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Mines and
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Division

Summary of Field Work and Other Activities 1989

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Foreword

During 1989, the Ontario Geological Survey carried out detailed, regional and province-wide compilation geoscience studies throughout the province. In addition, projects were undertaken in co-operation with Mines and Minerals Division geologists, personnel from universities and private consulting firms. Special geoscience programs were also undertaken in several areas under the Canada–Ontario Mineral Development Agreement (COMDA–ERDA) and with Northern Development Fund support. The 1989-90 year is the final one for COMDA. Project involvement by the various participants is summarized in individual reports.

A major effort of the Survey continues to be the "Geology of Ontario" project. This project consists of compilation geology and geophysical maps and an accompanying volume to mark the centennial of the Ontario Geological Survey in 1991.

The Survey continues to develop an electronic "fast-track" report and map publication service which will allow the Publication and Cartographic Services Unit to edit and produce a typeset report and coloured map within six months. This capability will have a significant positive impact for our clients.

A geophysical project has been initiated which will provide clients with new products. The project is the creation of a single continuous Master Aeromagnetic Grid for the province of Ontario. The Geological Survey of Canada is participating in the project and providing data from 41 surveys. A data base containing all the levelled aeromagnetic data in a flight line archive format will also be generated for users. From the grided data, colour total field magnetic maps, enhanced, processed derivative maps and shaded relief maps can be produced.

The locations of the areas investigated in 1989 are compiled on two maps of the province at the beginning of this report. Preliminary results of field work and other activities are outlined in this summary, which contains reports 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 mineral resource evaluation of these areas, which will be of value in current mineral exploration and 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 work data through the winter and will be preparing reports on these investigations for publication. In the interim, uncoloured preliminary maps with comprehensive marginal notes will be released for distribution. Notices of the release will be mailed to all persons or organizations on the Mines and Minerals Division publications release notification list, and will be published in technical journals and other media.

V.G. Milne

Director
Ontario Geological Survey

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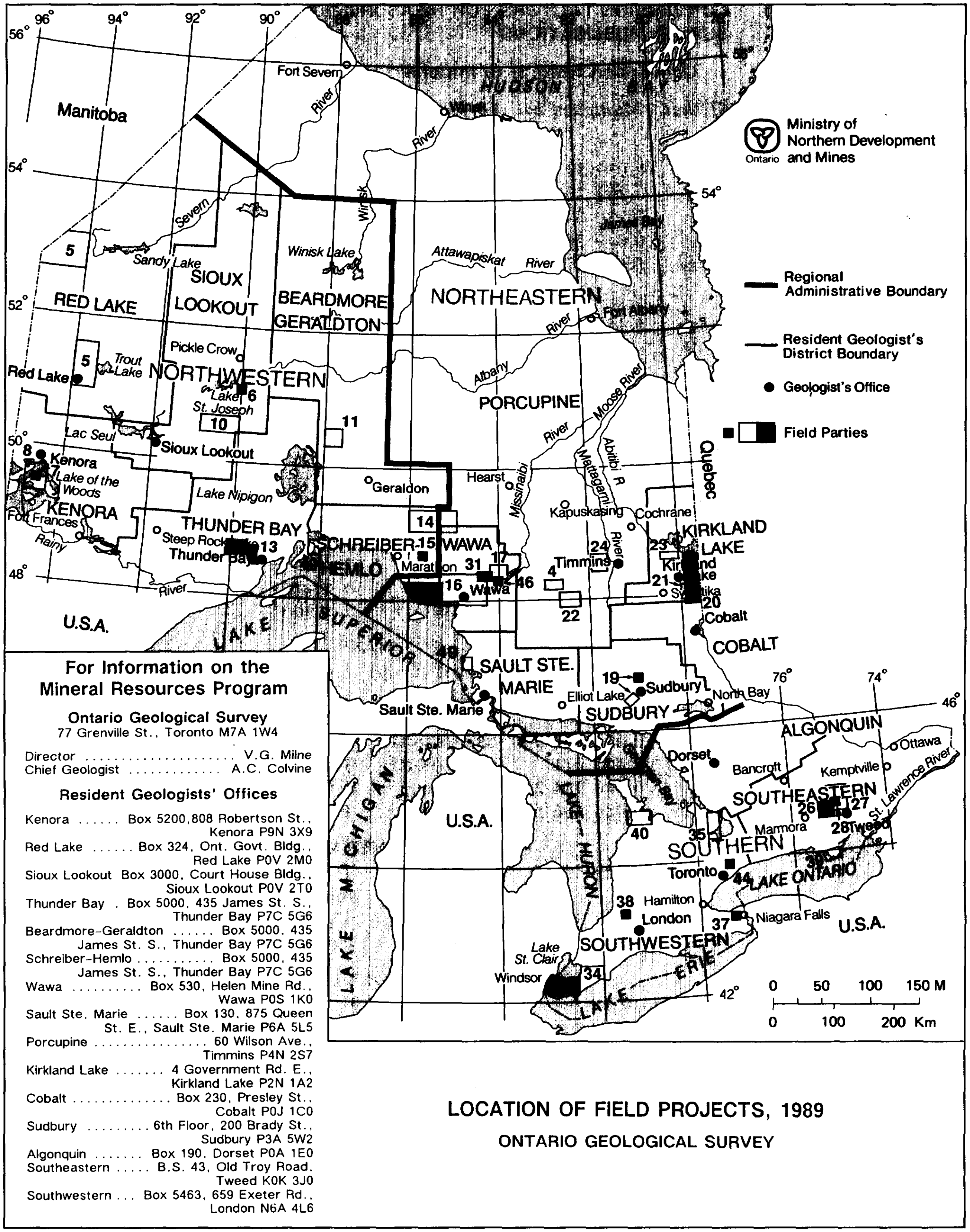
Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 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

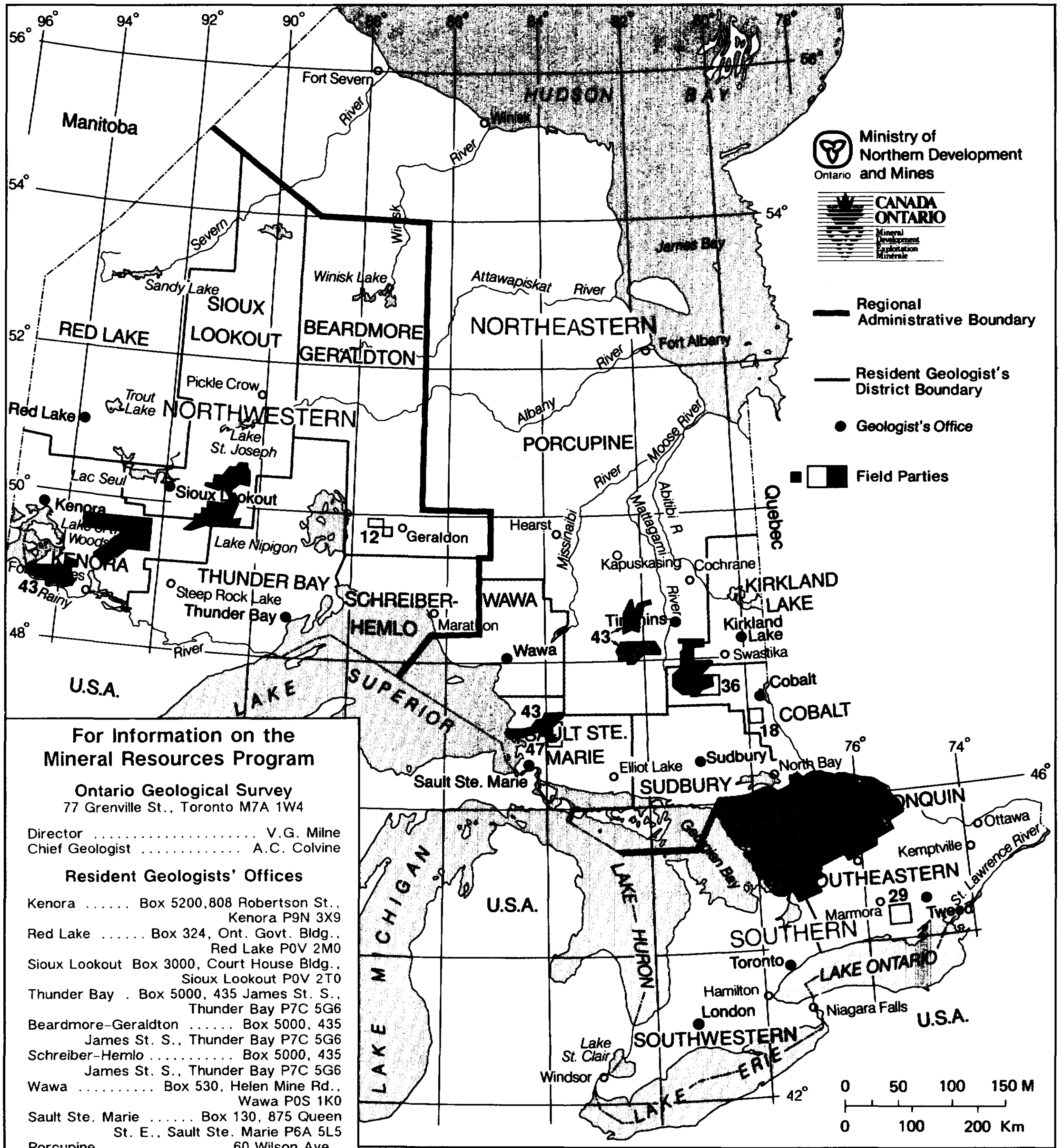
OTHER USEFUL CONVERSION FACTORS

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 cooperation with the Coal Association of Canada.



Location of Field Parties, base budget 1989



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LOCATION OF JOINTLY FUNDED FIELD PROJECTS,*† 1989

MINISTRY OF NORTHERN DEVELOPMENT AND MINES
ENERGY, MINES AND RESOURCES CANADA

* These projects are part of the five-year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario

† These projects are part of the five-year 1987 Airborne Geophysical Survey Program for Northern Ontario which is funded by the Northern Development Fund

Location of Field Parties, jointly funded projects 1989

Precambrian Geology Programs

1. Summary of Activities 1989, Precambrian Geology Section

A.C. Colvine

Chief Geologist, Precambrian Geology Section, Ontario Geological Survey.

Thirty projects directed by the Precambrian Geology Section during 1989 are reported in this volume. This represents a substantial decrease from 1988, due to the completion of a number of projects directed by the Ontario Geological Survey (OGS) under the five-year Canada–Ontario Mineral Development Agreement (COMDA). Nevertheless, the section can report a successful year with many significant achievements.

In the section's basic mapping program, five areas were investigated at a 1:50 000 scale, and five at a detailed 1:15 840 scale. Several more detailed field investigations, mainly around major, known mineral deposits or in areas of high economic potential, were also conducted. Office-based investigations were centred on the preparation of a volume and maps (1:1 million scale) for the Geology of Ontario project, scheduled for completion in 1991 to celebrate the centennial of the OGS and its predecessors. Efforts to prepare new 1:250 000 scale compilation geological maps and work on a digital computer-based mapping and geological data storage system continued. The section also continued its co-operative, multiyear program on the Sudbury Structure with the University of Munster in Germany.

Reconnaissance mapping at a 1:50 000 to 1:100 000 scale continued from 1988 in the Berens River Subprovince north of Red Lake to subdivide large areas of granitic terrain and possibly identify economic targets. Synoptic mapping projects were begun in the Lake of the Woods area and in the Wawa area to integrate and interpret the results of recent detailed mapping. Synoptic maps and reports represent the culmination of several years of detailed mapping, and are valuable products which are frequently used by the mineral exploration industry.

Two projects were undertaken which combine detailed geological mapping in a more regional context. In the Savant and Sturgeon lakes area, selected detailed mapping will be used to complement recent mapping in a regional geological synthesis. Similarly, new detailed mapping is being conducted in the Larder Lake area to re-examine long-lived problems with the structural geology and stratigraphy.

Detailed mapping projects were conducted in the Caron Lake area north of Pickle Lake, in the Lake of the Woods area, west of Geraldton, northeast of Lake Nipigon around Toronto Lake and near Madoc in southern Ontario. All of these projects are in areas of considerable economic potential. In the Lake of the Woods area and east of Geraldton, the 1989 projects complete multiyear detailed mapping programs. The Caron Lake project constitutes the first year of a detailed mapping program of the Misehkow River area along the boundary of the Uchi and English River subprovinces of the Superior Province. Results are encouraging and this research will help to better define the nature of the subprovince boundary in this area and will provide valuable data on the economic potential of this little known part of northern Ontario.

Tectono-stratigraphic investigations, comprising very detailed mapping in the area of the Hemlo gold deposit, were completed this year. This detailed work has revealed the very complex geological history of the Hemlo area, and continues to provide clues to the search for other large and rich deposits. Preparation of a report and maps is in progress.

Other specific and detailed field investigations dealt more directly with aspects of economic geology. Studies of the setting and metallogeny of known gold deposits continued in the Missanabi–Renabie area and in the Swayze belt of the

Abitibi–Wawa Subprovince of the Superior Province. Other, broader metallogenetic investigations and detailed mapping projects were located in the Temagami greenstone belt, the Matheson area of the Abitibi Subprovince and around the Deloro pluton near Madoc in the Grenville Province. All of these projects will provide information on specific deposits and mining camps that, in general, will lead OGS and mineral exploration geologists to a better understanding of Ontario's mineralization environments.

Work on the OGS centennial project continues. The geological map of Ontario at a scale of 1:1 million is well under way and projected for release in 1990. The preparation of a tectonic map and a metallogenetic map is in progress, and contributions to the centennial volume are currently being written. Minor field investigations, for example on the stratigraphy and sedimentation of the Grenville Supergroup and on stratigraphic and metallogenetic problems in the Grenville Province, were conducted during the summer to clarify geological relationships before embarking upon writing parts of this comprehensive centennial volume.

The section has contributed to seismic investigations currently being planned or carried out in various parts of Canada as part of the Lithoprobe project. Preliminary Lithoprobe surveys were performed in 1987 across parts of the Abitibi Subprovince and the Kapuskasing structural zone in Ontario. These surveys provide geoscientists with a three-dimensional picture of the earth's crust and a base for understanding the stratigraphic and structural assembly of the Shield and its mineralization environments. Several of our geologists are involved in the interpretation of the Abitibi and Kapuskasing Lithoprobe profiles and in the planning of future profiles in the Abitibi Subprovince, the Sudbury structure and the Grenville Province. Related to this effort is the trenching done in the Kapuskasing structural zone, where poor exposure prevented reliable interpretation of the seismic data.

Two post-graduate students of the Institute of Planetology of the University of Muenster, Federal Republic of Germany, continued their investigations on the Sudbury Breccia and the heterolithic breccias of the Onaping Formation, both rock units related to the origin of the Sudbury Structure. The 1989 investigations constitute the sixth field study done by the German institute in the Sudbury area in co-operation with the Ontario Geological Survey. The objective of this co-operative program is a better understanding of the origin of the Sudbury Structure, possibly the only multiring structure on Earth.

Several of our geologists continue to play a substantial role in the national and international geoscience community. Staff presented scientific talks at several conferences and a number of papers were published or submitted for publication in scientific journals. Staff members acted as referees or auditors of scientific papers, and as supervisors or referees for university dissertations, and were invited to lecture at major international universities.

2. Project Unit 89-23. Geology of Ontario: Update for 1989

P.C. Thurston

Senior Research Geologist, Ontario Geological Survey.

INTRODUCTION

The Geology of Ontario project will provide an overview of the geology of the province, involving participation of the Geophysics/Geochemistry Section, the Engineering and Terrain Geology Section and the Precambrian Geology Section of the Ontario Geological Survey. The project will produce a series of maps, covering the entire province at a scale of 1:1 000 000 and including bedrock geology, tectonic, metallogenic and surficial geology maps, and primary and derived magnetic and gravity maps. An accompanying volume will provide a description of the entire geologic column from Middle Archean to Pleistocene. This volume will consist of: an introduction; a descriptive summary of the province, incorporating a discussion of the major mineral deposit types; a thematic section, providing summary statements on aspects of the geology, for example, Archean structural geology; and a summary emphasizing tectonic development of the geology of the province.

As of September 1989, assembly of the geological map is essentially complete and it is ready to be submitted for final cartography and printing. Compilation of the tectonic map has started (*see* Stott, Paper 3, this volume), and will be followed by conceptual design of the metallogenic map. Compilation of the magnetic maps is well advanced and production of the gravity maps will follow shortly (*see* Gupta, Paper 45, this volume). Compilation of the surficial geology map of southern Ontario is well advanced and the surficial geology map of northern Ontario is essentially complete. Various parts of the accompanying volume are in progress.

The Geology of Ontario project accomplishes far more than simply a recompilation of the geology of the province. The distinction of Middle Archean from Late Archean supracrustal rocks has fundamental implications for mineral potential with respect to copper-zinc deposits and komatiite-related nickel deposits. The project will generate many practical mineral deposit-related spin-offs and will have an effect in areas such as environmental geology, land use planning decisions and planning for future OGS mapping. Some of these relationships are discussed below. In this report, brief mention is made of work in progress by various OGS staff, which constitute personal communications to be reported more fully in the various maps and the Geology of Ontario volume. For the sake of brevity, these individuals are referenced by name only.

GEOLOGICAL MAP

The new geological map uses lithostratigraphic subdivisions for Precambrian supracrustal units, where possible, and stratigraphic subdivision for the Phanerozoic. The legend for the new map has undergone minor change since 1988, principally with respect to subdivision of the Middle Archean (3400-2900 Ma) greenstone units. The final legend for this subdivision now recognizes most of the supracrustal units of the younger greenstone belts: mafic metavolcanic rocks, felsic to intermediate metavolcanic rocks, quartz-rich metasedimentary rocks and ultramafic metavolcanic rocks.

In addition, the diabase dikes and equivalent intrusions have been subdivided into swarms, based upon the nomenclature of Halls and Fahrig (1987). With advancing knowledge of the timing of dike events, work by I. Osmani and R.H. Sutcliffe has linked most dike swarms with particular tectonic events; therefore, subdivision into the various swarms listed in Table 2.1 is warranted. An example of the utility of dike swarm subdivision is shown in Figure 2.1.

SUBPROVINCE TYPES

Subprovinces within the Superior Province are predominantly fault-bounded regions; each displays relative homogeneity of rock association, structural regime and age range. The Superior Province can be subdivided into granite-greenstone, sedimentary, gneissic and plutonic subprovinces (Figure 2.2). These attributes can be compared directly (*see* Stott,

TABLE 1. DIABASE DIKES IN THE SUPERIOR PROVINCE OF ONTARIO. AGES ARE BASED ON PRECISE U/Pb GEOCHRONOLOGY.

Grenville Swarm	~575 Ma
Frontenac Swarm	850–900 Ma
Logan and Nipigon Sills	1109 Ma
Pigeon River and Pukaskwa Swarms	
Abitibi Swarm	1141 Ma
Mackenzie Swarm	
Sudbury Swarm	1238 Ma
Molson Swarm and Related Sills (Sutton Inlier)	1884 Ma
Wabigoon Swarm	
North Channel Swarm	1900 Ma
Preissac Swarm	
Marathon Swarm	
Kenora–Fort Frances Swarm	
Nipissing Sills	2219 Ma
Matachewan and Hearst Swarms	2454 Ma

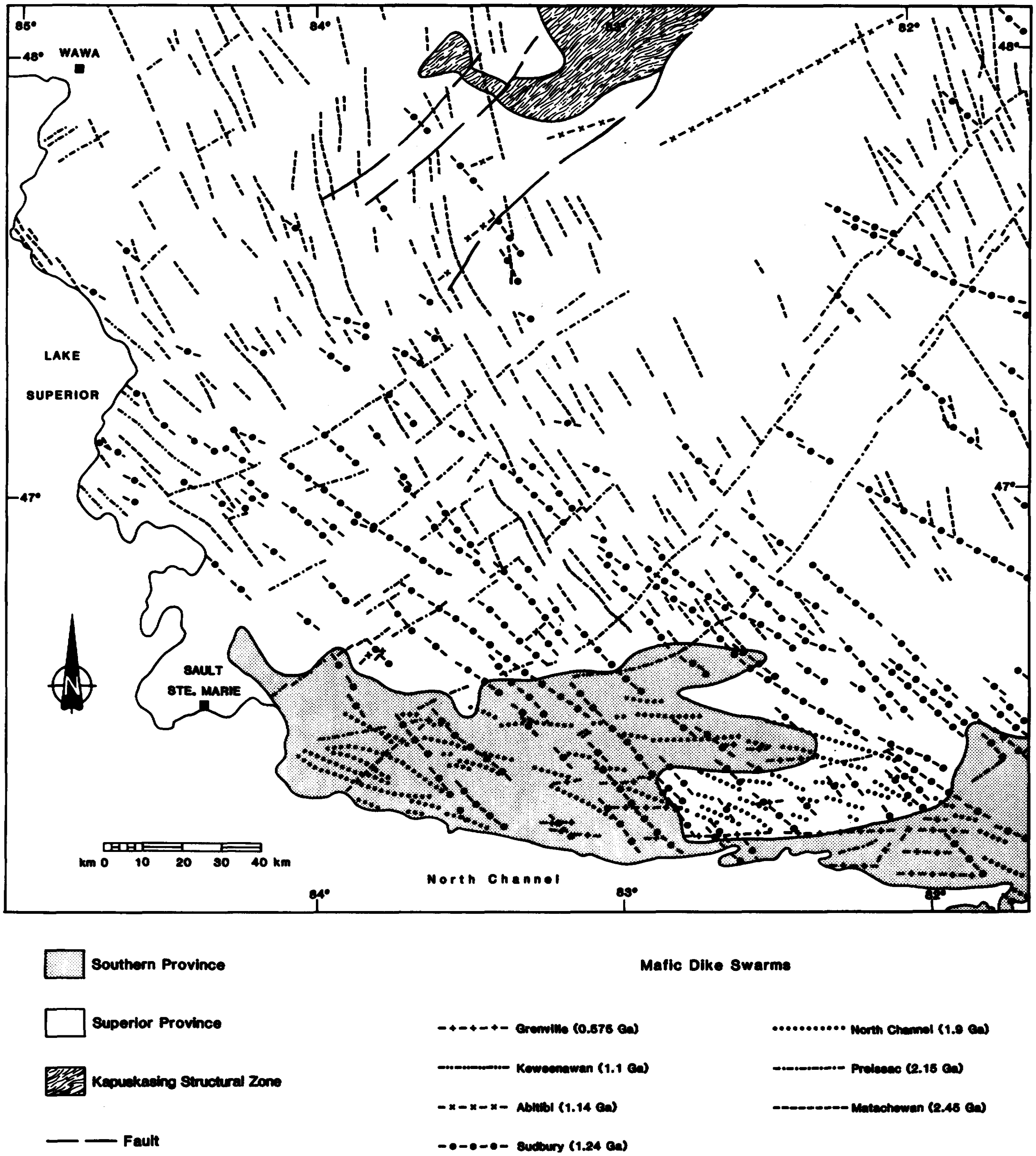

Figure 2.1. *Diabase dike swarms in the vicinity of Sudbury and Sault Ste. Marie, illustrating the many swarms present in the southern part of the Superior Province and the Southern Province.*

Paper 3, this volume) to the terranes of modern orogens.

GREENSTONE SUBPROVINCES

Granite-greenstone subprovinces contain at least four types of greenstone lithostratigraphic assemblages (Thurston and Chivers, in press), which form the basis of some of the greenstone belt units on the revised geological map. These lithostratigraphic assemblages are:

1. quartz-rich platform sequences and resedimented equivalents (Cortis 1988; Cortis et al. 1989) which, based on limited data, approach ~3 Ga

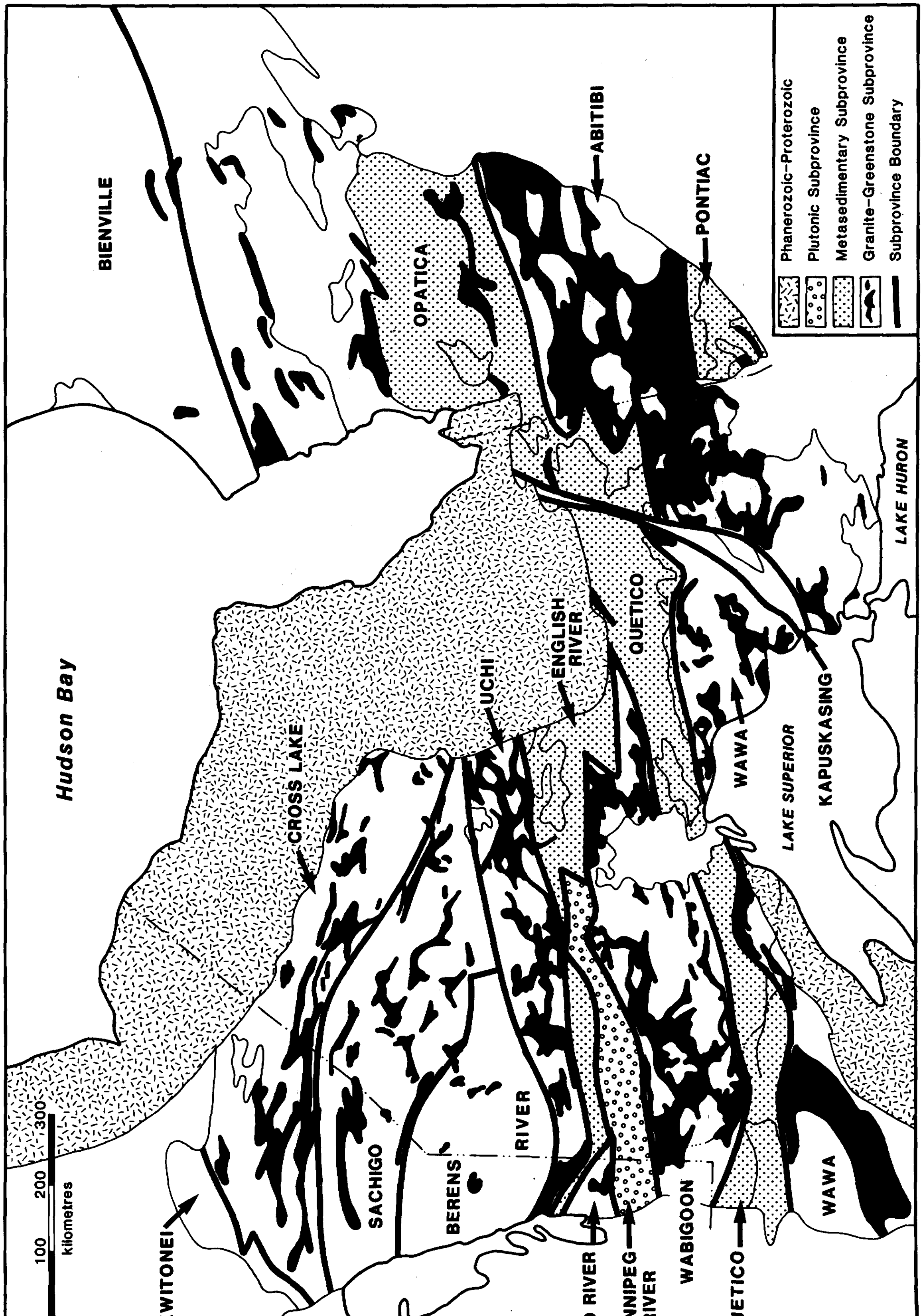

Figure 2.2. *Subdivisions of the Superior Province into granite-greenstone, sedimentary, gneissic and plutonic subprovinces.*

2. mafic plain sequences (~2.7 Ga) of tholeiitic and komatiitic massive flows with thin pillowed tops, intercalated with deep water pelagic sediments
3. mafic to felsic, cyclical (arc-type) volcanic sequences (~2.7 Ga) ranging from full fractionation type to bimodal (Thurston et al. 1985), which are variably subaerial to subaqueous
4. pull-apart basins (Timiskaming-type sequences), often unconformaoly overlying older greenstones, usually fault bounded, and characterized by fluviatile sediments and alkalic to calc-alkalic volcanics. These sequences have been proposed (based upon suggestions of G.M. Stott) as varying from simple extensional basins developed during the waning stage of arc volcanism (e.g., Carter 1988) to true pull-apart basins characterized by strike-slip faulting during basin development (e.g., the Timiskaming of the Abitibi Subprovince (Cooke and Moorhouse 1969)).

The granite-greenstone subprovinces as developed by Card and Ciesielski (1986) are listed below from north to south. Our compilation, however, suggests some modifications in the existing subprovince nomenclature may be required. The following discussion makes use of precise U/Pb ages determined by D. Davis and F. Corfu at the Royal Ontario Museum.

SACHIGO SUBPROVINCE

The Sachigo Subprovince of Card and Ciesielski (1986) is the northernmost of the granite-greenstone subprovinces. However, the region north of the Stull Lake–Wunnummin Lake fault zone (Osmani and Stott 1988) is dominated by arc volcanics without the platform sequences which typify greenstone belts within the subprovince south of this fault zone. Therefore, future revision of the Card and Ciesielski scheme may designate this distinctive region the Cross Lake Subprovince (cf. Stockwell 1982)

Lithologic trends within the greenstones of the Sachigo Subprovince greenstones vary from east to southeast. Belts trend across the subprovince; Osmani and Stott have traced them, via migmatite screens and aeromagnetic trends, into the northern part of the Uchi Subprovince. Greenstone belts in the southern part of the Sachigo Subprovince and the northern Uchi Subprovince include arc and platform sequences. As well, there is no major shear zone separating the Uchi and Sachigo subprovinces; for example, in the area north of Red Lake (Stone 1988). Therefore, our work (Stott and Thurston) has shown that the southern Sachigo Subprovince is similar to the northern part of the Uchi Subprovince—revisions to subprovince boundaries may reflect this.

UCHI SUBPROVINCE

The Uchi Subprovince consists of distinct northern and southern parts. The northern part contains 2.9 to 2.8 Ga, platform-type greenstone belts (Thurston and Chivers, in press), which generally trend east but commonly wrap around granitoid batholiths, resulting in less common northeast and northwest trends. The southern part contains 2.8 to 2.7 Ga, east-trending arc volcanics and subordinate, pull-apart basin sequences (e.g., Birch Lake). The northern and southern parts are locally separated by shear zones which may be of regional significance (Stott et al. 1989).

BIRD RIVER SUBPROVINCE

This subprovince lies between the English River and Winnipeg River subprovinces (Card and Ciesielski 1986). At present, no boundary fault between the Winnipeg River and Bird River subprovinces has been located within Ontario.

WABIGOON SUBPROVINCE

The Wabigoon granite-greenstone subprovince consists of three distinct regions:

1. the western Wabigoon, between Lake Winnipeg and the Atikokan area
2. the Wabigoon plutonic axis (formerly termed the "diapiric" axis)
3. the eastern Wabigoon, which consists of the Geraldton–Beardmore, Tashota–Onaman and Marshall–O'Sullivan domains (after Blackburn and Johns 1988)

The western and eastern parts of the Wabigoon Subprovince contain mafic plain sequences (Thurston and Chivers, in press) and 2.7 Ga (Davis et al. 1986) arc volcanics with minor pull-apart basins (e.g., the Seine sequence of Davis et al. (1989) and the Sunshine Lake volcanics (Blackburn 1979)). The Wabigoon plutonic axis, in the central part of the subprovince, consists predominantly of granitoids and greenstones. Within this granite-greenstone region are isolated remnants of an older (2.9 Ga) platformal greenstone sequence (i.e., Atikokan and Lumby Lake sequences) that overlies a 3.0 Ga plutonic suite. Both the platformal sequence and the plutonic suite were subjected to a 2.8 Ga metamorphic event (Davis and Jackson 1988). The boundaries between the Wabigoon plutonic axis and the flanking eastern and western Wabigoon are as yet undefined.

The widespread but fragmentary evidence for an ancient supracrustal and plutonic crustal development and a 2.8 Ga metamorphic event (e.g., Davis and Jackson 1988; Davis et al. 1986) in the Wabigoon plutonic axis contrasts with the significantly younger greenstone development and 2.7 Ga metamorphism in the terranes to the east and west. The tectonic significance of the various subdivisions of the Wabigoon Subprovince remains obscure but the geological record locally contains remnants of an older sialic and greenstone crust against which younger greenstones were deposited or tectonically juxtaposed.

ABITIBI SUBPROVINCE

This subprovince contains greenstones ranging in age from 2750 to 2700 Ma. There are, however, minor 2.8 Ga greenstones and plutonic units in the Wawa area (Turek et al. 1984). The subprovince consists of arc volcanics, mafic plain sequences and pull-apart basins such as the Timiskaming (Thurston and Chivers, in press). The eastern part of the subprovince has been considered a simple synclinorium (Jensen 1985). Recently completed geochronological work has shown that there is no systematic younging toward the centre of the greenstone belt (Corfu et al., in press). The general distribution of rock units and the structural and geochronological data show that the eastern part of the Abitibi Subprovince in Ontario is a series of shear-bounded panels that display a consistent younging direction, which cannot be explained by regional scale folding alone. The structural and geochronological data indicate that near layer-parallel shear zones facilitated assembly of greenstone sequences into what is now the Abitibi Subprovince. The Abitibi, perhaps in common with the Wabigoon Subprovince, represents an Archean analogue to a composite terrane, for it is cut by two major, east-trending, subprovince-parallel shear zones (the Porcupine–Destor and the Cadillac–Larder Lake shear zones) that had a protracted history.

SEDIMENTARY SUBPROVINCES

The previous edition of the provincial geological map (Ayres et al. 1971) did not distinguish sedimentary (English River and Quetico) subprovinces from sediments in greenstone belts. Subsequent work has shown that these sedimentary subprovinces consist of vast areas of wacke, with slightly coarser clastic sediments at the margins and minor mafic and/or ultramafic units, mapped as intrusions, sediments and tectonically emplaced bodies. The deformation pattern in the Beardmore–Geraldton area (Percival and Williams 1989), an area not obscured and complicated by late strike-slip faulting, shows that the Quetico is best explained as an accretionary prism shortened against the older volcanic rocks of the Wabigoon Subprovince. The English River Subprovince may also fit this model, although the subprovince boundary is enormously complicated by late faulting (Williams 1988; Sanborn-Barrie 1988). The prevailing view has been that the metamorphism of sedimentary subprovinces is characterized by the presence of a central, high rank node fitting a thermal anticline model (Thurston and Breaks 1978). However, Breaks and co-workers have mapped two occurrences of granulite facies units along the margins of sedimentary subprovinces (Breaks 1988; *see* Williams and Breaks, Paper 14, this volume). Metamorphism of sedimentary subprovinces is partly a function of local and regional granitoid emplacement, but is also controlled by processes of tectonic thickening, especially at subprovince margins. The development of rare metal pegmatites around late plutons is in part controlled by the regional metamorphic milieu.

GNEISSIC SUBPROVINCES

Many areas previously considered gneissic subprovinces, such as the English River and Quetico subprovinces, are now classified as sedimentary subprovinces. Some areas of gneissic rocks, such as the Berens River Subprovince, are now classified as plutonic subprovinces.

The Kapuskasing Structural Zone (KSZ) is composed of a variable succession of granulite and amphibolite facies meta-igneous gneisses and supracrustal rocks (Percival and Card 1985). These represent the midcrustal levels of the varied granite-greenstone and sedimentary subprovinces that the KSZ traverses. The KSZ is not considered to be a separate subprovince type because of its inhomogeneity and its western, gradational contact with normal subprovince rocks and structures.

PLUTONIC SUBPROVINCES

Plutonic subprovinces include the Berens River and the Winnipeg River subprovinces. The Berens River Subprovince includes 2.9 Ga granitoid units (Krogh et al. 1974) and intensely deformed, north-trending greenstone remnants (Cortis et al. 1988) which lithologically resemble the platformal greenstones of the Sachigo and northern Uchi subprovinces. These units are cut by K-feldspar megacrystic granitoids of 2.7 Ga age (Krogh et al. 1974). Although the subprovince is bounded on the north by the Bearhead fault zone (Osmani and Stott 1988), there is no distinct tectonic boundary at the south margin. The similarity of structural trends in the greenstone remnants and in foliated plutonic rocks (Stone 1988; *see* Stone, Paper 05, this volume) suggests the Berens River Subprovince may represent a deep erosional level of the northern Uchi or southern Sachigo granite-greenstone subprovinces. This was extensively invaded by granitoids 2.7 Ga, and therefore may represent the deep levels of a continental magmatic arc (cf. Hoffman 1989).

The Winnipeg River Subprovince includes gneissic units and granitoids that are 3.17 to 2.7 Ga in age (Corfu 1988). The bulk of granitic activity is ~2.7 Ga and this subprovince may also represent a continental magmatic arc (Hoffman 1989).

GRANITOIDS

The legend for the new geologic map includes a fourfold subdivision of Superior Province granitoids into: a gneissic tonalite suite, a foliated tonalite suite, a diorite-monzonite-granodiorite suite and a massive granodiorite to granite suite. This subdivision was devised mainly by R.H. Sutcliffe, G.P. Beakhouse and G.M. Stott. Geochronologic data suggest that these lithologic subdivisions represent the generally observed, secular, local and regional progression in granitoid magmatism. In addition, ages of ~2.7 Ga posttectonic granites become younger southward from the Uchi to the Abitibi Subprovince (Stott et al. 1987). However, anomalous features that modify this arrangement include:

1. overprinting of the overall southward-younging pattern by ~2.7 Ga K-feldspar megacrystic granitoids in the Berens River and Sachigo subprovinces (Corfu et al. 1985)
2. posttectonic plutons in the Sachigo Subprovince, which may be older than those in the subprovinces to the south (Stott et al. 1989). Posttectonic plutonism in the Sachigo Subprovince is older than the 2.7 Ga Kenoran orogenic event and may reflect an earlier, pre-Kenoran orogeny.

SOUTHERN PROVINCE

Progress is being made in synthesizing the stratigraphy of the Huronian Supergroup in the Southern Province. New work on the Huronian volcanic rocks (Thessalon greenstones, Jolly 1987) and the Livingston Creek Formation (G. Bennett and B.O. Dressler) will be reported in the Geology of Ontario volume. The legend for the geologic map for units of the Southern Province has benefited from several new U/Pb zircon ages, which eliminate former stratigraphic ambiguities (e.g., Davis and Sutcliffe 1985).

GRENVILLE PROVINCE

Relative to the 1971 edition of the provincial geologic map (Ayres et al. 1971), substantial progress has been made in our understanding of the Grenville Province. Following Davidson (1984), the Grenville Province has been subdivided by R.M. Easton into blocks bounded by major shear zones, i.e., a succession of terranes including the Grenville Front Tectonic Zone (largely reworked Archean units), the Central Gneiss Belt (largely lower and middle crust), the Central Metasedimentary Belt Boundary Zone (formerly the Central Metasedimentary Belt, now subdivided into the Bancroft, Elzevir and Sharbot Lake terranes) and the Frontenac Terrane. The Bancroft, Elzevir and Sharbot Lake terranes are fault bounded and characterized by distinctive volcanic assemblages (*see* Easton, Paper 25, this volume). The tectonic pattern is similar in scale to, and was developed using criteria consistent with, those developed for the Superior Province (*see* Stott, Paper 3, this volume).

PHANEROZOIC

The legend for Phanerozoic units has been extensively revised such that, whereas major subdivisions are based on geologic periods, as shown in last year's report (Thurston 1988), individual stratigraphic units are also shown. Units are displayed either at the formation or group level, depending upon the demands of the final map scale. This will allow much more detailed information to be presented on a province-scale map. In contrast to the 1971 edition (Ayres et al. 1971), several major fault systems cutting the Paleozoic stratigraphy, mainly in southern Ontario, are shown. This work, by D. Russell and M.D. Johnson, will affect continuing neotectonic studies in southern Ontario. The new map will also show the major subdivisions of the Grenville Province even where covered by Paleozoic rocks, allowing the interpretation that fault reactivation of Grenville structures occurred during Phanerozoic time.

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3. Project Unit 89-47. The Tectonic Assemblage Map of Ontario

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INTRODUCTION

Ontario is underlain by a prominent and accessible portion of the North American craton and some of the most important tectonic events in the formation of this craton are exposed here. In recent years, workers have attempted to decipher these events with greater confidence, although the critical patterns of age relationships and tectonic setting are still being debated and tested. We have reached a stage at which we can fruitfully begin to compile tectonic elements of this craton in Ontario as we presently understand and interpret them. As part of the Geology of Ontario project, we are presently assembling a tectonic assemblage map of Ontario, to be published at a scale of 1:1 000 000, which will illustrate the distribution of tectonic assemblages and ages of rocks in the tectonic provinces, orogens, fold belts and basins of Ontario. The map will comprise four map sheets and a sheet containing the legend and time-space charts for the Archean, Proterozoic and Phanerozoic eons.

The purpose of this summary is to explain the rationale for the map's design, to review its legend and format, and to illustrate, as an example, part of the map and legend from the Archean Uchi Subprovince.

RATIONALE FOR THE MAP

Keppie (1981) stated that "A tectonic map attempts to portray the origin and evolution, in space and time, of a region". By its nature, a tectonic map is interpretive. Plate tectonic theory is used as the basis for map design and interpretation for modern tectonic maps; however, the application of plate tectonics for the Archean is only recently being developed with field-based analyses. Since the tectonic assemblage map of Ontario must convey our best interpretation of the origin and evolution of rocks ranging in age from Middle Archean to Cretaceous, it was decided that the map should build on basic features such as rock age, structures, and depositional or tectonic setting, that can be represented in each of the tectonic domains (tectonic provinces, orogens or basins). The degree of understanding of the tectonic framework and setting in each of these domains and, hence, the degree of required interpretation, vary widely across Ontario. Accordingly, we are faced with multiple challenges: to convey as much useful and relevant information as possible without harming the aesthetic appeal and readability of the map; to accommodate the diversity of knowledge of different tectonic domains in Ontario within a legend that is not unwieldy for the reader and yet still conveys the principal subdivisions within each domain; and to extrapolate our local knowledge as much as possible so as to interpret the tectonic patterns in each domain on a regional scale. To fulfill these objectives, a number of aspects were incorporated into the map design.

There are two basic features that can be portrayed with varying degrees of interpretation across all tectonic domains in Ontario: 1) subdivisions of plutonic and supracrustal units by age, and 2) subdivisions of supracrustal rocks into depositional or tectonic settings. Since the Archean Superior Province is by far the largest domain in Ontario, the limits to our understanding of this domain inherently govern how we portray these tectonic elements. At present, the tectonically relevant aspect with the best control across Ontario is the subdivision of supracrustal sequences and plutonic suites by age. We are at present able to identify more subdivisions of age than of tectonic setting in the Archean. Of the cartographic elements (colour, ornamentation, symbols and alphanumeric notations) available for portraying patterns, colour is the most visibly dominant and will be used to show age of supracrustal sequences and plutonic rocks.

Assigning supracrustal rocks to depositional or tectonic settings can be most readily accommodated by identifying tectonic assemblages, which are the basic tectonic components defined in the Canadian Cordillera, for example, by Gabrielse and Yorath (1989): "most of which are bounded by unconformities, reflect specific depositional or volcanic settings and/or responses to one or more tectonic events...(and each of which)...is identified according to the age range of its components...". By subdividing supracrustal rocks into tectonic assemblages, we obtain a greater flexibility in portraying units that are recognized with varying degrees of confidence.

Features to be shown symbolically on the map include the traces of major folds, regional stratigraphic younging directions, general schistosity and aeromagnetic trend lines, and faults.

Major age subdivisions to be used for both the Tectonic Assemblage Map and the Geology Map of Ontario (Table 3.1) are consistent with Plumb and

TABLE 3.1. PRECAMBRIAN TIME SUBDIVISIONS FOR THE TECTONIC AND GEOLOGY MAPS, GEOLOGY OF ONTARIO PROJECT.

Eon	Era	Sub-era	Boundary Age (Ma)	Map Notation
			570	
Proterozoic		Late		P7
	Neoproterozoic		700	
		Early		P6
			900	
		Late		P5
	Mesoproterozoic		1400	
		Early		P4
			1600	
		Late		P3
			1860	
	Paleoproterozoic	Middle		P2
			2250	
		Early		P1
			2500	
Archean				
			<2680	A9
		Late to	2690–2680	A8
	Neoarchean	Middle	2710–2690	A7
			2730–2710	A6
			2800–2730	A5
			2800	
		Early		A4
			2900	
		Late		A3
	Mesoarchean		3000	
		Early		A2
			3400	
	Paleoarchean		>3400	A1

All era boundaries are consistent with Plumb and James (1986), with the exception of the Mesoarchean–Neoarchean boundary, which was selected to be 2900 Ma. Most sub-eras are consistent with Okulitch (1988).

James (1986) and the Decade of North American Geology geologic time scale (Palmer 1983), with the exception of the Mesoarchean–Neoarchean boundary, which was chosen to be 2900 Ma instead of 3000 Ma. The time scale chosen for Precambrian era boundaries is chronometric. However, the boundaries are intended as much as possible not to overlie major orogenic events but rather to coincide with breaks between notable volcanic, plutonic and deformational events of probable regional significance. Our approach is therefore consistent with Plumb and James (1986), but we have also adopted age boundaries proposed for sub-eras by Okulitch (1988), who subdivided Precambrian time using general chronostratigraphic or chronolithic principles.

It should be emphasized that the choices of time subdivision are made for convenience in portraying natural age groupings in Ontario. They are subject to revision or addition in future and are not precisely defined. Further age subdivisions in the Proterozoic correspond to boundaries of Proterozoic sub-eras of Okulitch (1988). Age subdivisions of the Archean have been chosen to illustrate regional age patterns across the Superior Province. They are not primarily intended to represent sub-eras, although some of the age boundaries appear to be fundamental breaks in the Archean record. These age boundaries are convenient and widely applicable; they represent our best effort at this time and are naturally subject to revision in future as more age determinations become available and mapping progresses. Their primary role in this map is to reveal the symmetric and asymmetric patterns of age across each tectonic province or fold belt.

The names assigned to Precambrian eras in Table 3.1 have been chosen for ease of reference to time subdivisions. The Archean eras are consistent with Okulitch (1988) and the names have been adopted from him. However, in order to logically follow this name convention for Proterozoic eras as well, it was decided to propose the names as shown rather than Okulitch's choice of retaining the names (Aphebian, Helikian, Hadrynian) originally proposed by Stockwell (1964). These terms are not widely used in Ontario.

LEGEND

The legend for the tectonic assemblage map is presently being prepared. It will be subdivided into separate eras and will consist of: a list, in chronological order, of tectonic assemblages with names and brief descriptions of assemblage lithology; a list of plutonic suites with brief descriptions of their distinguishing characteristics and relation to surrounding rocks; and a general list of regionally significant structures. Accompanying the legend for each era is a time-space diagram summarizing the tectonic assemblages in each subprovince or comparable tectonic domain (some of which may be distinguishable as terranes), the principal age determinations used in erecting the subdivisions of age for supracrustal strata and plutonic suites, the relative timing of crustal exhumation and erosion, and regional scale deformation.

Each major rock type—volcanic, sedimentary and plutonic—within each tectonic province is assigned a separate colour hue on the map and, for each rock type, each age subdivision is assigned a separate colour intensity or progression in colour hue. The colour intensity will generally decrease with age of rocks so that the reader will more readily be able to distinguish the tectonic subprovinces as well as the pattern of ages within each.

Tectonic settings will be identified by a set of notations.

MAP FORMAT

The map uses, as a base, the new geology map of Ontario upon which layers of information and interpretation have been added. Stratigraphic and plutonic units are grouped by age. These are further subdivided into tectonic assemblages and plutonic suites, respectively. Structures of regional scale or importance are shown, notably, younging directions of strata, major folds and faults, and trajectories of schistosity and gneissosity defined from aeromagnetic anomaly and geology maps. Also shown are numbered symbols (referenced in the time-space diagram of the legend sheet) at the sample locations of critical age determinations of volcanic and plutonic units and at sample locations in plutons for which the petrogenetic origin has been interpreted. A notation code on each tectonic assemblage specifies the age, assemblage name and tectonic setting, if interpreted. The code on each plutonic body specifies

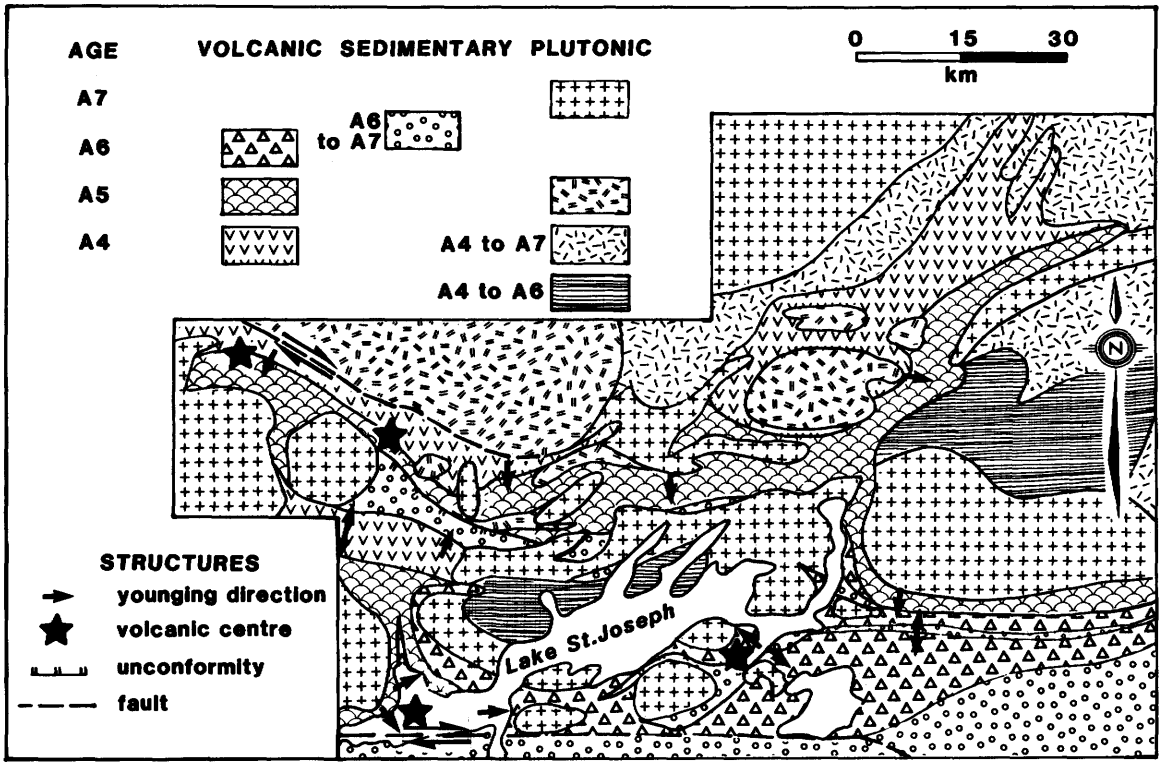

Figure 3.1. *A portion of the central Uchi Subprovince in northwestern Ontario, showing some of the elements that will appear on the tectonic assemblage map. The age subdivisions and their notations as shown in the legend of this figure are listed in Table 3.1. Note that there is an uncertainty of age for some units that is shown by using more than one age subdivision, e.g., A4 to A6 (i.e., 2900-2710 Ma) for tonalitic gneisses in this region. Age subdivisions as shown are interpreted principally from age determinations by F. Corfu, J. Satterly Geochronology Laboratory, Royal Ontario Museum (Corfu and Stott 1989).*

the age, plutonic suite and dominant modal composition.

EXAMPLE—UCHI SUBPROVINCE

As an illustration of the kinds of patterns to be shown on the final map, Figure 3.1 shows the interpreted distribution of ages of volcano-sedimentary strata and some of the major structures for the central part of the Uchi Subprovince. By correlating patterns of electromagnetic conductors and aeromagnetic anomalies with the supracrustal geology, particularly volcanic cycles, and available geochronology (Corfu and Stott 1989), we can identify an asymmetric distribution of ages of strata southward across this region. In addition, by using dated plutons as time markers, we can erect a time-space framework of events which includes some of the regional history of deformation. This region of the Uchi Subprovince records evidence of stacking of volcanic cycles to form repeated bimodal sequences, and evidence of older strata thrust over younger. These patterns occur in other granite-greenstone terranes across Ontario and are fundamental elements in the tectonic framework that can be erected for this part of the North American craton. The implications of the structural patterns and symmetric and asymmetric patterns of age of volcanic strata will be discussed in a volume on the geology of Ontario currently in preparation (*see* Paper 2, this volume).

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4. Site Survey for Continental Drilling in the Kapuskasing Structural Zone

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INTRODUCTION

The Canadian Continental Drilling Program (CCDP) is planning to begin a program of scientific drilling in several geologic environments across Canada. One of the early targets of this program is the Kapuskasing structural zone (KSZ). The KSZ comprises a broad zone of multiply deformed, high-pressure granulites, representing 25 to 30 km deep, late Archean crust that was emplaced at shallower crustal levels during the late Archean to early Proterozoic. It is separated from lower metamorphic grade rocks of the Abitibi Subprovince to the southeast by the Ivanhoe Lake fault zone. The KSZ is thought to represent the lower segment of an apparently continuous, oblique, crustal cross section, composed (from east to west) of: 1) moderately to shallowly, north-dipping zones of granulite gneisses; 2) the Wawa gneiss terrane; and 3) the granites and greenstones of the Michipicoten greenstone belt.

The granulite gneisses contain mineral assemblages indicative of formation at pressures of 6 to 9 kbar (Percival 1981a, 1983), and include disrupted supracrustal rocks as well as paragneiss, orthogneiss, tonalite gneiss and anorthosite (Bursnall 1989a; Moser 1989; Leclair and Nagerl 1988; Percival and McGrath 1986). The Wawa gneiss terrane is a zone of generally shallowly dipping, lower pressure, predominantly tonalitic gneiss containing prominent domal structures (Moser 1988; Percival and Card 1985). Mineral assemblages in the rocks of the Michipicoten greenstone belt are indicative of formation at pressures of 3 to 5 kbar.

Based on both these relationships and geophysical data summarized in Percival and Card (1985), the base of the KSZ is thought to be a southeast-directed, north-northwest-dipping thrust exposing the mid-crust beneath the granites and greenstones of the Abitibi Subprovince immediately east of the Ivanhoe Lake fault zone.

Utilizing the notion that the KSZ represents a crustal section through a granite–greenstone subprovince, more detailed knowledge of this type of crust has obvious important implications for Archean lode gold deposits, given the lower crustal connection for this deposit type (Colvine et al. 1988). Therefore, to understand this type of crust better in a relatively poorly exposed area, high-resolution seismic lines were shot across the KSZ by the Lithoprobe project (West and Hurley 1989). These revealed a number of shallow-dipping reflectors which could be projected close to surface. Shallow drilling has been proposed (Percival 1988) through the CCDP to examine these reflectors. The predrilling site survey reported in this summary (Figure 4.1)

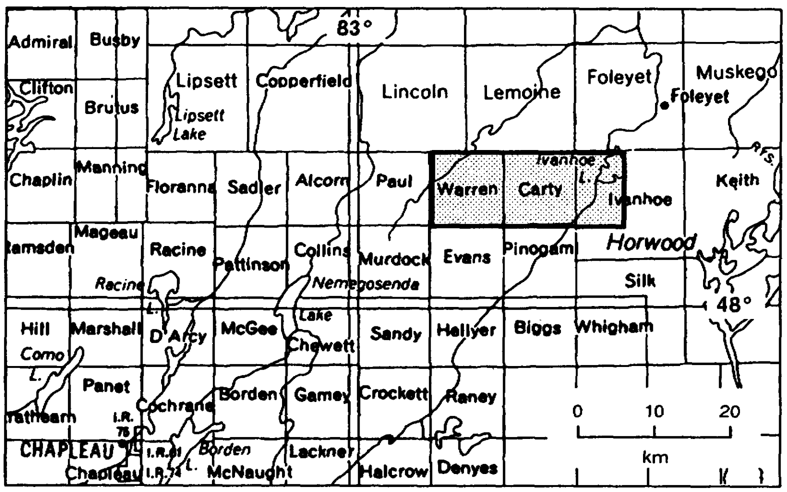

Figure 4.1. *Location map of the study area.*

was carried out to: 1) attempt to trace the shallow-dipping reflectors to surface, where trenches through unconsolidated glacial deposits might expose them; and 2) create new surface exposures close to the seismic lines by trenching across the trace of the Ivanhoe Lake fault zone.

METHODOLOGY AND SITE SELECTION

The predrilling site survey consisted of shallow trenching, the cleaning of outcrops, and a high-resolution seismic survey to locate more precisely the near-surface extension of the reflectors. A total of fourteen trenches, including enhancement of existing outcrop, were created at two localities near Ivanhoe Lake (Figure 4.2). Earth removal was accomplished using a backhoe, a large (22 ton) tracked shovel, and a water tanker and pumps. A total trench length of approximately 1000 m has been produced, of which approximately 600 m is new exposure. Total exposure length resulting from this operation is about 825 m; not all segments of the trenches, however, are perpendicular to strike and there is some along-strike duplication. Trenches are 2.5 to 5 m wide, in general, but locally exceed 25 m in width.

Lithoprobe seismic reflection profiles across the KSZ revealed two sets of reflectors (Cook 1985; Geis et al. 1988; West and Hurley 1989): 1) a set of shallow northwest- to north-dipping reflectors thought to be related to the Ivanhoe Lake cataclastic zone, and 2) a set of northwest-dipping reflectors farther to the west that are probably due to lithologic boundaries within the rocks of the KSZ. The first set of reflectors may be shear zones defining the base of the Kapuskasing plate, supporting the southeast-directed thrust model of Percival and Card (1983). The projection of these reflectors to the surface from a high-resolution section of Lithoprobe line 2 does not, however, precisely coincide with the mapped position of the Ivanhoe Lake fault zone in that area. This discrepancy may be accounted for by: 1) significant steepening of the highly reflective zone as it approaches the surface, 2) younger faults that truncate the reflectors at some depth beneath the surface, or 3) the reflectors do not represent the basal shear zone to the KSZ but some other feature. The existence of multiple ages, orientations and displacement senses of steeply inclined faults within the Ivanhoe Lake fault zone, some of which are of probable late Proterozoic age (Bursnall 1989a, 1989b), attests to a complex and protracted origin for the zone and implies that it may not solely represent the

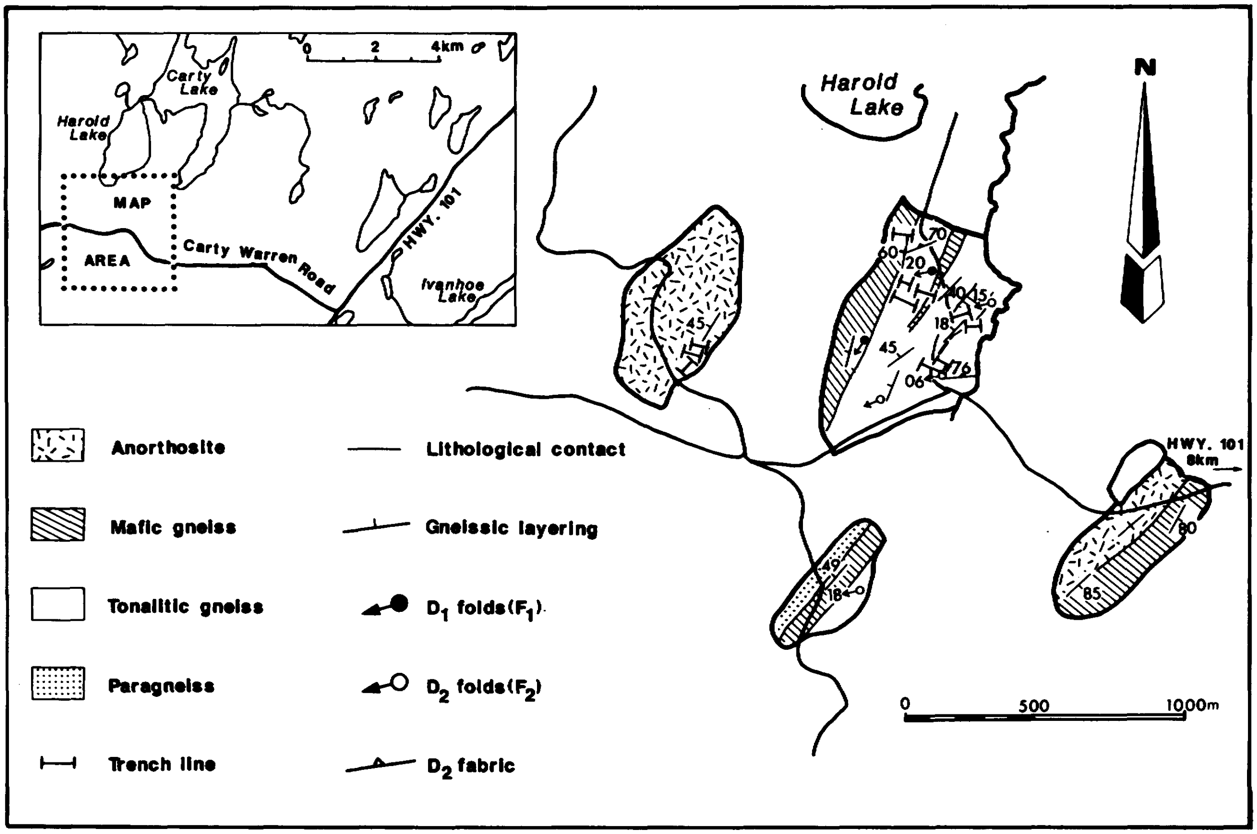

Figure 4.2. *Simplified geological map of the Carty-Warren haulage-road site area, the Shawmere anorthosite and subjacent mafic-tonalitic gneisses. Trenches are indicated by heavy lines.*

surface expression of the basal transport zone for the Kapuskasing rocks in this area. At a number of areas, the fault zone is seemingly dominated by younger structures, including normal- and strike-slip displacements that overprint fabrics that cannot unequivocally be assigned to the earlier thrust phase (Bursnall 1988, 1989a, 1989b).

The surface extrapolation of the second set of reflectors from Lithoprobe line 2 seemed to project to a broad, 1 to 3 km zone encompassing the lower border zone of the Shawmere anorthosite and underlying northwest-dipping, predominantly mafic to tonalitic gneisses (Figures 4.2 and 4.3). The scale and contrast of gross lithologic layering in that area, based on limited exposure, might be the cause of the high-energy reflections (Percival 1988). However, the high-resolution, shallow-depth, dynamite reflection survey, directed by B. Milkereit (Geological Survey of Canada), has confirmed the existence of high-energy reflectors but indicates that the surface emergence of these most likely occurs 1 to 2 km southeast of this location; significantly lower energy reflectors are present in the area defined by the earlier extrapolation (B. Milkereit, personal communication, 1989).

Both the Shawmere high-reflection zone and the Ivanhoe Lake fault zone have been proposed as shallow drilling targets for a CCDP pilot project. The results from these drill holes should provide valuable information regarding: 1) the lithologic and structural characteristics of the high-energy reflectors present beneath the Shawmere anorthosite that have not been observed in surface outcrop, and 2) the meso- and microstructural character of the northwestern boundary of the Ivanhoe Lake fault zone at depth and, possibly, demonstrate that Abitibi rocks structurally underlie Kapuskasing high-grade gneisses. Both targets could be reached through relatively shallow holes of 0.5 to 1 km depth. Ground-clearing operations in both areas were carried out in the period from June to mid-September, and the high resolution, shallow seismic reflection survey was accomplished along two subparallel lines containing the trenched area (Carty-Warren haulage road, *see* Figure 4.2) produced during June of this year. Detailed lithological and structural mapping and sampling of all sites have been carried out since completion of trenching across the zones. Early seismic work has indicated that these zones would contain the surface expression of the seismic reflectors. It is important to note that the dynamite-based survey has provided three-dimensional control on the reflectors and that the locations of some have shifted, as noted above.

SHAWMERE ANORTHOSITE AND SUBJACENT SEQUENCE

Locally very thick overburden, in places greater than 50 m (B. Milkereit, personal communication, 1989), modified the initial proposal of a single trench across the southern Shawmere anorthosite contact at the Carty-Warren haulage-road site (Figure 4.2). Utilizing as much existing outcrop as possible, eleven trenches were dug close to logging roads off the Carty-Warren haulage road, resulting in an across-strike exposure of approximately 480 m within the country rocks to the Shawmere anorthosite and 100 m within the anorthosite (Figure 4.2). A gap of approximately 400 m in exposure between the two sections, representing a structural thickness of 200 to 300 m, has not been significantly reduced.

The Carty-Warren haulage-road sites contain northeast-trending, mafic and tonalitic gneiss, and minor paragneiss. Dips are moderate to gentle to the northwest. The northwesternmost unit (i.e., closest to the anorthosite) is a laterally persistent mafic body that is at least 40 m thick and is intruded by veins of anorthosite. Tonalite gneisses dominate the section: layering within these is very pronounced, seemingly laterally persistent, and ranges from a centimetre- to metre-size scale; it is discordant locally, and postdates the earliest folds observed in the trench area. Rare inclusions of mafic gneiss containing a pre-existing fabric confirm the existence of at least one earlier deformation event. Other tonalitic rocks occur as anastomosing patches and veinlets of leucosome.

Mafic gneiss ranges in composition from mafic granulite (with clinopyroxene and garnet) to garnet hornblendite. The mafic granulites may reach thicknesses as great as 50 m and locally contain compositional layering, in excess of 10 cm in width, defined by variations in hornblende concentrations; tonalite leucosome within these is generally less than 15 percent. Other mafic gneiss varieties are typically less than 1.5 m thick, slightly discordant to gneissic layering, discontinuous, and commonly boudinaged; pegmatitic hornblende tonalite is a ubiquitous marginal phase to disrupted garnet hornblendites.

A three-fold deformation sequence has been observed within the newly exposed rock in the trenches and generally confirms the deformation sequence postulated from mapping of existing outcrop early in the field season. The earliest structures, here designated F_1 for convenience, are isoclinal to tight, gently inclined folds of layering with west- to northwest-plunging hinge lines parallel to a locally prominent mineral lineation: the relationship of these folds to the planar fabric in mafic inclusions has not yet been determined. Second-phase folds (F_2) are close to tight, gently west-plunging on steeply north-dipping axial surfaces: they possess a weak axial-surface fabric that transposes layering and tonalitic-leucosome veins, producing a well-developed rodding lineation. High-strain zones, defined by tightening of early folds and marked thinning of layering, may be related to the second-deformation phase. Third-phase folds (F_3) are rare; they are open, subhorizontal to gently plunging structures on approximately north- to northeast-trending, steep axial surfaces. At least two sites are affected by younger faulting, and it is possible that the region may be cut by southwest-trending, steeply inclined faults. This deformation sequence is similar, but not identical, to the deformation histories derived from areas 20 km to the southwest (Bursnall 1989a) and 60 km to the west (Moser 1988, 1989). Precise correlation between these three areas has yet to be worked out but, for example, those fabrics referred to as S_3 in Figure 4.3 may be equivalent to the planar fabric associated with F_2 structures in the Carty-Warren haulage-road area.

Two large ridges perpendicular to strike and one essentially strike-parallel within the Shawmere anorthosite (Figure 4.2) have been cleared and partially cleaned. The larger area measures 90 m by approximately 35 m at its widest point. Massive anorthosite and gabbroic anorthosite (with 10 to 30 percent combined hornblende and pyroxene) predominate. An irregular, 7 to 20 m thick ultramafic zone (garnet+clinopyroxene+orthopyroxene) made up of close-spaced blocks within gabbroic anorthosite occurs in two of the stripped areas; it exhibits a well-developed, 2 to 3 cm thick, amphibole-rich reaction margin against the enclosing anorthosite, and pronounced but convoluted internal layering.

IVANHOE LAKE FAULT ZONE

The Ivanhoe Lake fault zone occupies an integral and central position within the broader Ivanhoe Lake cataclastic zone, which consists of locally pervasive, interlaced networks of narrow, discontinuous, mylonitic and cataclasite seams and rare pseudotachylyte. The cataclastic zone's structures are best developed within a few hundred metres of the Ivanhoe Lake fault zone, where they are folded and predate normal and strike-slip faults. Two southeast-trending trenches were made (near milepost 6 of the Aube Logging-McChesney Lumber road) in order to expose the transition from KSZ gneisses, through the Ivanhoe Lake fault zone, into Abitibi Subprovince rocks.

The main trench (200 m) contains 40 m of bog at midsection, but nearby outcrops along strike provide partial coverage of the exposure gap. Mapping in the vicinity indicates that the extrapolated position of Abitibi Subprovince mafic metavolcanics on the trench line occurs approximately 150 m from the southeastern termination of the trench (these are not represented on Figure 4.2).

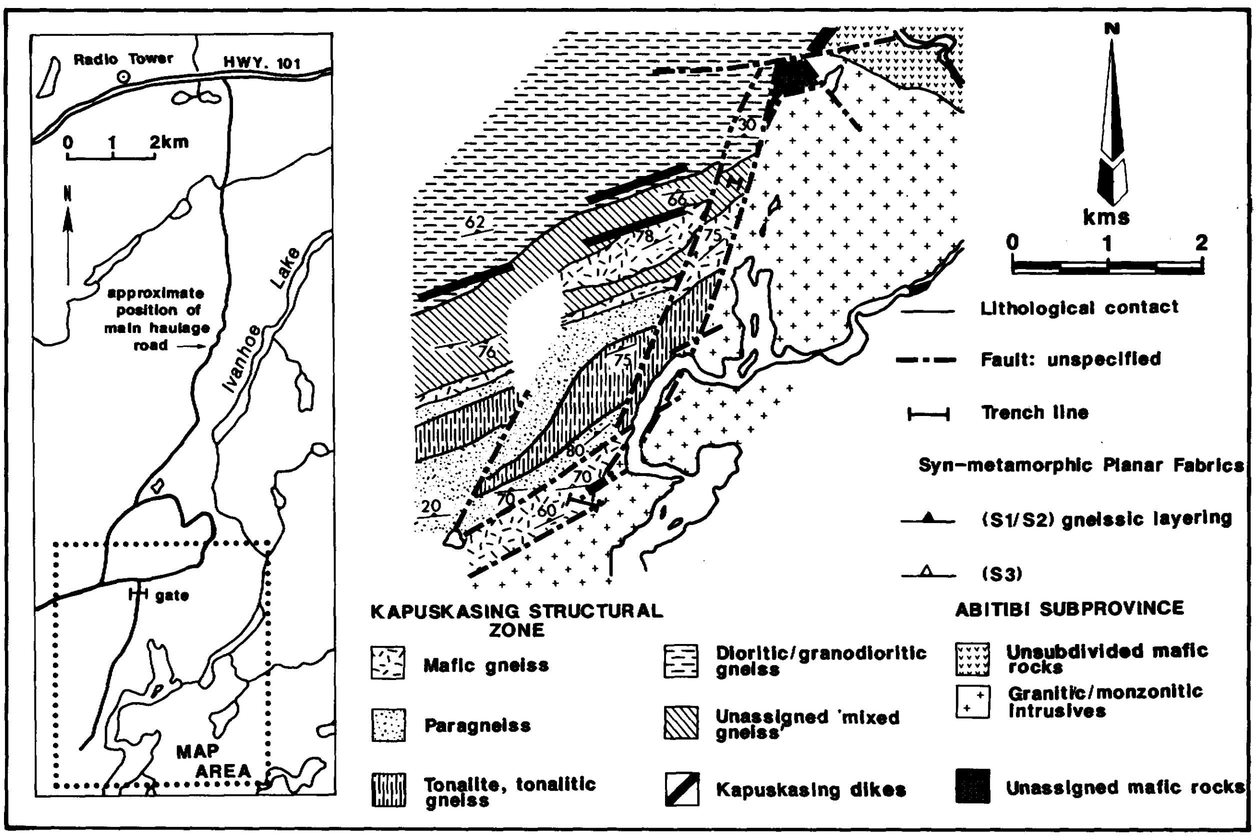

Figure 4.3. *Simplified geological map of the Ivanhoe Lake fault zone site area. Trenches are indicated by heavy lines.*

Limited detailed mapping within the main trench has revealed a section of highly deformed, tonalitic, plagioclase-phyric gneiss containing narrow zones of inclusions of garnet-bearing mafic gneiss, some containing pre-existing fabrics and folds. Mylonitic shear zones and cataclasite veins that postdate high-grade metamorphism occur throughout the section; they are cut by lamprophyre dikes which are themselves affected by brittle shears. Pseudotachylyte (or ultracataclasite) is present at a number of locations and, at two localities, it has been subsequently affected by a period of ductile strain. Deformation intensity within the tonalites, defined by grain size and fabric development, in general seems to increase southeastwards towards the contact with a coarse- to medium-grained, quartzofeldspathic rock that has been preliminarily identified as a highly deformed pegmatite or quartz monzonite. In detail, however, strain intensity varies considerably across the section: a number of very fine grained, approximately 1 m thick zones, that seem to be derived from the adjacent coarse- to medium-grained tonalitic gneiss, may represent localized higher strain levels. In places they exhibit a strong planar fabric and a fine lineation but, more typically, they are homogeneous and seemingly structureless internally. These zones are spaced at 15 to 30 m intervals throughout the section, and, close to the southeastern end of the trench, a strong planar fabric within one of them is overgrown by amphibole (?) porphyroblasts; moreover, subsequent strain is indicated by the presence of minor quartz-filled strain shadows. Clarification of the status of these relationships, particularly those in the presumed contact zone, will require further microstructural and, probably, geochemical analysis. The youngest structures that are present are generally steep, brittle shear zones that contain lineations with steep to shallow plunges; subhorizontal slickenside striae, exhibiting dextral kinematics, may be related to northeast- to east-trending faults in this area (Bursnall 1988, 1989a).

The second trench in this area is shorter ($\approx$80 m) but provides almost continuous exposure of rocks that are unaffected by the latest period of faulting (northeast- to east-oriented set described above); fine-scale cataclasites and other microshears are also much less obvious. The trench exposes mylonitic tonalite gneiss that may predate the mylonites mentioned above, based on relationships observed between the two trenches. These gneisses are cut by epidote-rich cataclasite veins and other fractures, and are intruded by pseudotachylyte (or ultracataclasite) veins. The prominent, east-trending foliation and compositional layering, to the west of the site, have been deflected into an attitude of subparallelism with the extrapolated north-northeast trace of the Ivanhoe Lake fault zone (here a topographic depression) accompanied by a significant reduction in dip from approximately 45°N to approximately 20°NW. This observation indicates a possible sinistral offset along the fault, but no slip-line indicators have been observed. Although fractured granitic pegmatite is present at the southeastern end of this trench, no part of the section is considered to be representative of unaltered rock from the Abitibi greenstone terrane.

CONCLUSIONS

Ground-clearing operations in two geologically critical areas within the Kapuskasing structural zone have been successful in that a large area of regionally significant units have been uncovered. This will allow for further detailed mapping to be conducted in previously poorly exposed ground and permit sampling for a variety of purposes to take place. Although the regionally important questions—1) the origin of high-energy reflectors beneath the Shawmere anorthosite, and 2) the precise status of Ivanhoe Lake fault zone structures with regard to KSZ evolution—have not been answered, the ground-clearing operation has raised further questions that may facilitate a solution to these outstanding problems. Why, for example, does the well-layered and compositionally varied sequence beneath the Shawmere anorthosite not produce high-energy reflections? The limited surface outcrop in the area where the reflectors do project to the surface is not markedly different compositionally from that in the trenched area. The clean and virtually continuous exposures adjacent to the Ivanhoe Lake fault zone have encouraged further research, and the results from recently initiated geochronological and microstructural studies are eagerly anticipated. In addition, the trenched areas should form an excellent base for crustal drilling as well as other independent research; they are also easily accessible for field trips (excepting the main Ivanhoe Lake fault zone trench, which requires a key from the District Office, Ontario Ministry of Natural Resources, Chapleau). Those interested in further information should contact the authors.

ACKNOWLEDGMENTS

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5. Project Unit 88-34. Geology of the Berens River Subprovince: Cobham Lake and Nungesser Lake Areas

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INTRODUCTION

This report summarizes the results of field mapping in two segments of the Berens River Subprovince and neighbouring areas in northwestern Ontario. The objectives of this survey are: 1) to produce lithostructural maps of felsic plutonic areas in the Berens River Subprovince; 2) to examine the structural characteristics of the subprovince and its boundaries; 3) to compare the lithostructural maps with large scale geological reconnaissance maps and aeromagnetic maps (this comparison will help in the interpretation of other unmapped areas of northern Ontario); 4) to evaluate the geology and mineral potential of the western part of the Favourable Lake belt and the few small greenstone belts within the Berens River Subprovince; and 5) to investigate deformation zones for their gold potential.

The Berens River Subprovince is a large domain of mainly massive, felsic plutonic and gneissic rocks that, in Ontario, extends from the Manitoba border to, possibly, east of Pickle Lake. At the Ontario–Manitoba border it is 240 km wide; near Pickle Lake, approximately 50 km wide.

In the south, the subprovince is bounded by the metavolcanic-metasedimentary Red Lake and Birch–Uchi belts of the Uchi Subprovince; in the north, by the Favourable Lake and North Spirit Lake belts of the Sachigo Subprovince. Subprovince boundaries are locally marked by faults (Osmani and Stott 1988) whose extents are not completely defined.

Previous geological surveys (Douglas 1926; Hurst 1930; Derry and MacKenzie 1931; Bennett et al. 1969; Ermanovics 1970; Ayres et al. 1973; Herd et al. 1987) have not subdivided the felsic plutonic and gneissic rocks in large parts of the Ontario segment of the Berens River Subprovince. Similarly, the map coverage of the west part of the Favourable Lake belt is at a reconnaissance scale and dates back more than 20 years (Bennett et al. 1969).

The study areas are situated in the vicinities of Cobham Lake and Nungesser Lake (Figure 5.1). The Cobham Lake area, approximately 2300 km^2 in size, includes the northern part of the Berens River Subprovince and a strip of the adjacent Sachigo Subprovince. It is approximately 240 km north of the town of Red Lake and is accessible by float-equipped aircraft. The Nungesser Lake area is of similar size to the Cobham Lake area and spans the southern margin of the Berens River Subprovince, including part of the Red Lake belt in the Uchi Subprovince. The centre of this area is situated approximately 50 km north of Red Lake. Access is by the Nungesser Road, various logging roads and by float-equipped aircraft. Work in this area marks a continuation of mapping initiated in 1988 (Stone 1988).

COBHAM LAKE AREA

ECONOMIC GEOLOGY AND MINERAL EXPLORATION

Known mineral occurrences lie within and adjacent to the Favourable Lake belt at the north margin of the map area. Principal among these occurrences is the Johnson showing, which is situated on a small point of land at the west end of Borland Lake (locality 1, Figure 5.2; Figure 5.3). The sulphide minerals here consist of less than 10 percent pyrrhotite, pyrite, argentite, galena, sphalerite and arsenopyrite, which occur as irregular stringers and disseminations within sheared biotitic melanosome segments of migmatitic metawacke (Massive Energy Limited, File OM87-1-C-001, Resident Geologist's office, Ministry of Northern Development and Mines, Red Lake).

