striking second foliation. Locally, interference fold patterns were observed that indicate that 2 periods of folding affected these rocks.

The structural domain in the northeastern part of the map area is characterized by first generation foliations that are layer parallel and most commonly northwest striking. They are axial planar to isoclinal folds whose axes were deduced from reversals in stratigraphic tops. Northeast- and less commonly west-northwesterly striking foliations and small shear zones cut the first generation foliations. Sinistral displacement of units was observed on both of the later structures.

The structural domain in the northwestern part of the map area is characterized by a predominant foliation that is northeast striking, and there is much greater deformation here than elsewhere. Many of the rock units are schistose, and pervasive iron carbonate alteration is widespread. Bedding is only locally preserved and where observed indicates geologic units are striking either northwest or north. Interference fold patterns were observed that indicate the first generation of folds are northwest striking, and that they were refolded about northeast-trending fold axes. In many places, northeast-striking faults or kink bands sinstrally offset bedding and the northwest-striking fold axes.

A major northwest-striking fault coincident with the Weigand River is inferred to cut the supracrustal rocks. Subhorizontal slickensides indicate movement was largely strike slip, and the map pattern suggests movement was predominantly dextral. The fault separates the northeastern and northwestern structural domains. Intense iron carbonate alteration, sparse disseminated pyrite, chalcopyrite and green mica were observed in the northern part of the fault. Geochemically anomalous gold and arsenic accompany the alteration and sulphide mineralization.

A penetrative, northwest-striking foliation is weakly to well developed in the granitic rocks. Near the contact with the Neoarchean supracrustal rocks, foliations are locally east trending. There is little physical evidence for a prominent northeast-striking fault portrayed on the Atikokan–Lakehead compilation map (ODM 1964). In a few places a northeast-striking spaced fracture set was observed; however, most of the rocks in the area of the inferred fault are massive.

The Paleoproterozoic metasedimentary rocks are essentially undeformed with a widely spaced east-striking fracture set only locally developed. They are flat lying and sit unconformably on top of the Neoarchean granitic rocks.

ECONOMIC GEOLOGY

There are no known economic mineral deposits in the map area. The Hanna Mining Company explored the northern part of Marks Township for iron in the late 1950s and discovered 2 areas with magnetite-chert mineralization. Surface and diamond-drill exploration determined that the iron content was too low to be economic at that time. Magnetite-jasper iron formation occurs in several places throughout the map area, but nowhere does it appear to be concentrated enough to be economic.

Exploration for base metals has been limited, and there are no known occurrences in the map area. The felsic metavolcanic rocks west of the Adrian Lake road in Adrian Township contain disseminated pyrite, and electromagnetic conductors in this area may be worth exploring (OGS 1991d). Although there are no known gold occurrences in the map area, there are several areas where alteration and sulphide mineralization suitable for hosting gold occur. The major northwest-striking fault contains intense pervasive iron carbonate alteration and veining, disseminated pyrite, chalcopyrite and green mica. Preliminary results from selected grab samples from this zone returned 0.009 ounces Au per ton and up to 485 ppm As.

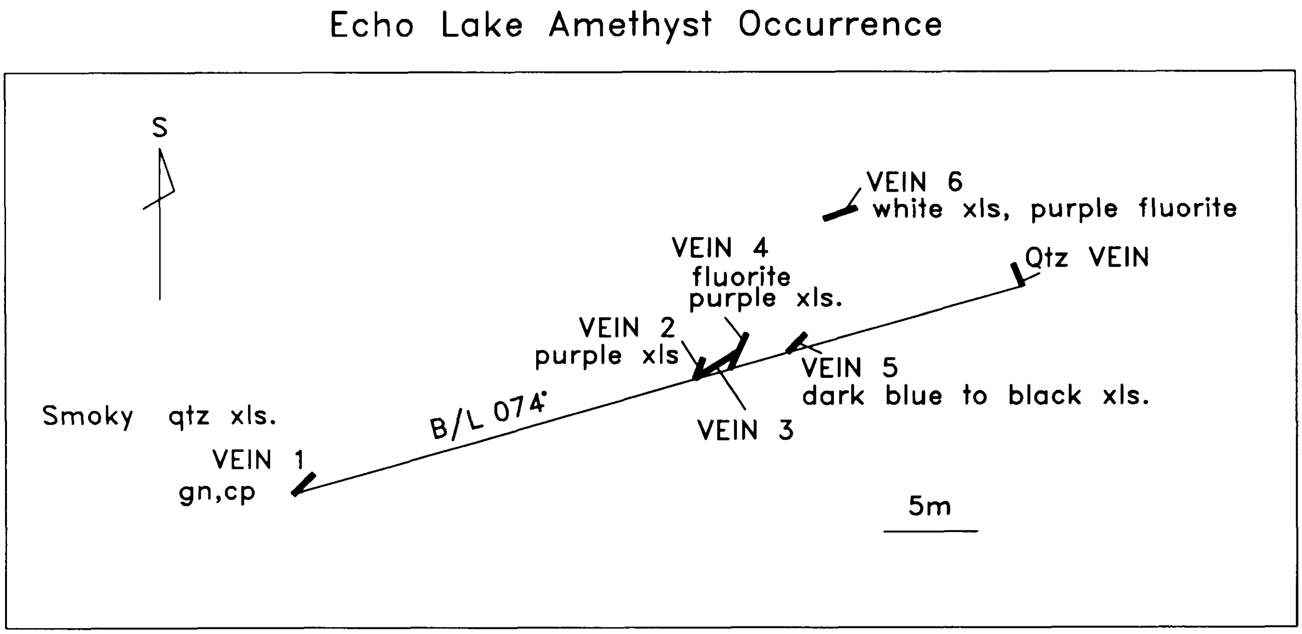

Figure 41.3. Geology of Echo Lake amethyst occurrence.

Extensive iron carbonate alteration was observed in the intermediate and mafic metavolcanic rocks in the northwest part of Adrian Township. Locally, quartz veining accompanies the alteration.

Approximately 1500 m west of the Adrian Lake road in the northern part of Adrian Township, intense iron carbonate alteration has affected a 200 m² area. This area is coincident with a pronounced airborne magnetic high and may be worthy of further exploration (OGS 1991d).

Tanton (1931) reported that an amethyst vein was reported to be located in Lot 12, Concession I in Marks Township near Echo Lake. This occurrence was not located, but traverses by the field crews discovered 2 amethyst occurrences east of Echo Lake. The first occurrence is located in Lot 10, Concession II in Marks Township approximately 600 m north of a gravel pit at the end of the Concession II road. Here, a single northeast-striking vein of purple amethyst is hosted in pink- to red-weathering granodiorite to granite. The vein is only a few centimetres wide and is exposed for slightly over 1 m. Crystals are small (5 mm to 1 cm in size), and there did not appear to be extensive alteration associated with the vein.

The second occurrence is located 600 m east of Echo Lake in Lot 11, Concession II. Here, 6 veins hosted in pink-weathering granodiorite were found over an area of 30 by 5 m. Four veins are northeast striking, and the other 2 strike easterly. The most easterly vein (Figure 41.3, No.1) contains well-developed smoky quartz crystals; minor galena, chalcopyrite and less commonly green fluorite were observed. The vein is vuggy, and there is extensive silicification of the footwall. The No. 2, No. 4 and No. 5 veins (*see* Figure 41.3) contain large (up to 4 cm in size) clear, purple and dark purple amethyst crystals. The largest and darkest purple crystals were obtained from the No. 5 vein. Columnar fluorite is well developed on the No. 4 vein. On each of these 3 veins, the best crystals are developed on the northeast hanging wall. The No. 3 vein (*see* Figure 41.3) contains well-formed white to purple crystals up to 2 cm in size. The No. 6 vein (*see* Figure 41.3) contains well-formed clear and frosted crystals up to 1 cm in size resting on botryoidal clear and purple fluorite.

These 2 occurrences appear to be similar to other amethyst occurrences in the Thunder Bay area, and the commercial viability of this area remains untested.

REFERENCES

Carter, M.W. 1985. Precambrian geology of Horne Township, Thunder Bay District; Ontario Geological Survey, Preliminary Map P.2856, scale 1:15 840.

——— 1986. Precambrian geology of Forbes and Conmee townships area, Thunder Bay District; Ontario Geological Survey, Preliminary Map P.2990, scale 1:15 840.

Ontario Department of Mines 1964. Atikokan–Lakehead sheet, Kenora, Rainy River and Thunder Bay districts; Ontario Department of Mines, Map 2065, scale 1:253 440.

Ontario Geological Survey 1991a. Airborne electromagnetic and total intensity magnetic survey, Shebandowan area; Ontario Geological Survey, Map 81 578, scale 1:20 000.

——— 1991b. Airborne electromagnetic and total intensity magnetic survey, Shebandowan area; Ontario Geological Survey, Map 81 579, scale 1:20 000.

——— 1991c. Airborne electromagnetic and total intensity magnetic survey, Shebandowan area; Ontario Geological Survey, Map 81 590, scale 1:20 000.

——— 1991d. Airborne electromagnetic and total intensity magnetic survey, Shebandowan area; Ontario Geological Survey, Map 81 591, scale 1:20 000.

Tanton, T.L. 1931. Fort William and Port Arthur and Thunder Cape map-areas, Thunder Bay District, Ontario; Geological Survey of Canada, Memoir 167, 222p.

Williams, H.R., Stott, G.M., Heather, K.B., Muir, T.L. and Sage, R.P. 1992. Wawa Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.485–539.

42. Geology and Mineral Potential of Oliver Township, District of Thunder Bay

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INTRODUCTION

The present work is part of a two-year project to carry out geological mapping of Oliver and Ware townships, District of Thunder Bay. The purpose of the mapping is to characterize the geology of the area and assess the mineral potential.

Oliver Township, which was mapped during the present field season, is located 36 km west of the city of Thunder Bay (Figure 42.1). It is bounded by latitudes 48°31'00" and 48°24'00" and longitudes 89°37'00" and 89°28'00", and covers an area of approximately 175 km². Access to, and within, the map area is excellent. Highways 102 and 11–17 are located close to the township's northern and southern boundaries, respectively, and a network of well-maintained gravel and paved roads provide access to the interior.

PREVIOUS MAPPING AND EXPLORATION

The following information has been summarized from previously published reports (Tanton 1924; Moorhouse 1960) and from the assessment files, Resident Geologist's office, Thunder Bay.

Early work in the area had focussed mainly on assessment of the potential for iron and silver deposits. The eastern limit of the Matawin Iron Range extends to the western edge of Oliver Township, and a few claims had been staked on pyrite showings by the early 1920s (Tanton, 1924). Several silver mines were being worked to the south and southwest of the area as early as the late 1800s, and the Proterozoic rocks in the southern part of Oliver Township were known to host silver (Tanton 1924). Numerous trenches, test pits and shafts tested a locally brecciated, quartz-veined zone, trending northeasterly from the southern township boundary to slightly east of the town of Murillo. Amethyst occurrences had also been noted along this zone, and copper values had been reported at some of the workings. No gold showings were known of at this time (Tanton 1924).

The area had been previously mapped by Coleman (1902) and Tanton (1924, 1938). Little exploration or geological mapping has been carried out within the township. Regional mapping was carried out by Moorhouse (1960) and Pye and Fenwick (1963, 1965). Carter (1985, 1990) mapped Conmee and Forbes townships, adjoining Oliver Township to the west.

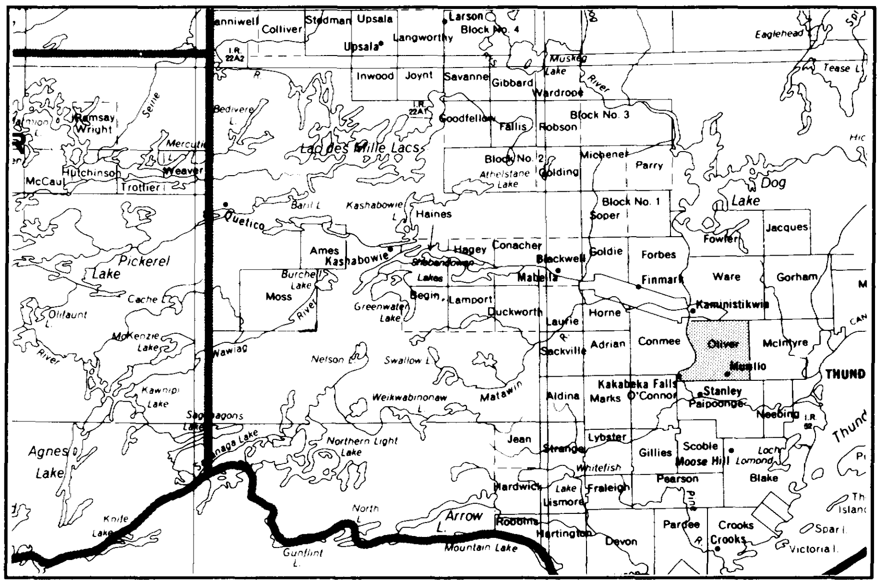

Figure 42.1. Location of the study area, scale 1:1 584 000.

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Northern Ontario Development Agreement
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Minerals • Minéraux

This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

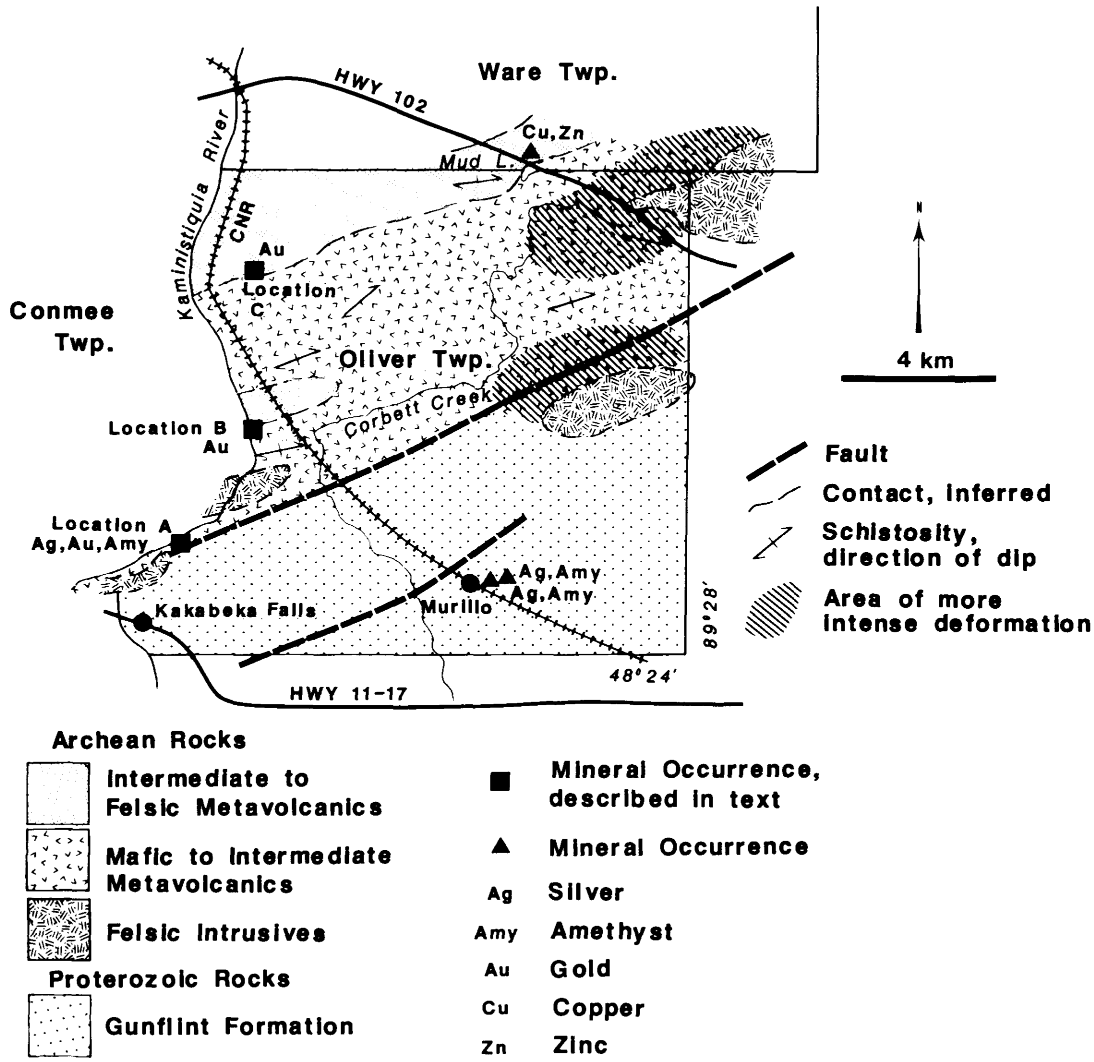

Figure 42.2. General geology and location of mineral occurrences in Oliver Township.

Several theses dealing with various aspects of the geology of the area are on file at the Resident Geologist's office, Thunder Bay.

Recent exploration in the area has centred on 2 claim groups: the Moore–Grayson occurrence (location A, Figure 42.2); and the Calvert–Wing option (location B, Figure 42.2). As the result of stripping and trenching in the early 1970s, Moore and Grayson reported values of 0.24 ounces Au per ton. Trenching and sampling in 1985, and 90.22 m of diamond drilling in 1989 by Moore failed to duplicate these results. The claims were allowed to lapse, but were recently re-staked.

The Calvert–Wing claims were staked shortly after published reports by Carter (1985) indicated values of up to 0.24 ounces Au per ton in a mineralized shear zone on the west bank of the Kaministiquia River, in Conmee Township. Line cutting, soil geochemistry and geological mapping were carried out on the claim group by Inco Gold Company in 1987. Follow- up geophysical surveys (magnetometer, VLF, IP) and 738.84 m of diamond drilling were carried out by Inco Gold Company in 1988. No significant results were reported on the portions of the claims which extended into Oliver Township. Drilling results in Conmee Township were not considered encouraging, and the option was dropped. More recent diamond drilling (151.18 m) in 1990 by Ovalbay Geological Services Inc. were not encouraging and the claims were again returned to their owners.

A grab sample of sericitized, sheared metavolcanic rock collected in 1975 by staff of the Resident Geologist's office in Thunder Bay from an outcrop located along Highway 102 near Mud Lake, assayed 0.24% Cu, 0.87% Zn, 0.12 ounces Ag per ton and 0.005 ounces Au per ton (Fenwick and Scott, 1976). Reconnaissance mapping in the early 1980s by Amax of Canada Ltd. was carried out in this area and in the rest of the felsic metavolcanic belt which continues into the northwestern portion of Oliver Township (J. Scott, Resident Geologist's office, Thunder Bay, personal communication, 1992). No results were reported from this mapping.

GENERAL GEOLOGY

Oliver Township straddles the boundary between the Superior Province and the Southern Province. The northern half of the township lies within the Wawa Subprovince of the Superior Province, and the southern half of the township lies within the Southern Province.

Archean rocks of the Shebandowan greenstone belt (Williams et al. 1991) underlie the northern and central portions of the study area (*see* Figure 42.2). These consist of mafic to felsic metavolcanic rocks with minor interbedded metasedimentary rocks, and various early to late felsic and mafic intrusive rocks.

The remainder of the township is underlain by rocks of the Proterozoic Gunflint Formation. Although scarce in outcrop, where exposed, the Gunflint Formation consists primarily of interbedded layers of chert, carbonate, shale, tuffaceous shale and taconite. A basal conglomerate unit, on the Proterozoic/Archean unconformity, is erratically distributed and is only exposed in a few outcrops. The unconformity crosses the central portion of the township at approximately 060°.

Metamorphism in the area is greenschist-facies grade, except near significant intrusions where contact metamorphism has slightly elevated the grade. The degree of deformation is variable throughout the area. Two areas of more intense deformation have been outlined (*see* Figure 42.2).

Depth of overburden in the area is variable. Portions of the township are covered by up to 50 m of till, particularly the southern part of the township. As a result, surface mapping of the geology in the southern third of the township was supplemented by information gathered from water well logs, on file with the Ministry of Environment in Thunder Bay.

Metavolcanic and Metasedimentary Rocks

Mafic to intermediate metavolcanic rocks represent the majority of the volcanic rocks in the township. They form a broad, northeasterly trending belt, which extends from the Archean/Proterozoic contact to near the northern township boundary. Massive, porphyritic and pillowed flows are most abundant, with minor vesicular, amygdaloidal and hyaloclastic components. Small, discontinuous tuffaceous layers occur locally. Phenocrysts within the porphyritic units are predominantly hornblende ± feldspar.

Toward the eastern boundary of the township, several outcrops of a coarse-grained, gabbroic unit occur within the mafic to intermediate metavolcanic rocks. These could represent either gabbro intrusions, or coarse-grained flow centres.

Locally, minor clastic metasediments are interbedded with the mafic metavolcanics. These consist predominantly of magnetite-chert iron formation, wacke, siltstone and argillite.

Intermediate to felsic metavolcanic rocks are a relatively minor component in the stratigraphy, and they primarily occur in the northwest corner of the township. Fragmental deposits of heterolithic and monolithic tuff, lapilli tuff and tuff breccia predominate. Less commonly, massive and feldspar ± quartz-phyric flows occur in the more 1felsic units.

Felsic Intrusive Rocks

Three felsic stocks intrude the area. The northernmost stock is part of a larger syenitic to monzonitic body which extends into the township east of the study area. It is medium grained, equigranular, and moderately to strongly magnetic.

Two smaller medium-grained, equigranular, tonalitic stocks occur closer to the central portion of the township.

Mafic Intrusive Rocks

Mafic intrusive rocks are a minor component within the supracrustal rocks in the study area. Small gabbro intrusions are found in the eastern part of the township. Lamprophyre dikes are found throughout the Archean rocks and are narrow, recessively weathering and contain up to 25% medium- to coarse-grained biotite crystals.

Proterozoic Rocks

Excellent descriptions of the Gunflint Formation in the area are contained in reports by Goodwin (1956) and Moorhouse (1960). Within the study area, the Proterozoic rocks consist predominantly of flat-lying to subhorizontal, interbedded layers of chert, carbonate, shale, tuffaceous shale and taconite. The basal unit of the Gunflint Formation, a heterolithic pebble conglomerate, is exposed primarily in the central portion of the township, on the Archean/Proterozoic contact, and at Kakabeka Falls. This unit generally consists of irregular patches of the conglomerate unconformably overlying moderately to weakly weathered Archean felsic intrusive rocks. Clasts within this unit consist of well-rounded pebbles, up to 4 cm in size, predominantly of milky quartz, with less abundant granitic, jaspillitic, mafic and chert pebbles within a sandy matrix.

STRUCTURAL GEOLOGY

The degree of deformation in the study area varies from weak to moderately strong. A weakly developed foliation is normally present, generally striking northeast with steep northerly dips. Near large intrusions, this fabric becomes more strongly developed and begins to reflect

Table 42.1. Analytical results of samples taken during the 1992 field season.

Sample No.	Location	Au (ppb)	Ag (ppm)	Cu (ppm)	Zn (ppm)	Rock Type
RIF–92–551	700 m southwest of the west end of Saari Rd. (Location C, Figure 2)	153	1.6	16		Becciated chert-magnetite ironstone interlayered with mafic to intermediate lapilli tuff
RIF–92–556	Same as above	112	0.4	15		Same as above
GHB–92–072	1.5 km northeast of the north end of 3rd Sideroad	<5	<0.2	100		Coarse-grained mafic rock (either gabbro intrusion or coarse-grained volcanic flow)
GHB–92–076	Same as above	<5	<0.2	135		Same as above
GHB–92–084	Same as above	6	<0.2	120		Fine-grained mafic volcanic
RIF–92–162	North side of Pole Line Road, 300 m east of Mining Road			872		Brecciated Proterozoic metasediments with quartz ± carbonate ± amethyst veining
GHB–92–190	South side of Highway 102, 100 m east of Mud Lake Road			73	122	Schistose, pillowed mafic volcanic
GHB–92–200	Ware Township, on the north side of Highway 102, 1.2 km west of Mud Lake Road			15	193	Schistose, sericitized, feldspar and quartz-phyric felsic volcanic
RIF–92–138	East shore of Kaministiquia River, 2.5 km west of the west end of 7th Concession			46	136	Interlayered mafic to intemediate tuff and tuff breccia, with 3% py and 5% magnetite clots
RIF–92–132	East shore of Kaministiquia River, 1.3 km northwest of the west end of John Street Road			109	38	Moderately sheared mafic to intermediate volcanic with up to 8% py
RIF–92–136	East shore of Kaministiquia River, 700 m northwest of the west end of John Street Road			41	108	Rusty-weathering, moderately schistose mafic volcanic with 5% py

the trend of the contact of the intrusive body. Two areas of more intense deformation have been outlined close to 2 of the felsic intrusions in the township (*see* Figure 42.2). In these areas, the foliation is crosscut by a weak fracture cleavage and, less commonly, by minor S- and Z-folds, whose axial planes are subparallel to the local fabric. Carbonate ± epidote alteration is often present.

Several minor shear zones were mapped during the present field season. These structures were narrow, moderately well developed, and could not be traced over any appreciable distance. They appear to be related to the later intrusions. They generally trend northeasterly and, less commonly, northwesterly.

Quartz veining, fracturing and jointing are common throughout all units in the township. These structural features can be generally categorized into 3 predominant trends: northeasterly, northwesterly, and easterly. The dip of these features varies from subvertical to subhorizontal.

ECONOMIC GEOLOGY

Both the Proterozoic and Archean rocks of Oliver Township have the potential to host several types of mineral deposits. Silver, gold, copper and amethyst are known to occur in brecciated and veined (quartz ± carbonate ± amethyst) zones within the Proterozoic rocks. Low gold and copper values have been reported from sheared zones within mafic to intermediate metavolcanic rocks. Copper and zinc mineralization was noted in sericitized shear zones within the felsic metavolcanics near Mud Lake, Ware Township, immediately north of Oliver Township. This belt of felsic metavolcanics extends into the north and northwest parts of Oliver Township. A small felsic stock in Conmee Township to the west was reported to host molybdenite (Carter 1985). This stock is closely related to the small felsic intrusions which occur in the central portion of Oliver Township.

Results from sampling during the current field season are summarized in Table 42.1.

GUIDELINES FOR PROSPECTORS

The intermediate to felsic volcanic rocks in the northwestern part of the township have the potential to host copper and zinc mineralization and merit further investigation. Several pyritized, narrow shear zones were noted in outcrops of mafic to intermediate metavolcanic rocks on or near the eastern shore of the Kaministiquia River, in the west-central part of the township. These areas deserve more work, particularly when interbedded ironstone is also present. The amethyst potential of many of the old silver and copper occurrences in the Proterozoic rocks in the southern part of the township has never been fully assessed. In light of current marketing and promotional projects, these showings deserve more attention.

SUMMARY

The mapping carried out in Oliver Township this field season had 2 immediate results.

1. Several areas of old workings, previously unrecorded, were located and mapped.
2. The Moore–Grayson occurrence (location A, Figure 42.2), which was open for staking at the beginning of the field season, was re-staked toward the end of the summer due to the interest in the amethyst potential of the claims. Although mentioned in early reports on the area (Tanton 1924), the presence of amethyst at this and at the Pole Line Road occurrence (*see* Economic Geology) had been neglected until the present mapping reconfirmed these showings.

REFERENCES

Carter, M.W. 1985. Forbes and Conmee townships, District of Thunder Bay; *in* Summary of Field Work and Other Activities 1985, Ontario Geological Survey, Miscellaneous Paper 126, p.60–65.

——— 1990. Geology of Forbes and Conmee townships; Ontario Geological Survey, Open File Report 5726, 188p.

Coleman, A.P. 1902. Iron ranges of northwestern Ontario; Ontario Bureau of Mines Report, v.11, p.128–151.

Fenwick, K.G., and Scott, J.F. 1976. Report of the North Central Regional Geologist; *in* Annual Report of the Resident and Regional Geologists, 1975, Ontario Division of Mines, Miscellaneous Paper 64, p.39–54.

Goodwin, A.M. 1956. Facies relations in the Gunflint iron formation; Economic Geology, v.51, p.565–595.

Moorhouse, W.W. 1960. Gunflint iron range in the vicinity of Port Arthur, District of Thunder Bay; Ontario Department of Mines, Annual Report, v.69, pt.7, p.1–40.

Pye, E.G. and Fenwick, K.G. 1963. Lakehead–Shebandowan sheet, District of Thunder Bay; Ontario Department of Mines, Preliminary Geological Map P.177, scale 1 inch to 2 miles.

——— 1965. Atikokan–Lakehead sheet, Kenora, Rainy River, and Thunder Bay districts, Ontario; Ontario Division of Mines, Map 2064, scale 1:63 360.

Tanton, T.L. 1924. Eastern part of Matawin Iron Range, Thunder Bay District, Ontario; Geological Survey of Canada, Summary Report for 1924, pt.C, p.1c–27c.

——— 1938. Quetico sheet (east half), with marginal notes; Geological Survey of Canada, Map 432A.

Williams, H.R., Stott, G.M., Heather, K.B., Muir, T.L. and Sage, R.P. 1991. Wawa Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.485–539.

43. The Manitouwadge Mineral Resource Geologist Project

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INTRODUCTION

The Manitouwadge Mineral Resource Geologist Project was initiated in January 1991, to stimulate and facilitate mineral exploration within a 50 km radius of the township of Manitouwadge (Figure 43.1). Primary objectives of the project include: the compilation, research and investigation of new and previously known mineral occurrences in the Manitouwadge area; preparation of an Open File Report documenting these occurrences; provision of client services via property examinations, field trips, sample analyses and information dispersal; and provision of public education via prospecting classes, technical presentations and poster displays. The project operates in conjunction with the Schreiber–Hemlo Resident Geologist Program and is scheduled to terminate on March 31, 1993. It is hoped that this project will enhance the geological data base for the Manitouwadge area and possibly assist in the discovery of new mineral resources to replace those currently being depleted.

This report provides a brief summary of the field work and other activities completed as of September 21, 1992. Details regarding the work performed in 1992 will be presented in the Report of Activities 1992, Resident Geologists, which is a Miscellaneous Paper scheduled to be released in March of 1993 by the Ministry of Northern Development and Mines. Details regarding the work performed in 1991 are given by Schnieders et al. (1992). An Open File Report documenting the metallic and/or economic mineral occurrences in the Manitouwadge area is scheduled for release in 1993. Approximately 110 known mineral occurrences are reported to occur within the Manitouwadge area. Information regarding many of these occurrences will be presented in this Open File Report.

MINING ACTIVITY AND MINERAL EXPLORATION

One base metal and 3 gold mines are currently producing in the project area. The Geco Division Mine (Noranda Inc.) in Manitouwadge has mined over 51 000 000 tons of copper and zinc ore since opening in 1957. At the current production rate of approximately 3500 tons milled per day, ore reserves will be exhausted in 4 to 5 years (H. Lockwood, Geco Division Mine, personal communication, 1992). The Golden Giant Mine (Hemlo Gold Mines Inc.), the David Bell Mine (Teck-Corona Operating Corporation) and the Williams Mine (Williams Operating Corporation), all located in the Hemlo area, produced a total of over 1 250 000 ounces of gold in 1991 (Schnieders et al. 1992).

Although the project area is being actively explored for gold and base metals by numerous prospectors and several major exploration companies including Noranda Inc. (Geco Division), Noranda Exploration Company Ltd., Newmont Exploration Limited and Placer Dome Inc., the number of active mineral exploration projects undertaken in 1992 was down relative to 1991.

Several interesting and previously undocumented mineral occurrences were discovered in the Manitouwadge area by prospectors in 1991 and 1992. These include the Theresa Lake copper occurrence (Ontario Prospectors Assistance Program funded), the Lampson Road copper-zinc occurrence, the McGraw Lake copper occurrence, the Thomas Lake Road sulphide occurrence and the Spruce Bay zinc occurrence (Table 43.1; *see* also Figure 43.1). Work on these properties is ongoing.

FIELD WORK

At the time of writing, 52 properties had been visited and examined in the last 2 field seasons (*see* Table 43.1 and Figure 43.1). These comprise 40 base metal or sulphide properties, 9 gold properties, 1 platinum group element (PGE) property, 1 molybdenum property and 1 graphite property. A total of 441 grab, chip and channel samples were collected and submitted for multielement analysis to determine metal content and chemical alteration, where applicable. Property-scale geological mapping was performed on several of the properties. During the past 2 years, the Manitouwadge Mineral Resource Geologist Program served 293 clients (including mineral exploration company personnel, federal and provincial government geologists, prospectors and members of the general public) and dealt with 166 telephone inquiries regarding the Manitouwadge area.

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This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

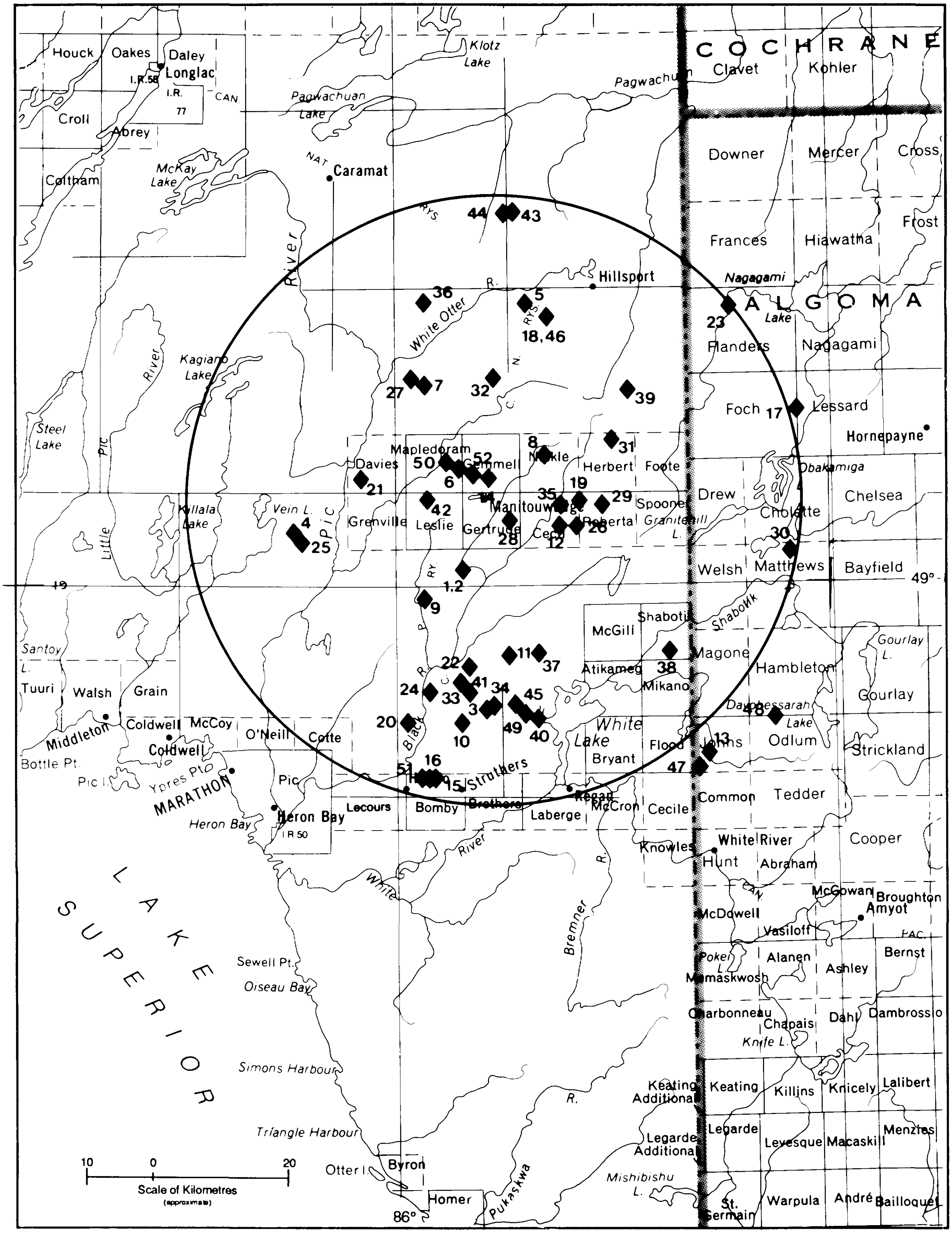

Figure 43.1. Manitouwadge Mineral Resource Geologist Project; solid diamonds indicate property visits in 1991 and 1992 (keyed to Table 43.1).