Approximately 74 boreholes, totalling 8139 m in length, were drilled at the Johnson showing between 1947 and 1986 by Berens River Mines Limited, Noranda Exploration Co. Ltd., Astrabrun Mines Ltd. and Massive Energy Limited. The drilling outlined 391 985 t of probable ore reserves grading 289 g/t Ag and 0.69 g/t Au (Massive Energy Limited, File OM86-1-C-15, Resident Geologist's office, Ministry of Northern Development and Mines, Red Lake). The mineralization occurs within three distinct zones that plunge to the southeast at 45° and lie mainly beneath the waters of Borland Lake.

The association of silver and gold with minor amounts of sulphides, notably galena, is common in the Favourable Lake belt. Banded iron formation and metawacke in northern parts of the belt that were not mapped by the present survey are reported to contain this type of mineralization (Orlac Red Lake Mines Ltd., Cobham River area; Madsen Red Lake Gold Mines Ltd.; Resident Geologist's office, Ministry of Northern Development and Mines, Red Lake) (locality 2, Figure 5.2).

The Murray–Stewart showing, located centrally in the Favourable Lake belt at the east edge of the

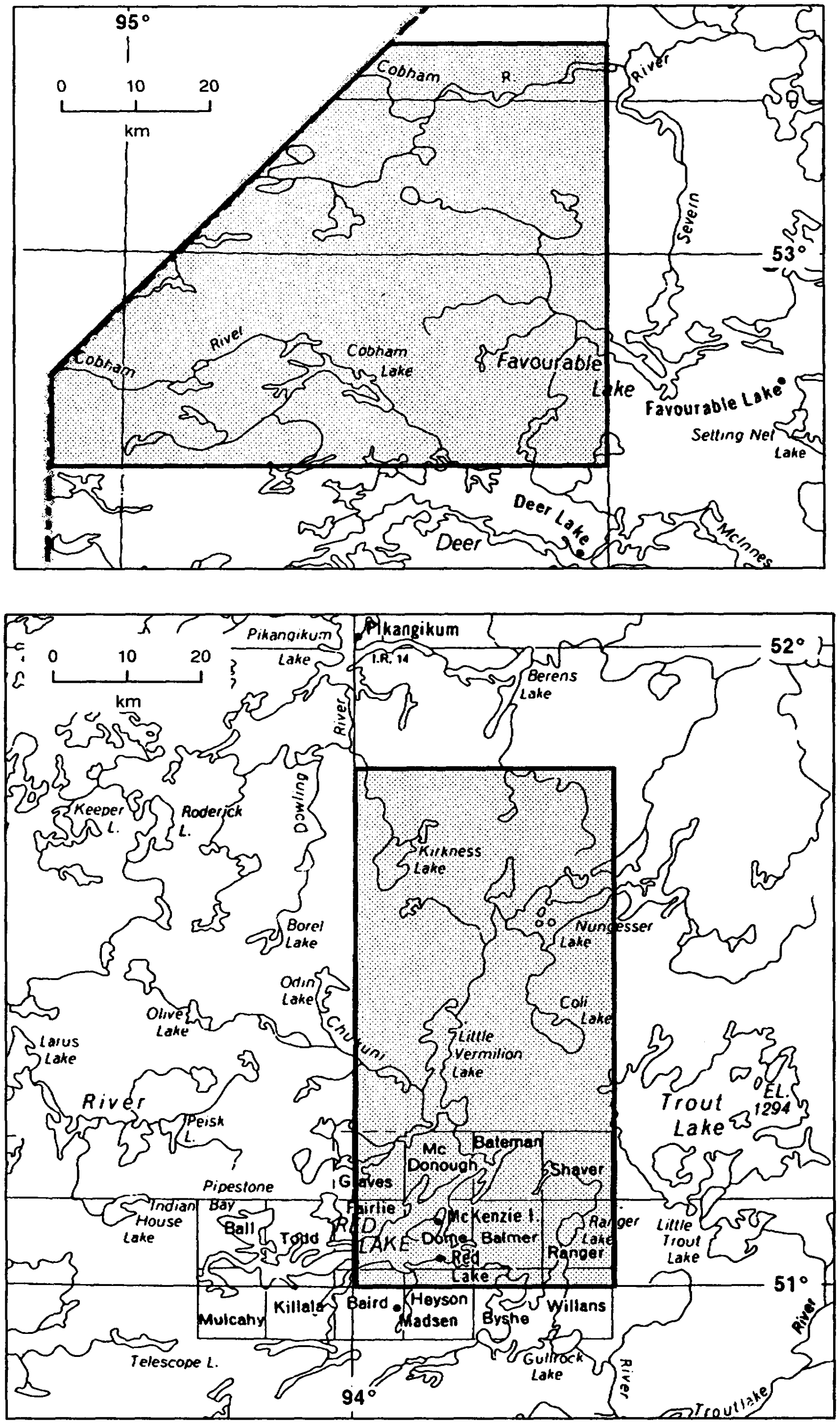

Figure 5.1. *Location maps, Cobham Lake area and Nungesser Lake area.*

present map area (locality 3, Figure 5.2; Figure 5.3) consists of a quartz vein, 125 m long and averaging 20 cm wide, which contains argentiferous galena, chalcopyrite and pyrite (Hurst 1930). The vein is hosted by porphyritic feldspar tuff of dacitic composition. Sulphide-bearing iron formation, shown bordering the intermediate to felsic metavolcanic unit in Figure 5.3, contains anomalous gold and silver (10 to 80 ppb and up to 2.3 ppm, respectively; Master Resources and Developments Ltd., File No. 2.9414, Resident Geologist's office, Ministry of Northern Development and Mines, Red Lake).

Conductive gossan zones northwest of Borland Lake show pyrite, pyrrhotite and chalcopyrite mineralization and contain gold values ranging from 10 to

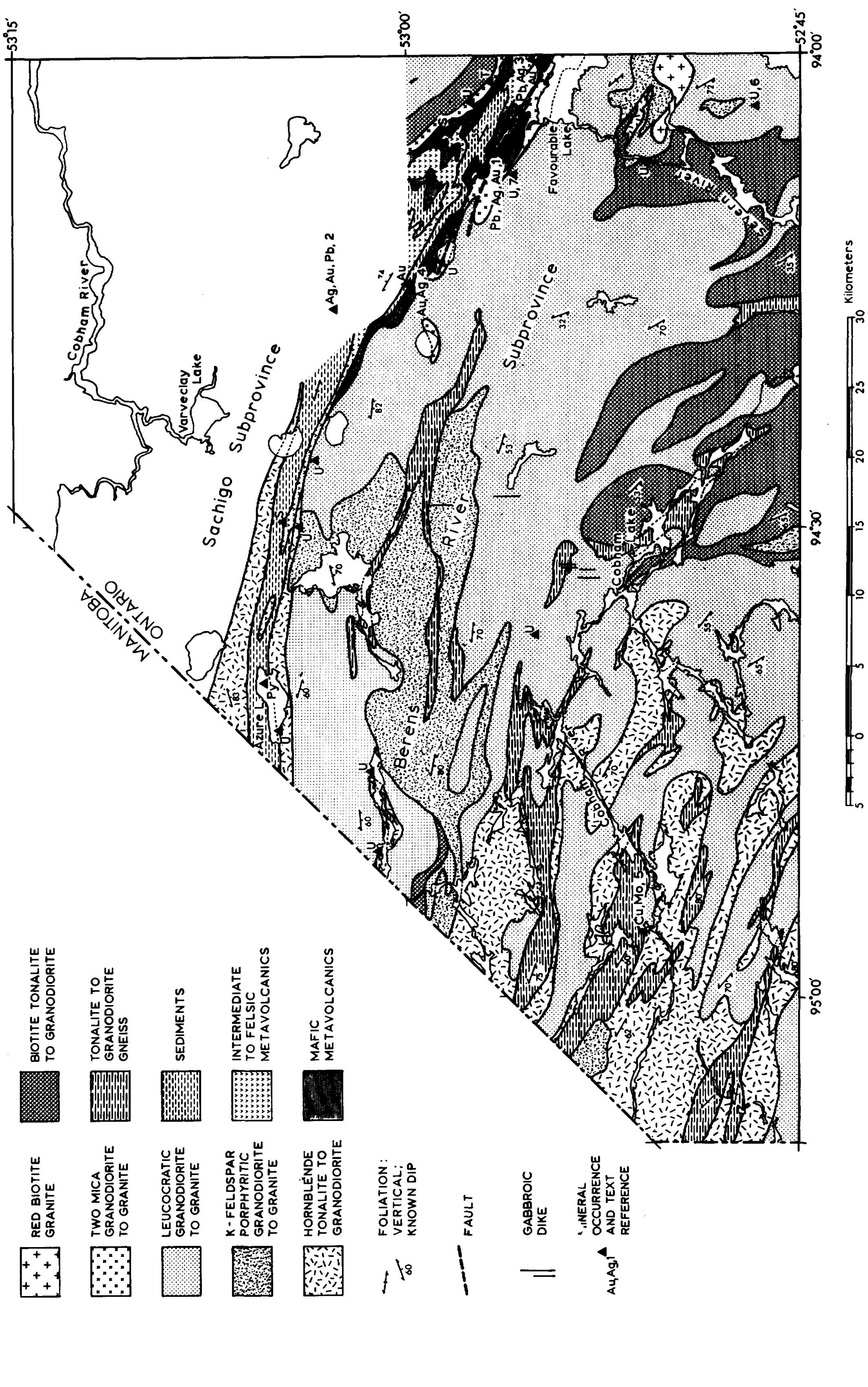

Figure 5.2. *Geology and mineral occurrences in the Cobham Lake area, northern Berens River Subprovince.*

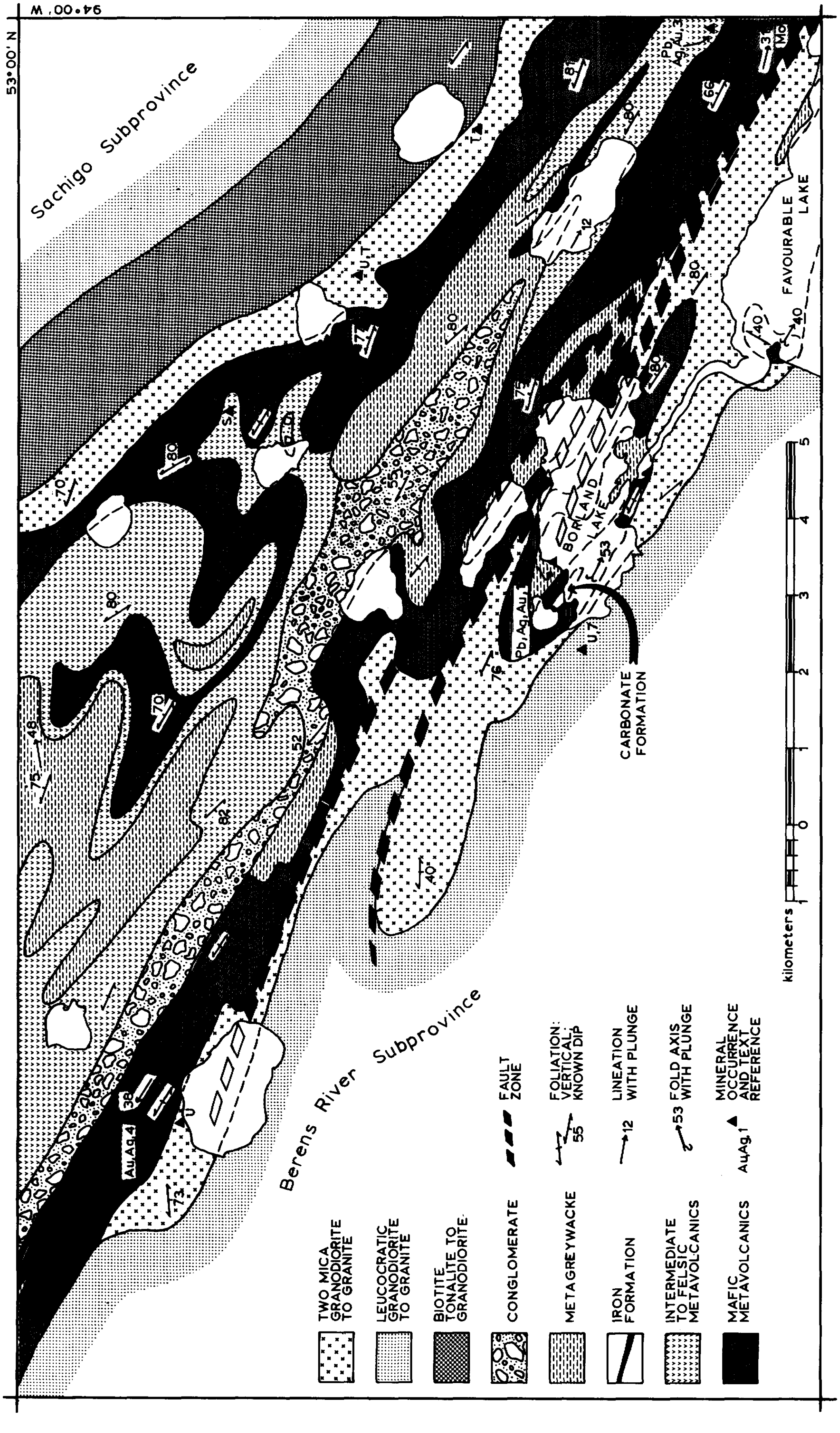

Figure 5.3. *Geology of the Favourable Lake belt, Boriand-Favourable lakes area.*

105 ppb and silver values of up to 3 ppm (Noranda Exploration Co. Ltd., File No. 2.9310, Resident Geologist's office, Ministry of Northern Development and Mines, Red Lake). The main showing (locality 4, Figure 5.2; Figure 5.3) occurs in a metamorphosed iron formation at the contact of mafic metavolcanics with two-mica granite.

During the present survey, sulphide-bearing gossan zones, typically several metres wide, were identified in the western segment of the Favourable Lake belt (Figures 5.2, 5.3). These siliceous, weathered zones within metawacke and intermediate to felsic metavolcanics may provide additional targets for precious metal exploration.

Chalcopyrite and molybdenite within north-trending fractures in granitic intrusive rocks of the Cobham River area (locality 5, Figure 5.2) are a rare example of base metal mineralization in the Berens River Subprovince. The fractures, typically 5 mm wide, transect tonalite and granodiorite and have been interpreted as subsidiary elements of a fault underlying the Cobham River (Daniel Meekis, File No. 2.2634, Resident Geologist's office, Ministry of Northern Development and Mines, Red Lake).

Occurrences of uranium minerals are common in the map area, particularly at the margins of the Favourable Lake belt. Zones of anomalous radioactivity, of up to 230 counts per second (cps) intensity, and patches of uranophane stain are associated with pink aplitic granite in the southeast corner of the area (locality 6, Figure 5.2; Noranda Exploration Co. Ltd., File No. 2.2433; Union Gas Limited, File No. 2.2858; Resident Geologist's office, Ministry of Northern Development and Mines, Red Lake).

West of Borland Lake (locality 7, Figure 5.2; Figure 5.3), radioactivity as high as 500 cps is reported in "hotspots" a few metres in diameter (Union Gas Limited, File No. 2.2858, Resident Geologist's office, Ministry of Northern Development and Mines, Red Lake). The uranium minerals are associated with disseminated molybdenite and pyrite at the contact of two-mica granite with leucocratic biotite granite.

During the present survey, several uranium occurrences were identified on the basis of metre-scale patches of uranophane stain or radioactivity in excess of 100 cps. These occurrences, shown in Figure 5.2, are mainly associated with pegmatitic two-mica granites at the margins of the Favourable Lake belt. Garnet, tourmaline and large books of mica typically constitute 5 to 10 percent of the two-mica granite on the north side of the Favourable Lake belt. This unit has potential for rare metal mineralization.

GENERAL GEOLOGY

The Cobham Lake area is underlain by felsic plutonic rocks of the Berens River Subprovince and metavolcanic rocks of the western portion of the Favourable Lake belt of the adjacent Sachigo Subprovince (Figure 5.2). The subprovince boundary is marked by the Bear Head fault zone to the east and an intrusive granite contact to the west.

The plutonic rocks of the Cobham Lake area can be subdivided into six principal groups. Among the oldest rocks are early, sodic, tonalitic to granodioritic orthogneisses, which are widespread and occur as thin belts or xenoliths in younger rocks. They are quartzofeldspathic, typically display a prominent but discontinuous mineralogical layering, and contain amphibolitic xenoliths.

Tonalitic to granodioritic rocks are coarse grained, foliated and white to grey. A hornblende-bearing variety is concentrated in the southwest corner of the area and on both sides of the Favourable Lake belt. Biotite tonalite and gradational units of tonalitic gneiss are interdigitated with younger potassic intrusions in the south-central part of the Cobham Lake area.

The early sodic plutonic rocks are intruded by potassium-feldspar porphyritic, biotite granodiorite to granite, which in turn is intruded by leucocratic, biotite granodiorite to granite and rare, massive, red, biotite granite. The leucocratic granodiorite to granite underlies approximately half of the mapped area and is typically pink and inequigranular, and ranges from fine grained to pegmatitic. Partly assimilated xenoliths of tonalite, tonalite gneiss and amphibolite are present throughout this unit.

The Favourable Lake belt is composed of intensely foliated and metamorphosed rocks of both volcanic and sedimentary origin. Black, gneissic, fine-grained, mafic metavolcanics are concentrated along the southern margin of the belt. Pillows are recognized in the least deformed segments of this unit at the eastern side of the map area (Figure 5.3).

A discontinuous unit of fine-grained, laminated, intermediate to felsic metavolcanics of probable tuffaceous origin extends through the narrow western extension of the Favourable Lake belt. Both monolithic feldspar porphyritic and heterolithic pyroclastic units are present to the east.

The western and northern parts of the belt are predominantly underlain by poorly bedded metawacke, which is composed of quartz, feldspar and about 20 percent biotite. Rounded quartz granules up to 5 mm in diameter are locally present. A marker unit of boulder conglomerate can be traced almost the full length of the belt. The clast population is made up of approximately equal proportions of mafic and felsic metavolcanics, chert and usually less than 10 percent tonalite. The clasts are highly stretched, giving the unit a streaky, gneissic appearance.

Thin, cherty iron formations occur at contacts between some of the metavolcanic units within the belts. A 10 m-thick section of coarse marble with interbedded meta-arkose and quartz sandstone is exposed on the west shore of Borland Lake.

White, pegmatitic, two-mica granite occurs at the margins of the Favourable Lake belt, as well as in dikes which transect supracrustal units within the belt. Accessory garnet and tourmaline are noted in the granite. The two-mica granite and tonalite give way within a few kilometres north of the belt to pink granodiorite to granite of both the potassium-feldspar porphyritic and leucocratic varieties.

STRUCTURE

Structural trends defined by mineral foliations, gneissosity, lithologic contacts and the Favourable Lake belt show an arcuate pattern in the map area. These features strike east at the Manitoba border, and curve south-southwest in the Severn River area (Figure 5.2). Although foliations in the Favourable Lake belt are mainly subvertical, dipping to both the north and south, those in the Berens River Subprovince have consistent south to southwest dips, as indicated by the cluster of poles in the northeast quadrant of the equal area net (Figure 5.4).

The Favourable Lake belt everywhere shows evidence of having undergone a high level of deformation. Supracrustal rocks are strongly foliated and the eastern part of the belt is complexly folded (Figure 5.3). Primary structures, such as pillows in mafic metavolcanics and beds in metasediments, are difficult to recognize except at the eastern end of the belt. West of Borland Lake, clasts within the metaconglomerate unit are strongly elongated, giving outcrops a streaky gneissic appearance. At one locality in the centre of the belt, the principal axes of 100 felsic metavolcanic, mafic metavolcanic and tonalitic clasts were measured on a horizontal outcrop face. The three lithologic types of clasts yielded average aspect ratios of 42:95, 32:60 and 15:37, respectively, indicating that the belt has been highly strained.

Mineral lineations and minor folds within the Favourable Lake belt show shallow to moderate plunges to both the north-northwest and south-southeast (Figure 5.5). In contrast, mineral lineations from biotite tonalite and gneissic units have shallow south-southeasterly plunges (Figure 5.5). The orientation of the latter group of lineations may reflect the overall southerly structural trend in the southeastern part of the map area.

The Bear Head fault zone is marked by a splayed zone of protomylonitic to mylonitic two-mica granite and sheared supracrustal rocks at the south margin of the Favourable Lake belt. This fault, which is well developed east of the map area (Corfu and Ayres 1984; Osmani and Stott 1988) splays and dissipates in the Borland Lake area, west of which no faulted rocks were identified. Mineral lineations within the mylonites are subhorizontal, implying

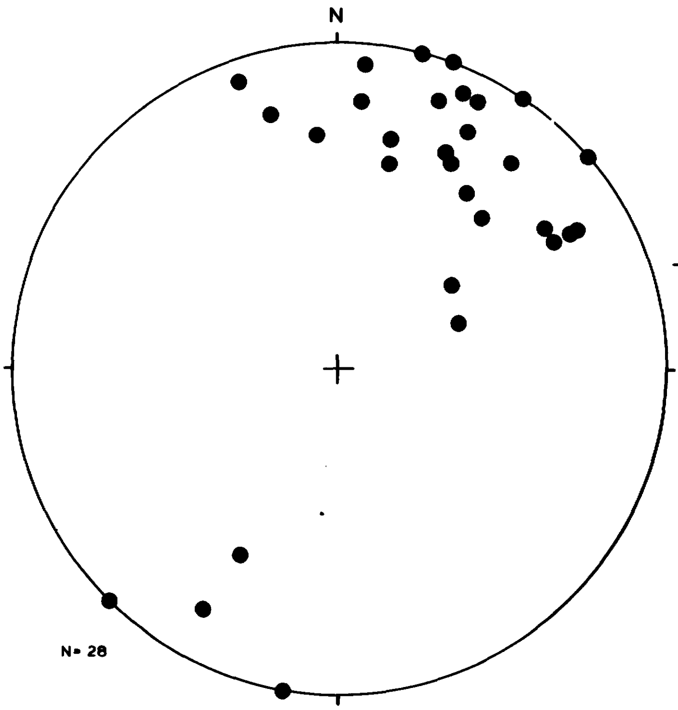

Figure 5.4. *Poles to foliations, Cobham Lake area.*

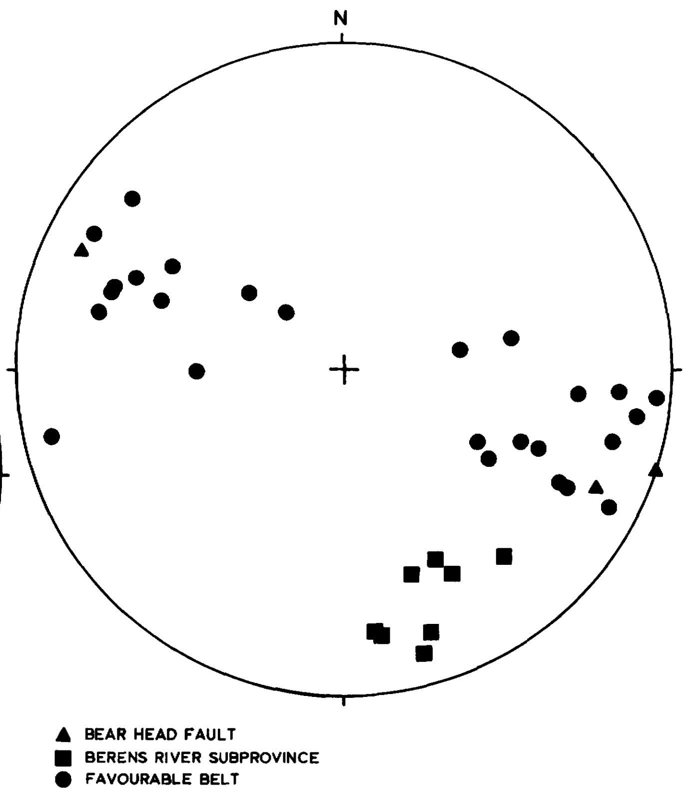

Figure 5.5. *Mineral lineations, Cobham Lake area.*

TABLE 5.1. MINERAL ASSEMBLAGES OF THE FAVOURABLE LAKE BELT.

Rock Type	Locality	Assemblage
Metasedimentary migmatite	Azure Lake, 94°44′	garnet-biotite-feldspar-quartz
Metasedimentary migmatite	94°35′	garnet-cordierite-biotite-feldspar-quartz
Metasedimentary migmatite	94°32′	garnet-biotite-feldspar-quartz
Mafic metavolcanics	94°20′	garnet-actinolite?
Metawacke	Borland Lake, 94°06′	garnet-cordierite-andalusite? garnet-cordierite

transcurrent motion (Figure 5.5). Lithologic contacts show conspicuous Z-shaped drag folds where they are cut by the Bear Head fault zone, suggesting a dextral sense of shear.

Supracrustal rocks at the south margin of the Favourable Lake belt are cut by dikes of two-mica and leucocratic biotite granite. The dikes also cut hornblende tonalite where it is present at the belt boundary. The injected granitic material increases in abundance southward and gives way over distances of a few hundred metres to large potassic intrusions in the north part of the Berens River Subprovince. The subprovince boundary here is best described as a gradational intrusive contact that is locally overprinted by a dextral transcurrent fault.

North-trending, subvertical gabbroic dikes transect felsic plutonic rocks in the centre of the map area (Figure 5.2). The dikes appear undeformed and may belong to the Molson Swarm (Ermanovics and Fahrig 1975), which extends south from the Fox River belt in Manitoba. North-trending, epidote-filled fractures are present in many outcrops in the northwest part of the area and, together with gabbroic dikes, indicate a component of brittle deformation that may have occurred in the Early Proterozoic.

METAMORPHISM

Tonalitic, gneissic and supracrustal rocks show evidence of metamorphism at amphibolite facies everywhere in the map area, with the possible exception of the east part of the Favourable Lake belt.

Within the Berens River Subprovince, supracrustal rocks are rare and tonalites and gneisses are typically well foliated and contain a mineral assemblage of quartz + feldspar + biotite + hornblende. A small unit of metasedimentary migmatites near the Manitoba border at Warrington Lake contains the assemblage garnet + biotite + sillimanite.

Metamorphic grade and deformation intensity appear to decrease to the east in the Favourable Lake belt, possibly in relation to a general widening of the belt. Ayres (1978) reported a rare occurrence of kyanite within the belt at the Manitoba border. Metamorphic assemblages for the belt are summarized in Table 5.1. Mafic metavolcanics contain black hornblende and metasediments are generally migmatized, showing garnet + biotite assemblages. Eastward, mafic metavolcanics develop greenish amphibole and possibly chlorite. Metasediments north and east of Borland Lake are not partially melted and contain garnet, cordierite and possibly andalusite.

NUNGESSER LAKE AREA

ECONOMIC GEOLOGY AND MINERAL EXPLORATION

Mineral exploration and the economic geology of the Nungesser Lake area prior to 1989 were described previously by the author (Stone 1988). To the author's knowledge, no exploration activity has taken place in the area in 1989.

GENERAL GEOLOGY

Field investigations were continued in the Nungesser Lake area (Figure 5.1) to provide greater resolution of the lithostructural domains identified in 1988 and to extend mapping south to the Red Lake belt. Descriptions of the main lithologic subdivisions in the Nungesser Lake area were given by Stone (1988). Pirie (1981) and Wallace et al. (1986) reviewed the geology of the Red Lake belt.

Among the salient features derived from the latest mapping is the recognition of a hornblende granodiorite to granite pluton northeast of Kirkness Lake (Figure 5.6). The unit locally contains pyroxene and may be gradational to quartz syenite, quartz monzonite and quartz monzodiorite (as defined by Streckeisen 1976). It is among the youngest intrusions in the area.

A thin, curved and discontinuous belt of highly deformed and metamorphosed supracrustal rocks extends north from Nungesser Lake. The belt consists of approximately equal proportions of metasedimentary migmatites and amphibolite gneiss of probable mafic volcanic protolith. A small unit of intermediate metavolcanic breccia occurs east of Berens Lake.

During the present survey, mafic and intermediate metavolcanics in the Anderson Lake area were

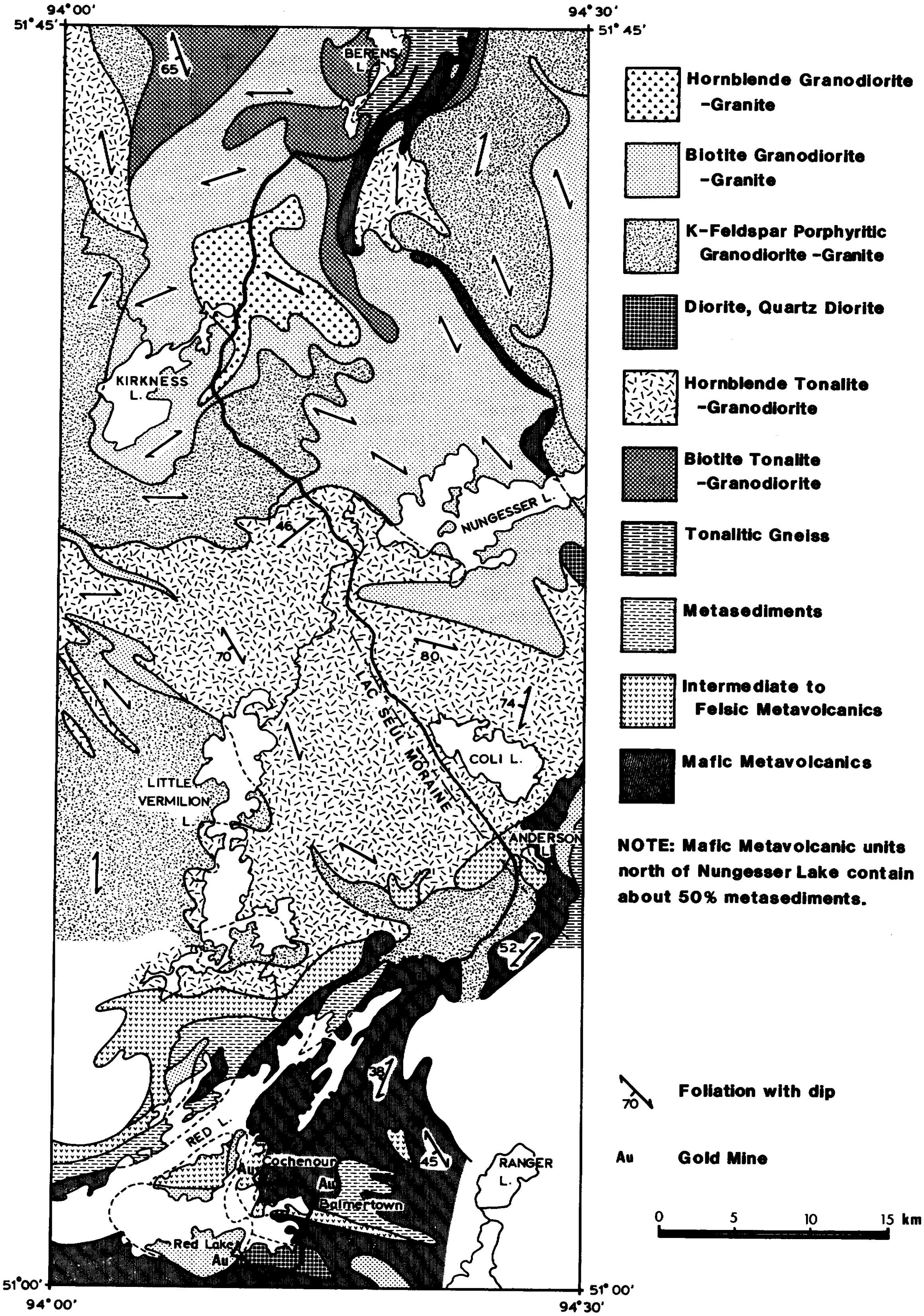

Figure 5.6. *Geology of the Nungesser Lake area, southern Berens River Subprovince.*

traced farther south and west than shown by previous mapping (Horwood 1945). They extend beneath the Lac Seul moraine and may be separated from the northeast arm of the Red Lake belt by a narrow unit of hornblende-biotite granodiorite.

Hornblende tonalite to granodiorite of the Little Vermilion Lake batholith intrudes the north margin of the Red Lake belt. Close to the contact, the mafic content of the tonalite increases, possibly due to assimilation of the country rock. No evidence of a major structural break was found at the contact.

DISCUSSION

Both of the areas of the Berens River Subprovince studied show a very large proportion of felsic plutonic rocks, although small belts of supracrustal remnants are present. Suites of sodic intrusions and gneisses (biotite tonalite to granodiorite, hornblende tonalite to granodiorite, hornblende-biotite tonalite to granodiorite gneisses) are intruded by late potassic rocks (potassium-feldspar porphyritic granodiorite to granite, leucocratic biotite granodiorite to granite, hornblende granodiorite to granite). The potassic suite typically constitutes half of each area and represents a major magmatic and thermotectonic event.

Although both areas share common lithologic units, each has a unique pattern of contact geometry. The Nungesser Lake area is underlain by large lobate intrusions of batholithic proportions. In contrast, a striped pattern of interdigitated units is apparent in the Cobham Lake area. Conspicuous concentrations of hornblende tonalite to granodiorite and biotite tonalite to granodiorite occur in the southwest and southeast corners of the Cobham Lake area, respectively. These may be the remnants of separate batholithic complexes that were subsequently dismembered by narrow granite units.

Potassic intrusions presently occupy about half of each of the map areas and typically contain 10 to 30 percent partly assimilated xenoliths of tonalite and granodioritic gneiss. Xenoliths of supracrustal rocks are rare. This implies that the sodic suite was once much more extensive in the Berens River Subprovince and may have undergone widespread anatexis during granite emplacement.

The boundaries of the Berens River Subprovince are marked by intrusive contacts of felsic plutonic rocks against neighbouring metavolcanic belts. Uranium occurrences are concentrated at the northern boundary of the subprovince, part of which is overprinted by the dextral, transcurrent Bear Head fault.

The west part of the Favourable Lake belt consists of approximately equal proportions of highly deformed and metamorphosed volcanic and sedimentary rocks. Lead and silver are commonly associated and occur in deformed metasedimentary migmatites, veins and sulphide-bearing iron formation.

ACKNOWLEDGMENTS

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6. Project Unit 89-17. Geology of the Caron Lake Area

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INTRODUCTION

Field investigations of the Caron Lake area (Figure 6.1) were conducted in 1989 in order to expand the present geological data base and to stimulate exploration interest in the Pashkokogan–Misehkow greenstone belt of the Uchi Subprovince, which is located between the Kagami pluton to the north and the English River Subprovince to the south (Stott et al. 1989; Thurston and Stott 1988). The area encompasses a 17 km wide cross section of the bedrock from the English River Subprovince northward to the Kagami pluton.

The Caron Lake area was first investigated by W.S. Dyer (1934) during reconnaissance mapping of the Pashkokogan–Misehkow area. Subsequent mapping programs have been carried out in adjoining areas to the west and north of the present map area by Goodwin (1965), Clifford (1969), Sage and Breaks (1982), Stott et al. (1987) and Stott et al. (1989). In 1986, the Caron Lake area was included in a regional airborne magnetic-electromagnetic survey of the Pickle Lake area by the Geophysics/Geochemistry Section of the Ontario Geological Survey (Ontario Geological Survey 1986).

During the summer of 1989, approximately 300 km^2 of area, bounded by latitudes 50°55′00″N and 51°07′00″N and by longitudes 89°55′00″W and 90°12′00″W, was mapped at a scale of 1:15 840. The centre of the map area is located 50 km south-southeast of Pickle Lake in the District of Thunder Bay. Highway 599 crosses the northwestern corner of the map area and boats may be launched on Osnaburgh Lake to gain access to its northern part. Access to the central and southern parts of the map area is by float-equipped aircraft which permit access to Greenbush, Caron, Aldous, Kent, and Frain lakes and the Pashkokogan River.

MINERAL EXPLORATION

Mineral exploration in the Caron Lake area has largely consisted of reconnaissance exploration for base and precious metals using geophysical surveys followed by limited diamond drilling. The results of this work are on file with the Assessment Files Research Office, Ontario Geological Survey, and have been summarized below.

In 1970, Selco Exploration Company Limited did ground magnetic and electromagnetic surveys on several groups of claims in the Caron Lake area. Subsequently, two diamond-drill holes totalling 215.8 m were drilled in the vicinity of East Pashkokogan Lake, immediately west of the map area. Metasediments with graphite and minor sulphides were reported.

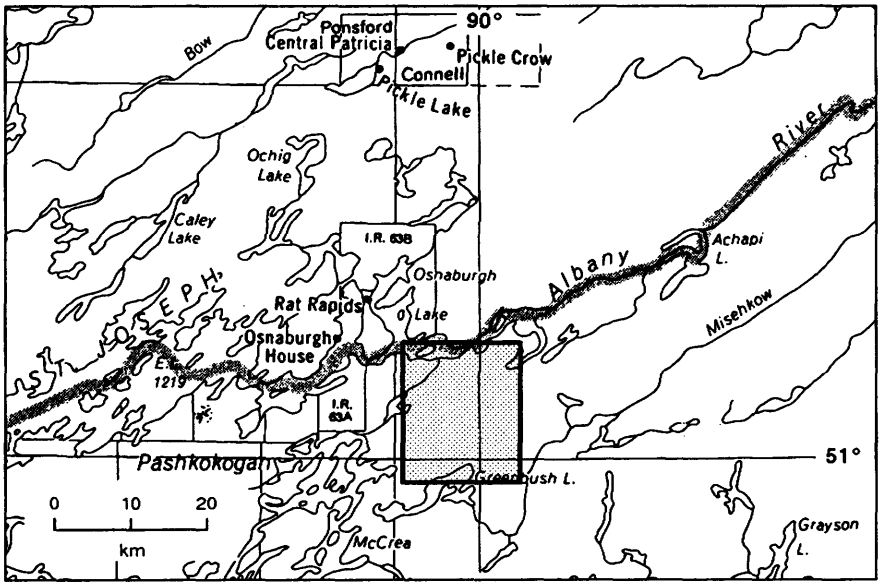

Figure 6.1. *Location map of the Caron Lake area.*

In 1971, Falconbridge Nickel Mines Limited did ground magnetic and electromagnetic surveys on a block of 40 claims along the Pashkokogan River, followed by the drilling of five holes, totalling 438 m, into mainly metagabbroic rock containing as much as 10 percent disseminated pyrrhotite, pyrite, and chalcopyrite.

In 1971, Canadian Nickel Company drilled nine holes totalling 458.7 m on six small, widely separated groups of claims within the Caron Lake area. Metavolcanic and metasedimentary rocks containing 1 to 2 percent disseminated sulphides were reported.

As of June 1989, there were eight blocks of claims, totalling 200 claims in good standing, within the map area. Many of these claim groups were investigated in 1987 and 1988 by St. Joe Canada Incorporated (name changed in 1988 to Bond Gold Canada Incorporated) by conducting airborne magnetometer and electromagnetic surveys.

GENERAL GEOLOGY

The supracrustal and plutonic rocks of the Caron Lake area are interpreted to be Archean in age (Figure 6.2).

The supracrustal rocks comprise interlayered clastic sedimentary rocks, calc-alkalic fragmental volcanic rocks, tholeiitic volcanic flows and units of magnetite-rich arenite, iron formation, and komatiite. In both the Uchi and English River subprovinces (*see* Figure 6.2), the supracrustal rocks have been subjected to middle to upper amphibolite-facies metamorphism and to intense deformation. Large tonalite-trondhjemite-granodiorite stocks intrude the supracrustal rocks. The Kagami pluton (Stott et al. 1989) is a large tonalitic batholith to the north of the map area. White, granitoid pegmatite forms metre- to kilometre-sized sills, dikes, and stocks within the sedimentary rocks.

The most abundant rocks within the area are sedimentary rocks, metamorphosed to paragneisses and schists that are intruded by sills, dikes and stocks of granitic pegmatite. There is a greater abundance of metavolcanic rocks and accompanying mafic, volcanogenic, metasedimentary rocks interlayered with the sedimentary rocks in the Uchi Subprovince than in the English River Subprovince (*see* Figure 6.2). Otherwise, the rock types, metamorphic grades, and structural trends are similar in both subprovinces and no noticeable increase in deformation occurs at the projected boundary of the two subprovinces (*see* Figure 6.2). Previous studies have indicated that the boundary between the English River and the Uchi subprovinces extends through the Caron Lake area along the north shore of Greenbush Lake (Breaks et al. 1978; Ontario Geological Survey 1980). This boundary is shown on Figure 6.2 and, in this summary, reference is made to it for convenience only, as there are geological features common to the areas north and south of its projected location in the map area. These common features indicate that this location may require modification.

The area has been subjected to several folding, faulting, and shearing events. Some of the tonalite-trondhjemite stocks and the white granitoid pegmatite bodies have undeformed, primary textures. All other rocks, including the Kagami pluton, have strongly developed, east-trending, steeply dipping foliations. Only in a few places can the facing directions be determined in the metasedimentary-metavolcanic succession.

The major fold structures are the doming of the supracrustal rocks by the Kagami pluton and the development of two east-striking synclines and one anticline in the Uchi Subprovince (*see* Figure 6.2). In the English River Subprovince, all the rocks dip north except where minor folds are present.

SUPRACRUSTAL ROCKS

The sedimentary rocks consist of quartz-rich wacke, siltstone, mudstone, and arenite, metamorphosed to form banded biotite-feldspar-quartz paragneiss and schist. Depending on their original composition, they contain garnet, sillimanite, or muscovite with or without staurolite. Some quartzites also occur.

In both the English River and Uchi subprovinces, the sedimentary rocks contain alternating, narrow, continuous zones of magnetite-rich and magnetite-poor biotite-feldspar-quartz schists (ironstone). The most prominent of these ironstone units occurs near the projected boundary between the English River and Uchi subprovinces (*see* Figure 6.2). Less prominent zones of ironstone occur to the south, in the English River Subprovince, and farther to the north, within the metasedimentary rocks of the Uchi Subprovince.

Only minor amounts of banded iron formation with chert layers are present in the map area and, where found, are interlayered with the calc-alkalic felsic tuffs.

Garnetiferous to nongarnetiferous, amphibolitic lenses and layers, 1 cm to 2 m thick, are interlayered with less mafic, quartz-rich wacke layers of similar thicknesses. These interlayered rocks are locally abundant above, below and within sections of the supracrustal succession that include tholeiitic basalt flows. The amphibolitic layers are interpreted to be metamorphosed volcanogenic detritus from proximal tholeiitic flows. Some of the amphibolitic layers contain up to 10 percent fine- to coarse-disseminated sulphide mineralization over distances of a kilometre, and are responsible for most of the electromagnetic anomalies in the area (Ontario Geological Survey 1986).

The calc-alkalic volcanic rocks are mainly pyroclastic rocks comprising tuff, crystal and lapilli tuff, and tuff breccia.

The basaltic to andesitic tuff breccias consist of strongly flattened fragments in a darker coloured, schistose, amphibole-rich matrix. The fine-grained, grey, banded schists that are interlayered with the tuff breccias are presumed to have been bedded tuffs and crystal tuffs and lack the high quartz and mica contents associated with the sedimentary schists. Graded bedding of volcanic fragments and crystals is preserved in a few of the tuffaceous units. Generally, the basaltic to andesitic, calc-alkalic volcanic rocks have been metamorphosed and deformed to hornblende-feldspar schists.

The calc-alkalic dacites and rhyolites are banded to massive, light-coloured rocks comprising fine-grained quartz and feldspar. Relict, 1 to 3 mm sized quartz and feldspar pyroclasts are preserved, which distinguish them from the sedimentary rocks

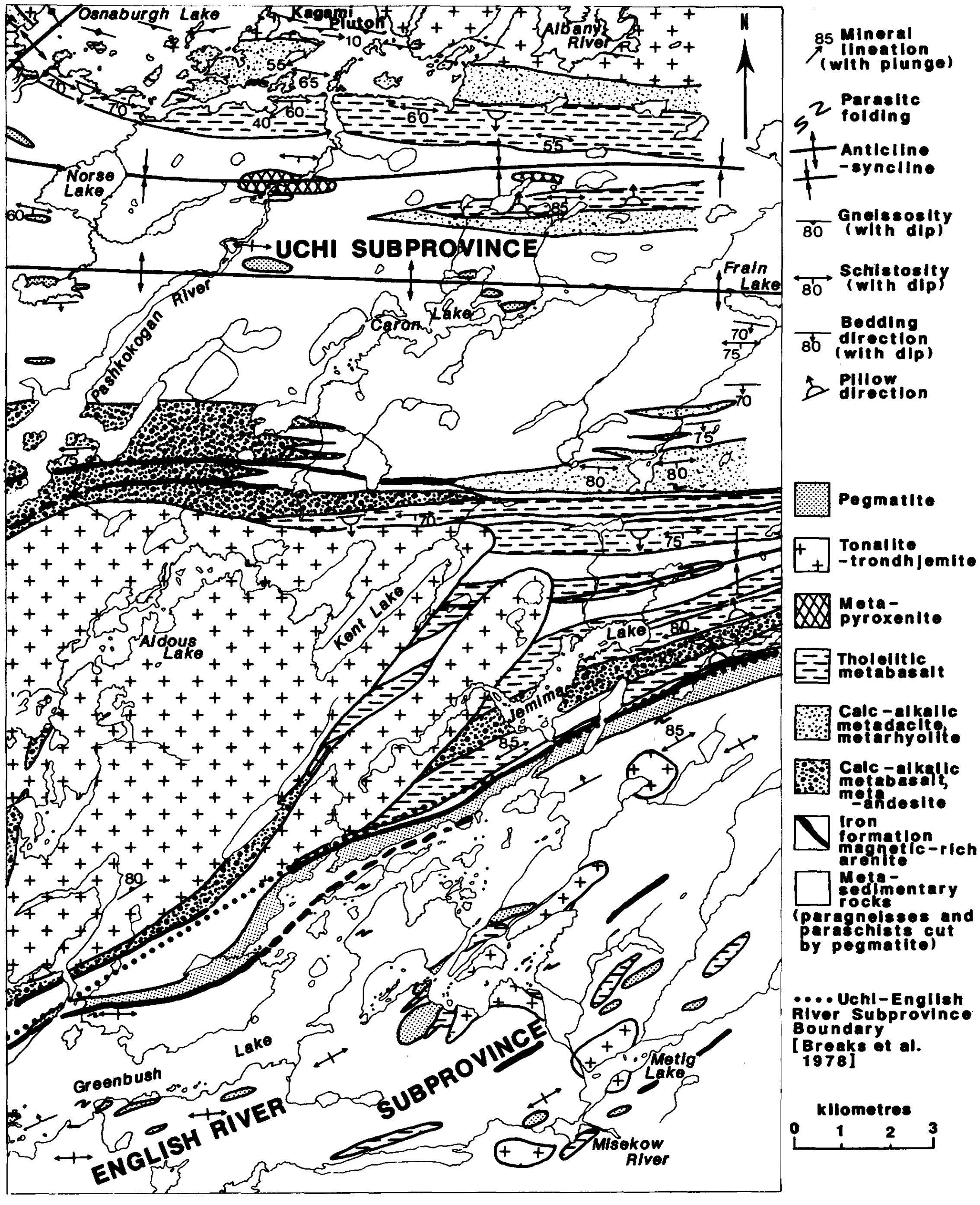

Figure 6.2. *General geology of the Caron Lake area.*

with similar mineralogy. However, toward the margins of the Kagami pluton, the volcanic rocks are recrystallized and homogenized, and become difficult to distinguish from fine-grained, deformed, subvolcanic, feldspar porphyry. The volcanics are recognized by the uneven distribution and size range of the recrystallized feldspar pyroclasts and by some preserved bedding.

The calc-alkalic volcanic rocks occur mainly within the Uchi Subprovince (*see* Figure 6.2). They are concentrated in the middle of the supracrustal succession, between the sedimentary rocks and the tholeiitic basaltic flows.

The tholeiitic basalts are Mg-rich and are associated with subordinate amounts of tremolitic, peridotitic komatiite and basaltic komatiite. Tholeiitic, Fe-rich basalts are absent in the supracrustal succession. The Mg-rich, tholeiitic basalts consist of deformed massive and pillowed flows. Some of the massive flows contain amphibolitized pyroxene phenocrysts up to 2 cm in size. Most of these coarse-grained rocks grade into finer grained basalt and are interlayered with pillowed flows. Garnet porphyroblasts are developed within most of the rocks of tholeiitic basalt composition.

The tholeiitic basalts are present in both the English River and Uchi subprovinces (*see* Figure 6.2). In the Uchi Subprovince, these rocks, along with amphibolitic sedimentary rocks, occupy the cores of the two synclines, which suggests that tholeiitic volcanic rocks may be the youngest group of supracrustal rocks of the area.

PLUTONIC ROCKS

The plutonic rocks are mainly granitoids, except for mafic subvolcanic sills and stocks that are present in the Uchi Subprovince along the Pashkokogan River (*see* Figure 6.2). The mafic intrusions are actinolite-tremolite rich and may have been pyroxenites.

The equigranular, homogeneous, granitoid rocks of tonalite-trondhjemite-granodiorite composition form large stocks, including the Kagami pluton on Osnaburgh Lake, and several stocks in the vicinity of Greenbush Lake that intrude the supracrustal rocks of the Uchi and English River subprovinces. Near Greenbush Lake, these granitoid rocks are undeformed to weakly deformed with a weak gneissic texture. The Kagami pluton is deformed into east-trending augen gneisses transected by a later, vertically oriented, brittle deformation trending 030°.

The white granitoid pegmatites are closely associated with paragneiss and schist. They are composed of alkali feldspar, quartz and mica. The mica can be centimetre-sized books of either biotite or muscovite that form up to 20 percent of the rock. Accessory minerals include garnet, tourmaline, hornblende, beryl, apatite, fluorite, and corundum. The pegmatites form lenses that are a few metres both long and wide to kilometre-long sills and dikes that are up to about 200 m wide and contain numerous xenoliths of the host paragneiss. Most of the larger pegmatite bodies appear not to be zoned and to have formed by the coalescence of numerous smaller pegmatite bodies.

The pegmatites occur throughout the English River Subprovince portion of the map area (*see* Figure 6.2), but most are close to the contact between the sedimentary rocks and the volcanic rocks north of Greenbush Lake. In the Uchi Subprovince, these pegmatite bodies are equally concentrated in the sedimentary rocks over a wide area extending from Norse Lake toward Frain Lake.

STRUCTURE

In the English River and southern parts of the Uchi subprovinces, foliations range in strike from 070° to 090° with dips that are from 70° north to 60° south. Mineral lineations plunge eastward. In the northern half of the map area, the foliations range from 080° to 120° in strike, with dips from 55° to 85° south. Here, the mineral lineations in the supracrustal rocks plunge westward, whereas those in the Kagami pluton plunge shallowly to the east. The only major change in the foliation direction occurs in the northwestern part of the map area, on the west side of the Kagami pluton, where the foliations in the supracrustal rocks trend northwest to north. Parasitic folds have an "S" asymmetry in the northwestern part of the map area: elsewhere throughout the map area, they have a "Z" asymmetry.

The reversal of parasitic folds around the Kagami pluton and the outward facing of the strata (*see* Figure 6.2) indicate that this pluton is a southwest-plunging anticlinal structure. South of the Kagami pluton in the Uchi Subprovince, there are two east-trending synclines separated by a complementary anticline. No major fold axes were detected in the English River Subprovince (*see* Figure 6.2). Within the English River Subprovince, younging directions are mainly north-facing, except in "Z"-shaped parasitic folds.

No noticeable increase in the deformation of the rocks occurs across the English River and Uchi subprovinces' boundary as defined by Breaks et al. (1978). Pseudotachylyte occurs in widely separated locations, one of which is at the outlet of Jemima Lake close to this boundary. Other occurrences are in the Kagami pluton and in the calc-alkalic metavolcanic rocks and metasedimentary rocks in the northern part of the area.

In much of the area, bedding and flow contacts have been tectonically disturbed to such a degree that most of these supracrustal rocks can only be described as being layered or banded. The author considers much of this layering and banding within the supracrustal rocks to be a result of tectonic disruption of the bedding and flowage contacts of different rock types, as opposed to tectonic imbrication over significant distances of different rock types.

ECONOMIC GEOLOGY

The Caron Lake area has potential for base metal, precious metal and rare-element pegmatite discoveries.

Many amphibole-rich, sulphide-bearing conductors shown on the electromagnetic-magnetic maps of the Ontario Geological Survey (Ontario Geological Survey 1986) have not been thoroughly explored either for base metal or precious metal content. Some of these conductors are spatially associated with magnetite-rich arenite or iron formation and may have formed as a result of sulphidization of the iron oxides and, therefore, may be a favourable host for gold mineralization (Hall and Rigg 1986). The other sulphide-bearing rocks that are interlayered with the metavolcanic and metasedimentary rocks tend to have strike lengths of several kilometres, which indicates that they may be either exhalative in origin or were chemical precipitates in a reducing environment during the deposition of the supracrustal rocks. These sulphide-bearing rocks would be favourable for the concentration of syngenetic or epigenetic base metals and/or precious metals.

The pegmatitic bodies in both the English River and Uchi subprovinces remain to be explored for their rare element contents. According to Cerny and Meintzer (1988), the pegmatites were generated in a sedimentary environment and are favourable hosts for Li, B, Be, Nb, Ta and other rare elements.

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7. Project Unit 89-10. Geology of the Poplar Island Area, Lake of the Woods

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INTRODUCTION

The 1989 field season marked the completion of a five-year program of detailed (1:15 840 scale) bedrock mapping of the Lake of the Woods greenstone belt (*see* Ayer 1984, 1985, 1988; Ayer et al. 1987; Ayer and Sweeny 1986; Morrice 1986; Morrice and MacMaster 1987; Smith 1987). This program has provided the mineral exploration industry with a comprehensive geological data base, and will be the foundation for a synoptic study of the greenstone belt (*see* Paper 8, this volume). In 1989, detailed mapping of the Poplar Island and Windigo Island areas (Figure 7.1) was completed. The Poplar Island map area encompasses 285 km^2, and is bounded by latitudes 49°12'N and 49°20'N and longitudes 94°25'W and 94°50'W. It lies south of the Falcon Island area mapped by Ayer (1988) and southeast of the Monument Bay area mapped by Morrice and MacMaster (1987), and extends westward to the Canada–USA boundary. The Windigo Island map area is west of the Falcon Island map area (*see* Figure 7.1).

Access to most of the area is by boat from the town of Kenora, some 60 km to the north, and from Nestor Falls, located 60 km east from the centre of the map area.

MINERAL EXPLORATION

There is no record of any exploration activity in the map areas on file at the Resident Geologist's office, Kenora, or in the Assessment Files Research Office, Ontario Geological Survey.

GENERAL GEOLOGY

Parts of the present area are included in geology maps by Lawson (1885) and Ziehlke (1974). The area is underlain by Archean volcanic and sedimentary rocks and subvolcanic intrusions, all of which have been metamorphosed to amphibolite facies. These rocks are intruded by the Aulneau and Sabaskong batholiths. An Early Proterozoic diabase dike intrudes all the rocks of Archean age.

Supracrustal Rocks of the Poplar Island Area

The supracrustal rocks have been subdivided into two major stratigraphic units, designated as the Lower Mafic group and the Upper Diverse group (*see* Paper 8, this volume)

The Lower Mafic group (LMG) lies at the base of the exposed stratigraphic section in the area. It

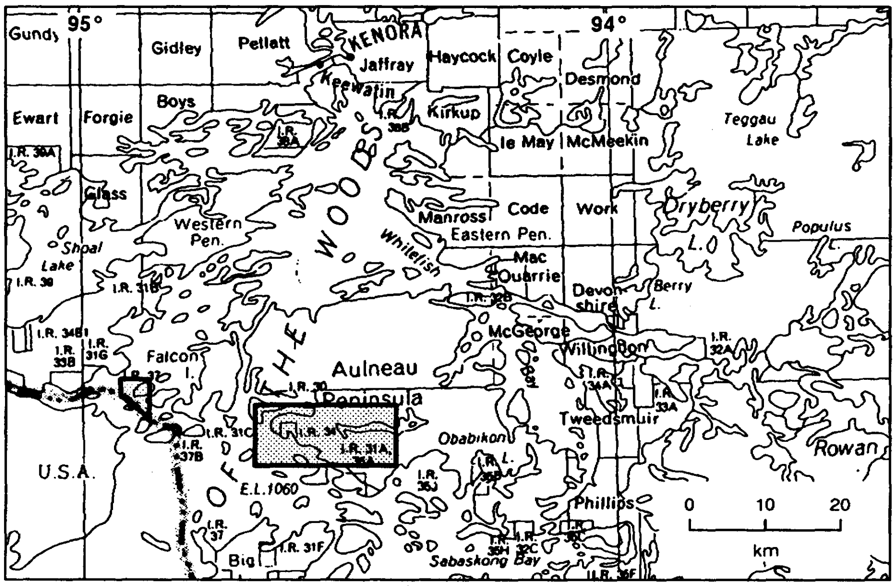

Figure 7.1. *Location map of the Poplar Island Area and Windigo Island Area, Lake of the Woods.*

consists of fine- to medium-grained, aphyric mafic flows with locally recognizable pillows. Units of mafic flows with strongly flattened, coarse-grained, plagioclase phenocrysts were observed as horizons up to 20 m thick. The LMG occurs as a southeast-trending horizon, which is 1.5 km wide in the northwest and broadens to about 5 km wide in the nose of a syncline in the eastern part of the map area. On the south limb of the syncline, the LMG has been largely removed by the intrusion of the Sabaskong batholith. The LMG is within the contact strain aureole created by the intrusion of the Aulneau batholith to the east and northeast of the syncline.

The Upper Diverse group (UDG) conformably overlies the LMG and occurs in the central part of the syncline (Figure 7.2) which extends northwestward into the Falcon Island area. It consists of three subgroups: intermediate to felsic pyroclastic horizons, mafic to ultramafic flows, and metasediments.

Subgroup 1 of the UDG consists of a lithologically diverse sequence of intermediate to felsic pyroclastic rocks deposited by debris flow mechanisms. These pyroclastic rocks range in size, and degree of sorting, from tuff breccia to lapilli tuff and tuff, and locally grade into tuffaceous wacke and siltstone. The volcanic fragments are heterolithic, mafic to felsic and set in a fine-grained recrystallized matrix.

Subgroup 2 is composed of pillowed to massive flows ranging from mafic to ultramafic in composition. Mafic flows are more abundant than ultramafic flows, and are dark green in colour on both the fresh and weathered surface. The ultramafic flows are tremolitic to talcose, with a grey fresh surface and an orange-brown weathered surface.

Subgroup 3 of the UDG consists of horizons of fine-grained feldspathic and tuffaceous wackes of varying thicknesses, interbedded with thinly laminated siltstone. Felsic to intermediate tuff breccia and lapilli tuff are locally interbedded with these sediments.

Intrusive Rocks of the Poplar Island Area

Metamorphosed ultramafic to felsic subvolcanic sills and dikes intrude the supracrustal rocks. A 2 km by 15 km locally differentiated sill occurs in the northern part of the map area. The mafic part of the sill consists of medium- to coarse-grained gabbro and the ultramafic part consists of pyroxenite to peridotite. Felsic synvolcanic dikes and sills are typically plagioclase porphyritic. The phenocrysts may also have quartz and ferromagnesian minerals.

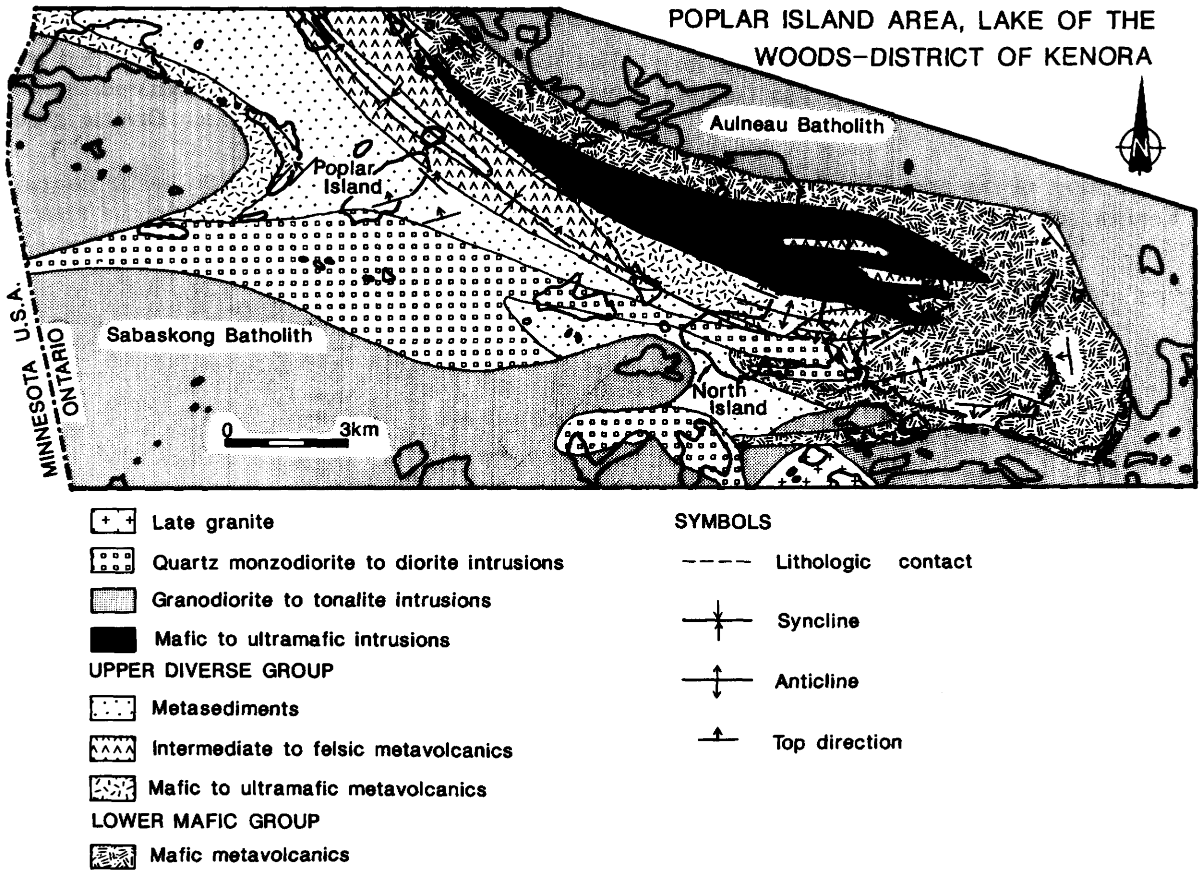

Figure 7.2. *General Geology of the Poplar Island Area, Lake of the Woods.*

The Aulneau batholith marks the northern boundary of the Lake of the Woods greenstone belt in the Poplar Island area. It consists of a strongly foliated, pretectonic, medium-grained granodiorite. The southern border of the greenstone belt is marked by various phases of the Sabaskong batholith. The predominant phase of this batholith is a medium- to coarse-grained granodiorite rich in biotite. In places, the granodiorite is rich in hornblende and contains large (up to 4 cm) phenocrysts of alkali feldspars. The eastern part of the Sabaskong batholith consists mainly of tonalite. A gneissic fabric is evident at the southernmost exposures.

An east-striking granitic dike about 2 km wide and 20 km long intrudes the supracrustal rocks on the northern side of the Sabaskong batholith. The lithology of the dike ranges from medium-grained, pink quartz monzodiorite to black diorite and to monzodiorite with mafic xenoliths up to a metre long. A relatively fresh, pink, medium-grained granite is present in the southeastern part of the area. These characteristics, and the unfoliated nature of the intrusion, suggest that the body is posttectonic in origin.

Geology of the Windigo Island Area

In the Windigo Island area (not shown in Figure 7.2), the northwest-trending supracrustal rocks are part of the UDG. In the north, a thick unit of felsic pyroclastics is predominantly composed of monolithic tuff breccia with minor lapilli tuff and tuff. It is succeeded to the southeast by a 100 m to 200 m thick unit of thinly bedded feldspathic wacke and siltstone. These are overlain to the southeast by a thick unit of mafic to intermediate, clinopyroxene-phyric breccia of debris flow origin. This unit grades from tuff breccia to thinly bedded tuff. The supracrustal rocks are intruded by a southwest-trending apophysis of the Falcon Island stock that extends south to the Canada–USA border. Observed phases of the stock are mainly medium-grained pink syenite and minor black diorite.

STRUCTURAL GEOLOGY

The interpretation of the fold axes shown in Figure 7.2 was based on a few observed reversals in the facing directions of pillowed volcanic rocks and graded metasediments. A major syncline extends southeastward from the Falcon Island area (Ayer 1988). Two minor anticlines occur north and south of the synclinal axis in the eastern part of the map area. Minor, strongly foliated zones of ductile deformation occur locally, but no major deformation zone was observed.

ECONOMIC GEOLOGY

There is no record of any mineral exploration in the Poplar Island area. A number of gossan zones were found during the present survey, from which grab samples were collected for analysis. These zones contain pyrrhotite and/or pyrite and occasionally chalcopyrite. A small rusty zone in the sedimentary rocks at the northeast tip of North Island contains minor disseminated chalcopyrite. An analysis of a sample of this mineralization returned 18 ppb Au and 670 ppm Cu (Geoscience Laboratories, Ontario Geological Survey). All other samples analyzed contained less than 10 ppb Au.

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8. Project Unit 89-10. Regional Geology Of The Lake Of The Woods Area

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INTRODUCTION

Over the past seven years, the Ontario Geological Survey (OGS) has carried out an extensive program in the Lake of the Woods greenstone belt in the western Wabigoon Subprovince. The supracrustal rocks of the greenstone belt, its internal stocks, and the margins of the external batholiths have been mapped at a scale of 1:15 840 (Davies 1983; Ayer et al. 1985; Ayer and Gil 1986; Morrice 1986; Ayer and Sweeny 1987; Ayer et al. 1988; Ayer 1988; Morrice and MacMaster 1988; *see* Paper 7, this volume). Several of the external batholiths were mapped at 1:50 000 scale (Ziehlke 1974; Sanborn-Barrie 1987). Other components of the program were mineral deposit (Smith 1985; Smith and Thomas 1986; Davies and Smith 1988) and structural (Sanborn 1986; Buck and Ayer 1987) studies.

The work reported here is the initial phase of a synoptic project to provide a regional synthesis of the geological data from these recent studies in an area of about 2700 km^2 in the Lake of the Woods area (Figure 8.1). The aim of the project is to integrate this geological information into synoptic maps and a synoptic report, which will provide a stratigraphic and structural framework to aid mineral exploration. This year's studies concentrated on lithostratigraphic and structural problems which had been identified during previous work by the author, and on extending stratigraphic units and structures into the Western Peninsula (Davies 1983) and Monument Bay (Morrice and MacMaster 1988) areas.

MINERAL EXPLORATION

The study area has a long history of mineral exploration and mining, dating back to a gold rush in the 1880s. Since then, gold has remained the principal commodity of interest; however, there was also considerable exploration for base metals in the 1960s and 1970s. Past-producing gold mines in the area include the Wendigo (67 423 ounces Au), the Sultana (15 977 ounces Au), the Kenricia (2533 ounces Au), and the Gold Hill (1090 ounces Au) mines. More extensive descriptions of these and other mineral occurrences are given in Beard and Garratt (1976) and Davies and Smith (1988). Recent exploration has been summarized in OGS annual compendia.

Gold exploration in the study area during 1989 (as of September 1, 1989) included diamond drilling and geological, geochemical and geophysical surveys

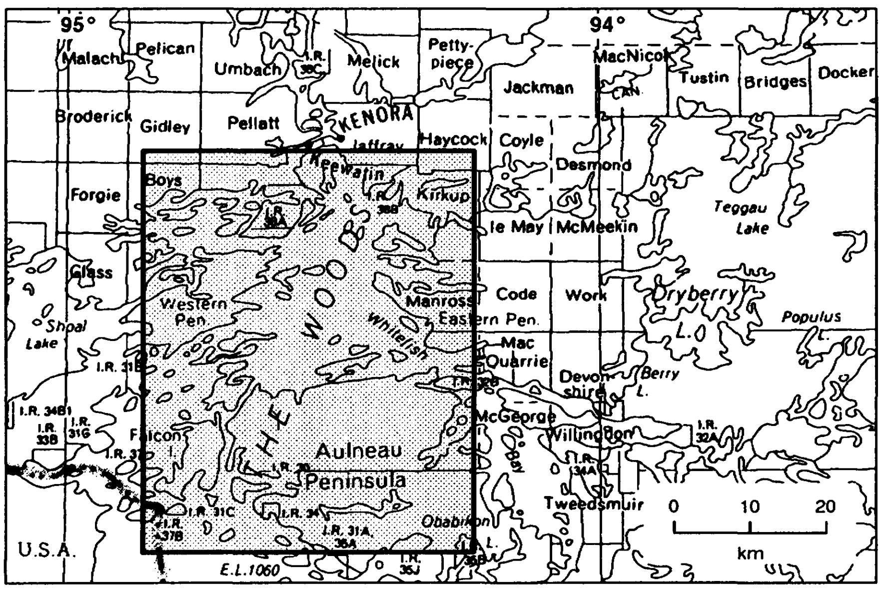

Figure 8.1. Location map of the Lake of the Woods Area.

by Noranda Exploration Company, Limited in the vicinity of Chisholm Island and Echo Bay; diamond drilling and geological, geochemical and geophysical surveys in the Abernathy Lake area by Mingold Resources Limited; and a geophysical survey in the Hatmaker Lake area by Ian McLandress of Winnipeg, Manitoba.

GENERAL GEOLOGY

The study area is in the Lake of the Woods greenstone belt (LWGB) in the western portion of the Wabigoon Subprovince, which is a major subdivision of the Superior Province. The LWGB consists of deformed and metamorphosed assemblages of volcanic and subordinate sedimentary rocks with an overall east-west alignment. This assemblage is bounded by the Sabaskong and Aulneau batholiths to the south, by the Dryberry batholith to the east, and by granitoids of the English River Subprovince to the north (Figure 8.2). The supracrustal succession commonly face away from the marginal batholithic complexes. Two broad deformation zones transect the LWGB (Figure 8.3): the Crowduck Lake–Witch Bay deformation zone (CWDZ) in the north and the Pipestone–Cameron deformation zone (PCDZ) in the south. The Barrier Islands fault (BIF) divides the LWGB into northern and southern portions.

Lawson (1885) recognized that the LWGB supracrustals are significantly different from the Huronian rocks with which they had been previously included (Bell 1882), and named them the Keewatin Series. Goodwin (1965) proposed a stratigraphy for Lake of the Woods consisting of two superimposed sequences: the Lower and Upper Keewatin. Both sequences are composed, in ascending order, of mafic volcanic rocks, felsic volcanic rocks, and sedimentary rocks. Recent work by the OGS (Ayer and Sweeny 1987; Ayer 1988) suggests four major lithostratigraphic groups (Figure 8.2). The oldest is the Lower Mafic group (LMG), which is conformably overlain by the Upper Diverse group (UDG). The Warclub group (WG) conformably overlies the UDG in the southern part of the LWGB, and the White Partridge Bay group (WPBG) overlies the UDG in the northern portion of the LWGB.

Lower Mafic Group

This succession occupies the lowermost portion of the exposed stratigraphy. The LMG is found along the north and south peripheries of the LWGB, where it is intruded by the marginal batholiths. It is also found in the cores of anticlines in the central part of the belt. The group is characterized by monotonous successions of pillowed and massive mafic flows, which range in composition from Mg-rich to Fe-rich tholeiitic basalt. Regional stratigraphic correlation of the group is aided by laterally extensive horizons of plagioclase-megaphyric basalt within it.

Upper Diverse Group

Rocks of this group are more abundant than those of other groups, and occupy much of the central portion of the LWGB. They conformably overlie the LMG. This group is composed of mixed, mafic to felsic, volcanic sequences and subordinate sedimentary horizons, which are characterized by abrupt lateral and vertical facies changes. The UDG consists of intercalations of three distinct lithologic subgroups. Subgroup 1, the most abundant, is a diverse sequence of mafic to felsic, calcalkalic pyroclastics and flows. These rocks typically contain phenocrysts of plagioclase $\pm$ clinopyroxene $\pm$ quartz. Pyroclastic rocks are a major component of the group and include debris flows, ash flows, air fall and reworked tuff. The lava flows are commonly pillowed and highly vesiculated. Subgroup 2 consists of a monotonous sequence of pillowed and massive mafic flows up to several kilometres thick and tens of kilometres long. The flows are typically aphyric and non-vesiculated, Mg-rich, tholeiitic to komatiitic basalt with minor ultramafic komatiites. Subgroup 3 consists of sedimentary rocks, which are intimately intercalated with the volcanics of the UDG. The sedimentary rocks consist of thinly to thickly bedded wacke, tuffaceous wacke, siltstone and minor oxide- and sulphide-facies ironstone. Thick, lenticular deposits of monolithic granitoid clast conglomerates occur in the Queen Island area (Johns 1987a).

Warclub Group

Rocks of the Warclub group are restricted to two bands in the south portion of the LWGB. The bands thicken east of the study area, where they have been interpreted to occur at the top of the stratigraphic column and to correlate across an anticline within the Black Lake volcanics (Johns 1987b). Investigations within the study area indicate localized intercalations with volcanic rocks; thus, while in some localities the WG occurs at the top of the section, in others they are overlain by volcanic rocks similar to those in the UDG. It is possible that some of this interdigitation may be the result of structural complexity.

WG rocks consist predominantly of thickly bedded turbidites which display normal grading from wacke to mudstone, and minor thin- to medium-bedded wacke and siltstone. Mafic to felsic pyroclastic volcanic rocks occur as rare intercalations within the sediments.

White Partridge Bay Group

The WPBG occurs at the top of the stratigraphic column in the northern portion of the LWGB. The base of this group consists of a coarsening upwards succession of wacke, siliceous siltstone, mudstone and minor paraconglomerate. This succession grades upwards into thickly bedded turbidites in the central portion. Cross-bedded wacke, interbedded with paraconglomerate containing rounded clasts of

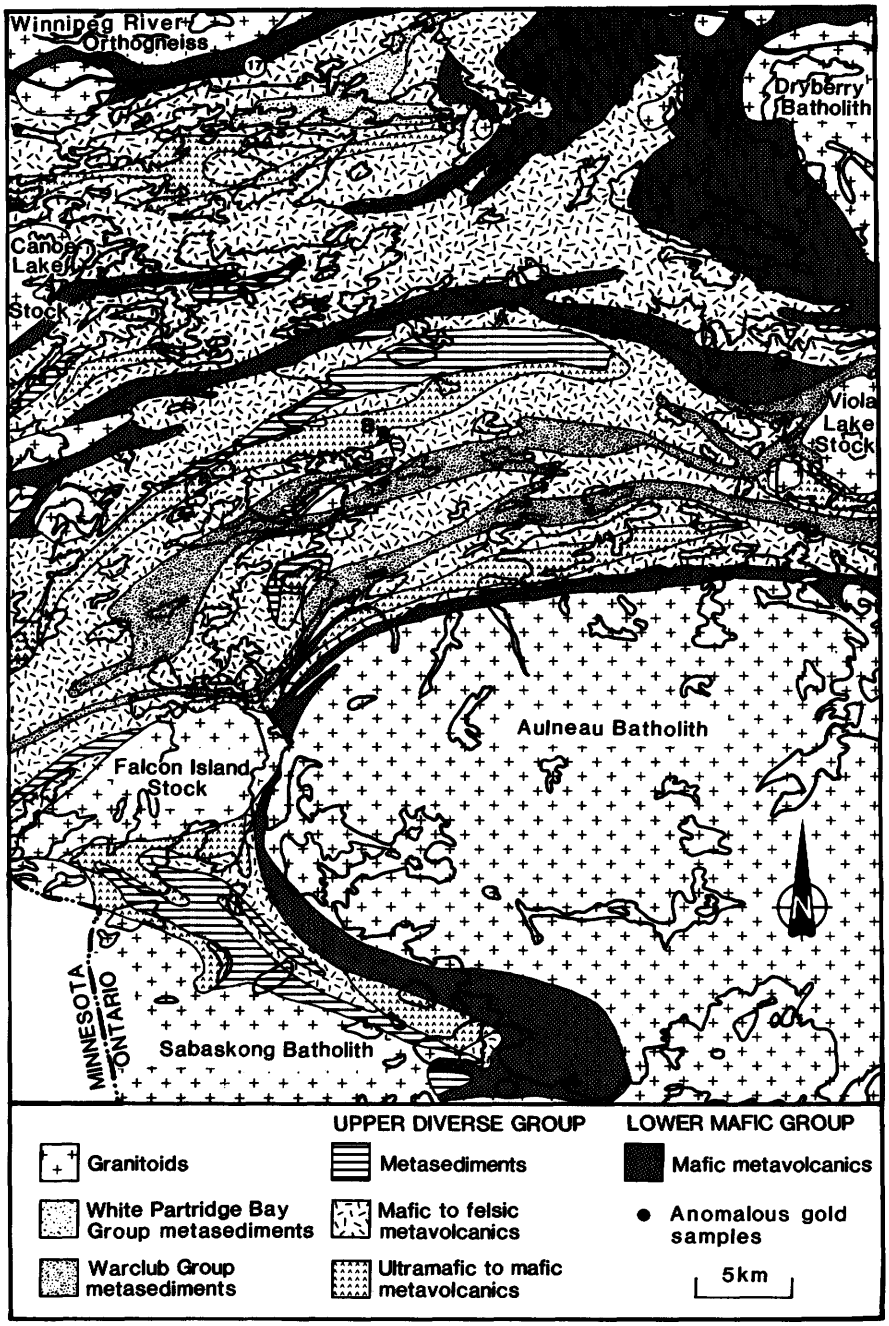

Figure 8.2. *General geology of the Lake of the Woods greenstone belt.*

granitoid rocks, occurs at the top of the group. Original interpretations were that the WPBG unconformably overlies the UDG (Ayer and Gil 1986), but the synoptic investigations confirm a conformable, gradational contact with the UDG, as indicated by Sanborn (1986). Evidence for this is found on the south side of the WPBG, where felsic pyroclastic rocks of the UDG underlie the sedimentary rocks near the base of the WPBG. As well, rare intercalations of felsic pyroclastic rocks occur within the sedimentary rocks near the base of the WPBG. Felsic pyroclastic rocks also occur locally as lensoid horizons stratigraphically higher in the WPBG.