Table 43.1. Property Examinations, Manitouwadge Mineral Resource Geologist, 1991 and 1992.

1.	Agonzon Lake molybdenum occurrence	27.	Middle Falls Road sulphide occurrence
2.	Agonzon Lake property	28.	Morley Lake copper occurrence
3.	Armand Lake property	29.	Moshkinabi sulphide occurrence
4.	Baarts–Donaldson copper occurrence	30.	Olivier sulphide occurrence
5.	Beavercross Lake copper occurrence	31.	One Otter Lake East property
6.	Big Nama Creek Mine[2,4]	32.	Otter Lake sulphide occurrence
7.	Bunny Lake sulphide occurrence	33.	Pinegrove Lake property
8.	Camp 54 Road sulphide occurrence	34.	Qued Resources property
9.	Dorothy Lake sulphide occurrence	35.	Rawluk Lake property
10.	East Barbara Lake sillimanite occurrence	36.	Rockbound Lake copper occurrence
11.	Fairservice zinc occurrence	37.	Roger Lake area
12.	Faries Lake property	38.	Shabotik copper-nickel-PGE occurrence[4]
13.	Forty-sixer property	39.	Snake Pit sulphide occurrence
14.	Geco Division Mine[1,4]	40.	Spruce Bay zinc occurrence[3,5]
15.	Golden Giant Mine[1]	41.	Summers Lake property
16.	Hemlo Highway Section	42.	Swill Lake property[5]
17.	Hitch Lake sulphide occurrence	43.	Taradale copper-silver occurrence
18.	Husak Road sulphide occurrence	44.	Taradale Lake graphite occurrence
19.	Ice Cream Lake Road sulphide occurrence	45.	Theresa Lake copper occurrence[3]
20.	Kusins lead-zinc occurrence	46.	Thomas Lake Road sulphide occurrence[3]
21.	Labrador copper occurrence	47.	Trapline property
22.	Lampson Road copper-zinc occurrence[3]	48.	Two Finger Lake property
23.	Leigh Siding area	49.	Wabikoba Creek property[5]
24.	Lenora–Argentex property	50.	Willecho Mine[2,4,5]
25.	Lloyd Davis sulphide occurrence	51.	Williams Mine[1]
26.	McGraw Lake copper occurrence[3]	52.	Willroy Mine[2,4,5]

[1] current producer
[2] past producer
[3] new occurrence
[4] visited during a field trip conducted in 1991
[5] visited during a field trip conducted in 1992

OTHER ACTIVITIES

A poster display, entitled "Mineral Occurrences, Prospects and Mines in the Manitouwadge Area", was presented at the Ontario Mines and Minerals Symposium held in Toronto during December 1991. A poster display and an oral presentation, entitled "Mineral Occurrences and Exploration Potential of the Manitouwadge Area", were presented at the Thunder Bay Mines and Minerals Symposium held in Thunder Bay during April 1992. An oral presentation, entitled "Prospecting Opportunities in the Manitouwadge Area", was presented at a prospector's information session held in Marathon during January 1992. A course on basic prospecting was presented in Manitouwadge during February 1992. This course was attended by 58 people and was very well received. Primary and secondary school classes, as well as members of the general public, were given guided tours through a Mining Sequence display set up by the Ministry of Northern Development and Mines in Thunder Bay during February and June, 1992. Exploration company personnel and/or government geologists were given tours of the Wabikoba Creek property, the Swill Lake property, and the Geco Division, Willroy, Big Nama Creek and Willecho mine properties. In addition to the above, exploration in the Manitouwadge area was promoted through numerous informal discussions with prospectors and exploration company personnel.

Assistance was provided to Geological Survey of Canada geologists I. Kettles and E. Zaleski, both of whom are working in the Manitouwadge area on multi-year NODA–funded projects initiated in 1991.

Several geological short-courses and seminars were attended including: an "Exploration Geochemistry Workshop" presented in Toronto by the Geological Survey of Canada during March of 1991; short-courses on "Industrial Minerals" and "Five-Element Vein Systems" presented in Thunder Bay by Dr. S. Kissin of Lakehead University during February and March of 1992, respectively; and a symposium devoted to "Contemporary Approaches to Exploration for Metallic Mineral Deposits" presented in Thunder Bay by the Canadian Institute of Mining and Metallurgy during March of 1992.

ACKNOWLEDGMENTS

Numerous prospectors and geologists provided valuable information and assistance during the past 2 years. Exploration personnel from Geco Division (Noranda Inc.) and Noranda Exploration Company Ltd. provided access to proprietary information regarding mineral occurrences in the Manitouwadge area. Field trips familiarizing the author to the geology of the Manitouwadge area were conducted by H. Williams, F. Breaks, E. Zaleski, V. Peterson, I. Wolfson, B. Schnieders and M. Smyk. Assistance in the field was provided by T. Oja and B. Nelson provided technical support and lapidary services. K. Fenwick, B. Schnieders and M. Smyk reviewed and edited this report. S. Warren provided typing and word processing support.

All analytical work was performed by the Timiskaming Testing Laboratory, Ministry of Northern Development and Mines, Cobalt.

REFERENCES

Schnieders, B.R., Smyk, M.C. and McKay, D.B. 1992. Schreiber–Hemlo Resident Geologist's District–1991; *in* Report of Activities, 1991, Resident Geologists, Ontario Geological Survey, Miscellaneous Paper 158, p.121–163.

44. Mining Lands Branch — Provincial Claim Map Inventory

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INTRODUCTION

An accurate and up-to-date-index of the province's mining claim status maps is available on dBase IV® . The prime objective of the project was to compile claim-map information into a database for use in the planning process for the initiation of a major computer-based project for digitizing all map-based mining-lands information.

INDEXING CONSIDERATIONS

The primary purpose of this project was to compile an accurate index of the most current claim maps available. These maps are relied upon to provide a comprehensive visual image of the status of mining lands in the province.

In each Mining Division, the Ministry of Natural Resources (MNR) Index Maps were used to compile a preliminary list of provincial township and area maps. MNR and Ministry of Northern Development and Mines (MNDM) map indices were cross-referenced to ensure complete coverage and accuracy. Discrepancies in spelling of geographical names were resolved using the Energy, Mines and Resources–Gazetteer of Canada, Ontario Edition. Data from the preliminary lists was entered into a personal computer database utilizing dBase IV® software, where it could be easily manipulated and updated.

PRIORITIZING CONSIDERATIONS

Since the digitization of the claim maps will be done in stages, it was deemed necessary to capture map information that could be used in project planning and prioritization.

Site visits were conducted at each of the 9 Mining Recorder Offices where all map sheets were assessed for the following particulars:

1. Exploration Activity: this was measured by gauging the areas covered by active unpatented mining claims.
2. Lands Closed to Staking: this was measured by gauging the areas covered by parks, wildlife preserves, etc.
3. OBM, Digital OBM and CROWNPARCELS Coverage: MNR has been actively pursuing a comprehensive provincial mapping program known as Ontario Basic Mapping (OBM). MNR has also initiated a database called CROWNPARCELS which contains Crown lands information and dispositions in digital format. Availability of the above map information varies across the province.
4. Mineral Deposit Inventory (MDI): This data, obtained from the Geoscience Data Centre, Ontario Geological Survey–Information Services Branch, was used to provide an insight into past exploration activity and significant findings in a map area.

The information was entered into data fields.

DATABASE STRUCTURE

In addition to the above 4 fields, the following 10 data fields were recorded as map identifiers:

1. Map Name;
2. Map Type (township or area);
3. Mining Division;
4. Survey Status (township subdivision status – Lots & Concessions);
5. Plan Number;
6. MNR Index Map Number;
7. OBM Index Map Number;
8. MNR Base Map Area Number;
9. Comments;
10. Calculated Value (Numeric value calculated to rate map for planning).

DATA MANIPULATION

Using any of the fields in the database, a calculated value can be determined based on any formula depending on the results desired.

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As an example, if one wanted to gauge the level of exploration, with the area of alienated land and mineral potential in the Porcupine Division, one could apply a formula such as:

Exploration activity – Lands closed to staking + MDI = Calculated value.

This would yield a list of maps ranging from high activity through low alienated lands with high mineral occurrences to maps mostly covered by alienated lands.

The data is manipulated by exporting the dBase IV® file to a spread-sheet software (for formula calculations) and then importing back to dBase IV® for indexing according to the calculated value.

SUMMARY

The final Provincial Database Index File can be easily searched, indexed or updated using any standard IBM®–compatible computer. It is intended to function as a guide in planning of the map digitization process, and to serve as a common index for the Ministry of Northern Development and Mines and its clients.

BENEFITS

Compilation of this digital database will provide the Ministry of Northern Development and Mines and its clients with a common accurate index of geographic names and plan numbers of all township and area maps for the province.

The dBase IV® database can be manipulated with spread sheet software or desk top GIS or other tools to produce:

1. Provincial claim map index;
2. Mining Division claim map index;
3. Custom lists ranking maps to help clients gauge exploration activity, mineral potential, land availability and/or availability of digital map data in an area;
4. Custom lists ranking maps to aid in decision making for the Ministry of Northern Development and Mines' initiation of a major computer-based project for digitizing all map-based mining-lands information.

45. Mining Lands Branch – CLAIMS Client Service – Client Access to the CLAIMS Database

P. Hum

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INTRODUCTION

The Mining Lands Branch has successfully developed the Computerized Mining Lands Information Management System (CLAIMS) which is currently in operation in the Porcupine Mining Recorder's Office located in Timmins. Province-wide implementation of CLAIMS into the remaining 8 Mining Recorder Offices is in progress.

CLAIMS is a dedicated software package used to automate the administrative and records management functions of the mining recorder's office. CLAIMS is capable of processing records quickly, efficiently and accurately. Claim abstracts are computer generated and paper abstracts will no longer be kept on file. Record searches that would have taken days using the traditional paper abstracts can now be done in minutes using CLAIMS.

The Ministry of Northern Development and Mines is embarking on a project to develop a CLAIMS Client Service interface. The main objective of the project is to improve client service by providing clients fast and easy access to the computer information files and enhanced search capabilities available in CLAIMS.

CLAIMS CLIENT SERVICE

The current CLAIMS system is intended for internal office use only. Security enhancement considerations and complicated training are required to use it. The CLAIMS Client Service project will offer a secure, simplified client access interface through terminals located in the 9 Mining Recorder Offices, to allow easy searching of all claims on record in the local Mining Division only.

The CLAIMS Client Service will be a "self-service" environment on a computer terminal, located in the Mining Recorder Office, where an explorationist can browse through and select abstracts in much the same way as is done using the paper abstracts. He/she will have the option to view the abstract on the screen and/or print the abstract. He will have the added convenience of being able to conduct custom searches within minutes which would have taken days or been virtually impossible using the paper abstracts.

One example of the custom searches available on CLAIMS is the "Township Claim Report". The search is initiated by selecting a township. CLAIMS will then generate a report listing all the current claims in that township showing the claim status, due-date and recorded holder. The amount of time required to search a township containing over 200 claims would be minutes.

The amount of time required to do the same search in the "paper" office would have taken at least a full day. The client would have had to request a copy of the township map first. He/she would then copy all the claim numbers off the map and arrange them in numerical order. The staff would retrieve the record books and the client would then conduct his search.

BENEFITS

The CLAIMS system has enhanced the efficiency and accuracy of mining land tenure records with modern technology.

The CLAIMS Client Service will provide the client with improved and enhanced service through direct access to the local Mining Division CLAIMS information in the local Mining Recorder Office.

Clients will save significant amounts of time and effort in conducting searches by using the computer query and report.

Clients will have access to a greater range of up to date information on claim status and ownership.

The Ministry will benefit from this "self-service" in reduced staff time and disruption currently needed to service on-demand requests.

Clients will receive faster service for all inquires.

Clients will have increased confidence in the accuracy and timeliness of the information.

SUMMARY

There is a definite need and benefit to the exploration industry for the client to access the advantages offered by modern technology in CLAIMS. The CLAIMS Client Service will fulfil that need.

Completion of the CLAIMS Client Service project will be in the spring of 1993. This will include all software development, hardware purchase and installation for client use at each of the 9 Mining Recorder Offices.

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46. Real Time Image Processing of Airborne Survey Data

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INTRODUCTION

A four-year project to update airborne survey databases in Ontario was initiated during the summer of 1992. Modern technology permits the imaging of large-dimension, numerical grids on standard personal computer hardware. Several commercial software systems are available to display colour images and to manipulate the basic colour patterns. These produce effects relating to lithological boundaries and structural features pertaining to the area under examination. The use of these systems for real time imaging (RTI) in mineral exploration has increased throughout the last decade and this increased use has been influenced by decreasing hardware costs and published availability of digital data.

Digital airborne survey data has been collected by the Ontario Geological Survey since 1975. Approximently 450 000 line kilometres of magnetic and electromagnetic data from 30 surveys are stored in archive form as unstandardized data sets. This project will reorganize the data sets into standardized, high-quality grids, formatted for commercially available RTI systems. Such a standardized archive of survey data will require minimum preparation prior to use on a personal computer equipped with an RTI system and thus will be a valuable aid to geological mapping and exploration projects in the surveyed areas.

PROJECT DESCRIPTION

A cost-effective method for viewing and analyzing patterns and trends contained in airborne survey grids is to utilize the toolbox found in RTI systems. These toolboxes normally consist of algorithms which transform the colour patterns in real time. Examples of the transformation routines are variable angle, shadow mapping, variable colour bar selection and isolation, and interactive colour bar filtering. Used in conjunction with the nature of the patterns contained in the basic colour image, the interpreter can enhance features significant to regional geology. In the process, here-to-for undetected patterns may emerge.

An example of this is apparent when looking for kimberlite intrusions using images derived from aeromagnetic data. Because kimberlite clusters are most likely to be synchronous, their associated magnetic fields will be similar in intensity and polarization. One can quite successfully identify kimberlite clusters using the Image analysis approach.

The quality of the image under analysis is central to the sucessful application of real time imaging. The footprint and resolution of the surveying system, and the levelling and positioning of the data in relation to the gridding process determines the level to which the data can be processed further. Gridded data which may produce contour maps containing minimum artifacts, such as herring-bone patterns, may be entirely unsuited to image analysis. In image construction, contoured isoanomalies which are line vectors are replaced by a raster of pixels. These are normally more representative of the surface of the data set and hence images are usually more sensitive to artifacts contained in the data. This simply means that airborne survey data destined for image analysis must undergo a higher quality compilation process in comparision to data to be represented only by contouring.

As each grid set is standardized, a system of gridding and imaging will be used to insure quality control. As well, gridding will be carried out using a 25 m interval instead of the normal 50 m spacing. The end result will allow larger scales of images to be represented before degradation of image quality becomes apparent.

Because of technological change in basic positioning and data compilation over the seventeen-year period of data acquisition, the data sets are more likely to contain positioning errors relative to age. Recent survey map bases have been semicontroled to Universal Transverse Mercator 6 degree topographic maps. This allows for relative positioning accuracies within a 10 m envelope. Most RTI systems are equiped to display UTM x-y coordinates so that features on the image may be located on topographic maps. Older surveys must undergo recompilation to the modern standard in order that positioning accuracies are maintained throughout the data base.

In order to estimate the magnitude of the previously described tasks, a seven-stage process was conceived to bring all data sets to an exceptable standard. Surveys having a range of specifications were catagorized according to the levels of processing to which the data set would

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have to be sujected to in order to reach the end result, an image quality, standardized data set. Quality control and project management will be the responsibility of the Ontario Geological Survey–Geoscience Branch and the recompilation will be contracted to the private sector.

BENEFITS

This project will result in a greatly improved ability to interpret geological areas where airborne survey data has been acquired. Renewed exploration effort will most certainly result from this new initiative. As well, a new level of effectiveness in field geology will be possible by integrating our geophysical data base and expertise directly with mapping programs. The ultimate benefit of this project would be realized if new mineralized areas were discovered, such as the case already documented over the past several years in the Kirkland Lake area and, in the past year, in the Shining Tree area.

Bringing the grids to image quality in a unified coordinate system will permit further processing and compilation of the survey areas and inclusion of the Provincial data sets into the Federal-Provincial areomagnetic master grid.

SUMMARY

The Ontario airborne survey data base will be developed further to provide high-quality images of approximately 30 data sets which have been acquired since 1975. Images will be transportable to floppy disks and formatted for current RTI technology.

These data will provide a useful aid to geological mapping and mineral exploration in the Province. Formated images will provide a convenient way of disseminating the data to personal computer users.

47. International Marketing of Ontario Dimension Stone

D. Spethmann

Mineral Sector Analysis Branch, Sudbury

INTRODUCTION

The "International Marketing of Ontario Dimension Stone" was initiated in April 1992 to promote Ontario dimension stone internationally and to attract investments to develop dimension stone resources in northern Ontario. The objectives of this two-year project are: 1) to design and fabricate portable dimension stone displays; 2) to participate at international and domestic trade shows and exhibitions to promote Ontario dimension stone, with a focus on northern Ontario stone; 3) to assemble a complete collection of Ontario dimension stone samples and prepare polished tiles for display purposes at trade shows, exhibitions, conferences, Sudbury head office, the Toronto Mines and Minerals Information Centre, Ontario's international trade offices, and the Royal Ontario Museum; and 4) to update the Ontario Dimension Stone directory and catalogue.

CURRENT ACTIVITIES

Marketing efforts began with the creation of 2 displays, produced in co-operation with the Creative Services Section of the Communications Services Branch. One, "Ontario Dimension Stone — the possibilities are endless" was exhibited at the Visions of Stone Show in Southampton, Ontario, July 3 to 5, 1992. Photographs and samples illustrating the variety of Ontario stones available will increase consumer awareness of the different commercial and residential applications of dimension stone, as well as the variety of Ontario stones available.

A second display "Ontario Dimension Stone — explore the opportunities", has been created for the Marble Institute of America, 48th Annual meeting, (Seattle, November 2 to 5). It will promote Ontario's dimension stone potential and its products. A geology map of Ontario with producers and prospect locations, photographs of operating quarries and potential sites, and Ministry of Northern Development and Mines publications are components of this display. Sample tiles of production stones and prospective developments will also be on view.