Intrusive Rocks

In the north, orthogneisses of the Winnipeg River Subprovince (WRS) are in either faulted, or intrusive contact with the supracrustal rocks of the LWGB. Geochronological evidence indicates that the ages of intrusions within the WRS range from much older than to contemporaneous with those of the LWGB (Beakhouse 1985). LWGB supracrustal

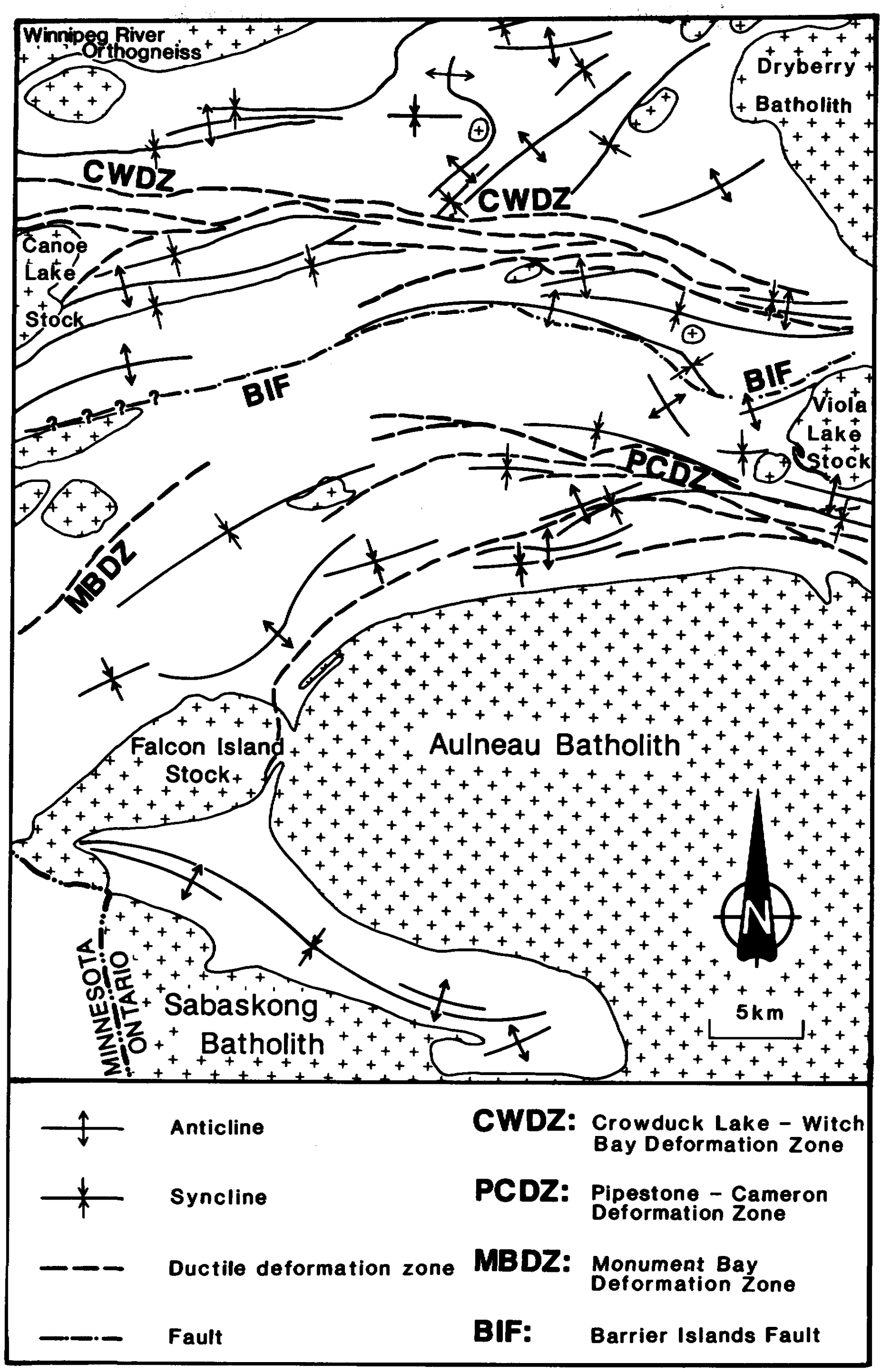

Figure 8.3. *Generalized structural geology of the Lake of the Woods greenstone belt.*

rocks are intruded by the Aulneau and the Sabaskong batholiths to the south, and the Dryberry batholith in the northeast. These batholiths are complex granitic intrusions with multiple phases emplaced over extended periods of time (Ziehlke 1974; Sanborn-Barrie 1987). Based on geochronological evidence, they are contemporaneous with volcanism (Davis and Edwards 1986). Smaller granitoid stocks, ranging in composition from quartz oversaturated to quartz saturated, have intruded the LWGB.

STRUCTURAL GEOLOGY

The LWGB has a complex history of deformation (Figure 8.3) involving three separate periods of folding and two shearing events (Ayer and Buck 1989). The earliest recognized deformation event (D_1) resulted from a north-south directed compression and produced large east-trending, shallowly plunging, F_1 folds with steeply dipping axial surfaces. The D_1 fabric, namely moderate to strong foliations and subvertical lineations, is widespread. Constriction is typically greater than flattening. A second deformation event (D_2) that also resulted from north-south directed compression produced F_2 folds with steeply dipping axial surfaces generally parallel to those of D_1 but with steeply plunging fold axes. The D_2 fabric is a spaced to pervasive, axial planar cleavage which overprints the D_1 fabric. D_3 folds are subhorizontal, north-trending structures restricted to the margins of late tectonic stocks. The D_3 fabric is not well developed.

Ductile deformation zones, defined by highly schistose and altered rock, occur on various scales throughout the area. Three major zones, with numerous smaller anastomosing splays off the main trend, have been identified. The Crowduck Lake–Witch Bay deformation zone (CWDZ) transects the LWGB in the north, and the Pipestone–Cameron deformation zone (PCDZ) and the Monument Bay deformation zone (MBDZ) occur in the southern part of the LWGB (*see* Figure 8.3). Kinematics in these deformation zones tend to be complex, but generally an early vertical and later subhorizontal component can be recognized (Sanborn 1986; Smith and Thomas 1986; Ayer and Buck 1989). Subvertical movement may have accompanied D_1 deformation, and subhorizontal movement may have accompanied D_2 deformation. This is consistent with the orientations of the F_1 and F_2 fold axes, respectively. Investigations this year indicate that both the PCDZ and MBDZ die out in the Western Peninsula area, and are thus not a single continuous structure as was previously suggested (Morrice 1989).

A less ductile, relatively narrow fault zone, identified as the Barrier Islands fault (BIF), divides the study area into northern and southern parts (*see* Figure 8.3). This fault is characterized by zones of intense carbonatization and fuchsitic alteration and is typically located along the southern margin of the central horizon of the LMG. Subvertical mineral lineations and the map pattern of the metavolcanic rocks on the the north side of the fault imply relative displacement was north-side-up. The fault locally truncates D_1 folds, indicating post-D_1 timing of displacement.

ECONOMIC GEOLOGY

Details of the numerous mineralized showings and deposits in the study area have been discussed in reports and maps for each specific map area (Davies 1983; Ayer et al. 1985; Ayer and Gil 1986; Ayer and Sweeny 1987; Ayer et al. 1988; Ayer 1988; Morrice and MacMaster 1988).

Gold mineralization is epigenetic and occurs in three distinct geological environments. The first is in relatively minor deformation zones associated with the margins of some granitic intrusions (e.g., the Dryberry batholith and the Sultana Island stock). The mineralization occurs in and around the intrusions, indicating that they represent a favourable structural environment and do not have a direct genetic relationship to the mineralization. The second gold-bearing environment is quartz veins within relatively brittle fracture zones (e.g., Kenricia Mine). This type of mineralization can occur anywhere within the LWGB. The third gold environment is within the major ductile deformation zones which transect the LWGB. Major loci of mineralization within the deformation zones are 1) the margins of the deformation zones where there are deviations in the trend of the zones (Ayer and Sweeny 1987), 2) subsidiary splays off the main parts of the deformation zones (Ayer et al. 1988), and 3) where the deformation zones are intersected at a high angle by the transition between amphibolite and greenschist facies of metamorphism (Morrice and MacMaster 1988).

Two previously unrecognized sites with anomalous gold values were located during the 1989 field work. One of these is on the southern tip of Shammis Island (Locality A—Figure 8.2). The mineralized zone is in carbonatized and locally fuchsitic mafic metavolcanics within the BIF. The gold mineralization occurs in extensional quartz veins that contain disseminated pyrite, chalcopyrite and galena. A grab sample of the quartz and sulphides contained 910 ppb gold (Geoscience Laboratories, Ontario Geological Survey). The second site is in a small extension of the Pipestone–Cameron deformation zone west of the Chisholm Island area (Locality B— Figure 8.2). The mineralized zone here consists of highly schistose and carbonatized mafic metavolcanics cut by contorted quartz-carbonate veinlets with disseminated pyrite and chalcopyrite. A grab sample of quartz and sulphides from this locality contained 350 ppb Au (Geoscience Laboratories, Ontario Geological Survey).

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9. Gold Studies in the Dryden Area

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INTRODUCTION

This report summarizes the results of investigation of some gold occurrences in the Dryden area (Figure 9.1) during the 1989 field season, in continuation of a regional study and inventory of these gold occurrences and their structural and lithologic setting (Blackburn et al. 1988, 1989; Parker and Perrault 1988). In 1989, field work focussed on the Lower Manitou Lake area (Figure 9.2) in order to define:

1. relationships between the gold occurrences and their host rocks
2. alteration and metamorphism
3. sulphide compositions
4. structure

In addition to reporting the preliminary results from this work, this summary also gives a more detailed account of the role of structure in the setting of gold

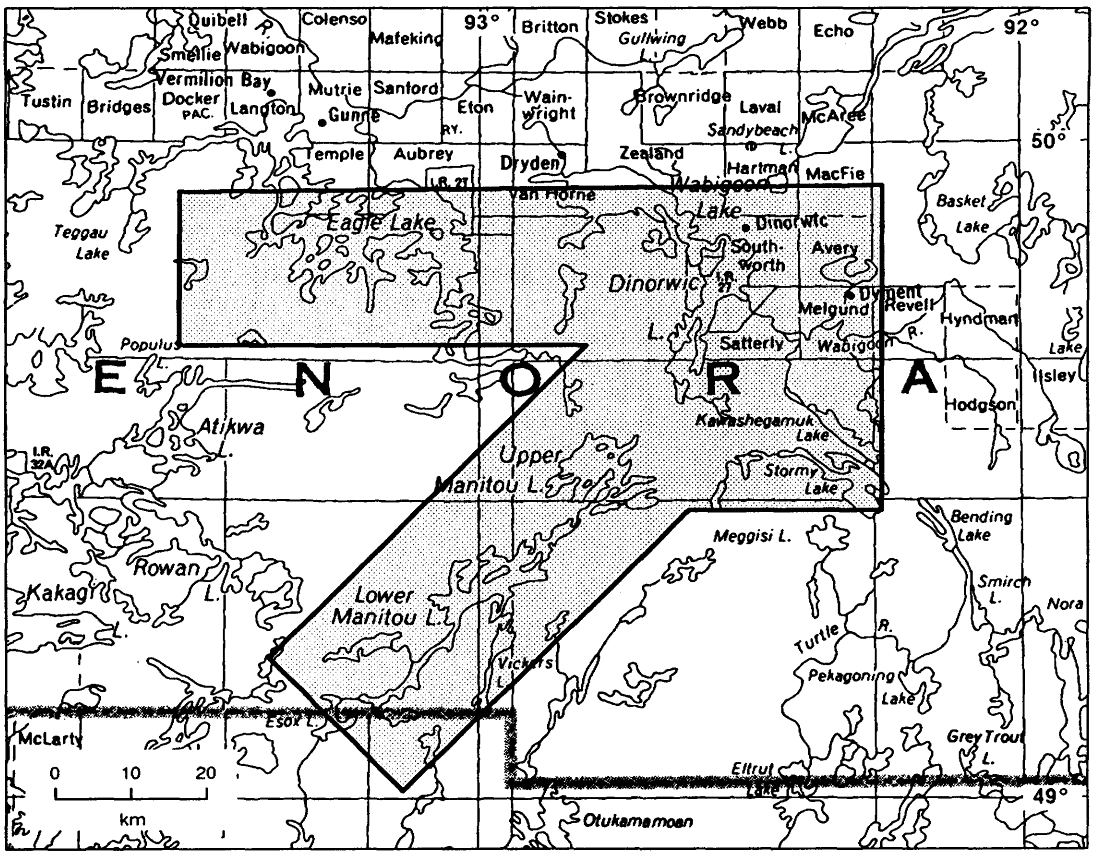

Figure 9.1. *Location map of the study area.*

CANADA ONTARIO
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This project A.6.8 is part of the five-year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

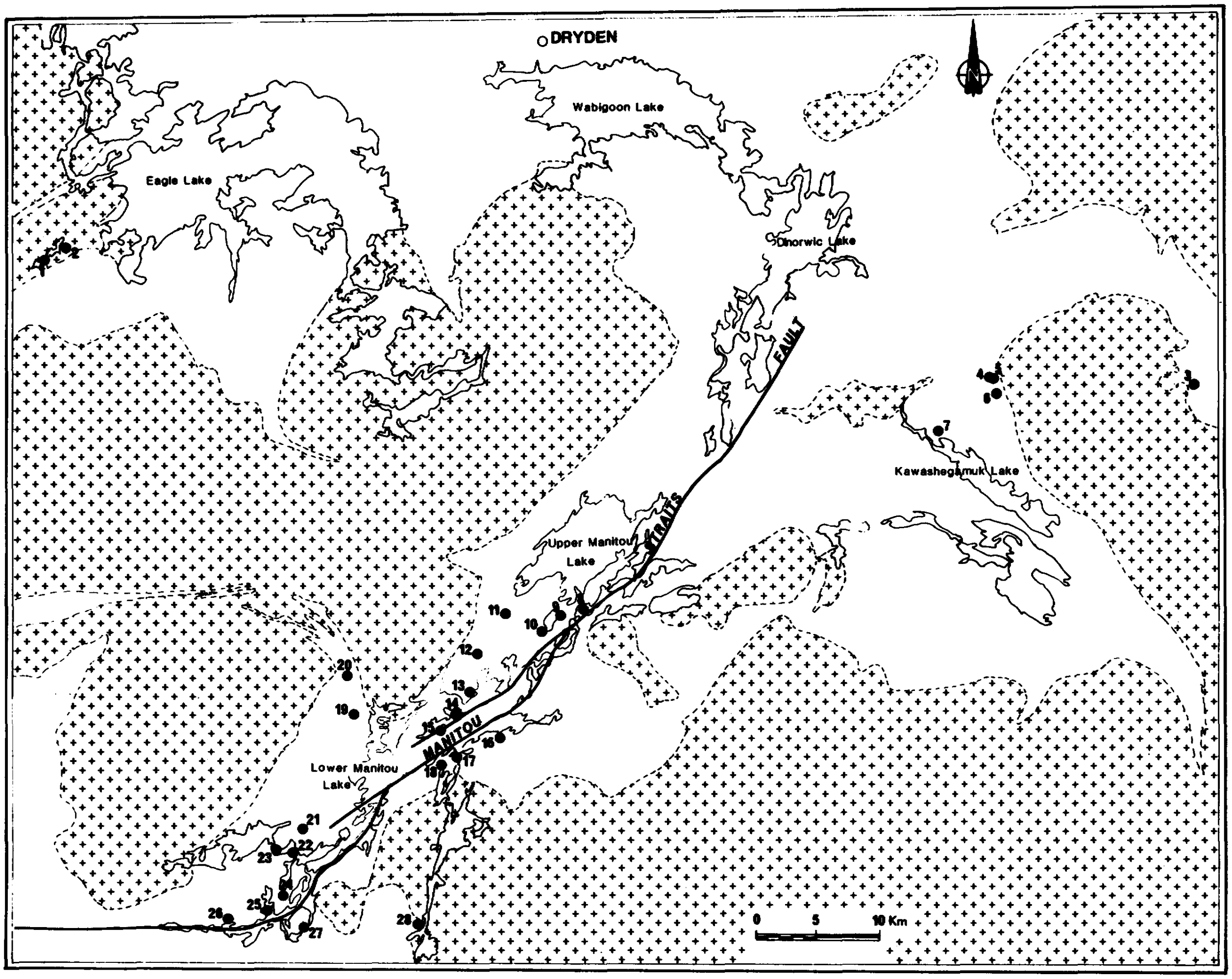

Figure 9.2. *Locations of investigated gold occurrences (see Table 9.1 for further information). The patterned (crosses) area indicates granitic rocks and the white area indicates supracrustal rocks.*

at the Sakoose Mine and adjacent Maw occurrences (Figure 9.3).

MINERAL EXPLORATION

Unless otherwise stated, the following section has been summarized from the files of the Resident Geologist, Ministry of Northern Development and Mines, Kenora.

Gold exploration in the Lower Manitou Lake area started in 1895 when the Swede Boys Syndicate started what was to be the first and last placer gold mining operation in the area. A shaft was later sunk on the syndicate's property, which is now known as the Merrill claims (Figure 9.2, number 11). Exploration activity between 1895 and 1899 was concentrated in and around Lower Manitou Lake. The Barker Brothers' Mine (19), the Beehive Mine (14), the Royal Sovereign Mine (13) and the Sairy Gamp property (23) were all developed during this period. In 1901, a shaft was sunk near Grant Lake on Gold Standard Mining Company's G-340 property (22), and in 1902 another shaft was sunk on Gold Standards' HW 271 property (21) at Nelson Lake.

The Manitou area was very active up to 1905, with shafts and pits being sunk on nearly every property. Major properties developed and mined during this period were the Glass Reef Mine (16), the Queen Alexandra Mine (9), the King Edward occurrence (10), the Gaffney occurrence (15) and the Royal Sovereign Mine (13). It was during this period that both a shaft and a pit were sunk on a gold-bearing vein at Vickers Lake (Smooth Rock occurrence, number 28).

After 1905, exploration remained sporadic until 1933. Between 1933 and 1945, the Dryden Red Lake occurrence (12) was developed, the Merrill claims (11) were investigated, and 457 m of drilling was done on the Gaffney occurrence (15). The Gates Lake occurrence (25), which included the Peep Bay occurrence (24), was trenched and drilled

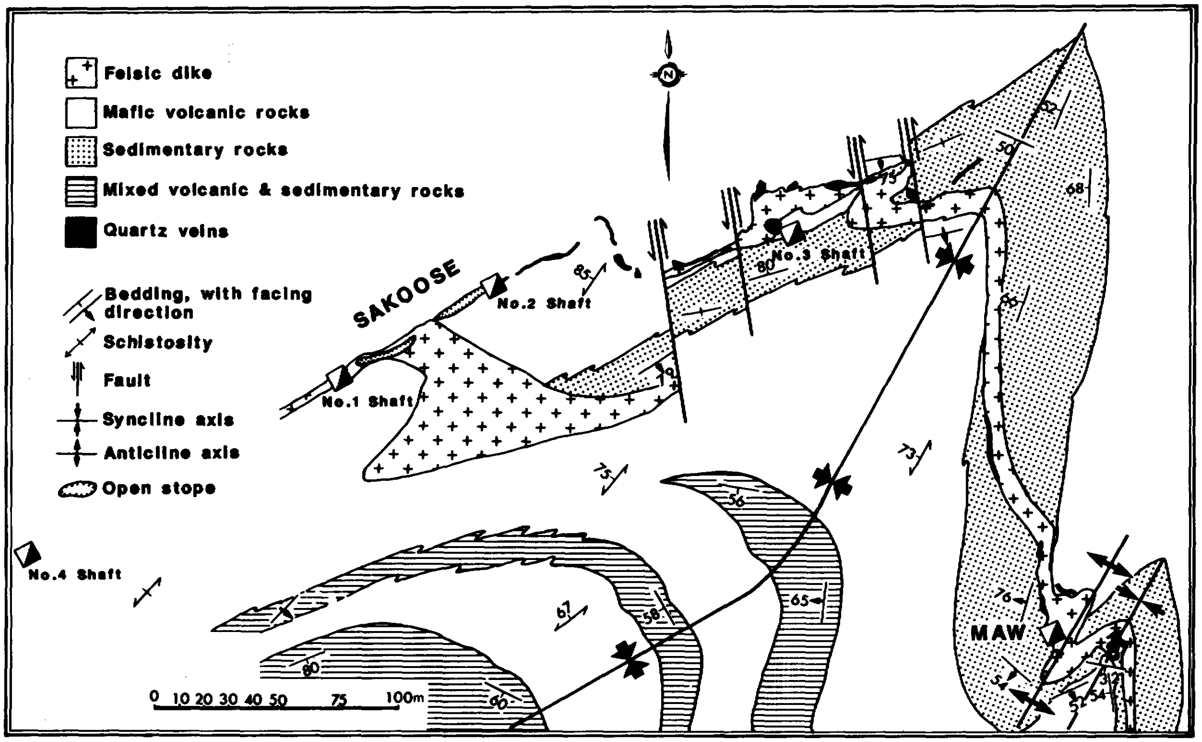

Figure 9.3. *Structural setting of the Sakoose Mine and the Maw occurrences.*

between 1942 and 1944. The Austin antimony occurrence (26) was trenched and drilled in 1941.

The next period of activity began in the early 1980s and has continued to the present. St. Joe Canada Inc. first optioned the Reliance claims to the north of the King Edward occurrence (10) in 1982 and explored them until 1987. Several diamond-drill programs were conducted by the company. In 1984, Teck Corporation, along with San Paulo Explorations Inc., started exploration on the Gaffney occurrence (15) and by 1987 had outlined 300 000 tons of ore grading 0.15 ounce per ton gold. Sennol Resources Limited and Northair Mines Limited conducted a geological mapping and drilling program at the Smooth Rock Lake occurrence (28) during this period. In 1984 and 1985, exploration by Sparton Resources Inc. was concentrated at the Gates Lake (25), Peep Bay (24) and Sorry Mac (27) occurrences; the Aronson Lake occurrence (18) was explored by Jalna Resources Ltd.

In 1988, Black Cliff Mines Ltd. conducted geological mapping in the Barker Bay area, which included the Barker Brothers Mine (19) and the Petrie occurrence (20).

In 1989, exploration was carried out in and to the north of the Manitou Stretch on Lower Manitou Lake. The Peep Bay (24), Gates Lake (25) and Sorry Mac (27) occurrences were included in a mapping and geophysical program conducted by Homestake Mineral Development Corporation. Rio Algom Exploration Inc. staked ground between Grant and Flossie lakes and conducted reconnaissance geological mapping during the summer. Stanley Morin acquired the Smooth Rock Lake occurrence (28) and did some stripping and geological and geophysical surveys.

PREVIOUS GEOLOGICAL WORK

The area lies within the Manitou–Stormy lakes and Straw–Manitou lakes areas mapped by Thomson (1934a, 1934b). C.E. Blackburn mapped the Lower Manitou–Uphill lakes area (Blackburn 1976). The Manitou lakes–Stormy Lake belt was included in an airborne electromagnetic and magnetic survey flown in 1979 and 1980 (Ontario Geological Survey 1980a, 1980b, 1980c). In 1988, B. Berger mapped the Manitou Stretch area (Berger 1988) and M. Smith mapped the Vista Lake area (Smith and Stephenson 1988).

PRELIMINARY RESULTS

The characteristics of 28 gold occurrences investigated during the summer of 1989 (Figure 9.2) are summarized in Table 9.1. Gold assay results reported in Table 9.1 represent the best results obtained by the author from grab and/or chip samples.

Most of these occurrences are of shear-hosted, quartz vein type and fissure-filling massive sulphide type. Gold occurs in the quartz, in narrow massive sulphide bands, and along the contacts between the

TABLE 9.1. CHARACTERISTICS OF INVESTIGATED GOLD OCCURRENCES (OCCURRENCES 4 AND 5 ARE DESCRIBED IN TEXT).

Occurrence Name (Map No. cf. Figure 9.2)	Host Rock	Alteration, Metamorphism (Minor Constituent)	Sulphide Major	Sulphide Minor	Gold Assay (oz/T)	Shear Trend	Shear Classification	Deposit Classification
S-500 (1) extension	quartz diorite	ank	py	cp, mc	0.134 (vein 1) 0.237 (vein 2) 1.88 (vein 3)	015/86W	dextral oblique slip, sinistral strike slip	central and extension shear-hosted veins
Barton (2)	quartz diorite	ank	—	py, cp visible gold	0.189	024/84N	—	shear-hosted vein
Black Fox (3)	metagabbro	—	py	—	50 ppb	125/85N	—	quartz plug and shear-hosted vein
Copeland Mine (6)	basalt	ank, dol, (fu)	py	po	40 ppb	010/53W	dextral dip slip, Wsd strike slip	shear-hosted and extension veins
Long Lake-McCracken (7)	quartz-feldspar porphyry	ser, Fe-carb	py, cp	visible gold	0.34	140/90	Wsd dip slip	shear-hosted and oblique vein
A-212 (8)	basalt	chl, carb	py	—	15 ppb	050° (?)	—	—
Queen Alexandra Showing (9)	grano-diorite	—	py, gn	—	pending	030/75E	—	shear-hosted vein
King Edward (10)	grano-diorite	calc	py	gn,cp, bn	0.014	030/56E	—	shear-hosted vein
Merrill (11)	basalt	chl, calc, S, bio, ay, si, hb	py	—	0.127	052/55S 030/65E	dip slip, sinistral strike slip	shear-hosted veins
Dryden Red Lake (12)	basalt	carb, mi, hb, plg	po	py	0.658	020/40E	dextral strike slip	shear-hosted vein
Royal Sovereign Mine (13)	basalt	chl-carb schist	py	cp	0.019 0.061 (wall rock)	048/62E	Nsd dip slip	shear-hosted vein
Beehive (14)	basalt	pyritized chl-carb schist	py	cp, mc	tr (vein 1) 0.538 (vein 2) 0.887 (vein 3)	080/70S 170/60E	sinistral strike slip, Nsd dip slip	central shear-hosted and extension veins
Gaffney (15)	quartz diorite	Fe-carb, S	py	cp	300 000T at 0.15 oz/T	070/75S 020/82E oreshoot plunge 70°SW	intersection of dextral oblique slip with sinistral strike slip	fracture-filled veins in shear zone
Glass Reef (16)	feldspar porphyry	ank, ser	po	py, cp	46 ppb	055° (?)	—	shear-hosted vein

TABLE 9.1. CONTINUED.

Occurrence Name (Map No. cf. Figure 9.2)	Host Rock	Alteration, Metamorphism (Minor Constituent)	Sulphide Major	Sulphide Minor	Gold Assay (oz/T)	Shear Trend	Shear Classification	Deposit Classification
Weasel (17)	chert	—	py	—	0.534 (vein 1) 0.255 (vein 2)	050/85E	Nsu dip slip	shear-hosted vein
Aronson Lake (18)	meta-sedimentary rock	gossan	py	cp, (po)	0.10 0.57 (wall rock)	030/82E	sinistral strike slip	quartz and massive sulphide-filled shear
Petrie (19)	mafic/ felsic rock	hb schist	—	—	2 ppb	175/80E	dextral strike slip	shear-hosted vein
Barker Brothers Mine (20)	basalt flow	hb schist	py	po, cp	0.694 1.013 (wall rock)	170/87W	dextral oblique slip	shear-hosted vein
Gold Standard HW 271 (21)	mafic rock	chl, ser, ank, calc, (si), (S)	—	cp, py, bn	pending	045/40N	Nsd dip slip	shear-hosted vein
Gold Standard G-340 (22)	pillowed andesite	ank, chl, ser, (fu)	—	py	pending	180° (?)	—	shear-hosted vein
Sairey Gamp (23)	mafic rock	ser, chl, Fe-carb	—	py	pending	075/90S	dip slip	shear-hosted vein
Peep Bay (24)	melagabbro, gabbro, andesite	ank, S, calc, (dol)	asp	py	pending	anasto-mozing shear 45°/70S	sinistral strike slip, Nsd dip slip, and fissile zone	massive sulphide-filled shears; central shear-hosted oblique extension veins
Gates Lake (25)	gabbro	ank, S, potassic	asp	py	pending	235/74W	fissile zone	massive sulphide-filled shears
Austin (26)	dacitic tuff	ser, S	Sb	py, asp	pending	090/70N	Nsu dip slip fissile zone	shear-hosted vein
Sorry Mac (27)	basalt	dol, ank, ser, chl, (fu), (bleaching)	asp	py, cp, po	0.34	030/80W	fissile zone	massive sulphide-filled shears shear-hosted veins
Smooth Rock Lake (28)	pillowed basalt	lim, S, (si), ep	po py	cp, mo, sp	0.914 1.219 (wall rock)	115/85N	dextral movement	Z-type oblique and extension shear-hosted veins

Note:

ank	*ankerite*	*carb*	*carbonate*	*mc*	*malachite*	*ser*	*sericite*
ay	*anthophyllite*	*chl*	*chlorite*	*mi*	*mica*	*si*	*silica*
asp	*arsenopyrite*	*cp*	*chalcopyrite*	*plg*	*plagioclase*	*sp*	*sphalerite*
bio	*biotite*	*dol*	*dolomite*	*po*	*pyrrhotite*	*Nsd*	*north side down*
bn	*bornite*	*fu*	*fuchsite*	*py*	*pyrite*	*Nsu*	*north side up*
calc	*calcite*	*gn*	*galena*	*S*	*sulphide mineralization*	*Wsd*	*west side down*
		hb	*hornblende*	*Sb*	*antimony*		

quartz veins and wall rocks. The wall rock was commonly found to have a low tenor (few hundred ppb or less) in gold. At the Barker Brothers Mine, however, the schistose wall rock yielded high grades of gold (Table 9.1). Gold is associated with both pyrite and chalcopyrite in the Lower Manitou Lake area, whereas arsenopyrite and pyrite predominate in the Manitou Stretch area.

Shear zones are characterized by altered, slaty, schistose or fissile rock. Each gold occurrence has a unique alteration pattern. The alteration products are, in decreasing order of importance, iron carbonate (ankerite, dolomite), chlorite, calcite, sericite, sulphide, mica (including fuchsite), hornblende, silica and anthophyllite. Fabric orientation and kinematic indicators, such as the rotation of S-fabric into C-fabric (cf. Robert 1987) and extensional veins, sigmoidal extension veins and oblique vein arrays (cf. Hodgson 1989), indicate that the first deformation event was strike-slip movement along the Manitou Straits fault. However, shallow lineations that would substantiate this interpretation are difficult to detect because they have been masked and overprinted by later, steep lineations which characterize the whole area. These later lineations, in conjunction with other kinematic indicators, suggest that dip-slip movement postdates strike-slip movement, and was responsible for south-side-up movement to the northwest of the Manitou Straits fault, and north-side-up movement to the southeast of the Manitou Straits fault, resulting in a structure that is similar to the "palm tree structure" described by Ramsay and Huber (1987, p.529).

The role of progressive deformation and its implications for gold exploration are illustrated by the analysis of the Sakoose Mine and Maw gold occurrence (Figure 9.2, numbers 4 and 5).

SAKOOSE MINE AND MAW OCCURRENCE

Location

The Sakoose Mine is located 46 km southeast of Dryden, north of Kawashegamuk Lake (Figure 9.2, number 4). The Maw occurrence is situated 200 m southeast of the number 3 shaft of the Sakoose Mine (Figure 9.3).

Workings at the Sakoose Mine consist of four shafts and two open stopes, all sunk on the same quartz vein system over a length of 280 m.

Previous Work

Unless otherwise stated, the following section has been summarized from the files of the Resident Geologist, Ministry of Northern Development and Mines, Kenora. Beck discovered the main vein of the Sakoose Mine in 1897. Three shafts were sunk by The Ottawa Gold Milling and Mining Co. Ltd. in 1900, but operations were suspended in 1902. By then, a total of 8028 tons of ore had been milled, yielding 3413 ounces of gold for an average grade of 0.425 ounce per ton gold. In 1931, the mine received renewed attention and, in 1934 and 1935, Sakoose Gold Mines Ltd. drilled seven holes totalling 906 m in length, and sank number 4 shaft. From 1944 to 1947, Van Houten Gold Mines Ltd. did 110 m of drifting and drilled 40 underground holes for a total length of 1196 m, and 51 surface holes for a total length of 1098 m. A total of 801 tons of ore were treated in the mill, from which 231 ounces of gold (0.288 ounce per ton gold) and 141 ounces of silver (0.176 ounce per ton silver) were recovered. Until the late 1970s the property was dormant, with the exception of some minor exploration work done in 1960. In 1978, Jim Redden restaked the property and did some surface work. In 1987 and 1988, Venturex International Mining Corp. and Nexus Resource Corp., in a joint venture option from Redden, did geological mapping, stripping, and drilled 26 holes totalling 3667 m in length between shafts 3 and 4. The best drill intersection was 0.3 ounce per ton gold over 6.86 m.

The Maw occurrence (Figure 9.2, number 5) was discovered in 1899, when the B. Greening Wire Company sank a shaft to a depth of 13 m. No further work was reported.

Geology

Both the Sakoose Mine and the Maw occurrences are situated within the Kawashegamuk Lake group, along the contact between a thick sequence of mafic metavolcanics and a wedge of epiclastic metasediments. Detailed geological mapping by Kresz (1987) suggests, on the basis of top determinations, that the Kawashegamuk Lake group faces homoclinally to the southwest. To the east, metavolcanics of the Kawashegamuk Lake group are intruded by massive granodiorite of the Revell batholith. Rock types (Figure 9.3) in the vicinity of the Sakoose Mine and the Maw occurrence consist of: mafic volcanics, including tuff, lapilli tuff, pillowed basalt, pillow breccia and massive flows; sedimentary rocks, including siltstone, argillite, wacke, chert, sulphide-bearing argillite and magnetite-bearing wacke; and felsic tuffs, interbedded with similar sedimentary rocks. Felsic dikes, that commonly exhibit a plagioclase- and/or quartz-porphyritic texture, intrude all of the above rock types.

Iron carbonate is the characteristic alteration product in sheared rocks.

Structural Geology

All rock types, including felsic dikes, have been folded into a syncline (Figure 9.3) in which the dip of the northwest limb is steeper than that of the southwest limb. Structural facing to the southwest is indicated by cross-bedding, graded bedding, slumping and flame structures in sedimentary rocks. The Sakoose Mine is located on the northwest limb of the syncline, whereas the Maw occurrence is on the southeast limb. Folding created a penetrative schistosity which strikes 050° and dips 85° to the northwest. The surface trace of the axial plane of the syncline trends 050° in the southwestern part of the map area, and is deflected to 037° in the northeastern part. This is due to the intrusion of the Revell batholith. The hinge of the syncline plunges at about 55° to the south-southwest. Major and minor Z-shaped drag folds are observed on the northwest limb of the syncline, and S-shaped drag folds occur on the southeast limb.

Deformation occurred during northwest-southeast compression, and involved folding, shearing and faulting. Initial strike-slip shear became oblique-slip shear, and the faults underwent a spatial re-orientation.

The first stage of deformation involved progressive folding, and sinistral north-south faulting and shearing which displaced the northwest limb of the developing fold. Sinistral delamination along bedding in the southeast limb propagated into crosscutting faults that also sinistrally displaced rock units on the northwest limb. In the northwest limb, shearing occurred both discordantly and concordantly to bedding. These shears were subsequently folded and intruded by felsic dikes. Delamination continued, mainly along the contacts between competent discordant felsic dikes and incompetent sedimentary and volcanic rocks, and also along contacts between interbedded sedimentary rocks.

Fabric orientation and kinematic indicators substantiate the authors' observations that strike-slip shearing was involved in the earlier deformation. On horizontal surfaces, the schistosity is clearly seen to have been rotated into the shear fabric. Shallow lineations, seen on wall rocks immediately adjacent to quartz veins, plunge at 36° to the south-southwest at the number 1 shaft and at 33° to the south-southeast at the Maw occurrence. Riedel shear fractures (cf. Robert 1987) are present and are attributable to the earlier deformation event. Shearing along the northwest limb of the syncline is dextral, and is accompanied by *en échelon*, right-stepping, shear-hosted quartz veins. The shear-hosted quartz vein in each step is connected by a short extensional quartz vein. These extension veins were slightly rotated within the shear zone, giving them a sigmoidal Z shape. In addition, individual blocks between north-striking faults were rotated, so that the moderate southeast dip on the northwest limb of the syncline was steepened and locally overturned. In contrast, shearing on the southeast limb of the syncline is sinistral. The opposing sense of movement on each limb of the fold is due to differing bedding orientations in the limbs.

This strike-slip shear controlled the emplacement of the gold-bearing quartz veins. Evidence for this is found in the three open cuts east of number 1 shaft, which are sunk on quartz veins occupying dilation zones associated with the dextral shear. In addition, data obtained from the shaft (Assessment Files, Resident Geologist's office, Ministry of Northern Development and Mines, Kenora) indicate that the ore shoot plunged at about 25° to 30° to the south-southwest, corresponding to lineations found on the surface near the number 1 shaft.

The second stage of deformation involved oblique slip shearing superimposed on the earlier shearing and faulting. Steep lineations, plunging at about 64° to the south-southwest, are related to this second stage and predominate throughout the area, overprinting the earlier phase of deformation. This oblique slip shear rotated the earlier quartz veins into the steep and flat dips observed both on surface and in drill sections at the Sakoose Mine. The drill sections show that quartz veins which dip southeast have *en échelon*, downward-stepping attitudes, and that later minor faults are parallel to the schistosity. These northeast-striking, oblique dip-slip faults display sinistral movement, with northwest blocks up.

Setting of Quartz Bodies

The felsic dike (Figure 9.3) structurally controls a good part of the gold-bearing shear zone. Quartz veins, pods and lenses occur predominantly along either contact of the felsic dike. Quartz veins also transect other lithologic units, and less commonly are contained within the felsic dike, or occur along the lithologic contacts of other units. The structure has led to two different settings which host gold-bearing quartz veins: shear fractures with conjugate vein arrays; and fold-related structures. At number 1, number 2 and number 4 shafts, oblique shear-hosted veins are combined with extension shear-hosted veins. At the number 3 shaft, shear-hosted veins are controlled by delamination and faulting. At the Maw occurrence, veins are of saddle reef type.

RECOMMENDATIONS FOR EXPLORATION

Previous exploration for gold at the Sakoose Mine has been concentrated between the number 3 and number 4 shafts. The recognition of the structural environment that controls the setting of gold mineralization now extends the favourable horizon around the fold nose to the southeast of the number 3 shaft. The Maw occurrence and the Sakoose Mine are on the same gold-bearing horizon. Moreover, the Copeland Mine (Figure 9.3, number 6), which is 1.4 km southeast of number 4 shaft, appears to lie on strike with the Maw occurrence, thus further extending the favourable gold horizon.

A dilational zone, with the possibility of quartz saddle reefs, may have developed in the felsic dike in the hinge of the syncline. These reefs may contain gold mineralization.

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10. Project Unit 89-19. Geology of the Savant Lake Area

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INTRODUCTION

This report presents some preliminary results of lithologic and structural mapping of Archean supracrustal and granitoid rocks in the Savant Lake area of northwestern Ontario. The goals of this project are to provide comprehensive geological mapping of the northern part of the Savant Lake area, for which only reconnaissance maps are available at present (*see* Moore 1928; Trowell 1986, 1988); and to re-examine a greenstone belt which to date has had no mineral production, but in which lithologic units, structural setting and alteration assemblages indicate potential for base and precious metal mineralization.

Detailed mapping (1:15 840) for much of this area was completed in the early 1970s (Bond 1977, 1979, 1980). Since that time, evidence accumulated from studies of a number of greenstone belts in Ontario demonstrates that lithological sequences within greenstone belts may not represent a purely stratigraphic assemblage but may, at least in part, represent a tectonic assemblage. Tectonic juxtaposition of units commonly results in an "out-of-sequence" stratigraphy which, on account of cryptic contact relationships, has been revealed most successfully using U-Pb zircon geochronology. Tectonically assembled sequences have been recognized in the Rainy Lake area (Davis et al. 1989), the Sioux Lookout area (Davis et al. 1988) and the Pickle Lake area (Corfu and Stott 1989). Recognition of out-of-sequence stratigraphy is particularly significant in efforts to correlate volcanic stratigraphy with high base metal potential (*see* Lesher et al. 1986). With this in mind, previous interpretations of stratigraphic relationships in the Savant Lake area were critically assessed.

The close spatial association recognized between gold mineralization and shear systems (Colvine et al. 1988) was investigated in the Savant Lake area where several regional-scale faults had been interpreted by previous workers. These structures were re-examined during this study to further define their extent, style of deformation, and potential for localizing gold mineralization. Additionally, an emphasis was placed on the recognition and description of deformation zones not previously mapped.

The study area is bounded roughly by latitudes 50°15′N and 50°30′N and longitudes 90°10′W and 90°50′W (Figure 10.1). Access to the central part of the area is gained by Highway 599 which trends northerly, linking the towns of Ignace and Pickle Lake, and by Highway 516 which trends easterly from Sioux Lookout to Highway 599. A network of logging roads provides good access to the southern part of the area. These roads appear on Ontario Basic Mapping (OBM) aerial photographs taken in 1983, which are available for the region south of

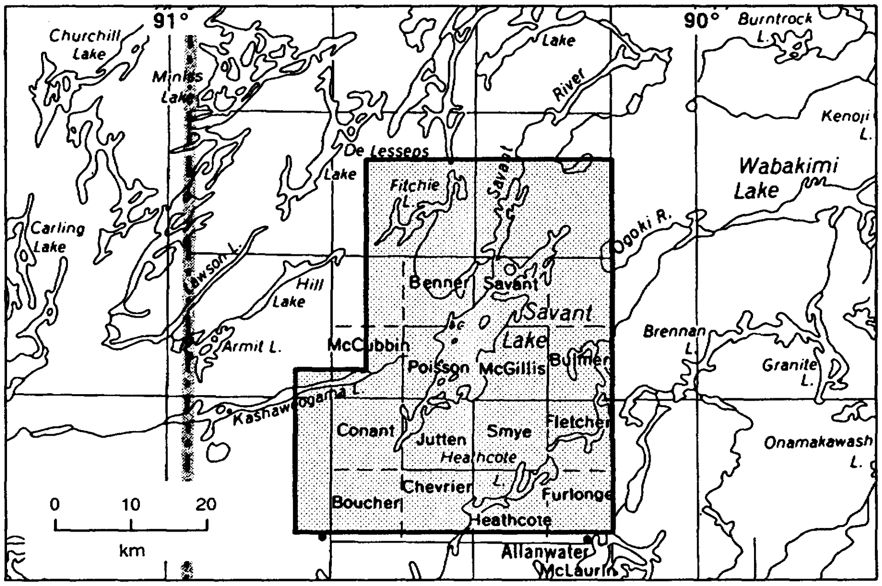

Figure 10.1. *Location map for the Savant Lake area, northwestern Ontario.*

latitude 50°25′N. The area east of Savant Lake can be accessed by a north-trending logging road which extends some 60 km from Highway 599. Several lakes in the area, including Savant Lake, require float-equipped aircraft for access. Winter roads from Highway 599 to Savant Lake are not accessible by four-wheel drive vehicle during the summer months.

PREVIOUS WORK

The first geological reconnaissance of the Savant Lake area was conducted by W.H. Collins (1910), who published a map at a scale of 1:253 440. E.S. Moore (1910) visited the area in 1909 to evaluate the iron deposits and published a map at a scale of 1:126 720. Moore returned to the area in 1928 to conduct a geological study of the entire Savant Lake area and published a report and a map at a scale of 1:126 720 (Moore 1928). Geological mapping of Conant, Jutten, McCubbin and Poisson townships at a scale of 1:31 680 was conducted by Rittenhouse (1936) for a PhD thesis. R. Skinner (1969) mapped the area at a reconnaissance scale of 1:253 440, and J.C. Davies et al. (1970) published a compilation map (Map 2169), also at a scale of 1:253 440.

A program of detailed mapping was initiated in the Savant Lake area by the Ontario Division of Mines following the development of the Mattabi Mine on nearby Sturgeon Lake in 1968. Detailed mapping (1:15 840) by W.D. Bond in the early seventies included McCubbin, Poisson and McGillis townships (Map 2357 *in* Bond 1977); Conant, Jutten and Smye townships (Map 2398 *in* Bond 1979); and the Houghton–Hough lakes area (Map 2424 *in* Bond 1980). More detailed mapping of parts of these townships was later carried out by Shegelski (1978) as part of a PhD study on Archean iron formations. Breaks (1980) published a revised compilation map (Map 2442) for the area at a scale of 1:253 440.

MINERAL EXPLORATION

Mineral exploration in the Savant Lake area has been ongoing since the turn of the century in the search for gold, iron, and massive sulphide mineralization; however, there has been no mineral production to date. Descriptions of past mineral exploration can be found in McInnes (1901), Miller (1903, p.82-90, 104, 105), Bond (1977, 1979, 1980) and Trowell (1986). A summary of recent mineral exploration activity in the area is provided below from information obtained from the Assessment Files, Resident Geologist's Office, Ministry of Northern Development and Mines, Sioux Lookout.

In 1977, an airborne survey delineated the Marchington Road sulphide zone, which underlies claims currently held by Umex Inc. These claims, designated the Marchington Road claims, extend for 7 km along Highway 516 from the junction of Highway 599 (Figure 10.2). The main sulphide zone was tested by Umex Inc. by diamond drilling more than 40 holes between 1977 and 1980. Several less continuous zones were discovered in a 600 m long zone south of this zone during the course of drilling. In 1983, 66 claims were geologically mapped and 10 claims geochemically sampled (Na, Cu, Pb, Zn) in order to reassess the base metal potential of the property. Geologic and drill-inferred tonnage is estimated at 216 000 tons grading 0.76 percent Cu, 3.19 percent Zn, 1.54 percent Pb and 1.81 ounces per ton Ag (Umex Inc., personal communication, 1989).

GML Minerals Consulting Ltd., on behalf of Stargazer Resources Ltd., conducted an extensive gold exploration program in 1981 and 1982 on 966 claims (now lapsed) extending from west of Kashaweogama Lake to the Northeast Arm of Savant Lake. The 1981 program of biogeochemical sampling, mapping and prospecting on 14 grids was followed in 1982 by ground and airborne geophysical surveying, trenching and diamond drilling of select targets. Drilling did not encounter any significant auriferous zones; however, several geologically favourable settings were reported.

Cumberland Resources Ltd., in a joint venture with Vestor Explorations Ltd. and Redfern Resources Ltd., carried out geological mapping and lithogeochemical sampling in 1985 on a 42-claim property straddling Highway 599, 6 km north of the town of Savant Lake (Figure 10.2). An additional 132 claims were staked in August 1985 and one claim, Pa349297, was leased from Eric Hadley. Work on the claim group was concentrated on the Hadley Zn-Pb-Cu-(Cd)-(Au) occurrence, discovered in 1969 during the construction of Highway 599 (*see* Trowell 1986, p.58-59). In 1984, Cumberland Resources Ltd. contracted Dighem Corporation to conduct an airborne geophysical survey over the claim group. In 1986, Cumberland Resources Ltd. and Noranda Inc. geochemically sampled and extensively drilled the claim group. Mineralization on the claim group includes the Hadley occurrence, a silicified, sericitic-pyritic occurrence at Sue Lake; anomalous Cu and Zn values in Na-depleted felsic metavolcanics; sphalerite-bearing felsic tuff; and pyrite-pyrrhotite stringers in sericitic felsic schist.

In 1987, Northern Dynasty Explorations Ltd. conducted a reconnaissance exploration program involving prospecting and geochemical sampling of over 52 claims in the western Kashaweogama Lake area (Figure 10.2). By March 1988, the property had been expanded to 96 claims. A winter program of ground magnetometer and EM-16 surveys was followed by mapping and sampling in 1988, which revealed several Au-mineralized showings.

McArthur Mills Explorations Ltd. currently holds 46 contiguous claims on the southwest shore of Savant Lake (Figure 10.2). The claims are situated

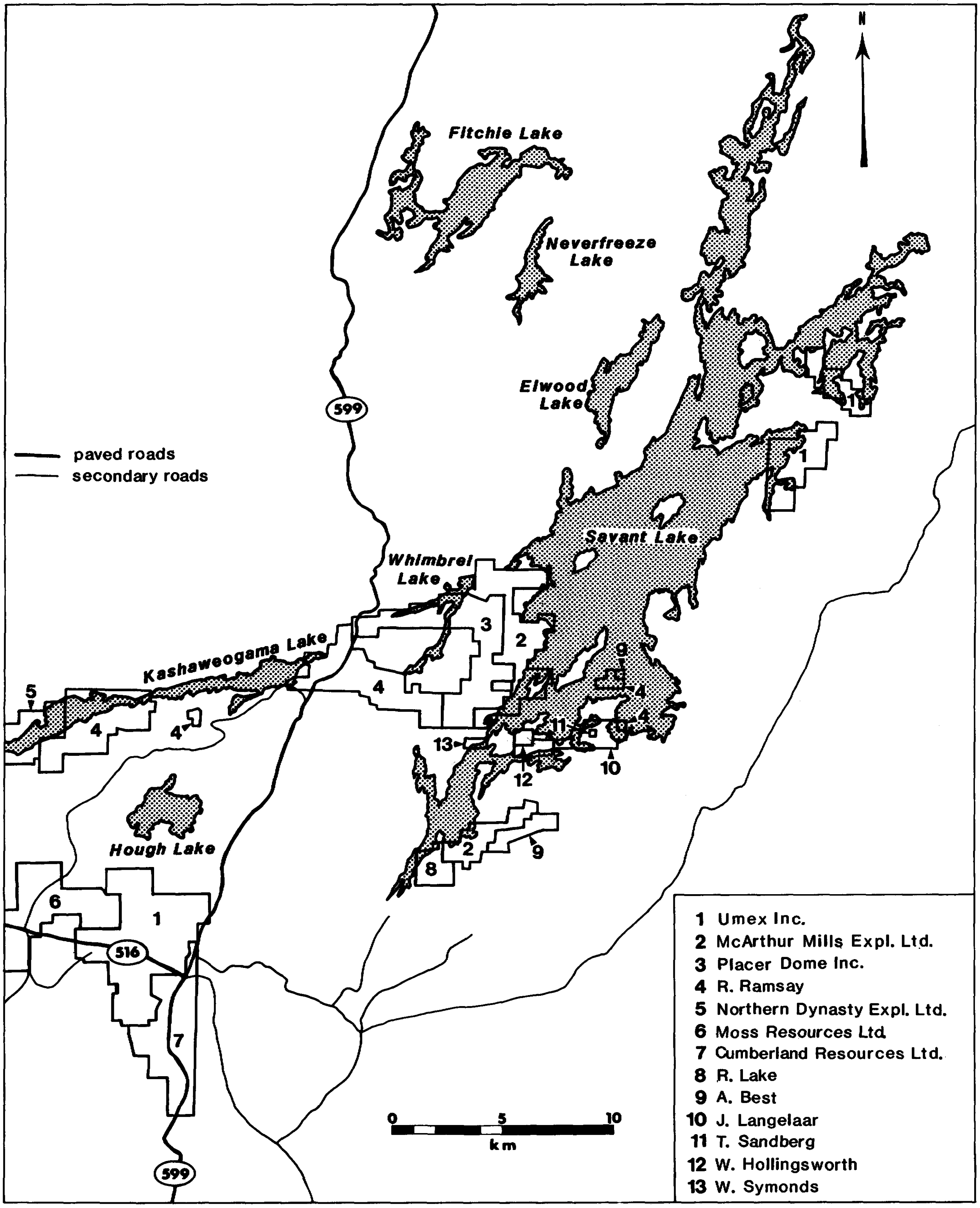

Figure 10.2. *Location of claims in the Savant Lake area (June 1989).*

immediately northwest of two showings: the One Pine Lake showing and the Shoal Gold occurrence. In June and July of 1987, Derry, Michener, Booth and Wahl carried out a program of ground geophysics, geological mapping, geochemical sampling and prospecting on behalf of McArthur Mills Explorations Ltd.

Redaurum Red Lake Mines Limited conducted a gold exploration program during the autumn of 1987 in the central Kashaweogama Lake area (Figure 10.2), on a claim block consisting of 39 contiguous claims of which 27 were optioned from R. Ramsay. By December 1987, an additional 12 claims were staked. Redaurum Red Lake Mine Limited's exploration program, for both gold and base metals, consisted of geological mapping (1 inch to 200 feet), geophysical surveys (VLF-EM, magnetometer), a geochemical soil survey and sampling.

In March 1987, Umex Inc. optioned 38 claims from G. Armstrong and A. Best on the eastern shore of north-central Savant Lake (Figure 10.2). In June 1988 following 1987 airborne magnetometer and VLF-EM survey results, detailed mapping was carried out by Umex with a focus on shear-controlled, base and precious metal enriched, quartz veins and locally sulphidized iron formation.

Placer Dome Inc. currently holds 61 contiguous claims in the Whimbrel Lake area east of Highway 599 (Figure 10.2). In the spring of 1988, Geosearch Consultants Ltd. conducted a total field magnetic survey and a horizontal-loop EM survey. Geological mapping of the property was conducted during the summer of 1988. In 1989, detailed geological mapping and sampling was carried out by Placer Dome Inc. on claims centred on the One Pine Lake occurrence, southeast of Whimbrel Lake.

A geological mapping and prospecting program was carried out by Moss Resources Ltd. during the summer of 1989 over a 228-claim property which straddles Highway 516, roughly 3 to 12 km west of Highway 599 (Figure 10.2).

GENERAL GEOLOGY

The Savant Lake area is dominated by metavolcanic and metasedimentary rocks which form part of the Wabigoon Subprovince of the Superior Province. The belt is bordered by foliated and gneissic granitoid rocks which, in part, may represent the Winnipeg River Subprovince, a plutonic terrain north of the Wabigoon Subprovince which is best exposed in the Kenora and Sioux Lookout areas.

The general geology of the area, as shown on Figure 10.3, is summarized from Bond (1977, 1979, 1980), Breaks (1980) and Trowell (1986). The terminology used is that of Trowell (1986), who subdivided the stratigraphy of the Savant Lake area into informal groups and formations on the basis of lithology and geographic distribution. Only the major units of Trowell (1986) are described.

SUPRACRUSTAL ROCKS

The Jutten volcanic group (JVG) forms a lowermost sequence of massive and pillowed tholeiitic basalts with minor ultramafic rocks and chert-magnetite ironstone. A sequence of conglomeratic wackes and quartz arenites, designated the Jutten sedimentary sequence (JSS), occurs near the base of the JVG in the northeast part of Savant Lake. This clastic sequence is described by Cortis et al. (1988), who suggested that these metasedimentary rocks may represent a platformal sequence (cf. Thurston et al. 1987) deposited in a shallow-water setting prior to more typical Archean (deep-water) mafic volcanism represented by the JVG. A polymictic conglomerate unit, the Sioux Narrows formation (SNF), unconformably overlies the JVG. This unit contains clasts of volcanic, intrusive (granitic) and possibly sedimentary origin. West of Savant Lake, the SNF is interpreted by Trowell (1986) to be transitional with intermediate pyroclastic rocks and flows of the Whimbrel Lake formation (WLF). In the South Arm of Savant Lake, the SNF is interpreted to define the base of the Savant sedimentary group (SSG) (Trowell 1986).

The central part of the area is dominated by the SSG and the Handy Lake volcanic group (HLVG). The SSG comprises feldspathic wacke and lithic wacke with interbeds of magnetite$\pm$chert ironstone. The HLVG consists of volcanic flows and pyroclastic rocks of variable composition interrupted locally by metasedimentary units.

GRANITOID ROCKS

Several felsic to intermediate plutons intruded the supracrustal rocks (Figure 10.3). Metamorphosed intrusions include porphyritic stocks exposed on Elwood and Seldom lakes, porphyritic sills exposed throughout the HLVG, the Conant Lake intrusion, the Heron Lake stock and the Hough Lake stock. Late- to post-tectonic intrusions include the Wiggle Creek stock, the Dickson Lake stock and the Grebe Lake stock.

Foliated and gneissic granitoid rocks border the Savant Lake greenstone belt. For instance, a homogeneous, foliated, quartz-porphyritic granodiorite intrusion is exposed throughout the North Arm of Savant Lake. The Northeast Arm is occupied by tonalite gneiss and foliated intrusive rocks of tonalitic to monzogranitic composition. Gneissic rocks are also exposed east of Savant Lake. Granitoid rocks which border the southeast part of the belt are dominantly massive to foliated rocks of granodioritic to tonalitic composition.

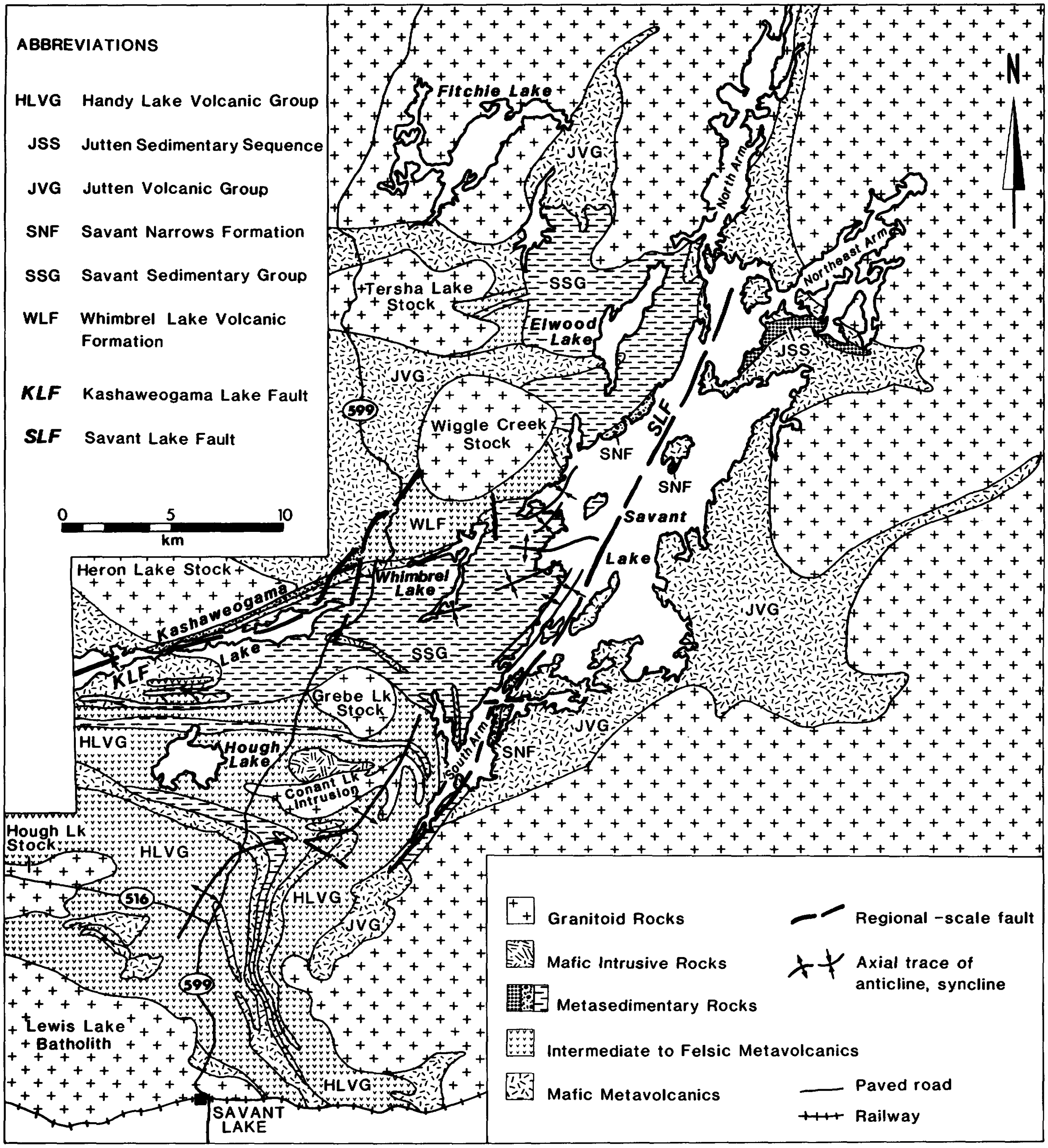

Figure 10.3. *General geology of the Savant Lake area after Bond (1977, 1979, 1980), Trowell (1986) and Breaks (1980). Structures examined during this study and described in the text are not shown on the map.*

SUMMARY OF PRELIMINARY STRUCTURAL OBSERVATIONS

Structural mapping conducted during the field program consisted of systematic measurement of planar fabrics, lineations, strain intensity, folds and deformation zones. Some preliminary observations regarding structural relationships in the area are summarized below. Interpretations of these structures and their significance in terms of the tectonic history of the area will be presented following a thorough evaluation of the data and additional laboratory studies.

FOLIATION

Throughout the eastern half of the area, a dominant, steeply dipping schistosity is developed which strikes northeasterly (040° to 060°). This single dominant fabric is maintained throughout the supracrustal rocks exposed on Savant Lake except in zones of higher strain intensity, where fabrics typically trend 065° to 085°.

Throughout the HLVG in the southwest part of the area, two strongly developed fabrics are observed. The first (S_1) is generally manifest as a spaced cleavage which is parallel to stratigraphy (S_0). S_1 is steeply dipping and varies in strike from southwest to southeast. An overprinting schistosity (S_2) strikes consistently to the east and commonly crenulates S_1. Neither S_1 nor S_2 appears to have resulted from deformation during development of a major anticline, proposed by previous workers (Bond 1979, 1980; Trowell 1986) to transect the HLVG (Figure 10.3), as these fabrics do not show a well-marked geometric relationship (i.e., axial-plane cleavage, convergent- and divergent-cleavage fans) to the fold geometry.

In the Northeast Arm of Savant Lake (Figure 10.3), the strike of gneissosity in granitoid rocks is easterly. This trend is at a high angle to the granite–greenstone contact, which strikes roughly south-southeast in this area. The fact that straight gneisses possessing an easterly strike are within several tens of metres of the granite–greenstone contact suggests that a major discontinuity exists between the Savant Lake greenstone belt and gneissic granitoid rocks that border the belt.

FOLDS

The JVG was first interpreted as a northwest-facing monoclinal sequence by Rittenhouse (1936). Subsequent workers have not significantly modified this interpretation and have suggested a possible thickness of the JVG in excess of 11 500 m (Bond 1977; Trowell 1986). During this project, a number of folds were identified which suggest that the structure of the JVG is more complex. For instance, the metasedimentary sequence (JSS) in northeast Savant Lake defines a southwest-closing, steeply plunging anticline. The regional schistosity in this area strikes 055° to 060° and is axial planar to this fold. Investigation of younging of mafic metavolcanic rocks and interbedded metasedimentary rocks south of the axial surface trace of this fold revealed a number of localities where younging of the JVG is to the south and southeast. These observations are consistent with folding of the Jutten mafic metavolcanics and the JSS about a southwest-closing anticline.

Bedding and younging data from the SNF conglomerate in central Savant Lake define a similar, southwest-closing anticline with a northeast-trending axial trace. The trace of this fold appears to be on strike with the axial trace of the anticline defined in the Jutten sequence to the northeast, and these may be the same fold. An associated axial-planar schistosity (045° to 055°) is steeply dipping.

Bond's (1977) interpretation of folds throughout the SSG on the western shore of central Savant Lake is that the axial trace of these folds strikes 035°, parallel to the Savant Lake fault (*see* Deformation Zones below). Data from this study support a reinterpretation of the strike of the axial trace of these folds to 045°. This reinterpretation remains in keeping with younging criteria, yet is more consistent with the 045° trend of the axial-planar cleavage throughout this region. Bedding–cleavage relationships at an outcrop scale confirm that cleavage in this region is axial planar to the folds and does not transect the folds at an angle to the axial plane (cf. Borradaile 1978).

Several folds were defined in the area near the South Arm of Savant Lake during this project which are consistent with the fold style described above.

The structural style of the SNF conglomerate, exposed both on the west shore of central Savant Lake and in the South Arm area (Figure 10.3), is one of tight to isoclinal folding and a high degree of transposition about a strongly developed cleavage which strikes 030° to 050°. Previous workers have interpreted bedding within this unit to parallel the tectonic direction, rather than tightly folded about that direction.

DEFORMATION ZONES

Rittenhouse (1936) first proposed that a regional-scale fault forms the main sedimentary–volcanic contact through central Savant Lake. Subsequent workers named this fault the Savant Lake fault (SLF) and attributed localized zones of intense penetrative schistosity to shearing along this structure (Bond 1977, 1979; Trowell 1986). The location of the SLF, as proposed by previous workers, is shown in Figure 10.3.

During the course of this mapping, a north-northeasterly (025°) schistosity coincident with the SLF was not recognized throughout the Savant Lake area. As previously stated, the regional trend of schistosity throughout Savant Lake is 040° to 060°.

Schistosity within more intense zones of deformation typically strikes east to east-northeast (060° to 085°). For example, near the narrowest part of Savant Lake, strongly tectonized metasedimentary rocks, interpreted by Bond (1977) to coincide with the SLF, possess a tectonic fabric which strikes 065° to 070°. The absence of a tectonic fabric striking 025° parallel to, and associated with, the SLF is interpreted here as evidence to suggest that the SLF may represent an early fault boundary between the JVG and SSG, which controlled the stratigraphy of the belt but was not responsible for subsequent modification of this stratigraphy.

The Kashaweogama Lake fault (KLF) is exposed along the northern side of Kashaweogama Lake (Figure 10.3). This deformation zone trends 070°, dips steeply northward, and possesses steep, downdip mineral lineations that reveal dominantly dip-slip movement across the KLF. Preliminary observations suggest that displacement is north-side-up. Observations of strain intensity, fabric attitudes and differential displacement in rocks east of Kashaweogama Lake suggest that the KLF may be traced east of Highway 599, across the northern part of Whimbrel Lake, and into central Savant Lake. This interpretation contrasts with that of Bond (1977), who proposed that the KLF bends toward the north in the eastern Kashaweogama Lake area. Fabrics in the eastern part of Kashaweogama Lake are not consistent with a north-striking deformation zone in this area.

Variably altered (iron carbonate) and tectonized rocks located northwest of Hough Lake display a strong, east-striking schistosity and mineral lineations that plunge moderately to steeply eastward. Tectonic transposition of magnetite-bearing metasedimentary rocks into very straight, east-striking, centimetre-scale bands is pervasive throughout this area. Shear fabrics are locally developed within altered metavolcanic rocks and reveal north-side-down, right-handed movement. This movement may be conjugate to that of the KLF to the north, which would suggest that the wedge-shaped block of metasedimentary rocks between Kashaweogama Lake and Hough Lake was downthrown relative to the surrounding stratigraphy (Figure 10.4).

Tectonic transposition of magnetite-bearing metasedimentary rocks northwest of Hough Lake would explain the map patterns of previous workers, in which narrow metasedimentary horizons strike due east, but the strike of contacts between adjacent volcanic units is southeast (Bond 1980). Similarly, bedding within less-deformed metasedimentary rocks between the two deformation zones is at a high angle to these zones (Figure 10.4) and to the tectonically transposed stratigraphy within them.

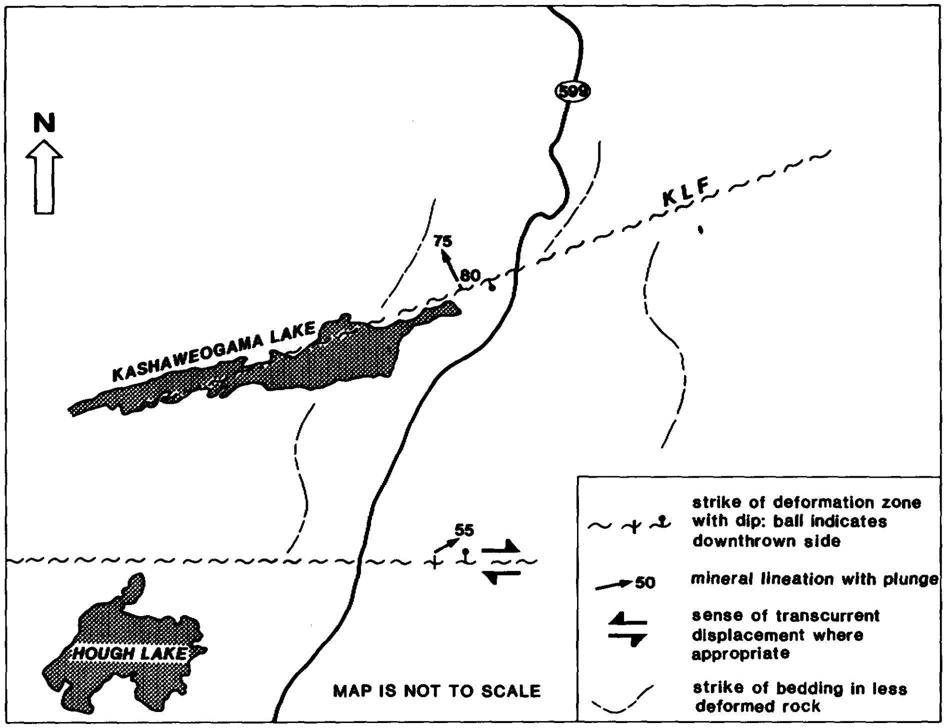

Figure 10.4. *Sketch showing preliminary observations of structural relationships near Kashaweogama and Hough lakes. KLF denotes Kashaweogama Lake Fault.*

UNCONFORMABLE CONTACTS

Observations in the northeast Savant Lake area suggest that an unconformity may exist between the Savant Lake greenstone belt and bordering granitoid rocks. Evidence for this is threefold. Firstly, conglomeratic units of the JSS can be demonstrated, by younging relationships, to occur near the base of the JVG. This suggests that this sedimentary sequence represents some of the earliest formed rocks in the belt. Secondly, the dominant two clast types in the conglomerate at most localities are fine- to medium-grained, equigranular granitoid clasts and vein-quartz clasts. The matrix of the conglomerate varies in composition from a chemically mature quartz arenite to feldspathic wacke, which at most localities is texturally immature. These features suggest that the source of the JSS was, in part, a nearby felsic (quartz-bearing) granitoid terrain. Thirdly, an abrupt structural discontinuity between the greenstone belt and the granitoid terrain in this area is suggested by the high angle between the strike of the granite–greenstone contact and the strike of gneissosity in the adjacent granitoid rocks.

An angular unconformity can be demonstrated between the JVG and the SNF conglomerate in the South Arm area of Savant Lake. Here, well-preserved, pillowed mafic metavolcanics of the JVG young to the northwest, indicating that the JVG stratigraphy strikes northeast in this region. The mafic metavolcanics are in contact with conglomeratic rocks which are derived dominantly from a mafic volcanic source. The base of the conglomerate, at the contact with pillowed volcanics, contains boulder-size clasts of ferruginous chert and minor jasper pebbles. The trend of the volcanic–conglomerate contact trends roughly 115°, at a high angle (80°) to the strike of JVG stratigraphy, and is tightly folded.

RECOMMENDATIONS FOR MINERAL EXPLORATION

The Savant Lake area has a long history of mineral exploration activity and continues to be an active area in the search for both gold and volcanogenic massive sulphide deposits. In the area, occurrences of precious metals are spatially associated with zones of strong deformation intensity, commonly accompanied by carbonate±silica alteration and the development of quartz veins. These zones typically strike 070° to 090° and may display obvious differential movement, as observed along the KLF; they may display strong iron-carbonate alteration, as noted northwest of Hough Lake; or, they may be characterized by intense flattening, such as in the area near Stillar Bay. These observations and the spatial distribution of precious metal occurrences suggest that precious metal mineralization in the Savant Lake area is controlled by easterly striking deformation and/or alteration zones.

The southwest part of the Savant Lake area shows potential for base metal mineralization. Hydrothermal alteration of volcanic rocks of the HLVG is revealed by the local development of aluminosilicate minerals such as staurolite, kyanite, andalusite and sillimanite. Semi-massive to massive aggregates of sulphide minerals such as pyrite, pyrrhotite, sphalerite, chalcopyrite and galena are known to occur throughout this area.

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11. Project Unit 89-12. Geology of the Toronto Lake Area, Eastern Wabigoon Subprovince

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INTRODUCTION

The Toronto Lake area (Figure 11.1) is a relatively unexplored part of the eastern Wabigoon Subprovince with potential for base and precious metal mineralization. It is 8 km west of the Marshall Lake base metal deposit and adjacent to the southern boundary of the English River Subprovince. The map area (approximately 265 km^2) is bounded by latitudes 50°18′45″N and 50°30′N and by longitudes 87°45′W and 87°56′30″W. The area is 240 km northeast of Thunder Bay and is accessible by aircraft and by a seasonal gravel road which extends 107 km north of Highway 11 via Highway 801.

MINERAL EXPLORATION

Asbestos, nickel and gold mineralization were discovered in the southern part of the map area in the 1950s and 1960s. Pye (1968) described the exploration activity in the area prior to 1962. Since 1962, exploration in the area has been limited to minor activity in the early 1970s for base metals and, in 1984, for precious metals. No economic deposits have yet been outlined.

During the 1989 field season, a number of mining claims were staked by local prospectors along the south and west side of Toronto Lake over previously discovered asbestos and nickel showings hosted by mafic and ultramafic intrusions. Recently staked mining claims west and north of Ketchikan Lake cover ground previously explored for gold and base metals.

The northern part of the area is relatively unexplored.

GENERAL GEOLOGY

SUPRACRUSTAL ROCKS

The supracrustal rocks in the map area are composed of Archean mafic, intermediate and felsic metavolcanic rocks and related intrusions, which were intruded by Archean felsic granitoid plutons and Archean to Proterozoic diabase dikes (Figure 11.2). The supracrustal rocks are divisible into two groups, each with distinct lithologies, morphologies and metallogeny.

Group 1

The first group of supracrustal rocks extends from the eastern boundary of the map area along the

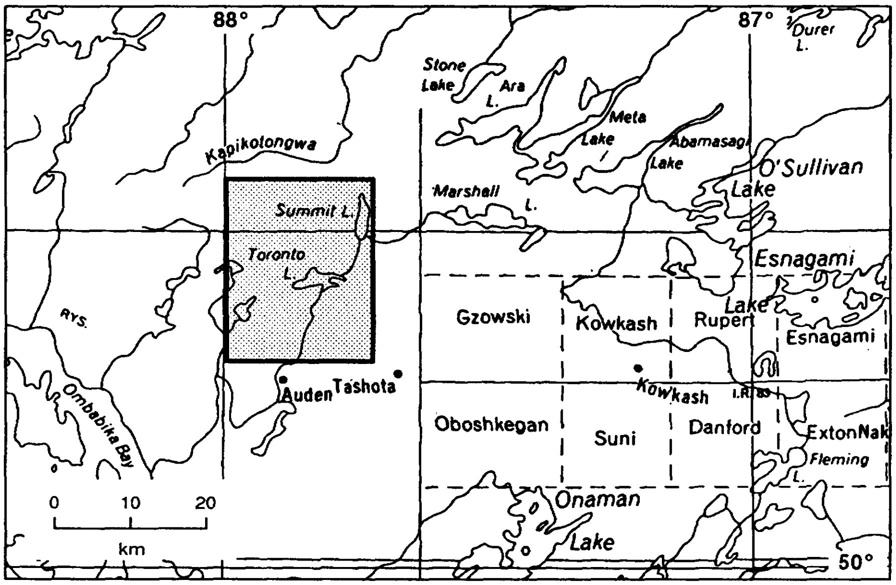

Figure 11.1. *Location map of the study area.*

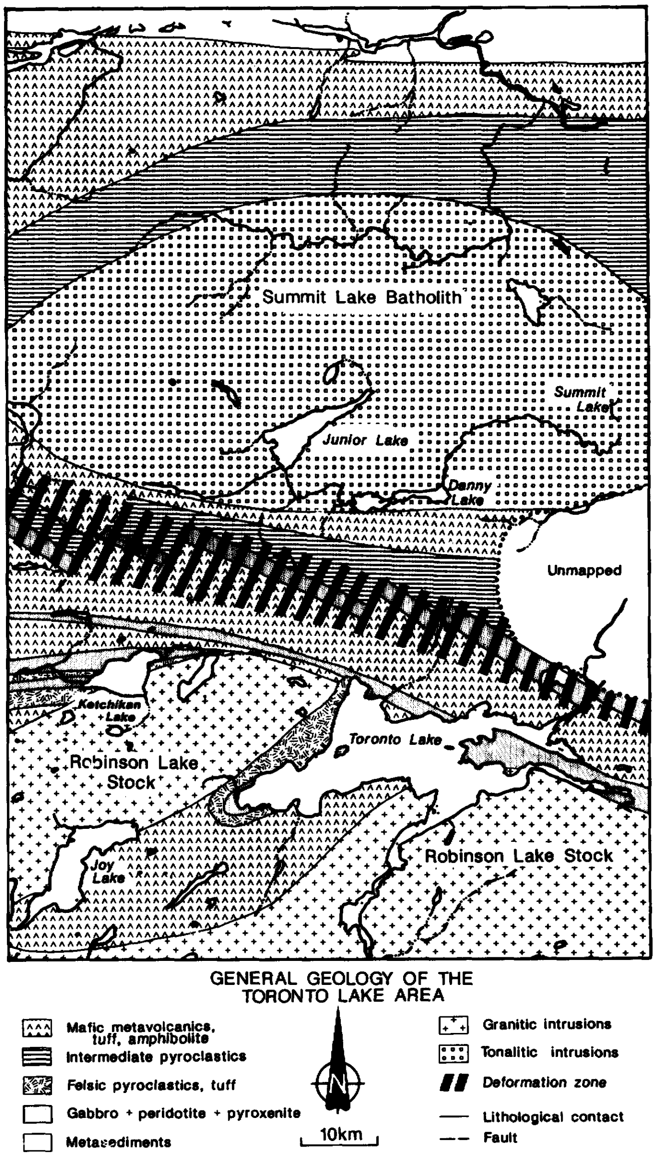

Figure 11.2. *General geology of the Toronto Lake area.*

southern side of Toronto Lake to west of Ketchikan Lake. This compositionally bimodal group is composed of mafic flows and pyroclastic rocks and associated mafic and ultramafic intrusions, and felsic pyroclastic rocks.

The mafic metavolcanic rocks in this group are composed predominantly of massive flows, with subordinate pillowed flows and minor heterolithic, mafic pyroclastic rocks. The flows are generally dark green to black weathering and resemble the gabbroic rocks that form part of the sills.

The mafic and ultramafic intrusions occur as layered sills composed of peridotite and/or pyroxenite bases and gabbro tops or gabbro bases and anorthosite tops. These sills appear to extend across the entire map area and are more or less continuous except where they are interrupted by faulting, boudinage or granitic intrusions. A white weathering anorthosite which extends from the central part of Toronto Lake to Ketchikan Lake is a good marker unit in this group.

The felsic pyroclastic rocks of this first group are composed of crystal lithic tuff, lapilli tuff, tuff breccia and quartz-muscovite schist. They occur west of Toronto Lake, along the south shore of Toronto Lake and at Ketchikan Lake. These rocks are white to light grey weathering and generally contain greater than 10 percent quartz phenocrysts. The felsic metavolcanic rocks west of Toronto Lake were intruded by gabbro dikes, similar to the gabbro in the mafic and ultramafic sills.

Stratigraphic facings in the first group of rocks are rare, but a few pillows indicate that the stratigraphy youngs to the north. The apparent layering in some of the mafic and ultramafic sills, from peridotite to pyroxenite and/or gabbro to anorthosite, also indicates a north-facing stratigraphy.

The mafic and ultramafic rocks of this group are potential hosts for copper-nickel-platinum-gold mineralization, whereas the felsic pyroclastic rocks are potential hosts for zinc-copper base metal mineralization.

Group 2

The second group of supracrustal rocks extends west-northwest from the eastern boundary of the map area north of Toronto Lake, and underlies nearly two-thirds of the map area. This group consists predominantly of mafic flows, pyroclastic rocks and gabbro, intermediate pyroclastic rocks, and minor clastic metasedimentary rocks.

Mafic metavolcanic rocks occur north of Toronto Lake, where they are composed of hornblende-porphyroblastic, pillowed and massive flows, and along the northern boundary of the map area, where they are composed of thinly bedded tuff and garnetiferous amphibolite. A coarse-grained, "knobby" gabbro sill over 10 km long north of Toronto Lake intruded the mafic flows and is a reliable marker unit. A major deformation zone, marked by intense shearing, occurs along the contacts of this sill and is the locus for carbonate and minor sulphide mineralization.

Intermediate metavolcanic rocks, composed of tuff and minor heterolithic tuff breccia, form a continuous west-northwest-trending unit in the north-central part of the map area. They are hornblende- and biotite-bearing, commonly contain less than 5 percent quartz phenocrysts, and weather grey to brown. The intermediate metavolcanic rocks extend east of the map area, where they are contiguous with intermediate and felsic metavolcanic rocks that host copper-zinc mineralization at Marshall Lake (Amukun 1985). In the map area, the intermediate metavolcanic rocks are intruded by the Summit Lake batholith, with which they are compositionally similar.

Wacke, derived schists, and metatexite occur along the northern boundary of the map area, where they form a separate unit and are interbedded with mafic tuff and garnetiferous amphibolite. These rocks are brown weathering, micaceous and commonly contain garnet and staurolite porphyroblasts.

North of Toronto Lake, pillowed flows of the second group of supracrustal rocks consistently face north or northeast. Deformation and metamorphism in the mafic tuff and wacke along the northern boundary of the map area have destroyed most primary features; however, in a few places stratigraphy appears to young to the south. A large syncline with the Summit Lake batholith occupying the axial zone is inferred from these observations.

The second group of supracrustal rocks may contain base metal mineralization similar to that at Marshall Lake (8 km east). Structurally controlled gold mineralization might be expected within the deformation zone north of Toronto Lake.

Boundary Relationships

The boundary between the two groups of supracrustal rocks is marked by a shear zone in the western and central parts of the map area, and by a conglomerate in the east. The conglomerate is unique in the area, in that it contains rounded clasts, up to 50 cm in diameter, of felsic metavolcanic rocks, vein quartz, mafic metavolcanic rocks and gabbro in a sandy to chloritic matrix. Laminated siltstone and wacke beds locally form units up to 2 m thick within the conglomerate, and graded beds within these units young to the north. The conglomerate may be structurally emplaced and allochthonous to the map area; however, the presence of gabbro clasts texturally similar to gabbro in the underlying mafic and ultramafic sills suggests a local derivation and, therefore, that a significant hiatus in volcanism occurred before deposition of the second group of supracrustal rocks.

INTRUSIVE ROCKS

The supracrustal rocks are intruded by two Archean granitic batholiths. The Summit Lake batholith is a deformed tonalitic pluton, occupying the axial zone of an inferred syncline in the north central part of the map area. This batholith is texturally variable at the outcrop scale, with textures ranging from fine-grained aphanitic to coarse-grained quartz phenocrystic. Commonly, the pluton is a medium-grained biotite tonalite containing 5 to 15 percent quartz phenocrysts. Hornblende is common in several places and in a few outcrops it is the only mafic mineral present. Large-scale silicification occurs as quartz veining along the northeastern contact of the pluton with intermediate metavolcanic rocks. These features suggest that the pluton is hypabyssal. Several of the textures within the pluton are similar to those found in the host intermediate metavolcanic rocks, suggesting that the pluton may have supplied magma for the formation of the intermediate metavolcanic rocks.

The Robinson Lake stock (Amukun 1979) is a potassium feldspar-megacrystic granite that occurs along the southern margin of the map area. The stock is homogeneous, with little textural variation, and is massive, except near the contact with the supracrustal rocks where it is mylonitized. Several small aplite and pegmatite dikes intrude the supracrustal rocks; otherwise, the contact with the supracrustal rocks is abrupt.

Diabase dikes from 5 cm to 100 m wide intrude the supracrustal rocks and the granitic plutons. These dikes were generally intruded along pre-existing structural weaknesses and are aligned north-northeast, northwest and west-northwest. Three types of diabase were recognized. The most common diabase occurs in the north-northeast-trending dikes and is medium-grained, equigranular and contains hornblende, pyroxene and plagioclase. Plagioclase-phenocrystic diabase (Matachewan type) occurs in northwest-trending dikes and is most common south of Toronto Lake. Rare, coarse-grained equigranular diabase with white and pink feldspar is also most likely to occur in the northwest-trending dikes. All diabase weathers a distinctive brown to orange-brown and is magnetic, which distinguishes the dikes from mafic metavolcanic rocks.

STRUCTURE AND METAMORPHISM

The map area has undergone a regional deformation which has been modified by intrusion of the granitic plutons. The regional deformation is characterized by dextral rotation of west-northwest-trending stratigraphy and structures. A major deformation zone north of Toronto Lake contains several of the structural features that are also observed throughout the map area. Here, a west-northwest-trending gabbro sill has undergone dextral rotation and has been faulted into several blocks. Each block is marked by northeast-trending, quartz-filled extension fractures and sheared contacts with the surrounding, intensely sheared and carbonatized mafic metavolcanic rocks. Each block is bounded by north-northeast-trending sinistral faults, some of which are occupied by diabase dikes. Lineations within this zone plunge moderately to the north-northwest which, when combined with the dextral rotation, indicates that there was a component of north-side-up vertical movement. Elsewhere in the map area, northeast-trending foliations overprint west-northwest-trending structures and create small-scale Z-folds or dextral faults. The resulting structures are favourable hosts for gold mineralization.

The Robinson Lake stock has locally modified the regional deformation pattern by enhancing the northeast structural trend on the west shore of Toronto Lake. This has resulted in transposition of stratigraphy and folding of the supracrustal rocks and associated mafic and ultramafic sills in the Joy Lake area.

Much of the Toronto Lake area has attained lower amphibolite facies metamorphism as shown by the development of staurolite in clastic metasediments, garnet in the intermediate metavolcanic rocks and garnet, hornblende and epidote plus feldspar segregations in the mafic metavolcanic rocks. Only the central part of the map area, where chlorite, brown carbonate and actinolite in mafic metavolcanic rocks occur, is at greenschist grade metamorphism.

ECONOMIC GEOLOGY

Gold, nickel, copper, lead and asbestos mineralization occur in the southern part of the map area. Gold was discovered in the 1960s in a small amphibolite outlier within the Robinson Lake stock, where it is associated with arsenopyrite, pyrite and molybdenite in a small shear zone less than 1 m wide and 50 m long. Gold values up to 0.4 ounce per ton were returned from assays; however, trenching and diamond drilling failed to show any continuity to the mineralization (Assessment Files Research Office (AFRO), Ontario Geological Survey).

Asbestos mineralization occurs as small veinlets within peridotite on the southwest shore of Toronto Lake. Fiber lengths from 1/32 to 3/16 inch were observed; however, diamond drilling failed to encounter sufficient veinlet density to warrant commercial development (AFRO, Ontario Geological Survey). Nickel was encountered in the peridotite; however, assay values indicated that the mineralization was erratic and generally low (less than 0.3 percent Ni) in grade (AFRO, Ontario Geological Survey).

Nickel and copper mineralization is associated with a gabbro-anorthosite sill on a large peninsula on the east side of Toronto Lake. Diamond drilling by Noranda Exploration Company in 1970 encountered widely spaced, low-grade mineralization (0.01 percent Cu, 0.03 percent Ni) and no further work was carried out (AFRO, Ontario Geological Survey).

Copper, zinc and lead sulphides were encountered in felsic metavolcanic schist in diamond-drill holes under Toronto Lake, north of an island in the western part of the lake. Assay values were not reported and no further work was carried out (AFRO, Ontario Geological Survey). Pyritic felsic tuff and schist were observed during the field work along the south side of this island and further prospecting is warranted in this area.

Several previously unreported trenches were discovered during the field work west of Ketchikan Lake. Pyrite, pyrrhotite and chalcopyrite, located along the contact between sheared felsic metavolcanic rocks and gabbro or peridotite, were observed in these trenches. Airborne electromagnetic anomalies detected by the recently released Ontario Geological Survey airborne survey maps (Tashota–Geraldton–Longlac Area, Maps 81277 and 81278, 1989) correspond with the mineralization in the trenches. Further investigation in this area is warranted.

The felsic metavolcanic rocks west of Toronto Lake warrant further investigation for base metal mineralization. Sulphides occur in several places at the contacts between the metavolcanic rocks and gabbroic sills and, in at least one place on the west shore of Toronto Lake, massive pyrite and pyrrhotite occur within rusty felsic schist. The flight lines of the airborne survey of the Tashota–Geraldton–Longlac area are almost parallel to the strike of the rocks in this area, resulting in the detection of only weak electromagnetic responses. Any airborne conductor in this environment would be worth investigating.

Along the southeast shore of Toronto Lake, in the area where the lake narrows to a small channel, sheared and altered peridotite and gabbro occur. Quartz and brown carbonate veining are common and pyrite and chalcopyrite are locally present in quantities up to 10 percent. This area should be explored for gold mineralization.

A large deformation zone was mapped approximately 2.5 km north of Toronto Lake. Intensely sheared and carbonate altered mafic metavolcanic rocks, commonly with disseminated pyrite, occur in several places within this zone, and this environment is a favourable host for gold mineralization.

The central and northern parts of the map area have received little exploration. The Tashota–Geraldton–Longlac area airborne survey (Maps 81263, 81264) detected numerous electromagnetic conductors on the north side of the Summit Lake batholith and traverses in this area by the field crew detected both widely disseminated and locally massive pyrite, pyrrhotite, chalcopyrite and magnetite mineralization in mafic tuff and amphibolite. In several places, the total iron content of the rock approached 15 percent and the term "lean ironstone" may be used to describe these rocks. An iron deposit occurs east of the map area (Amukun 1985) and may be the "along strike" extension of the mineralization seen in the Toronto Lake area. Gold and base metals may occur in this environment.

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12. Project Unit 89-16. Geology of the Lapierre Lake Area and Lindsley Township

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INTRODUCTION

The map area (Figure 12.1) includes Lapierre, Hipel and Lindsley townships and an area of approximately 45 km² extending from the northern boundary of Lapierre Township north to Altitude Lake.

This area forms part of the "Sturgeon River gold belt", east of Lake Nipigon. The southwestern part of the map area is approximately 15 km by road from the settlement of Jellicoe. The city of Thunder Bay is 230 km to the southwest.

Access to Lapierre Township is provided by the Kinghorn Road, which departs from Highway 11, 8 km east of Jellicoe. Various parts of Lapierre Township and the Altitude Lake area are easily accessed by old logging roads. The southern part of Hipel Township is accessed by the Turkey Lake road (which may not be travelled by motorized vehicles), which departs from Highway 11 at the Sturgeon River bridge in Colter Township. The central and northern parts of Hipel Township are best reached by float-equipped aircraft. Highway 11 traverses Lindsley Township, and numerous gravel roads originating from it give access to most parts of the township and to Wildgoose Lake.

MINERAL EXPLORATION

Information on exploration work was retrieved from the Assessment Files Research Office, Ontario Geological Survey, and from the Office of the Resident Geologist (Beardmore–Geraldton), Ontario Ministry of Northern Development and Mines, Thunder Bay.

In the 1970s, the area was explored for massive sulphide deposits. During the 1980s, mineral exploration has been focussed primarily on gold. Exploration work began in the area following gold discoveries in the Sturgeon River and Geraldton areas.

By 1989, most of the area underlain by supracrustal rocks was staked. The various properties

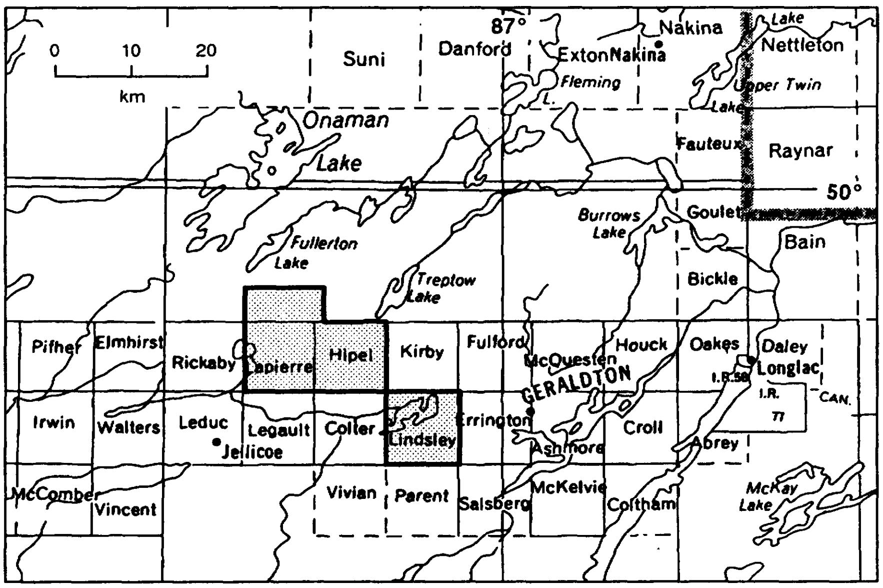

Figure 12.1. *Location map for the Lapierre Lake area and Lindsley Township.*

CANADA ONTARIO Mineral Development Exploration Minérale

This project A.5.1 is part of the five-year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

have been explored by prospecting, airborne and ground geophysical surveys, geological mapping, trenching and diamond drilling. Recent exploration activity in each of the townships is summarized below.

LAPIERRE TOWNSHIP

In 1987, an airborne magnetometer (AM) and electromagnetic (AEM) survey were conducted for Golden Earth Resources Inc. over a group of 66 claims around Jory Lake in southern Lapierre and northern Legault townships. This claim group (locally known as the "Missing Link property") is underlain by intensely sheared and carbonatized metavolcanics that are exposed in one place by a trench. Several old trenches and test pits on the property expose quartz veins and stringers mineralized with pyrite and arsenopyrite.

Ground magnetic, AM and AEM surveys were carried out on several claim groups around the Dikdik (Orphan) gold mine north of Atigogama Lake (Figure 12.2). The mine, which produced 2460 ounces of gold during the mid-1930s (Mason and White 1986), is included in a group of 27 claims held by Kidd Resources Ltd. in 1989.

Extensive overburden trenching and stripping carried out by Seaway Base Metals Ltd. 1.3 km north of the Dikdik Mine has exposed the contact between granodiorite of the Kaby Lake stock (Mackasey and Wallace 1978) and metavolcanics. Most of the trenching is situated in Rickaby Township.

Two large claim blocks in Lapierre Township were included in the AM and AEM surveys flown in 1987 for Coulson Exploration Limited.

In 1980, Dome Exploration (Canada) Ltd. did follow-up work on airborne electromagnetic (AEM) anomalies on two groups of nine claims each. Six diamond-drill holes were sunk, for a total of 492 m. No significant mineralization was reported.

Hudson Bay Exploration and Development Co. Ltd. carried out a ground exploration program in 1971 and 1972, which consisted of magnetic and EM surveys and drilling to investigate AEM targets in the general Sturgeon River area. Eight diamond-drill holes totalling 800 m were completed in southern Lapierre Township. The holes intersected narrow bands of graphitic pyrite and pyrrhotite with minor chalcopyrite. In 1971, the Canadian Nickel Co. Ltd. drilled two short holes, totalling 99 m, that intersected graphitic sulphides near the northeast corner of Delisle Lake.

In 1972, Amax Exploration Inc. carried out a ground exploration program on two claim groups in Lapierre Township to investigate AEM anomalies. The work consisted of magnetic and EM surveys, geological mapping and soil geochemical sampling.

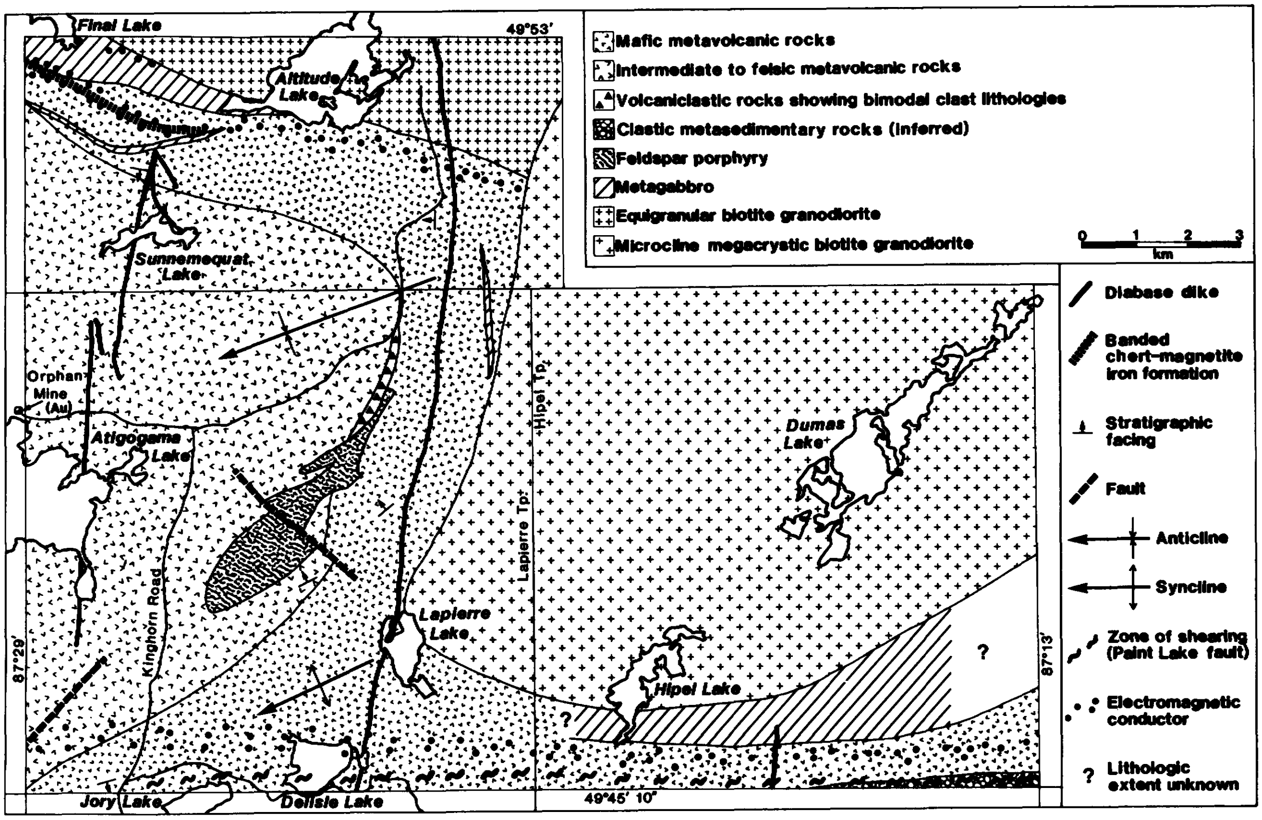

Figure 12.2. *Generalized geology of the Lapierre Lake area.*

Three diamond-drill holes totalling 356 m were put down by the company in southwestern Lapierre Township. During the same year, copper mineralization was located a few hundred feet southeast of Atigogama Lake by D. Thorsteinson, and limited test pitting and trenching was carried out (Mackasey 1974).

ALTITUDE LAKE AREA

In 1987, an AM and very low frequency electromagnetic (VLF-EM) survey was carried out for Beardmore Gold Stake on a group of 71 unsurveyed claims west of Sunnemequat Lake.

An AM and an EM survey were carried out for Coulson Exploration Limited on a group of 98 claims south of Fullerton Lake. A 150 m long trench, exposing a quartz vein sparsely mineralized with chalcopyrite and molybdenite, was located by the field party on this property 1.5 km east of Final Lake.

In 1989, Final Lake Syndicate held a group of 14 claims, centred on Final Lake, on which ground magnetic and EM surveys were carried out. The field party found pyrite mineralization in sheared rock at the northwest end of Final Lake.

HIPEL TOWNSHIP

In 1989, B. Nelson of Jellicoe held 27 unsurveyed claims situated at Dumas Creek. During the 1980s, ground magnetic, AM and EM surveys, and a self potential survey were carried out. A number of trenches in overburden expose sheared metagabbro hosting deformed quartz veins that are locally mineralized with black tourmaline and minor sulphides.

In 1989, Panthco Resources Inc. held a block of 48 claims south of Hipel Lake. Ground magnetic and EM work and geological mapping were carried out on the property in 1988. The field party noted black tourmaline veins and pods, up to 1 m in size, in coarse-grained gabbro on the west side of Hipel Lake. On the east side of the lake, pyrite- and chalcopyrite-bearing quartz veins were noted in an area stripped of overburden.

Hudson Bay Exploration and Development Co. Ltd. carried out a diamond drilling program in 1986 on a large claim block east of Dumas Lake in Kirby and Hipel townships. The property is underlain by porphyritic granodiorite (Beakhouse and Chevalier 1983).

LINDSLEY TOWNSHIP

Two former producing mines are located in eastern Lindsley Township (Figure 12.3). The Jellicoe gold mine was active between 1937 and 1940, and the Tombill gold mine was developed in 1936 and mined until 1942, when ore reserves were exhausted (Mason and White 1986).

Between 1980 and 1987, Dome Exploration (Canada) Ltd. conducted an extensive exploration program, including a magnetometer survey and diamond drilling, in central Lindsley Township.

GENERAL GEOLOGY

LAPIERRE LAKE AREA

Lapierre and Hipel townships were mapped in 1935 by E.L. Bruce as part of a regional mapping program of the Sturgeon river area (Laird 1936; Bruce 1936). Mackasey (1974) conducted field work in Lapierre and Hipel townships as part of a 1:15 840 scale mapping program, and the Altitude Lake area has been mapped by W.W. Moorhouse (1938).

Aeromagnetic maps (ODM-GSC 1963a; OGS-GSC 1988a, 1988b; OGS 1989a–d) are available for the area mapped by the present survey.

The map area is underlain by Archean metavolcanic and granitic rocks. The Paint Lake fault, characterized by a wide zone of shearing, parallels the southern limit of the map area and marks the boundary between the metavolcanic plutonic Onaman–Tashota terrane and the Beardmore–Geraldton metavolcanic-metasedimentary belt to the south (Pye et al. 1966).

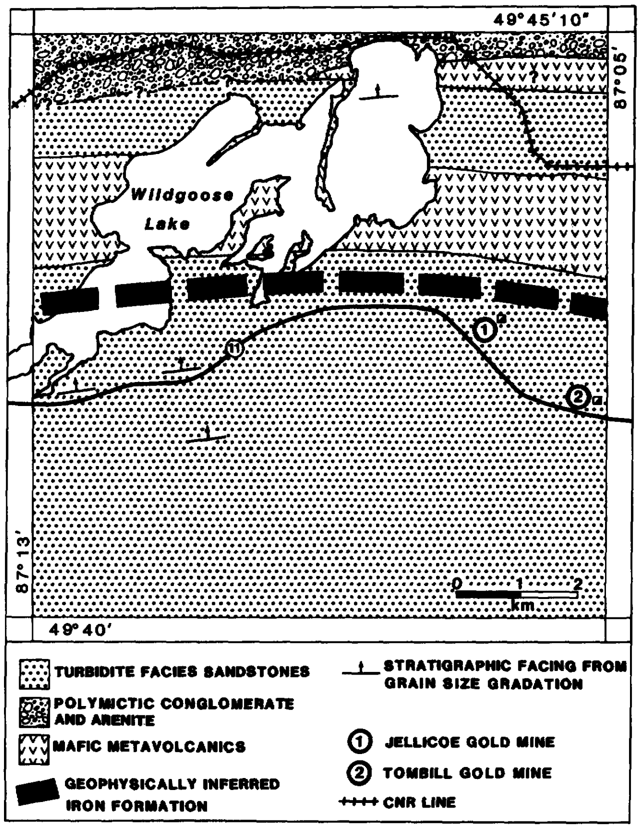

Figure 12.3. *Generalized geology of the Lindsley Township.*

The supracrustal rocks consist almost entirely of metamorphosed volcanic and related intrusive rocks. A narrow horizon of chemical sediments, represented by banded iron formation, has been identified but no clastic metasediments were recognized in outcrop within the map area.

Metamorphosed volcanic rocks consist of massive to pillowed mafic flows, which are commonly amygdaloidal, and intercalated pillow breccia, hyaloclastite and tuff. In many places, particularly near the granitic rocks to the north, the volcanic rocks have been sheared and recrystallized to amphibole schists. Top directions, obtained mainly from pillow shapes, indicate that the metavolcanic rocks young away from the granitic batholith (*see* Figure 12.2).

These mafic rocks are overlain to the west by a thick succession of intermediate metavolcanics, consisting of massive amygdaloidal flows, flow breccia, and monolithic, aphyric and plagioclase-phyric lapilli tuff and lapillistone. West of the map area, felsic volcanics of dacitic to rhyolitic composition were mapped by Mackasey and Wallace (1978). This suggests a distinct compositional trend from mafic to felsic in a westerly direction. In northern Lapierre Township, the transition from mafic to intermediate volcanics is marked by a volcanic breccia with a compositionally bimodal clast population. In central Lapierre Township, an elliptical body of feldspar porphyry probably represents a shallow, subvolcanic intrusion related to the intermediate volcanics.

Sill-like metagabbro intrusions within the mafic volcanic assemblage are most likely related to the mafic volcanism.

A narrow horizon of banded iron formation has been identified within mafic metavolcanics in the northern part of the map area. This chemical sedimentary unit forms a continuous stratigraphic marker, consisting of alternating bands of magnetite, recrystallized chert and fibrous amphibole; sulphides are also present. The unit has a distinct, easterly-trending, linear magnetic signature on the aeromagnetic map (OGS 1989a). A strong EM anomaly coincides with the magnetic anomaly (OGS 1989a).

The supracrustal rocks to the north are intruded by the Onaman–Twin lakes batholithic complex. Two distinct marginal phases of the batholith occur within the present map area. In the Altitude Lake area, the granitic rocks are dominated by a medium- to coarse-grained, equigranular biotite granodiorite which is foliated near the contact. This phase is cut by a wide lobe of the second phase, composed largely of microcline-megacrystic biotite granodiorite, which underlies most of Hipel Township.

Several north-striking diabase dikes of probable Early Proterozoic age cut the Archean rocks.

LINDSLEY TOWNSHIP

Lindsley Township was mapped by E.L. Bruce (1935) shortly after the initial discoveries of gold in the Geraldton area. Lindsley Township is included in aeromagnetic maps 2142G (ODM-GSC 1963b), C21475G and C41475G (OGS-GSC 1988c, 1988d) and 81325 (OGS 1989e).

The bedrock is largely obscured by thick glacial sediments. Because of this, mapping during this survey consisted of visiting outcrops shown on Bruce's (1935) map and finding exposures that were created by construction of Highway 11 and various access roads. The geological units shown on Figure 12.3 are largely extrapolated from the adjacent townships of Legault and Errington. The most abundant exposed rocks are well-bedded turbiditic sandstones, composed of feldspathic arenites and wackes, which underlie the southern two-thirds of the township. In the uppermost part of that thick sedimentary unit, a strong magnetic anomaly (OGS–GSC 1988b; OGS 1989e) denotes the presence of iron formation. The overlying metavolcanic unit to the north is not exposed. This unit is in turn overlain by turbiditic sandstones which are exposed in only one outcrop, at Wildgoose Lake. Polymictic conglomerate with intercalated, coarse-grained, quartzofeldspathic arenite beds is exposed in the northeast corner of the township.

STRUCTURAL GEOLOGY

LAPIERRE LAKE AREA

Top indicators and stratigraphic relationships clearly suggest that the metavolcanics form a broad, west-plunging syncline across the entire western part of the map area. However, south-facing pillows in northwestern Legault Township (Mackasey et al. 1976) suggest a west-plunging anticline flanking the syncline in southern Lapierre Township (*see* Figure 12.2). The axial region of the anticline is intruded by the large granodiorite mass underlying Hipel Township at Lapierre Lake (*see* Figure 12.2). In southern Lapierre and Hipel townships, an intense schistosity related to the Paint Lake deformation zone affects the southern limb of the anticline. Across the syncline, schistosities developed parallel to lithologic contacts increase in intensity towards the Onaman–Twin lakes batholith. Strong tectonic lineations developed within the schistosity plunge at moderate angles to the west. An axial planar foliation, characterized by crenulations and west-plunging chevron folds, occurs in the northern part of the map area.

LINDSLEY TOWNSHIP

Lindsley Township lies entirely within the Beardmore–Geraldton belt, whose structure is dominated by east-striking, mafic metavolcanic and metasedimentary rocks. Top determinations obtained from graded beds suggest a north-facing sequence. Regional structural studies by Williams (1987) indicate that wide shear zones are developed along major lithologic contacts. Williams (1987) proposed that the Beardmore–Geraldton belt has an imbricated stratigraphy, and is at the north margin of an accretionary prism represented by the metasedimentary rocks of the Quetico Subprovince.

ECONOMIC GEOLOGY

LAPIERRE LAKE AREA

Lapierre and Hipel townships are situated in the eastern part of the "Sturgeon River gold belt". The Dikdik (Orphan) gold mine, which produced 2469 ounces of gold and 644 ounces of silver (Mason and White 1986), is located just beside the township line in Rickaby Township (*see* Figure 12.2).

A strong east-trending electromagnetic conductor at Delisle Lake (OGS 1989c) parallels the southern boundary of the map area. Graphitic sulphide zones consisting of pyrrhotite and pyrite have been intersected by diamond drilling. Another very strong magnetic anomaly, overprinted by a prominent EM conductor (OGS 1989a), occurs south of Final and Altitude lakes. Banded iron formation, mineralized with pyrite, was found in two places along this geophysical anomaly. Pyrite mineralization also occurs in sheared gabbro at the north end of Final Lake.

On the "Missing Link property" north of Jory Lake in southern Lapierre Township, quartz-ankerite veins and stringers carrying pyrite and arsenopyrite cut intensely sheared and carbonatized metavolcanics. Anomalous concentrations of gold have been found on this property (B. Nelson, Prospector, personal communication, 1989).

Base metal sulphides occur in a few veins within the map area. B. Nelson of Jellicoe discovered chalcopyrite and galena in a white calcite vein hosted in sheared gabbro in southern Hipel Township. Chalcopyrite mineralization in quartz-ankerite stringers has been reported southeast of Atigogama Lake (Mackasey 1974). West of Altitude Lake, a quartz vein in granodiorite carries minor amounts of chalcopyrite and molybdenite. Two known Cu-Zn-Pb-Ag base metal occurrences in central Rickaby Township are hosted by fragmental felsic volcanic rocks (Mackasey and Wallace 1978).

LINDSLEY TOWNSHIP

Two former producing gold mines are situated in Lindsley Township (*see* Figure 12.3). The Jellicoe Mine produced a total of 5675 ounces of gold and 515 ounces of silver from a 14 722 ton orebody between 1937 and 1940 (Mason and White 1986). The Tombill gold mine in eastern Lindsley Township was developed in 1936 and yielded a total of 68 739 ounces of gold and 8595 ounces of silver from 190 622 tons of ore (Mason and White 1986).

These former gold deposits are situated on-strike with the large former gold mines at Geraldton, which occur along a major zone of shearing known as the Barton Bay lithotectonic zone (Macdonald 1988).

Ore at the Jellicoe Mine was composed of quartz veins and stringers in sheared meta-arkose and metawacke (Mason and White 1986). At the Tombill Mine, gold was contained in silicified, sheared and brecciated metaturbidites and porphyry and formed a 2000 foot (600 m) long, east-striking mineralized zone (Pye 1951).

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13. Project Unit 87-16. Alkalic Rocks of the Thunder Bay Area

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INTRODUCTION

This project, which began in 1987, is a study of the petrochemistry, petrology, metallogeny and tectonic setting of alkalic (shoshonitic) extrusive and intrusive rocks which occur in the Shebandowan belt of the Abitibi Subprovince in the Thunder Bay area (Figure 13.1). The results of these field and laboratory investigations will provide data for an interpretation of the lithotectonic and crustal evolution of the study area. The area of investigation comprises the townships of Conacher, Duckworth, Blackwell, Laurie, Goldie, Horne, Forbes and Conmee, and the Dawson Road Lots, centred about 55 km northwest of Thunder Bay (Figure 13.1).

Previous work on the project (Carter 1987a, 1988) indicated that alkalic (shoshonitic) rocks occur in two sequences within the study area: an older Keewatin-type and a younger Timiskaming-type. No alkalic rocks were previously known to be associated with the Keewatin metavolcanics in the area. This year's field work, therefore, was designed to either confirm the existence of Keewatin alkalic metavolcanic rocks, or to demonstrate that the supposed Keewatin alkalic rocks were, in fact, Timiskaming units that had been tectonically intercalated within the Keewatin sequence.

Other objectives of the investigations in the 1989 field season were:

1. to study the nature of the contact zone between the southern boundary of the northern belt of Timiskaming-type rocks (Carter 1984, 1987a, 1988) and Keewatin-type rocks at three locations
2. to map in greater detail a contiguous area of southeastern Duckworth and southwestern Laurie townships, where alkalic (shoshonitic) rocks are associated with Keewatin-type rocks. This work was completed to determine whether these shoshonitic rocks, which are similar to those in the younger Timiskaming-type rocks, are part of the Keewatin-type sequence or are infaulted Timiskaming-type rocks.

GENERAL GEOLOGY

The Keewatin-type sequence underlies the southern half of the area and comprises an east-striking, mainly subaqueous and predominantly volcanic sequence. This sequence consists of komatiitic and

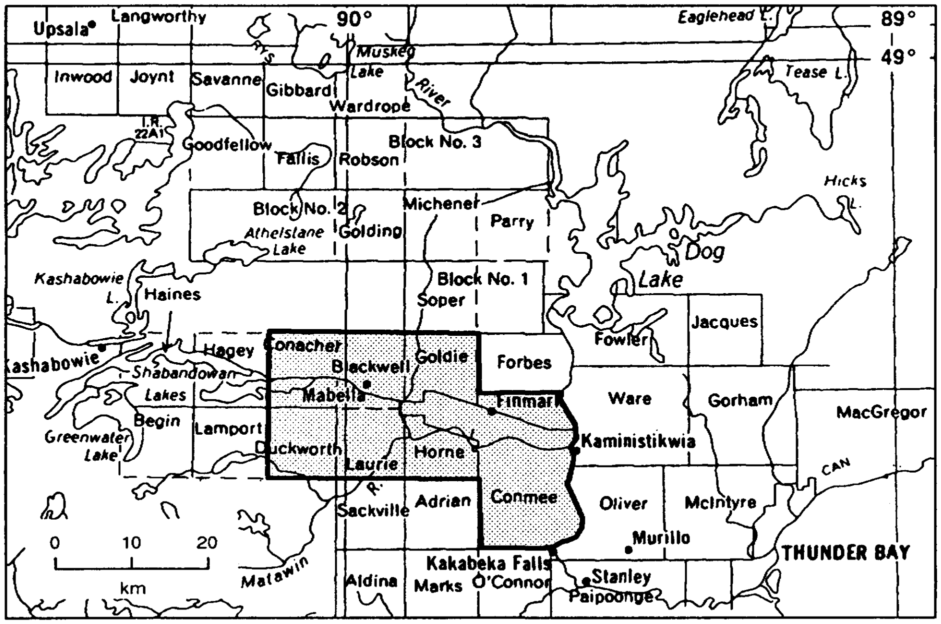

Figure 13.1. *Location map for the Thunder Bay area.*

tholeiitic metavolcanic rocks in its lower part and calc-alkalic and alkalic (shoshonitic) rocks in its upper part, along with subordinate clastic and chemical metasediments consisting of mudstone, wacke and ironstone which occur in both parts of the sequence. The shoshonitic rocks comprise absarokite, shoshonite, latite and toscanite flows and pyroclastics.

The Timiskaming-type sequence, as here defined, occurs in two subparallel, east-striking belts crossing the central part of the area. These are referred to as the northern and southern belts. The Timiskaming-type sequence is composed of calc-alkalic and alkalic (shoshonitic) metavolcanic rocks, and clastic and chemical metasedimentary rocks. The shoshonitic rocks consist of shoshonite and latite flows and pyroclastics, which are distributed around two major central volcanic complexes in the western part of the northern belt in southern Conacher Township. These volcanic centres consist of subvolcanic hornblende-feldspar porphyry bodies with associated pyroclastics. Flows and pyroclastics are found in other areas throughout the northern and southern belts. Evidence (Carter 1987a, 1988) suggests that the metasedimentary rocks of the Timiskaming-type sequence have alluvial-fluvial depositional characteristics, indicating that they are continental subaerial deposits deposited in fault-bounded pull-apart basins. The northern boundary of the northern belt is probably formed by the Conmee fault, which is collinear with the Postans fault mapped by Morin (1973) in Conacher Township in the western part of the study area. No evidence, such as disruption of lithological units, fault breccias or shearing, was obtained to suggest that the southern belt is fault bounded.

Intrusive alkalic stocks consisting of pink-weathering, pink and brown feldspar-hornblende porphyry, and quartz-hornblende porphyry were identified in southern Conacher Township, in southwestern Blackwell Township and in northern Conmee Township. These stocks are associated with the central volcanic complexes. A stock composed of pink, massive, composite alkalic hornblende-quartz monzonite, biotite-diopside monzonite and diorite, intrudes the alkalic (shoshonitic) pyroclastics and tholeiitic metabasalts in northern Conmee Township. Dikes of mauve and brown shoshonitic lamprophyre cut both the Timiskaming-type and Keewatin-type rocks, and are considered by the author to belong to the same magmatic suite as the alkalic rocks within the Timiskaming and Keewatin sequences.

STRUCTURAL GEOLOGY

The study area is part of the Shebandowan tectonic belt, which is believed to have undergone two deformation events ($D_1$and D_2; Stott 1985).

The Keewatin-type rocks are isoclinally folded about easterly to southeasterly trending axes in the region northwest of the Mokomon fault in southeastern Conmee Township, and along northeasterly axes southeast of this fault. A well-developed, steeply dipping foliation is found in the rocks in the metamorphic aureole of the Sundbar–Batwing batholith in the southern part of the map area. Mineral and extension lineations within these rocks are best developed in the southwestern part of the area and plunge to the northwest.

The rocks of the Timiskaming-type sequence are also isoclinally folded about southeasterly trending axes. A well-developed, steeply dipping foliation which trends east-southeasterly is developed in these rocks in the northern belt, and is associated with a mineral lineation which plunges steeply to the east-northeast.

FIELD INVESTIGATIONS

Two areas where likely exposure of the contact between the Timiskaming-type and Keewatin-type rocks has been indicated by previous mapping (Carter 1985, 1988) were examined during the 1989 field season:

1. along highways 11 and 17 in the Dawson Road Lots, about 4 km west of Finmark Road
2. in south-central Conacher Township, south of the Inco Limited mine road

Unfortunately, the two rock groups were not seen in contact within either area. The Timiskaming-type rocks in south-central Conacher Township consist of highly sheared polymictic conglomerates. The shearing strikes west-southwesterly with dips of 55° to 75° to the northwest.

The contact between the Timiskaming-type and Keewatin-type rocks is not exposed in the area straddling the southern half of the boundary between southeastern Conacher and southwestern Blackwell townships, south of Highway 11. Although exposure is very poor here, the approximate eastern limits of the Timiskaming-type central volcanic complex southeast of Shebandowan (Carter 1988), and the strike of the contact between the Keewatin-type and Timiskaming-type rocks were established. The westward extension of the Timiskaming-type rocks into Conacher Township north of Highway 11 was also established. These rocks had previously been mapped as Keewatin-type by Morin (1973).

Mapping in southeastern Duckworth Township and southwestern Laurie Township was undertaken to obtain additional evidence of the relationship between alkalic (shoshonitic) rocks which resemble Timiskaming-type rocks, and Keewatin-type rocks with which they are interlayered. The results of the mapping are shown on Figure 13.2. Rocks in the area consist of an interlayered group of rhyolite flows, rhyolite lapilli tuff, rhyodacite and dacite flows and tuffs, latite and latitic tuff breccia, and minor andesite, basalt and wacke. Map patterns of marker units, foliation trends, lineation patterns and

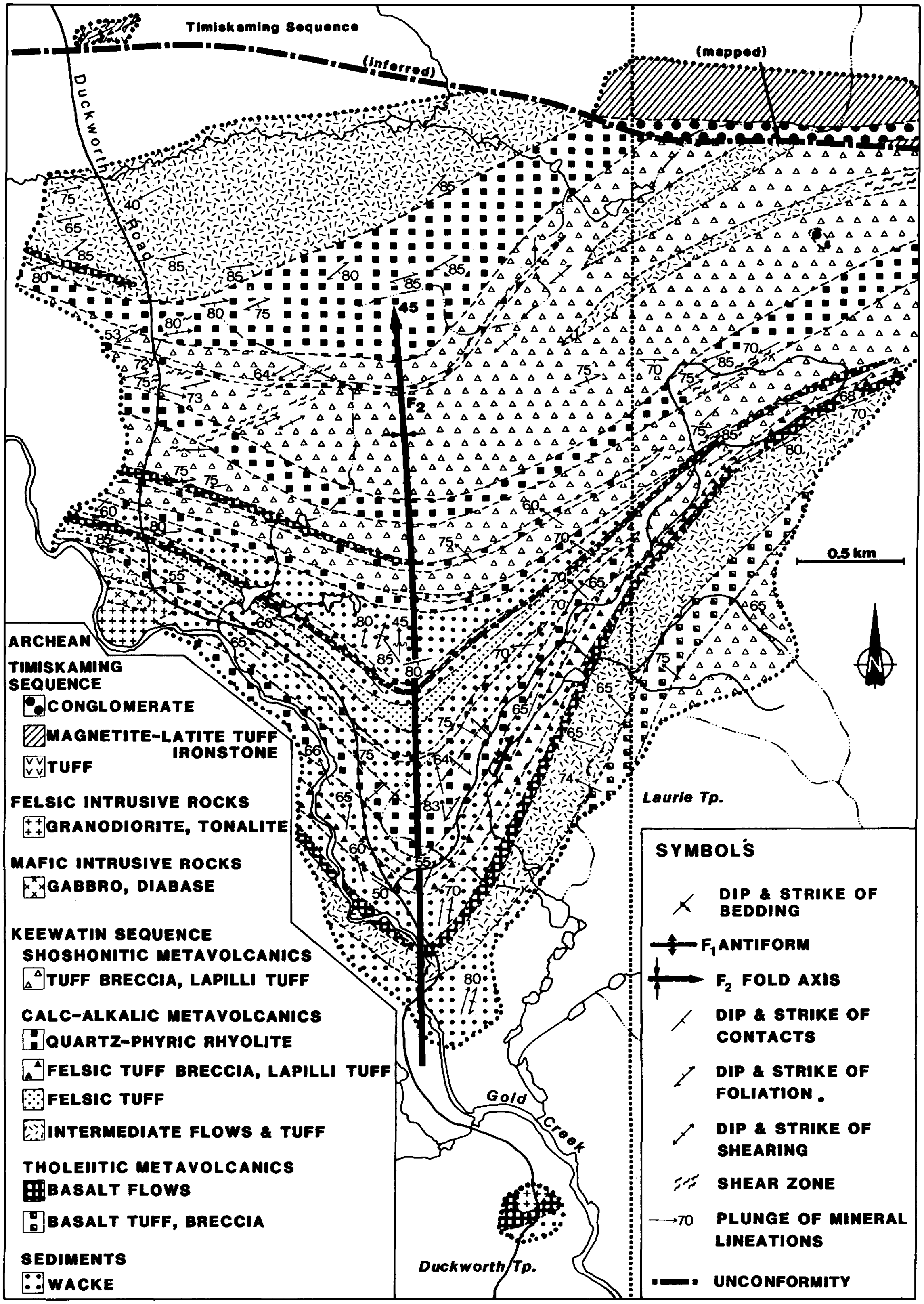

Figure 13.2. *Geological sketch map of southeastern Duckworth Township and southwestern Laurie Township.*

minor folds were used to establish the presence of two phases of folding. The first produced tight isoclinal folds trending west-southwesterly (Carter 1987b) in southwestern Laurie Township. Later refolding was about a north-south synformal axis plunging 45° northwards in southeastern Duckworth Township.

A primary foliation trends west-southwesterly, parallel to the foliations observed in Laurie Township (Carter 1987b). A second foliation, resulting from the refolding, trends north-northeasterly on the western limb of the second fold and swings through a northerly trend at the hinge of the fold to a northwesterly trend on the eastern limb. Mineral lineations and minor folds show that this local second fold plunges 45° north. The second phase of folding is believed by the author to be due to local compression between two adjacent lobes of the Sunbar–Batwing batholith (cf. Schwerdtner et al. 1979).

The interlayering of the shoshonitic rocks with typical Keewatin-type rocks, to form a pattern consistent with a local refolding of the Keewatin-type rocks by the later Sundbar–Batwing batholith, suggests that these shoshonitic rocks are older than the Timiskaming-type shoshonitic rocks. Although a tectonic interleaving prior to the refolding of the Keewatin-type rocks could account for the observations, a tectonic interleaving is very unlikely and the author believes that the shoshonitic rocks resembling the Timiskaming-type rocks are part of the Keewatin-type sequence. Evidence for this interpretation was accumulated during this field season, as follows:

1. The similarity of foliation and lineation trends in both the shoshonitic rocks interlayered with the Keewatin-type rocks and the Keewatin-type rocks indicates that the shoshonitic rocks are part of the Keewatin-type sequence. Shear zones mapped in the area strike east-northeast and cut the strike of the lithologic units, indicating that the shoshonitic rocks in the southern area are not later, infaulted outliers of the Timiskaming-type sequence found to the north.
2. Mapping to the northeast, in central Laurie Township (Carter 1987b), did not reveal any shoshonitic tuff breccia units in the Timiskaming-type sequence of the southern belt. These rocks, however, occur in the Keewatin sequence. This is an indication that the two sequences are different. If they were the same, and if the alkalic rocks were infaulted, the tuff breccias should also be found in the Timiskaming sequence of the southern belt.
3. The rhyolitic rocks, so common in the Keewatin-type sequence of this area, are absent from the Timiskaming-type rocks of the southern belt. This indicates that the two rock groups represent different sequences, both of which contain alkalic metavolcanics.
4. The Timiskaming sequence of the southern belt (northern part of Figure 13.2) strikes approximately east to northeast. It contains magnetic ironstones and can be traced on aeromagnetic maps (ODM-GSC 1961, 1962). An unconformity, with the Keewatin sequence lying to the south, has been mapped. This Keewatin sequence strikes differently from the Timiskaming and contains alkalic metavolcanics interlayered with calc-alkalic and tholeiitic metavolcanics. Therefore, the author believes that these alkalic rocks form an integral part of the Keewatin sequence and were not tectonically emplaced.

MINERAL EXPLORATION

It is beyond the scope of this summary report to describe the economic geology and mineral exploration in the area of investigation. This has been done by the author in other publications (Carter 1984, 1985, 1986, 1987b). In 1989, mineral exploration activity in the area was being carried out by Inco Gold Co.

CONCLUSIONS

Field work during 1989 has shown that:

1. Conclusive evidence for a faulted relationship between the northern belt of Timiskaming-type rocks and the Keewatin-type rocks which occur to the south in the Dawson Road Lots in the Goldie and Horne townships area could not be obtained, because of the absence of critical exposure.
2. The Timiskaming-type rocks of the northern belt can be traced westwards into Conacher Township and as far north as the Postans fault, which is collinear with the Conmee fault as mapped by Carter (1986) in the Dawson Road Lots in the Forbes and Conmee townships area. This suggests that this fault system forms the local northern boundary of the northern belt of the Timiskaming-type rocks.
3. Shoshonitic volcanic rocks that resemble those in the Timiskaming-type sequence but are interlayered with Keewatin-type rocks in southeastern Duckworth Township and southwestern Laurie Township can, on the evidence available, be explained as being part of the Keewatin-type sequence.

Conclusions based on field investigations in this part of the Shebandowan belt from 1987 through 1989 indicate that alkalic (shoshonitic) volcanic rocks occur as part of an earlier Keewatin-type, predominantly subaqueous sequence, and as part of a later Timiskaming-type, continental fluvial-alluvial sequence. In the Keewatin-type rocks these shoshonitic rocks are restricted to the upper, intermediate to felsic part of the sequence, which forms a linear belt extending from Conmee Township in the east to Duckworth Township in the west. The Timiskaming-type sequence occurs in two, subparallel, east-striking belts exposed across the central part of the area. Both sequences have been isoclinally folded, generally along east-southeasterly trending axes. Similar alkalic (shoshonitic) subvolcanic intrusives and shoshonitic lamprophyre dikes cut both the Keewatin-type and Timiskaming-type sequences. High precision radiometric age dating of some of the shoshonitic plutons and shoshonitic lamprophyre dikes and the two alkalic sequences will constrain the timing of the shoshonitic magmatism of the area.

Establishment of shoshonitic magmatism in the Keewatin-type volcanic sequence can, by comparison with similar rocks in modern settings (Carter 1987a), suggest that these rocks were initially formed in a convergent, subduction-related, continental margin, island arc zone in the Late Archean, and show similarities with Phanerozoic plate tectonic regimes.

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14. Project Unit 89-13. Geological Studies in the Manitouwadge–Hornpayne Area

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INTRODUCTION

Many areas in the Superior Province in Ontario are underlain by lithologically diverse rocks that have been both deformed and metamorphosed. The normal difficulties of exploration for mineralization are compounded in these terranes by the fact that stratigraphic complexity is often hidden behind structural complexity. The litho-structural mapping techniques used in this project allow lithological distribution, deformation state, and probable protoliths to be determined, and offer the possibility of deciphering the relationships between rock units and any mineralization that might be contained therein. This project was initiated to conduct such litho-structural mapping in the Manitouwadge–Hornpayne area, at a reconnaissance scale, with the objective of increasing the effectiveness of mineral exploration.

Accounts of sulphide mineralization (Thompson 1932) and the development of base metal mines in the Manitouwadge area (Figure 14.1), reviewed by Friesen et al. (1982), spurred geological mapping by the Ontario Geological Survey in the immediate vicinity of Manitouwadge by Pye (1960) and Milne (1974), and further afield, by Milne (1968), Coates (1968, 1970) and Giguere (1972). These studies are the foundation for this regional reconnaissance study. This summary first describes the rock types and structures contained therein, and then attempts to describe the structural development in terms of its significance for mineral exploration.

GENERAL GEOLOGY

Aside from the area of the Manitouwadge synform, the geology of the Manitouwadge–Hornpayne area is known on a reconnaissance scale only, except where mapping by Noranda Exploration Company, Limited has outlined local geological detail. In the vicinity of Manitouwadge (Figure 14.2), a highly strained, 1 to 2 km thick volcano-sedimentary rock sequence of unknown facing occurs in a reclined, east-northeasterly trending regional-scale synform. These rocks consist of mafic, intermediate to felsic volcanics and derived sediments, including banded magnetite and silicate ironstone. Intruded into, and lying both structurally above and below, these rocks are several generations of intermediate to felsic intrusions, producing sheeted bodies of diorite, tonalite, granodiorite, granite and attendant aplites and pegmatites. Most of these deformed rocks are generally of amphibolite-facies grade of metamorphism. Much of the thickening of the stratigraphy within the hinge of

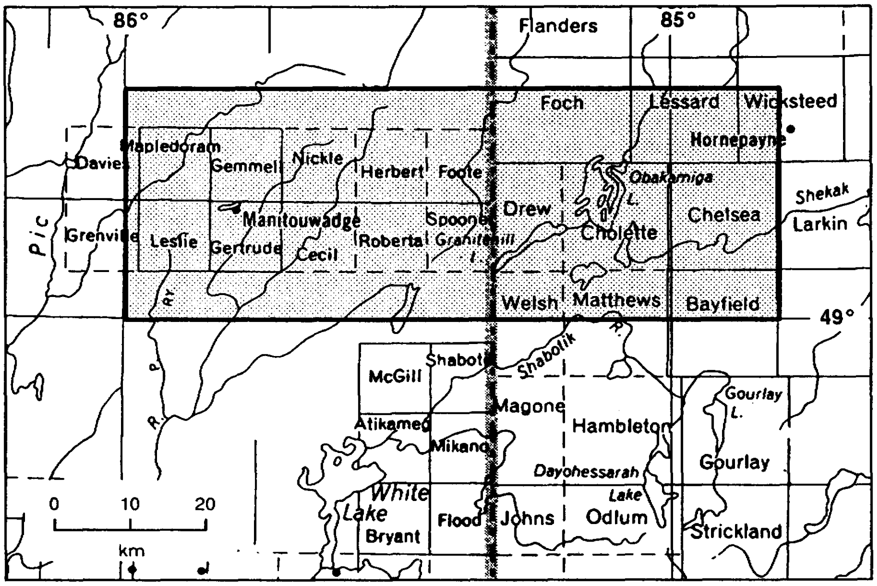

Figure 14.1. *Location map for the Manitouwadge–Hornpayne area.*

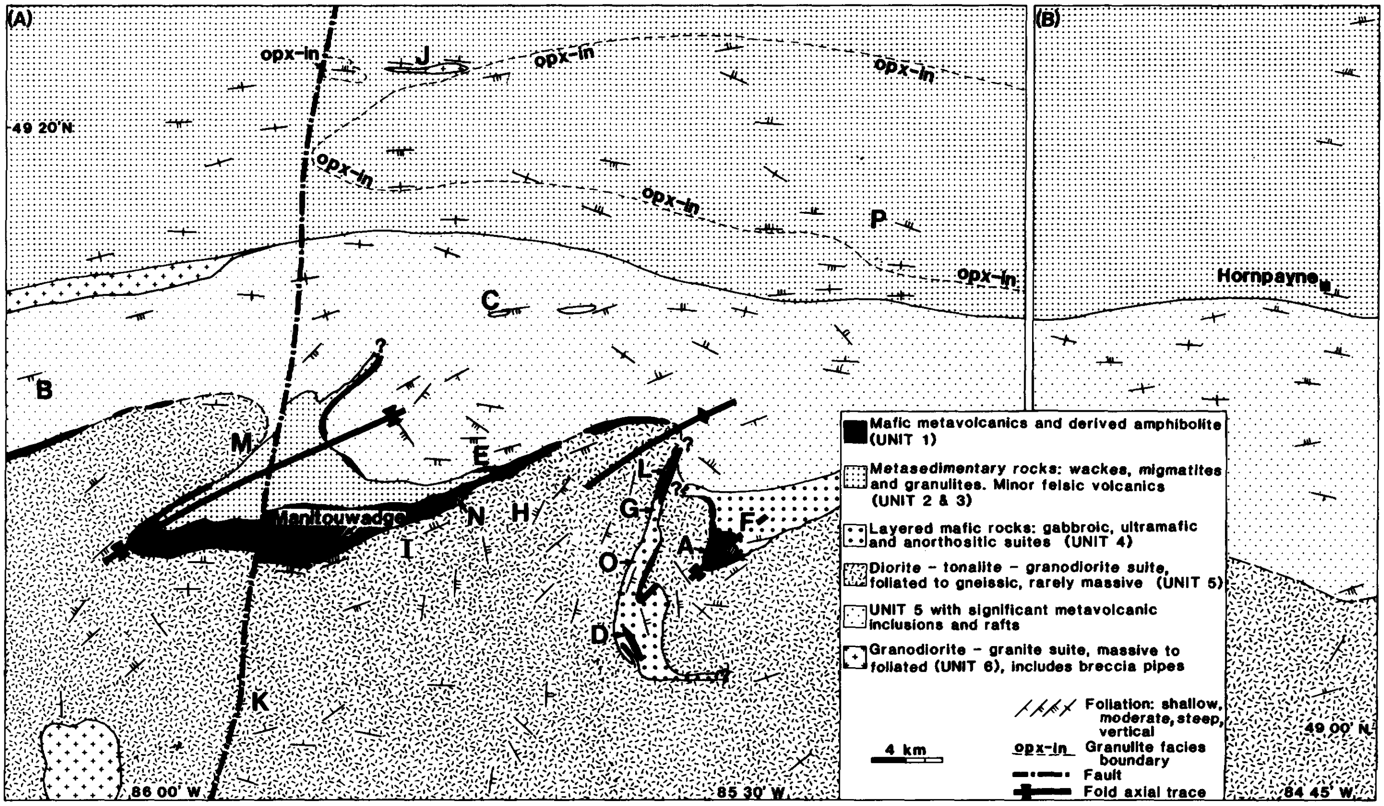

Figure 14.2. *Geological maps of the (a) Manitouwadge and (b) Hornpayne areas; compiled from Coates (1968, 1970), Milne (1968, 1974), Pye (1960), Giguere (1972), unpublished Noranda Inc. data, and this study. Areas and locations cited in text: A—Moshkinabi Lake, B—Manitou Falls, C—Fox Creek Siding, D—Faries Lake, E—Wowun Lake, F—South of Moshkinabi Lake, G—North of Faries Lake, H—Gaugino Lake, I—Manitouwadge Lake, J—Beavercross Lake, K—Barehead Lake, L—Emerald Lake, M—Nama Creek, N—Mose Lake, O—West of Rawluk Lake, P—Poppy Lake.*

the synform is apparent, due to the obliquity of the fold axis relative to the present erosional surface; a down-plunge projection of the folded stratigraphy reveals that there is only slight thickening of the strata at the southwest end of the fold. Mineralization in the Manitouwadge area consists of deformed massive sulphides spatially associated with banded ironstone horizons; the sulphides are considered by many workers to be of volcanic hydrothermal origin.

The Manitouwadge synform contains a more diverse and slightly thicker stratigraphic succession than the one developed elsewhere in the region. It is part of a generally easterly trending, discontinuous layer of mafic metavolcanics engulfed by tonalite that form the northern edge of the Abitibi–Wawa Subprovince (*see* Figure 14.2). These supracrustal rocks abut the dominantly metasedimentary migmatites of the Quetico Subprovince to the north, forming the boundary between the two contrasting subprovinces. Stratigraphic thickness within these regionally developed, predominantly mafic volcanic and layered intrusive rocks rarely exceeds 1 km. Sporadically developed screens of amphibolite and anorthositic layered intrusions occur along strike from the Manitouwadge synform within a sea of shallow to steeply dipping, foliated to gneissic tonalites and granitoids.

The supracrustal screens (*see* Figure 14.2) exhibit complex outcrop patterns within intrusive rocks of tonalitic to granodioritic composition (Milne 1968; Giguere 1972). Large bodies, such as the Black Pic complex, form the southern border of the synform, representing the predominant rock type to the south of, and within, the core of the Manitouwadge synform. These bodies are in continuity with tonalite complexes bordering and engulfing granite-greenstone terrane to the south (Milne 1968).

Data collected during reconnaissance traverses along road systems in the Hornpayne area (*see* Figure 14.2) confirm the continuation eastwards of lithological and structural patterns. There, the boundary between predominantly migmatitic metasedimentary terrane and mafic inclusion-rich tonalitic gneiss, foliated tonalite and mafic metavolcanic terrane to the south, is a zone of highly strained tonalitic gneisses and complex, deformed polymictic agmatites, intruded by less deformed granitoids.

LITHOLOGIC UNITS AND THEIR DISTRIBUTION

A large number of rock types have been recognized on an outcrop scale but few form mappable units. In the following descriptions composition, distribution and extent, origin and state of preservation or modification are catalogued for each major rock type and groupings are made on the basis of inferred origin.

UNIT 1: MAFIC METAVOLCANICS

Mafic metavolcanic rocks are the predominant rock of supracrustal origin in the area, within the Manitouwadge synform and along strike to the east (e.g., Moshkinabi Lake; *see* Figure 14.2, Location A) and west (e.g., Manitou Falls; *see* Figure 14.2, Location B). These metavolcanics form screens up to 1 km thick between foliated to gneissic tonalites.

Variably deformed and altered, massive, striped, pillowed, brecciated, amygdular, garnetiferous, schistose, coarse-grained and veined variants of these mafic rocks have been recognized at an outcrop scale, but individual varieties do not form mappable units at the reconnaissance scale. The mafic metavolcanics consist of hornblende and plagioclase, with minor diopside, epidote, quartz, sphene, biotite and garnet; some are feldspar-porphyritic, others contain epidote- and diopside-rich alteration preserved as elongate zones up to several metres long. Some metavolcanics are veined with amphibole, perhaps a product of hydrothermal alteration; others are extremely coarse grained, dominated by a decussate growth of amphibole, representing a response to post-magmatic recrystallization. Many mafic metavolcanics display insignificant magnetism.

Many outcrops lack clear evidence for a supracrustal origin, but are ascribed one because they are in continuity with rocks for which a supracrustal origin can be demonstrated. Pillow structures, rare and highly elongate parallel with the local stretching lineation, are locally preserved in mafic metavolcanic rocks south of the Geco Mine and in the Faries Lake and Moshkinabi Lake areas.

Many examples of amphibolite display a strong foliation caused by strain-induced differentiation of amphibole into layers along which an elongation of amphibole to form a mineral lineation is characteristic.

A style of alteration, producing garnet, cordierite, anthophyllite or gedrite in these mafic rocks, is typical of the "footwall" zone to the sulphide deposits in the Manitouwadge area. This style has been located elsewhere, such as at Swill Lake, and to the east of Fox Creek Siding (*see* Figure 14.2, Location C).

In general, mafic supracrustal rocks north of the Manitouwadge synform and south of Hornpayne occur as screens and inclusions within foliated tonalite.

UNIT 2: INTERMEDIATE TO FELSIC METAVOLCANICS

Within the Manitouwadge synform, pale-coloured, centimetre- to decimetre-scale, layered rocks and massive breccias of quartzofeldspathic composition, with minor biotite content, are probably of volcanic origin. With some reservations, both Pye (1960) and Milne (1974) previously assigned some of these rocks a sedimentary origin (*see* Unit 3 below). Felsic breccias exhibiting the effects of strong ductile deformation occur within the "hanging wall" of the Geco deposit, and are similar to aplitic-textured felsic rocks north of Swill Lake. Elsewhere, as at Faries Lake (*see* Figure 14.2, Location D), rocks of felsic to dioritic composition are so strongly deformed that their original features are obscured, but some, apparently fragmental rocks, may have had a volcanic origin. Finely layered rocks consisting of particles up to several millimetres across, including rock fragments in a grey quartzofeldspathic matrix, occur within the "hanging wall" strata at the Geco mine site and elsewhere, such as east of Wowun Lake (*see* Figure 14.2, Location E). These may be tuffaceous in origin. An occurrence of grading in rocks exposed in a roadcut leading to the No. 4 shaft at the Geco Mine locally indicates a southerly facing stratigraphy, but considering the abundance of isoclinal folds and layer-parallel shears within this sequence, no regional interpretation of facing is warranted.

Equivalent rocks of this composition and origin have not been recognized outside the Manitouwadge synform, reflecting not only their original distribution but also the obliterating effects of high strain and concomitant metamorphic recrystallization. Clastic rocks of volcanic aspect, recognized during the project, require further study to determine their origin. The tonalite suite may in part represent subvolcanic equivalents of the pale-coloured volcanic rocks that occur within the dominantly mafic sequence.

UNIT 3: METASEDIMENTARY ROCKS

Two distinct metasedimentary lithologic associations can be recognized within the Manitouwadge region. Wackes with associated pelites predominate over subordinate banded magnetite and silicate ironstones.

North of the Manitouwadge synform, and to the north of the most northerly mafic supracrustal unit, metamorphosed greywackes occur in various states of migmatization, often intensely sheeted by tonalite. Blue-grey migmatitic metawackes consist of quartz, feldspar and biotite, whereas associated pelitic rocks consist of dark-coloured garnetiferous and amphibole-rich decimetre-scale layers. Orthopyroxene- and garnet-rich, brown to grey metasedimentary rocks have a greasy appearance, signifying granulite-facies regional metamorphism. Within the metasediments, concordant, boudinaged and folded mafic layers of amphibolitic composition, less than 1 m thick, are common but volumetrically insignificant. Even less common are diopside-dominated pods and lenses up to several metres long, of unknown origin, possibly representing the metamorphosed equivalents of calc-silicate layers.

Metasediments tend to be richer in biotite and layered on a larger scale than the intermediate to felsic clastic metavolcanics with which they may be confused. Additional problems in identification occur when both rock types are first intruded by sheets of tonalite and then highly deformed. Deformation has frequently obliterated unequivocal evidence that could be used to distinguish between them. In many areas small-scale distinction is problematic, but major outcrop areas of tonalite and metasediment have been recognized with confidence.

Banded ironstones occur both within the mafic volcanics and in the quartzofeldspathic sedimentary and volcanic rocks of the Manitouwadge synform. They are especially thick in the hinge area (Pye 1960; Milne 1974), where metre-scale thicknesses of magnetite- and amphibole-dominated ironstone occur. Oxide-bearing ironstones are converted to sulphide-bearing assemblages in the vicinity of the massive sulphide mineral deposits. Ironstones are also associated with mafic and metasedimentary rocks in the thin supracrustal screens along strike from the Manitouwadge synform. Minor amounts of lean banded ironstone, up to 0.7 m thick, occur in contact with a possible flow-top breccia in mafic metavolcanics associated with the Moshkinabi Lake complex (*see* Unit 4 below). There, about 80 per-cent of the ironstone is composed of 0.5 to 1.5 cm thick bands of chert. The remainder consists of bands rich in diopside, accompanied by minor disseminated magnetite. Magnetite-rich bands are rare.

UNIT 4: MAFIC LAYERED INTRUSIVE SUITE

Thin screens of mafic supracrustal rocks within the foliated to gneissic tonalite terrane contain layers of peridotite, gabbro and anorthosite forming intrusions which exhibit cumulate textures and an overall gabbroic to leucogabbroic bulk composition. Two previously undocumented mafic layered complexes were identified between Emerald and Faries lakes (*see* Figure 14.2, Locations G and D respectively), and in the Moshkinabi Lake area (*see* Figure 14.2, Location F). These are separated by a north-south oriented mass of biotite hornblende diorite at least 20 km^2 in area, consisting of a strongly lineated, slightly foliated mass well exposed at the southern end of Ice Cream Lake. Highly deformed, stoped blocks of anorthosite lie within the less deformed diorite.

Faries Lake Complex

A dominantly anorthositic mass, at least 12 km in length and between 0.5 and 3 km wide, whose northern and southeastern extremities have yet to be delineated, includes anorthositic gabbro, gabbroic anorthosite, gabbro and rare anorthosite (*sensu stricto*). Thin screens of mafic metavolcanics, converted to amphibolite, occur throughout. The high state of strain and grain-size reduction in this mass make distinction between comminuted gabbroic

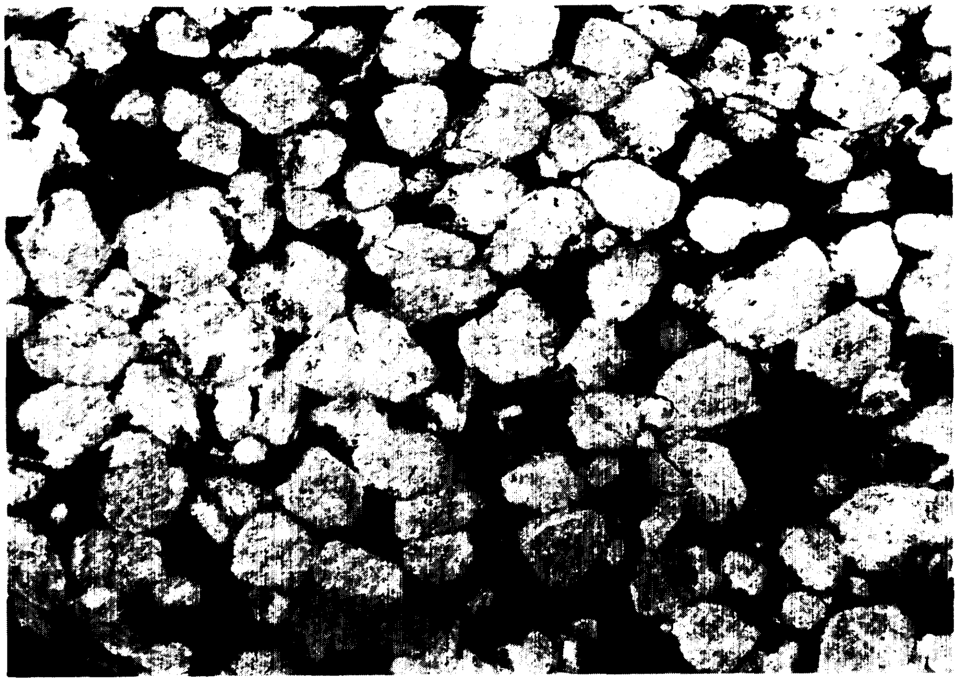

Photo 14.1. *Leopard rock composed of gabbroic anorthosite from the Moshkinabi Lake complex. Glomeroporphyritic texture is produced by plagioclase megacrysts embedded in a hornblende-rich matrix. Coin diamater 2.3 cm.*

rocks and deformed mafic metavolcanics difficult. The contact of the Faries Lake body with surrounding tonalitic rocks is well exposed on the northeastern shoreline of Faries Lake, where intensely mylonitized biotite tonalite and pink granite structurally overlie anorthositic rocks. The actual contact is featured by a tectonic breccia zone at least 15 m in thickness, which is composed of centimetre- to metre-sized blocks of gabbroic anorthosite, anorthosite, amphibolite, metawacke, granitic ultramylonite and trondhjemite. At a slightly higher structural level, mylonitic tonalite above the breccia zone is overlain by intensely deformed anorthositic rocks containing inclusions of more mafic material.

These observations suggest imbrication and interleaving of anorthositic and tonalitic rocks, possibly a result of both sheeting and thrusting. Linear fabrics within the tectonic breccia zone parallel those developed regionally within the tonalites and anorthosites, and imply a coeval development of this deformation with the D_2 episode. In general, plagioclase-rich members of the suite are highly deformed, forming gneisses and mylonitic rocks that have subsequently been intruded by tonalites, to form inclusions and agmatites such as those at Fox Creek Siding and in the Hornpayne area. Mylonitization of the anorthositic rocks prior to the emplacement of the tonalite could be attributed solely to the intrusion of the tonalite suite but it seems more likely that the tonalites were intruded into rocks that were already undergoing an intense, though inhomogeneous deformation.

Moshkinabi Lake Complex

The Moshkinabi Lake layered mafic complex is probably more extensive than the Faries Lake complex. The southwestern part of the Moshkinabi Lake complex occurs as a body at least 3 km across by 5 km long near Moshkinabi Lake in Roberta and Hebert townships. This area was previously mapped (Giguere 1972) as mafic metavolcanics and metasediments. A linear train of small, ovoid, positive aeromagnetic anomalies on OGS–GSC Maps 2169G and 2180G (OGS–GSC 1963a, 1963b) suggests that the body extends some 15 km to the northeast. Compositional layering in relatively undeformed rocks, from peridotite, through gabbro and leucogabbro to anorthosite, occurs over thicknesses of several tens of metres as part of a cyclic succession well exposed to the south of Moshkinabi Lake (*see* Figure 14.2, Location F). The grading of mineral proportions in these cyclic sequences suggests that they top to the north in that area. A lower contact of this complex with enclosing foliated tonalites illustrates similar field relations to those described for the upper mylonitized contact of the Faries Lake complex.

Plagioclase-rich rocks occur as layers and discordant sheets and veins within both ultramafic rock types. Layers up to 3 m thick have compositions varying from gabbroic anorthosite to anorthositic gabbro. Texturally, these coarse-grained rocks may be equigranular, clotty or porphyritic; impressive "leopard-textured" rock is locally developed (Photo 14.1).

Gabbroic rocks commonly occur within the complex, varying from massive equigranular to porphyritic rock to some that are magmatically layered (Photo 14.2). Layering is visible as regular variation in both grain size and composition, and the presence in some layers of uniformly distributed mafic-rich clots.

Ultramafic rocks in this mass consist of two distinct varieties: rusty, brown-weathering metapyroxenite, and green-weathering actinolitic rocks. Representative exposures of these rocks may be found in Roberta Township (*see* Figure 14.2, Location F).

Metapyroxenite is distinguished by good preservation of cumulate texture, typically containing up to 80 percent medium- to coarse-grained hypersthene, embedded in a finer-grained matrix of undeter-

Photo 14.2. *Layering in Moshkinabi Lake complex caused by alternation of fine-grained gabbro (marked by hammer), coarse-grained gabbro (lower right) and clotty gabbro (upper part of photo), layering is cut by granite dikes.*

mined secondary minerals. Locally, the hypersthene is poikilitically enclosed by irregular masses of magnetite measuring up to 4 cm across.

Actinolitic ultramafic rocks are characterized by decussate intergrowths of actinolite in a matrix of another, darker amphibole and minor chlorite, plagioclase, magnetite and hypersthene.

Several undeformed granite pegmatite sheets, up to 30 cm wide, occur within the gabbroic rocks in Roberta Township. The sheets are bordered by distinctive, continuous metasomatic halos from 8 to 23 cm wide, which have locally imprinted upon the ultramafic host, converting it to hornblendite and biotite-rich rock. The presence of large masses of hornblendite within the pyroxenitic sequence is ascribed to a larger scale version of this process of metasomatic change.

UNIT 5: DIORITE-TONALITE-GRANODIORITE SUITE

The predominant rock type in the region is a grey, foliated to massive tonalite. It consists of plagioclase, quartz and biotite, but hornblende- and diopside-bearing examples, often of dioritic composition, may be traced on aeromagnetic maps because of their magnetite content. Dark varieties sometimes display magmatic textures, including layering, orbicular structure and possible magma mixing (Photo 14.3), and occur as early phases. Hornblendites and meladiorites occur as inclusions within later rocks; as a general observation, darker phases are intruded by, and therefore pre-date, lighter phases. A leucotonalite, almost free of mafic mineral, but sometimes containing as much as 5 percent magnetite, is the last major component of this suite.

All rocks in the tonalite suite are cut by ubiquitous but volumetrically insignificant dikes of hornblende-porphyritic diorite. These dikes are rarely more than 1 m wide and are typically net-veined, with felsic centres. Some of these dikes are strongly foliated, yet straight; others are unfoliated, suggesting that as a suite they have escaped much of the regional fabric formation.

Granular, homogeneous diopside-biotite-feldspar rock occurs as rare pods and folded sheets within the tonalite. Of unknown origin, they are similar in appearance to pods and lenses found within the granulite-facies metasediments in the northern part of the area.

Tonalites clearly intrude and contain inclusions of all mafic, sedimentary, volcanic and layered mafic intrusive rocks. A broad unit of mafic inclusion-rich to agmatitic, foliated tonalite occurs between the dominantly metasedimentary migmatites of the Quetico Subprovince and the supracrustal rocks of the Manitouwadge synform and its on-strike equivalents (*see* Figure 14.2). The tonalites therefore post-date the production of supracrustal rocks and associated layered complexes. The tonalite suite and most examples of the hornblende porphyritic dike suite are cut by the potassic (granitoid) suite.

Several examples of magmatic breccias occur within the tonalite suite. North of Faries Lake (*see*

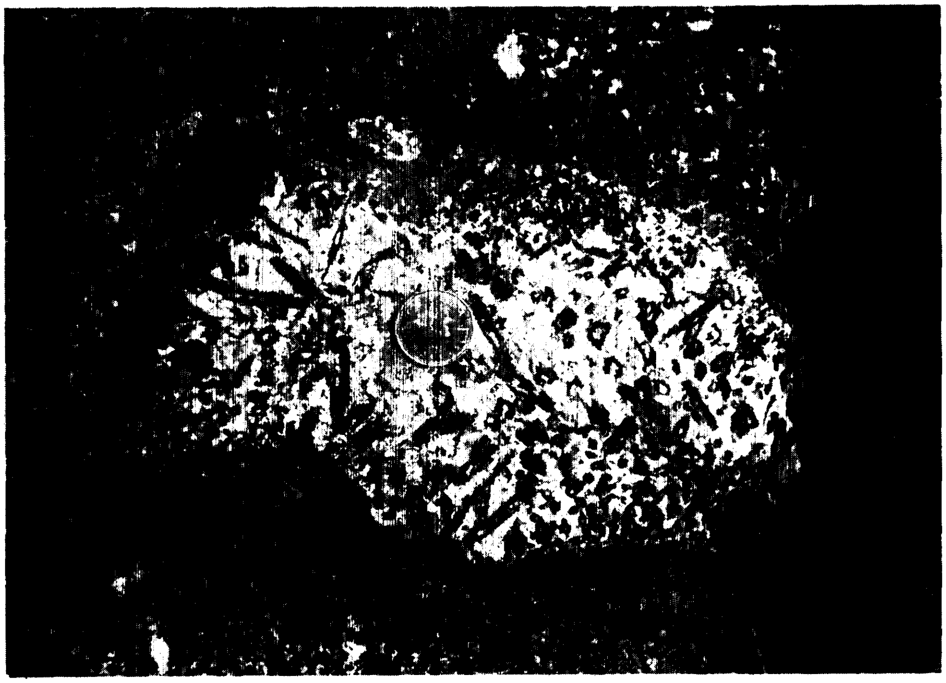

Photo 14.3. *Texture possibly indicative of magma mixing in marginal unit of Black Pic batholith. A small pod of quartz diorite with skeletal hornblende grades into gabbro. Coin diameter 2.6 cm.*

Figure 14.2, Location G), to the east of Gaugino Lake (*see* Figure 14.2, Location H) and 2 km south of Rawluk Lake, angular, metre- to centimetre-sized blocks of locally derived tonalitic, gabbroic and anorthositic material are cemented together in a granitoid matrix of unknown composition. These breccias are cut by granitic pegmatites and are considered to be late-magmatic, high-level, fluid-escape features; they do not appear to be mineralized. One of the Faries Lake area breccias is cemented by a fine- to medium-grained, tan-coloured, chlorite-amphibole rock, possibly an altered metavolcanic rock. Another breccia occurrence, north of Rawluk Lake, measures 20 by 35 m and is elongate within the regional fabric in the enclosing diorite. This breccia differs from others in having a matrix of fine-grained amphibolitic material of mafic composition.

There is no evidence to date that there is a spatial control on the composition of the tonalite suite; all members of the suite may be found throughout the area.

Where relatively undeformed, (e.g., just south of Manitouwadge Lake (*see* Figure 14.2, Location I) at the northern edge of the Black Pic batholith (Milne 1968)), intrusive relations, igneous textures and primary mineralogies are recognizable in massive to slightly foliated dioritic to tonalitic rocks. Elsewhere, the rocks in this suite are foliated to gnessic, intrusive relations are destroyed or equivocal, and metamorphic textures and mineralogies prevail. Inclusions of relatively melanocratic members of the suite occur as foliated inclusions within later, leucocratic members.

Within the Black Pic batholith, the flat-lying internal structure, quaquaversal (outward facing) dips and interleaved or sheeted nature with the surrounding and internal supracrustal rocks suggest that the tonalites are regionally developed, domal, sheeted masses. Deep levels are strongly foliated with a subhorizontal planar fabric that exhibits a poorly developed, north-trending rodding and mineral-elongation lineation, such as at Agonzon Lake. Upper structural levels of the tonalite are cut by abundant granitic sheets of pegmatite and aplite, and are more massive except where in contact with supracrustal rocks, where they attain a gneissic foliation.