FIELD ACTIVITIES

By September 1992, the author had visited a total of 28 sites (Table 47.1) representing current producers, advanced prospects, and promising prospects. Samples were either collected or requested for the Ontario stone collection and displays. Throughout the year, other site visits and sample collection will complete the Provincial inventory.

The Ontario Dimension Stone Producers and Products Directory was updated during the summer of 1992 in conjunction with the Mineral Development Section of the Mineral Development and Rehabilitation Branch and printed in September 1992. It is available from Linda Davis, Library, 159 Cedar Street, 6th floor, Sudbury, (705) 670–7130.

FUTURE WORK

Future work will include the updating of the Ontario Dimensional Stone Catalogue, continuation of the sample collection and the compilation of a stone property data base.

Participation at several international and domestic tradeshows and exhibitions is being planned for 1993.

ACKNOWLEDGMENTS

The author is indebted to the producers, and to the staff of the Ministry of Northern Development and Mines regional offices who have provided invaluable assistance on property visits and sample collection. Special thanks to colleagues in the Mineral Development Section and to the NODA co-ordinator's staff for all of their support. The creative efforts of L. Turnbull and communcication planning efforts of J. Aitken are gratefully acknowledged. M. Gerow's insight and knowledge on the dimension stone industry are gratefully appreciated.

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Table 47.1. Dimension stone property examinations.

Site		Status
1.	Jarvis Resources advanced	prospect
2.	River Valley advanced	prospect
3.	St. Charles	prospect
4.	Lavigne gneiss	prospect
5.	Manitou Stone advanced	prospect
6.	Positano Granite	producer
7.	Royal Oak Resources	prospect
8.	McLaren's Bay Mica Stone	producer
9.	Thorne Quarry	producer
10.	Senator Stone advanced	prospect
11.	Ann Black site	prospect
12.	Gould Lake	prospect
13.	Kapikog Lake	prospect
14.	Lehman Quarry	producer
15.	McFadyen	producer
16.	Tasso Lake	producer
17.	Ted Boyes and Sons Quarry	producer
18.	Jeffery Quarry	producer
19.	McBride Quarry past	producer
20.	Ardbeg advanced	prospect
21.	Milford Bay	prospect
22.	Rama Red	producer
23.	Marathon Red	prospect
24.	Marathon Black past	producer
25.	Dotted Lake	prospect
26.	Butler Quarry past	producer
27.	Triangle Lake	prospect
28.	Palin Granite	producer

48. Site Evaluation and Market Testing of Ontario Anorthosite Deposits. Anorthosite Mapping and Sampling, Northeastern Ontario

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The economic potential of high-alumina feldspar rocks in Ontario has been noted for several years (Marmont 1988). Provincial resources and the production technology for use in various market sectors was summarized by Dolan et al. (1991). As follow-up, detailed examination has begun on anorthosite feldspar bodies. Attention is concentrated on the plagioclase feldspar rocks as these have been less well documented. The work continues and consolidates studies that began in 1991 in northwestern Ontario, and earlier in the Grenville Province of southern Ontario (Schneiders et al. 1991; Marmont 1988).

Anorthosites in northeastern Ontario are being investigated as raw materials for the chemical industry. Alternative uses in the ceramic and filler industries are considered secondary in the northeast sector of this study, as the Grenvillian bodies, which are closer to markets, seem to have more suitable properties. They are described by Marmont (1987, 1991). The quality and specifications of material for two different market segments were outlined from previous work. For the fillers and ceramics markets, materials that have consistent physical properties, pale colour and very low iron, suggest pure monomineralic feldspar rocks as raw materials. For the chemicals industry, Norwegian trials (Gjelsvik 1980) have shown a direct connection between the dissolution behaviour of the feldspar and its anorthite content. Alumina is easily extracted from anorthosite with greater than 60% anorthite. Moreover, bodies containing feldspar with a Si:Al ratio less than 1.5 are particularly suitable for chemicals use (Dolan 1991).

Anorthosite bodies in the province are of 2 types, different in age, form and feldspar composition. The older, generally Archean, bodies are layered cumulates in which the feldspar compositions are largely greater than An_{70}. The younger bodies, that are common in the Canadian Grenville Province, are massif-form intrusions whose feldspar is less anorthitic, in the An_{40-60} range (Marmont 1988).

Anorthosite rocks with the highest alumina and calcium contents identified by previous investigations were chosen for detailed field study as they are most easily and completely dissolved by strong acids. The resultant alumina in solution could provide feedstock for the chemicals industry, and a by-product of amorphous silica would also be produced. Low values of Fe, Ca Na, Mg required in the solute indicate that the raw material must be pure, or amenable to simple beneficiation.

In order to target bodies with appropriate chemistry, the whole-rock oxide values of known deposits (Dolan et al. 1991) were searched for values likely to represent pure feldspar bodies with a high anorthite content. Pure monomineralic plagioclase containing 60% anorthosite would theoretically show values of 29.5% Al_2O_3 and 12% CaO. This reasoning was checked against the whole rock chemistry of anorthosites that had independently shown favourable acid leach behaviour (Hamer 1981a, 1981b).

The approach confirmed that the Archean Shawmere body near Foleyet, and the River Valley intrusion near Sudbury in the Grenvillian terrane appear to have favourable characteristics. Furthermore, the Archean Bad Vermilion body near Fort Frances seems promising. Two other bodies, the East Bull Lake and the Shakespeare-Dunlop, were included in the suite for examination because they were closer to markets and, in addition, other geological studies on them are in progress.

The chemical suitability of the Shawmere and Bud Vermilion bodies was further roughly tested before more detailed field work began. Material obtained from the Provincial Core Libraries in Timmins and Kenora leached in 6N HCl gave good recoveries of dissolved alumina.

MINING AND BENEFICIATION

If these deposits are to be economic, certain criteria must be met. In addition to purity and leach behaviour, the deposits must be of sufficient tonnage and dimensions to make mining practical. Moreover, the mineralogical suite present will benefit or disadvantage downstream beneficiation and chemicals production.

A good deposit will have the following characteristics:

1. Overall tonnage of about 5 million tonnes of pure material to be mined at 30 000 tonnes/year. This

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translates to a total of 11 000 to 12 000 m^3, equivalent to an annual extraction of 50 by 100 by 2 m.

2. Horizons of pure material 25 to 30 m wide, sufficient to allow comfortable use of standard quarry equipment.
3. Coarse grain-size with simple intergrowth patterns that aid mineral separation.
4. Less than 5% dark minerals, or a simple mineralogy that is easily beneficiated.
5. Little alteration of the plagioclase.
6. Little secondary tectonic granulation which adversely increases the amount of fines and causes screening difficulties. Recrystalization accompanying granulation also commonly results in less anorthitic secondary feldspar.
7. Whole rock oxide values of greater than 29% Al_2O_3 plus greater than 12% CaO.
8. Low contents of secondary calcic phases (calcite, scapolite) that will adversely increase acid consumption at the dissolution stage.

FIELD OBSERVATIONS

Preliminary observation from the Shawmere body confirm the structural complexity of the deposit (Riccio 1979). The megacrystic units in the gabbroic core of the body are magnetic. Percival and Krough (1983) concluded that the megacrystic units are later and less anorthitic. It may, therefore, be possible to discriminate low-anorthite areas on their high magnetic signature. The oxide phases were sampled to examine their special characteristics. Bare areas 190 by 35 m are available for sampling. Equigranular anorthosite can be observed over strike lengths of 175 m, and 35 m width. At the site trenched for the Canadian Continental Drilling Program (Percival et al. 1991), parallel bands 28 to 30 m wide occur. The feldspar is reported as $An_{80\text{-}90}$. Secondary carbonate is present in minor fracture fillings and extends as alteration of the feldspar, with the formation of hornblende. This alteration appears to be related to northeast-trending structural zones and coincides locally with zones mapped as leucogabbro and gneiss-textured anorthosite (Riccio 1979). Mapping deleterious carbonate will be important as carbonate will adversely increase acid consumption during processing.

It seems that the scale of layering and the overall dimensions of the units are sufficiently large to allow easy mining access if the material purity is confirmed. Mapping of secondary carbonate, and establishing a relationship between feldspar composition and the content of magnetic phases now become important steps in the evaluation.

REFERENCES

Dolan, M.L., Hains, D.H. and Ash, D.R. 1991. High alumina rocks in Ontario; Ontario Ministry of Northern Development and Mines, Industrial Minerals Background Paper 10, 130p.

Gjelsvik, N. 1980. Extracting alumina from acid soluble anorthosites by the Anortal process; *in* Light metals, American Institute of Mining Engineers, p.133–148.

Hamer, C.A., Quon, D.H.H. and Winer, A.A. 1978. Extraction of alumina from Canadian non-bauxite materials; Report MRP/MSL 78–111 (OP&J), CANMET, Ottawa, 13p.

——— 1981a. Hydrochloric acid leaching of alumina from Ontario and Quebec anorthosites; Report MRP/MSL 81–91 (TR), CANMET, Ottawa, 9p.

——— 1981b. Acid extraction processes from Canadian non-bauxite sources at CANMET; Report 81–2E, CANMET, Ottawa, 14p.

Marmont, C. 1987. Feldspar in the Parry Sound–Huntsville–Hailburton area; Ontario Geological Survey, Open File Report 5686, 133p.

——— 1988. Feldspar in the Parry Sound–Huntsville–Haliburton area; Ontario Geological Survey, Open File Report 5686, 133p.

——— 1991. Building stone, feldspar and limestone resources in central Ontario; Ontario Geological Survey, Open File Report 5760, 499p.

Percival, J.A. and Krough, T.E. 1983. U–Pb zircon geochronology of the Kapuskasing Structural Zone and vicinity in the Chapleau–Foleyet area, Ontario; Canadian Journal of Earth Sciences, v.20, p.830–843.

Percival, J.A., Bursnall, J.T., Moser, D.E. and Shaw, D.M. 1991. Site survey for the Canadian Continental Drilling Program's pilot project in the Kapuskasing Uplift; Ontario Geological Survey, Open File Report 5790, 34p.

Riccio, L. 1979. Geology of the north-eastern portion of the Shawmere Anorthosite Complex, District of Sudbury; Ontario Geological Survey, Open File Report 5338.

Schneiders, B.R., Smyck, M.C. and Hinz, P. 1991. Schreiber–Helmo Resident Geologist's District — 1990; *in* Report of Activities 1990, Resident Geologists, Ontario Geological Survey, Miscellaneous Paper 152, p.141–171.

49. Aggregate Resources Inventory Highway 17 (Blind River to Bruce Mines)

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INTRODUCTION

A regional aggregate resources assessment study of the Highway 17 corridor between Blind River and Bruce Mines (Figure 49.1) was initiated by the Sedimentary and Environmental Geosciences Section of the Ontario Geological Survey in the autumn of 1992. The purpose of this study is to provide an inventory and evaluation of the sand, gravel and bedrock resources within the project area. The results of this study will be used to outline all aggregate resources and determine the quality and quantity of aggregate.

BEDROCK GEOLOGY

The study area lies within the Southern Province of the Canadian Shield and is divided by the northwest-trending Murray Fault (Giblin and Leahy 1979). North of this structure, 3 major bedrock units belonging to the Paleoproterozoic Huronian Supergroup occur. Metasedimentary rocks of the Lorrain Formation occupy the northwest part of the area, while metasedimentary rocks of the Gowganda Formation dominate the southeast. Intrusive rocks of the Nipissing diabase occupy an extensive area in the north central part of this region.

South of the fault structure, Neo- to Mesoarchean felsic intrusive and metamorphic rocks dominate in the southeastern part of the area. Immediately west of these rocks is an area of Paleoproterozoic volcanic rocks belonging to the Elliot Lake Group. The west part of the area, south of the Murray Fault, is underlain by Paleoproterozoic metasedimentary rocks of the Huronian Supergroup. These rocks are intruded by the Nipissing diabase.

The Nipissing diabase is of particular interest to the present study, as it has considerable utility from an aggregate perspective. Aggregate from this source has a high resistance to abrasion and finds use in asphalt and some high strength concretes. Other uses include riprap and railway bed material. Approximately 20% of the study area is occupied by the Nipissing diabase.

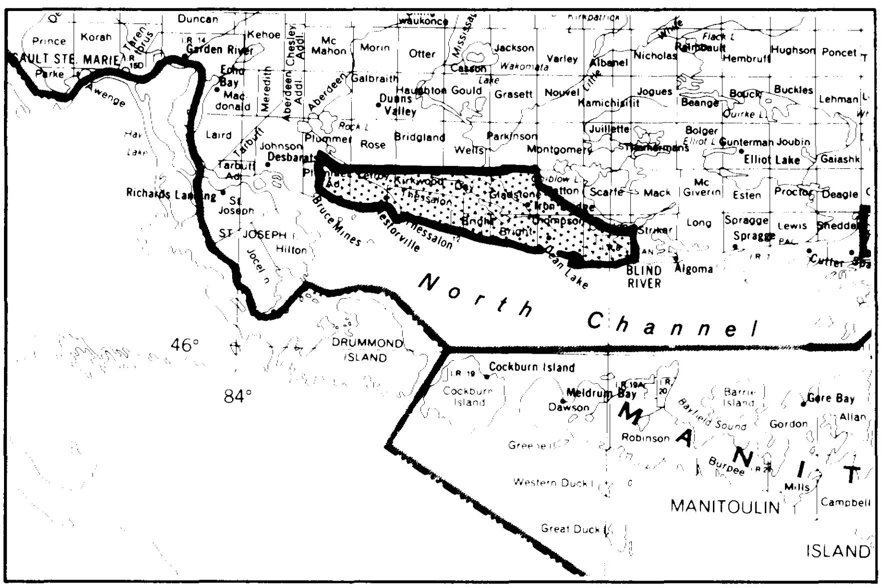

Figure 49.1 Location map of the study area, scale 1:1 584 000.

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This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

SURFICIAL GEOLOGY

Quaternary mapping coverage of the study area is limited. Previous mapping includes regional coverage by Boissonneau (1965), Northern Ontario Engineering Geology Terrain Studies (NOEGTS) by VanDine (1980a, 1980b) and most recently by Barnett et al. (1991). An aggregate assessment for the extreme western part of the study area has been completed by the Aggregate assessment Office of the Ontario Geological Survey (1988).

The oldest surficial material in the area is a bouldery silty sandy till (Boissonneau 1965). The till was deposited by glacial ice that advanced in a south to southwesterly direction (VanDine 1980a, 1980b). Till is usually not well suited for aggregate use, as it often contains excess fines and oversize clasts. In some cases, till may be suitable for fill materials.

Mapping also indicates the presence of Pleistocene Epoch glaciofluvial outwash, glaciolacustrine sands and gravels and minor ice-contact deposits (Barnett et al. 1991). Approximately 15% of the study area is covered by these deposits. These deposits are of obvious importance to the present study and, for the most part, the aggregate potential of these deposits is rated as fair to good (VanDine 1980b).

Within the study area, Holocene organic-rich deposits are also present (Barnett et al. 1991). The value of these materials from an aggregate standpoint are minimal.

PROJECT OUTLINE

The project consists of 3 stages: 1) a prefield phase; 2) a field investigation component; and 3) a third stage to analyze and compile results and complete an aggregate assessment report.

The prefield phase involves compiling all available information relevant to the aggregate resources of the Highway 17 corridor between Blind River and Bruce Mines and completing a preliminary airphoto interpretation for the area. The airphoto interpretation exercise is designed to identify and delineate all potential sand and gravel deposits.

The field investigation component is designed to map and evaluate the aggregate deposits within the study area. Field mapping involves verifying all potential aggregate deposits identified through airphoto interpretation, collecting aggregate samples for quality testing, investigating all pit and quarry sites in detail and conducting reconnaissance level drilling, backhoe and/or geophysics programs in significant aggregate sources. Mapping to outline the extent of the Nipissing diabase is also conducted as part of the field investigation.

The third phase of the project, data evaluation and report generation involves the following:

1. Generation of maps in which all aggregate deposits and bedrock formations are identified, delineated, defined and classified according to the Aggregate Resource Inventory Paper (ARIP) system.
2. Preparation of tables which estimate the area and tonnage of possible resources, identify all operating and nonoperating sand and gravel pits and aggregate quarries and report all results from any test holes, geophysics and sample analysis. Text included in the report will summarize the aggregate resources of the study area.

REFERENCES

Barnett, P.J., Cowan, W.R. and Henry, A.P. 1991. Quaternary geology of Ontario, southern sheet; Ontario Geological Survey, Map 2556, scale 1:1 000 000.

Boissonneau, A.N. 1965. Surficial geology, Algoma, Sudbury, Timiskaming, and Nipissing; Ontario Department of Lands and Forests, Map S465, scale 1:506 880.

Giblin, P.E. and Leahy, E.J. 1979. Sault Ste. Marie–Elliot Lake sheet, NTS 41 J,K/NE,N/SE,O/S, Ontario; Ontario Geological Survey, Map 2419, scale 1:253 440.

Ontario Geological Survey 1988. Aggregate resources inventory of the Echo Bay–Bruce Mines area and St. Joseph Island, District of Algoma; Ontario Geological Survey, Open File Report 5640, 131p.

VanDine, D.F. 1980a. Thessalon area, NTS 41J/SW, 41K/SE, Algoma District, Ontario; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 97, 16p.

——— 1980b. Blind River area, NTS 41J/SE, Algoma, Manitoulin and Sudbury districts, Ontario; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 98, 14p.

50. The Industrial Minerals Program in Northwestern Ontario

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INTRODUCTION

The evaluation of industrial mineral resources in northwestern Ontario continued in 1992. The "Industrial Minerals" program was initiated in March of 1991. The purpose of the program is to stimulate exploration, development and production of industrial minerals in northwestern Ontario. Project objectives are to: document and investigate new and previously known industrial mineral occurrences; add to the industrial minerals database; provide client services via property visits, sample analyses and information exchange; introduce public education through prospector classes, oral presentations and poster displays; and increase awareness of northwestern Ontario industrial minerals at technical seminars, workshops and conferences.