The tonalite-dominated terrane to the east and south of Manitouwadge passes into the sediment-dominated terrane to the north through a zone of transition, involving sheeting of tonalite into metasedimentary migmatites. These sheets become less common northwards and most, if not all, of the tonalite suite occurs outside (i.e., to the south of the zone of granulite-facies metamorphism.

UNIT 6: GRANITIC SUITE

Cutting the tonalite suite, supracrustal rocks and their associated layered mafic intrusions are minor amounts of a granitic suite, dominated by potash feldspar, plagioclase and quartz. Apart from the Fourbay Lake pluton in the southwest portion of the region, most of these rocks are minor intrusions, represented by generally unfoliated to slightly foliated aplites and pegmatites of granitic composition. These rocks therefore post-date the main body of tonalites; however, they are sometimes affected by the regional deformation to the extent that they are folded, boudinaged and foliated, usually concordant with structures within the enclosing host.

In the far north of the area (*see* Figure 14.2, Location J), a slightly foliated granitic rock several kilometres long and of unknown north-south extent, probably sheet-like in shape, cuts the migmatitic metasediments and associated tonalites and diorites.

Sheeting, and separating metasedimentary rocks from tonalite in the western part of the region is a migmatized and slightly foliated monzonite.

UNIT 7: DIABASE DIKES

Most of the dikes are south-southeast- or north-northeast-trending, undeformed, linear structures containing a dark grey, brown-weathering, medium- to coarse-grained, sometimes feldspar-porphyritic diabase. Insufficient data exist to determine which dike orientation is older.

One outcrop on the main Manitouwadge–Hemlo road (*see* Figure 14.2, Location K) is unique for the presence of curved joints in an otherwise undeformed diabase. The joints occur in sets of shallow west-plunging non-cylindrical cones and so may be the result of compression directed orthogonally across the dike contact.

STRUCTURAL GEOLOGY

Bedding has not been uneqivocally recognized in the metasedimentary migmatites. Similarly, within the Manitouwadge synform and the outlying supracrustal rocks, there is a general lack of primary igneous and sedimentary structures. This is significant, for it distinguishes the Manitouwadge area from larger greenstone belts that typically exhibit well-preserved primary structures.

D_1 AND D_2 STRUCTURES

A pervasive fabric (S_2), defined by compositional layering, migmatitic veining, and schistosity (Figure 14.3a), is the result of a second phase of deformation (D_2) (Table 14.1). It is best preserved, undeformed by later structures, in a large area north of the Manitouwadge synform. An earlier phase of deformation (D_1) produced isoclinal folds of a previous layering (S_1) and an associated lineation (L_1) that is rarely preserved. D_1 folds in the migmatitic metasediments are preserved within rare refolded folds (Photo 14.4) which exhibit folded lineations that cut acutely across the D_2 hinge lines. D_1 structures are rare because they have been almost completely re-

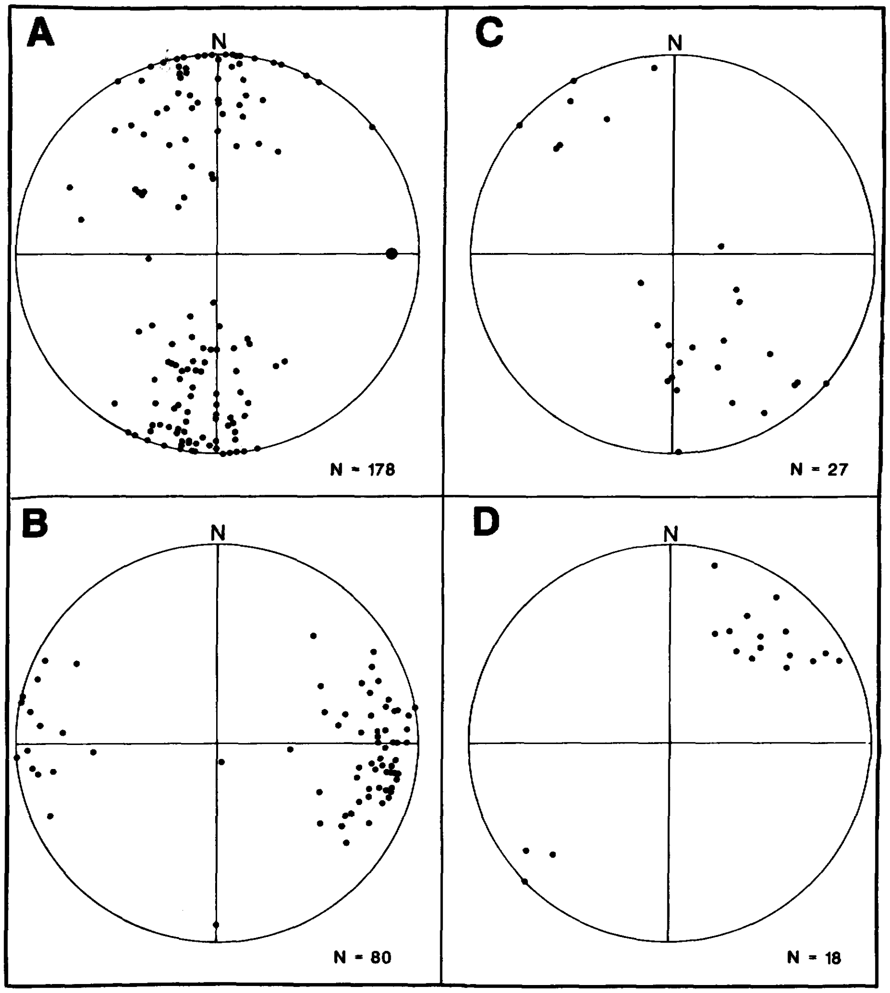

Figure 14.3. *Schmidt equal area plots of planar S_2 and linear L_2 data, a) schistosity and gneissic foliation, large data spot denotes calculated regional fold axis, and b) mineral and extensional lineations, northern Manitouwadge area, where re-oriented by D_3; c) schistosity and gneissic foliation, and d) mineral and extensional lineations associated with D_5, Nama Creek area.*

oriented by the D_2 deformation which is represented by mesoscopic, shallow easterly to westerly plunging isoclinal folds, and a regionally developed rodding lineation and biotite elongation (L_2) (Figure 14.3b) in the metasedimentary terrane. The shallow plunging style of D_2 is probably not original; it has been reworked by a regionally developed ductile shear deformation (D_3) that exhibits dextral kinematics. In tonalite-dominated terrane, where D_3 reworking is less intense, D_2 rodding plunges generally to the northeast to north-northeast and is developed on shallowly to moderately north-dipping foliation surfaces.

D_3 STRUCTURES

D_2 fabrics are clearly deformed within the Manitouwadge synform (Figures 14.4a and b) and in other D_3 structures such as those around Emerald and Moshkinabi lakes (*see* Figure 14.4c and d; Table 14.1). However, D_2 fabrics have largely been re-oriented in the migmatitic metasedimentary terrane to the north. Map patterns of D_3 folds at the tonalite-supracrustal rock interface indicate the curvature of D_3 fold traces, when traced northwards, become parallel with the regional structure in the metasedimentary terrane.

In both the Manitouwadge and Moshkinabi fold structures, L_2 rodding and fold axis lineations are slightly dispersed by the D_3 folding around northeasterly, shallowly plunging axes. In shallowly north-dipping rocks, pervasive L_2 rodding and D_3 fold axes are nearly parallel, making it appear that the rodding formed during the D_3 deformation episode. D_3 strain is manifested in the central part of the region as northeast- to east-northeast-trending, kilometre-scale, Z-style, asymmetric folds such as the Manitouwadge synform, and is caused by a regional dextral shear couple, acting on originally moderately to shallowly north-dipping foliation surfaces. This same couple caused dextral-sense asymmetry and

TABLE 14.1. STAGES OF DEFORMATION, THEIR FABRICS, CHARACTER AND ORIENTATION, FOR THE MANITOUWADGE REGION.

Stage	
D_1	Poorly preserved in metasedimentary terrane as earliest recognizable layering, not seen in tonalite terrane, no orientation known, developed S_1 and L_1.
D_2	Regionally developed schistosity, migmatitic leucosome and axial planar fabric S_2 in supracrustals, differentiated layering and schistosity in tonalites. S_2 and associated L_2 were originally developed as moderately north-dipping foliation and north-northeasterly plunging lineation respectively. Structural facing of D_2 folds in metasediments unknown because D_1 previously obliterated bedding.
D_3	Inhomogeneously developed folds and fabrics. Major D_3 folds such as the Manitouwadge and Emerald-Moshkinabi Lake synforms have shallow to moderate, east-northeast to northeast-plunging axes that deform S_2 and L_2 fabrics. These folds curve clockwise northwards and become parallel with easterly trending metasedimentary migmatite terrane; D_2 fabrics in metasediments are redeformed by D_3 structures, S_2 becoming steeply dipping and L_2, shallowly east- or west-plunging.
D_4	Inhomogeneously developed easterly trending shear zones associated with micaceous rocks within the south limb of the Manitouwadge synform. Steeply west-plunging Z folds, asymmetric boudinage and extensional crenulation fabrics indicate localized dextral simple shear with sub-horizontal transport direction.
D_5	Inhomogeneously developed northeast-trending sinistral shear zones, particularly on the northwest edge of the Manitouwadge synform, producing sub-horizontally plunging L_5 lineations and steeply to vertically dipping S_5 planar banding in gneisses and schists. Relationship to other deformation stages in doubt.

Photo 14.4. *Isoclinally refolded D_1 fold in migmatitic metasediments near Poppy Lake. Coin diameter 2.6 cm.*

development or re-orientation of rodding and D_2 fold axes into a shallowly plunging attitude on the predominantly vertical to steeply north-dipping S_2 foliation in the migmatitic metasediments to the north of the tonalite-dominated region.

Areas close to the hinge zones of the D_3 regional-scale folds, delineated by mafic supracrustal and associated anorthositic rocks, characteristically display a strong and nearly constant elongation of minerals and small-scale fold axes in association with locally variable, but weakly developed, foliation orientations. Some of the rocks in these hinge zone areas are characterized by the display of little or no foliation, but have a marked lineation such as around Emerald Lake (*see* Figure 14.2, Location L). These L-tectonites occur sporadically throughout the area, and are considered to be the result of near orthogonal superimposition of two shear strains in fold hinge zones, a useful mapping tool in complex areas.

D_4 STRUCTURES

A broad zone of asymmetric, Z-style folds (D_4) and associated extensional crenulation fabrics on a metre to centimetre scale occurs in the northern half of the area, especially close to the contact between metasedimentary migmatites and the tonalite-supracrustal domain to the south (*see* Table 14.1). D_4 structures represent evidence for dextral shearing not seen in the foliated tonalites to the south of the metasedimentary rocks.

A local zone of D_4 deformation occurs along the southern limb of the Manitouwadge synform, centred on the ore zone where highly altered, micaceous rocks have focussed strain and disrupted ore bodies already strained and re-oriented by preceding deformations. There, steeply west-plunging, asymmetric, Z-style D_4 folds fold the S_2 foliation and distort the L_2 rodding lineation. Increasing amounts of D_4 deformation, like that of D_3, have the effect of rotating L_2 lineations towards a more shallow east-plunging orientation.

SINISTRAL SHEARS (D_5 ?)

Sinistral shears on an outcrop to regional scale deflect the S_2 fabric. Their effect on D_3 structures is equivocal: one such shear zone forms the northwest

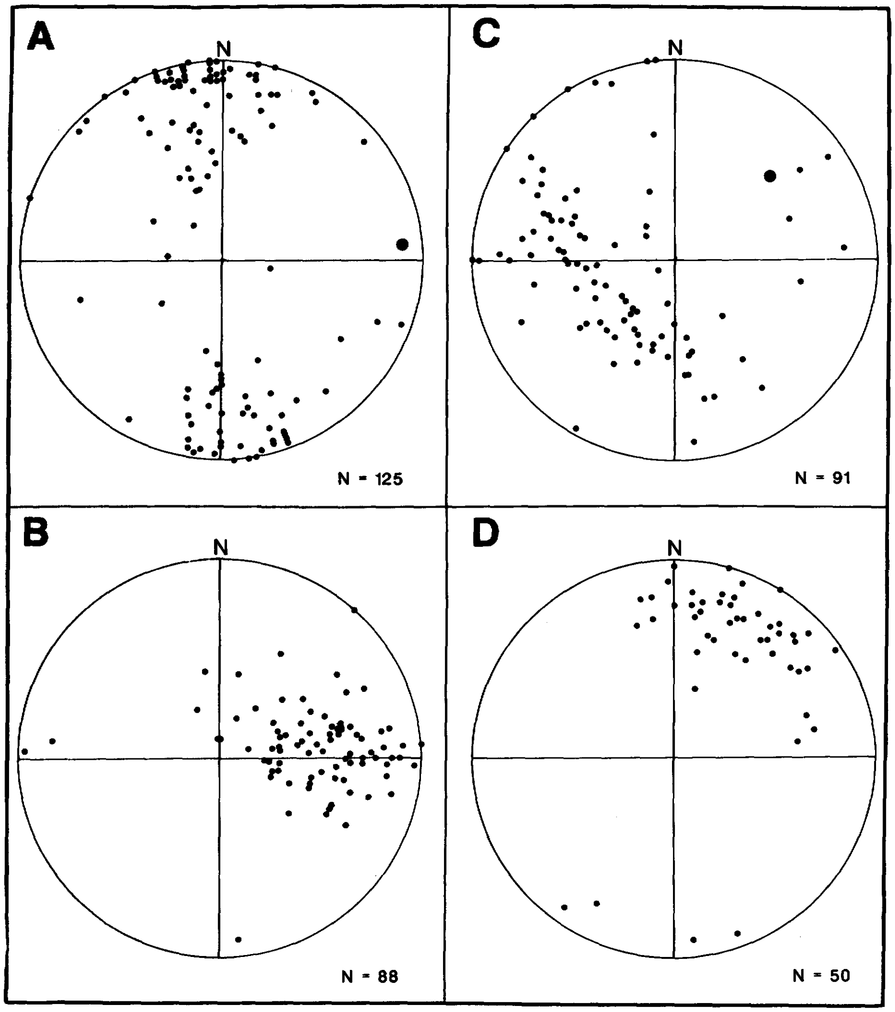

Figure 14.4. *Schmidt equal area plots of planar D_2 and linear L_2 data, a) schistosity and gneissic foliation, and b) mineral and extensional lineations, Manitouwadge synform; c) schistosity and gneissic foliation, and d) mineral and extensional lineations, Moshkinabi Lake area. Large data spots denote calculated regional D_3 fold axes.*

boundary of the Manitouwadge synform (*see* Figure 14.2, Location M) and extends into the area to the southwest. There, around Nama Creek, steeply dipping, northeast-trending, strongly foliated, amphibole-bearing gneisses and outcrop- to metre-scale shear zones are evidence of strong deformation that is not seen on the east side of the synform (*see* Figure 14.3c and d). Kinematic indicators suggest a sinistral sense of displacement with a shallowly plunging transport direction. Although ascribed to a D_5 stage, they may be synchronous with and complementary to D_3 or D_4 (*see* Table 14.1).

STRUCTURAL RELATIONS AROUND THE MINE SITE AT GECO

Eastward plunging rodding and mineral elongation lineations developed in both the "hanging wall" and "footwall" rocks become less steeply plunging towards the ore zone. The similarity between the rodding near the ore zone, and that observed regionally implies that the sulphide bodies in the ore zone have been subjected to intense strain, becoming elongate along steep to moderately eastward plunging axes.

In the Geco and Willroy ore zones, abundant, steeply west-plunging, asymmetric Z-style folds, when viewed on horizontal surfaces, have the appearance of kinks. These, and associated extensional shears and crenulations, rotated boudinage and fish structures attest to the development of a dextral simple shear regime. The relative timing of the Z-style folds was during or after the formation of muscovite, after the production of much quartz veining and after the D_2 deformation that produced the ore rodding.

In Mose Lake (*see* Figure 14.2, Location N), the abundance of Z folds increases to the north, towards the ore zone; in addition the steep easterly plunging L_2 lineation in mafic rocks clearly becomes shallower. The L_2 rodding here, and at equivalent exposures close to the ore zone, displays a variation in plunge, ascribed in part to the effects of D_3 deformation (Figure 14.3b) and to differential rotation during a subsequent period of simple shear D_4.

SIGNIFICANCE OF DEFORMATION

The high state of deformation recorded everywhere in supracrustal rocks, both within the Manitouwadge synform and in screens within the tonalite terrane, suggests that the observed stratigraphic ordering and complexity is secondary. The succession of mafic, felsic and sedimentary rocks must have been modified by ductile strain and repeated by folding and perhaps thrusting. Any anticipated correspondence between the present stratigraphy and volcanogenic models is purely fortuitous and is unlikely to be a reliable exploration tool.

The original, pre-deformation distribution of sulphide units within the complex area of the ore zone is not yet fully understood.

Recognition of regional stratigraphic facing within the Manitouwadge synform from observation of one local pillow top (Pye 1960), and on sporadic and usually spurious grading within thinly laminated, highly deformed volcanics and sediments is unwise. The zonation of copper and zinc in the highly deformed ore bodies has also been used as a top indicator (Friesen et al. 1982), but given the structural state of the ore bodies, this too, needs further work.

There is every indication that the supracrustal rocks and the tonalites have undergone much the same styles and orientations of deformation. Supracrustal rocks and associated igneous complexes are generally more deformed than the host tonalite, having undergone a deformation episode prior to tonalite intrusion.

Early stages in the deformation history (D_1 and D_2) elongated and disrupted the sulphide orebodies, whatever their mode of origin. The near-parallelism of D_2 and D_3 fold axes, the regional asymmetry of the Manitouwadge synform and companion D_3 structures and their orientation relative to the subprovince margin, combined with outcrop evidence for dextral-sense ductile shear, allows the hypothesis that D_2 and D_3, although locally exhibiting discrete structural characters, were part of a transpressional continuum that culminated in the focussing of strain at a late stage in the D_4 shear zones (cf. Percival and Williams 1989). D_3 deformation reoriented already deformed ore into a series of near vertical, east plunging bodies. D_4 deformation developed as narrow, brittle-ductile dextral shear systems within the ore zone and its associated micaceous rocks, disrupting it further.

DISTRIBUTION AND CHARACTER OF METAMORPHISM

Amphibolite- and granulite-facies metamorphic rocks have been recognized; their distribution is probably related to tectonic thickening processes rather than proximity to local heat sources.

Relatively well-preserved metasediments occur in a particularly large screen between two masses of tonalite to the southwest of Mooseskull Lake, but even these contain garnet and cordierite in quartzofeldspathic veins.

A lensoid belt of granulite-facies metasedimentary migmatites up to 10 km wide occurs in a generally easterly trending zone north of the tonalites, (e.g., west of Poppy Lake; *see* Figure 14.2, Location P). A "knotty pine" aeromagnetic signature, characteristic of metasedimentary granulites, is largely coincident with this high-grade zone, where metamorphic reactions have produced magnetite. North of the granulites, magnetic relief is relatively insignificant.

Orthopyroxene has been recognized in metasedimentary granulites as far east as Upper Flanders Lake, but not as far west as the Caramat Road. Extension of granulite-facies conditions further east to Hornpayne, on the basis of aeromagnetic signature, was not complimented by the presence of orthopyroxene in tonalites or metasedimentary rocks; perhaps granulites occur at shallow depths in this region.

ALTERATION AND MINERALIZATION

Alteration of mafic "footwall" rocks to the north of the ore zone at the Geco mine site has produced much garnet and cordierite, along with aluminous amphiboles. "Hanging wall" rocks are also altered, producing rocks enriched in silica, potash and alumina. These two alteration patterns are complementary, loss of alkalis in the "footwall" being matched by the growth of muscovite in the "hanging wall". Most rocks, both above and below the ore zone, appear to be enriched in alumina.

Alteration of mafic metavolcanic rocks also occurs west of Swill Lake, within the core, and along the northwestern boundary, of the Manitouwadge synform at Nama Creek.

The most extensive alteration outside the Manitouwadge synform occurs in the Faries Lake complex (*see* Figure 14.2, Location O). A 50 m wide chlorite-muscovite-garnet-anthophyllite zone, having a strike length of at least 450 m, is situated on a Geco Mines Ltd. claim block approximately 1 km west of Rawluk Lake (Greg Charlton, Geco Mines Ltd., personal communication, 1989). This zone broadly overprints a contact between anorthositic rocks and mafic metavolcanics. The zone developed during two stages.

The first alteration stage formed a syn-deformational chlorite-muscovite assemblage in a folded, anastomosing veinlet system contained in a highly altered anorthosite host. Fold axes and a weakly developed mineral lineation on vein surfaces are concordant with D_2 linear elements present in the immediate surroundings.

A second alteration stage produced anthophyllite-bearing assemblages consisting of randomly oriented, coarse-grained, nearly monomineralic aggregates of anthophyllite and minor plagioclase; these cut the chlorite-bearing assemblage. Anthophyllite-bearing alteration assemblages developed during a static, annealing metamorphism and apparently occurred preferentially in mafic metavolcanics, where coexistence of anthophyllite with medium- to coarse-grained red garnet is common. Towards the margin of the alteration zone, veins and ovoid patches contain anthophyllite-garnet-hornblende-plagioclase in a mafic metavolcanic host. Disseminated pyrite occurs locally within the altered mafic metavolcanics.

The timing of the earlier alteration with respect to volcanism is known only in a relative sense; it developed after the emplacement of anorthosite, but prior to D_2 deformation.

Alteration also occurs within mafic metavolcanic screens that lie within dominantly tonalitic terrane, such as that seen between Rabbitskin and Dead lakes. Some of these rocks are extremely garnetiferous and rich in magnetite.

CONCLUSIONS AND PRELIMINARY RECOMMENDATIONS

1. Many of the magnetic anomalies in the northern portion of the area are represented by magnetic, granulite-facies, metasedimentary migmatites and associated dioritic intrusions. Some of these relatively melanocratic and magnetic rocks had been considered to be of mafic metavolcanic origin (Giguere 1972).
2. The supracrustal stratigraphy of the Manitouwadge synform decreases in thickness away from the synform, ultimately becoming no more than discontinuous screens of mafic rocks within extensive areas of foliated to gneissic tonalites.
3. Intermediate to felsic rocks of volcanic origin occur within the Manitouwadge synform; they may also be present within outlying parts of the mafic supracrustal screens. The high deformation state of rocks in these thin supracrustal units makes positive identification of protoliths difficult.
4. Within the thin mafic metavolcanic rocks that form screens in the tonalite terrane, well-preserved layered mafic intrusions exhibit compositional layering from peridotitic bases to anorthositic tops. Exploration for copper, nickel and platinum group elements is warranted within the Faries Lake and Moshkinabi Lake mafic layered complexes. We are aware of only limited copper exploration, specifically in the Moshkinabi Lake mass (Giguere 1972).
5. No primary sedimentary or volcanic structures in the supracrustal rocks can be used to determine the local younging direction in the Manitouwadge synform. High strain state, decimetre- to outcrop-scale isoclinal folding, ubiquitous planar and linear fabric formation and intense alteration have effectively removed or obliterated primary structures, or rendered them unreliable as stratigraphic younging criteria.
6. Other examples of the alteration style seen in the "footwall" of the Geco deposit, involving formation of abundant garnet in mafic rocks and the production of aluminous assemblages, have been located in a few isolated areas within or close to the Manitouwadge synform. Some of these zones of alteration are associated with lithologic contacts of mafic volcanic with either overlying felsic volcanic rocks, or with anorthositic rocks. In the Geco–Willroy ore zone, the lithologic sequence and its attendant sulphide-bearing lenses have been highly strained; the ore zone(s) is unlikely to have escaped modification by both folding and thrusting during this process.

ACKNOWLEDGMENTS

Good-humoured and capable assistance from Peter Campbell contributed to the smooth operation of this project. An introduction to the local geology and access to unpublished information was facilitated by Hugh Lockwood and Greg Charlton of Noranda Inc., Geco Division. The help of Mark Smyk, Staff Geologist for the Schreiber–Hemlo Resident Geologist's District, is gratefully acknowledged. The Ministry of Natural Resources is thanked for making staff-house facilities available.

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15. Project Unit 83-50. Geology of the Hemlo Deposit Area: A Tectono–stratigraphic Study

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INTRODUCTION

This year marked the final season of field work in a program to provide comprehensive documentation of the bedrock geology in the area encompassing the Hemlo deposit. Previous summaries of field work for this project have been released as Muir (1985, 1986, 1988) and Muir and Elliott (1987). The two months spent in the field this season led to coverage of irregularly shaped areas totalling approximately 10 km^2, almost entirely within Bomby Township. These areas included parts of the Hemlo deposit and its environs, and are centred about 35 km east of Marathon (Figure 15.1). General mapping was undertaken at a scale of 1:5000 with more detailed mapping of selected, stripped areas and outcrops at scales of 1:1000, 1:500 and 1:200.

The main purposes of this season's work were to map areas between previously mapped sections; resolve problems revealed by previous mapping; and extend mapping of the area to the west of previously mapped limits, north and south of Highway 17, to include at least all existing stripped sections on the Golden Sceptre property. In addition, a detailed map was made of a recently exposed outcrop of part of the "C Zone" on the Williams Mine property.

GENERAL GEOLOGY

WESTERN PART OF THE MAP AREA, NORTH OF HIGHWAY 17

This area extends from the boundary between the Williams Mine property (Williams Operating Corporation) and the Golden Sceptre property (Hemlo Gold Mines Inc.) to slightly beyond Botham Lake, and north for about 1.5 km from Highway 17 (Figure 15.2). All units in the area dip to the north. A section (mapped mainly from stripped exploration zones) across this area, east of Botham Lake, comprises, from south to north:

a. highly deformed (flattened, sheared), locally pillowed, locally gneissic, mafic tholeiites near the suspected Hemlo fault (Highway 17)
b. heterogeneously deformed (folded (locally at least three phases), transposed, sheared) metasediments consisting of wacke, arenite, siltstone, magnetite ironstone and distinctive conglomerate
c. variably deformed and altered, pillowed, mafic tholeiites
d. pyroclastic (volcaniclastic?), intermediate to felsic, plagioclase- and/or quartz-phyric deposits

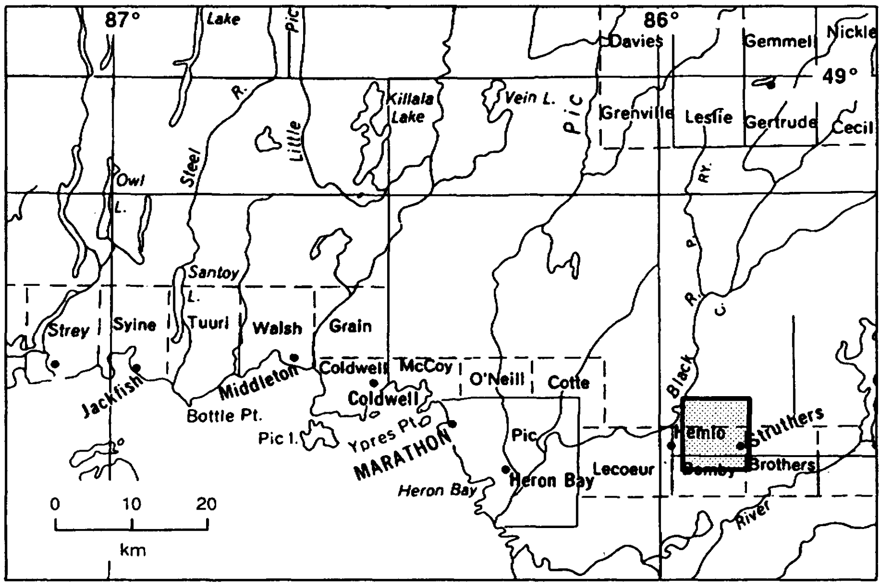


Figure 15.1. *Location map of the Hemlo deposit area.*

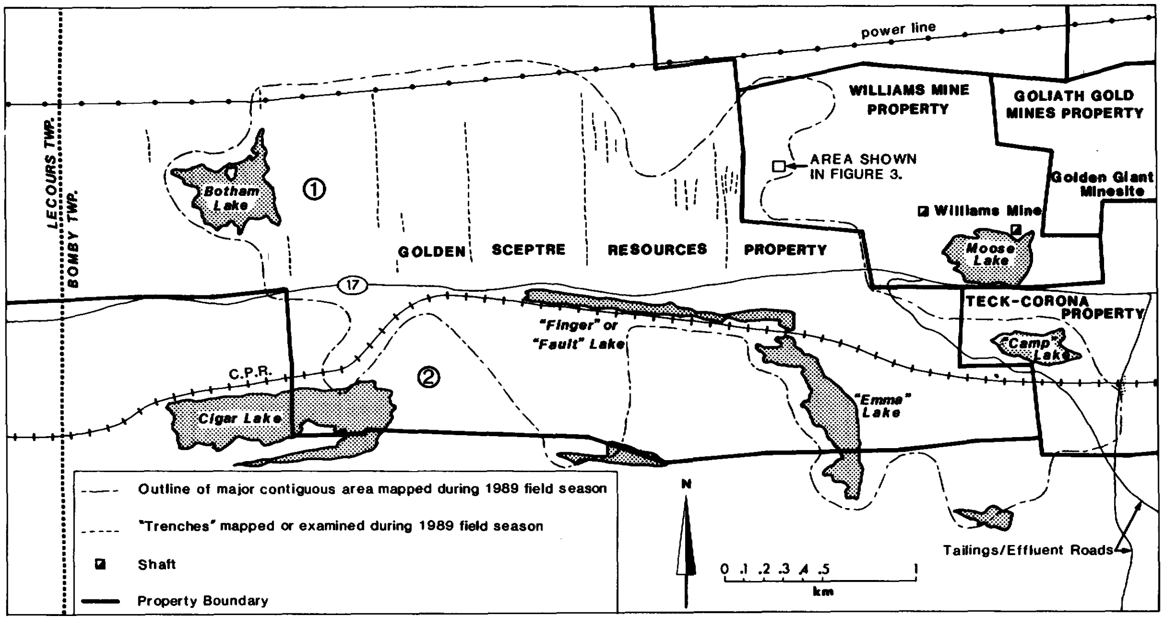


Figure 15.2. *Location of the three areas of mapping this season:*
1. *western part of the map area, north of Highway 17*
2. *western part of the map area, south of Highway 17*
3. *detailed mapping—Williams Mine property: C Zone*

e. volcaniclastic (i.e., reworked, unconsolidated material) deposits of the pyroclastic material which is rhythmically layered (bedded) locally

f. epiclastic (chemically and/or mechanically eroded material from lithified sources) deposits such as wacke and siltstone, with grading locally preserved, which, together with cleavage relationships, provide evidence of large- and medium-scale F_2 folding

The pillowed unit in "a" changes eastward along strike into gneissic amphibolite. The magnetite ironstone units in "b" can be traced more or less continuously to the east for about 3 km. Near the Hemlo fault, the metasediments are highly transposed and/or sheared and locally contain staurolite, garnet and possibly andalusite. The pillowed unit in "c", with top directions locally appearing southward (i.e., overturned), pinches out within a few hundred metres to the east. Westward, it appears to form a more or less continuous unit at least to Lake Superior (almost 30 km strike length). About 1 km northwest of Botham Lake lies another(?) unit of pillowed mafic tholeiites which locally appear to be silicified.

The rocks of "d" are complexly layered (primary and/or tectonic) and display apparent sequences of felsic arenites ("tuffs") and conglomerates ("lapilli tuffs", "lapilli stones", "tuff breccias"). The coarser and finer deposits continue westward at least into Lecours Township, about 1 km west of Botham Lake, and are associated with felsic, plagioclase-phyric rocks which do not display obvious primary layering and may represent a thick flow(s) or hypabyssal intrusion(s). To the east, the rocks of "d" display more and coarser varieties of fragmental rocks and are associated locally with felsic, plagioclase + quartz-phyric rocks, which also display no obvious primary layering.

The rocks of "e" are possible turbidite units and appear to be locally interbedded with epiclastic units of similar depositional mode. The rocks of unit "f" are, for all intents and purposes, the same as the turbiditic wackes and siltstones that are found at Highway 17 near Cedar Creek, about 6 km to the east.

It is apparent from mapping sections through the Hemlo area and from examining outcrop-scale features that a simple "layer-cake stratigraphy" is not present on a scale of metres to tens of metres. The geological section described above is no exception. Evidence from outcrops (e.g., *see* section on Williams Mine property "C Zone") reveals numerous examples of tight to isoclinal folds (some intrafolial), strike-parallel to near-parallel faults, dislocated fold limbs, moderate to strong alteration which locally has considerably changed the original composition of the rocks, and ductile shear with later still brittle-ductile faults and still later brittle faults. An example of this sequential faulting is found in the vicinity of Botham Lake where substantial fracturing and cataclastic brecciation are associated with extensive hematization, local calcite $\pm$ quartz veining, and rebrecciation.

On a larger scale, however, there is an apparent continuity to the stratigraphy. This is evident from the distribution of the mafic volcanic rocks, turbiditic wackes and siltstones, and the felsic, clastic and/or fragmental units from one part of the map area to another.

WESTERN PART OF THE MAP AREA, SOUTH OF HIGHWAY 17

This area extends westerly from the tailings roads, roughly south of Moose Lake to Cigar Lake and south from Highway 17 for up to 1 km (Figure 15.2). The exposure in much of this area is sparse and there is no exploration stripping. These two factors combine to reduce the detail that can be obtained, and as such, less time was spent here. Some of the best exposures are on the shore of "Emma" Lake. A section across this part of the area comprises, from north to south:

a. locally gneissic, locally pillowed, mafic tholeiites as in "a" above
b. intermediate to locally felsic, fine-grained, volcaniclastic deposits, commonly with relatively inconspicuous layering, and locally interbedded(?) with staurolite-garnet-bearing metasediments
c. intermediate volcaniclastic and/or pyroclastic deposits (fine- to medium-size clasts/fragments) with plagioclase $\pm$ quartz phenoclasts/phenocrysts
d. medium to coarse, intermediate, somewhat polymictic/heterolithic, volcaniclastic/pyroclastic rocks which have been moderately to highly deformed (flattened, stretched) and locally appear gneissic
e. epiclastic wackes and local siltstones which are variably schistose
f. deformed mafic rocks presumably of volcanic origin
g. more wackes

The rocks of "b" may extend eastward to become the feldspathic volcaniclastics (see Muir 1988) in the vicinity of the tailings roads, where they are better exposed. The rocks of "c" do not seem to continue eastward. The fragmental rocks of "d" were not identified to the east but outcrops on "Emma" Lake show that what appear to be fragmental rocks in the horizontal dimension appear to be gneissic in the vertical dimension. A change in the orientation of elongation lineations in the rocks from one area to the other might explain the tendency towards a more gneissic appearance in the east, where shallow easterly plunges are found. Rocks of "e", "f" and "g" do not appear to continue to the east as consistent units. The mafic units that border the Pukaskwa gneissic complex to the south (Muir 1988) were not encountered in the limited section completed here.

There are similarities and differences between lithologies north and south of the Hemlo fault (which is roughly coincident with Highway 17). However, the differences may be sufficiently significant to consider the fault to be a major structural break. This possibility is supported by the limited available geochronological data, which indicate significant differences in the ages of interpreted volcanic rocks at Hemlo and at Heron Bay, which lies about 35 km to the west (Corfu and Muir 1989a). Furthermore, somewhat equivocal indications, found during the course of the project, suggest that the terrain north of the fault largely faces south and is overturned (e.g., Muir 1985). Although no reliable younging directions have been noted south of the Hemlo fault, it is possible that younging directions are to the north, if the mafic rocks adjacent to the Pukaskwa gneissic complex are the lowest in the supracrustal sequence. In any case, the geochronological results and younging directions indicate that more detailed work is required to substantiate the presence of a major structural break.

DETAILED MAPPING—WILLIAMS MINE PROPERTY: C ZONE

During the summer, an area of rock about 40 m by 40 m within the "C Zone" was cleaned by some of the Williams Mine staff. A cursory examination of this outcrop indicated several features of geological interest pertinent to many of the perplexing problems regarding the history of the Hemlo deposit. As such, detailed mapping of the outcrop was undertaken (Figure 15.3) in order to complement the previous detailed mapping done for this project (*see* Muir 1986, 1988).

The outcrop consists of folded, ductilely sheared, brittly faulted, and altered units of

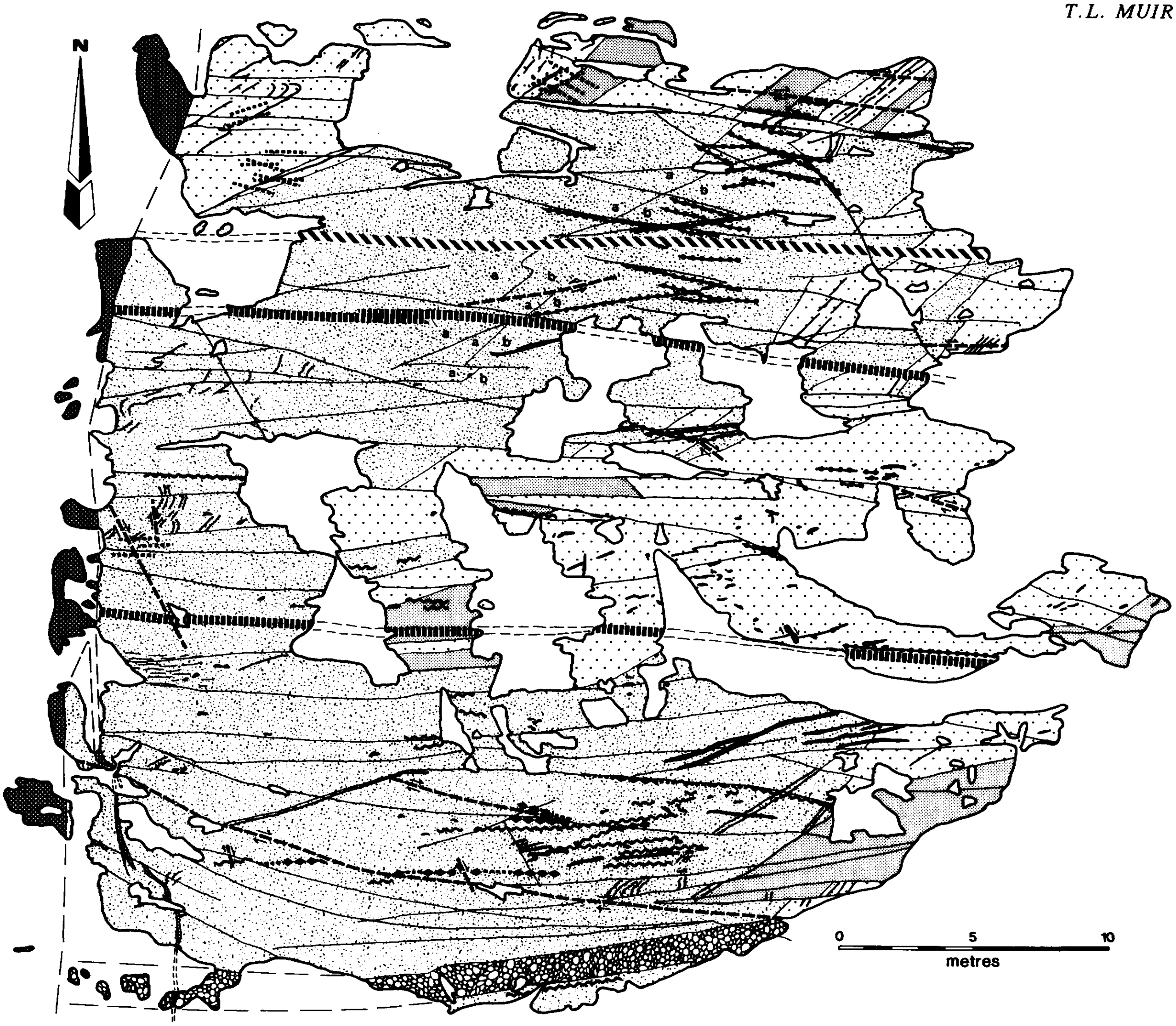
a. plagioclase + quartz-phyric fragmental rocks consisting of heterolithic lapilli stone and pyroclastic breccia
b. relatively monolithic lapilli tuff, and
c. volcaniclastic and/or epiclastic sediments

Several east-striking dikes of intermediate to felsic composition have intruded these units, as has a Late Precambrian to Early Proterozoic, subalkalic diabase dike.

Alteration is pervasive but variably distributed. Feldspathization and biotitization are most common. Moderate carbonatization with associated chloritization is locally present but nonetheless extensive in this outcrop.

Mesoscopic mineralization consists of molybdenum-bearing, feldspathized and/or silicified rocks, and pyritized feldspathized rocks which are present as tabular, vein-like zones less than 3 cm thick. The zones strike at about 270° and 290°, are oblique to the layering (bedding) in the units which, because of folding, strikes from 235° to 260°, and are themselves dextrally offset along discrete shears at about 300°.

The style of folding and offsetting of limb stratigraphy displayed in this outcrop have been noted



LEGEND

Overburden

DIKES, VEINS

Diabase

INTRUSIVE CONTACT

Quartz veins, stringers, knots

Biotite gabbro

Plagioclase porphyry

Granodiorite

INTRUSIVE CONTACT

Fragmental rocks (pyroclastic, volcaniclastic)
- a coarse
- b medium to fine

Granule to pebble conglomerate

Wacke

SYMBOLS

ALTERATION (vein-like)

Feldspathization (and/or silicification?)

Silicification, molybdenite

Feldspathization, pyrite (± Au?)

Iron carbonate

FAULTS (ductile and/or brittle)

Sense of displacement known

Planar schistose zones –sense unknown

BEDDING

Internal bedding

Unit contact

Figure 15.3.

Simplified sketch map of detailed mapping of a recently exposed C Zone outcrop, Williams Mine property. Location shown in Figure 15.2.

elsewhere on a sub-metre scale. The presence of these features on a scale of up to 10 m suggests that they may also be present on a scale of tens to hundreds of metres, particularly because of the difficulties in tracing units from outcrop to outcrop throughout parts of the area. Understanding this is important in interpreting a map in such terrain.

In addition, mapping of this outcrop provides evidence that at least some stages of alteration and/or mineralization (e.g., vein-like alteration striking at 290°) are synchronous with and/or postdate the development of axial planar cleavage during regional folding of the supracrustal rocks (S_2). This corroborates relationships described in previous summaries. As there is generally a good correlation between gold and molybdenum within the Hemlo deposit, this chronological evidence may also permit a better definition of the timing of the mineralization sequence. Some limits on the timing of mineralization with respect to geochronological sampling are discussed in Corfu and Muir (1989b).

ACKNOWLEDGMENTS

The author appreciated the assistance of Jason Payne this summer, and discussions in the field with Bernie Schnieders and Mark Smyk (Ontario Ministry of Northern Development and Mines, Thunder Bay). The following are also thanked for their cooperation and helpful discussions during the field season: Al Guthrie (Williams Mine), Peter Brown (Golden Giant Mine), Paul Bankes (David Bell Mine), Doug McIlveen (Hemlo Gold Mines Inc., exploration), and Jerry Grant (MSc student, Queen's University).

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16. Synoptic Studies in the Michipicoten Greenstone Belt

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INTRODUCTION

Regional geological mapping of a large part of the Wawa area began in 1979, and was completed in 1988. Work is now proceeding towards integrating geological data with various remote sensing, geophysical and geochemical techniques to provide a model for the evolution and development of the Michipicoten supracrustal rocks.

It is hoped that this program will eventually encourage the development of a broadly based mineral-oriented economy for the Wawa area.

HISTORY

In 1976, an extensive review of the geological data base for Wawa was undertaken in preparation for a regional geological mapping program which would hopefully result in a more diversified economy for the Wawa area. Limited reconnaissance mapping was conducted in 1978, and, in 1979, regional mapping was begun at a scale of 1 inch to 1/4 mile. The target area was 12 townships within the central portion of the Michipicoten greenstone belt which resulted in three reports covering blocks of four townships each. The original project concept was to ultimately produce a synoptic report integrating the essentials of the first three reports and develop models for the evolution of the belt emphasizing potential economic development.

In 1987, the Wawa project was expanded to include three additional townships and a portion of Dunphy Township, and the production of a fourth report. By the end of 1978, a total of 15.25 townships covering an area of 1400 km^2 had been mapped (Figure 16.1).

Petrologic modelling was de-emphasized during regional mapping; this aspect was to be investigated at the synoptic level. Work towards a synoptic report was started early in 1981 with sampling for geochronological purposes.

G. McGill (McGill and Schrady 1986) of the University of Massachusetts began detailed structural studies in 1983, and Z. Arias, of Queen's University, after completing structural studies in the Goudreau area (Arias and Heather 1987) began regional geological structural studies in 1987 under an Ontario Geoscience Research Grant. In 1987, K. Heather (Heather and Arias 1987; Heather and Buck 1988; Paper 17, this volume) began studies of the ore deposits of the Wawa area with a strong emphasis on structural geology.

Aeromagnetic and electromagnetic surveys were completed in 1988 (Barlow 1987, 1988) and regional geochemical surveys have been completed by Fortescue and Stahl (1987) and Fortescue and

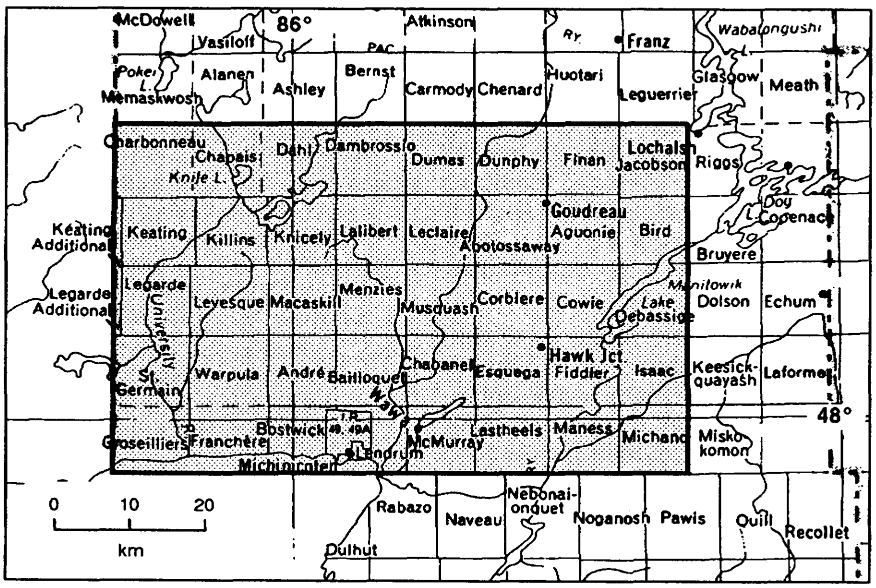

Figure 16.1. *Location map of the study area.*

Nakashima (1988). Geochemical studies are continuing (Paper 47, this volume).

An airborne survey was conducted over the Michipicoten supracrustal belt in 1987 to obtain radar data by the Radar Data Development Program of the Canada Centre for Remote Sensing, Department of Energy, Mines, and Resources, Canada (Mussakowski and Trowell 1988). In co-operation with the Ontario Centre for Remote Sensing, various digitized data sets, i.e., radar, geophysics and LANDSAT images have been combined in an attempt to identify new methods for mineral exploration (Mussakowski and Trowell 1988).

Geochronological studies begun by Turek et al. (1982, 1984, 1988) are continuing at present. Field mapping was used as a basis for geochemical sampling for petrologic modelling and was completed in 1987 and 1988.

METHODOLOGY

The recognition of complex structures in the Wawa rocks resulted in a different style of 1 inch to 1/4 mile mapping than is customary. Shoreline, stream valleys and closely spaced traverses in critical areas were emphasized during mapping, and standard 1 inch to 1/4 mile traverses given lower priority. This was done to maximize the volume of structural data, particularly facing data, to unravel the major regional structures. Rock chemistry was directed towards rock identification and providing the mineral exploration industry with a lithogeochemical base for exploration work.

Field observations were recorded on acetate overlays of 1 inch to 1/4 mile airphotos provided by the Ministry of Natural Resources and these data were transferred to cronaflex base maps.

GOALS

The principal goal of the synoptic report is to provide an integrated data base incorporating geological, geophysical, geochronological, remote sensing and geochemical information. These data cover the area mapped by the author since 1979 and incorporate regional data as required for modelling. General information on distribution, structure and alteration associated with mineral deposits is to be summarized.

A second goal of the synoptic report is to develop a model to outline the formation and evolution of the Michipicoten supracrustal rocks which hopefully will define new directions, or targets, for mineral exploration. Development of models for the formation of the Michipicoten supracrustal rocks will hopefully expand our understanding of other Archean supracrustal terranes.

It is hoped that the co-operative program between the Ontario Centre for Remote Sensing and the Ontario Geological Survey will develop new mapping techniques and produce new ideas and concepts to assist in understanding the Michipicoten Supracrustal sequences.

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17. Project Unit 89-15. The Geological and Structural Setting of Gold Mineralization in the Renabie Portion of the Missanabie–Renabie Gold District, Wawa Gold Camp, Wawa

K.B. Heather

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INTRODUCTION

This summary presents the preliminary results of the continuation in 1989 of studies designed to evaluate the metallogeny of gold within the Wawa gold camp, which comprises the Mishibishu Lake district (Heather 1985, 1986), the Michipicoten district, the Goudreau–Lochalsh district (Arias and Heather 1987; Heather and Arias 1987), and the Missanabie–Renabie district (Heather and Buck 1988). In 1989, this study focussed on the eastern portion of the Missanabie–Renabie district, in the vicinity of the Renabie gold mine. The area is located on the eastern end of the Michipicoten greenstone belt, approximately 70 km northeast of Wawa, and is accessible via Highway 651 from Highway 101 (Figure 17.1). In this area, significant gold mineralization occurs at the Renabie gold mine, which is within the Wawa domal gneiss terrane, outside but adjacent to the Michipicoten greenstone belt. The purpose of the work conducted in 1989 was to describe the geological characteristics and structural setting of this unusual auriferous system, in order to provide a more comprehensive understanding of the metallogeny of gold in the Wawa gold camp.

METHODOLOGY

Systematic collection of lithologic, structural, alteration, metamorphic and commodity occurrence data was completed during the summer of 1989 for portions of Leeson, Brackin, southern Rennie and northern Stover townships, at a scale of 1:15 840 (Figures 17.1 and 17.2). Selected areas of mechanically stripped bedrock were mapped at a scale of 1:100.

MINERAL EXPLORATION

Descriptions of past mineral exploration in the Missanabie–Renabie district can be found in Coleman (1898), Wilmott (1898), Thomson (1926), Burwash (1937), Bruce (1944), Horwood (1944), Bruce (1948), Riley (1971), Thurston et al. (1977), Bennett (1978), Srivastava and Bennett (1978), and Heather and Buck (1988).

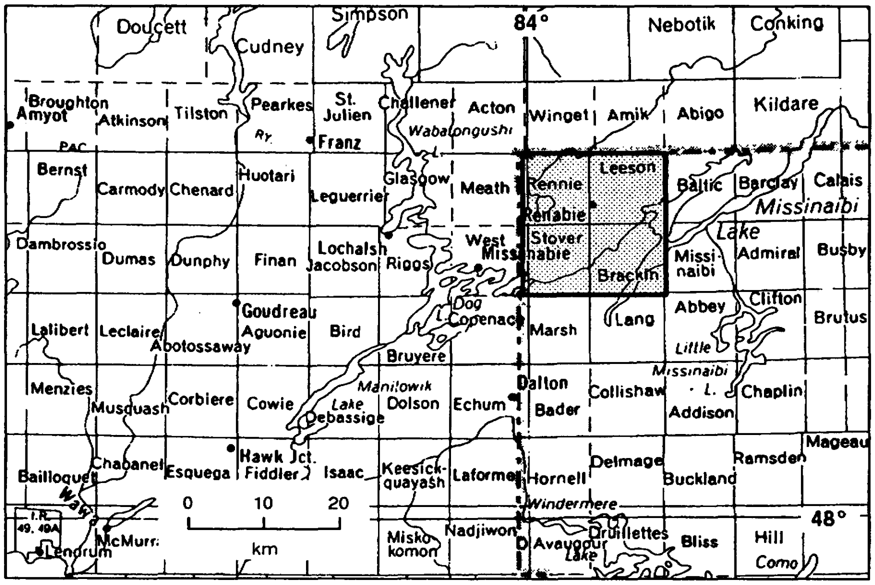

Figure 17.1. *Location map of the study area.*

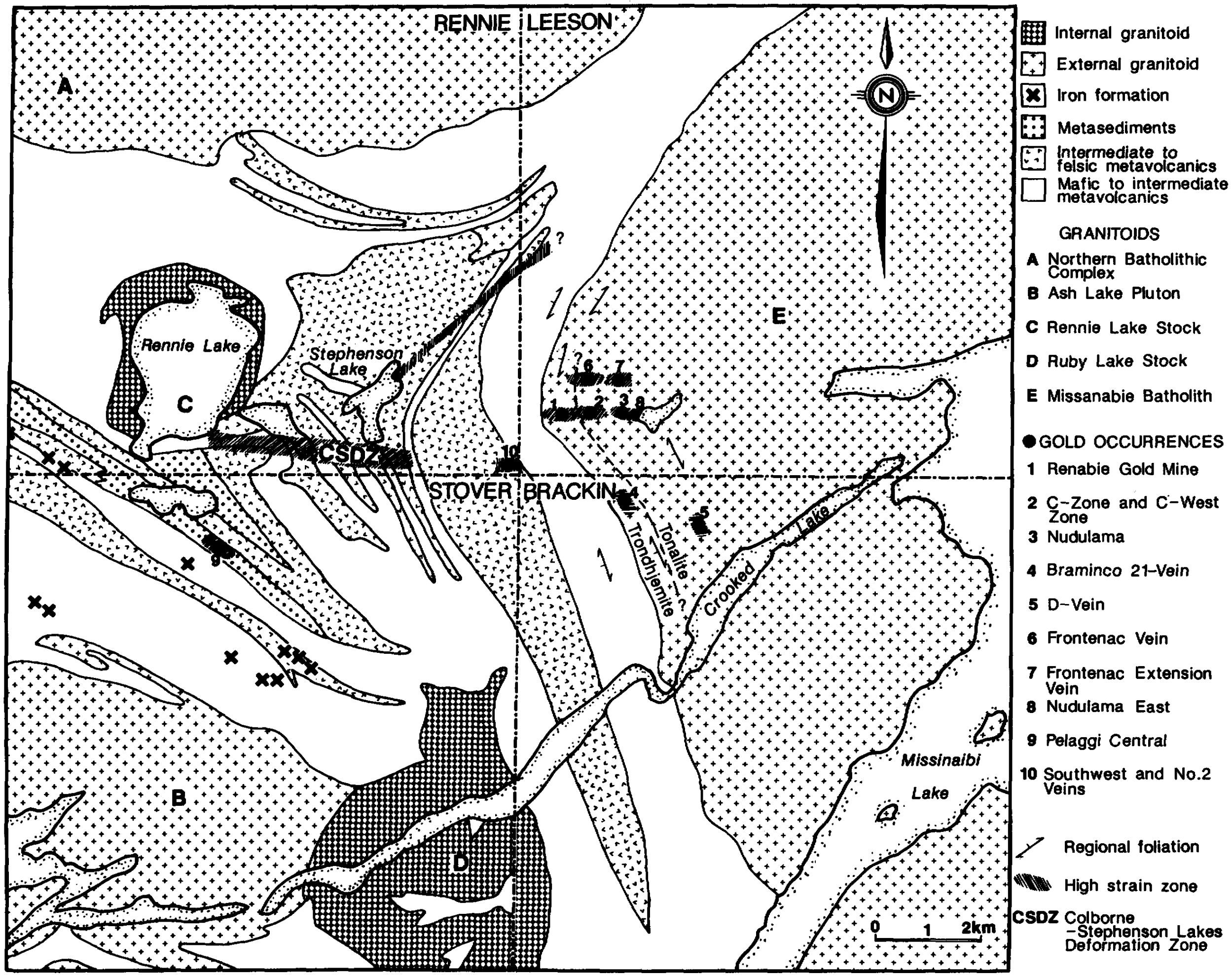

Figure 17.2. *General bedrock and structural geology for Rennie, Stover, Leeson and Brackin townships. Also included are the locations of gold occurrences discussed in the text.*

Production continues from the Renabie gold mine at a rate of 650 tons per day (F. Kurz, Renabie Gold Mines Limited, personal communication, 1989). The one millionth ounce of gold from this mine was poured in May 1989. The only exploration or development activity observed during the 1989 field work was a program of surface stripping, trenching and sampling, carried out by Renabie Gold Mines Limited on the Frontenac occurrence, the C-Zone and the Tower Zone.

GENERAL GEOLOGY

The general geology of Glasgow, Riggs, Meath, West, Rennie and Stover townships has been documented at a 1:15 840 scale by Bruce (1944), Riley (1971), Bennett (1978), and Srivastava and Bennett (1978). This work is summarized in Heather and Buck (1988). The general geology of Leeson and Brackin townships has been documented by Bruce (1944), Ferguson (1968), and Bennett (1978) and is summarized below.

MAFIC TO INTERMEDIATE METAVOLCANIC ROCKS

The western half of Brackin Township and the immediate western edge of Leeson Township are underlain by massive to locally pillowed, mafic metavolcanic flows, which may attain amphibolite metamorphic grade adjacent to the granitoids to the east (Figure 17.2).

GRANITOID INTRUSIONS

Most of Leeson Township and eastern Brackin Township are underlain by granitoid rocks which have been classified by previous workers (Bruce 1944; Ferguson 1968; Bennett 1978; Kilias 1984; Callan and Spooner 1987; Callan 1988) using a variety of classification schemes. In this study, a field-based classification consistent with that used by staff at the Renabie gold mine was adopted. This classification subdivided the granitoids into biotite- and hornblende-bearing trondhjemites and tonalites. Both Bruce (1944) and Ferguson (1968) made a distinction between a marginal zone of foliated, leucocratic granitoid rocks, referred to here as trondhjemite, and more heterogeneous, foliated to gneissic, melanocratic granitoid rocks, referred to here as tonalite (Figures 17.2 and 17.3). Both phases are dominantly biotite bearing; however, hornblende-bearing phases are locally encountered. Mafic mineral contents in the marginal trondhjemite range from 5 to 15 percent, while within the tonalite they range from 10 to 35 percent. In addition, pegmatite and several aplite dike phases were mapped.

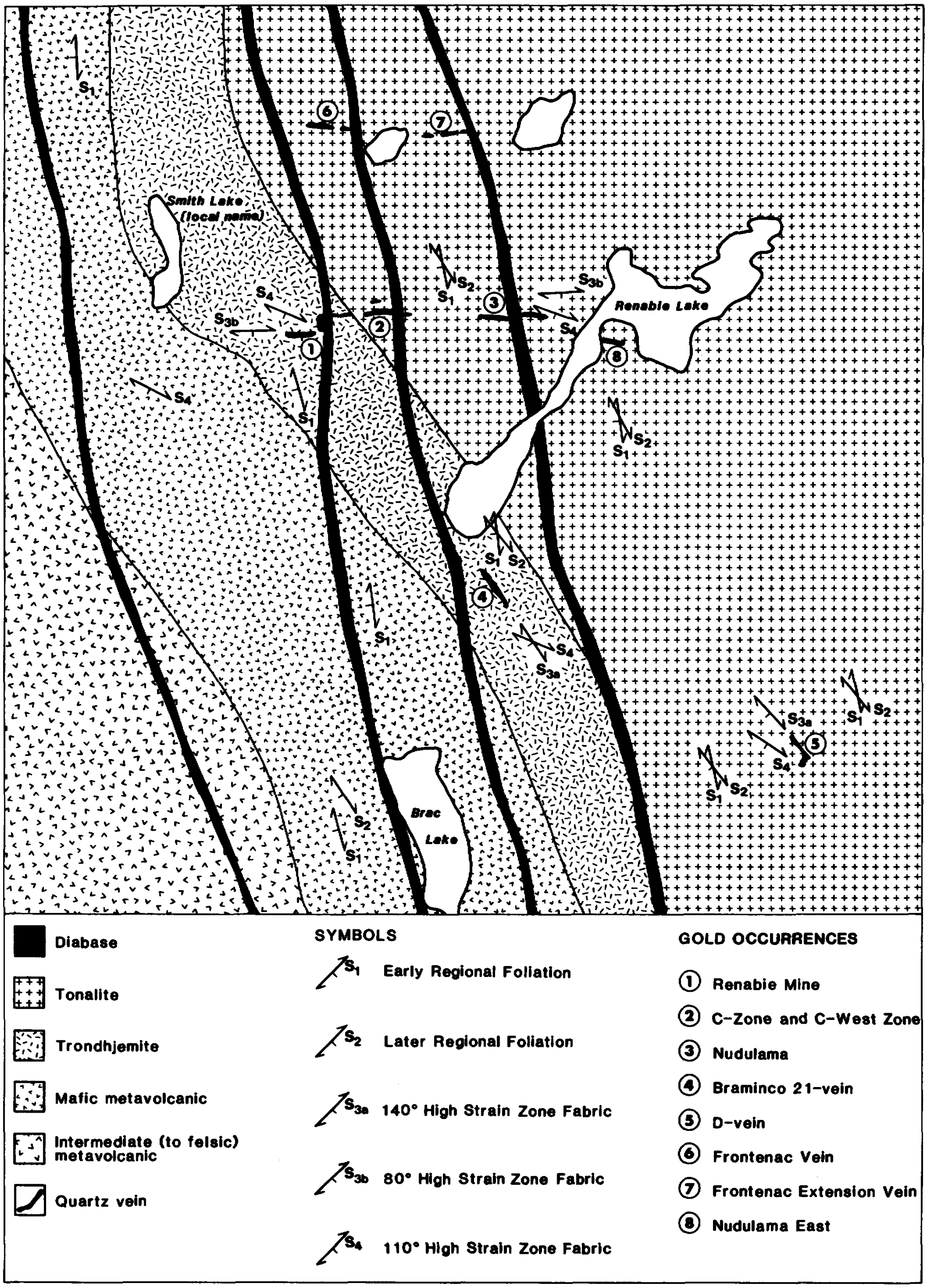

Figure 17.3. *General bedrock geology and simplified structural geology of the granitoid rocks in the vicinity of the Renabie gold mine.*

LAMPROPHYRE DIKES

Several biotite-rich dikes were identified during the course of field mapping, but, due to deformation and alteration it was difficult to determine whether they were lamprophyre or mafic dikes. They will be referred to here as "lamprophyre dikes". At least three types of lamprophyre dikes have been identified in the field. The earliest type is thought to be lamprophyric, but due to its pre- to syn-deformation age, now consists of schistose biotite and Fe-carbonate. A second lamprophyre dike locally intrudes and incorporates xenoliths of this first type of dike and other wall rock types. However, it too is pre- to syn-deformation and therefore, commonly schistose. Within the greenstone belt, these early lamprophyre dikes are roughly concordant with the 140° axial planar cleavage (e.g., Peleggi Central gold occurrence; Figures 17.2 and 17.4). The dikes commonly are foliated parallel to their contacts (i.e., 140°) and locally folded into Z-shaped folds. Within the trondhjemite-tonalite, these lamprophyre dikes are typically strongly deformed and commonly are spatially associated with the gold-mineralized zones. There is a third, late set of biotite lamprophyre dikes which crosscut all the deformation fabrics and the gold-bearing quartz veins (Bennett 1978; Callan 1988).

DIABASE DIKES

Northwest- and northeast-trending diabase dikes crosscut all rock types in the area; however, their relationship to the late biotite lamprophyre dikes is equivocal. These dikes vary from being massive and equigranular to plagioclase porphyritic (phenocrysts locally up to 15 cm long).

STRUCTURAL GEOLOGY

EARLIEST REGIONAL FOLIATION (S_1)

An early regional foliation (S_1) within the trondhjemite-tonalite granitoids is defined by the preferred orientation of pancake-shaped biotite aggregates and flattened quartz crystals. This regional foliation trends from 155° to 200° (averaging 165°) and dips moderately to steeply to the west, approximately concordant with the greenstone-granitoid contact to the west (Figures 17.2 and 17.3). Within the mafic metavolcanic rocks immediately adjacent to the granitoids, the regional foliation is defined by a penetrative schistosity approximately parallel to the greenstone-granitoid contact to the east (Figures 17.2 and 17.3).

An early set of aplite dikes is commonly seen folded about an S_1 axial planar foliation. Locally, a second set of aplite dikes intrudes parallel to the S_1 foliation and is axial planar to the folded aplite dikes. The S_1 foliation is commonly modified and rotated by later flattening and shear fabrics.

LATER REGIONAL FOLIATION (S_2)

A second regional foliation (S_2) within the trondhjemite-tonalite granitoids appears to be defined by crude, S-shaped sigmoids of the earlier flattened biotite aggregates and quartz crystals (S_1) and may represent a reflattening of S_1. The S_2 foliation strikes 155° to 135° and dips moderately to steeply to the southwest; the strike averages 145° throughout much of the trondhjemite-tonalite rocks outside zones of higher strain. The development of the S_2 foliation varies from faint to strong relative to the S_1 foliation it overprints. Generally, the overprinting relationship between the S_1 and S_2 foliations is very subtle, except where the development of the S_2 foliation is strong to intense.

EARLY HIGH STRAIN ZONES (S_{3a} and S_{3b})

Superimposed on the S_1 and S_2 foliations are zones of higher strain, characterized by the development of an intense ductile schistosity (S_{3a} and S_{3b}), which is defined by sericite, biotite, quartz and feldspar. Two prominent high strain zone orientations were mapped in the trondhjemite-tonalite granitoids (Figures 17.2 and 17.3). One (S_{3a}) strikes approximately 140° (range = 135° to 145°) and dips moderately to steeply to the southwest; the other (S_{3b}) strikes 080° (range = 075° to 085°) and dips moderately to steeply to the south. These discrete high strain zones range in width from centimetres to several tens of metres. The "Braminco Number 21 Shear Zone" (Callan 1988) is an example of a high strain zone that strikes 140°, while the C-West Zone is an example of a high strain zone that strikes 080° (Figure 17.3). Rotation, folding and transposition of the regional S_1 and S_2 foliations into these high strain zones (Figure 17.4) are suggestive of a sinistral component of horizontal displacement within the 140° zones, while both dextral and sinistral components of horizontal displacement have been documented within the 080° zones. Petrographic studies are planned to resolve the kinematics within these high strain zones. Mineral lineations (e.g., feldspar, quartz and biotite aggregates) within the 140° zones plunge moderately to the northwest, while those within the 080° zones plunge moderately to the west.

High strain zones striking 080° seem to be more prevalent around, and north of, the Renabie–C–Zone–Nudulama area, while high strain zones striking 140° are more prevalent south of that area (Figure 17.3). The relationship between and relative timing of the two types of high strain zone (S_{3a} and S_{3b}) are equivocal at this time. Both types are rotated, folded and transposed by a later high strain zone, which strikes approximately 110° (Figure 17.4).

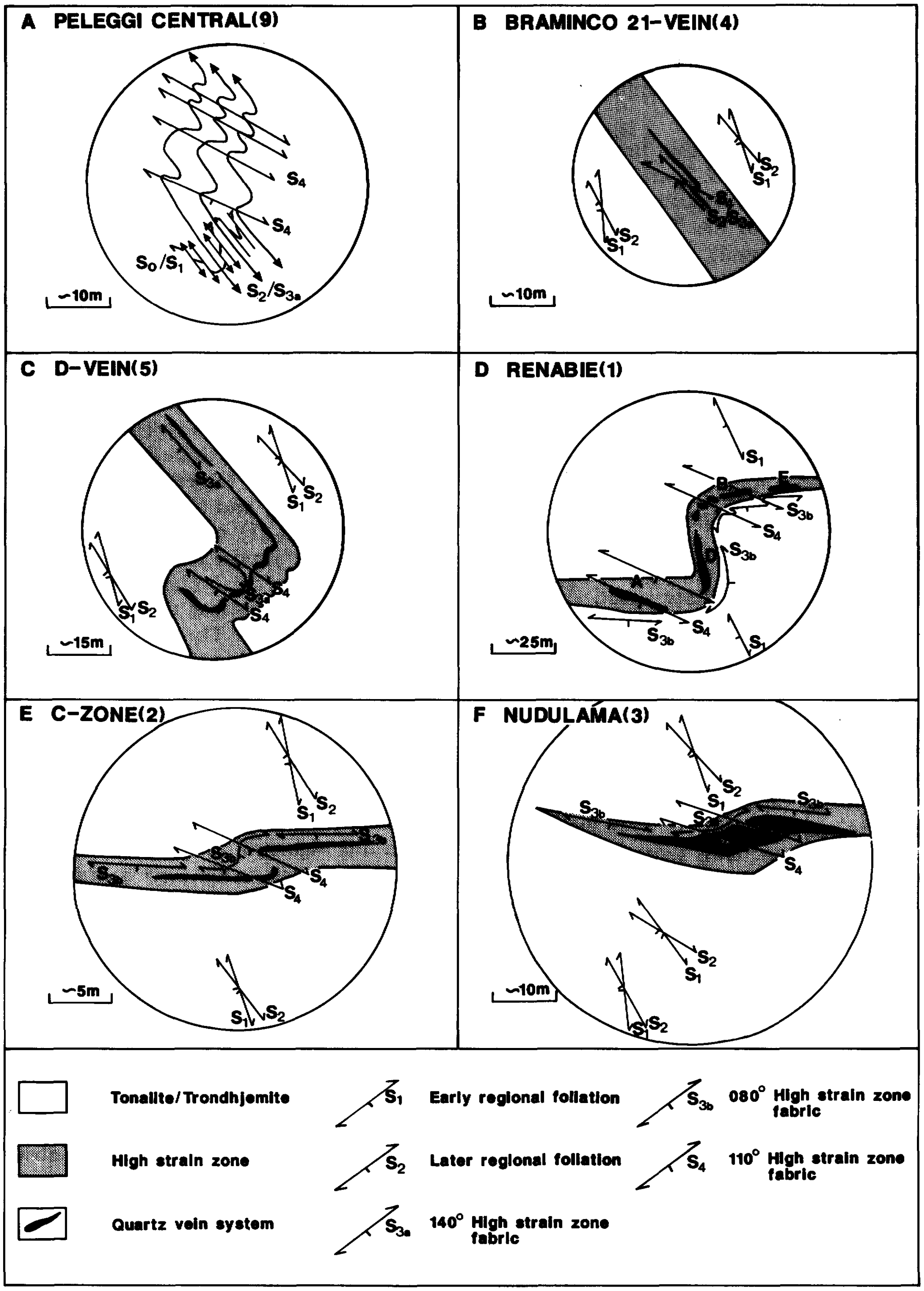

Figure 17.4. *Schematic representation of relationships among structural fabrics, observed at selected gold occurrences. Relationships are greatly simplified and the scale bars are approximate. Numbers in the brackets following the occurrence name correspond to those in Figure 17.3.*

LATE HIGH STRAIN ZONE (S_4)

Locally superimposed on the S_{3a} and S_{3b} high strain zones is a strong to intense, ductile schistosity (S_4), which trends between 105° and 125° and is defined by sericite and smeared, relict aggregates of feldspar and quartz. Although the S_4 schistosity is most persistently developed in the S_{3a} and S_{3b} high strain zones, reflecting the pre-disposition of these fissile, phyllosilicate-bearing, sheared rocks to manifest the

110° fabric, it also develops locally into discrete high strain zones which rotate, crenulate, fold and transpose the S_{3a} and S_{3b} schistosities. The S_4 high strain zones range in width from several centimetres to several tens of metres.

At the southern end of the Braminco Number 21 open pit (Figures 17.3 and 17.4), an S_4 schistosity (110° trend) crosscuts an intense S_{3a} shear fabric (145°) within the "Braminco Number 21 Shear Zone" (145° trend). That same 110° fabric produces Z-shaped crenulations or kink-like folds of the S_{3a} schistosity and subparallel quartz veins (Figure 17.4). At the western end of the surface exposure of the "B-Zone" (085°-trending), a strong S_4 schistosity (110° trend) crosscuts and produces S-shaped crenulations of the intensely developed S_{3b} shear fabric (085° trend) and subparallel quartz veins (Figures 17.3 and 17.4).

The S_4 schistosity is the dominant fabric within the auriferous areas of the Renabie gold mine, the C-Zone open pit, and the Nudulama West and East open pits (Figure 17.4), where the quartz vein systems appear to be folded, dismembered and transposed about the S_4 fabric. Conversely, away from these complexly folded areas on the tails (or limbs) of the orebodies, the S_{3b} fabric is more dominant (Figure 17.4). Similarly, at the D-Vein occurrence (Figures 17.3 and 17.4), the S_4 (approximately 120°) fabric is best developed in the mineralized nose areas of a large, fold-repeated, quartz vein system, whereas the S_{3a} (approximately 140°) fabric is strongest on the northeastern, straight limb of the same quartz vein system. Two tentative hypotheses are formulated from these observations:

1. The S_4 fabric appears to be axial planar to folded S_{3a} and S_{3b} high strain zones.
2. Domains of higher gold tenor in the S_{3a} and S_{3b} high strain zones correspond with the intense development of S_4 and attendant disruption of the quartz vein systems.

These hypotheses must still be rigorously tested.

STRUCTURAL CHRONOLOGY IN THE GRANITOIDS

There has been a significant amount of folding in the Renabie area and, as such, early geological and structural features have been modified by subsequent events. Recognizing this, and for ease of discussion, the following structural chronology uses unmodified, average azimuths to identify each structural event.

An early S_1 (165°) flattening fabric is overprinted by a later S_2 (145°) flattening fabric. The S_1 and S_2 flattening fabrics are rotated, crenulated and transposed along the S_{3a} (140°) and S_{3b} (080°) high strain zones. All of these fabrics are locally rotated, crenulated and transposed along zones of S_4 (110°) fabric development. Late northwest- and northeast-trending brittle faults, similar to those documented in the supracrustal rocks (Heather and Buck 1988), offset and displace all of the previously mentioned fabrics and quartz vein systems.

RELATION TO THE GREENSTONE BELT

The apparent structural chronology documented in the granitoids is very similar to that in the supracrustal rocks (Heather and Buck 1988). At the Peleggi Central gold occurrence (Figures 17.2 and 17.4), bedded intermediate tuffs, lapilli tuffs and volcanic breccias are folded about a 140°-trending, spaced, axial planar cleavage (S_2) which shuffles and transposes the bedding (S_0/S_1), sinistrally on the northeast limb of a southeast-closing fold and dextrally on the opposite limb of the same fold. A foliation (S_1?) defined by the preferred orientation of micaceous minerals and parallel to bedding (S_0) is locally preserved, but also is folded (Figure 17.4). Superimposed on both S_1 and S_2 are local, narrow zones of higher strain (S_{3a}?) oriented subparallel to parallel to the S_2 (140°) axial planar cleavage. Z-folds with a 110°-trending axial planar cleavage (S_4) rotate, crenulate, and transpose the S_0/S_1 and S_2/S_{3a} foliations (Figure 17.4). The orientations and chronology of foliations within this portion of the greenstone belt are similar to those described for the granitoid rocks.

In east-central Rennie Township, an intense zone of 065°-trending, ductile high strain is coincident with a strong airphoto lineament (Figure 17.2). There is evidence of folded and boudinaged layering within this high strain zone. Boudins and amphibole lineations plunge moderately to the west-northwest. This zone appears to be part of a strong, northeast-trending lineament stretching from Michipicoten Harbour in the west to the far northeast tip of the Michipicoten greenstone belt in the east. Locally, this 065° fabric was seen to sinistrally crenulate a 140° fabric (S_2/S_{3a}). This 065° high strain zone has an orientation similar to those of the Emily Bay deformation zone and a northeast-trending splay from the Dog Lake deformation zone (Heather and Buck 1988). Preliminary indications suggest that the 065°-trending high strain zone may postdate the S_1 through S_4 fabrics.

ALTERATION

Alteration within the trondhjemite-tonalite granitoids is restricted to the S_{3a} (140°), S_{3b} (080°) and S_4 (110°) zones of high strain. The alteration consists of abundant hematite (giving the rock a distinctive reddish colour in the field), as well as sericite, quartz, pyrite and minor carbonate. Personnel from the Renabie gold mine refer to this rock as "red altered trondhjemite", as opposed to the less altered, "grey altered trondhjemite". Primary biotite and/or hornblende in the trondhjemite-tonalite are destroyed within the highly altered and strained zones. There is evidence to suggest that the early alteration zones, related to the S_{3a} and S_{3b} high strain zones, are deformed by the later S_4 high strain zones, which have a similar alteration assemblage.

QUARTZ VEINING

Multiple generations of quartz veins occur within the trondhjemite-tonalite rocks. The earliest (interpreted) are "bull-white", non-auriferous, and of limited strike extent. They are not associated with zones of high strain and are roughly parallel to the S_1 (165°) fabric. A later generation of quartz veins is confined to the S_{3a} (140°) and S_{3b} (080°) zones of high strain, which also rotate, fold and transpose the earlier veins. All of these veins are further rotated, folded and transposed by the S_4 (110°) high strain zones (e.g., the D-vein is folded about an S_4 fabric; Figure 17.4). Small, syn-S_4, quartz veins have been observed; however, their extent has not been fully documented. The latest set of quartz veins recognized to date has a trend between 035° and 040°, and crosscuts all the flattening and shear fabrics described above (i.e., S_1 through S_4).

The majority of the quartz veins found in mineralized areas have undergone some deformation. Many of the better mineralized veins have undergone one and possibly two phases of folding, shearing and transposition. A wide spectrum of rotated, folded, and transposed quartz vein geometries is preserved within the known gold occurrences in the granitoid rocks. The D-vein (Figures 17.3 and 17.4), for example, occupies an S_{3a} (140°) high strain zone which is folded into open (and locally tight), shallowly northwest-plunging M-folds within an S_4 (120°) high strain zone. In contrast, the Nudulama and C-Zone (Figures 17.3 and 17.4) quartz vein systems have undergone such extensive folding, dislocation, and transposition within an S_4 (110°) high strain zone that recognizable folds in the quartz veins are rare. Typically, the quartz veins have hooks on their ends, which is typical of folded and transposed material (Figure 17.4). Underground at the Renabie gold mine, there are numerous examples of folded (locally refolded), dislocated, and transposed quartz veins within the mineralized zones. The surface projections of veins from the Renabie orebody have an S-shaped geometry (Figures 17.3 and 17.4). The plunges of minor folds of quartz veins at the Renabie gold mine are parallel to the 50°SW plunge of the orebody as a whole. At the surface, the Renabie orebody appears to be a large, complex, S-shaped fold which becomes progressively more dislocated and transposed parallel to an intense S_4 (110°) fabric (Figure 17.4) with depth. This may explain the lensoid and pod-like character of the quartz veins within the orebody. Additional work is planned to document down-plunge geometry of the orebody.

Refolded folds are locally preserved within the quartz veins (e.g., D-vein occurrence and the Nudulama East occurrence). Many of the mineralized veins are strongly sheared and contain narrow sericite-chlorite shears, while veins with little or no sericite-chlorite slips typically carry poor gold values.