MINING ACTIVITY

Currently, 4 industrial mineral commodities are being produced in northwestern Ontario. These are granite, crushed quartz, soapstone and crushed granite. A new producer, Palin Granite Canada Inc., began production at their Pine Green Granite quarry, located approximately 36 km north-northeast of Kenora. Nelson Granite Ltd. continued to produce pink granite from its quarry, west of Vermilion Bay. An increase in production of crushed quartz was seen at Crystal Quarries Ltd. quarry, southwest of Eagle Lake, near Dryden. Finally, soapstone blocks are extracted by P. Thorgrimson, from the former Grace Mining Company quarry on Eagle Lake, southwest of Dryden. At Cygnet Lake, north-northwest of Kenora, A. Minor and T. Hansen started production at their crushed red granite quarry, the material will be used for landscaping and precast concrete.

FIELD WORK

A total of 49 field visits (Figures 50.1 to 50.3; Table 50.1), representing 17 industrial mineral commodities, were conducted to locate, sample, examine and record high-potential occurrences.

The following sites were sampled to evaluate their

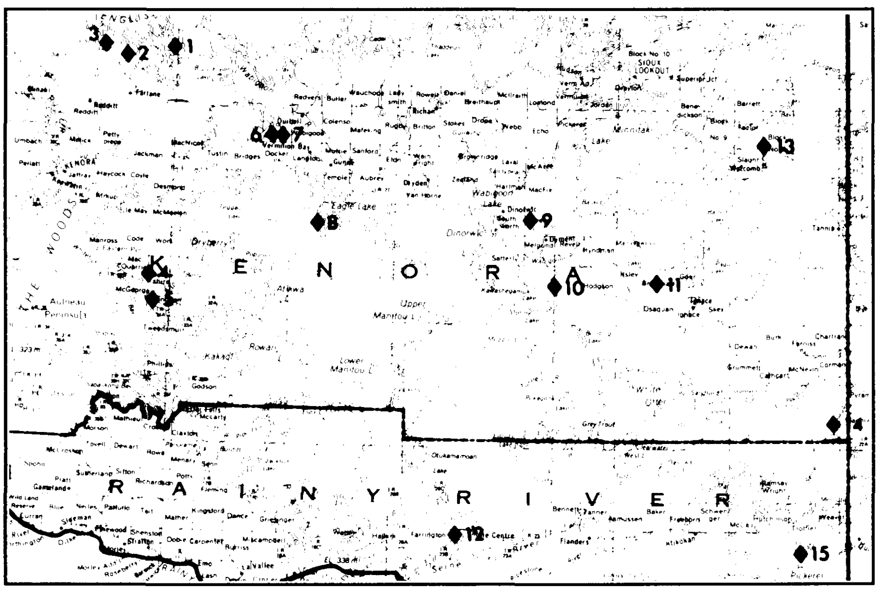

Figure 50.1. Northwestern Ontario industrial minerals program, property visits, 1992 (keyed to Table 50.1).

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This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

Table 50.1. Industrial mineral property examinations, 1992.

Location		Commodity
1.	Jones Road (Lount Lake Batholith)	red granite
2.	Red Deer Lake (Lount Lake Batholith)	red granite
3.	Pine Green Granite Quarry[2] (Lount Lake Batholith)	green granite
4.	Sioux Narrows	slate
5.	Snake Bay (Lake of the Woods)	aggregate
6.	Triangle Lake Road	pink granite
7.	Granite Quarriers Inc.[1]	pink granite
8.	Crystal Quarries Ltd.[2]	crushed quartz
9.	Dyment quarry[1] railway	ballast
10.	Kawashegamuk Lake Occurrence	fluorite
11.	Butler Quarry[1]	grey granite
12.	Bad Vermilion Lake Intrusion	anorthosite
13.	Watcomb quarry	railway ballast
14.	van Nostrand Lake	pink granite
15.	Eva Lake Intrusion	grey granite
16.	Trafalger Bay (Northern Lights Lake)	soapstone
17.	Taman Lake crushed	black granite
18.	Tib Lake Intrusion	anorthositic gabbro
19.	Puddy Lake	soapstone
20.	Chrome Lake	chromite
21.	A. Niemi (Ware Township)	porphyritic granite
22.	C. Herbert (Ware Township)	aggregate
23.	Penassen Lake Stock	red granite
24.	Wolf River	buff sandstone
25.	Black Bay Peninsula	red sandstone
26.	Black Bay Peninsula	buff sandstone
27.	Black Bay Peninsula	black sand
28.	Black Bay Peninsula	agate
29.	Moss Lake Intrusion	gabbroic anorthosite
30.	Vert Island	red sandstone
31.	Little Bear Quarry Road	migmatite
32.	Gravel River	calcite
33.	Dickison Lake	quartz
34.	Rossport porphyritic	granite
35.	Pic Island	nepheline
36.	Neys Power Line	nepheline
37.	D. Petrunka[1]	red granite
38.	D. Petrunka[1]	black granite
39.	C.S. Downey (Shack Lake)	spectrolite
40.	Wilkinson Occurrence	spectrolite
41.	Coldspring quarry[1]	black granite
42.	C.P.R. quarry[1]	black granite
43.	Northern Eagle	barite
44.	Dotted Lake Batholith[1]	pink granite
45.	Loken Lake	granite gneiss
46.	Thomas Lake Occurrence	graphite
47.	Greta–Greer Road	granite gneiss
48.	Croll Lake Stock	crushed granite
49.	Chipman Lake syenite,	diorite

[1] visited during a field trip conducted in 1992
[2] currently producing

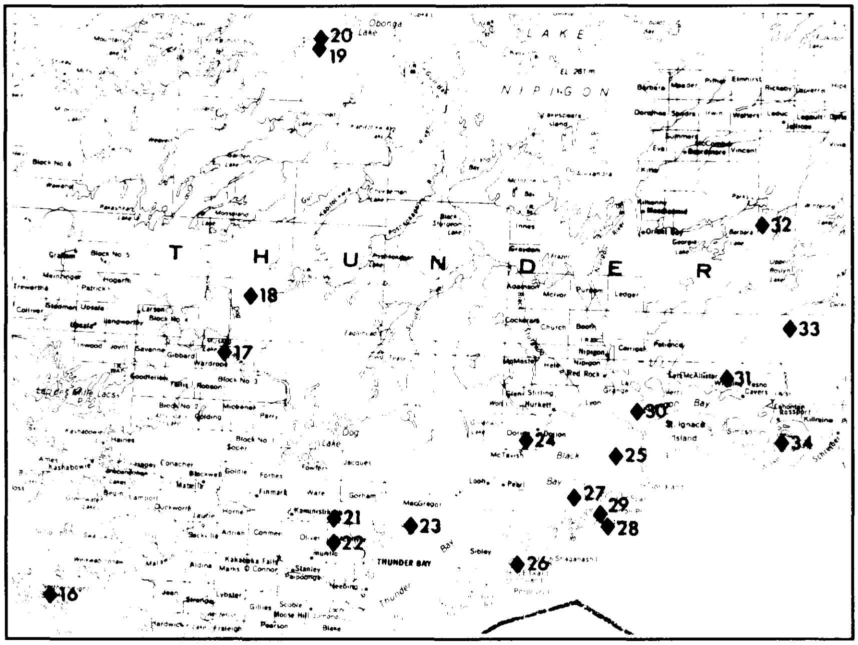

Figure 50.2. Northwestern Ontario industrial minerals program, property visits, 1992 (keyed to Table 50.1).

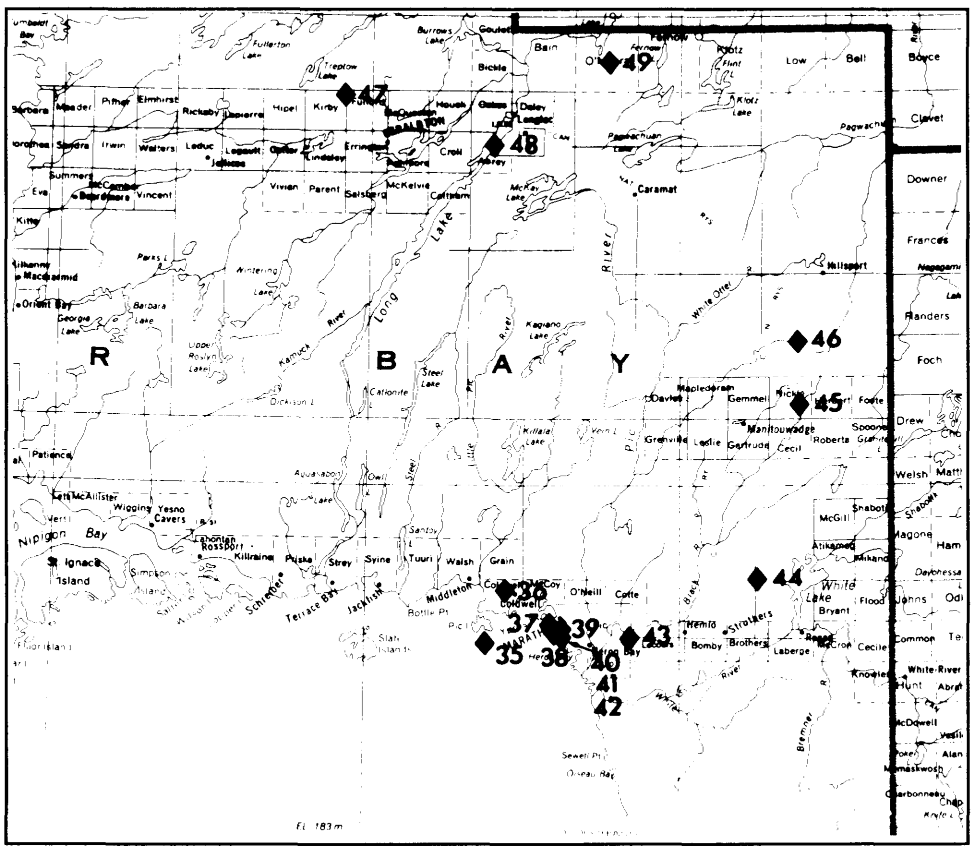

Figure 50.3. Northwestern Ontario industrial minerals program, property visits, 1992 (keyed to Table 50.1).

dimension stone potential: black metapyroxenite from Taman Lake northwest of Thunder Bay; porphyritic red-granite from the Penassen Lake stock in MacGregor Township (Scott 1990); and the van Nostrand Lake stock west of Upsala. Samples were cut and polished to evaluate their attractiveness and ability to take a finish. Further field work will be conducted to establish field parameters required for potential dimensional stone sites.

In conjunction with a province-wide study of anorthosites, a number of anorthosite intrusions were examined. Samples were taken from 2 sites: the Bad Vermilion Intrusion located south of Mine Centre, and the Moss Lake Intrusion on the Black Bay Peninsula. Chemical analyses are pending, thin sections have been made and are being examined. Sample descriptions and results will be released in the Report of Activities 1992 Resident Geologists. This report will be released in March of 1993.

OTHER ACTIVITIES

A display, titled "Industrial Mineral Activities in Northwestern Ontario", was presented at the Thunder Bay Mines and Minerals Symposium in April of 1992, at the Institute on Lake Superior Geology in Hurley, Wisconsin in May of 1992, and at the Current Activities Forum held in Chisholm, Minnesota in October of 1992. Oral presentations, dealing with prospecting for industrial minerals, were presented to prospector information sessions and classes in Manitouwadge, Marathon, Red Lake, Ignace, Beardmore and Thunder Bay. Other activities included a tour of Cold Spring Granite's quarries and fabrication plants in Cold Spring, Minnesota, and participation in presenting a Mining Sequence display in Thunder Bay.

FUTURE WORK

Future work will include a published Open File Report on industrial mineral occurrences in northwestern Ontario. Classes and seminars will continue to be given to inform and educate prospectors on opportunities and prospecting techniques for industrial minerals. Project results and recommendations will be published in the Report of Activities 1992 Resident Geologists to be released in March 1993.

ACKNOWLEDGMENTS

This report was edited by K.G. Fenwick and reviewed by B.R. Schnieders. M.C. Smyk provided assistance on a number of property visits in the Marathon area. D. Laderoute provided similar assistance in the Kenora District. S. Warren reviewed this report and provided professional and efficient secretarial support throughout the year. Assistance in the field and office was provided by B. Lucas, whose efforts are gratefully appreciated. B. Nelson, Assistant Drill Core Library Geologist, was responsible for the preparation of the voluminous samples required by this program. Staff of the Mineral Development Section in Kenora provided valuable assistance in liasing with prospectors throughout northwestern Ontario. Numerous company representatives and prospectors provided invaluable information and field assistance on occurrences in northwestern Ontario.

REFERENCES

Scott, J. 1990. Geology of MacGregor Township; Ontario Geological Survey, Open File Report 5719, 82p.

51. Industrial Minerals and Building Stone in the Districts of Nipissing, Parry Sound and Sudbury

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INTRODUCTION

This report describes the field work conducted in the second year of a program to evaluate the economic potential of industrial minerals and building stone in the district of Parry Sound and parts of the districts of Nipissing and Sudbury. Results of the first year's activities, a summary of previous work, and current exploration and mining activity have been reported by Marmont (1991b, 1992). The 3 districts are within that part of the province designated as "Northern Ontario", and as such are eligible for enhanced incentives for development. The study area is limited to areas of Grenvillian geology; consequently, only those parts of Sudbury and Nipissing districts which lie south of the Grenville Front Tectonic Zone are included (Figure 51.1). The study area includes parts of 3 Resident Geologists' districts; they are defined approximately as follows: Algonquin District south of French River–North Bay–Mattawa; Cobalt District north and east of North Bay; and Sudbury District north of French River and west of North Bay. The project will be completed by the spring of 1994.

Field work during 1992 has focussed on building stone and anorthosite.

BUILDING STONE

Production

Commercial production of building stone in the project area has continued during 1992. At Parry Sound, the Mill Lake Stone Quarry produces 1/2 inch to 4 inch thick granitic flagstone and similar thinly splitting granite gneisses are being produced at the Jeffery and Boyes quarries near Burk's Falls. Micaceous quartzite flagstone is produced at Thorne (Thorne Brilliant Stone Quarry), and at Reynolds Lake (McLaren's Bay Mica Stone Quarries), approximately 20 kilometres to the northwest.

Dimensional black granite is being quarried by International Mining Company Limited near River Valley.

During 1992, test blocks of dimensional granite have been extracted from several sites in the project area, for the purposes of sawing and polishing tests and marketing.

Current Program

The primary objective of the current field program is to identify sites having recoverable resources of granite suitable for large block extraction. Reconnaissance of ductile shear zones in the Parry Sound area is also being undertaken in order to evaluate flagstone potential.

During the spring, air photo interpretation was completed for the Parry Sound District and for granitic bodies in the Sturgeon Falls–Marten River area. Significant outcrops within 2 km of roads were noted, and many were duly visited during the summer. At the time of writing, field work is continuing. It is planned to extract small blocks from 9 of the most promising sites. These will be sawn and polished to assist in assessing their aesthetic characteristics and structural competence. Hand samples, exfoliated slabs and photographs of the sites are available for viewing at the office of the Resident Geologist in Dorset.

The desirable criteria for a potential dimensional stone prospect are: substantial exposure, lithological uniformity, low density of joints and fractures, durability of the stone, absence of deleterious minerals, and attractiveness.

Nine sites have been identified which satisfy most of these criteria. All but "Snug Harbour" are located entirely or partly on Crown Land. They are summarized below.

Site Descriptions

SAND BAY, CARLING TOWNSHIP

This site is located in lots 38 and 39, Concession VIII, in Carling Township (NTS 41H/8; UTM 552300E 5032300N). Several outcrops consist largely of coarse-grained pegmatite, with marginal areas of attractive pink-maroon migmatite. Pegmatite is not widely used as an architectural stone because the large grain size and feldspar cleavages exceed the thickness of the panels, making the stone prone to fracture. However, when glued to a firm substrate or used in thicker slabs and blocks, the stone can be used to great effect. This site is remarkable for its extent and absence of joints within the

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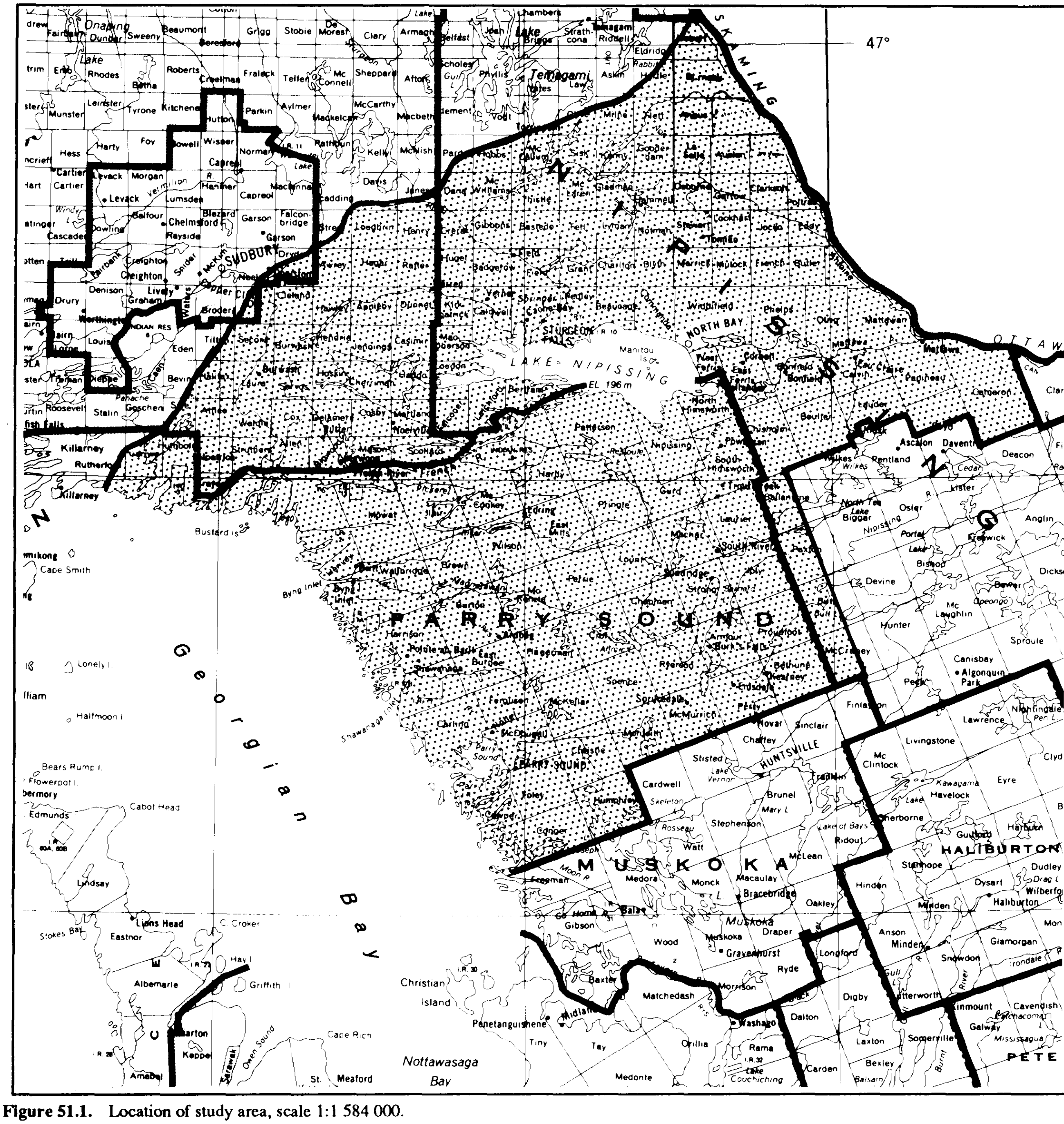

Figure 51.1. Location of study area, scale 1:1 584 000.

pegmatite. Two outcrops, measuring 30 by 60 m, and 30 to 50 m by 300 m display joint spacing ranging up to 30 m. Country rocks are attractive pink and grey migmatites. The depth extent of the pegmatites is not known, however, it is possible that they form relatively thin folded caps on top of the migmatites. Joint spacing in the migmatite is also widely spaced, hence two distinctive products could be obtained from these sites.