GOLD MINERALIZATION

Gold mineralization is associated with disseminated to massive pyrite, with accessory amounts of galena, molybdenite, and chalcopyrite, within quartz veins and locally within the surrounding wall rocks. Some of the best sulphide concentrations were found along the margins of strongly deformed quartz veins, along narrow seams of sericite and chlorite within deformed quartz veins, or in the noses of folded quartz veins with an S_4 (110°) axial planar fabric. In the Renabie gold mine, gold occurs in quartz veins and in zones of sulphide concentration. However, not all quartz veins or zones of sulphide concentration contain economic concentrations of gold (Staff, Renabie Gold Mines Limited, personal communications, 1989). More detailed evaluation of the siting and distribution of gold within the Renabie gold mine is planned.

DISCUSSION AND RECOMMENDATIONS

The trondhjemite-tonalite rocks located immediately east of the Michipicoten greenstone belt, in the area around the Renabie gold mine, have undergone a complex structural history similar to that documented previously in this study for the greenstone belt. Significant gold mineralization in the granitoid rocks seems to be related to areas which have been deformed by early flattening (S_1 (165°) and S_2 (145°)) and development of ductile high strain zones (S_{3a} (140°) and S_{3b} (080°)), followed by the later (possibly progressive) development of ductile high strain zones (S_4 (110°)) which rotate, fold, and transpose the earlier high strain zones, quartz veins, alteration and, possibly, lower grade gold mineralization. Strongly deformed lamprophyre dikes are intimately associated with the mineralized quartz veins in the majority of the gold occurrences within the trondhjemite-tonalite rocks. The majority of these early dikes seem to occupy S_{3a} (140°) and S_{3b} (080°) high strain zones, which are rotated, folded and transposed by the later S_4 (110°) high strain zones. These syn-S_{3a} and syn-S_{3b} lamprophyre dikes seem to act as strong competency contrasts within the more homogeneous trondhjemite-tonalite rocks, and have localized extensive quartz veining and S_4 (110°) high strain zones. All of the significant gold occurrences have a strong S_4 high strain zone superimposed on an earlier high strain zone (i.e., S_{3a} or S_{3b}). The S_{3a} and S_{3b} high strain zones, by themselves, are viable gold exploration targets, as are the S_4 high strain zones; however, areas where the S_{3a}, S_{3b} and S_4 high strain zones are coincident are preferred. This may indicate that:

1. The gold is redistributed from the S_{3a} and S_{3b} high strain zones during the development of the S_4 zones.

2. The gold was introduced late, synchronous with the development of the S_4 high strain zones.

3. The gold is part of a protracted, complex history involving both the development of the S_{3a} and S_{3b} high strain zones and of the S_4 high strain zones.

Whichever scenario applies, the superposition of the S_4 (110°) high strain zones appears to be of critical importance in generating economically interesting gold deposits in the Renabie Mine area.

To date, there have been no significant gold discoveries in the supracrustal rocks immediately west of the Renabie Mine area (Figure 17.2). The Colborne–Stephenson lakes deformation zone, a high strain zone trending 085° to 090° (Heather and Buck 1988), is located approximately 5 km west of the Renabie Mine. This deformation zone may be the on-strike equivalent of the 080° to 090° (S_{3b}) high strain zone recognized within the granitoid rocks at Renabie. To the southwest of Renabie are the Southwest and No. 2 veins, which are hosted in high strain zones within mafic to intermediate metavolcanic rocks (Figure 17.2). There is a possibility that the Colborne–Stephenson lakes deformation zone, the Southwest and No. 2 veins, and the high strain zone at Renabie may be part of the same zone, which has been displaced sinistrally, along northwest brittle faults, as one moves eastward. This interpretation is tentative, due to poor bedrock exposure; nevertheless, it represents a favourable, grass roots, gold exploration target.

ACKNOWLEDGMENTS

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18. Project Unit 87-01. Geology of Part of the Temagami Greenstone Belt, District of Nipissing, Including Relationships Between Lithologic, Alteration, and Structural Features and Precious-Metal Occurrences

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INTRODUCTION

Previous studies of the Temagami greenstone belt (Savage 1935; Moorhouse 1942; Bennett 1978) have provided an excellent geological framework for more detailed examinations of the geology and mineralization of the belt. This project was initiated to address structural, lithologic and alterations problems identified from these previous studies; to provide a rationale for the distribution and localization of known mineralization; and to identify areas where new mineral occurrences might be discovered. Results of previous work in the project have been reported in Fyon and O'Donnell (1987) and Fyon et al. (1988). Work carried out in 1989 comprised detailed (1:8000 scale) mapping of Archean rocks in parts of Briggs and Chambers townships (Figure 18.1).

In this paper, a revised lithostratigraphic subdivision of the metavolcanic and metasedimentary rocks is described briefly, the lithostratigraphic subdivisions are extrapolated to both northern and southern parts of the belt, and correlative rock sequences are interpreted. Chondrite-normalized, rare earth element (REE) patterns of metavolcanic rock are discussed as one of several criteria on which the lithostratigraphic subdivision and correlations are based. The relevance of these observations to commodity distributions and potential exploration targets is discussed.

GENERAL GEOLOGY

Previous descriptions of the Temagami greenstone belt include those by Savage (1935), Moorhouse (1942) and Bennett (1978). The greenstone belt

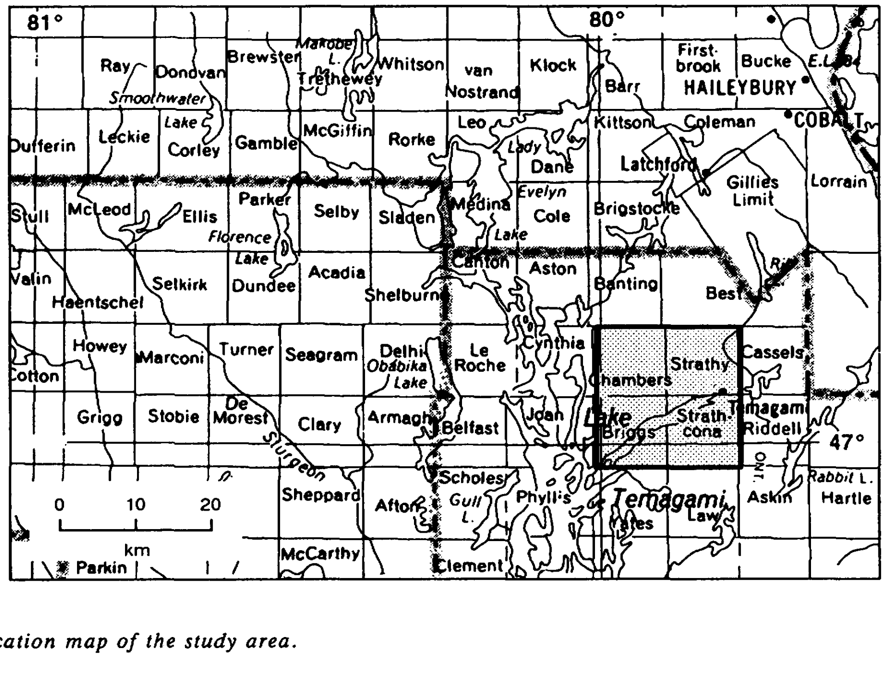

Figure 18.1. *Location map of the study area.*

CANADA ONTARIO Mineral Development

This project A.4.2 is part of the five-year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

consists of tholeiitic and calc-alkalic metavolcanic rocks and associated clastic and chemical metasedimentary rocks, which have been folded about an east-trending synclinal axis (Tetapaga Syncline, *see* Bennett 1978). Three granitoid intrusions (Strathy-Chambers, Iceland Lake and Spawning Lake) were emplaced into the greenstone belt (Bennett 1978). Fyon and Crocket (1986), Fyon and O'Donnell (1987), and Fyon et al. (1988) developed a threefold lithostratigraphic subdivision of the volcano-sedimentary rocks (Figure 18.2), based on observations made on the north limb of the Tetapaga Syncline. In the following sections, this lithostratigraphic subdivision is revised and extrapolated to include rock sequences on both the north and south limbs of the syncline. The structural characteristics of the area, described previously (e.g., Fyon and O'Donnell 1987; Fyon et al. 1988), have been considered during the formulation of the lithostratigraphic subdivision and correlations, and are not restated here.

SEQUENCE A

Sequence A (*see* Figure 18.2), formerly named the Lower Volcano-sedimentary package (Fyon et al. 1988), is a south-facing metavolcanic package which is best exposed in Chambers and northern Strathy townships. The basal unit of this sequence consists of massive and pillowed, iron-rich, tholeiitic basalt flows. Some flows are feldspar megacrystic, but variolitic flows have not been recognized. Most of the sequence consists of intermediate and felsic, calc-alkalic, effusive and fragmental rocks, which overlie the tholeiitic flows. The top of the sequence includes a thin (100 to 200 m) unit of oxide-facies iron formation, and an assemblage of fragmental, ultramafic rock, magnesium-rich pyroxenitic flows, and heterolithic clastic metasedimentary rocks, which conformably overlie the iron formation. While the unit of magnesium-rich extrusive rocks may represent the initiation of a new volcanic episode, younger than sequence A, it is included with sequence A because the oxide-facies iron formation and the ultramafic fragmental units are spatially associated across Strathy and Chambers townships. The limits of the sequence are defined by the Strathy-Chambers batholith to the north, and by the oxide-facies iron formation–ultramafic fragmental couple to the south and east. The interface between sequence A and the successive sequence to the south and east (sequence B, described below) is the locus of the Net–Vermilion lakes deformation zone (Fyon and O'Donnell 1987; Fyon et al. 1988).

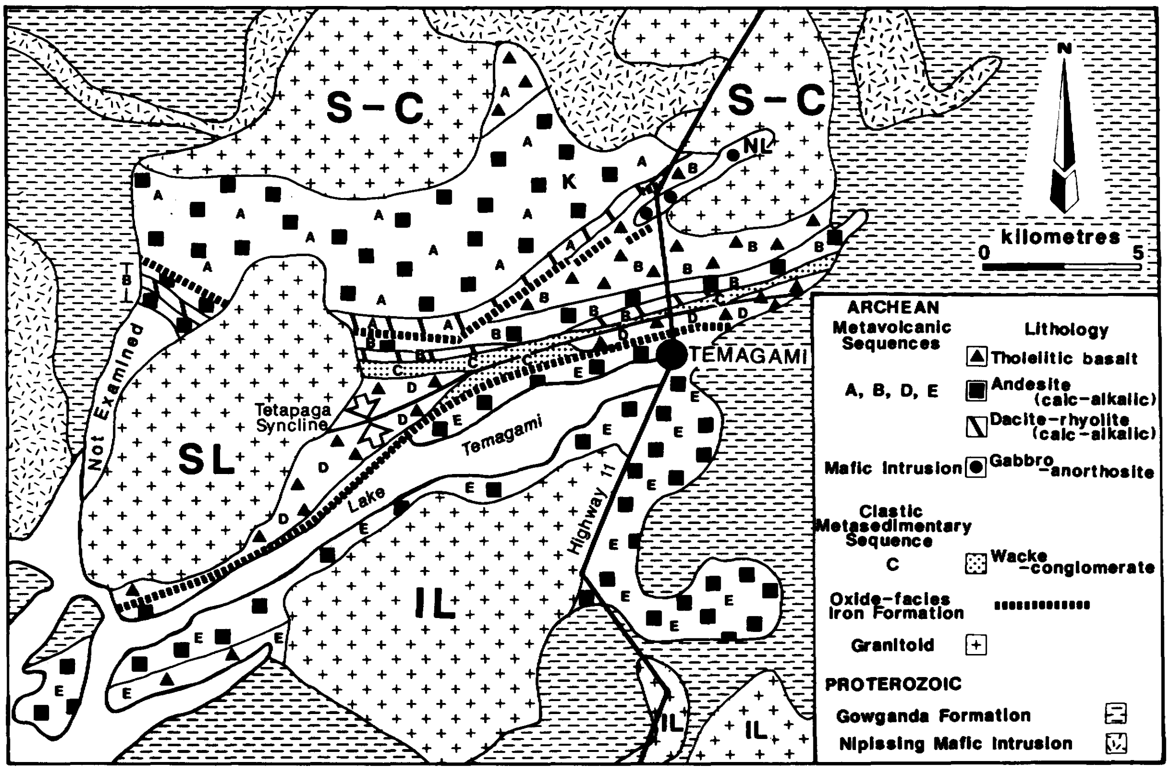

Figure 18.2. *Simplified distribution of Archean intrusions, metavolcanic rocks (sequences A, B, D, E) and metasedimentary rocks (sequence C), and Proterozoic rocks in the Temagami greenstone belt. Abbreviations are: S-C = Strathy-Chambers trondhjemite-granite batholith; SL = Spawning Lake granite stock; IL = Iceland Lake trondhjemite-granodiorite batholith; NL = Net Lake gabbro-anorthosite intrusion; K = Kanichee dunite-gabbro intrusion. Note that rhyolitic rocks occur interlayered at the top of sequence E, but are not resolved at this scale.*

The chondrite-normalized rare earth element (REE) patterns of the iron-rich, tholeiitic basalts are flat and average 10 times chondrite, but display a marked negative europium anomaly. The REE patterns of the intermediate and felsic, calc-alkalic metavolcanic rocks are characterized by fractionated, heavy rare earth element (HREE) depleted patterns (La_N/Yb_N = 6 to 50), and no significant negative europium anomaly.

SEQUENCE B

Sequence B (*see* Figure 18.2), formerly named the Middle Volcano-sedimentary package (Fyon et al. 1988), is a south-facing metavolcanic package which is most completely developed in Strathy Township. It consists of a lower unit of iron-rich, tholeiitic basalt flows (some of which are feldspar megacrystic and variolitic), and an upper unit of intermediate and felsic, calc-alkalic, effusive and fragmental metavolcanic rock.

The contact between sequences A and B is complex. Along the Net–Vermilion lakes deformation zone, in northern Strathy Township, iron-rich, tholeiitic basalts at the base of sequence B are juxtaposed against the iron formation–ultramafic fragmental unit at the top of sequence A. Conversely, along the Net–Vermilion lakes deformation zone, in southern Chambers Township, andesitic and rhyolitic metavolcanic rocks at the top of sequence B are juxtaposed against the iron formation–ultramafic fragmental units at the top of sequence A. Thus, using the iron formation–ultramafic fragmental unit as a datum, the lower two thirds of sequence B is missing or was removed where sequence B is juxtaposed against the top of sequence A (Fyon et al. 1988), along the Net–Vermilion lakes deformation zone. The sequence is bounded to the south by an east-trending unit of clastic metasedimentary rock (sequence C, described below).

The REE patterns of the iron-rich, tholeiitic basalts are flat, average about 10 times chondrite, and display a small, negative europium anomaly. The REE patterns of the rhyolitic metavolcanic rocks of sequence B are relatively flat ($La_N/Yb_N = <5$), average 10 to 30 times chondrite abundance, and display a marked, negative europium anomaly. These rocks also have low Zr/Y ratios (1.6 to 6.1) and low Sr abundances (15 to 50 ppm).

SEQUENCE C

Sequence C (*see* Figure 18.2) is a south-facing unit of clastic metasedimentary rocks which lies between the top of sequence B and a unit of iron-rich, tholeiitic basalt, which occupies the core of the Tetapaga Syncline (sequence D, described below). These metasedimentary rocks consist of thinly-bedded, turbiditic wacke-mudstone couplets and a wedge-shaped, eastward-thinning unit of coarse, heterolithic, matrix-supported conglomerate (Fyon and Crocket 1986). Fragment types in the coarse unit include diorite; iron-rich, tholeiitic basalt; feldspar-phyric andesite; quartz- and feldspar-phyric porphyry; aphyric (?) dacite-rhyolite, and rare vein quartz. No oxide-facies iron formation fragments were observed, nor is there any accumulation of banded oxide-facies iron formation associated with sequence C (Bennett 1978). The contact between sequences C and B appears to be conformable, although locally it is the locus of the Link Lake deformation zone (eastern Strathy Township) and of the Net–Vermilion lakes deformation zone (south-central Chambers Township). The contact between sequences C and D is equivocal, and is discussed below. Because the Tetapaga Syncline appears to be doubly plunging, clastic metasediments of Sequence C may crop out on the south side of the synclinal axis.

SEQUENCE D

Sequence D (*see* Figure 18.2), formerly named the Upper Volcano-sedimentary package (Fyon et al. 1988), occupies the core of the Tetapaga Syncline. It consists of massive and pillowed, iron-rich, tholeiitic basalt flows, none of which are variolitic or feldspar megacrystic. No consistent facing direction is recognized.

The contact relationships between sequence D and the adjacent sequences are equivocal. On the south limb of the Tetapaga Syncline in southern Strathy Township, the thickest accumulation of the basalt in sequence D is stratigraphically above the iron formation–clastic metasediment unit at the top of an andesitic pile (sequence E, described below); however, some of these basalts appear to be interlayered with the clastic metasedimentary rocks below the iron formation at the top of sequence E. This evidence is consistent with a conformable and gradational transition. The contact relationship between sequence D and the sediments of sequence C, on the north limb of the Tetapaga Syncline, is not known because of poor bedrock exposure. No iron-rich, tholeiitic basalt is interlayered with the clastic metasedimentary rocks of sequence C and, at one locality along Highway 11, the basalts of sequence D are strongly cataclastic and the adjacent metasedimentary rocks of sequence C are sheared. Thus, the contact between sequences C and D is locally structurally complex, whereas that between sequences D and E appears to be locally transitional.

SEQUENCE E

Sequence E represents most of the metavolcanic rock preserved on the south limb of the Tetapaga Syncline (*see* Figure 18.2). It consists of a poorly exposed lower unit of massive and pillowed, iron-rich, tholeiitic basalt flows (some of which are feldspar megacrystic); a central unit of intermediate, andesite and rhyolite effusive and fragmental flows and a thin (200 m) upper unit of oxide-facies iron formation underlain by turbiditic wacke-mudstone metasedimentary rock. The coarser-grained facies of the clastic metasedimentary deposits contain fragments of andesitic and dacitic-rhyolitic metavolcanic rocks; the compositional diversity observed in the metasediments of sequence C is not apparent in those occurring at the top of sequence E. No ultramafic fragmental rocks or other magnesium-rich flows have been recognized within this sequence. The sequence is bounded to the south by the Iceland Lake batholith and to the north by the iron-rich, tholeiitic basalts of sequence D. The eastern extent of this sequence into Strathcona Township was not examined during this study, and the distribution and type of the metavolcanic rocks in this area are inferred from previous studies (e.g., Bennett 1978; Johnston 1987). An apparent conformable contact exists between sequences E and D, as described above.

The REE patterns of the iron-rich, tholeiitic basalts are flat, average 10 times chondrite, and display a small negative europium anomaly. The calc-alkalic, andesitic and rhyolitic metavolcanic rocks all have fractionated REE patterns (La_N/Yb_N = 5 to 20), and no significant negative europium anomaly.

SEQUENCE CORRELATIONS

The following criteria have been used to correlate rock sequences: 1) chemical affinity (e.g., tholeiitic), 2) REE patterns, and 3) distribution of oxide-facies iron formation. These tentative correlations are made with regard to the structural complexities described by Fyon and O'Donnell (1987) and Fyon et al. (1988).

SEQUENCES A AND E

Sequences A and E, located on the north and south limbs of the Tetapaga Syncline, respectively, are each capped by an oxide-facies iron formation, and contain calc-alkalic metavolcanic rocks having fractionated, chondrite-normalized REE patterns with no significant negative europium anomaly. On this basis, the iron formation and calc-alkalic metavolcanic deposits of sequences A and E are tentatively interpreted to be stratigraphically correlative. This represents a change from our previous interpretations, in which the calc-alkalic rocks of sequences B and E were correlated (e.g., Fyon and O'Donnell 1987; Fyon et al. 1988). The iron-rich tholeiitic basalt flows at the base of each of these sequences are also tentatively correlated, although the chemistry of each basalt unit has not yet been exhaustively compared.

SEQUENCE B

The upper part of sequence B is characterized by interlayered, rhyolitic and dacitic, subaqueous, pyroclastic flows, which have a flat, "tholeiitic-like", chondrite-normalized REE pattern showing a pronounced negative europium anomaly. Neither the type of volcanism nor the REE geochemistry of these metavolcanic rocks is typical of any other metavolcanic rock sequence in the Temagami greenstone belt. Hence, it is concluded that the andesites and rhyolites of sequence B are not correlative with those of sequences A, D and E. Tentatively, it is also concluded that the iron-rich, tholeiitic basalt unit at the base of sequence B is not correlative with those of sequences A, D and E, although few volcanological or geochemical criteria permit unequivocal distinction, and this hypothesis remains to be more rigorously tested. Thus, sequence B may represent either a second volcanic cycle or an allochthonous sequence which has been structurally interleaved between sequences A and C. Structural relationships between sequences A and B and the wedge-shaped extent of sequence B (Fyon et al. 1988) are consistent with an allochthonous origin, although these relationships do not unequivocally eliminate alternative hypotheses (e.g., a second volcanic cycle).

SEQUENCE C

By virtue of their proximity on either side of the Tetapaga Syncline, the clastic metasediments of sequence C and those at the top of sequence E have been correlated (e.g., Fyon and Crocket 1986). However, some aspects of these two metasedimentary units are sufficiently different to question this correlation. Banded oxide-facies iron formation is interlayered with epiclastic wackes at the top of sequence E; no iron formation occurs in sequence C. The compositional diversity of the conglomerate fragments in sequence C contrasts with the less-diverse fragment compositions represented in the coarse deposits at the top of sequence E. Thus, it is tentatively concluded that sequence C is not correlative with the clastic metasediments and associated oxide facies iron formation at the top of sequence E.

SEQUENCE D

The iron-rich, tholeiitic basalts of sequence D differ from those in sequences A, B and E in that neither variolitic nor feldspar-megacrystic flows are present. Feldspar-megacrystic flows are characteristic of the tholeiitic basalts in the other sequences, and variolitic basalt occurs in sequence B. Therefore, the iron-rich, tholeiitic basalts of sequence D may not be correlative with those of sequences A, B or E and may represent a second cycle of tholeiitic basalt effusion, following the accumulation of an earlier package of metavolcanic and metasedimentary rocks (sequences A and E). This hypothesis is consistent with the contact relationships (described above) between sequences D and E.

INTRUSIONS

More comprehensive discussions of the intrusive rocks in the area are provided by Bennett (1978), Fyon and O'Donnell (1987), and Fyon et al. (1988). Some characteristics of the intrusions relevant to the lithostratigraphic subdivision and metallogenic evolution of the belt are summarized here.

EARLY MAFIC AND ULTRAMAFIC INTRUSIONS

Remnants of a gabbro-diorite intrusion occur primarily as xenoliths within the Strathy-Chambers batholith in northeastern Chambers Township, and as a coherent body in southeastern Best Township (P. Born, Geologist, Ministry of Northern Development and Mines, personal communication, 1989). The xenoliths within the Strathy-Chambers batholith are interpreted to represent stoped portions of the lower part of sequence A. A layered, gabbro-anorthosite intrusion occurs within the iron-rich, tholeiitic basalts in sequence B in northern Strathy Township (Net Lake intrusion, *see* Fyon and O'Donnell 1987; Good 1987). Both of these mafic intrusions are associated with feldspar-megacrystic, tholeiitic basalt flows, to which they may be genetically related (e.g., Phinney et al. 1988).

A layered dunite-gabbro intrusion of possible komatiite affinity (Good 1989) cuts calc-alkalic metavolcanic rocks of sequence A in western Strathy Township. This intrusion may be cogenetic with the thin unit of ultramafic fragmental and associated magnesium-rich, effusive metavolcanic rocks, which overlie the oxide-facies iron formation at the top of sequence A.

LATE GRANITOID INTRUSIONS

Three granitoid intrusions were emplaced into the greenstone belt. The Strathy-Chambers and Iceland Lake batholiths are pre- to syntectonic, trondhjemitic intrusions, whereas the Spawning Lake stock is a posttectonic granite intrusion.

Strathy–Chambers Batholith

The Strathy–Chambers batholith, located in northern Chambers and Strathy townships, consists of granite and chlorite-bearing trondhjemite phases, classified using normative anorthite, albite, and orthoclase proportions (Barker 1979). The trondhjemite phase occurs principally in Chambers Township, and the granite phase occurs in northern Strathy Township. It is not known if these represent two distinct plutons or a compositional evolution of a single intrusion. The batholith was emplaced prior to or during the earliest regional, north-directed compressional event, before the development of the Net–Vermilion lakes deformation zone (Fyon et al. 1988). It intrudes and metamorphoses metavolcanic rocks of sequence A and the iron-rich, tholeiitic basalts at the base of sequence B.

Samples of the chlorite trondhjemite are characterized by Al_2O_3 abundances in excess of 14.5 weight percent, low absolute Yb contents (<1 ppm), and fractionated REE patterns (La_N/Yb_N = 10 to 22) which have negative europium anomalies (Eu/Eu* = −0.6 to −1.0). Samples of the granitic phase are characterized by Al_2O_3 abundances less than 14.5 weight percent, Yb abundances greater than 2 ppm, and less fractionated REE patterns (La_N/Yb_N = 4 to 6) which display marked, negative europium anomalies (Eu/Eu* = −5.2 to −13.7).

Iceland Lake Batholith

The Iceland Lake batholith, located in Briggs and Strathcona townships, is a composite chlorite (hornblende) trondhjemite–granodiorite intrusion, based on normative anorthite, albite, and orthoclase proportions (Barker 1979). It was emplaced prior to or during the earliest, north-directed compressional event, and the development of the Northeast Arm deformation zone (Fyon et al. 1988). All sampled phases are characterized by fractionated REE patterns (La_N/Yb_N = 20 to 30), which have Eu/Eu* values close to zero (−2.7 to +1.4). Abundances of Al_2O_3 in samples of trondhjemite (15.5 to 16.0 weight percent) overlap with those of samples of the granodiorites (15.4 to 17.0 weight percent). The abundance of Yb of all samples does not exceed 1 ppm.

Spawning Lake Stock

The Spawning Lake stock is a posttectonic, microcline-megacrystic, hornblende-biotite granite. This intrusion truncates all regional stratigraphic and structural trends, but bears none of those deformation fabrics. REE patterns are strongly fractionated (La_N/Yb_N = 10 to 40), and do not show a marked, negative europium anomaly (Eu/Eu* = −0.3 to −2.3).

COGENETIC INTRUSIVE AND VOLCANIC ROCKS

Samples of the Iceland Lake batholith display fractionated REE patterns which lack a significant negative Eu anomaly. These chemical characteristics are shared by the calc-alkalic metavolcanic rocks of sequences A and E, and the trondhjemite phase of the Strathy-Chambers batholith. It is tentatively concluded that the Iceland Lake trondhjemite and the trondhjemitic phase of the Strathy-Chambers batholith were comagmatic with the calc-alkalic, metavolcanic rocks in sequences A and E. Conversely, the granitic phase of the Strathy-Chambers batholith has less-fractionated, "tholeiitic-like" REE patterns with significant negative europium anomalies. These patterns are qualitatively similar to those of the dacitic and rhyolitic metavolcanic rocks of sequence B. This similarity may indicate that the granite phase of the Strathy-Chambers batholith was comagmatic with the dacitic and rhyolitic metavolcanic rocks of sequence B. If valid, an allochthonous origin for sequence B may be incorrect. Additional geochemical characterization is required to more rigorously test for comagmatism between the granite phase of the Strathy-Chambers batholith and the rhyolites of sequence B.

The steeper, more-fractionated REE pattern of the microcline-megacrystic granite of the Spawning Lake stock is qualitatively similar to those of the trondhjemitic phases of the Iceland Lake and Strathy-Chambers batholiths, and to those of the calc-alkalic metavolcanic rocks of sequences A and E. This may indicate a comagmatic origin; however, the late-emplacement age of the Spawning Lake stock indicates that it was not coeval with sequences A and E, or the Iceland Lake and Strathy-Chambers trondhjemite intrusions.

METALLOGENIC RELATIONSHIPS

With the existing structural and revised lithostratigraphic constraints, it is possible to begin to address the metallogenic history of the belt. This history is discussed chronologically, from those metal assemblages which evolved earliest to those whose localization was dependent on later events. In some cases, several habits of mineralization occur within a single, mineralized area (e.g., nickel-sulphide concentrations), which reflects the complex history of the belt.

MAGMATIC Ti-V-Cr OXIDE CONCENTRATIONS

The igneous layering of the Net Lake gabbro-anorthosite intrusion is analogous to that of other layered, Archean gabbro-anorthosite intrusions. These intrusions are sometimes associated with accumulations of cumulate magnetite, ilmenite, or chromite (e.g., Phinney et al. 1988). Cursory examination of the Net Lake intrusion has not revealed the presence of any oxide accumulations; however, disseminated (cumulate?) magnetite occurs in the Best Township gabbro intrusion (P. Born, Geologist, Ministry of Northern Development and Mines, personal communication, 1989).

INTRUSION-HOSTED Ni-Cu SULPHIDES

Tholeiitic Affinity

Nickel-copper sulphides occur in the Net Lake intrusion in several different habits (Fyon and O'Donnell 1987; Good 1987). Disseminated and net-textured pyrrhotite-chalcopyrite-pentlandite mineralization represents magmatic sulphide concentrations. Locally, however, sulphide minerals are concentrated in quartz-chalcopyrite-pyrite-pyrrhotite veins and sulphide-rich-impregnated zones, which occur within shear zones interpreted to belong to the Net–Vermilion lakes deformation zone (Fyon and O'Donnell 1987).

Komatiitic Affinity

Several habits of nickel- and copper-bearing sulphides occur within the Kanichee intrusion (James and Hawke 1984; Good 1989). The tholeiitic (James and Hawke 1984) or komatiitic affinity (Good 1989) of this intrusion remains debated. Both magmatic (disseminated) and "modified" or redistributed sulphide concentrations occur in the intrusion. Copper-nickel-precious metal concentrations occur in secondary veins and adjacent sulphide-bearing halos, and are typical of the redistributed, magmatic-sulphide habit (James and Hawke 1984, Good 1989).

VOLCANIC-ASSOCIATED MASSIVE BASE METAL SULPHIDES

While unequivocal concentrations of volcanic-associated, massive, base metal sulphide mineralization have not yet been discovered in the Temagami greenstone belt[1], several characteristics of the rhyolitic fragmental rocks at the top of sequence B indicate that this may be a favourable package in which to explore for this type of mineralization. A large area of silicification, coincident with numerous sulphide occurrences, occurs in eastern Strathy and western Cassels townships (Boot Bay zone: *see* Fyon and Crocket 1986; Fyon and O'Donnell 1987; Born 1988). Some geochemical characteristics of these rhyolites, described above, are similar to "Type FIII" rhyolites described by Lesher et al. (1986), which are frequently associated with volcanic-associated, massive, base metal sulphide mineralization in the Superior Province. Within the context of the revised lithostratigraphic subdivision of the study area, the favourable sequence is restricted to the wedge-shaped package on the north side of the Tetapaga Syncline.

GOLD

No significant gold concentrations occur within the east-northeast-striking Link Lake deformation zone, the northeast-striking Northeast Arm deformation zone, the east-striking segment of the Net–Vermilion lakes deformation zone in Chambers Township, or the east-striking Tasse Lake deformation zone in Chambers Township. However, many gold occurrences are located within the northeast-striking segment of the Net–Vermilion lakes deformation zone in Strathy Township, and along north-trending deformation zones, which strike perpendicularly to the granite-greenstone contact of the Strathy-Chambers batholith in Strathy Township (e.g., Bennett 1978).

The localization of the large number of gold occurrences in the northeast-striking segment of the Net–Vermilion lakes deformation zone is interpreted to reflect the oblique, sinistral component of slip along this zone, which therefore behaved as a dilational "jog" and experienced a component of extension (Fyon et al. 1988). The localization of gold oc-

[1]*The setting and characteristics of the Temagami copper mine have not yet been comprehensively studied during this project, and we, therefore, reserve interpretation of this deposit.*

currences along north-striking deformation zones, clustered close to the south contact of the granite phase of the Strathy-Chambers batholith in Strathy Township, is a mode of occurrence similar to that described elsewhere in the Superior Province (Stott and Smith 1988), and may indicate that this localization of gold was related to emplacement of the Strathy-Chambers batholith. A molybdenite-chalcopyrite-bearing, quartz-cemented breccia pipe, which occurs in basaltic flows of sequence B close to the southern contact of the granite phase of the Strathy-Chambers batholith in northern Strathy Township, may also owe its origin to the emplacement of this granite intrusion (Fyon and O'Donnell 1987).

SUMMARY

A tentative lithostratigraphic subdivision has been extended to both the north and south limbs of the Tetapaga Syncline. The oldest volcano-sedimentary sequence consists of iron-rich, tholeiitic basalt at the base, a middle unit of andesitic rock and an upper unit of rhyolite, capped by oxide-facies iron formation and associated clastic metasedimentary rocks (sequences A and E). A second unit of iron-rich tholeiitic basalt (sequence D) conformably overlies this sequence, and is preserved within the core of the Tetapaga Syncline. Trondhjemitic phases of the Strathy-Chambers and Iceland Lake batholiths share some geochemical characteristics with the andesitic and rhyolitic metavolcanic rocks of sequences A and E, with which they may be comagmatic.

On the north limb of the Tetapaga Syncline, a wedge-shaped sequence of iron-rich, tholeiitic basalt, andesite, and rhyolite (sequence B) is structurally juxtaposed against the adjacent metavolcanics (sequence A) to the north and west, but its contact relationship with a unit of clastic metasedimentary rocks (sequence C) to the south is equivocal. Andesites and rhyolites of sequence B, restricted to the north limb of the Tetapaga Syncline, may be "allochthonous". The geochemistry of the rhyolites at the top of sequence B is consistent with their derivation from a high-level magma chamber (e.g., Lesher et al. 1986), and, as such, they represent a favourable target for exploration of volcanic-associated, massive, base metal sulphides.

Magmatic copper- and nickel-sulphide mineralization occurs associated with a layered gabbro-anorthosite sill (Net Lake intrusion) and a dunite-gabbro stock (Kanichee intrusion), interpreted to be of Archean age and of tholeiitic and komatiitic affinity, respectively (Good 1989). This sulphide mineralization has been locally redistributed into shears and veins during subsequent deformation. The Net Lake sill could contain magmatic iron-titanium-chromium oxide accumulations, although none were observed during our cursory examination.

Virtually all gold occurrences are within the northeast-striking segment of the Net–Vermilion lakes deformation zone in western Strathy Township and several north-striking shear zones which are oriented perpendicularly to the granite-greenstone contact of the Strathy-Chambers batholith. A molybdenite-chalcopyrite-bearing, quartz-cemented breccia pipe also occurs in basalts close to the southern contact of the granite phase of the batholith in northeast Strathy Township. The localization and origin of these occurrences may be related to this granite phase of Strathy-Chambers batholith magmatism.

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19. Breccias of the Sudbury Structure

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INTRODUCTION

The investigations reported here are part of a five-year co-operative scientific project initiated in 1984 between the Ontario Geological Survey and the University of Münster. The aim of this project is to gain a better understanding of the breccias of the Onaping Formation and the breccias in the footwall of the Sudbury Igneous Complex, which will result in a better understanding of the origin of the Sudbury Structure itself. The present studies are in partial fulfillment of the requirements for PhD degrees at the University of Münster.

The breccias of the Onaping Formation were studied in the southeastern part of Capreol Township (Figure 19.1), within an area previously mapped by Muir (1981). This area is easily accessible by gravel roads which extend from Regional Road 86 and from Highway 545. The Sudbury Breccias were investigated mainly southeast and north to northeast of the Sudbury Igneous Complex (Figure 19.2).

MINERAL EXPLORATION

The most productive nickel-copper sulphide deposits of the Sudbury District are located in the southern parts of the area of investigation, but it is beyond the scope of this report to describe the mining and exploration activities that have been carried out in this area by the mining industry over many years.

Close spatial relationships between the Sudbury Breccia and the sulphide-bearing sublayer, as, for example, at the Frood-Stobie Mines in McKim Township and the Manchester Offset in Falconbridge Township, were pointed out by Dressler (1984) and Grant and Bite (1984). The reader is referred to Pye et al. (1984) for detailed information about the economic geology of the area.

To the authors' knowledge no significant mineralization occurs within the breccias of the Onaping Formation in the southeastern part of Capreol Township.

FIELD INVESTIGATIONS

BRECCIAS OF THE ONAPING FORMATION IN THE EAST RANGE OF THE SUDBURY STRUCTURE

M.E. Avermann

Detailed (1:4000 scale) mapping of the breccias of the Onaping Formation in the southern part of the East Range was completed in the 1989 field season.

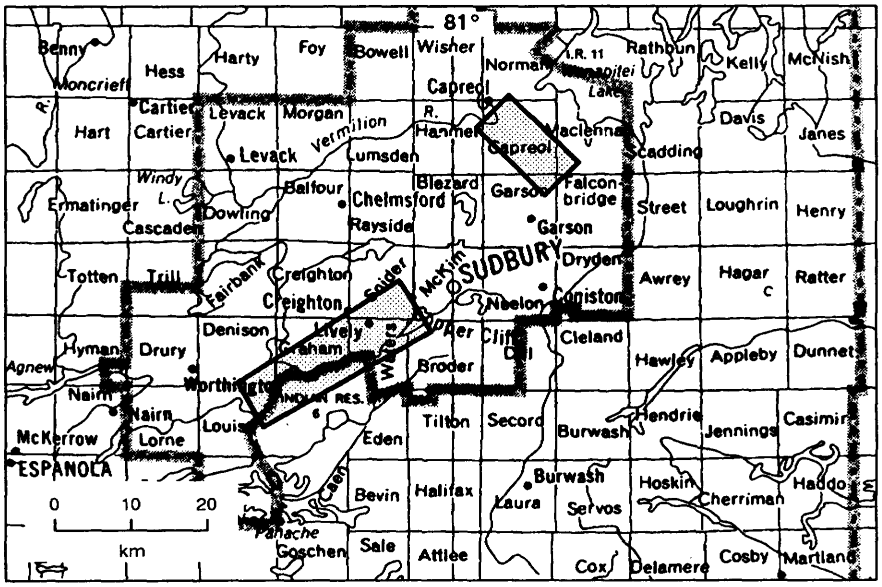

Figure 19.1. *Location map of the study area.*

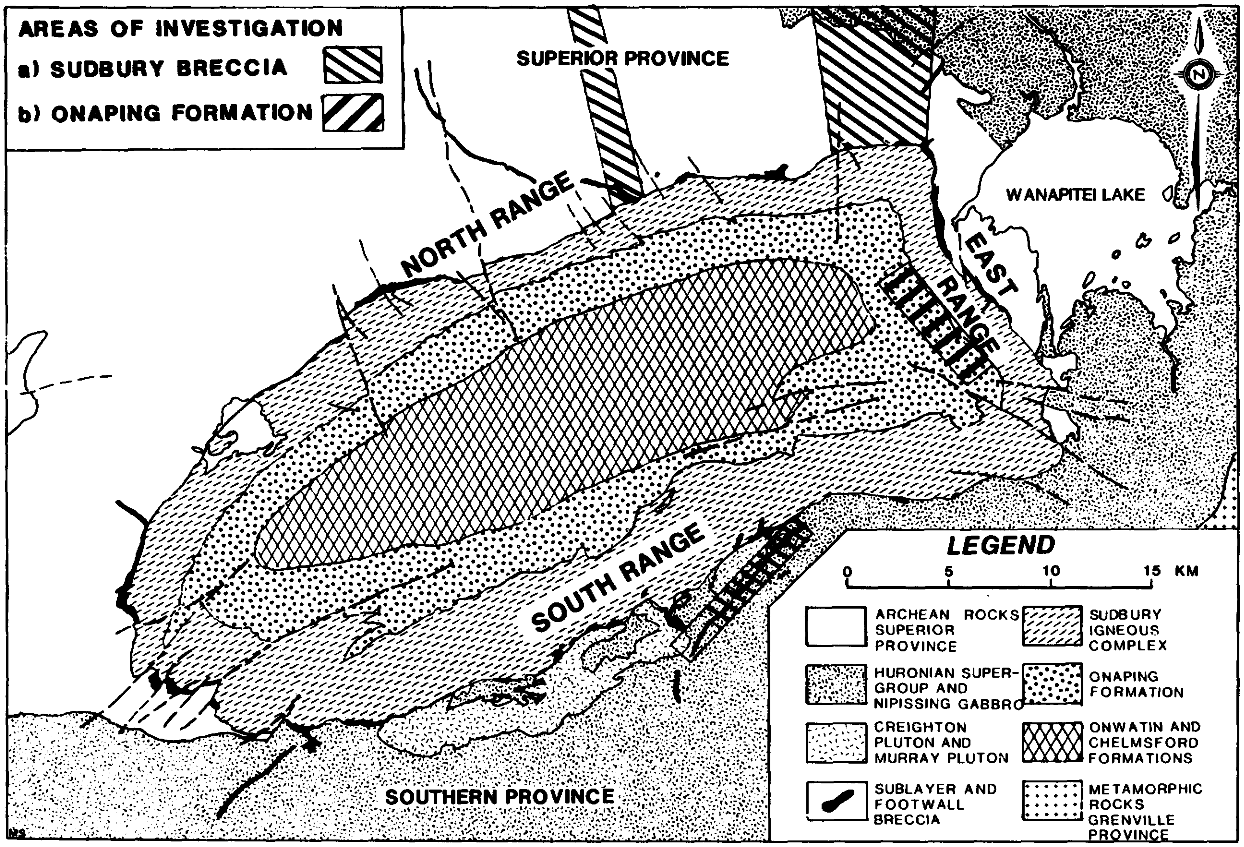

Figure 19.2. *The Sudbury Structure and the location of field areas.*

This study was initiated in 1988 (Avermann and Müller-Mohr 1988).

The Onaping Formation, which has been described in detail by Muir and Peredery (1984), consists of four units: the Basal, Gray and Black members, and the "Melt Bodies". The three members are heterolithic breccias consisting of various Archean and Proterozoic rock fragments. Many of the rock and mineral fragments exhibit shock metamorphic features, such as planar elements in quartz and feldspars. In addition, diaplectic (shock metamorphic) recrystallized glass fragments occur in the Gray and Black members. The Basal Member is similar in appearance to the Gray and Black members, but contains no recrystallized glass fragments. Brockmeyer (in preparation) considers the Basal Member and the "Melt Bodies" to belong to a single unit, and interprets the matrices in both to be igneous. The matrices of the Gray and Black members consist of fine-grained mineral, rock and recrystallized glass fragments.

Investigations in 1989 were focussed on the Gray and Black members. Included in these investigations were the following studies.

1. Breccias within breccias, suggestive of multiple brecciation, have been observed in several places in both the Gray and Black members (Muir and Peredery 1984; Brockmeyer, in preparation). The rock fragments in these two members are mainly supracrustal rocks, derived from units of the Proterozoic Huronian Supergroup. Fragments of Archean granitic and gneissic rocks are also present but are not common. Minor massive sulphide fragments have also been observed.
2. The "chlorite shard horizon" (Muir and Peredery 1984) was investigated in some detail. It lies between the Gray and Black members, is up to 30 m thick, and exhibits gradational contacts with both the Gray and Black members in most places. Only one sharp contact, previously described by Muir (1981), has been observed in the area of investigation. The chloritized shard-bearing horizon is thought to be continuous around the Sudbury Structure (Muir and Peredery 1984) but may be absent in some places.
3. An attempt was made to subdivide the Black Member into two breccia units, based on fragment population and size, and on the carbon content of the matrix. Laboratory investigation will show if this preliminary subdivision can be substantiated.

In addition to these studies, a large number of samples were taken for petrological and geochemical investigations. Whole rock and rare earth element (REE) analyses and carbon isotope studies are planned, hopefully to provide information that will lead to a better understanding of the origin of the Onaping Formation.

SUDBURY BRECCIAS

V. Müller-Mohr

The Sudbury Breccias are pseudotachylites (Dressler 1984) that occur in the footwall rocks of the Sudbury Igneous Complex. This spatial distribution points to a close genetic relationship between these breccias and the Sudbury Structure. The breccias have been previously studied, on a regional basis, by several workers, including Dressler (1984) and Müller-Mohr (1988). Additional references to these studies are given by Dressler (1984).

The Sudbury Breccias occur as dikes or irregularly shaped bodies which range from veins a few millimetres wide to zones tens of metres across. A major part of this year's field work was a study of the largest described breccia zone (Dressler 1984), which is about 11 km long and 350 m wide.

Contacts between the breccia matrix and both host rock and fragments are commonly sharp. Gradational contacts have been observed in only a few places (Dressler 1984). Fragments are mostly rounded to subrounded. In a few places, they are distinctly elongated (this is particularly true of the sedimentary fragments) and some fragments have been stretched to schlieren-like shapes. The fragments are commonly derived from the host rocks, but "exotic" fragments occur in some places, indicating that at least some transport has occurred (e.g., Dressler 1984; Müller-Mohr 1988).

The matrix of the breccia commonly consists of a very fine grained rock flour. In hand specimen, "compact" matrices (without flow lines) or schlieren-like matrices can be distinguished. The latter type of matrix is much more abundant in the breccias hosted by supracrustal rocks of the Huronian Supergroup of the South Range than in breccias hosted by Archean granitic rocks and gneisses of the North Range. In thin section, an igneous matrix with fine pyroxene microliths has been observed, indicating the involvement of a melt phase.

Crosscutting dikes were observed in one outcrop (Kitchener Township) during this year's field season. The matrix of the South Range breccias exhibits a distinct schistosity and an extensive recrystallization of matrix minerals, due to the Penokean Orogeny.

A breccia dike extends about 11 km southward from east of Highway 69 in Blezard Township towards Copper Cliff, in the large zone upon which work was concentrated this year. This dike was mapped in detail in order to increase understanding about the formation of such a large breccia dike. The contacts of the dike are sharp, but small apophyses extend into the host rock. In some places, these apophyses may have led to further brecciation of the host rock, thus supplying the dike with new fragments. Fragments are generally aligned parallel to the contacts but in places exhibit a rather turbulent configuration. Several profiles perpendicular to the length of the dike have been studied and sampled in order to define the intensity of the mixture of fragments within the breccia dike.

Samples of the matrices of large breccia fragments within the breccia dike (i.e., breccias within breccias) were taken in order to compare their geochemistry with that of the matrix of the dike itself. This study will possibly aid in understanding processes of multiple brecciation. A detailed study of the changes in geochemistry across the contact between fragments and matrix will be done to evaluate the degree of mixing between the matrix and the fragments.

The investigation of Sudbury Breccia in the eastern parts of the North Range was confined to profiles extending from the lower contact of the Sudbury Igneous Complex to about 20 km to the north (e.g., along a power line through Bowell, Kitchener and Roberts townships). The distribution, as well as the appearance, of Sudbury Breccia occurrences in this area will be compared with breccias along Highway 144, which were investigated in an earlier stage of the project (Avermann and Müller-Mohr 1988).

Finally, the Sudbury Breccia will be compared with breccias from known impact craters in order to gain a better understanding of its origin.

FUTURE WORK

Field work for these two studies of the breccias of the Sudbury Structure was completed in 1989. Laboratory studies, including petrography and geochemistry, will be used to provide insight into the origin of the matrices of the breccias, the amount of interaction between fragments and matrix, and the processes responsible for the generation of the breccias. An additional component is the comparison of the Sudbury Breccias with those from known impact structures.

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20. Project Unit 88-22. Configuration of the Abitibi Greenstone Belt: Comment on LITHOPROBE Seismic Reflection Profiles

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INTRODUCTION

Understanding how rock units and structures extend to depth is crucial to the understanding of the configuration of Archean greenstone belts and the mineral deposits that they contain. Yet, such depth projections are, in general, poorly constrained. Progress in understanding the "vertical dimension" of the Abitibi greenstone belt is being made through the integration of geological and geophysical data, (*see* Figure 20.1 for location of study area). For example, recent LITHOPROBE seismic reflection experiments in Ontario and Québec indicate that the gold-mineralized regional fault zones, the Destor-Porcupine and the Cadillac-Larder (Figure 20.2), extend to at least 15 km below the surface of the Earth. The profiles also indicate numerous shallowly to moderately dipping geological elements. In this summary, some features of the LITHOPROBE seismic reflection profiles acquired in Ontario, lines 12 and 12A, are described and the geological implications briefly considered.

Details of the geological setting can be found in numerous summary papers (Dimroth et al. 1982; Dimroth et al. 1983a, 1983b; Jensen and Langford 1985; Hubert et al. 1984; MERQ-OGS 1983) and will not be repeated herein. Details of the acquisition and processing of the seismic reflection data, and further information regarding the profiles and their interpretation, can be found in Jackson et al. (1988), Jackson et al. (1989), Mayrand et al. (1988) and Mayrand et al. (1989). Two other manuscripts addressing the interpretation of the seismic reflection profiles are in preparation (Jackson et al., in preparation; Mayrand et al., in preparation).

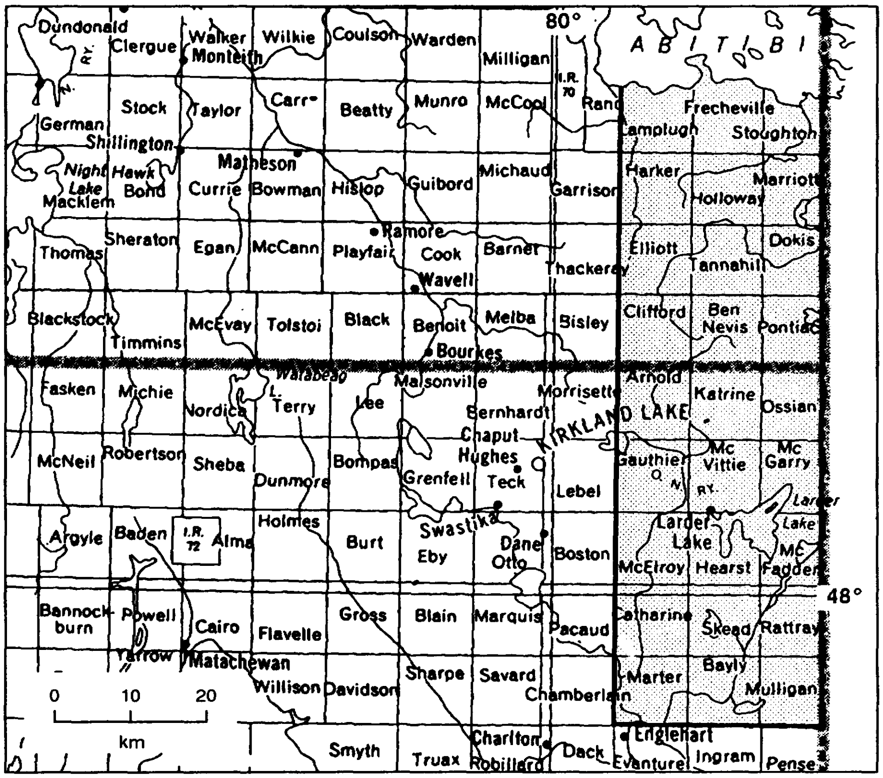

Figure 20.1. *Location map of the study area.*

SEISMIC REFLECTION PROFILES

Line 12 (Figures 20.2 and 20.3) crosses both the Destor-Porcupine Fault Zone and the Cadillac-Larder Fault Zone. The northern half of this line reveals laterally extensive subhorizontal reflective zones. Near the Destor-Porcupine Fault Zone, the reflective zones are disrupted. Based on these disruptions, the fault zone extends to at least 15 km below the surface of the Earth; however, the geometry of the fault zone at depth is not constrained and several interpretations are possible (Figure 20.4). Subhorizontal reflective zones are also present in the southern half of the profile, but are not as laterally extensive as those in the northern half.

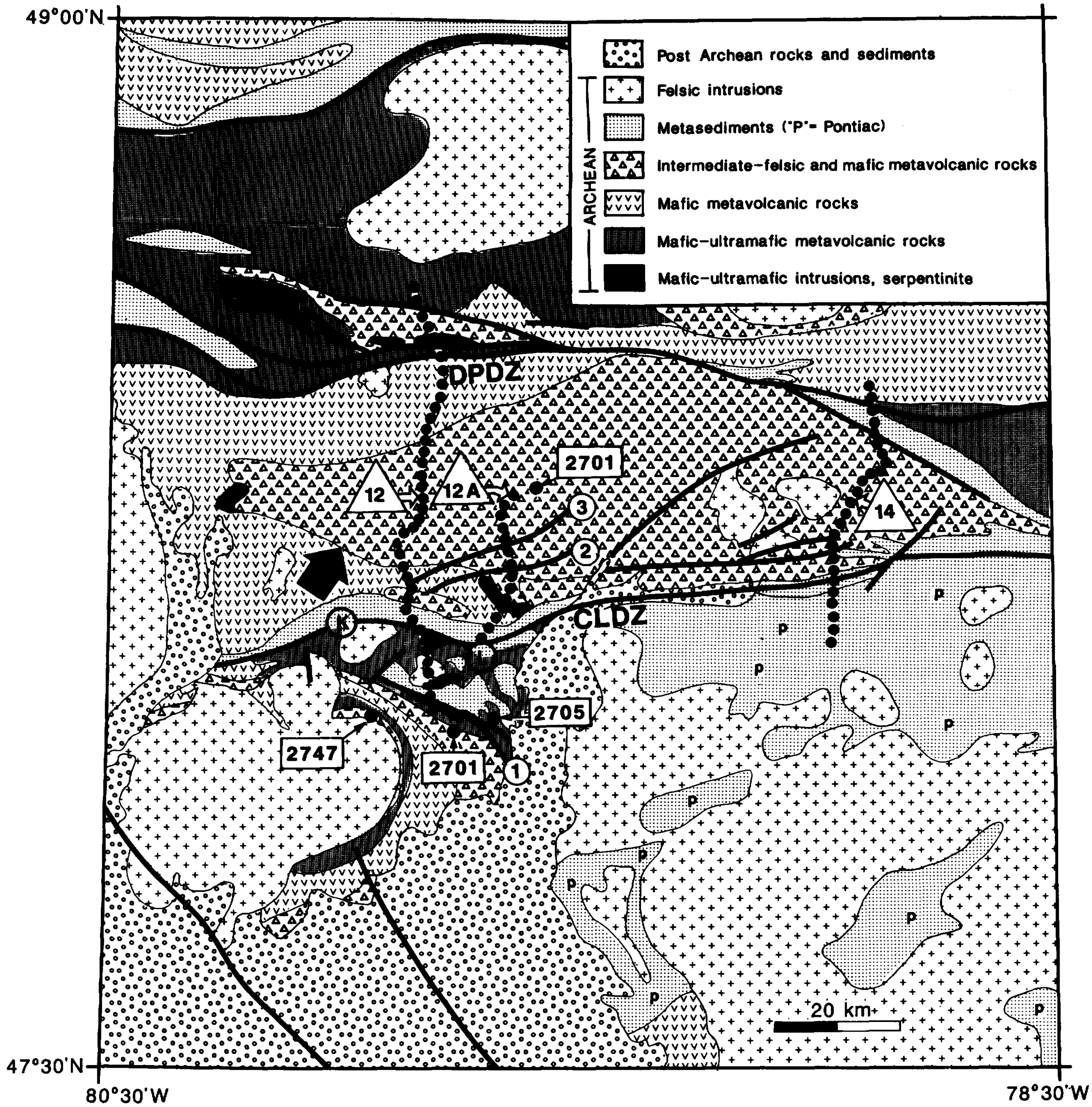

Figure 20.2. *Map showing locations of LITHOPROBE seismic reflection lines 12 and 12A (Ontario), and line 14 (Québec). CLDZ and DPDZ stand for Cadillac-Larder and Destor-Porcupine deformation (fault) zones, respectively. For the "group" names corresponding to lithologic subdivisions of this diagram see MERQ-OGS (1983). The circled 1, 2 and 3 represent the Lincoln-Nipissing Deformation Zone, the Mulven Lake Fault, and the Misema-Mist Lakes Fault, respectively. The circled K and L are the town sites of Kirkland Lake and Larder Lake, respectively. Numbers in rectangles refer to U-Pb zircon ages (from Corfu et al. in press; Mortensen, referenced in Corfu et al., in press). "P" stands for Pontiac metasediments.*

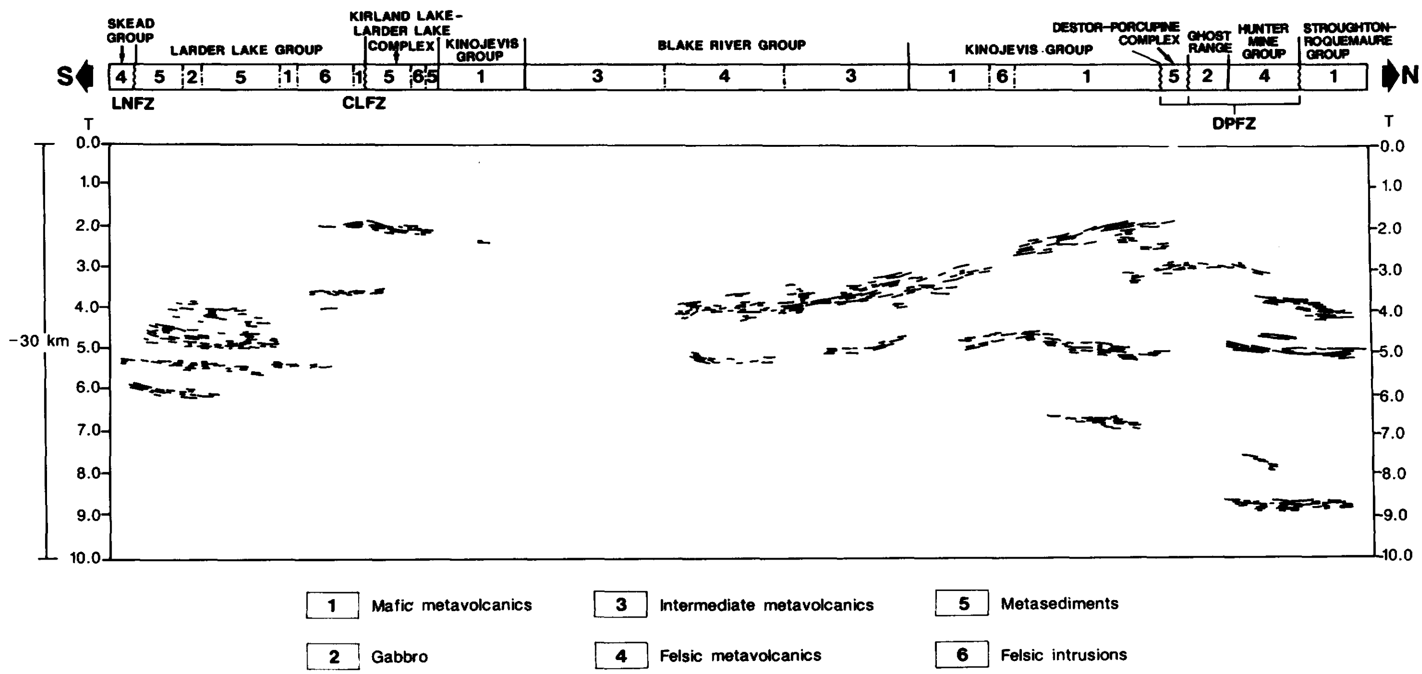

Figure 20.3. *Line sketch of LITHOPROBE seismic reflection line 12. T=two-way travel time in seconds (1 s equals approximately 3 km). Ratio of vertical to horizontal scale is approximately 1.45:1.00. Group names after MERQ-OGS (1983); see also Dimroth et al. (1982) and Jensen and Langford (1985). LNFZ, CLFZ, and DPFZ stand for Lincoln-Nipissing Fault Zone, Cadillac-Larder Fault Zone, and Destor-Porcupine Fault Zone, respectively.*

Line 12A (Figures 20.2 and 20.5) extends from the Cadillac-Larder Fault Zone to the centre of the Blake River Group. The southern half of this profile displays numerous subhorizontal to shallowly dipping reflective zones that terminate beneath the Mulven Lake Fault and/or the Misema-Mist Lakes Fault. This suggests that one or both of these structures extends to a depth of approximately 15 km. The reflective zones in this profile extend at least to the subsurface projection of the Cadillac-Larder Fault Zone. These reflectors are not disrupted north of the fault zone, implying that the fault zone dips to the south, consistent with mine sections near the profile that indicate steep to moderate southerly dips (e.g., Thomson 1943).

DISCUSSION

The most important features of the profiles are: 1) the abundance of subhorizontal reflectors; 2) the lateral extent of some of the reflectors; and 3) the inferred depth of some of the fault zones (i.e., >15 km).

The shallowly dipping nature of the reflective zones and imaging/processing difficulties in the upper 6 km of the profiles make correlation of reflectors with surface geology difficult. Reprocessing of approximately the upper 6 km of the profiles is in progress at both the Geological Survey of Canada and University of Toronto to help resolve the ambiguity in interpretation of these reflectors.

With the exception of the core of the Blake River Group, most of the rock units and structures within the Abitibi greenstone belt are reported to be steeply to moderately dipping; yet the geological elements causing the reflections are subhorizontal. Numerous scenarios can be constructed to explain this paradox, including: 1) surface structures that shallow with depth and/or root in subhorizontal master detachments, as in thrust-imbricated terranes; 2) subhorizontal intrusive bodies; and 3) several generations of listric normal faults—the oldest of which would now be subhorizontal, causing both the reflectors and the general vertical orientation of the units (e.g., Proffett 1977; Gibson et al. 1986; Hodgson 1983).

It is likely that all three scenarios account for at least some of the reflectors for the following reasons. Firstly, the large volume of mafic volcanic rocks preserved in the Abitibi greenstone belt is likely related to some form of extensional tectonic environment. Secondly, large felsic batholiths postdate the mafic volcanism and are widespread within and external to the Abitibi greenstone belt and thus are expected to be present beneath the metavolcanic rocks. Finally, much of the Abitibi greenstone belt was metamorphosed only to subgreenschist to greenschist facies and was subject to regional compressive tectonism; therefore, exposed crustal levels likely suffered some form of thrust imbrication. Indeed, thrust faults are documented in several localities of the Abitibi greenstone belt.

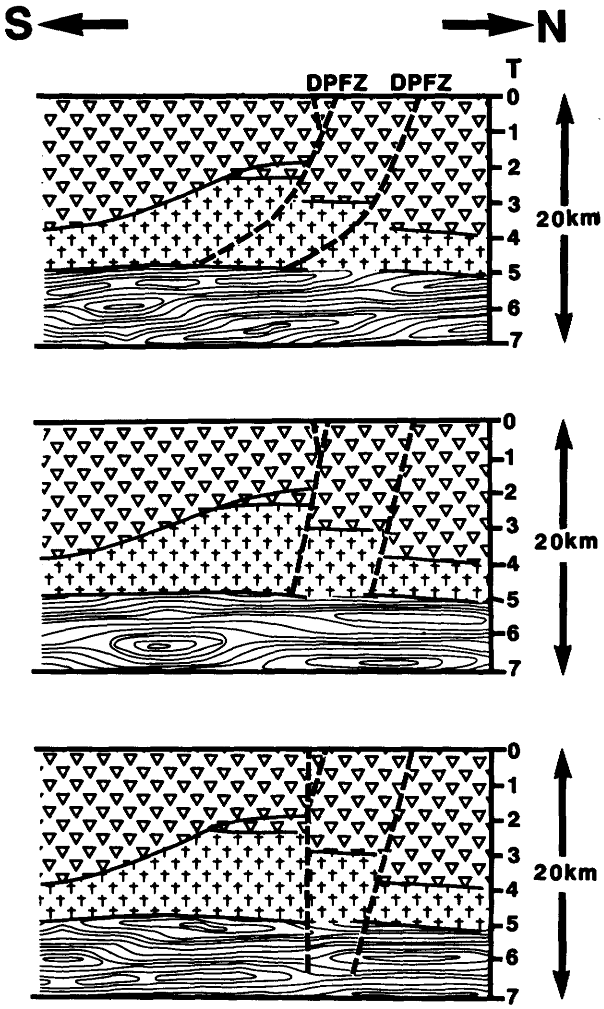

Figure 20.4. *Sketch of some possible extensions to depth of the various branches of the Destor-Porcupine Fault Zone (DPFZ). Regions delineated by triangular pattern, crossed pattern, and wavey pattern are interpreted to consist of supracrustal rocks, felsic intrusive rocks and gneisses, and felsic to mafic gneisses and intrusive rocks, respectively.*

Continued integration of available geological data, new geological data obtained through systematic mapping programs, seismic reflection data, and other geophysical data should result in a better understanding of the configuration of the Abitibi greenstone belt and the setting of its mineral deposits.

ACKNOWLEDGMENTS

In addition to the authors, this summary is based on the efforts of numerous individuals, including: A. Green[1], C. Hubert[2], J. Ludden[2], L. Mayrand[1], B. Milkereit[1], and G. West[3]. The acquisition, processing and interpretation of the seismic data were funded by: Natural Sciences and Engineering Research Council of Canada, Energy Mines and Resources Canada, Ontario Geological Survey, Ministère de l'Énergie et des ressources du Québec, and the mineral industry.

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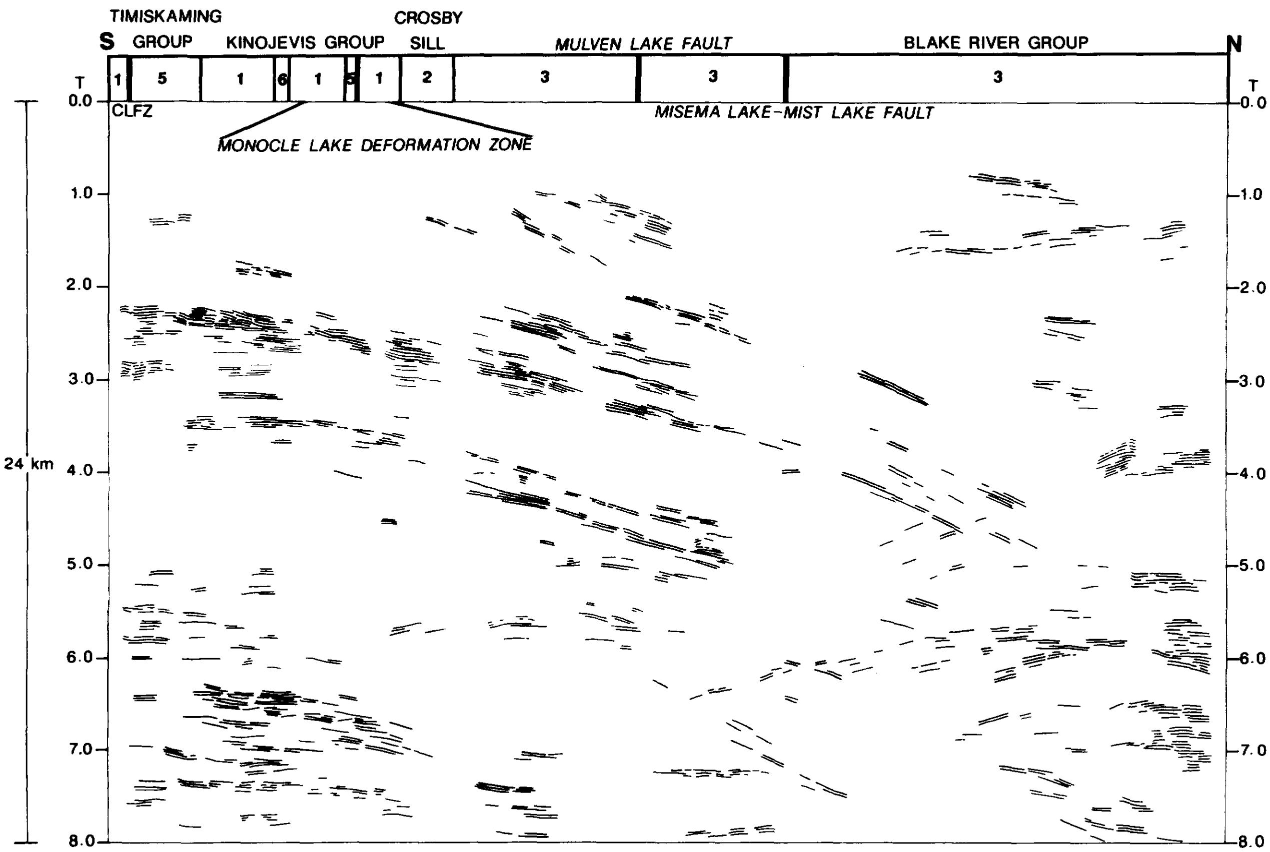

Figure 20.5. *Line sketch of LITHOPROBE seismic reflection line 12A'. T=two-way travel time in seconds (1 s equals approximately 3 km). Ratio of vertical to horizontal scale is approximately 1.45:1.00. Group names after MERQ-OGS (1983); see also Dimroth et al. (1982) and Jensen and Langford (1985). CLFZ stands for Cadillac-Larder Fault Zone. Numbering scheme for lithology as per Figure 3.*

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21. Project Unit 88-33. Geology of Parts of Pacaud, Catharine, and Southernmost Boston and McElroy Townships

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INTRODUCTION

Metavolcanic and metasedimentary rock groups of the Late Archean Abitibi greenstone belt (AGB) are, in general, well-defined (Jensen 1985; Jensen and Langford 1985). How the groups relate to one another, both structurally and stratigraphically, is not as well known. Recent structural (e.g., Hodgson et al., in preparation) and geochronological data (Corfu et al., in press) indicate "out of sequence" stratigraphy and tectonic juxtaposition of units. In addition, recent seismic reflection data (Jackson et al. 1989; Mayrand et al. 1989) reveal numerous subhorizontal reflectors beneath the surface of the AGB, in contrast to the generally reported steep dips of units and structures at surface. These recent developments require that the structure and tectonic history of the AGB be re-examined.

The present map area lies at the northeast margin of the Round Lake Batholith in parts of Catharine, Pacaud, and southernmost Boston and McElroy townships (Figure 21.1). The area is underlain chiefly by mafic to ultramafic metavolcanic rocks and associated subvolcanic intrusions, felsic metavolcaniclastic rocks, granitoid intrusions and numerous dikes. Iron, copper and gold are the main types of mineralization within the area. Recent exploration and mining activity is summarized in Meyer et al. (1988).

A variety of studies and data sets produced by many different individuals during the past 70 years exists for the current map area, including: 1) geological maps of Catharine and Marter townships (Grant 1963), Boston and part of Pacaud townships (Lawton 1959), McElroy and part of Boston townships (Abraham 1951), and Skead Township (Hewitt 1951); 2) synoptic stratigraphic studies, compilation studies, and mineral deposit studies including those of Jensen (1985 and references therein), Ridler (1969 and 1975), Burrows and Hopkins (1922), Bell (1928), Hodgson (1983) and Lafleur (1986); and 3) contoured aeromagnetic maps at 1:20 000 scale (Maps P.2270, P.2271, P.2273, P.2274, Ontario Geological Survey 1979).

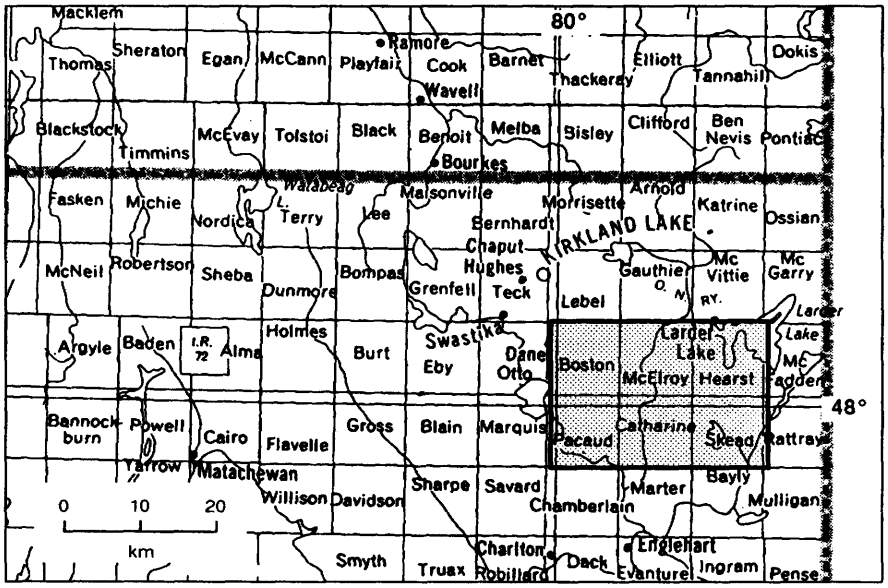

Figure 21.1. *Location map of the study area.*

The purpose of this project, then, is to upgrade mapping coverage of the southern AGB and provide a consistent geological data base. The results of this study will be incorporated into a regional evaluation of the AGB in the Larder Lake area.

GENERAL GEOLOGY

Supracrustal units within the area are divided into two lithostratigraphic groups and one structural complex (Figures 21.2 and 21.3). From the Round Lake Batholith (RLB) outwards, these are (1) the Pacaud Structural Complex, which is a heterogeneous assemblage of highly strained metavolcanic rocks; (2) the Catharine Group comprising mafic to ultramafic metavolcanic rocks; and (3) the ~2701 Ma (Corfu et al. in press), intermediate to felsic, metavolcaniclastic Skead Group (Jensen 1985). The tonalitic-granodioritic RLB, which is ~2.68 to 2.71 Ga (Wanless, *in* Lafleur 1986), occupies most of the western portion of the map area and has a highly

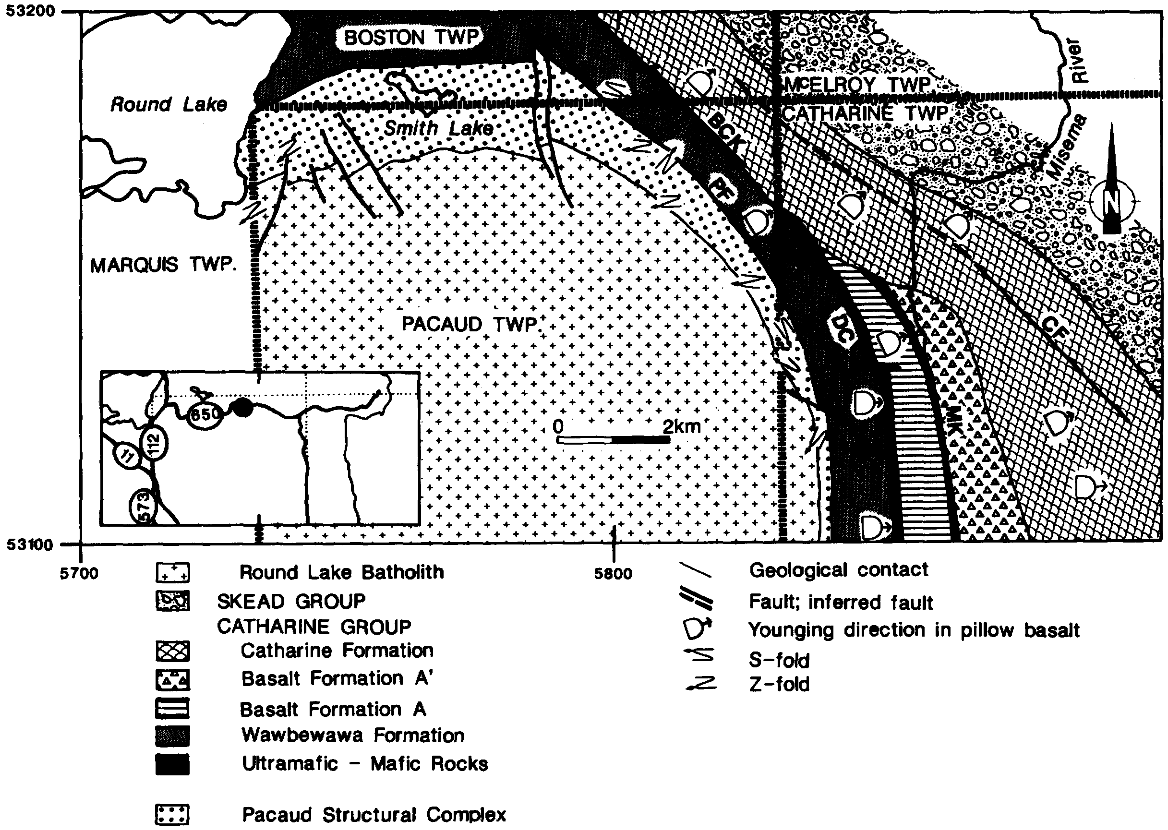

Figure 21.2. *General geology of map area. Numbers at margin of diagram are UTM co-ordinates. "BCK", "DC", and "MK" stand for Boston Creek Komatiite, Depression Complex, and Misema Komatiite, respectively. "PF" and "CF" stand for Pacaud Fault and Catharine Fault, respectively. Inset map shows location of major highways (large numbers) and the hamlet of Boston Creek (dot).*

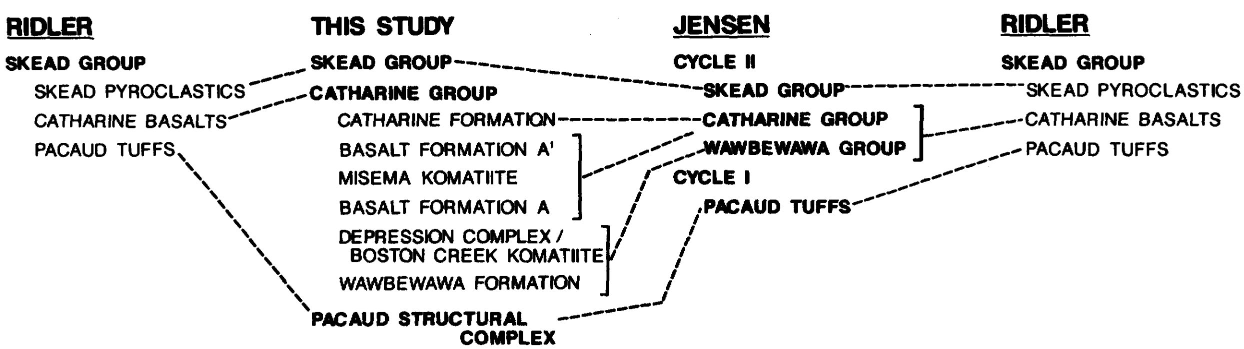

Figure 21.3. *Correlation of nomenclature used in this study with those of Jensen (1985) and Ridler (1969).*

strained (mylonitized) margin in contact with the supracrustal rocks.

The approximate correlations of subdivisions made in this study with those of Jensen (1985) and Ridler (1969) are shown in Figure 21.3. In this report, "Catharine Group" refers to all the metavolcanic rocks between the Pacaud Structural Complex and the Skead Group, and "Catharine Formation" refers to a specific subunit of this group (Figures 21.2 and 21.3). Names used in this report are informal and are used for ease of discussion and description.

LITHOLOGY

ROUND LAKE BATHOLITH

Within the map area, the RLB is represented by foliated biotite ± hornblende tonalite to granodiorite. Descriptions of units, their geochemistry, and a summary of mineralization of the batholith can be found in Lafleur and Hogarth (1981) and in Lafleur (1986).

SUPRACRUSTAL ROCKS

Pacaud Structural Complex

The Pacaud Structural Complex is a heterogeneous assemblage of highly strained supracrustal rocks that are metamorphosed, in general, to greenschist facies (Jolly 1978). The Pacaud Structural Complex was previously referred to as the "Pacaud Tuffs" (e.g., Ridler 1969; Jensen 1985). These rocks were called "tuffs" because of their fine grain size and well-banded character adjacent to the RLB; however, "...the banding may be partly due to shearing parallel to the margins of the Round Lake Batholith since other primary textures such as graded bedding, cut and fill, crossbedding and so on, have not been reported... (despite) ...specific search in regions of excellent rock exposure..." (Ridler 1969, p.14). Principal lithologies within the complex include compositionally banded mafic to intermediate rocks, foliated massive flows and/or sills, moderately to highly strained pillow basalts, felsic to siliceous banded rocks, and a persistent lens of sulphide facies (locally oxide facies) iron formation adjacent to the batholith (e.g., Lawton 1959). The complex tends to be intermediate to mafic (locally felsic) in composition near the batholith and mafic (locally ultramafic) towards the Catharine group.

The fine grain size and banded character of many rocks within the Pacaud Structural Complex, interpreted previously to be of primary origin (e.g., Ridler 1969 and 1975), are interpreted here to reflect the highly strained state of the rocks. Structures that indicate high strain include isoclinal and rootless folds of layering, quartz veins and felsic veinlets; foliation fish (e.g., Hanmer 1986); tightly folded and attenuated pillow selvages; and millimetre-wide veinlets that have small (1 to 2 mm wide) feldspar porphyroclast trains. These structures likely formed as a result of diapiric emplacement of the RLB into the metavolcanic assemblage.

Numerous dikes are present within the Pacaud Structural Complex and include biotite lamprophyre, feldspar ± quartz porphyry, diorite and syenite. Dikes comparable to the RLB were not found in the map area. Most dikes are not as deformed as the rocks that enclose them; however, some quartz-feldspar porphyry dikes and aphanitic felsic dikes are foliated, folded and boudinaged.

Southeast of Boston Creek, the Pacaud Fault separates the Pacaud Structural Complex from the Wawbewawa Formation. Between Round Lake and Boston Creek, however, there is a southward transition (~200 m) from low-strain, pillowed basalts (delineated as "Wawbewawa" by Jensen 1985) into highly strained mafic rocks of the Pacaud Structural Complex. Within this transition zone, both highly strained banded mafic rocks and pillowed basalts are present.

Catharine Group

The Catharine Group consists principally of mafic to ultramafic metavolcanic rocks and subvolcanic intrusions (Figures 21.2 and 21.3). Formations of the group young eastward away from the RLB. Units are described here in the sequence that they occur outwards from the RLB. This order does not, however, represent a stratigraphic order. Indeed, the distribution of units suggests structural juxtaposition of units and, consequently, "stratigraphic" reconstructions should be approached with caution.

The Wawbewawa Formation is defined as the mafic metavolcanic succession that lies north and east of the Pacaud Structural Complex and west of the Boston Creek Komatiite and the Depression Complex. This formation consists principally of pillowed basalts and associated massive, medium-grained flows and/or gabbroic sills. Pillowed basalts of the formation are generally pale green, aphanitic, and non-amygdaloidal. Massive, polysutured ultramafic rocks are locally present towards the top of the formation. In the Smith Lake area, basalts are darker green than, but presumably correlative with (e.g., Jensen 1985), those of the Wawbewawa Formation east of the RLB.

The Boston Creek Komatiite, the Depression Complex, and the Misema Komatiite are ultramafic-mafic rocks that, because of pyroxene-spinifex texture, are interpreted to be of flow origin. All three units are magnetite-bearing and have associated positive aeromagnetic anomalies (Ontario Geological Survey 1979).

The Boston Creek Komatiite has been well studied near O'Donald Lake (Stone et al. 1987). Mapping during the present survey has extended the known limits of the flow another 1.5 km to the southeast. If this unit is correlative with either the Depression Complex or the Misema Komatiite, then its strike length exceeds 15 km. Pyroxene crystals forming the spinifex texture are subhorizontal, indicating that the flow is dipping nearly vertically. The flow is locally highly differentiated and is laterally variable in both degree of differentiation and in thickness. In Pacaud Township (south of the "K" in "BCK" of Figure 21.2), an exceptionally differentiated ~75 m section of the flow consists of five main layers. From base to top, these are: (1) serpentinized peridotite, (2) magnetite-bearing, cumulate pyroxenite containing pyroxene crystals subparallel to the base of the flow, (3) magnetite-bearing gabbro that increases in plagioclase content upwards until the rock is a leucocratic magnetite-bearing leucogabbro to anorthosite, (4) very coarse pyroxenite to gabbro (pyroxene crystals, pseudomorphed by amphibole, are ~10 to 20 cm long and 1 to 2 cm wide) with leucogabbro anorthosite interstitial to, and crosscut, the large pyroxene crystals, and (5) pyroxene spinifex-textured rock at the top of the flow. The top of the flow is in conformable (?) contact with a thin, intermediate to felsic tuff and fine-grained metasediment.

The Depression Complex crops out, rather poorly, in a topographic depression in western Catharine Township, south of the Boston Creek Komatiite. The complex contains ultramafic and mafic rocks similar to some layers of the Boston Creek Komatiite, including medium-grained, magnetite-rich gabbro and leucogabbro, and coarse-grained gabbro to pyroxenite. Spinifex texture was identified in two locations. This unit is associated with a large aeromagnetic anomaly that is larger than that of the Misema Komatiite, but comparable to that of the Boston Creek Komatiite. This suggests that the Depression Complex and Boston Creek Komatiite might be correlative.

The Misema Komatiite is a pyroxene spinifex-bearing ultramafic flow that crops out in the Misema River valley, extending from at least 1 km south of the Catharine–Marter township boundary to two-thirds of the way up Catharine Township, where it angles northwest towards the Boston Creek Komatiite. In contrast to the Boston Creek Komatiite and the Depression Complex, a magnetite-bearing leucogabbro-anorthosite zone has not been found in association with the Misema Komatiite.

Between the Depression Complex and the Misema Komatiite are massive to pillowed, basaltic flows and/or sills and medium- to coarse-grained subvolcanic gabbro ("Basalt Formation A" of Figures 21.2 and 21.3). The flows tend to be grey to dark grey and, less commonly, green in colour. Characteristically, the basalt flows are commonly plagioclase phenocrystic to glomeroporphyritic. Between the Misema Komatiite and Catharine Formation are basalts and gabbroic rocks similar to "Basalt Formation A" and referred to here as "Basalt Formation A′". "Basalt Formation A′" differs from "A" in that the flows tend to be pale green, amygdules are common, and plagioclase phenocrystic to glomeroporphyritic flows are not as common.

The Catharine Formation consists predominantly of dark grey to black, amygdaloidal, pillowed basalts and subordinate massive flows and/or sills. Variolitic basalts are present near the top of the formation and are spatially associated with the Catharine Fault. The base of the formation cuts across other formations of the metavolcanic section and suggests that the base of the formation is at or near a fault. The top of the formation is in sharp contact with the Skead Group. The intermediate to felsic metavolcanic rocks of the Skead Group within 1 to 2 m of this contact are locally schistose or in sheared contact with the top of the Catharine Group. Embayed contacts, without obvious shearing, can also be observed. The contact between the Catharine and Skead groups is interpreted as a sheared primary contact.

Skead Group

The Skead Group consists predominantly of intermediate to felsic metavolcaniclastic rocks (e.g., Hewitt 1951; Abraham 1951; Lawton 1959; Grant 1963; Jensen 1985). The main rock types are bedded tuffs, heterolithic to monolithic fragmental rocks, massive feldspar ± quartz-bearing units, and minor greywacke and conglomerate. Fragmental units within the group are highly variable with respect to lithology and angularity of fragments and the degree to which the fragments are either clast or matrix supported. Bedding contacts are not common, but can be found in the finer grained units, particularly near the contact with the Catharine Formation. In general, the Skead Group does not display penetrative fabric; however, fractures are common.

STRUCTURAL GEOLOGY

ROUND LAKE BATHOLITH STRAIN AUREOLE

The most prominent structural feature of the map area is the high strain zone localized at the contact between the Round Lake Batholith and the metavolcanic rocks. Penetrative deformation in this zone is subparallel to the batholith supracrustal contact and decreases in intensity away from the contact in both directions.

Within approximately 1 km of the batholith-supracrustal contact, the RLB is a well-foliated, protomylonitic to mylonitic, commonly gneissic, tonalite to granodiorite. Ribbon quartz and rotated and rounded feldspars are common within this region. Steeply plunging lineations, including quartz elongations, amphibole, and elongate biotite aggregates, are locally present.

The supracrustal rocks of the Pacaud Structural Complex possess a penetrative mica foliation subparallel to the margin of the batholith. This foliation is locally axial planar to folds of compositional layering and is itself commonly folded and kinked. The folds and kinks have variable plunges, but, their asymmetry in most cases indicates that the batholith side moved up relative to the surrounding supracrustal rocks (i.e., folds "climb" towards the supracrustal rocks, not the batholith). Locally, the penetrative foliation is overprinted by an east-trending crenulation cleavage. Other structural features indicating high strain within the complex have been noted in the lithologic descriptions.

MESOSCOPIC STRUCTURES IN THE CATHARINE GROUP

Penetrative fabrics within the Catharine group tend to be subparallel to the margin of the RLB and decrease in intensity away from the batholith. At distances greater than ~1.5 km away from the batholith, in southern Catharine Township, penetrative foliations are difficult to discern. In northern Catharine and Pacaud townships, penetrative foliations are common.

Fractures, fracture cleavages and quartz veins are common structures that postdate the penetrative foliations. Common orientations for these features are northeast, north, and east-southeast. Shallow, north-dipping quartz veins and fractures are also locally abundant. The orientations of fractures, fracture cleavages and quartz veins mimic the orientations of the main map-scale faults (see below).

FAULTS

Numerous faults and local shear zones crosscut rocks within the region. The most prominent fault types are: (1) faults radial to the RLB (*see* Lawton 1957), (2) the northwest-trending Pacaud and Catharine faults, and (3) northeast-trending, small-displacement faults that disrupt the Boston Creek Komatiite (*see* Lawton 1959).

The northwest-trending Pacaud Fault was recognized by Lawton (1959) on the basis of discordance between foliation directions in the Pacaud Structural Complex (" Pacaud Tuffs") and the adjacent mafic metavolcanic rocks. Localized shearing, folded and boudinaged quartz veins, slight carbonate alteration and pyritization at a railway outcrop north of Boston Creek are presumably related to the fault. Talc schists are present within some of the shear zones. Preliminary interpretation of fold and fabric relationships suggests that southeast-side-up dextral displacement occurred along the fault.

The northwest-trending Catharine Fault and related structures are located within the Catharine Formation near the contact between the Catharine and Skead groups. This fault is characterized by intense fracturing, shearing, quartz and locally quartz-tourmaline and tourmaline veins, carbonate $\pm$ green mica alteration and gold mineralization. Variolitic basalts and small gabbroic and felsic intrusive rocks commonly are spatially associated with this fault. The fault is well developed in central Catharine Township, but not as well developed in northwestern Catharine and southeastern Boston townships. Interpretation of quartz vein arrays, rotated quartz veins, offset veins, and bridging structures indicate dextral shear along the fault.

Other zones of shearing and faulting include well-developed schistosities within the Skead Group near the contact with the Catharine Group; an east-trending zone of shearing and carbonate alteration on the east and west sides of Smith Lake; and local, carbonatized quartz vein-bearing shear zones beneath the base of the Misema Komatiite and near the base of the Catharine Formation.

METAMORPHISM

Metamorphic grade within the metavolcanic rocks around the RLB is generally of greenschist facies. Around the much smaller syenitic Otto stock, there is an amphibolite facies aureole (Jolly 1978). Samples were collected to examine the relationship between metamorphism, deformation and the granitoid rocks.

ECONOMIC GEOLOGY

Iron, copper and gold are the main types of mineralization within the map area.

Iron and copper mineralization is primarily restricted to a small sulphide facies iron formation lens around the Round Lake batholith (*see* Lawton 1959). The copper mineralization is in the form of copper sulphide (mainly chalcopyrite and bornite) replacement of iron formation minerals (Bell 1928). The mineralization appears to be localized by cross faults that cut both the batholith and the iron formation (Bell 1928).

Gold mineralization is, in general, restricted to a northwest-trending corridor near the Catharine Fault. Gold occurs primarily in sulphide-bearing quartz veins that are enclosed in carbonate-altered and pyritized country rocks. The degree of fracturing, shearing, carbonate alteration and quartz $\pm$ tourmaline veining appears to be highest in central Catharine Township. Shallowly dipping quartz veins north and south of the fault (e.g., the Miller Independence gold mineralized quartz vein; Lawton 1959) may be "flat veins" that splay from the main fault.

DISCUSSION

CATHARINE FAULT

The spatial correlation of variolitic basalts and the Catharine Fault invites speculation that either there is a favourable stratigraphic localization of the fault, or perhaps that the variolite-forming process, in this area, is in some way linked to hydrothermal and mechanical processes that formed the Catharine Fault. In either case, the correlation of the variolitic basalts and the fault can be used as an exploration aid in this area.

DISTRIBUTION OF METAVOLCANIC ROCKS

From Figure 21.2, it can be seen that the Catharine Formation truncates other metavolcanic formations. In addition, local shearing was observed near the base of the formation. If the truncation of these units were a primary volcanic feature (e.g., volcanic unconformity), then, because of the angularity of the truncation, talus-like deposits might be expected near the truncation. Such deposits were not observed. Although a tectonic origin for the truncation of units is favoured, it is not known what the orientation of the units was when they were truncated (e.g., thrust-imbrication versus strike-slip displacement).

The distribution of lithologic units within the present area and the fault interpretation used to explain this distribution may hold true for a much larger area than that of this study. Between the northeast margin of the RLB and the southeast margin of the McElroy Stock, the apparent across-strike thickness of the Catharine and Skead groups is approximately one half of that between the western margin of the batholith and eastern Saint Anthony Lake (*see* Map 2205, Pyke et al. 1973). This apparent thickening could be explained by regional faulting similar to that proposed for the present map area (e.g., Figure 21.4). Alternatively, a primary thickening of the volcanic pile may also account for the thickening of some units (e.g., Skead Group; Jensen 1985).

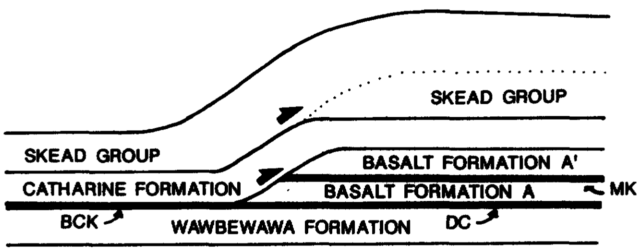

Figure 21.4. *Diagram illustrating how the increase in width of Catharine and Skead groups, within and east of map area (see map in Pyke et al. 1973; and discussion in text), can be explained. Faults indicated are inferred.*

EMPLACEMENT OF THE ROUND LAKE BATHOLITH

Lafleur (1986) concluded that the final stage of ascension of the Round Lake Batholith was accommodated by solid state diapirism. This mechanism explains the lack of a significant thermal aureole, the rounded nature of the eastern margin, and the solid state deformation features of the margin of the batholith. The presence of folds of foliation that "climb" away from the batholith and the paucity of tonalite dikes in the surrounding country rocks in the present map area are additional data that support Lafleur's conclusions.

SUMMARY

To date, the principal results of this study of the stratigraphy and structural geology of the Abitibi greenstone belt in the Larder Lake area are:

1. Newly identified basalt and komatiite units have been mapped.
2. The distribution of map units suggests regional tectonic truncation and juxtaposition of units.
3. Rocks adjacent to the Round Lake Batholith, previously delineated as "tuffs", consist almost entirely of highly strained mafic metavolcanic rocks.
4. At least the final stages of emplacement of the Round Lake Batholith were accomplished by solid state diapirism.
5. There is a brittle-ductile, carbonatized, gold mineralized, northwest-trending fault near the contact between the Catharine and Skead groups.

ACKNOWLEDGMENTS

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22. Project Unit 88-06. The Geological Setting of Gold Mineralization in the Horwood Lake Area of the Swayze Belt

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INTRODUCTION

The aim of this project, initiated in 1988 (Siragusa 1988), is to assist gold exploration in the Swayze belt by documenting the geological setting of known occurrences in the belt. During the 1989 field season, occurrences in the Horwood Lake area (Figure 22.1) were examined. Three occurrences were mapped at a 1:200 scale, and sampled for lithogeochemical and petrological studies. In addition, the Joburke Mine area near Mackeith Lake in northeastern Keith Township was examined briefly, and reconnaissance traverses were carried out to locate other occurrences for future study.

GENERAL GEOLOGICAL SETTING

The area in which the three occurrences are located is dominantly underlain by tholeiitic, often pillowed, basalt of greenschist facies metamorphic rank. Subordinate lithologies include minor felsic metavolcanic rocks, stocks of hornblende metagabbro and serpentinite, and granitic intrusions. The area is transected by two major faults; the Horwood Lake fault (Breaks 1978), which trends north through the study area, and the Hardiman Bay fault (Breaks 1978), which trends approximately northeast through the study area. The two faults intersect in south-central Horwood Township.

DETAILED INVESTIGATIONS

Occurrence 1

The first occurrence examined in detail is in southeastern Silk Township (Figure 22.2), and is hosted by a relatively small metagabbro unit on the south side of a segment of the east-northeast-trending Hardiman Bay fault. This occurrence is currently owned by Orofino Resources Limited (formerly Orofino Mines Limited), a subsidiary of Northgate Exploration Limited. Gold was discovered here in 1933 (Laird 1936). Since then, the property has been extensively explored by several companies, including Hollinger Consolidated Gold Mines Limited, Orofino Mines Limited, Camflo Mines Limited and Northgate Exploration Limited. The most recent work, which began in October 1987 and was completed in June 1988, comprised a program of underground development. This development, described

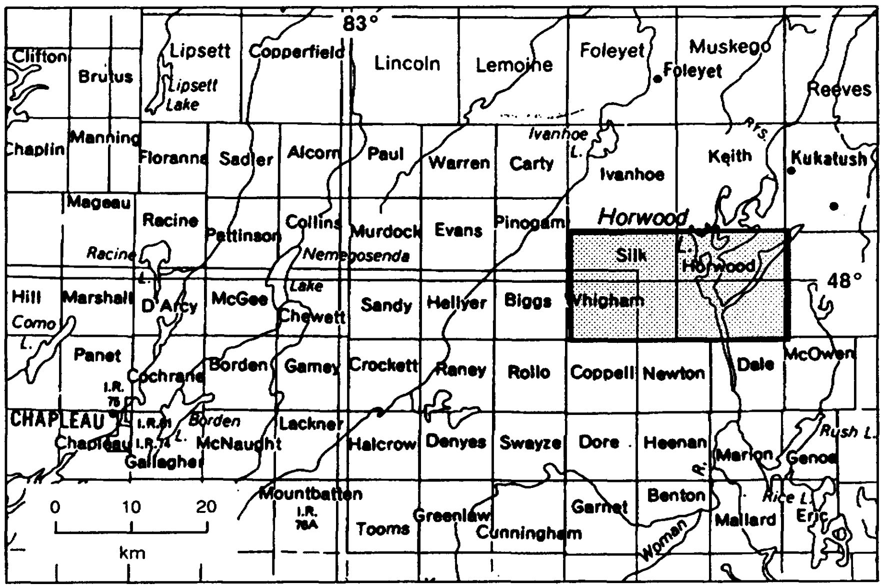

Figure 22.1. *Location map of the study area.*

in detail by Luhta et al. (1989), included a decline driven for 682 m, crosscutting and drifting (at three sublevels) totalling 1008 m, raising for 241 m, and drilling of 145 holes totalling 3683 m. Surface drilling of 12 holes totalling 427 m was also completed.

It was recently reported that:

"Proven, probable and mineable reserves to a depth of 340 feet stand at 136,500 tons grading 0.203 oz gold per ton. Below the 340 ft level, the company has outlined geological reserves of 1.3 million tons grading 0.11 oz. That includes 500,000 tons of grade 0.18 between the 340 and 950 ft levels." (*The Northern Miner* 1989)

Although the underground workings were inaccessible during the 1989 field season, excellent exposures in clearings north and south of the shaft provided information about the mineralization and its setting. Most outcrops in the southern clearing consist of uniform hornblende metagabbro. One or more of quartz veins, a moderately developed gossan, and porphyry dikelets are present in a few scattered localities. Textural variations suggestive of

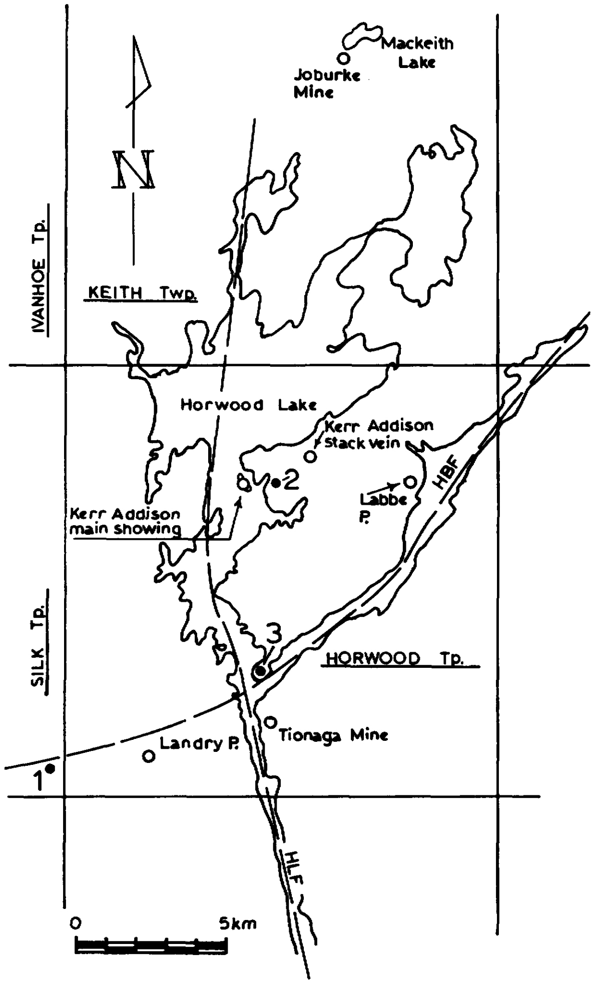

Figure 22.2. *Locations of occurrences mapped in detail (full circles) and of other localities visited (open circles). HLF = Horwood Lake Fault, HBF = Hardiman Bay Fault.*

gradational contacts between metagabbro and metavolcanic rocks were observed on the western edge of the southern clearing. Similar contact relationships between gabbro and volcanic rocks have been observed in drill core from this property (W.F. Gilman, Northgate Exploration Limited, personal communication, 1989). Breaks (1978), however, reported chilled intrusive contacts of metagabbro in the general area. This suggests that, as in other parts of the Swayze belt (Siragusa 1987), metagabbro and metabasalt may be comagmatic, and that the variable contact relationships reflect local emplacement conditions.

The northern clearing is more interesting, as it contains exposures of variably silicified metagabbro, two kinds of porphyry, and a relatively pronounced gossan. Detailed mapping and geochemical sampling were completed on these outcrops. The field relationships indicate that the metagabbro was first affected by brittle deformation, which produced extensive fracturing, dominantly along an east to east-northeast trend. This trend is parallel to the segment of the Hardiman Bay fault on the north side of the occurrence. Fractures dip to both the north and south. Sheet-like quartz veins occupy some of the fractures or segments of them, and represent the earliest silicification seen in the area. The veins vary from less than 1 cm to a maximum of about 9 cm in thickness, and some contain sparse to locally massive concentrations of pyrite and chalcopyrite. Disseminations or small nodules of these sulphides, however, are also randomly distributed in the metagabbro.

The metagabbro, and the quartz veins occupying the fractures, underwent further brittle deformation associated with the emplacement of porphyritic intrusive rocks. One of these intrusions is leucocratic, and is characterized by ubiquitous and dominantly euhedral plagioclase phenocrysts. This rock truncates the quartz veins hosted by the metagabbro, with contacts that are commonly very sharp and angular in outline. As the prominent dikes of this leucocratic porphyry were intruded along northeast and southeast trends, the outcrop pattern of this rock is unusually X-shaped.

Both the metagabbro and the leucocratic porphyry are intruded by a fine-grained, reddish-grey, quartz-poor porphyry, which contains minute dark phenocrysts of both tabular and acicular habit. It is apparently less abundant than the leucocratic porphyry. Buckling of small dikes of this rock in metagabbro, and partial shearing of a larger unit which intrudes both metagabbro and leucocratic porphyry, indicate moderate deformation after its intrusion. The prominent outcrop pattern is also X-shaped, and essentially parallel to that of the leucocratic porphyry. At one locality, a 40 cm thick dike of this rock occurs in the centre of a larger dike of leucocratic porphyry.

Silicification, associated with the intrusion of both types of porphyry, consists of small quartz lenses or discontinuous veinlets, locally found along their contacts. In the area mapped, this later silicification appears to be less traceable and considerably less abundant than the silicification that predated the emplacement of the porphyries.

Occurrence 2

Occurrence 2, which is hosted by metavolcanic rocks, is east of the Horwood Lake fault. The location of this occurrence appears to be that recorded for the Lefever–Desourdy–Silams occurrence (Mineral Deposit Files, Geoscience Data Centre, Ontario Geological Survey; Gordon et al. 1979). The descriptions of this occurrence in these references, however, differ significantly from the observations made by the author.

Occurrence 2 consists of a subvertical, northwest-trending quartz vein, which is up to 10 cm thick and contains disseminated to massive pyrite, pyrrhotite and chalcopyrite. It is hosted by moderately foliated, northwest-trending, felsic metavolcanic rocks which dip steeply to the northeast. The vein is intermittently exposed over a strike length of approximately 30 m.

The southern tip of the vein abuts against a diabase dike. Apart from the northerly trend of this dike, no structural feature appears to reflect the presence of the nearby Horwood Lake fault.

Occurrence 3

Occurrence 3, known as the "Deburmac prospect" (Gordon et al. 1979), is hosted by metavolcanic rocks and is located virtually at the intersection of the Horwood Lake and Hardiman Bay faults. Past exploration of the Deburmac prospect included test pitting (1933 to 1936) and at least 850 m (2788 feet) of diamond drilling (1946). Values up to 0.40 ounce of gold per ton were reportedly obtained in surface sampling, but no encouraging results were obtained by diamond drilling.

In the summer of 1989, three old trenches were found approximately 88 m inland of the northern shore of Horwood Lake. Two were completely filled by overburden. The largest trench is 36 m long, about 4 m wide and 4 m deep. Sheared, carbonatized basalt, with a maximum exposed width of about 90 cm and a total exposed length of 2 m, occurs in western segments of this trench. The carbonatized basalt contains a 5 cm thick, sheared quartz vein. A strong gossan affects the quartz vein and its host. The shearing trends northwest and dips northeast, which differs from the attitude of both the Horwood Lake and the Hardiman Bay faults.

RECONNAISSANCE INVESTIGATIONS

Joburke Mine Area

In the summer of 1989, exploration was being carried out at several localities near the Joburke Mine, a past producer of 16 467 ounces of gold (Gordon et al. 1979). This work included stripping to remove overburden, pressurized water cleaning of outcrops, and diamond drilling. Features pertinent to gold mineralization that are readily apparent in outcrops include widespread east-trending ductile shearing and an abundance of carbonatization and gossans.

Other Localities

The Labbe prospect (Gordon et al. 1979) was examined in a reconnaissance fashion. This occurrence is exposed in a contact zone between basalt and granite, close to the north-northeast-trending segment of the Hardiman Bay fault. Here, relatively major shearing affects the granite, but not the basalt. The shearing trends 090°, although the Hardiman Bay fault is nearby.

Evidence of past exploration was found at four other occurrences. These include the Landry prospect (Gordon et al. 1979), the Kerr Addison main showing, the Kerr Addison stack vein (Gordon et al. 1979), and the Tionaga Mine, a past producer of 2299 ounces of gold and 404 ounces of silver. In the summer of 1989, the headframe of the Tionaga Mine was still standing, but no outcrop was accessible at the shaft site. Low gold values in the nearby muck pile were previously reported (Thurston et al. 1977).

CONCLUSIONS

Several gold occurrences, including a past producer (Tionaga Mine), are clustered around Horwood Lake, which is the locus of two prominent intersecting faults.

A possible genetic relationship between these faults and gold occurrences was considered. Data from the mapping of the Orofino occurrence are consistent with this possibility, in that silicification of fractures parallel to one of these faults resulted in the mineralized quartz veins in the metagabbro. It is also apparent, however, that the mechanical response to deformation of the metagabbro was dominantly brittle, while that of the metabasalt was mainly creep. Furthermore, the metagabbro is enclosed by metabasalt, and this condition, per se, could be the main reason why fracturing and accompanying favourable dilatancy developed in the metagabbro. Such a condition, therefore, is possibly more significant than the similarity in trend between fractures and fault. In addition, the structural trends of three other occurrences (Numbers 2 and 3, and the Labbe prospect) are clearly at variance with those of the faults. This could imply that late and dominantly brittle deformation of regional extent (i.e., the faults) may offset or disrupt mineralization associated with earlier structures. Because of this, it appears that any genetic link between the two faults and the gold mineralization is, at best, speculative.

The ductile shearing and carbonatization seen in Keith Township suggests that the gold potential of the section of the Swayze belt north of Horwood Lake is higher than previously considered. This section of the belt comprises east-trending mafic to felsic metavolcanic rocks, metasediments, and intrusive rocks of ultramafic to felsic composition. Prolonged ductile deformation of these rock types is not likely to have resulted in diffusion of mineralizing fluids. On the contrary, it is likely to have resulted in selective mineralization along discrete planar structures or lithologic sections of the affected stratigraphy. Hence, there is potential for ore concentrations at specific traceable horizons or contacts.

ACKNOWLEDGMENTS

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23. Project Unit 89-21. Geological Investigations of the Destor–Porcupine Deformation Zone East of Matheson

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INTRODUCTION

The Destor–Porcupine deformation zone (DPDZ) is a critical structure to both the geological development and the gold metallogeny of the late Archean Abitibi greenstone belt (AGB). The DPDZ extends in a generally east-trending direction from the Kukatush Lake area of the north Swayze greenstone belt, east of the Kapuskasing structure (Milne 1972), for over 350 km across the central AGB. It passes through Timmins (Pyke 1975) and has been traced across to the Val d'Or area in the province of Quebec (Dimroth et al. 1983). It represents a major structural and stratigraphic discontinuity, across which time and lithologic correlations are difficult (Jensen 1985a). Furthermore, the DPDZ is well known for its association with gold mineralization (Hodgson 1986). Thus, the structural interpretation of the DPDZ places constraints on tectono-stratigraphic models proposed for the formation of the AGB (Dimroth et al. 1983; Gibson et al. 1986; Hubert et al. 1984), and on the localization of gold mineralization.

This summary presents preliminary results describing the structural, metamorphic and alteration characteristics of the DPDZ, of the lithologies affected by it, and the relationship to gold mineralization. The aim of the program is to place gold metallogeny into a better regional geological and structural context, and to improve the understanding of the tectonic and ore-forming processes that occurred during the Archean.

Early regional geological assessment in the area of the DPDZ east of Matheson occurred after the discovery of gold in the Beatty–Munro–Hislop townships area (Moore 1937). The coincidence of areas of gold mineralization with linear easterly trending faults, termed "breaks", was soon recognized throughout the Timmins–Kirkland Lake area. Mapping of Michaud Township by Satterly (1949) and of Guibord and Hislop townships by Prest (1953, 1957) established the position of the DPDZ in the middle of these townships. The understanding of the position and extent of the DPDZ east of Matheson has remained essentially unchanged since then, apart from the identification of some splay faults to the east in Harker and Holloway townships (Whittaker 1986). Parts of the current map area (Figure 23.1) were later mapped by Jensen (1974, 1985b, 1985c) and Johnstone and Trowell (1985). Unfortunately,

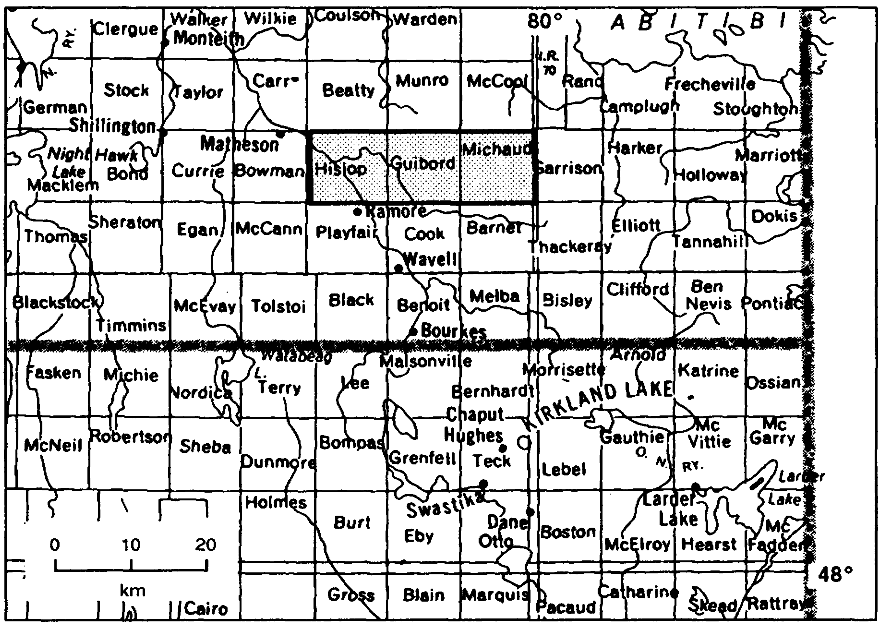

Figure 23.1. *Location map of the study area.*

the limits of mapping by Jensen and by Johnstone and Trowell are virtually coincident with the DPDZ, and consequently the relationships across the DPDZ have remained poorly understood.

During the 1989 field season, all of Hislop, Guibord and Michaud townships (*see* Figure 23.1) were examined, except for some parts of southern Guibord Township which were rendered inaccessible by flooding. Some modifications have been made to the distribution of lithologies reported by Jensen (1974) and Johnstone and Trowell (1985). Additionally, a large amount of structural, alteration and metamorphic data, particularly fracture and vein orientations, have been systematically recorded throughout the area. The mapping of the townships, data storage, retrieval and interpretation have been aided by use of a field portable computer system as described by Brodaric and Fyon (1988, *see* Paper 30, this volume). As bedrock exposure is low (5 to 10 percent), information from diamond-drill holes and overburden drill holes has been assembled from mineral exploration assessment reports. Some of this data has been used in the schematic interpretation of regional geology portrayed in Figure 23.2.

STRATIGRAPHY AND LITHOLOGY

The stratigraphic model presented here for the central AGB is based on the mapping of Jensen (1985c), augmented by high precision U-Pb zircon age dating (Corfu et al., in press). All rock types in the map area have been metamorphosed and the prefix "meta" is implicit.

Komatiitic and tholeiitic volcanic rocks of the Stoughton–Roquemaure Group (SRG) are overlain by the tholeiitic basalts and minor rhyolites of the Kinojevis Group (KG), which in turn are overlain by the calc-alkalic volcanic suite of the Blake River Group to the south (not present in the map area). Clastic sedimentary rocks, while not directly dated, are interpreted to be of two distinct ages, based on unconformable relationships found in the Timmins area (Pyke 1975). The earlier sedimentary group, referred to as the lower member of the Porcupine Sedimentary Group (PSG) by Pyke (1975), occurs as a 5 to 10 km wide, easterly trending belt within the DPDZ and close to the inferred contact between the SRG and the KG. The lower member of the PSG has been variously interpreted as rift basin sediments, oceanic basin sediments and fault zone trench sediments (Dimroth et al. 1983; Hubert et al. 1984; Gibson et al. 1986; Hodgson 1986), depending upon the tectonic model applied. The younger Timiskaming Group (TG) sedimentary and associated alkalic volcanic rocks are fault-bounded, occurring in association with major deformation zones such as the DPDZ, and are interpreted as being late (Dimroth et al. 1983; Hodgson 1986). The TG is recognized as the upper member of the PSG by Pyke (1975).

BASALTIC VOLCANIC ROCKS

Basalts are the most common rock type in the map area, and generally occur as massive to pillowed flows with lesser intercalations of pillow and flow top breccias and variolitic lavas. The SRG dominates the volcanic stratigraphy of the area, with the KG basalts present only in the southeastern corners of Michaud and Hislop townships. The SRG basalts are more often pillowed and exhibit moderate to very strong fracturing in regular orientations of varying density. These are readily distinguished in the field from the KG basalts, which are more commonly massive with thinner pillowed flow units. Facing directions indicate north- to northeast-younging north of the DPDZ, and south- to southwest-younging south of this zone. The DPDZ appears to separate the SRG to the north from the KG to the south; however, nowhere in this map area was a stratigraphic contact between the SRG and the KG observed. The reversal of facing directions across the DPDZ and the mélange of rock types within the DPDZ (described below) serve to highlight why stratigraphic correlation across this zone is difficult. However, the limited exposure in some critical areas south of the DPDZ does not permit a complete assessment of the contact relations between the SRG and the KG, and it is therefore possible that the stratigraphic succession may be preserved here.

KOMATIITIC VOLCANIC ROCKS

In general, komatiitic rocks of the SRG were identified on the basis of diagnostic textural features, such as spinifex crystal growth or polygonal jointing. No attempt was made in the field to further subdivide these rocks into basaltic and peridotitic komatiites.

The komatiitic volcanic rocks in the Froome Hill area in north-central Hislop Township have been previously identified as intrusive breccias of gabbroic composition (Prest 1957; Johnstone and Trowell 1985) within gabbroic to peridotitic plutonic rocks. During this investigation, a sequence of intercalated olivine spinifex-textured flows, pillowed flows and coarse flow top and pillow breccias was observed near the crest of the hill. No breccias of tectonic or intrusive origin were encountered in the current study. Some of the komatiitic flows are coarse grained, possibly indicative of lava ponding. The stratigraphy here is similar to that in Munro Township, where type sections for SRG komatiites are found (Arndt et al. 1977).

Komatiites are exposed just south of Highway 101 in the northeast corner of Guibord Township. Olivine and pyroxene spinifex-textured flows and flow breccias are interlayered with tholeiitic pillowed lavas and a knobby-weathering peridotitic sill. Undeformed spinifex zones are seen immediately adjacent to highly deformed spinifex-bearing volcanic breccias.

Highly altered and often schistose rocks in which primary textures are destroyed are presumed

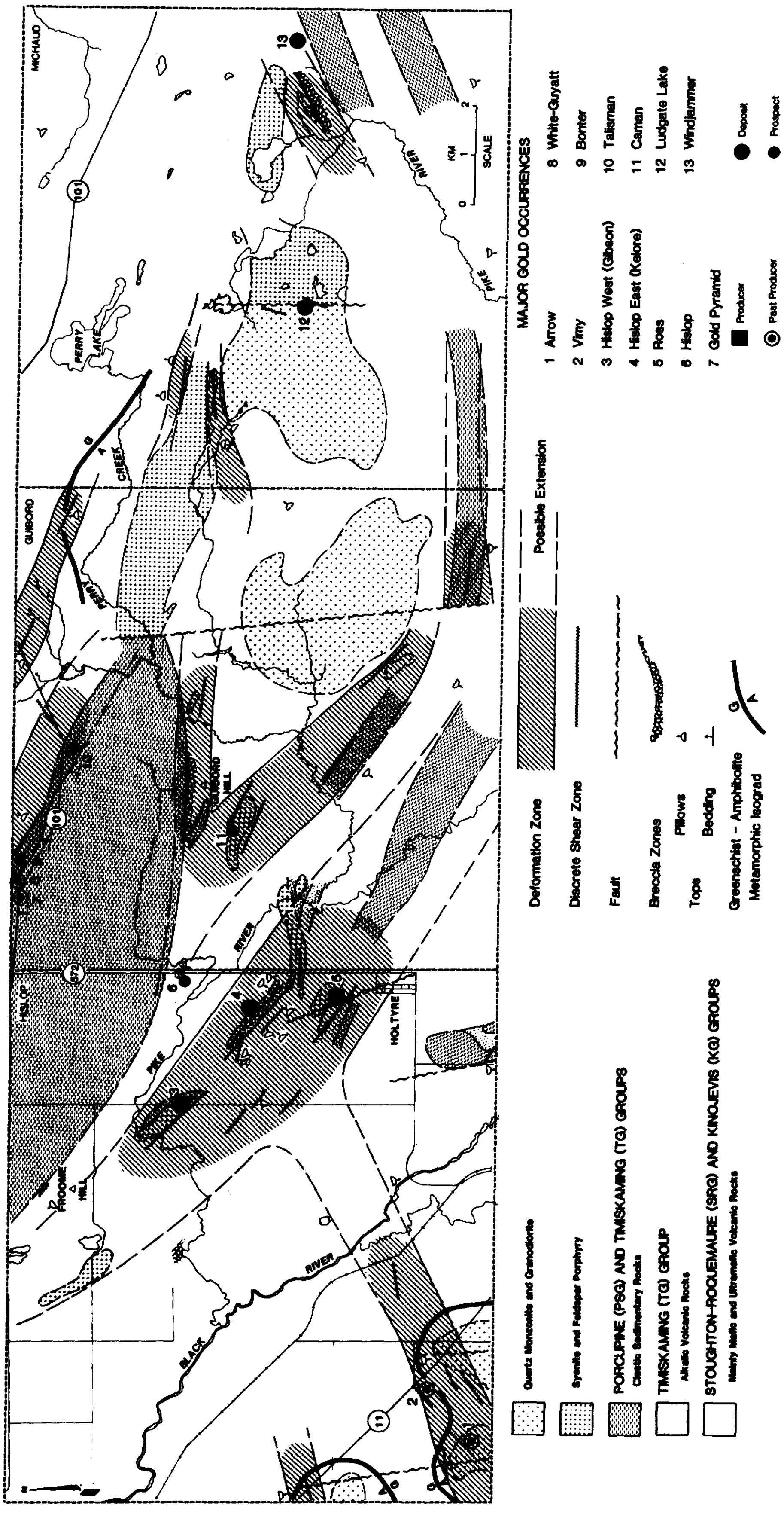

Figure 23.2. *Generalized geology and structure of the DPDZ and environs in Hislop, Guibord and Michaud townships.*

to be komatiites from their mineralogy (e.g., talc, green mica, ankeritic carbonates), and are closely associated with the DPDZ. However, the poor exposure and the high deformation intensity generally limit interpretation to magmatic affinity.

CLASTIC SEDIMENTARY ROCKS

Sedimentary rocks are poorly exposed in the map area. The best exposures are on the flanks of the northern sedimentary belt in north Hislop and Guibord townships (*see* Figure 23.2). A sequence of intercalated, north-facing lithic arenites and argillites is observed along the western half of the north boundary of Guibord Township, near the White–Guyatt, Gold Pyramid and Talisman mines. A similar north-facing sequence is observed at the southern contact of the sedimentary belt on the north flank of Guibord Hill. This sedimentary belt was interpreted to be older than all other rock types (Satterly 1949; Prest 1953, 1957), but was later correlated with the lower PSG (ODM 1973). All other sedimentary rocks in the map area occur as relatively thin lenses, many of which have been interpreted from diamond drilling (*see* Figure 23.2). Thus, whether their contacts are stratigraphic or tectonic remains open to question. All of these thin sedimentary sequences are assigned to the TG.

Two important observations were made which place the assignment of the northern sedimentary belt to the lower PSG in doubt. Firstly, volcanic rock fragments composed of chlorite, green mica and ankerite (i.e., "green carbonate") are present in an intraformational conglomerate observed near the Talisman Mine (*see* Figure 23.2). Green carbonate alteration is characteristic of altered and deformed komatiites within the DPDZ and may be equivalent in age or younger than the TG. Secondly, argillites occurring in fault contact with gabbroic rocks and basalts on the west side of Guibord Hill contain cobbles of diorite which are mesoscopically similar to the Guibord Hill diorite. The Guibord Hill diorite intrudes the volcanic stratigraphy exposed on the hill. If the diorite cobbles were derived by erosion from the Guibord Hill diorite, the inferred existence of an unconformity between the igneous and sedimentary rocks would imply that the sediments are correlative with the TG. In these two examples, rocks assigned to the lower PSG contain fragments which may be equivalent in age to the younger TG. Thus, all sedimentary rocks in the area may be TG. Alternatively, lower PSG and TG may occur unconformably or in fault contact, analogous to the Timmins area (Pyke 1975). These uncertainties indicate the need for a more critical evaluation of the assignment to the lower PSG of some sedimentary rocks along the eastern extension of the DPDZ.

The majority of the TG identified in the southern parts of the map area (*see* Figure 23.2) consists of greywacke and argillite similar to that seen in the lower PSG, with lesser polymictic conglomerate. The largest exposed area of TG conglomerate occurs southwest of the Ross Mine. The TG is poorly exposed and is presumed to be bounded by DPDZ structures, by analogy to the Kirkland Lake and Timmins areas (e.g., Hodgson 1986).

GRANITOID PLUTONIC ROCKS

Quartz-poor (<10 percent quartz) granitoid rocks, termed syenites in the field, predominate in the smaller stocks and dikes in the area, and are very common within the DPDZ. However, roughly equal proportions of syenite and quartz monzonite-granodiorite occur in the larger plutons located in east Guibord and west Michaud townships (*see* Figure 23.2). Most of the quartz-rich granitoid rocks contain biotite, while hornblende appears more common in the quartz-poor varieties. The large granodioritic pluton in southeastern Guibord Township contains abundant mafic xenoliths, presumably of amphibolitized basaltic country rock. The quartz-poor intrusive rocks may have an alkaline affinity, but this requires geochemical data for confirmation.

A very strong, northerly trending deformation zone, marked by mylonitization and fracturing, occurs at the contact between two intrusive phases. It is best exposed in the Ludgate Lake trenches in central Michaud Township (*see* Figure 23.2). The earlier intrusive phase, an equigranular monzonite to quartz monzonite, was intruded by dikes of a very coarse, potassium feldspar "megacrystic" syenite. The megacrystic intrusive phase becomes predominant to the north and east. It is often altered to a reddish colour, as are many of the syenitic intrusive rocks near the DPDZ, possibly the result of disseminated hematite inclusions in the feldspar matrix (Troop 1986; Whittaker 1986).

LAMPROPHYRIC DIKES

Dikes with lamprophyric characteristics, including some fine-grained, carbonate-bearing mafic dikes, are common throughout the map area, although their mineral assemblages, colour and frequency vary widely. Two prominent groups of lamprophyres, identified on the basis of phenocryst mineralogy, are present in the area: kersanites (biotite phlogopite phenocrysts) and spessartites (hornblende phenocrysts). The former are more common. Based on their distribution in the study area, the lamprophyre dikes show no obvious spatial association with any single structural or plutonic feature. They do show a strong spatial association with the DPDZ. However, the distribution of lamprophyre dikes elsewhere in the central AGB is poorly known.

All of the lamprophyre dikes are moderately to strongly carbonate-bearing and generally weather to a rusty brown colour. The dikes generally occupy locally strong fracture orientations, and are commonly present in areas of known gold mineralization examined. However, they also occur in areas of no known mineralization. It is therefore possible that the increased exposure generally afforded in areas of mineralization may unfairly reinforce their relationship to gold. An interesting observation made at several localities where gold mineralization occurs is that the lamprophyre dikes are deformed, and contain stoped xenoliths or fragments of granitoid intrusive rocks (e.g., Vimy gold mine, Hislop Township). This indicates that these lamprophyres were emplaced after the granitoids and earlier than or synchronous with later deformation.

DESTOR–PORCUPINE DEFORMATION ZONE ASSEMBLAGE

The DPDZ unit is characterized by a mélange of green carbonate rocks, argillaceous sedimentary rocks, semiconformable intrusive porphyries and tectonic breccias. For the most part, these rocks are highly altered, with carbonatization being the most significant alteration type. In many instances, the protolith(s) to the extremely deformed and altered rocks cannot be identified. In light of this and because of the lithologic heterogeneity over relatively short intervals, the DPDZ assemblage was given lithologic unit status.

DIABASE DIKES

Diabase dikes of the Matachewan swarm are ubiquitous in the map area, but are not depicted in Figure 23.2 for clarity. The dikes are almost exclusively north-trending, although there are a few instances of northwest- or northeast-trending Matachewan dikes. A strong and consistent north-striking fracture set present in the country rock is often found parallel to the dike orientation, and this fracture is commonly the locus of quartz veining and hydrothermal alteration. Proterozoic diabase magmas may have accessed pre-existing zones of weakness such as those manifested by intense fracturing and veining. This hypothesis is constrained by the predominant northerly trend of the Matachewan dikes, indicating that the tectonic environment during the Proterozoic favoured the re-opening of fractures in this orientation.

DEFORMATION STYLE IN THE DPDZ

The DPDZ is interpreted to be an extensive zone of deformed rocks, on the basis of the location of discrete shear zones and the presence of highly carbonatized and veined rocks (*see* Figure 23.2). The outline of the DPDZ as shown on Figure 23.2 includes windows of less deformed and altered rock. Discrete shear zones are characterized by both brittle and ductile features. A dextral sense of shearing is indicated for the horizontal component of movement in most discrete shears by cleavage–schistosity relationships and by asymmetrical folding of veins and fractures. In a few localities, a south-side-down vertical component to shearing is observed, compatible with the increasingly lower metamorphic grades to the south (Jolly 1980). The southside-down, southward-inclined attitude of the DPDZ is also consistent with the model of listric normal faulting proposed by Hodgson (1986) and Gibson et al. (1986). It is stressed, however, that the discrete directions of movement observed may not necessarily be indicative of bulk displacements within the DPDZ. More field evidence is required from the eastern extension of the structure to test this model.

One of the best developed areas of brecciation occurs on the footwall of a shallowly dipping fault on the north flank of Guibord Hill, where the PSG is in contact with tectonic breccias and diorite of the DPDZ. Heavily carbonatized pillowed basalts near the Hislop gold occurrence on Highway 572 (*see* Figure 23.2) are brecciated *in situ* and have been cemented by a tourmaline matrix. Tectonic breccias are recognized from the relative homogeneity of fragments, generally comprising only the enclosing rock types, and from the angularity of all fragments. This is in contrast to TG sedimentary breccias and conglomerates of this area, which are very heterogeneous and often contain rounded to subrounded granitoid fragments.

The komatiites in northeast Guibord Township display a good contrast in ductile deformation intensity over a short distance. The contact between a northwest-striking, dextral, ductile shear zone and the undeformed spinifex-textured komatiites is very sharp, illustrating the competency contrast during deformation between flow breccia and spinifex lava. Deformed spinifex-bearing flow fragments are visible within the sheared komatiitic unit.

From field relationships, zones of most intense shearing within the DPDZ are localized almost exclusively along lithologic contacts where a significant competency contrast exists. Therefore, the limits of the DPDZ closely conform to the major contacts within the volcanic stratigraphy (i.e., komatiite–basalt, basalt–rhyolite), syntectonic plutons, and the central PSG belt.

North-trending brittle faults are interpreted from the abundant fracturing, diabase dikes and aeromagnetic patterns observed in specific areas (*see* Figure 23.2). However, the lithologic and structural truncations inferred by Figure 23.2 should be treated cautiously, as no exposure occurs in these areas to support the interpretation. No kinematic indicators were seen in these faults, which may be late or synchronous with the granitoid intrusive suites.

FOLDING

Little evidence of folding was found in the supracrustal rocks. Pillow facing directions in the vicinity of the Kelore property (Goldpost Resources) indicate a large northwest-trending open synclinal fold; however, it is not clear whether this fold is related to the major east-striking zone of deformation to the north. Parasitic, tight S-folds, to which the dominant cleavage in this area could be axial planar, were identified in the vicinity of the White–Guyatt Mine. However, larger-scale tight folds cannot be substantiated, as all exposures where top determinations could be made indicated northerly facing directions.

FRACTURING

Brittle fracturing is prominently developed throughout the map area, except in the cores of ductile shear zones and in ultramafic rocks. These exceptions are generally poorly exposed and, consequently, most structural data on the deformational history of the area must come from fractures and veins. Most of the fractures or cleavages occur as spaced sets, with a minimum density of one per 5 m. Fractures in the KG tend to be poorly developed and of low density, in comparison with more prolific fracture development in the SRG lavas.

North-trending (345° to 015°) fractures are important in most of the map area, and may be occupied by all vein or dike types. Northeast- (035° to 070°) and northwest- (290° to 320°) striking fracture arrays are also common, although their distribution may be domainal and they require further analysis.

Near discrete shear zones, a diamond-shaped fracture pattern is frequently developed with planar features about 25° apart. The bisectrix to these fractures is generally parallel to the boundary of the ductile shear zone. Although such fracture–shear orientations are very consistent with those observed in classic Riedel brittle ductile shears, there are alternative mechanisms for the development of these fracture and vein arrays which need not be related to the DPDZ shearing event.

METAMORPHISM

Regional metamorphic grade in the study area is greenschist facies, except adjacent to intrusions, where amphibolite facies conditions were attained. Both Prest (1953, 1957) and Satterly (1949) use the term "diabasic lavas" to describe basaltic rocks within amphibolite contact aureoles of the granitoid intrusions. These amphibolitized rocks are generally composed of equigranular intergrowths of plagioclase and hornblende. An assemblage containing metamorphic pyroxene, garnet and epidote occurs in amphibolitized basalts just north of Perry Creek in Michaud Township (*see* Figure 23.2). Irregular epidote-quartz-calcite pods and veinlets occur in basaltic rocks close to intrusive contacts, and probably result from metamorphic devolatilization reactions involving fluid transfer, such as:

$$3 \text{ chlorite} + 10 \text{ calcite} + 21 \text{ quartz} \leftrightarrows 2 \text{ epidote} + 3 \text{ actinolite} + 10\, CO_2 + 8\, H_2O$$

Epidote is probably indicative of upper greenschist conditions at higher P-T conditions than were obtained by burial metamorphism or crustal compression.

MINERALIZATION AND ALTERATION

Several occurrences of gold mineralization were examined during the field season, including the Hislop West and Hislop East (Kelore) deposits of Goldpost Resources in Hislop Township, the White–Guyatt, Gold Pyramid and Talisman mines in Guibord Township, and the abandoned trenches at the Ludgate Lake deposit in Michaud Township (*see* Figure 23.2). All gold mineralization is associated with quartz ± carbonate veins and may be hosted in one or a combination of extensively brecciated, fractured and sheared rocks. The trends of the structures present are generally subparallel to the main trend of the DPDZ. North-trending structures intersecting the DPDZ are very common in areas of mineralization, such as at the Ross Mine (Troop 1986) and at the Ludgate Lake deposit (*see* Figure 23.2). The orientation of mineralized structures will be examined in more detail in conjunction with an analysis of regional fracture and vein orientations.

The Hislop East and West deposits provide excellent examples of the contrasting styles of mineralization that are present in the area, similar to the contrast previously reported for the Ross Mine (Troop 1986). At the Hislop East (Kelore Mine) property, a linear zone of disseminated gold mineralization is present in a brecciated fault zone characterized by green carbonate fragments. This zone lies between altered komatiitic flows and a very competent, silicified syenite porphyry dike. In contrast, mineralization at the Hislop West–Gibson zone is confined to discrete, high grade quartz veins near the brecciated and altered contact zone between syenite and basalt. At the Kelore Mine, a correspondence exists between the deformation style and the alteration assemblage developed in the komatiitic rocks. Where ultramafic komatiites are carbonatized, brittle deformation (e.g., brecciation) resulted. Where hydrous assemblages predominate, ductile deformation (e.g., intense schistosity) resulted.

The alteration associated with gold deposits within the DPDZ east of Matheson has been well described (Whittaker 1986). Carbonatization, manifest by ankerite in the core of shear zones and by calcite-dolomite toward the margins, is by far the most common alteration type. Hematitization, occurring both as specularite fracture coatings and as hematite inclusions in feldspar, is particularly common in association with syenitic intrusive rocks. Other alteration minerals include sericite, quartz, anhydrite, tourmaline and chlorite, typical of those generally found with Archean gold mineralization (Colvine et al. 1988). However, similar alteration is also characteristic of the entire DPDZ in this area, and gold is obviously not present in economic concentrations throughout the zone.

Alteration is often fracture controlled rather than pervasive, as a result of the brittle nature of deformation. A good example of this occurs at the Canadian Arrow deposit where intense potassium feldspar–hematite alteration is focussed within about 1 cm of discrete quartz veins (Cherry 1982; McNeil and Kerrich 1986). In the vicinity of the Gold Pyramid Mine in north Guibord Township, fracture-controlled alteration is observed in an interbedded argillite-arenite sequence. Two fracture cleavages, one parallel to bedding at 100° and the other at 197°, are rimmed with yellow sericitic alteration selvedges which extend several centimetres from the cleavages.

SUMMARY OF RESULTS

The most significant preliminary results of the 1989 field work are:

1. Deformation within the DPDZ is heterogeneous. The DPDZ consists of relatively undeformed blocks within blocks of highly deformed and altered rocks. The zones of high strain are marked by discrete shear zones at major lithologic contacts, such as those between sedimentary and plutonic rocks with volcanic rocks.
2. In mafic rocks, brittle diamond-shaped fractures extend from the locus of ductile shearing, and may represent a change in deformation style from ductile to brittle, on the outer edges of "brittle–ductile" shear zones. Brittle shear zones or faults are marked by extensive brecciation of one lithologic unit against another relatively more competent one, as at the Kelore (Hislop East) deposit and at the Ross Mine (Troop 1986). Areas of gold mineralization show a strong correlation with the intersection of north-striking fracture zones and the DPDZ; however, the density of north-striking fracture zones away from mineralized areas is poorly constrained.
3. A dextral sense of horizontal slip is indicated for many of the ductile shear zones, particularly those oriented in a northwesterly direction. The apparent vertical component of movement is south-side-down, consistent with normal faulting, but this interpretation should be treated with caution at this stage.
4. The green carbonate and diorite fragments in the northern sedimentary belt are potentially incompatible with a stratigraphic assignment to the lower member of the PSG. It is conceivable that all or part of the sedimentary rocks along this part of the DPDZ are equivalent in age to the TG.
5. Both biotite- and hornblende-bearing lamprophyre dikes have been identified. These dikes occupy all principal fracture orientations, are often deformed, and may contain fragments of the granitoid rocks with which they are spatially associated. Based on their distribution in the three townships which comprise the study area, the lamprophyre dikes show a strong spatial association with the DPDZ. However, the distribution of lamprophyre dikes elsewhere in the central AGB is poorly known. Similarly, lamprophyre dikes are common near gold mineralization in the study area, but their distribution away from the well-exposed mineralized areas is less well constrained.
6. There are extensive amphibolite metamorphic aureoles along the north edge of the Michaud–Guibord syenite stock, and around the Arrow intrusions in southwestern Hislop Township. The absence of identifiable metamorphic halos around some of the larger intrusions in Guibord and Michaud townships may be related to the poor exposure, or to significant post-plutonic faulting.

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24. Project Unit 89-11. Geology of the Kamiskotia Area, Abitibi Subprovince

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INTRODUCTION

This summary presents an overview of the geology, tectonic setting and U-Pb geochronology of the Kamiskotia area (Figure 24.1). A map and report on the geology and mineralization of this area in the Abitibi greenstone belt will be produced. A lithologic and structural description is first provided, with emphasis on the Kamiskotia gabbroic complex (KGC), based on recent (1984 to 1989) field mapping. Second, a review of recent U-Pb geochronology for the Kamiskotia area is presented. These ages provide precise constraints on tectonic relationships in the area, and allow for time-stratigraphic correlation with other areas in the southern Abitibi Subprovince. The correlation between the Kamiskotia and Kidd Creek volcanic rocks is specifically addressed because it has implications for base metal exploration in the region.

The goals of this project are to provide a detailed geological and tectonic framework for the Kamiskotia area in the context of regional development of the Abitibi greenstone belt, and to provide information for the exploration of magmatic nickel-copper-platinum group elements, volcanogenic copper-zinc, lode gold and high technology metal (yttrium, rare earth elements) deposits in the region.

PREVIOUS STUDIES

Earlier studies in the Kamiskotia area have been limited to lithologic mapping and geophysical surveys by the Ontario Department of Mines (Berry 1944; Wolfe 1970), some of which included limited major-element geochemical studies (Middleton 1973, 1975, 1976). More recently, Pyke (1982) included the geology of the Kamiskotia volcanic rocks in his regional synthesis of the Timmins area. A series of high resolution aeromagnetic maps were produced by the Ontario Geological Survey that cover the eastern half of the area (Barlow 1988).

The project reported in this summary is complemented by a structural and U-Pb geochronologic study (Barrie and Davis, in press) and an Nd-Sr isotopic study (Barrie and Shirey, in preparation) on the KGC and surrounding Archean rocks, which stem from doctoral thesis work at the University of Toronto (Barrie, in preparation).

GEOLOGY OF THE KAMISKOTIA AREA

Central to the Kamiskotia area is the KGC, which is a large, synvolcanic, tholeiitic intrusion that is part of a cogenetic, intrusive—extrusive suite (Hart 1984). It is overlain by, and in part gradational with, related rhyolites, basalts and volumetrically minor

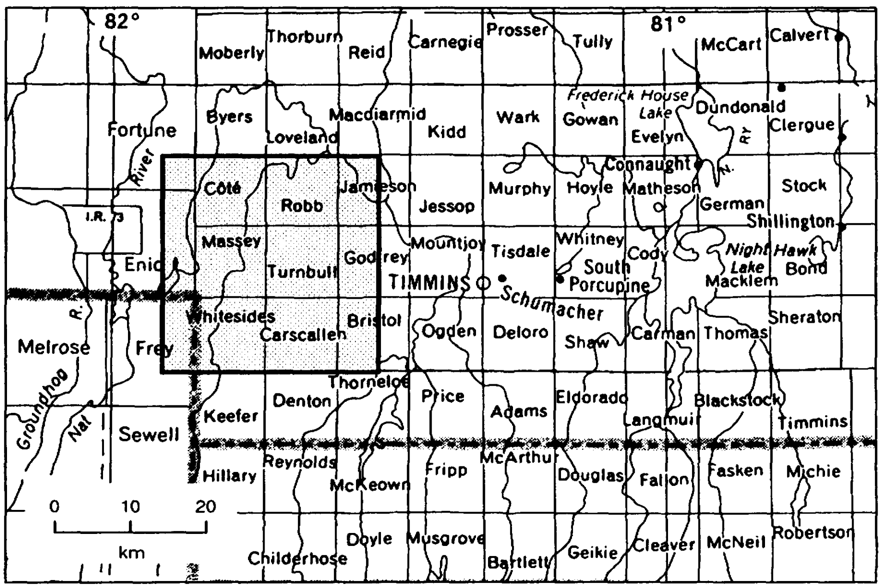

Figure 24.1. *Location map of the Kamiskotia area.*

evolved basalts and andesites. This volcanic sequence hosts copper-zinc mineralization that to date, has produced over 5 million tons of ore (Pyke and Middleton 1970). The KGC is underlain by the Lower Mafic Volcanics (LMV), composed of unrelated mafic and intermediate metavolcanics, and a 2 m thick, cherty, oxidè-sulphide iron formation. This stratigraphic succession is generally near-vertical and faces to the north and east.

Four granitoid masses, composed of hornblende ± biotite tonalite to granite and locally rimmed with contact intrusive breccia, have intruded the stratigraphy. These include Granitoid A, predominantly tonalitic, which exhibits mixed magma textures with fine-grained and locally pillowed KGC rocks. Granitoid A is believed to have intruded the base or the margin of the KGC during its crystallization, with limited magma mixing (described below). Granitoid B is also predominantly tonalitic and has a well-developed foliation fabric parallel to its margin. Granitoids C and D, to the west and south of the KGC, are composed of several discrete plutons that range in composition from trondhjemite-tonalite to granodiorite-granite.

Regional metamorphism up to lower greenschist facies has affected the stratigraphy. Within 1 to 3 km of Granitoids B, C and D, the metamorphic grade is up to middle amphibolite facies.

The known westernmost limit of the Destor–Porcupine fault zone (DPFZ), a major fault that extends hundreds of kilometres across the Abitibi Subprovince, is present in the LMV to the south. Lode gold mineralization and minor incompatible element-enriched intrusive rocks, including an unusual suite of ultramafic lamprophyres, are associated with the fault zone in this region (Figure 24.2). The north-northwest-trending mafic dikes of the Matachewan suite cut all of this stratigraphy and the DPFZ.

KAMISKOTIA GABBROIC COMPLEX

The KGC is subdivided into four zones on the basis of field and petrographic observations and geochemistry:

1. the Lower Zone (LZ)—partly layered, olivine-bearing cumulates along the southern and western margin
2. the Middle Zone (MZ)—gabbronorite and anorthositic gabbronorite cumulates
3. the Upper Zone (UZ)—partly layered, ferroan gabbronorite, anorthositic gabbronorite and hornblende gabbro cumulates
4. granophyric rocks of intermediate and felsic composition above and along strike with the UZ cumulates. The UZ-granophyre contact is irregular, and stoped blocks of partially hybrid-

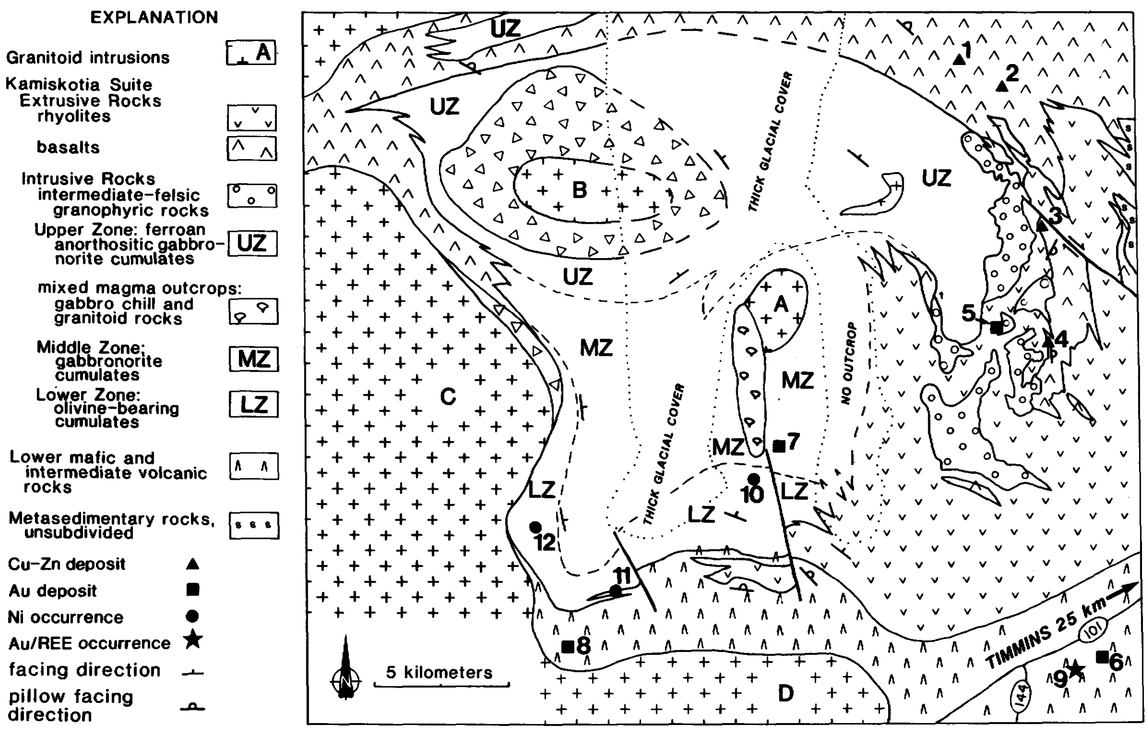

Figure 24.2. *Geology of the Kamiskotia area. Mines (none currently producing) and mineral occurrences labelled as follows: 1. Kam Kotia Cu-Zn mine; 2. Jameland Cu-Zn mine; 3. Canadian Jamieson Mine; 4. Genex Mine; 5. Lally Au mine; 6. Holmer Au mine; 7. DeSantis Au property; 8. Union Au mine; 9. Croxall REE and Au property; 10-12. Ni-Cu occurrences.*

ized granophyric rock within chloritized, quartz-rich UZ gabbro occur locally (Hart 1984).

Within the MZ, a wide variety of mixed magma textures between gabbroic and tonalitic-granodioritic rocks occur over a 1 km by 5 km area (*see* Figure 24.2). Well-preserved liquid-liquid textures are present, such as pillow-like masses of chilled gabbroic material up to 1 m by 1 m with quenched rims that contain fine-grained, radiating, acicular clinopyroxene and plagioclase aggregates, encompassed in coarse-grained tonalite. The pillows are phenocryst-poor, with aphyric margins that grade into uniform, medium-grained cores. Less well-defined agmatitic rocks with greater than 60 percent felsic intrusive material are found near and within the bounds of Granitoid A. These textures are similar to those found in well-documented mixed magma zones in mafic intrusions, such as the Tigalak and Newark Island layered intrusions in Labrador (Weibe and Wild 1983; Weibe 1987).

Facing directions within the LZ and UZ are determined from cumulates with cross-bedding structures, or from pyroxene-rich to plagioclase-rich gradations within individual cumulus layers. Unfortunately, thick glacial deposits cover a substantial portion of the MZ and prevent a more detailed structural analysis in this area (*see* Figure 24.2). It is possible that a synform with a north-trending axis is present in the southwestern KGC. Granitoids B, C and D represent antiformal structures, and in general, facing directions are away from their margins.

The KGC cumulates have been subjected to varying degrees of post-solidus alteration. For example, clinopyroxene is commonly partly or completely replaced by tremolite-actinolite and hornblende, and plagioclase is commonly altered to sericite, chlorite and clay. Generally the UZ cumulates are slightly altered, whereas the MZ and LZ cumulates are moderately altered. Except for rare sheared outcrops, primary textures are readily discerned in outcrops and in hand specimens.

PETROGRAPHY OF THE CUMULATE ROCKS

The following petrological descriptions emphasize the primary cumulus and post-cumulus mineralogy as determined from outcrop, hand specimen and petrographic observations.

The LZ is distinguished from the MZ and UZ by the sporadic presence of cumulus olivine in the LZ. It is generally a medium-grained, meso- to adcumulate, with clinopyroxene, orthopyroxene, olivine and plagioclase as cumulus phases. Chromite and sulphides occur sporadically as trace phases in the cumulates, and the LZ hosts several minor occurrences of low grade nickel-copper sulphide mineralization. Serpentinized peridotite, layered troctolite, and olivine norite adcumulates are found 1 to 3 km south of the mixed magma outcrops. Less magnesian orthocumulus to mesocumulus gabbroic rocks predominate along the southern contact.

The MZ is composed of massive, medium- and coarse-grained mesocumulate to adcumulate, with clinopyroxene, orthopyroxene and plagioclase as cumulus phases. Titaniferous magnetite, ilmenite and sulphides occur as accessory intercumulus phases. Subpegmatitic and pegmatitic textures are common.

The UZ is predominantly composed of massive and layered, medium- and coarse-grained meso- and orthocumulate. Plagioclase, clinopyroxene, orthopyroxene, and locally titanium-magnetite are cumulus phases; apatite and biotite occur as intercumulus phases. Wolfe (1970) reported hornblende gabbro and hornblendite outcrops in the southeastern part of the UZ. Plagioclase commonly constitutes greater than 70 percent of the mode, and several metre-thick anorthosite layers (greater than 90 percent plagioclase) occur locally. Inverted pigeonite with clinopyroxene exsolution is common. Generally, UZ rocks have a seriate texture and show no petrographic evidence for post-cumulus overgrowths.

GEOCHEMISTRY

The cumulates show a tholeiitic iron-enrichment trend, with magnesium numbers decreasing from 84 to 36 up-section. The cumulates are characterized by flat rare earth element (REE) patterns with LaN/YbN = 0.4 to 2.6, and range from 0.6 to 2 times chondrite abundances for olivine-bearing LZ adcumulates, and 10 to 25 times chondrite abundances for upper UZ meso- to orthocumulates. Europium anomalies are strongly positive for the LZ and diminish up-section to the upper UZ, which has slight negative Eu anomalies. The mixed magma chill compositions have magnesium number = 54 to 58, LaN/YbN = 0.8 to 1.2 and slight negative europium anomalies.

STRUCTURAL FABRIC ANALYSIS IN THE KAMISKOTIA AREA

Two prominent features are discerned using penetrative and non-penetrative foliation measurements (Figure 24.3): (1) contact strain zones parallel to the margins of granitoids B, C and D, and (2) east-trending foliations, particularly in the Kamiskotia volcanic rocks.

Contact strain zones are defined by the presence of a foliation that parallels the margins of the intrusions. The foliation fabric is primarily schistosity; however, gneissosity is developed locally between the margins of granitoids B and C, within amphibolite-grade LMV rocks and in leucocratic tonalite lenses that may represent partial melting of LMV material. The contact strain zones extend up to 2 km to either side of the granitoid margins, and locally up to 5 km into the country rocks. The intensity of penetrative deformation diminishes with distance from the contacts. From the available outcrops, it appears that granitoid B is completely rimmed by penetratively deformed rocks, thus defining a contact strain aureole.

In contrast to the other felsic intrusions, granitoid A does not have a contact strain zone defined by foliations. Here, the foliations are predominantly weak and non-penetrative; penetrative fabrics are confined to local, east-northeast-, east-southeast-, or north-trending high strain zones that contain quartz ± pyrite veins. Possible flexures on the western side of granitoid A may be related to strain from neighbouring granitoid intrusions. Significantly, fabrics within the granitoid A region indicate that the granitoid was emplaced in a manner entirely different from that of the other felsic intrusions. As mentioned above, granitoid A is characterized by a variety of mixed magma textures with the basal part of the MZ of the KGC, indicating that it was emplaced during the solidification of the KGC and was therefore contemporaneous with it.

The second prominent feature noted is the pervasive, east-striking foliation fabric across the Kamiskotia area, particularly in the volcanic rocks to the east (*see* Figure 24.3). This fabric is non-penetrative, cuts directly across strike, and continues relatively undisturbed through the granitoid A region. It is most pervasive in the vicinity of base metal mineralization where hydrothermally altered volcanic rocks and sulphide lenses are particularly susceptible to deformation. In volcanic rocks to the north, the fabric has a west-northwest trend; to the south, the foliations trend west-southwest. The deflection of foliations away from the easterly trend in the volcanic rocks may be the result of a competency contrast between locally altered volcanic rocks and the more competent, relatively unaltered intrusions to the west. Within the contact strain zone of granitoid C, the east-striking fabric is manifested as a weak, non-penetrative foliation or parting cleavage which locally cuts the foliation produced by the emplacement of granitoid C.

Lineations (Figure 24.4) and L-S fabrics (Flinn 1965) were recorded for outcrops with penetrative deformation wherever possible. In the Kamiskotia area, highly prolate fabrics are concentrated in two areas: (1) between granitoids B and C, and (2) along the northern contact of granitoid D, extending toward a part of the westernmost DPFZ. Between B and C, there are two prominent lineation trends, one plunging steeply to the north-northeast along the northwest contact of granitoid C, and the other with a shallow northwest-plunging orientation. Both of these may be related to granitoid C emplacement. The steep north-northeast-plunging lineations are consistent with an upward diapiric movement of granitoid C with respect to the surrounding lithologies. The shallow northwest-plunging lineations are found within granitoid C, within its intrusive breccia zone and in the KGC near granitoid B, and are interpreted to overprint any previous fabric formed from emplacement of granitoid B. This fabric may be a product of ballooning by granitoid C against a competent wall of granitoid B, creating a subhorizontal stress regime where the less competent mantling material was attenuated parallel to the C axis of the strain ellipsoid. Alternatively, it may reflect strain created by flow of magma and/or crystal

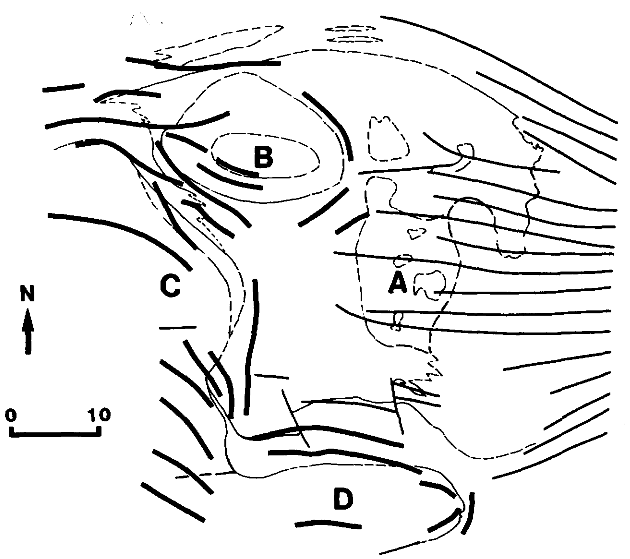

Figure 24.3. *Foliation trajectory map. Light lines represent predominantly non-penetrative foliations due to N-S compression; bold lines represent penetrative planar fabrics due to granitoid emplacement.*

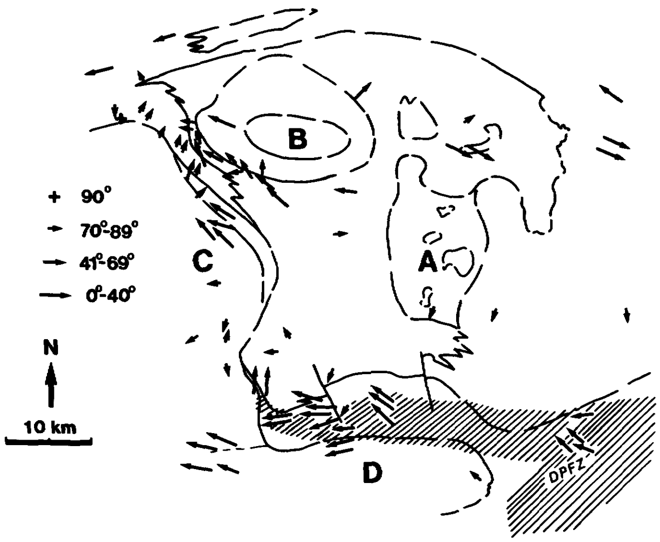

Figure 24.4. *Lineation map with high strain zones marked with hatchured pattern. Note that the western extent of the Destor–Porcupine fault zone (DPFZ) extends to the east and south of Granitoid D; a splay continues to the north within the Lower Mafic Volcanic rocks.*

mush within granitoid C after the formation of a gneissic carapace and wall. Similar models have been proposed to explain subhorizontal stretching fabrics in crescentic granitoid plutons (Schwerdtner et al. 1983).