SNUG HARBOUR, CARLING TOWNSHIP

Survey control is poor, but this site appears to be located in the northeast corner of Lot 72, Concession 12, Carling Township (NTS 41H/8; UTM 555600E 5025650N). The site occupies a small hill with an area of about one-half hectare (ha), and rises some 15 m above the surrounding terrain. Exposure is fairly good, revealing a purplish-hued migmatite, cut by irregular pegmatite veins. The migmatite appears to be sound, and joint spacing of up to 7 m indicates potential large block recoveries of over 50%. On the west side of the hill, a number of large blocks (10 to 20 t) have fallen away leaving a small cliff some 2 to 3 m high. This material can therefore be easily removed for testing, and a good working face is in place. The pegmatite veins will result in a certain amount of waste.

STAR LAKE RED, CHRISTIE TOWNSHIP

This is an attractive pinkish-red gneissic granite located in lots 11 and 12, Concession IV, Christie Township (NTS 31E/5; UTM 598400E 5022900N). The granite is well exposed over a strike length of 400 m, and has a uniform crenulated gneissic foliation, colour and texture. Joint spacing varies, but exceeds 10 m as a single set in the central part of the ridge. At the west end, frost action has wedged out a number of solid blocks measuring 2 by 2 by 2 m.

STAR LAKE PINK, CHRISTIE TOWNSHIP

This site is located some 700 m southwest of the red granite described above, in lots 13 and 14, Concession IV (NTS 31E/5; UTM 597700E, 5022500N). The stone is a pink and grey banded migmatite. Moss and thin soil-cover result in patchy exposure of the stone, but many areas display joint spacing in excess of 4 m. The site is a gently rounded hill some 20 m high, occupying an area of about 4 ha.

TURTLE LAKE, CHRISTIE TOWNSHIP

An area of about 1.5 km^2, located one kilometre northeast of Turtle Lake, contains many outcrops of banded pink and grey migmatite. In most places, the joint spacing is too close to permit recovery of a high proportion of large quarry blocks. However, one outcrop, in the northeastern part of the area (Lot 10, Concession I), contains more widely spaced joints. The outcrop is almost 1 ha in size, with a relief of 4 to 5 m (NTS 31E/5; UTM 600500E 5019900N).

BURNT LAKE, CONGER TOWNSHIP

A pink gneiss (meta-arkose?) is well exposed over an area of several hectares in lots 7 and 8, concessions VIII and IX, in Conger Township (NTS 31E/4; UTM 590600E 5008500N). The southern part of the main outcrop, and a smaller (1 ha) outcrop 200 m to the east are situated on Crown land. The gneiss has a weak foliation, is quartz-rich, medium-grained with wispy migmatitic layers which are a slightly paler hue. The texture is sugary, and the stone weathers to a brownish-pink colour to a depth of 10 cm or more. The main joint set strikes east, and a minor set trends northeast. Joint spacing is commonly greater than 3 m, and is most favourable on the eastern outcrop.

GOULD LAKE, CONGER TOWNSHIP

This site consists of 2 parallel, southeasterly trending roches moutonees located in Lot 11, Concession IV, Conger Township (NTS 31E/4, UTM 590800E 5003950N). The southwestern outcrop is 160 m long, 30 to 40 m wide, and up to 8 m high. The stone is an attractive migmatite with a purple or mauve hue. Gneissic layering trends parallel to the ridge, but is contorted in the third dimension. The main joint set is transverse to the ridge with spacings up to 11 m. In the central part of the outcrop is a swarm of more closely spaced, obliquely trending joints. Measurement of the distribution of vertical joints indicates that as much as 75% of the ridge can be recovered as blocks greater than 2 by 3 m. The flanks of the ridge reveal only minor development of horizontal joints.

KAPIKOG LAKE, CONGER TOWNSHIP

This site is a bare hill several hectares in area, with 10 to 20 m relief in lots 19 and 20, concessions I and II, Conger Township (NTS 31E/4; UTM 588800E 5000300N). The stone is a weakly migmatitic, reddish, medium-grained gneiss, with wispy lighter coloured patches. It is remarkably uniform over the whole area, although locally the migmatization process is either less well or more strongly developed. Joint spacing and orientation are variable, as might be expected over such a large area, but parts of the outcrop appear capable of producing large quarry blocks.

GRUNDY LAKE, MOWAT TOWNSHIP

Two large outcrops just east of Grundy Lake Provincial Park exhibit widely spaced joints in attractive granitic gneiss. The eastern outcrop, in Lot 19, Concession XVI (NTS 41H/15; UTM 548400E, 5088400N), consists mainly of medium-grained, foliated, pink granite gneiss with layers of disseminated hornblende porphyroblasts and minor migmatite. The western cluster of outcrops, in lots 21 and 22, Concession XVI (UTM 547500 to 800E 5088300N), also has widely spaced joints in a similar stone.

All of the above sites will be described in greater detail in an Open File Report to be released early in 1993. In addition, a number of sites were identified which appear to be less prospective than the ones described above (by virtue of, for example, relatively small size, poor exposure, less favourable joint spacing, difficult access), but which could, nonetheless, provide a quarriable resource: these will also be described in due course. Files on all sites are available for viewing at the Dorset Resident Geologist's office, along with topographic maps showing the location of outcrops identified from air photos.

ANORTHOSITE

Bodies of anorthositic rock are widely distributed within the study area (Easton 1990; Lumbers 1971a, 1971b, 1973, 1975, 1976a, 1976b). The Whitestone, Parry Island and River Valley bodies have previously been evaluated as possible sources of alumina (Ripley 1979) as possible sources of feldspar suitable for the ceramics, glass, filler and insulation industries, and as dimensional stone (Marmont 1988, 1991a; Marmont and Johnston 1987; Marmont et al. 1988). Dolan et al. (1991), reported that anorthosite containing feldspar having a Si:Al ratio lower than 1.5 is suitable for certain chemical applications. Such feldspars have anorthite contents greater than about An_{70}, and occur in "layered" anorthositic bodies, commonly of Archean age. Less anorthitic plagioclase feldspars (An_{40} to An_{60}) occur in "massif-type" intrusions which are typical of the Canadian Grenville Province.

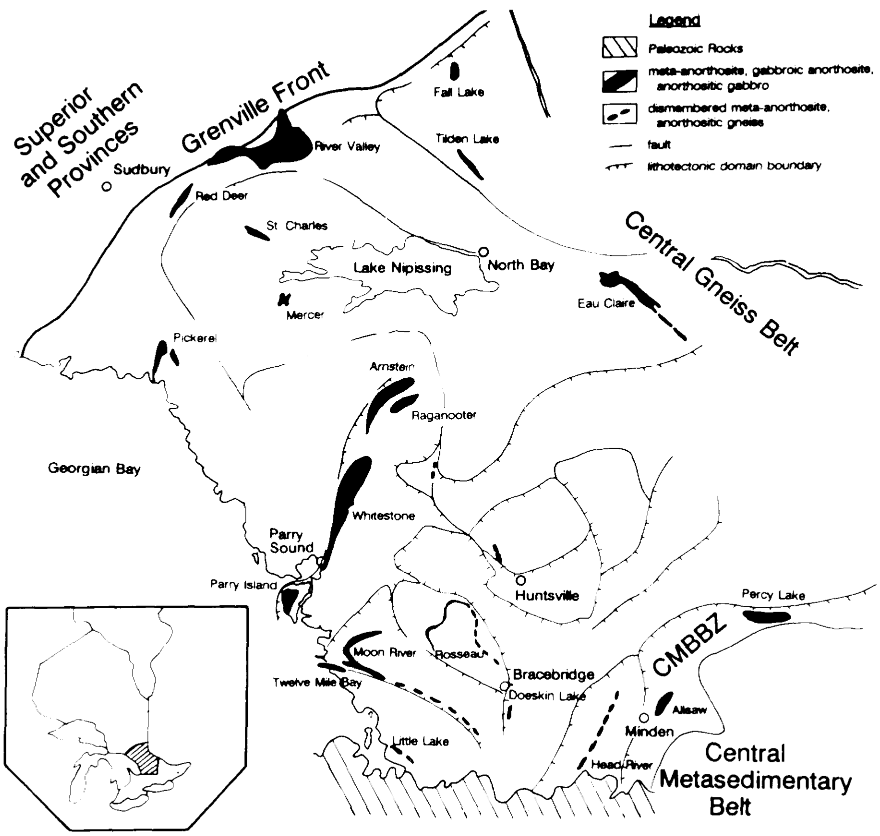

Figure 51.2. Location of anorthositic bodies in central Ontario (modified slightly *after* Easton (1990)).

In light of the report by Dolan et al. (1991), a program co-ordinated by Dr. J. Springer (Ministry of Northern Development and Mines, Mineral Development Section, Sudbury) was initiated to evaluate anorthositic feldspar resources across the Province. As part of this effort, this author has conducted field evaluation of anorthosites in the Sudbury–North Bay–Mattawa region, and P. Hinz (this volume) reports on anorthosite in the northwestern Region. At the time of writing, H. Veldhuyzen has just commenced work in the northeastern Region. Veldhuyzen will co-ordinate the sampling of appropriate material, and will commission beneficiation tests and laboratory evaluation of the suitability of Ontario anorthosites for chemical, ceramic, glass and filler applications.

In the Sudbury–North Bay–Mattawa region, anorthosites of both massif and layered type occur (Figure 51.2). The River Valley and Red Deer anorthosites are of the layered type, with recessive-weathering calcic feldspar. The Eau Claire and Fall Lake bodies may also be of this type. The St. Charles, Mercer, Pickerel River and Tilden Lake bodies appear to be of "massif" type similar to those previously described by Marmont (1991a).

Photo interpretation of all bodies was undertaken in order to identify large outcrops. The bodies were then traversed in an attempt to identify significant areas of clean anorthosite. True anorthosite (Buddington 1939) is defined as that containing more than 90% plagioclase feldspar, the balance commonly being pyroxene or hornblende (± olivine, ± biotite). For an anorthosite to have potential commercial applications, it would likely need to be purer than 95% plagioclase. Because plagioclase weathers to a white colour, the composition of anorthositic rocks can usually be measured on clean outcrop surfaces, and expressed as colour index.

No significant volumes of anorthosite were observed during the summer's work. The River Valley and Red Deer bodies are mainly anorthositic gabbro, with substantial amounts of gabbroic anorthosite. Nothing could be mapped as anorthosite on an outcrop scale, only as erratic patches within a more mafic host. Thin layers, 1 to 2 m thick, occur within shear zones which transect the River Valley body.

Clean anorthosite was observed in the Eau Claire Anorthosite, but exposure is so poor that estimation of anorthosite resources is not practical. The body is sheared, and the anorthosite is likely interlayered with gabbroic anorthosite and gabbro.

The St. Charles Anorthosite is fairly consistent in composition, being predominantly a gabbroic anorthosite with a colour index around 15. Locally, the colour index is as low as 7 or 8, but no substantial volumes of such material appear to be present.

The Pickerel River Anorthosite is also a fairly uniform gabbroic anorthosite with a colour index of 15. Locally anorthositic layers a few centimetres thick occur in recrystallized zones. Gabbroic phases are locally present.

The Mercer Anorthosite is essentially a gabbroic anorthosite, but several areas, well exposed in prominent white outcrops, have colour indices of 10 to 12, approaching anorthosite, *sensu stricto*.

The Tilden Lake Anorthosite contains some clean anorthosite, but it appears to be too thin and poorly exposed to be of interest.

On the basis of field observations during the summer of 1992, it appears that none of the anorthosites studied is a suitable source of plagioclase feldspar. On the basis of the available literature (Ashwal et al. 1983; Riccio 1979), the Shawmere and Bad Vermilion anorthosites appear to be more prospective "layered-type" sources of high-calcium high-aluminum feldspar, while the Whitestone and Percy Lake anorthosites (Marmont 1991a) are purer than their Sudbury area "massif-type" counterparts.

ACKNOWLEDGMENTS

The author is grateful to R. McKeown for very competent assistance during the summer.

SELECTED BIBLIOGRAPHY AND REFERENCES

Ashwal, L.D., Morrisom, D.A., Phinney, W.C. and Wood, J. 1983. Origin of Archean anorthosites: evidence from the Bad Vermilion Lake Anorthosite Complex, Ontario; Contributions to Mineralogy and Petrology, v.82, p.259–273.

Ashwal, L.D. and Wooden, J.L. 1989. A late Archean/early Proterozoic anorthosite intrusion in the Grenville Province; Geochemica et Cosmochimica Acta, v.53, p.633–641.

Buddington, A.F. 1939. Adirondack igneous rocks and their metamorphism; Geological Survey of America, Memoir 7, 354p.

Dolan, M.L., Hains, D.H. and Ash, D.R. 1991. High alumina rocks in Ontario; Ontario Ministry of Northern Development and Mines, Industrial Minerals Background Paper 10, 130p.

Easton, R.M. 1990. Meta-anorthosites in the Grenville Province of Ontario; *in* Mid-Proterozoic Laurentia–Baltica, Geological Association of Canada, Special Paper 38, p.387–397.

Fouts, C.R. and Marmont, C. 1989. Gneisses of the Parry Sound–Muskoka area: flagstone resources; Ontario Geological Survey, Open File Report 5725, 72p.

Lacey, J.K. 1989. Building stone inventory of the Sudbury Resident Geologist's area; Ontario Geological Survey, Open File Report 5271, 64p.

——— 1991. Building stone inventory of the Sudbury Resident Geologist's area, Volume 2; Ontario Geological Survey, Open File Report 5762, 35p.

Lumbers, S.B. 1971a. Geology of the North Bay area, districts of Nipissing and Parry Sound; Ontario Department of Mines and Northern Affairs, Geological Report 94, 104p.

——— 1971b. Tomiko area (west half), District of Nipissing; Ontario Department of Mines and Northern Affairs, Preliminary Map P.678, scale 1:63 360.

——— 1973. River Valley area, districts of Nipissing and Sudbury; Ontario Division of Mines, Preliminary Map P.844, scale 1:63 360.

——— 1975. Geology of the Burwash area, districts of Nipissing and Parry Sound; Ontario Department of Mines, Geological Report 116, 160p.

——— 1976a. Mattawa–Deep River area (western half), District of Nipissing; Ontario Division of Mines, Preliminary Map P.1196, scale 1:63 360.

——— 1976b. Mattawa–Deep River area (eastern half), District of Nipissing and County of Renfrew; Ontario Division of Mines, Preliminary Map P.1196, scale 1:63 360.

Marmont, C. 1988. Feldspar in the Parry Sound–Huntsville–Haliburton area; Ontario Geological Survey, Open File Report 5686, 133p.

——— 1991a. Building stone, feldspar and limestone resources in central Ontario; Ontario Geological Survey, Open File Report 5760, 499p.

——— 1991b. Industrial minerals and building stone in the districts of Nipissing, Parry Sound and Sudbury; *in* Summary of Field Work and Other Activities 1991, Ontario Geological Survey, Miscellaneous Paper 157, p.276–279.

——— 1992. Building stone opportunities in central Ontario — 1991 Supplement; Ontario Geological Survey, Open File Report 5825, 20p.

Marmont, C. and Johnston, M. 1987. Mineral deposits studies in the Huntsville–Parry Sound–Powassan area — a progress report; Ontario Geological Survey, Open File Report 5647, 221p.

Marmont, C., Zuberec, P.M. and Conrod, W.D. 1988. Industrial minerals, rare-earth elements, and building stone in the districts of Muskoka, Parry Sound and Nipissing, and the County of Haliburton; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.319–325.

Ministry of Northern Development and Mines. 1989. Staff of the Resident Geologist's Office, Dorset, Ontario. Building stone opportunities in central Ontario; Interim Report, 16p.

Riccio, L. 1979. Geology of the northeastern portion of the Shawmere Anorthositic Complex, District of Sudbury; Ontario Geological Survey, Open File Report 5338, 101p.

Ripley, L.G. 1979. Extraction of alumina from five Ontario anorthosites by the modified lime-sinter process; Report MRP/MSL 78–137 (IR) CANMET, Ottawa, 34p.

Rose, E.R. 1973. Geology of vanadium and vanadiferous deposits of Canada; Geological Survey of Canada, Economic Geology Report, no.27.

Roussel, D.H. 1978. Geology of the anorthositic sill at St. Charles, Ontario; *in* Current Research, Part A, Geological Survey of Canada, Paper 78–1A, p.163–168.

52. Industrial Minerals Assessment of Manitoulin Island

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INTRODUCTION

A program to evaluate the economic potential of industrial minerals on Manitoulin Island commenced in late June, 1992. Emphasis is being placed on outlining areas that contain high-purity carbonates, as well as evaluating the potential for building stone and cement. The presence of these value-added products would make the area more attractive for mineral development. The established database will also be useful in making informed land-use and development decisions on Manitoulin Island. The project will be completed in March 1995.

The study area encompasses the mainland mass of Manitoulin Island which is bounded by the shorelines of the North Channel, Georgian Bay, Lake Huron, and Mississagi Straight (Figure 52.1). It is covered by the following 1:50 000 NTS sheets: Meldrum Bay (41G/14), Silver Water (41G/15), Providence Bay (41G/9), Kagawong (41G/16), Manitowaning (41H/12 & 41H/11), and Little Current (41H/13).

GENERAL GEOLOGY

Manitoulin Island is underlain by Paleozoic rocks that range in age from the Middle Ordovician Verulam Formation to the Middle Silurian Amabel Formation (Table 52.1). Several small Precambrian quartzite inliers, belonging to the Huronian Supergroup, occur in the Sheguindah area.

Located on the northern edge of the Michigan Basin, the Paleozoic units dip gently southward at about 6 m/km. Ordovician strata consisting of limestones, dolostones, and shales occur on the north side of the island and account for about 25% of the land area. Silurian strata, consisting of mostly dolostones and some shales, occupy the remainder of the island. Mapping by Johnson and Telford (1985) found the Amabel Formation to be more complex than previously reported. They have identified 9 recurring lithologies which they grouped into 4 facies associations.

An Ordovician escarpment along the north side of the island, and the extension of the Silurian Niagara Escarpment near the middle of the island, have formed several prominent north and east facing cliffs. The Ordovician strata are typically not as well exposed as the Silurian strata, due in part to the recessive nature of the shales combined with more extensive glacial overburden. The Silurian Amabel Formation is generally well exposed

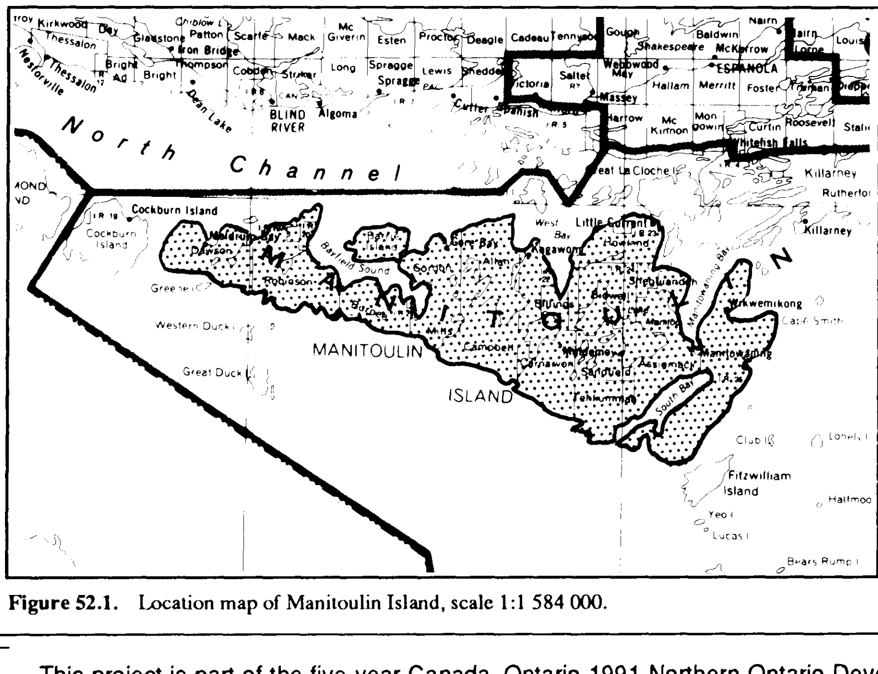

Figure 52.1. Location map of Manitoulin Island, scale 1:1 584 000.

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This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

Table 52.1. Paleozoic stratigraphy of Manitoulin Island, *after* Johnson and Telford (1985).

Middle Silurian	Amabel Fm. (17 to 40 m) Fossil Hill Fm. (23 to 34 m) St. Edmund Fm. (13.5 to 46 m) Wingfield Fm. (10 m) Dyer Bay Fm. (5 m)
Lower Silurian	Cabot Head Fm. (17 m) Manitoulin Fm. (9 to 20 m)
Upper Ordovician	Georgian Bay Fm. (92 to 137 m) Blue Mountain Fm. (40 m)
Middle Ordovician	Lindsay Fm. (23 m) Verulam Fm. (18 m)

along the south shoreline. Forest cover becomes more extensive toward the western end of the island, although overburden is generally only a few metres thick.

ECONOMIC GEOLOGY

At present, there are 3 active quarries on Manitoulin Island.

Standard Aggregates Inc. operates the largest marine quarry in Canada at the western end of the island in Dawson Township. Massive bedded dolostones of the Amabel Formation are excavated in a single lift of about 17 m. The quarry has been operating since 1980, it supplies chemical grade stone (30%) and construction grade aggregates (70%). The stone is shipped by lake freighter, from a dock adjacent to the quarry, to the United States and Canadian markets over an eight-month shipping season. Yearly production is approximately 2.4 million tonnes.

Hercules Stone Ltd. supplies both natural joint-faced blocks of Amabel Formation and glacially polished, thin-bedded dolostone of the Manitoulin Formation for use as landscaping stone in the Sudbury-Manitoulin area. Production is intermittent, on an as required basis.

H & R Noble Construction Ltd. operates the Cup and Saucer Quarry located in Bidwell Township. A single lift of about 5.5 m exposes 4.5 m of dolostone of the St. Edmund Formation capped by 1.0 m of the Fossil Hill Formation. The crushed stone, as well as gravel excavated adjacent to the quarry, are used locally as aggregates.

CURRENT PROGRAM

A review was made of geological reports concerning Manitoulin Island. Included in this review were reports outlining the physical and chemical requirements for the many uses of carbonates (Derry Michener Booth and Wahl, and the Ontario Geological Survey 1989). Chemical analyses for 2449 surface samples plus selected core samples from 29 diamond-drill holes on Manitoulin Island are contained in 2 open file reports (*see* Johnson and Telford 1981; Johnson 1983).

To outline potential areas for high purity–chemical grade dolostone, sample locations with SiO_2 less than 1.0% and SiO_2 less than 2.0% were plotted along with analyses of total impurities. Several potential areas of high purity stone, associated with 2 facies of the Amabel Formation, have been outlined. Other criteria such as topography, potential harbour sites, depth of overburden and formation thickness will be considered prior to the selection of sites requiring detailed sampling in 1993.

The criteria for high-purity limestone, to be used in the manufacture of lime, are a CaO content greater than 52% and a MgO content less than 1.75%. No previous samples have met this standard.

The requirements for cement are: 1) to use high-purity limestone and blend in clay or shale, silica, gypsum, and iron oxide to produce a mixture of the proper chemical composition, or 2) to use an argillaceous limestone (cement rock) which contains the ingredients for cement manufacture near the required amount. No samples of high-purity limestone were reported. The requirement for cement rock is a limestone with MgO less than 2.5%, SiO_2 less than 13%, and Al_2O_3 less than 3.7%. A total of 112 Ordovician samples representing surface and drill core samples were analyzed by Johnson (1983). Only 1 sample contained less than the required 2.5% MgO content. A total of 5 other samples contained MgO in the range 2.86 to 4.17% and met the other criteria. Surface samples were collected for analysis in 1992 in the area of the previous samples to confirm the chemistry and to determine the areal extent of the possible "cement rock". Ten samples were also collected from OGS Hole M79–10. This hole is located near one of the earlier samples and represents a typical section of the Georgian Bay Formation that would be encountered in quarrying.

Outcrops are also being evaluated for their building stone potential.

REFERENCES

Derry Michener Booth and Wahl and Ontario Geological Survey 1989. Limestone industries of Ontario, volumes I, II, III; Ontario Ministry of Natural Resources, Land Management Branch.

Johnson, M.D. 1983. Geochemical data: Manitoulin Island limestone-dolostone assessment project; Ontario Geological Survey, Open File Report 5383, 98p.

Johnson, M.D. and Telford, P.G. 1981. Preliminary results of 1978-1979 drilling programme, Manitoulin Island limestone-dolostone assessment project; Ontario Geological Survey, Open File Report 5360, 81p.

——— 1985. Paleozoic geology of Manitoulin Island; Ontario Geological Survey, Preliminary Maps P.2667 to P.2672 inclusive, scale 1:50 000.

53. Evaluation of Light and Heavy Rare Earth Content within Elliot Lake Mine Tailings

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Neodymium, one of the light rare-earth elements, is important for permanent magnets in the sensor and switching industries. Although the amounts used are small, the element has important attributes. Monazite is the principal ore mineral for the lanthanide rare earth elements that include neodymium.

In the Elliot Lake uranium ores, monazite is an important primary constituent (Roscoe 1969; Theis 1973). It is a resistate mineral that partitions with the heavy mineral suite of the Huronian sediments. These properties have also made it resistant to the processing that removed radioactive elements from the ores (Theis 1973; Prasad and Ruzicka 1992).

Acid leaching, which was used to recover uranium, thorium and yttrium, worked selectively and removed only portions of the rare earth elements. Comparison of the mill heads and tailings values at Denison Mines, for example, suggests that heavy rare earth elements (gadolinium, dysprosium, ytterbium and yttrium) were more effectively leached than light rare earth elements (lanthanum, cerium, neodymium and samarium). At the Rio Algom mill, by contrast, the whole rare-earth suite was assigned to the tailings by virtue of a different leach sequence.

Thus, it is possible that the Elliot Lake tailings constitute a stockpile of rare earth elements. Recent estimates of the tailings volume within the camp suggest a total of 150 million tonnes (Prasad and Ruzicka 1992).

This project will recover tailings material logged and stored at the CANMET Environmental Facility at Elliot Lake. The lanthanide plus individual element concentrations for a statistically representative sample of grains will be measured. If this phase shows promise, a more general examination of heavy minerals from other Elliot Lake tailings piles will conducted.

REFERENCES

Prasad, N. and Ruzicka, V. 1992. Yttrium, rare-earths, and radioactive elements in selected mine tailings, Elliot Lake, Ontario; *in* Current Research, Part C, Geological Survey of Canada, Paper 92–1C, p.53–58.

Roscoe, S.M. 1969. Huronian rocks and uraniferous conglomerates in the Candian Shield; Geological Survey of Canada, Paper 68–40, 205p.

Theis, N.J. 1979. Uranium-bearing and associated minerals in their geochemical and sedimentological context, Elliot Lake, Ontario; Geological Survey of Canada, Bulletin 304, 50p.

NODA • EDNO CANADA ONTARIO Northern Ontario Development Agreement Entente de développement du nord de l'Ontario Minerals • Minéraux

This project is part of the five-year Canada–Ontario 1991 Northern Ontario Development Agreement (NODA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the government of Canada and Ontario.

54. Native Liaison and Participation

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INTRODUCTION

The federal and provincial participants under the Canada–Ontario Northern Ontario Development Agreement (NODA) Administration, Communication and Evaluation Program, recognize that interaction between First Nations communities and the minerals industry must occur to enhance greater co-operative ventures. As a means of improving this interaction, this project was developed as a means of transferring new minerals information directly to interested First Nations communities through a liaison service with NODA field geologists and project managers. It would include provision of field trips, information sessions on project progress in individual communities, prospectors instruction and organization of awareness events for First Nation communities/reserves/organizations. The project is intended to establish a greater understanding of geoscientific research and the minerals industry in First Nations communities.

BACKGROUND

In 1924, Canada and Ontario passed Legislation entitled, "An Act for the Settlement of Certain Questions between the Governments of Canada and Ontario respecting Indian Reserve Land". This Act dealt with the transfer of certain other Reserve Lands, but also referred back to the Lands transferred by earlier (1915) legislation. It acknowledged that, with the consent of the bands, disposition of minerals on those Reserves could be made by the Federal Government for the benefit of the bands. This was a clear expression of Ontario's intent with respect to the Mineral Rights issue on the Reserve Lands transferred in 1915 (royalties collected by the Federal Government of Canada and the Province of Ontario were shared 50:50).

Sections of the 1924 Indian Lands Act can be superceded by the 1986 Indian Lands Agreement.

In 1991, Ontario acknowledged that the provisions of the 1924 Indian Lands Act did not apply to Treaty #3 First Nation reserve lands. Furthermore, in 1986, the governments of Canada and Ontario signed a Memorandum of Understanding (MOU) with the Nishnawbe-Aski Nation (NAN–Treaty #9) to enter into agreements that would provide the Nishnawbe–Aski Nation a greater role in the process of decision-making on matters that effect their lives. The 1986 commitment was reaffirmed in an Addendum to the Memorandum of Understanding in December 1989. On November 28, 1990, the Governments of Canada and Ontario and Nishnawbe–Aski Nation signed a three-year "Interim Measures Agreement" (IMA), on land and natural resources of that part of northern Ontario that is covered by Treaties #9 and #5. Under this agreement, the Nishnawbe–Aski Nation is entitled to be informed of any development, disposition of land or activities administered by Ontario Government regulation and will have "30 days" to respond to the proposed undertakings.

The agreement does not give the Nishnawbe–Aski Nation (NAN) direct management of the land and natural resources, rather allows for a process to share information, in response to the concerns expressed by the Nishnawbe–Aski Nation and its member communities.

In 1987, a Resource Development Agreement was signed by Dome Exploration (Canada) Limited and the Osnaburgh Indian Band, Windigo Tribal Council and the Government of Canada and the Government of Ontario.

In 1988, a similar Resource Development Agreement was signed by St. Joe Canada Incorporated with the Cat Lake Indian Band, Osnaburgh Indian Band and Slate Falls Indian Band, and the Windigo Tribal Council and governments of Canada and Ontario.

Recently, as a result of a renewed awareness of federal and provincial statutes by First Nations leaders/organizations, greater participation has been encouraged. It was an understanding in the past by all First Nations and Aboriginal Peoples that when treaties were signed with early European settlers, both parties or signatories to the agreement/treaty(s), would share the land.

The Government of Ontario as well as aboriginal communities recognize the need for mining and mineral exploration to be carried out in an environmentally responsible fashion; a principle that has been enshrined in the Province's new Mining Act. In the 1990s, with a more favourable political climate, the establishment of Resource Development Agreements, greater understanding of First Nations concerns by the private industry, prospectors, Ontario Geological Survey and Geological

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Survey of Canada staff, and greater participation of First Nations in the decision-making process, it can only be hoped that there will be a renewed increase in mineral exploration activity.

PROGRESS TO DATE

There are approximately 49 Canada–Ontario Northern Ontario Development Agreement (NODA) minerals projects approved for the 1992–1993 fiscal year, which fall under the following 6 program areas:

1. Mining and Minerals Technology
2. Geoscience
3. Information Transfer and Technology
4. Exploration Technology
5. Industrial Minerals and Economic Development
6. Administration, Communication and Evaluation

Projects initiated within these programs deal with a wide variety of subjects and include (not in any order) such diverse investigations as:

1. collection, classification and storage of files, maps and reports on past, current and future mining and minerals operations/activities;
2. till sampling, rock sampling, geochronologic and geochemical studies, airborne geophysical surveys, volcanology, alteration, metamorphism, ore mineralogy, petrographic studies, drilling, and chemical analyses;
3. compilation, research, analysis, investigation and reinterpretion of all existing data pertaining to rock deposits/mineral occurrences and tailing samples;
4. promotion and participation in international and national dimensional stone tradeshows, exhibitions, and conferences;
5. investigation and evaluation of industrial mineral markets and inventories of potential mineral aggregate deposits;
6. literature and field searches on a wide range of industrial minerals, which include dimensional stone (syenite, granite, gneiss/migmatite), crushed aggregate, limestone, aluminosilicates and garnets, pegmatites, building stone, graphite, quartzite, kyanite, vermiculite, silica, wollastonite, lime, and light and heavy rare earth elements;
7. detailed and regional lake and bottom sediment geochemical investigations; new geochemical mapping methodologies;
8. investigations of the stratigraphic record, new geoscience data bases;
9. new technology development and/or modification to address environmental and safety concerns as well as improve the mining industry's competiveness;
10. digitization of existing geoscience databases to improve access by the industry.

A native liaison officer was hired in late summer to implement the project. The first month and a half was spent with job orientation and familiarization. Past correspondence and files dealing with First Nations issues were reviewed and meetings held with individuals involved directly in various capacities with First Nations initiatives.

Following the issues orientation period, the focus was to become acquainted with as many individuals as possible involved with implementing the Canada–Ontario Northern Ontario Development Agreement projects. To date, project leaders located in the Algonquin, Sudbury, Porcupine, Thunder Bay and Schreider–Helmo districts and individuals located in the Sudbury main office have been contacted. Additionally, discussions and field visits have taken place with Resident Geologists, field geologists and staff from the Ontario Geological Survey and Geological Survey of Canada. In all, 16 NODA projects have been reviewed in areas such as the Swayze greenstone belt near Timmins and greenstone belts in the Manitouwadge and Shebandowan area.

These visits and interviews were necessary to provide a basic level of knowledge prior to contact and interaction with First Nations communities located in areas impacted by project work. A letter was recently sent to each First Nations reserve or community to serve as an introduction prior to meetings and presentation of project progress. A copy of the 1991–1992 NODA Summary Report, which includes the Agreement was also provided.

FUTURE PLANS

The process of project familiarization will continue throughout the winter. Follow-up meetings will be held with all First Nations communities interested in learning more of project results stemming from the NODA. Presentations will be arranged with project geologists and field trips planned for the spring. A report describing reception of this pro-active approach to government geoscientific investigations will also be prepared.

EXPECTED BENEFITS AND RESULTS

The goal of this project is to lay the foundation with the First Nations communities in northern Ontario for greater co-operation with the minerals industry. The information transfer comprising the most significant part of this exercise will serve to both educate and inform individuals of the basic scientific nature of government-led surveys and the usefulness of this information for various purposes.

55. Communications and Public Education

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Communication Services Branch, Sudbury

1991 COMMUNICATIONS ACTIVITIES SUMMARIZED

The Ontario Ministry of Northern Development and Mines (MNDM), together with Energy, Mines and Resources Canada (EMR) took the lead in developing a corporate identifier for the Northern Ontario Development Agreement (NODA), which established a new distinct identity while maintaining a link to the previous Canada–Ontario Mineral Development Agreement (COMDA). The Minerals sector of NODA took responsibility for producing Identification Guidelines in order to ensure consistency in the reproduction of the NODA identifier. These guidelines were provided to provincial and federal representatives from each of the 3 sectors of Minerals, Tourism and Forestry.

The Minerals Sector, including MNDM and EMR, co-ordinated a major media launch of the formal signing of NODA, which was in Sudbury on November 4, 1991, with simultaneous satellite launches in Sault Ste. Marie, Thunder Bay, Kirkland Lake and Timmins. The event hosted over 300 members of the minerals, forestry and tourism industries and saw both federal and provincial ministers attend the breakfast functions across the province. The event enjoyed a high level of coverage in all Canadian media, coast to coast, providing the minerals industry with immediate information following the announcement. This was accomplished through national TV link from Sudbury and a video and radio audio release from Kirkland Lake that was distributed on CNW's Canada-wide network.

In advance of a signed agreement, the Minerals Sector was allocated funds at the beginning of the 1991–1992 fiscal year to initiate several projects, which had been previously identified. The NODA Minerals Program(s) were first described at the Ontario Mines and Minerals Symposium in Toronto in December 1991 through a presentation by Leo Owsiacki and again at the EMR–GSC (Geological Survey of Canada) Open House and Minerals Colloquium in Ottawa in January 1992 through a poster board display. A summary of progress on these projects was published and distributed in March 1992. Two portable displays were developed and exhibited at the Prospectors and Developers Association Annual Conference (PDAC) in late March. Following the PDAC, the NODA exhibits were displayed at the Northwestern and Northeastern Mines and Minerals symposia in April in Thunder Bay and Timmins, respectively, and at the Canada–Wide Science Fair at Science North in Sudbury in May 1992. Logo buttons were produced and distributed as a means of highlighting NODA activities. Field hats and vehicle stickers were also produced for project personnel to assist in expanding the program's awareness in the north.

1992–1993 PROPOSED COMMUNICATIONS ACTIVITIES

Two primary communications objectives for the 1992–1993 fiscal year include dissemination of project information to the industry and general public and public education on the minerals industry in general.

Both EMR Canada and the Ontario MNDM will continue to approve new projects and arrange for media launches across northern Ontario. These projects will be announced from time to time to keep the public and industry informed of the work taking place across the province. Activities, such as the electromagnetic airborne survey in the Kirkland Lake area will be publicized through localized media events.

INFORMATION TRANSFER

In order to effectively disseminate information on a new project, press releases and/or a series of project launches were scheduled with the Minister of Northern Development and Mines.

A newsletter, aimed at the general public, will be produced and distributed in the Fall of 1992 and will serve to updatee and inform people of the location and goals of all approved projects to date. The 1992–1993 NODA Summary Report will detail, in more technical terms, the progress of all projects completed during the year and will be distributed in March 1993.

PUBLIC EDUCATION

A significant portion of the communications effort will focus on public education through venues such as exhibits, videos, print materials, and the development of an interactive computer display. Although geared toward the general public, special attention will be given to ensure that educational material is developed for Ontario school children.

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EXHIBIT DISPLAY SCHEDULE

Participation is these events (listed, with dates and locations, in Table 55.1) will enforce NODA's overall objective and outline specific initiatives undertaken by the Minerals Sector of NODA. A brochure will produced by EMR describing NODA's components and projects.

INFORMATIONAL MATERIALS

Various components (Table 55.2) will be designed to assist schoolteachers and students as well as the general public. Their purpose is to encourage Canadians to become more knowledgeable about the minerals industry, its products, its career opportunities, and its benefits to the Ontario economy.

Table 55.1. NODA exhibit display schedule, 1992–1993.

Event	Location	Date
Prospectors and Developers' Association Convention	Toronto	Mar. 92
MNDM Northwestern Symposium	Thunder Bay	Apr. 92
MNDM Northeastern Symposium	Timmins	Apr. 92
Canada–Wide Science Fair	Sudbury	May 92
Ontario Mining Week	Sudbury	June 92
Sudbury Gem and Mineral Show	Sudbury	July 92
Timmins Prospectors Rendez-Vous	Timmins	July 92
Cobalt Miners' Festival	Cobalt	July 92
International Conference	Sudbury	Aug/Sept 92
National Science and Technology Week	Ottawa	Oct. 92
MNDM Mines and Minerals Symposium	Toronto	Dec. 92
EMR–GSC Forum and Mineral Colloquium	Ottawa	Jan. 93

Plus up to 4 others in Central Northern and Northwestern Ontario.

Table 55.2. Proposed informational material.

Video	As a follow-up to the highly successful "Hidden Heritage" video, produced under COMDA, a new educational video will commence production in 1992–1993 with anticipated support from the minerals industry.
Ontario's Mineral Wealth	This high-quality flagship publication from the COMDA Agreement will be updated, slightly redesigned and re-released for distribution.
COMDA Final Report	This contains the complete project results document from the original COMDA Agreement which was not completed within the deadline time of the agreement. Since this document contains much material that pertains to Northern Ontario, it is a valuable scientific collection for the mineral and exploration industry.
Interactive Display	The initial development of an interactive display blending text, video, sound and graphics will be undertaken, to introduce the participant to the minerals industry in Ontario and outline the NODA initiative.
Print Materials	Various print materials will be produced during 1992–1993 which may include a "Teacher's Manual", produced originally as a companion piece to the COMDA video, "Hidden Heritage". Other publications under consideration are a companion brochure to accompany the NODA exhibit that could also be utilized by sector directors to outline the agreement for prospective contractors. Also included are a fall newsletter and a summary document published in time for the annual PDAC. Existing publications of Energy, Mines and Resources Canada and the Ontario Ministry of Northern Development and Mines that are applicable to the efforts of this communications activity, or are announcing a special anniversary or event pertaining to the Minerals Industry will be distributed during display activities to further reinforce the intergovernmental co-operation in this project.
Photo Library	Work will begin in the summer of 1992 on compiling a photographic library that can be utilized in documents throughout the agreement and in the final summary document in 1996. This will facilitate the development of classroom slide show sets for school use.

Index of Authors

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

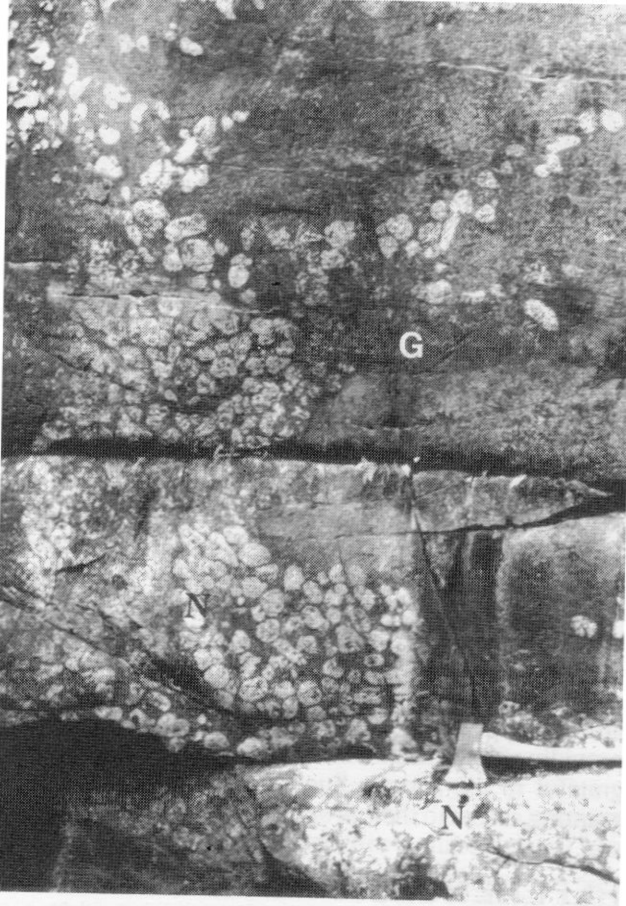
	Multiplied by	
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

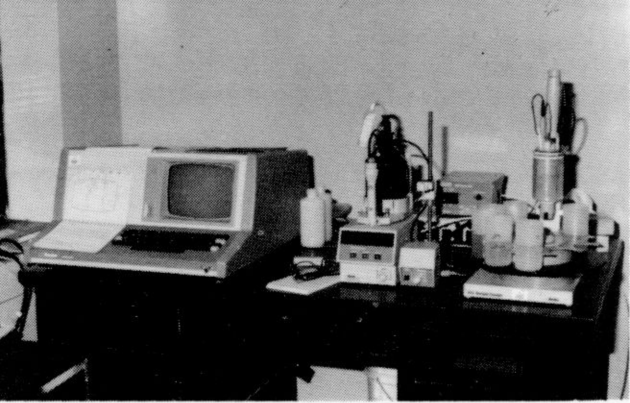
Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

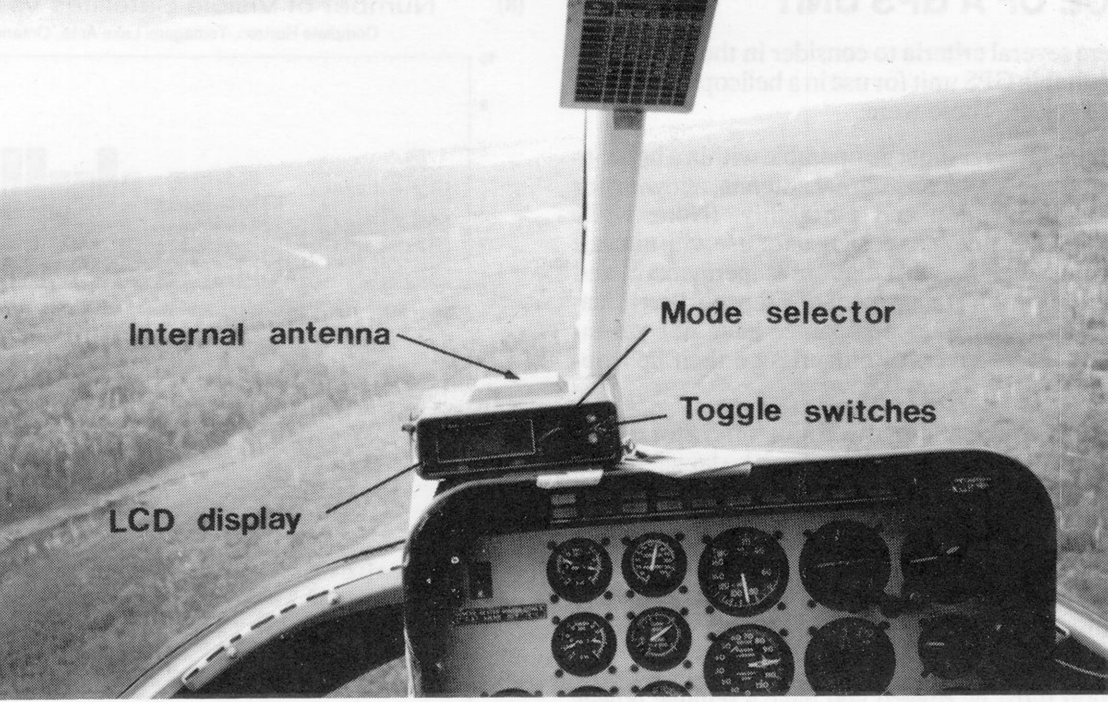

G
T


G
A
T

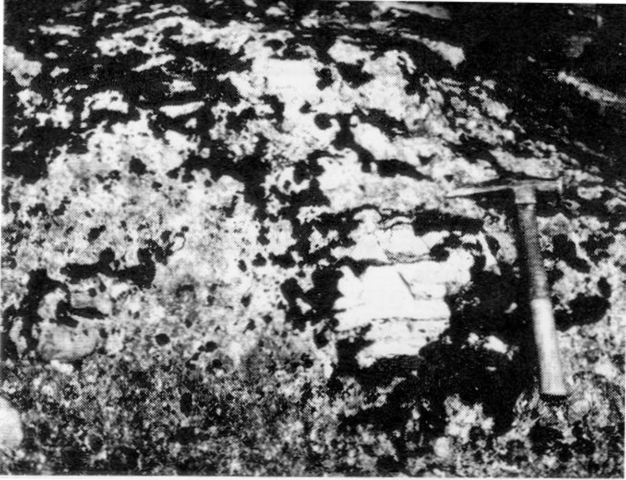

G
N


G
N
N




Mode selector
Internal antenna
Toggle switches
LCD display


0 1 2 3 4 5 6 7



L2
L2
L1
L1


0 1 2 3 4 5

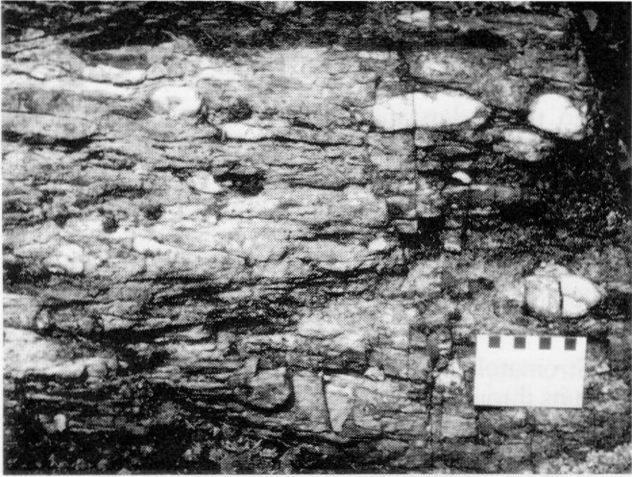
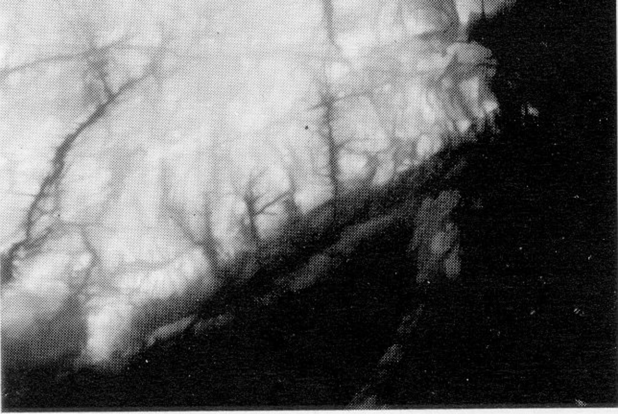
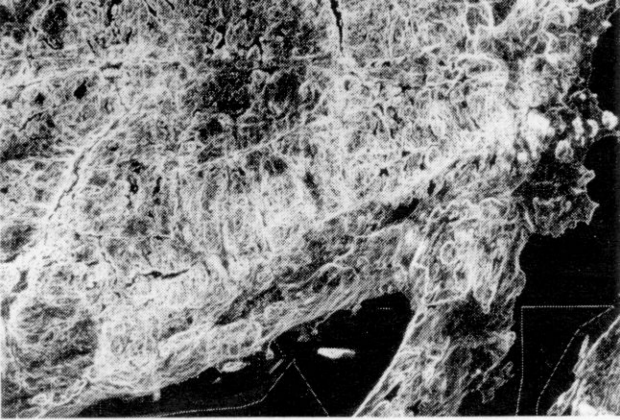
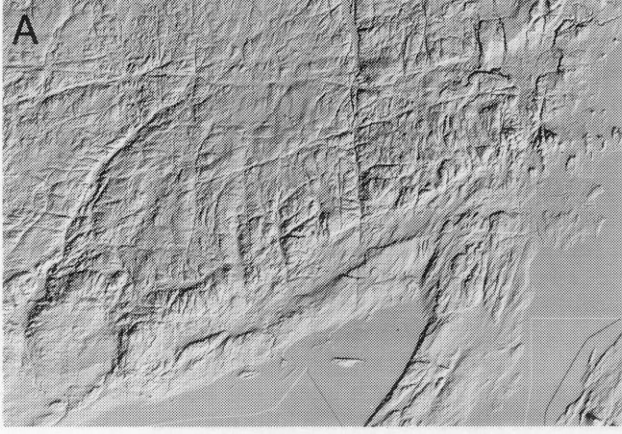
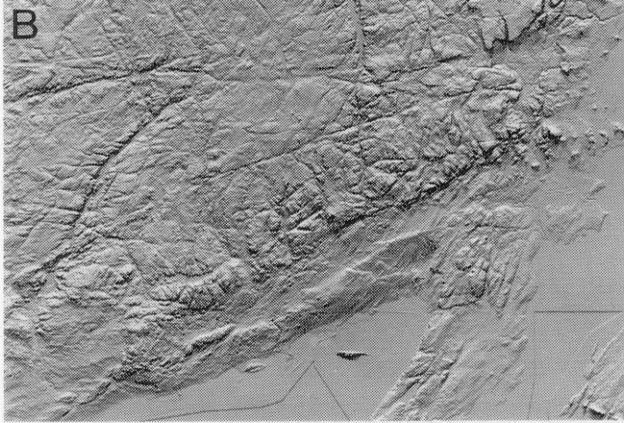


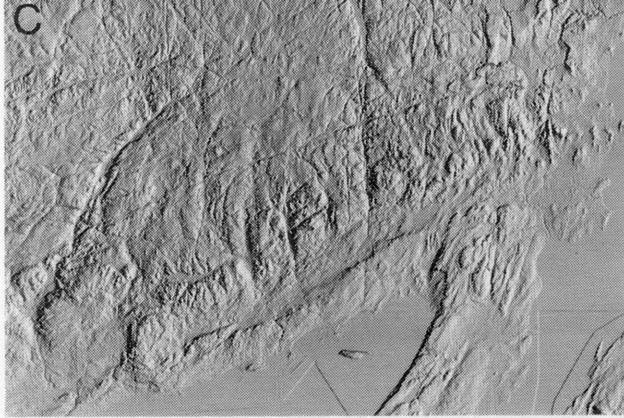
Photo 8.1 Monomictic, clast-supported quartz pebble conglomerate






A




C


A

B