A consistent, shallow west-plunging, stretching fabric is pervasive in highly strained LMV rocks north of granitoid D, and continues into the granitoid terrane at the contact between granitoids C and D (*see* Figure 24.4). This fabric extends to the east and merges with highly strained rocks of the westernmost DPFZ. Accompanying this fabric is a consistently dextral sense of displacement, noted on the subhorizontal plane in asymmetric, transposed fold hinges of siliceous material within strained LMV rocks and within shear zones in granitoid D. The domain of highly strained rocks in the LMV is interpreted as a splay of the DPFZ for two reasons: (1) it is continuous with the fabric in the DPFZ, and (2) it contains several occurrences of gold mineralization with syn- to posttectonic quartz tourmaline sulphide ± carbonate ± gold veins and associated carbonate alteration (*see* Figure 24.2), similar to occurrences found in the western DPFZ.

SUMMARY OF U-Pb GEOCHRONOLOGY

A summary of the chronology of Archean magmatic and structural activity in the Kamiskotia and Kidd Creek areas is presented in Figure 24.5. Three periods of magmatism occurred at approximately 10 Ma intervals:

1. felsic volcanism in the Kidd Creek area at 2717 to 2716 Ma
2. volcanism and hypabyssal mafic and felsic intrusions at 2707 to 2705 Ma, and
3. voluminous granitoid emplacement at 2696 to 2694 Ma

The timing of deformation events, constrained by geologic relationships and U-Pb ages, is in part coincident with and related to the magmatism, with regional crustal warping between 2705 and 2694? Ma, followed by contact strain zone development at 2696 to 2692 Ma. North-south compression may postdate contact strain development for granitoid C, and is possibly dated by closure of the U-Pb system in titanite from granitoid C at 2692 Ma. An undeformed garnetite dike adjacent to highly strained rocks of the DPFZ that contain gold mineralization

AGE	MAGMATIC EVENTS	DEFORMATION EVENTS	
2926 (+) Ma	*OLDER SIALIC CRUST (Inherited component in Granitoid C)*		
2717-1716 Ma	*KIDD CREEK, PROSSER RHYOLITES*		
>2707 Ma	*LOWER MAFIC VOLCANICS, IRON FORMATION*		
2707-2705 Ma	*KAMISKOTIA GABBROIC COMPLEX, KAMISKOTIA RHYOLITE, REID RHYOLITE, GRANITOID A*		
		ONSET OF REGIONAL CRUSTAL WARPING	
2696 Ma	*GRANITOID B*	*B CONTACT STRAIN DEVELOPMENT*	
2694 Ma	*GRANITOID C (zircon)*	*C CONTACT STRAIN DEVELOPMENT*	*NORTH-SOUTH COMPRESSION*
	GRANITOID D	*D CONTACT STRAIN DEVELOPMENT*	
2692 Ma		*THERMAL METAMORPHISM(?) (TITANITE, GRANITOID C)*	*TRANSPRESSION: DEVELOPMENT OF SHEAR ZONES ALONG THE WESTERN DESTOR-PORCUPINE FAULT ZONE*
2687 Ma	*GARNETITE DIKE*		

Figure 24.5. *Sequence of magmatic and tectonic events in the Kamiskotia–Kidd Creek areas. All U-Pb ages have 2-sigma errors of ±2 to ±4 Ma. Nunes and Pyke (1981) reported an age of 2717±4 Ma for the Kidd Creek rhyolite; this has been refined by the addition of an abraded and concordant zircon fraction to 2717±2 Ma. From Barrie and Davis, in press; and Barrie, in preparation.*

has been dated using garnet and titanite fractions. The dike is part of an ultramafic lamprophyre suite, parts of which are deformed. The U-Pb age for the garnetite dike is 2687±3 Ma, which may approximate a minimum age for late deformation along the western extent of the DPFZ (Barrie, in preparation).

DISCUSSION

GABBROIC COMPLEX—GRANITOID RELATIONSHIPS IN THE SOUTHERN SUPERIOR PROVINCE

One of the notable features of the Kamiskotia area is that voluminous tholeiitic magmatism was shortly followed by intrusion of calc-alkaline magmas. This phenomenon has been documented by geological and/or geochronological studies across the southern Superior Province, including the Bird River Sill in Manitoba (Trueman and Bannatyne 1982), the Bad Vermilion Complex in Ontario (Ashwal et al. 1985), Mulcahy Lake and related gabbroic intrusions in Ontario (Morrison et al. 1985), the Sturgeon Lake gabbro in Ontario (Davis and Trowell 1982), the Lac des Iles and related intrusions in Ontario (Sutcliffe 1986), the Montcalm Gabbroic Complex in Ontario (Barrie and Naldrett 1989), the Bell River Complex in Quebec (Sharpe 1968), and the Dore Lake Anorthosite in Quebec (Dimroth et al. 1986). It would appear that these relationships are widespread, and that the process of nearly coeval, voluminous mafic and felsic magma generation is integral to the development of granitoid-greenstone terranes in the Superior Province.

COGENESIS OF THE KAMISKOTIA GABBROIC COMPLEX AND KAMISKOTIA VOLCANICS, AND ITS SIGNIFICANCE WITH RESPECT TO FORMATION OF VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS

That the KGC and the Kamiskotia rhyolite are coeval, within error, strengthens geochemical arguments for a cogenetic relationship between them. That the REE abundances of the Kamiskotia felsic volcanic rocks and the underlying KGC granophyric cap are nearly identical strongly suggests that the rhyolites are eruptive equivalents of the granophyre (Campbell et al. 1981). Both have distinctive high, flat, chondrite-normalized patterns with strong negative europium anomalies (Figure 24.6), consistent with low pressure fractionation of mafic phases and plagioclase, and/or greater than 10 percent partial melting of slightly enriched tholeiitic basalts with flat REE patterns, similar to the evolved Kamiskotia basalts (Hart 1984). The rhyolites have been termed "Type IIIb" rhyolites by Lesher et al. (1986).

The presence of volcanic-hosted massive sulphide deposits at several stratigraphic levels in the Kamiskotia volcanic rocks is consistent with their identical U-PB age to the KGC. During crystallization and cooling, the KGC was fully capable of providing the heat necessary to drive hydrothermal convection cells that would leach metals from a volcanic pile and precipitate them on the paleoseafloor, given geologically reasonable permeability and temperature constraints (Cathles 1983). The KGC may also represent a magmatic source for a portion of the base metals. Hypabyssal gabbroic intrusions that underlie massive sulphide-bearing "tholeiitic" rhyolites are present elsewhere in the southern Superior Province, e.g., the Bad Vermilion Complex overlain by the Gagne Lake deposits in Ontario (Poulsen 1984), the Bell River Complex and Matagami Lake district (MacGeehan and MacLean 1980), numerous gabbro sills in the Noranda district, and the Dore Lake anorthosite overlain by the Patino–Lamoine Mine and other deposits (Guha et al. 1988). It seems likely that in these areas, as in the Kamiskotia area, the gabbroic intrusions are synvolcanic, and that they provided the heat necessary for massive sulphide-precipitating hydrothermal systems.

TIME-STRATIGRAPHIC CORRELATION BETWEEN VOLCANIC ROCKS OF THE KAMISKOTIA AND KIDD CREEK AREAS

Since the discovery of the Kidd Creek massive sulphide deposit in 1963 and subsequent discoveries of copper-zinc deposits in the Kamiskotia volcanics, several field-based studies have proposed a correla-

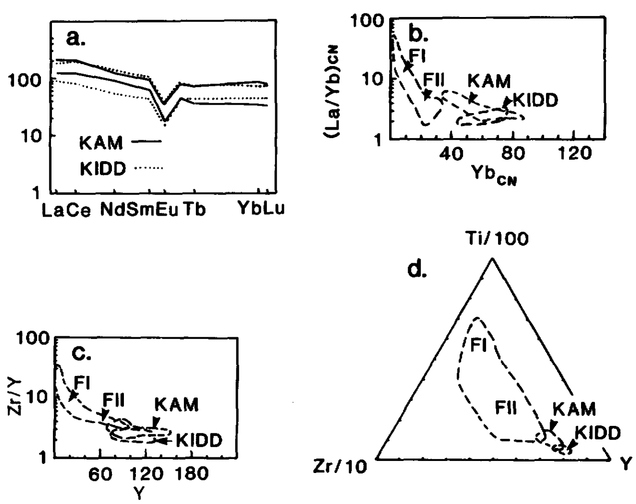

Figure 24.6. *Comparison of Kamiskotia and Kidd Creek felsic volcanic geochemistry, after Lesher et al. (1986). FI and FII represent barren, Superior Province calc-alkalic felsic volcanic rocks; the Kamiskotia and Kidd Creek volcanics, both massive-sulphide bearing, are particularly enriched in the heavy REE and Y.*

a. *REE chondrite-normalized diagram.*
b. *$(La/Yb)_{CN}$ versus Yb_{CN}.*
c. *Zr/Y versus Y.*
d. *Ti/100–Zr/10–Y ternary. Data from Barrie (in preparation), Hart (1984) and Lesher et al. (1986).*

tion between the two volcanic piles (Pyke and Middleton 1970; Pyke 1978, 1982; OGS-MERQ 1983). These reports noted their similar geochemistry (Figure 24.6), the presence of massive sulphide mineralization in both, and their general stratigraphic position below the metasedimentary rocks of the Tisdale Group in the Timmins area, and assigned them to the Upper Deloro Group. In the lithostratigraphic map of the Abitibi Subprovince (OGS-MERQ 1983), both volcanic piles are placed at the top of the Cycle III Volcanics, one of four cyclic volcanic packages tentatively correlated across the Abitibi Subprovince.

The U-Pb ages indicate that modification is necessary for the previous, tentative correlations (Pyke 1978, 1982; OGS-MERQ 1983) between the Kamiskotia and Kidd Creek volcanic piles. It is apparent that the Kidd Creek and Prosser rhyolites are at least 10 Ma older than the KGC, the Kamiskotia rhyolite, and the Reid rhyolite 11 km to the west-northwest of the Kidd Creek Mine. The Kidd mega-agglomeritic flow-banded rhyolite sample and the Kamiskotia flow-banded rhyolite sample both represent proximal volcanic facies and are proximal to mine sites. In contrast, the Prosser and Reid samples are crystal-ash tuffs intercalated with graphitic argillites, typical of distal, subaqueous volcanic facies: they may represent crystal-ash deposits distal to the Kidd and Kamiskotia volcanic centres, respectively.

TIME-STRATIGRAPHIC CORRELATION OF VOLCANIC ROCKS ACROSS THE SOUTHERN ABITIBI SUBPROVINCE

Four U-Pb ages for volcanic strata and one hypabyssal dunite sill to the east of the Kamiskotia area are coeval or slightly younger than the KGC and Kamiskotia rhyolite, from 2707±1.5 Ma to 2698±4 Ma (Corfu et al., in press). These include rocks previously included in the Upper Deloro, Tisdale, Skead, Larder Lake and Blake River groups. Mortensen (1987) reported preliminary U-Pb ages of 2698 Ma for rhyolites of the Blake River Group in the vicinity of base metal mineralization near Noranda, Quebec. Considering their similar geochemistry (Lesher et al. 1986; Ujike and Goodwin 1987), bimodality, and their association with base metal mineralization, the Kamiskotia volcanics correlate well with volcanic rocks in the upper Blake River Group in a lithostratigraphic sense.

LATE TRANSPRESSION ACROSS THE SOUTHERN SUPERIOR PROVINCE

Late north-south compression and transpression has been documented by structural and geochronologic studies for areas across the southern and central Superior Province, at major subprovince boundaries (Stott 1985; Corfu and Stott 1986; Stott et al. 1987; Davis et al. 1989) and within greenstone belts (Hubert et al. 1984; Dimroth et al. 1986; Hudleston et al. 1988). The majority of these studies have indicated that transcurrent motion on regional east- or east-southeast-striking shear zones is in a dextral sense, whereas a sinistral motion is indicated for east-northeast-striking shear zones. These observations are compatible with a subhorizontal stress regime oriented in a west-northwest–east-southeast sense (Stott et al. 1987). Dextral transcurrent motions along the Quetico–Wawa and Quetico–Wabigoon subprovince boundaries are tightly bracketed by U-Pb analyses of deformed and undeformed rocks at 2689 to 2684 Ma and 2696 to 2686 Ma, respectively (Corfu and Stott 1986; Davis et al. 1989). The timing and sense of displacement along these subprovince boundaries are virtually identical to the relatively late-stage dextral transpression recorded in the Kamiskotia area, implying a synchronous crustal shortening event across 1200 km of the southern Superior Province at approximately 2690 to 2685 Ma.

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25. Project Unit 88-05. Regional Mapping and Stratigraphic Studies, Grenville Province

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INTRODUCTION

A geological synthesis of the Grenville Province in Ontario is being undertaken as part of the Geology of Ontario Project. This synthesis involves both the preparation of a series of 1:50 000 and 1:250 000 scale geological maps of the Grenville Province in Ontario, as well as a synthesis of the geology of the Grenville Province, particularly with respect to controls on mineralization. Field work in 1989 involved a variety of activities related to preparing this synthesis for the Geology of Ontario volume, as well as completing ongoing projects. In addition, a limited amount of field checking was done related to the preparation of several 1:50 000 and 1:250 000 compilation maps of the area. These studies have led to a better understanding of the geologic framework of the Grenville Province, and will see fruition in the Geology of Ontario volume.

COMPILATION MAPPING

About 10 days were spent field checking 1:50 000 scale geologic compilation maps prepared for NTS sheets 31C/15 (Sharbot Lake), 31F/2 (Clyde

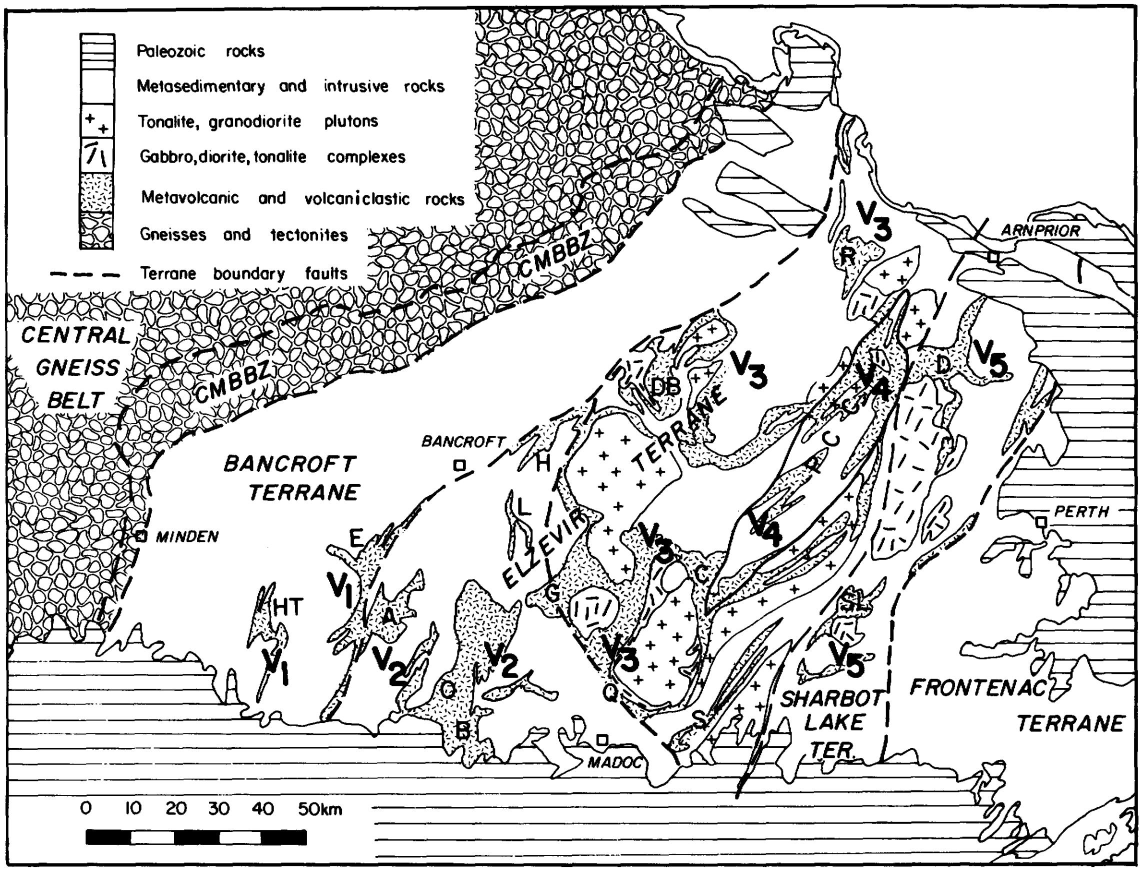

Figure 25.1. *Generalized distribution of volcanic and volcaniclastic rocks in the Central Metasedimentary Belt and location of major volcanic accumulations. V_1 through V_5 refer to volcanic-plutonic assemblages described in the text and in Table 25.1. Abbreviations: A—Apsley area; B—Belmont area; C—Cloyne-Mazinaw Lake area; CMBBZ—Central Metasedimentary Belt Boundary Zone; D—Darling area; DB—Denbigh area; E—Eels Lake area; G—Gilmour-Jordan Lake area; H—Hermon area; HT—Harvey Township; L—Limerick area; O—Oak Lake area; PCC—Palmerston-Clyde-Calabogie area; Q—Queensborough area; R—Renfrew area; S—Shovel Lake area; SL—Sharbot Lake area.*

Forks), 31C/10 (Tichborne), and 31C/14 (Mazinaw Lake). Mapping in the Madoc area by the author (*see* Paper 26, this volume) and Di Prisco (*see* Paper 27, this volume) will be incorporated into 1:50 000 compilation maps being prepared for NTS sheets 31C/11 (Kaladar) and 31C/12 (Bannockburn).

GRENVILLE VOLCANIC ASSEMBLAGES

Physical volcanology and facies analysis are powerful mapping tools which can be used to place constraints on the nature and possible tectonic setting of volcanism. To date, few such studies have been conducted in the Grenville Province, most notable being studies by Ayer (1979), Bartlett (1983) and Easton (1986, 1988). If Grenville volcanism occurred in an oceanic island-arc environment, as suggested by Brown et al. (1976), one might expect to find an abundance of pyroclastic rocks of intermediate to felsic composition (cf. Garcia 1978). If volcanism occurred in other environments, this should be reflected in the types of volcanic products observed in the field. Several weeks of the 1989 field season were spent in a reconnaissance of Grenville volcanic accumulations in order to outline the distribution of volcanic centres in the Grenville, and to better document the nature of Grenville volcanism.

Figure 25.1 outlines the distribution of volcanic and volcaniclastic rocks within the Grenville Province. As outlined in Table 25.1, five main volcanic and volcanic-plutonic assemblages can be outlined across the Central Metasedimentary Belt on the basis of lithology, chemistry, related plutonic rocks, associated mineralization, and limited geochronological information. Assemblages V_2 and V_3 comprise much of the area of classic Grenville studies, and mafic rocks of these two assemblages have been designated in the past as the Tudor Formation of the

TABLE 25.1. VOLCANIC AND VOLCANIC-PLUTONIC ASSEMBLAGES IN THE CENTRAL METASEDIMENTARY BELT, GRENVILLE PROVINCE.

Code	Major Lithologies	Age	Tectonic Setting
V_1	basalt, dacite–rhyolite, pyroclastics, related volcaniclastics, tholeiitic to slightly alkaline chemistry. Mineralization: pyrite; rusty schists and black shales associated with the metavolcanics locally show a variety of metal enrichments, including gold, copper, zinc. May be distal equivalent of assemblage V_1.	??	??
V_2	basalt, andesite, dacite, rhyolite, abundant felsic pyroclastics, related andesitic and dacitic volcaniclastics (e.g., Apsley Fm.), tholeiitic (mafic rocks) and calc-alkalic (intermediate to felsic rocks) chemistry. Associated gabbro and granite plutons. Includes classic Oak Lake, and Tudor Fms. Mineralization: pyrite, copper–zinc; rusty schists and black shales associated with the metavolcanics locally show a variety of metal enrichments, including gold, copper, zinc, lead, silver.	volc 1248–1290 Ma plut 1240–1245 Ma	back-arc/arc
V_3	basalt, gabbro sills, gabbro and pyroxenite plutons, mafic volcaniclastic sediments, tholeiitic chemistry. Associated with gabbro-diorite–tonalite complexes (e.g., Lingham Lake complex) and tonalite–granodiorite plutons (e.g., Elzevir); pillowed flows typically have very thin selvages. Includes much of the classic Tudor Fm. Mineralization: gold, talc, copper, potential for copper–nickel, actinolite.	volc ?? plut 1229 Ma min and 1270–1280 Ma	basal arc?/ oceanic?
V_4	basalt, andesite, dacite, rhyolite, abundant pyroclastics, volcaniclastic sediments, and quartzofeldspathic metasediments; tholeiitic basalts and calc-alkalic, intermediate to felsic rocks. Contact relations with assemblage V_3 unknown—may overlie it stratigraphically. Mineralization: copper–zinc–pyrite.	<1270 Ma?	arc/back arc?
V_5	basalt, gabbro sills, mainly flows, minor mafic pyroclastics, some exhalative rocks including black shales, sulphide-facies iron formation; pillowed flows typically have very thin selvages. Associated with gabbro–diorite intrusions; could be similar to V_3 but is not associated with large tonalite–granodiorite plutons. Mineralization: gold (particularly in deformed rocks), copper–zinc–pyrite; many zinc deposits are associated with dolomite marbles overlying the metavolcanics.	??	??

Hermon Group. Much of the typical Tudor Formation described by Lumbers (1967) represents sequence V_3. Other volcanic units of the Hermon Group, such as the Oak Lake, Turiff, and Burnt Lake formations (Lumbers 1967), correspond to assemblage V_2. These volcanic assemblages are separated from each other mainly by major fault systems, commonly corresponding to terrane boundaries. The only exception may be the assemblage V_3-V_4 contact near Mazinaw Lake and in the Palmerston-Clyde-Calabogie (PCC) area which could be a stratigraphic contact. Additional mapping along this contact, and in the Gilmour-Jordan Lake area, is needed to better outline contact relationships between the assemblages.

The geochronologic data base on these various volcanic assemblages is poor. No zircon dating has been published from volcanic or related rocks for assemblages V_1, V_4, and V_5. Davis and Bartlett (1988) have published several zircon ages from the Belmont area volcanics showing a spread in volcanism of 1248 to 1287 Ma. Using zircons, Silver and Lumbers (1966) dated felsic volcanic rocks from the Tudor Formation at 1286±15 Ma, however, the dated samples are most likely part of assemblage V_2. Plutonism quickly followed volcanism. Assemblage V_2 has been intruded by a variety of gabbroic and granitic rocks, which have zircon ages of 1242±3 Ma (Cordova gabbro, *see* Davis and Bartlett 1988), 1241±2 Ma (Deloro granite, *see* van Breemen and Davidson 1988) and 1242±20 Ma (Methuen granite, *see* Heaman et al. 1986).

Assemblage V_3 has not been directly dated, however, the tonalite-granodiorite Weslemekoon and Elzevir plutons have yielded zircon ages of 1226±25 Ma (Silver and Lumbers 1966) and 1229±11 Ma (Connelly et al. 1987), respectively. However, Larry Heaman (Geochronologist, Royal Ontario Museum, Toronto, personal communication, 1989) has reported zircon ages of 1270 to 1280 Ma from the tonalite-granodiorite suite plutons. Given the new data of Heaman, it would appear that assemblage V_3 might be older than assemblage V_2 if plutonism was synchronous with, or quickly followed, the cessation of volcanism.

LeBaron (1988) and LeBaron et al. (1987) have speculated that talcose rocks within assemblage V_3 adjacent to the Elzevir tonalite represent altered komatiites, primarily on the basis of geochemistry. Di Prisco (*see* Paper 27, this volume) examined this question briefly, as does this study. Assemblage V_3 in the Queensborough area consists of variably deformed gabbros, comprising up to 50 percent of the sequence, as well as fine-grained amphibolites (flows?) and mafic volcaniclastics. On the east side of the Elzevir tonalite, in the same structural or stratigraphic position, or both, are found a variety of gabbros and pyroxenites. At present, it seems most likely that the talcose rocks represent altered intrusive rocks, rather than true komatiites. As no primary textures remain in the talcose rocks, this question may never be truly resolved.

As noted in Table 25.1, different types of mineralization are more closely associated with some assemblages than others. This has obvious implications for exploration programs, with assemblages V_2 and V_4 being more likely to host volcanogenic massive-sulphide deposits, and with V_3 and V_5 being more likely to host copper-nickel, and possibly gold, deposits.

In summary, it should be noted that this is only a very preliminary study and analysis of the distribution of volcanic rocks in the Central Metasedimentary Belt. Follow-up studies will try to understand the contact relations between assemblages V_2-V_3 and V_3-V_4, respectively, and to further explore the economic implications of this work. Additional geochronological studies in the Central Metasedimentary Belt will serve to better establish possible correlations or noncorrelations between these sequences.

STRATIGRAPHIC STUDIES

A survey of stratigraphic nomenclature within the Grenville Province was begun in 1988 in order to determine which stratigraphic terms were worth retaining (or needed revision or abandonment) for use in Geology of Ontario and to produce a lexicon of formal stratigraphic terms in use in the Grenville Province in Ontario. Table 25.2 briefly summarizes some of the major recommendations of this process, with full documentation being provided in a forthcoming report. As can be seen from the above analysis of the volcanic rocks in the Central Metasedimentary Belt and in Table 25.2, many stratigraphic terms are still quite meaningful in the general vicinity of their type areas. Regional stratigraphic terminology and correlation need considerable rethinking in light of our improved knowledge of the geology of the Grenville Province, and it is premature to address this question in this preliminary report.

GEOCHEMICAL SAMPLING OF PLUTONIC ROCKS

In order to fill gaps in the existing geochemical data base for plutonic rocks in the Central Metasedimentary Belt and for use in the Geology of Ontario volume, representative samples were taken from a number of plutons for major, trace, and rare earth element geochemistry. Plutons sampled include the Barbers Lake granite, the Dalhousie Lake Amphibolite Complex, the Elphin granodiorite, the Gawley Creek syenite, the Mount Moriah syenite and the Pakenham granite.

TABLE 25.2. PARTIAL LIST OF STRATIGRAPHIC TERMS IN THE CENTRAL METASEDIMENTARY BELT—PRELIMINARY RECOMMENDATIONS.

Terms of Historic Significance But Which May Need Redefinition	Terms Suggested For Abandonment
Flinton Group (Moore and Thompson 1980)—It now appears that the Skootamatta, Stewart, and Madoc Formations are part of the Grenville Supergroup and are not correlative with the Flinton Group. The relationship of the Flinton Group (*sensu stricto*) to the Grenville Supergroup needs further examination.	*Joe Lake Volcanics* (Sangster 1970)—Term originally was poorly defined in terms of extent of the unit, and differences from other stratigraphic terms. Most of these rocks have subsequently been shown to be mylonitized gabbroic and mafic volcanic rocks (Easton 1988). Term has no local significance and should be redefined or abandoned.
Hermon Group and Tudor Formation (Lumbers 1967)—These units will probably need redefinition as a result of this study.	*Madoc Volcanics* (Hewitt 1968)—As outlined in Easton (*see* Paper 26, this volume), the evidence that there are any volcanic rocks within the Madoc Volcanics is minimal at best. The unit consists dominantly of porcelanites formed in the alteration halo of the Deloro granite. Term should be abandoned.
Mayo Group (Lumbers 1967)—Carbonate stratigraphy in the Central Metasedimentary Belt needs re-examination. This could result in additional subdivisions within the Mayo Group or a redefinition of the Group.	*Queensborough Acid Volcanics* (Hewitt 1968)—Most, if not all of these rocks are silicified metasedimentary rocks and felsites related to the alteration halo of the Deloro granite. Term should be abandoned.
Madoc Formation (Moore and Thompson 1980)—Term introduced for pelitic rocks thought to be part of the Flinton Group in the Madoc area. Although these rocks have been variably altered by the Deloro granite, unit is distinctive and can be traced out with relative ease; thus it has local significance. Should be retained. No indication that it is younger than the Grenville Supergroup, hence, it should be reassigned from the Flinton Group to the Grenville Supergroup.	*Stewart Formation* (Moore and Thompson 1980)—No indication that these rocks are distinctly different from other carbonate rocks in the immediate vicinity. Term has no real local significance. Should be abandoned.

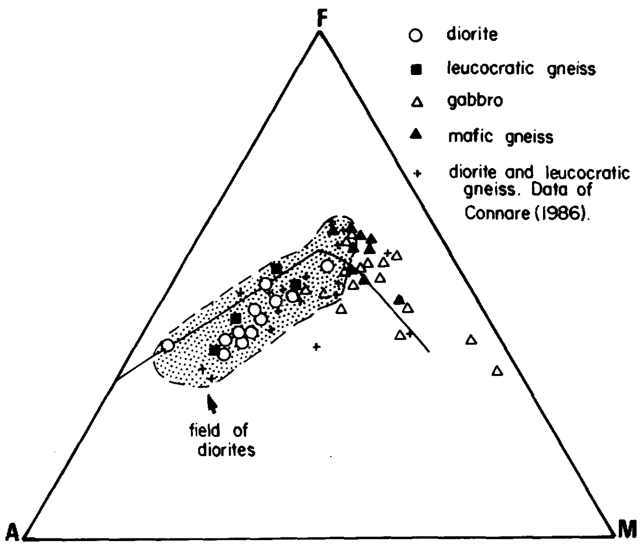

Figure 25.2. *AFM plot showing the three major geochemical suites present within the Parry Sound area. Unless noted otherwise, all samples were analyzed by the Geoscience Laboratories, Ontario Geological Survey, and are in the PETROCH data base. Crosses represent additional data for the McKellar Diorite and related leucocratic gneisses from Connare (1986).*

PARRY SOUND AREA GEOCHEMISTRY

Analysis of geochemical samples collected over the last few years as the result of Canada-Ontario 1985 Mineral Development Agreement (COMDA) funded field projects (Bright 1989; McRoberts and Tremblay 1988; McRoberts et al. 1988) has revealed the presence of several geochemical suites in the area as is summarized in Figure 25.2. Of particular interest is the tight cluster of these groupings. Follow-up sampling was conducted during the 1989 field season, and samples have been submitted for trace and rare earth element analysis. The results of these investigations will be reported more completely at a latter date.

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26. Project Unit 89-14. Regional Alteration Patterns and Mineralization Associated with the Deloro Granite, Grenville Province, Madoc Area

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INTRODUCTION

In 1866, the first discovery of gold in Ontario was made at Eldorado, associated with a small granitic plug located about 1.5 km north of the Deloro granite. Subsequent exploration in the late 1800s discovered several small gold-arsenic occurrences along the western margin of the Deloro pluton, chief of which was the Deloro Mine at Deloro which operated from 1899 to 1903. Renewed exploration activity for gold in the Grenville Province in the last few years has focussed on the Madoc area, and Noranda Incorporated has a low-grade, high-tonnage prospect near Malone, on the western margin of the Deloro granite (Kingston et al. 1989). In addition, the occurrence of wollastonite and iron skarn deposits adjacent to the Deloro granite has focussed attention on skarn-type mineralization in the Madoc area. Consequently, approximately three weeks of the 1989 field season were devoted to a study of the geologic setting, the metamorphic aureole and the mineralization of the Deloro granite over a 240 km^2 portion of the Madoc–Marmora area (Figures 26.1, 26.2).

PREVIOUS WORK

Geological mapping of the Deloro granite has been conducted at various scales: by Wilson (1940a, 1940b) at 1:63 360, by Saha (1959) at 1:15 840, by Hewitt (1968) at 1:31 680, and by Bartlett and Moore (1983, 1985) at 1:15 840. Detailed geochemical and petrographic studies of the pluton have been conducted by Saha (1959), Kuehnbaum (1973), Wu and Kerrich (1986), Wu and Macrae (1986), Wu (1984) and Abdel-Rahman and Martin (1987). The latter two studies contain considerable major, trace, and rare earth element data on the pluton. A precise U-Pb zircon age of 1241±2 Ma from the perthite granite phase of the Deloro granite has recently been published by van Breemen and Davidson (1988). Rb-Sr data on the pluton by Wanless and Loveridge (1972) and Bell and Blenkinsop (1980) suggest isotopic resetting occurred at ca. 1080 and 450 Ma.

Wilson (1965) briefly discusses the mineralization related to the Deloro granite. Hewitt (1968) documents the mineral occurrences present in Madoc Township, which includes the central and eastern parts of the Deloro granite. MacKinnon and

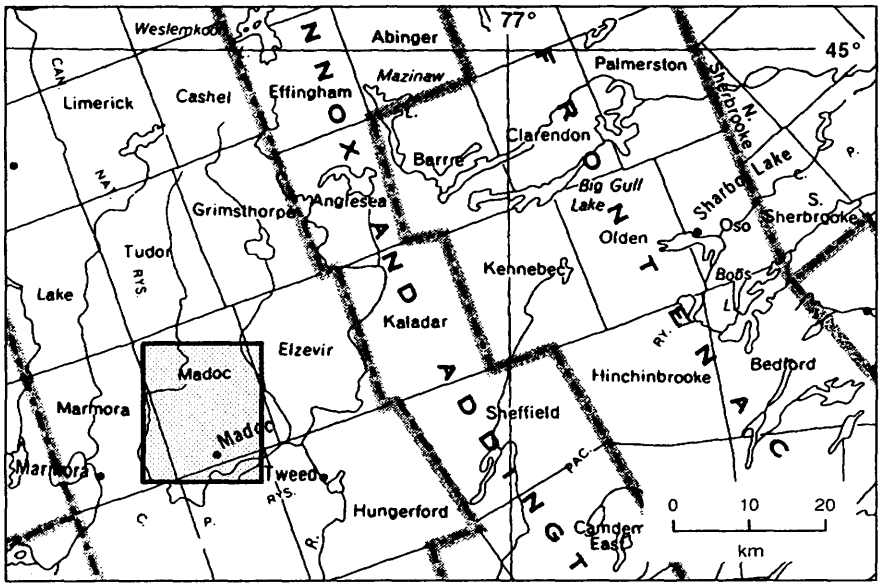

Figure 26.1. *Location map of the study area.*

Kingston (1987) have done a detailed study on the contact metasomatic wollastonite deposits present along the western margin of the Deloro granite.

GENERAL GEOLOGY

Figure 26.2 is a geologic sketch map of the Deloro granite and its environs showing the major rock types present in the intrusion, and alteration zones and mineral occurrences associated with it. Significant changes have been made to previous geologic maps of western and central Madoc Township as shown in Figure 26.2. Most significant are the recognition of an extensive alteration/contact metasomatic zone east of the Deloro granite; the elimination of the Madoc Volcanics and the Queensborough Acid Volcanic Centre of Hewitt (1968), and the discovery that the conglomerate horizons of the Skootamatta Formation (Bain 1960; Moore and Thompson 1980) are much more extensive than previously noted, and that they can be traced through the area previously mapped as the Madoc Volcanics. Brief descriptions of the major rock units in the area and the rationale for these major changes to the geology of the area are outlined below.

GRANITIC ROCKS

Saha (1959), Kuehnbaum (1973), and Abdel-Rahman and Martin (1987) have described the petrology and geology of the Deloro granite in detail. Diorite, syenite, and gabbro are found mainly along the west margin of the intrusion, with perthite granite making the core of the intrusion, and granophyric granite comprising most of the eastern part of the intrusion. The Malone and Empey granites (Figure 26.2) are probably satellite intrusions connected to the Deloro granite at depth.

A porphyry body located due west of Madoc closely resembles the syenite phase of the Deloro granite, but was previously placed in the Madoc Volcanics by Hewitt (1968). Miller and Knight (1914) considered this same porphyry to be part of the Moira Lake/Deloro granites. In addition, a number of small granite intrusions are found in the area between Highway 62 and Queensborough and may indicate that the Deloro granite shallowly underlies this area. It is also probable that the Moira Lake granite is connected to the Deloro granite at depth. The probable subsurface extent of the Deloro granite is shown in Figure 26.2, based on the distribution of granitic intrusions, country-rock alteration, and skarn mineralization in Madoc Township, as well as a regional, airborne, gamma-ray spectrometric, potassium and total-count uranium anomaly located over, and east of, the Deloro granite.

Contact metamorphism along the western margin of the Deloro granite has long been noted (Wilson 1965; Bartlett and Moore 1983; MacKinnon and Kingston 1987), and the talc deposits at the Henderson Mine have long been regarded as the product of hydrothermal alteration related to the Moira Lake granite (Wilson 1926; Easton et al. 1986). Alteration related to the east margin of the Deloro granite has not been previously described, and is more extensive than that found on the western and northwestern margin of the Deloro granite. This alteration has had considerable effect on the various lithologic units present in the area, as described below.

Based on distribution of the intrusive phases and the alteration pattern on the Deloro granite, it is likely that the intrusion is tilted, with the western part representing the deeper parts, and the northern and eastern parts representing the roof of the body. As outlined below, the distribution of mineralization around the intrusion may be zoned as well.

THE "MADOC VOLCANICS"

Hewitt (1968) described an extensive area of volcanic rocks of generally andesitic composition northeast of Madoc in the area roughly bounded by Highway 7 to the south, Highway 62 to the east, and the Deloro granite to the north and west. He termed these andesitic and rhyolitic rocks the "Madoc Volcanics", and reported the presence of massive and pillowed lavas, vesicular and amygdaloidal lavas, and agglomerate. These rocks were described (Hewitt 1968) as fresh, particularly in comparison with the Tudor Volcanics north and east of the area (Figure 26.2).

Six main lithologies were mapped by the author in the area underlain by the "Madoc Volcanics":

1. **Black Porcelanites.** These are massive, textureless, dark-grey to black, aphanitic, dense, conchoidal-fracturing rocks. In thin section, no volcanic textures are recognizable, and it is difficult to even say if these are igneous rocks. In thin section they are seen to consist of a fine-grained, felted mat of amphibole, andesine feldspar, epidote, opaque minerals and minor carbonate. The dark colour is due to the abundance of small opaque grains disseminated throughout the rock. Hewitt (1968) mapped these rocks as andesite.
2. **Felsites or Pink Porcelanites** (rhyolite of Hewitt 1968). These are massive, textureless, pink, red or white, aphanitic, conchoidal-fracturing rocks. They differ from the black porcelanites mainly in colour; in thin section, no textures indicative of a pyroclastic or other volcanic origin could be found.
3. **Altered Gabbro.** This consists of massive, dark-grey to black, conchoidal-fracturing rocks with elongate, 0.35 to 1 cm long hornblende laths forming a pseudodiabasic texture. In thin section, this rock shows igneous textures, although the hornblende laths are extremely corroded and large plagioclase grains have been recrystal-

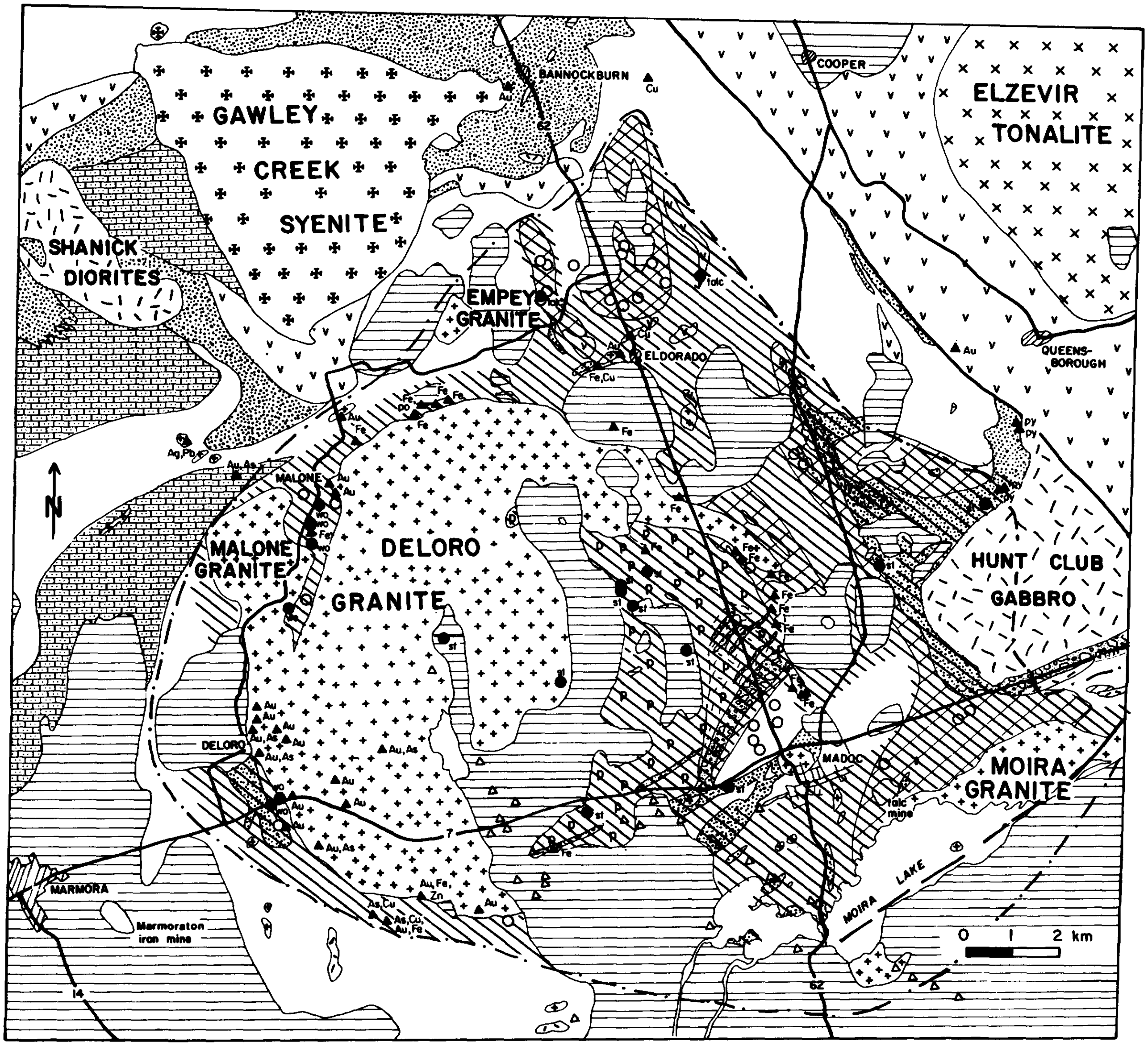

Figure 26.2. *Simplified geologic map of the Deloro granite and environs, showing regional-alteration zones, and distribution of gold and magnetite skarn mines and occurrences, and marble quarries in the Madoc–Marmora area. Geology from Saha (1959), Hewitt (1968), Bartlett and Moore (1983) and Easton (this study).*

lized into fine-grained feldspar aggregates. It is this unit that Hewitt (1968, p.5) described as an andesite, and which had a partial chemical-analysis result of 48.96 percent silica.

4. **Porphyry.** This rock is similar to the black porcelanite, except that it has abundant 0.25 to 0.75 mm sized, euhedral plagioclase laths, constituting 20 to 75 percent of the rock. The unbroken crystals, and their abundance, suggest that the rock is likely hypabyssal, and not a crystal tuff. In map pattern, the porphyry units are discordant with adjacent conglomerate units, consistent with an intrusive origin. Hewitt (1968) mapped this rock as an andesite.

5. **Altered Conglomerates.** These are similar to the black porcelanites in many respects, except that subround to round, pebble- to cobble-sized clasts are visible on the weathered surface. On fresh surface and in thin section, the clastic nature of the rock is indistinct to absent. Both matrix- and clast-supported conglomerates are present; all are heterolithic, and arenite interbeds are common. The latter have only been noted interbedded with the conglomerate units, largely because they otherwise resemble the black porcelanites. At UTM 18T, 300750E, 4931000N, channels and graded beds are present in an altered conglomerate horizon, indicating top to

LEGEND

- Paleozoic rocks
- Syenite (ca. 1085 Ma)
- Tonalite, granodiorite (ca. 1229 Ma)
- Granite, minor syenite, diorite, gabbro (ca. 1245 Ma)
  - zone of alteration
  - p black and pink porcelanite, porphyry, felsite
  - altered gabbro
- Metagabbro
- Predominantly massive, dolomite marble, minor felsite in zone of alteration
- Predominantly bedded, calcite marble
- Interbedded calcite marble, meta-arenite, metawacke (includes felsite in zone of alteration)
- Meta-conglomerate
- Meta-arenite, metawacke, pelite (includes felsite in zone of alteration)
- v Mafic metavolcanics, metagabbro sills, volcaniclastic metasediments

Symbols

- ▲ metallic mineral occurrence
- △ fluorite occurrence
- ● industrial mineral occurrence
- ○ marble quarry
- —— fault
- • ——•—— inferred subsurface extent of the Deloro Granite

Abbreviations

Ag - silver	po - pyrrhotite
As - arsenic	py - pyrite
Au - gold	st - stone
Cu - copper	wo - wollastonite
Fe - iron	Zn - zinc
Pb - lead	

Legend for Figure 26.2.

the south. Hewitt (1968) mapped some of these rocks as agglomerate.

6. **Breccias.** Breccias are locally present, and are generally of a jigsaw type where the angular fragments interlock, giving the appearance of an internally brecciated or fractured rock, not a transported rock. Breccias can be found in any lithology of units 1 or 2, and are commonly associated with zones of microfracturing (0.5 to 2 cm spaced fine fractures) of the host lithology. As with the altered conglomerates, the fragmental nature of the rock is only clearly visible on the weathered surface. A second type of breccia consists of breccias with plate-like, angular fragments, apparently in discrete, 1 to 3 m thick horizons. The platy breccias resemble platy-clast carbonate breccias that occur interbedded with marble turbidites in the area, and are probably silicified carbonate rocks. None of the breccias examined in the "Madoc Volcanics" resembles typical pyroclastic or volcaniclastic breccias.

A curious attribute of all these rock units is the apparent contradiction between the outcrop appearance and the fresh surface and thin-section appearance. Obviously, clastic rocks, such as the altered conglomerates, are virtually unrecognizable as clastic rocks in thin section. Further, definitive volcanic textures, or even contacts between flows, are absent from rocks that have been described as being fresher than the Tudor Volcanics.

Hewitt (1968) reported pillow-top measurements in the area of UTM 18T, 301850E, 4933975N and pillow lavas at UTM 18T, 300700E, 4931100N. Despite extensive searching, no features that could be interpreted as, or mistaken for, pillows could be found in either area. Host rocks in the former locality consist of altered gabbro and conglomerate, and, in the latter, consist of porphyry and altered conglomerate. The vesicles and amygdules reported by Hewitt (1968) occur in all units except the breccias, and show no consistent distribution with rock type, or with any features that could be construed as flow contacts or individual flows. At UTM 18T, 302250E, 4933400N, the "amygdules" are found in light-coloured alteration zones that overprint textures in the altered gabbro unit, suggesting a secondary origin for the amygdules. At UTM 18T, 306650E, 4933850N, irregular, 0.5 to 10 cm long vugs are present in an altered, coarse-grained sandstone/conglomerate unit, again suggesting a secondary origin of these calcite-filled cavities.

The most compelling evidence against a volcanic origin for many of these rocks is the abundance of altered conglomerate in the area underlain by the "Madoc Volcanics" (Figure 26.2). Both the altered gabbro and the porphyry units truncate bedding in the altered conglomerates, and thus would appear to be intrusive in origin, perhaps related to the Deloro granite. In addition, the difference between the pink and black porcelanites is one of colour rather than original composition, as indicated at UTM 18T, 301600E, 493400N where a typically grey, altered conglomerate changes on strike gradually into a pink, slightly sericitized rock. The grey rock was originally mapped by Hewitt (1968) as andesite, the latter as a rhyolite breccia. Contacts between the pink and grey porcelanites are typically diffuse, and, with the exception of colour, the two rock types are similar.

The unusual nature of the rocks previously shown as the "Madoc Volcanics" can be best explained if these rocks are considered to represent silicified and altered country rocks, and fine-grained intrusive phases related to the Deloro granite. Alteration and silicification in the conglomerates have partly obliterated the clastic nature of these rocks. The porphyry and the altered gabbro may be early phases of the Deloro granite which were altered and silicified during emplacement of the granophyric granite. The black and pink porcelanites could represent a variety of lithologies, possibly altered and silicified fine-grained sediments, or hydrothermally altered rocks of any number of protoliths that were subsequently silicified. Some of the porcelanites may also be altered hypabyssal phases of the Deloro granite. Although it is possible that some altered volcanic rocks are present in the area, they are no longer easily recognizable as such, and are volumetrically minor. Altered volcanic rocks present near Eldorado (UTM 18T, 300000E, 4940300N) are clearly recognizable as such, in contrast to the porcelanites, indicating that it is unlikely that any volcanic rocks are present in the "Madoc Volcanics".

CARBONATE ROCKS

Earlier workers (e.g., Miller and Knight 1914; Hewitt 1967) attempted to distinguish two types of carbonate rocks in the area: grey, bedded, fine- to medium-grained, calcitic marbles showing well-preserved sedimentary features which were termed "Hastings Series" marbles; and white, pink, blue-grey, and buff, medium- to coarse-grained, dolomite and calcite "crystalline" marbles of the "Grenville Series". This was, and is, an important lithologic distinction in the Madoc area. However, the relationship between the two marble types is not stratigraphic as earlier workers thought, but rather reflects the degree of alteration by the Deloro granite (with the "Hastings Series" rocks being unaffected by Deloro alteration, and the "Grenville Series" being variably affected).

The grey, calcitic marbles represent the typical metamorphosed carbonate rocks of the Grenville Supergroup in the area. Dolomite marbles occur in three settings in the area as listed below.

Firstly, as thin interbeds within the grey calcite marbles, the dolomite beds representing early seafloor diagenesis of the calcite marble or primary deposition of dolomite.

Secondly, as weakly dolomitized marble which locally shows faint-bedding textures and which locally preserve algal-laminate stromatolites. This type is well exposed at UTM 18T, 303350E, 4939250N, and at the stromatolite locality at the Madoc talc mine. This dolomite probably formed during burial diagenesis of the calcite marbles and is generally ivory or blue grey in colour.

Thirdly, as mainly buff dolomite associated with silicic rocks which were mapped by Hewitt (1968) as felsite and paragneiss. Many of these rocks are brecciated, with some breccias containing bedded fragments. The bedded fragments show bedding typical of the calcitic marbles in the area, although they have been subsequently dolomitized and variably silicified (e.g., UTM 18T, 303225E, 4939550N). In other cases, the breccias are probably early sedimentary breccias that have been re-dolomitized and silicified (e.g., UTM 18T, 303600E, 4937350N). The type 3 marbles seem to represent rocks subjected to a secondary-alteration event that was superimposed on top of the burial-diagenesis event, and in many instances, it is not possible to separate the effects that produced type 2 from those that produced type 3 marbles. This may be the result of the burial-diagenesis dolomitization, creating pore space that focussed fluid flow during intrusion of the Deloro granite. This fluid flow re-dolomitized, and locally silicified, the existing dolomites. For the most part, the felsites associated with the type 3 dolomites consist of buff-weathering, silicified, clastic metasedimentary rocks such as arenites and quartz arenites (e.g., UTM 18T, 306750E, 4937000N), although some may be hypabyssal phases of the Deloro granite.

Almost all the mineralization present around the Deloro granite is hosted in the type 3 marbles (Figure 26.2), and these rocks host the majority of the marble quarries in the area.

SILICEOUS CLASTIC METASEDIMENTS

As in the case of the carbonate metasediments, both unaltered and altered varieties of siliceous, clastic metasediments are present in the Madoc area. Along Highway 7, a variety of heterolithic clast- and matrix-supported conglomerates and intercalated arenite, quartz arenite, and calcarenites comprise the Skootamatta Formation (Bain 1960; Moore and Thompson 1980; *see* also Paper 27, this volume). Unaltered conglomerates of the Skootamatta Formation have been previously noted in the Madoc syncline (Hewitt 1968; Moore and Thompson 1980), and as shown on Figure 26.2, altered equivalents can be traced north and west of this syncline.

In addition to the conglomerates and arenites, wackes and slates of the Madoc Formation (Moore and Thompson 1980) are also present in the Madoc syncline. Partly altered equivalents of these rocks occur at UTM 18T, 303500E, 4931600N and 308000E, 4933250N, and it is possible that some of the black porcelanites, particularly those exposed on Highway 7 near UTM 18T, 300250E, 4930600N, are altered equivalents of these rocks.

As noted in the section on carbonate metasediments, variably altered and silicified, clastic metasediments are also present in the Queensborough area.

In Marmora Township to the east, Bartlett and Moore (1983, 1985) have mapped a wide range of siliceous, clastic sediments within the carbonate sequence, including arenites, wackes, and siliceous arenites probably derived from a volcanic source. Apart from the conglomerates, which commonly contain a high percentage of carbonate clasts, the metasediments in Madoc Township are similar in character and depositional setting to those present in Marmora Township.

GRENVILLE SUPERGROUP/FLINTON GROUP RELATIONS

Moore and Thompson (1980) considered rocks in the Madoc syncline to be correlative with the Flinton Group. They considered that an unconformable relationship existed between the Skootamatta Formation conglomerates and the Madoc Volcanics, and that the overlying Madoc Formation (slates) and Stewart Formation (dolomite and calcite marbles) were younger than the Grenville Supergroup. Miller and Knight (1914) could not determine if an unconformity or an intrusive relationship existed between the conglomerate and the "andesites" in the area.

The andesite at the classic contact (UTM 18T, 301500E, 4931500N) of Miller and Knight (1914) is actually the altered gabbro unit, and it is likely that this contact is intrusive. Recent construction has destroyed part of the classic outcrop, so it is not possible to see all the relationships Miller and Knight observed. However, altered conglomerates are present immediately north of this contact, and are similar to the Skootamatta Formation conglomerates in all aspects, other than their porcelanite character. Thus, the question remains as to whether this is really an unconformity or an alteration front. Top information from altered conglomerates in the area due west of Madoc indicates that the Madoc syncline can be traced west of the "volcanic" contact and that no structural discordance is present along the "unconformity". Further, the distinction between the Madoc and Stewart formations and adjacent rocks in the area appears to be simply a matter of degree of alteration, with the Stewart Formation consisting mainly of grey, bedded calcite marbles, and the surrounding marbles consisting of types 2 and 3 dolomites (*see* above under section "Carbonate Rocks").

In summary, there is no evidence that any geologically younger strata are present in the Madoc syncline, and the lithologic differences can be easily explained by the degree of alteration by the Deloro granite. Thus, there is no indication that Flinton Group strata are present in the Madoc area. The term Stewart Formation should be abandoned, as it serves no stratigraphic purpose. The Madoc and Skootamatta formations have local significance, but usage of these names should be expanded to include altered equivalents (such as the altered conglomerate unit). Both formations are considered by the author to be part of the Grenville Supergroup.

MINERALIZATION

The results of assays performed by the Geoscience Laboratories, Ontario Geological Survey on samples collected by the author from the map area are listed in Table 26.1. All samples were analyzed for Nb, but results for all samples were not complete at the time of publication.

GOLD

Gold is found in quartz-arsenopyrite veins along the western and northwestern margin of the Deloro granite, hosted in a variety of phases of the intrusion. Gold-bearing quartz veins are associated with shearing, and it is possible that a shear zone along the west margin of the pluton controls the distribution of gold in the area. The Noranda Incorporated gold property is hosted in a small satellite body of the Deloro granite which is now a protomylonite, but it is not associated with quartz-arsenopyrite veins as are most of the historic occurrences in the area, such as the Deloro Mine.

WOLLASTONITE

MacKinnon and Kingston (1987) and MacKinnon (in preparation) have described the setting of the wollastonite deposits around the Deloro granite. These deposits are present only along the west and northwest margin of the pluton. The absence of wollastonite on the north and east sides of the body may be related to the fact that this is the upper part of the intrusion. Hence, the country rocks were subjected to slightly lower temperatures, and greater fluid movement, than the west side: conditions which may not have been suitable for forming wollastonite.

IRON AND SULPHIDE SKARN DEPOSITS

As shown in Figure 26.2, a number of magnetite-skarn, pyrite, pyrrhotite, and copper deposits are scattered about the Deloro granite, particularly along the north and east margins of the body. In addition, many of these deposits are associated with small granite intrusions, and are generally hosted in dolomitized and locally silicified marbles. Many of these iron deposits were affected by late Proterozoic–early Paleozoic weathering effects which formed hematite in the upper parts of the deposits (Di Prisco 1987). A notable example is the Eldorado Mine, which was opened as a hematite-magnetite mine but which produced copper at depth. Thus, the surface expression of these deposits may not be a true indication of the type of mineralization that is present.

MARBLE AND AGGREGATE

As shown in Figure 26.2, past and present marble quarries around the Deloro granite are associated with the zone of dolomitization and silification found surrounding the intrusion, particularly on its north and east sides. This is because the altered rocks are better suited for extraction than are the grey, bedded, unaltered calcitic marbles common in the area. Dolomitization has served to make the grain size in the rocks more uniform, and it has changed the colour of the marbles to more attractive white, cream, buff, or pinkish varieties. Associated silicification has also made these rocks more competent than their unaltered counterparts.

A number of quarries in the area have produced roofing granules. Many of these are located in the massive, grey to black, locally microbrecciated, porcelanites. As in the case of the marbles, it is alteration associated with the Deloro granite that has given these rocks their commercial attributes.

NIOBIUM–TANTALUM–REE MINERALIZATION

Both Wu (1984) and Abdel-Rahman and Martin (1987) have documented the peralkaline geochemical nature of the Deloro granite. Niobium and tantalum mineralization is commonly associated with geochemically specialized granites such as the Deloro granite, which are characterized by enrichment in fluorine and by the development of pervasive, post-magmatic alteration. Alkali granites which contain alkali amphiboles, such as the Deloro granite, are associated mainly with niobium mineralization (Pollard 1989). The mineralization is usually associated with the upper, marginal phases of the intrusion, which commonly have been altered and microfractured (Pollard 1989). Niobium–tantalum–rare earth element (REE) mineralization has not been observed in the study area but might be present. The best target areas for this type of mineralization are along the eastern margin of the intrusion, where the granophyric phase is most widespread, and where locally, felsic microbreccias are present (Figure 26.2).

FLUORITE VEIN DEPOSITS

The Madoc fluorite district lies south of the Deloro granite, with the fault-controlled fluorite veins being hosted in the overlying Paleozoic strata. The concentration of these veins in the Madoc area may not be fortuitous. Phases of the Deloro granite have fluorine contents in the 1000 to 3660 ppm range (Wu 1984) and marbles and siliceous rocks adjacent to the pluton also have high (1300 to 2200 ppm) fluorine contents (Lalonde 1974). Thus, the source of some or all of the fluorine found in the veins may

TABLE 26.1. ASSAY RESULTS FROM SELECTED SAMPLES FROM THE MADOC AREA. Analyses by the Geoscience Laboratories, Ontario Geological Survey.

Sample Number	UTM Coordinates	Au (ppb)	Cu (ppm)	Nb (ppm)	Other* (ppm)
Granites					
89RME-0023A	E301350, N4936000	<2	5	26	
89RME-0023B	" "	<2	<3	28	
89RME-0056A	E301500, N4935300	<2	10	16	
89RME-0056B	" "	<2	7	23	
89RME-0101	E299300, N4939950	<2	11	15	
89RME-0120	E295650, N4938850	<2	<5		
89RME-0124	E307450, N4930500	<2	5		
89RME-0125A	E307350, N4931100	<2	<5		
89RME-0125B	" "	<2	<5		
89RME-0125C	" "	<2	<5		
89RME-0128	E303350, N4932850	<2	11		
89RME-0129	E303400, N4932750	<2	<5		
89RME-0130	E303250, N4932750	<2	13		
89RME-0131	E303275, N4932700	<2	5		
89RME-0134	E303400, N4932600	<2	<5		
89RME-0135	E303300, N4933200	<2	<5		
89RME-0139	E298100, N4932925	<2	104		
89RME-0140	E298175, N4932925	<2	66		
89RME-0174	E293400, N4936650	<2	41	36	106 Zn
Magnetite-Hematite Skarn Deposits					
89RME-0133A	E303325, N4232500	<2	7		
89RME-0133B	" "	22	10		15400 Mn
89RME-0133C	" "	6	15		
89RME-0138A	E298000, N4929450	<2	15		190 Zn
89RME-0138B	" "	27	550		500 Zn
89RME-0145A	E300100, N4935800	<2	10		145 V
89RME-0155A	E302900, N4935100	7	13		95 Zn
89RME-0159	E295250, N4938975	<2	9		890 Zn, 20700 Mn
89RME-0160A	E295250, N4939000	<2	90		
89RME-0160B	" "	3	215		
89RME-0161A	E295275, N4939025	<2	175		
89RME-0161B	" "	8	165		124 Zn
89RME-0161C	" "	15	266		223 Zn
89RME-0183A	E302000, N4935650	<2	<5	13	205 Zn
89RME-0183B	" "	15	5	<5	90 Zn, 267 Ce, 38 La
89RME-0183C	" "	<2	30	5	105 Zn
89RME-0184	" "	<2	85	<5	49 Ce, 38 La
87RME-0352	E301972, N4935658	ND	ND	ND	27 Zr, 64 Nd
87RME-0353	E293861, N4938133	ND	ND	ND	28 Zr, 60 Nd
Black Porcelanites					
89RME-0025	E301500, N4935300	2	12	ND	
89RME-0056C	E301500, N4935300	<2	75	23	
89RME-0056D	" "	<2	8	27	
89RME-0121	E297700, N4929425	<2	8		
89RME-0136	E299500, N4930550	4	13		
89RME-0141	E299550, N4932550	<2	6		
89RME-0142	E299650, N4935050	<2	5		
89RME-0145B	E300100, N4935800	<2	<5		175 Zn, 265 V
89RME-0151	E302550, N4934550	<2	<5		
Pink Porcelanites					
89RME-0024	E301500, N4935350	6	28	ND	
89RME-0132	E303300, N4232600	<2	12		
89RME-0149	E302900, N4934500	<2	19		
89RME-0150	E302600, N4934500	9			16900 Ti
89RME-0152	E302600, N4934000	3	<5		
89RME-0154A	E302800, N4934750	5	45		
89RME-0154B	" "	38	28		
89RME-0182	E301950, N4935600	<2	6	7	

TABLE 26.1. CONTINUED.

Sample Number	UTM Coordinates	Au (ppb)	Cu (ppm)	Nb (ppm)	Other* (ppm)
Altered Marbles, Felsite					
89RME-0091A	E303750, N4938025	5	6	<5	
89RME-0091B	" "	<2	5	<5	
89RME-0091C	" "	<2	11	<5	
89RME-0092A	E303700, N4938325	5	71	<5	
89RME-0093	E303350, N4939250	4	<5	<5	
89RME-0094A	E303225, N4939550	9	5	<5	
89RME-0094B	" "	<2	5	6	
89RME-0103	E302500, N4932400	<2	9	<5	
89RME-0107	E303600, N4942400	<7	9	<5	
89RME-0122A	E307100, N4932550	<2	7		
89RME-0122B	" "	<2	8		
Felsite, Silicified Metasediments, Other					
89RME-0092B	E303700, N4938325	5	39	5	
89RME-0097	E306750, N4937000	23	7	12	
89RME-0102	E303500, N4931600				
89RME-0117	E300150, N4943600	<2	8		
89RME-0100	E300000, N4940300	<2	137	<5	
89RME-0114A	E298500, N4944000	<2	61		266 Zn
89RME-0114B	" "	5	31		130 Zn
89RME-0145C	E300100, N4935800	<2	35		17100 Ti, 175 Zn

**Other elements represent abundances at or above detection limits of 0.1 ppm for Sb, 5 ppm for Ni, 10 ppm for Pb, 0.3 ppm Ag, 5 ppm Co. Detection limit for Au is 2 ppb, <5 ppm for Cu, <5 ppm for Nd and <10 ppm for Zn. Only Zn values >40 ppm are listed. Background levels in area are generally close to detection limits; samples 89RME-0103, 89RME-0107, 89RME-0102, etc., represent background levels in the marbles and clastic metasediments, respectively. ND = not determined.*

have been the Deloro granite. The ca. 450 Ma isotopic-resetting event in the area may have been related to formation of the fluorite veins.

DISCUSSION

This study has significant implications for both the regional geology of the Madoc area and for mineral exploration. Most important is the recognition that the metasomatic-alteration effects of the Deloro granite are more widespread than previously thought, and that many rocks previously considered to be volcanic in origin represent altered sedimentary or plutonic rocks. Although some altered volcanic rocks may be present in the area, they are volumetrically minor. There is no evidence that volcanic equivalents of the Deloro granite are present in the area, as suggested by Abdel-Rahman and Martin (1987), among others, nor is there any indication that these rocks represent a caldera structure. The Queensborough Acid Volcanic Centre of Hewitt (1968) consists predominantly of silicified, clastic metasedimentary rocks. Further, it is now clear that Madoc Township was underlain by the same package of dominantly carbonate metasedimentary rocks that underlies Marmora Township, and that this area was once a sizable carbonate depositional basin. This basin is bounded to the west, in stratigraphic contact, by the fault-imbricated Belmont Lake metavolcanics (Bartlett and Moore 1983, 1985). The eastern contact of the basin is a northeast-trending fault, possibly a thrust fault, that passes through Queensborough and juxtaposes deformed volcanic and gabbroic rocks and the Elzevir tonalite against the carbonate metasediments.

The Deloro granite may underlie much of the zone of alteration at shallow depths. Gravity data from the area show that the Deloro granite is best modelled as a slab extending slightly to the north of the surface contact and underlying the Paleozoic strata to the south (Real and Thomas 1987). Ultimately, small satellite intrusions such as the Moira granite, the Malone granite, and the syenite at the Marmoraton iron mine may be shown to be linked at depth. These satellite intrusions may be good candidates for mineral exploration, as they represent the uppermost and marginal parts of the intrusive complex and consequently are the most likely to be mineralized (Pollard 1989).

Recognition that there are three types of dolomitic marbles in the area, some of which have been dolomitized and silicified by the intrusion of the Deloro granite, has important implications for those attempting to do paleoenvironmental reconstruction of the carbonate depositional environment or map metamorphic isograds in the area. Although metamorphic grade in the Madoc area has generally been regarded to be at greenschist facies, Sampson

(1972) reported amphibolite-facies assemblages from the siliceous, clastic metasediments in the Queensborough and Madoc area, and kyanite has been reported from the Madoc Formation (Sampson 1972; Moore and Thompson 1980). These higher grade assemblages are all located in or near the alteration zones, and most likely represent the effects of contact metamorphism by the Deloro granite.

A number of Paleozoic outliers are present adjacent to, and overlying the Deloro granite (Figure 26.2). The distribution of these outliers may not be random, but may reflect zones of intense alteration which were weathered prior to the deposition of the Ordovician carbonate rocks in the area. Many of the mineral occurrences around the Deloro granite, particularly the iron deposits, have been affected by late Proterozoic–early Paleozoic weathering effects, as documented by Di Prisco (1987). As Paleozoic rocks overlie much of the eastern margin of the Deloro granite, the possibility of significant mineralization lying below the Paleozoic should not be discounted.

In terms of mineral exploration, almost all mineral occurrences and past producers in the area, whether they are precious or base metals, or industrial minerals, are related to the metasomatic-alteration zone of the pluton. This zone is much more extensive than previously thought, thereby increasing the area in which exploration targets may be present. Significantly, the geochemical nature of the pluton suggests that niobium, tantalum, and rare-element mineralization may be present adjacent to and in the granophyric phases of the intrusion, in addition to gold, wollastonite, iron, and marble occurrences. The potential for this type of mineralization was previously unrecognized.

"DELORO-LIKE" PLUTONS ELSEWHERE IN THE GRENVILLE PROVINCE

Is the Deloro granite unique? This is a difficult question to answer as detailed geochemical and petrologic data are not available for many plutons in the Central Metasedimentary Belt. The Barbers Lake granite, located 20 km north-northeast of Sharbot Lake, is a flourite-bearing granite that has a geochemical and oxygen-isotope signature similar to that of the Deloro granite (Wu 1984; Wu and Kerrich 1986). It is, however, peraluminous and does not show the same level of high-field strength element and rare earth element enrichment as the Deloro granite (Wu 1984; Wu and Kerrich 1986). It intrudes a pyroxenite-diorite-gabbro complex (the Dalhousie Lake amphibolite complex of Pauk (1984)); thus, the potential for skarn-type mineralization is diminished. Niobium enrichment has been reported from this intrusion (K. Ford, geologist, Geological Survey of Canada, written communication, 1989). Both the Deloro and the Barbers Lake granites have high ^{18}O values (roughly 10.0 per mil), which were interpreted by Wu and Kerrich (1986) to indicate exchange with hydrothermal fluids during cooling of the magma. Thus, high ^{18}O values may be an indicator of plutons that have good mineralization potential.

The Cheddar granite, located southeast of Bancroft, is an alkaline granite that also has high (920 to 2740 ppm) flourine contents (Wu 1984). Numerous uranium and thorium occurrences are associated with this intrusion (Bright 1987). Alteration zones have not been documented from the Barbers Lake or the Cheddar granites; however, in areas of higher grade metamorphism, it may be more difficult to discern metamorphic effects related to the plutons from the regional metamorphism.

SUMMARY

This study provides an integrated explanation for both metallic-element and industrial-minerals mineralization in the Madoc–Marmora area. Mineralization is related to emplacement of the Deloro granite, and the large alteration halo associated with the body. Important types of mineralization in the area are gold, arsenic, magnetite, copper, marble, industrial minerals (i.e., roofing granules) and wollastonite. In addition, the area has potential for hosting niobium and other rare-element mineralization.

The existence of a widespread alteration zone around the Deloro granite explains many previously controversial and contradictory aspects of Madoc area geology, including the Hastings and Grenville series relationships, the Grenville Supergroup/Flinton Group relationship near Madoc, and the distribution of metamorphic grade in the area.

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27. Project Unit 89-14. Geology of the Elzevir Area, Hastings and Lennox and Addington Counties

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INTRODUCTION

The Elzevir map area is located 50 km north of the town of Belleville and approximately 200 km northeast of Toronto. The map area covers about 550 km² and includes parts of Tudor, Grimsthorpe, Anglesea, Madoc, Elzevir, Kaladar, Huntingdon and Hungerford townships (Figure 27.1). It is bounded by longitudes 77°15'W and 77°30'W and by latitudes 44°30'N and 44°45'N. The main towns in the map area are Madoc, Actinolite and Queensborough. Good access to most of the area is provided by highways 7 and 62, county roads, and cottage and logging roads. The northwest corner of the map area is not easily accessible. Madoc Township was mapped by Hewitt (1968), but most of the map area has not been previously mapped in detail.

MINERAL EXPLORATION

Mineral exploration and production in the Elzevir area date back to the 1830s, when magnetite ore was extracted from the Seymour iron mine (Lot 11, Concession V, Madoc Township). Afterward, to the turn of the century, several mines produced iron ore (hematite, magnetite), pyrite, gold, and industrial minerals (talc, dolomite). The history of these early mines is summarized in Carter (1984) and Malczak et al. (1985). Geological Data Inventory Folios (GDIFs) are available for Elzevir (OGS 1984a), Grimsthorpe (OGS 1983), Madoc (OGS 1984b) and Tudor (OGS 1984c) townships and summarize exploration activity in these areas.

Currently there are two producers in the area (Figure 27.2). Stoklosar Marble Quarries Limited produces marble terrazzo chips in a mill located about 5 km north of Madoc along Highway 62. This mill is supplied by a number of quarries in the Elzevir and neighbouring areas. The second producer is the mining complex of Canada Talc Limited, located at the southeastern edge of the town of Madoc. Talc and marble are mined and quarried by open pit and underground operations and are treated in an on-site mill.

For the past five years, exploration has been very active in the Elzevir area, primarily for gold and industrial minerals (Assessment Files Research Office (AFRO), Ontario Geological Survey; Kingston et al. 1989). In 1986 and 1987, Lacana Mining Corporation (now International Corona Resources Ltd.) conducted an extensive exploration project south of County Road 20 (Barry occurrence, Elzevir Township) to evaluate the gold potential of quartz veins present along a shear zone (AFRO). Detailed geological mapping and diamond drilling (433.7 m)

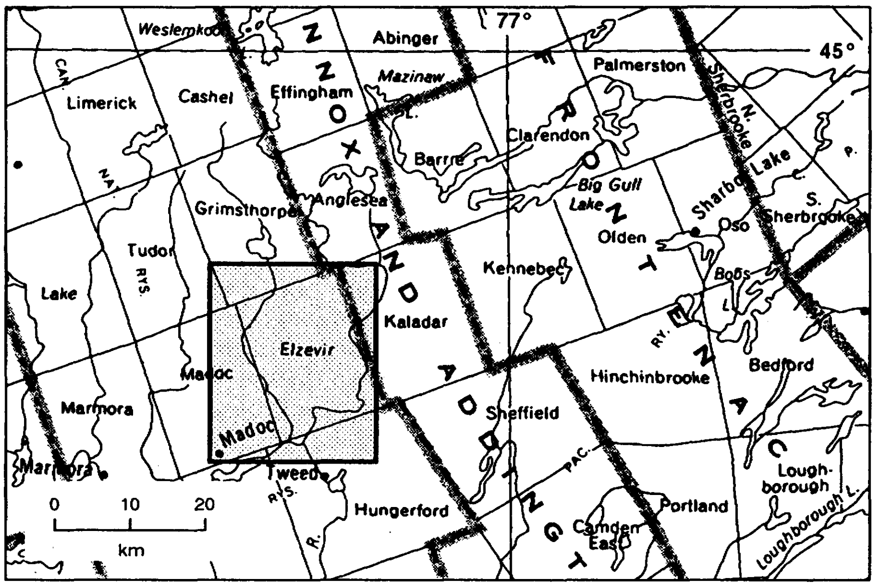

Figure 27.1. *Location map of the study area.*

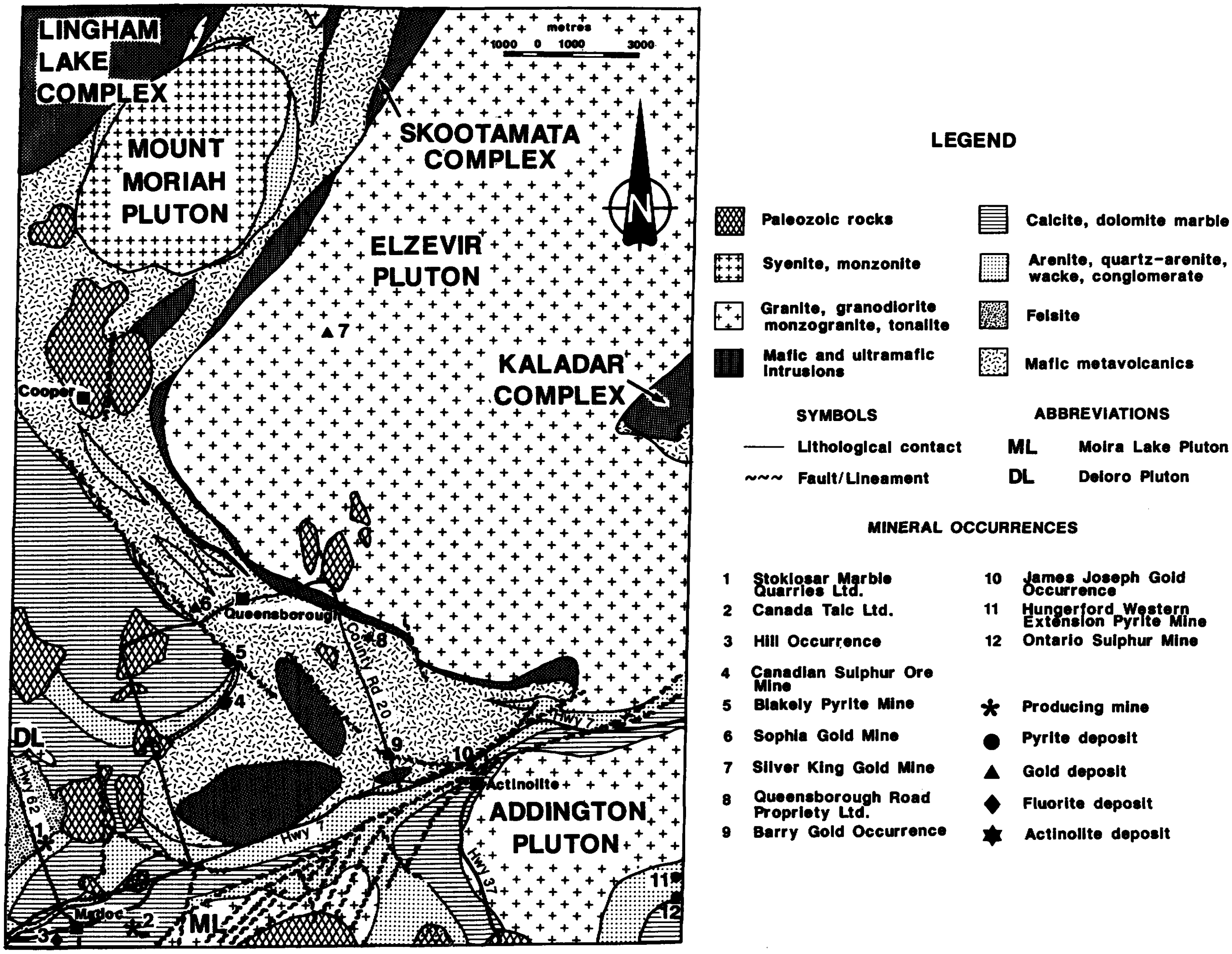

Figure 27.2. *Simplified geological map of the Elzevir area.*

were carried out on this property. In 1985 and 1986, Faith Mines Limited (a subsidiary of Arbor Resources Incorporated) carried out geological and geochemical surveys, accompanied by a diamond drilling program (total of 2766.7 m drilled), of various properties of the Sager family, in particular the former Sophia gold mine in Madoc Township (AFRO). Gateford Resources Incorporated, since 1987, has carried out geological work and diamond drilling (total drilling unknown) for gold on its property due southeast of Cooper in Madoc Township (AFRO).

Exploration for industrial minerals, especially talc, dolomite and calcite, and more recently actinolite, has been extensive in this area. Since the beginning of the century, talc was known to crop out around the Moira Lake and Elzevir plutons (LeBaron and van Haaften 1989). Twin Buttes Explorations Incorporated optioned several properties east of Cooper and Queensborough (Elzevir and Madoc townships) to assess talc deposits. Detailed geological mapping, followed by drilling totalling 736.1 m, was undertaken during the summer and fall of 1985 (AFRO). In 1985, Trisar Resources Limited carried out a geophysical investigation of the north margin of the Moira Lake pluton in Madoc Township, with the goal of delineating talc orebodies similar to those at the Canada Talc Limited Mine

(AFRO). More recently, Queensborough Road Properties Limited has been testing the feasibility of quarrying its actinolite deposit in Elzevir Township.

GENERAL GEOLOGY

The Elzevir area is underlain by rocks of Middle to Late Proterozoic age which form part of the Central Metasedimentary Belt of the Grenville Province (Wynne-Edwards 1972). Flat-lying rocks of Middle Ordovician age overlie the Precambrian basement in the south-central and western parts of the map area (Figure 27.2).

Two major structural blocks occur in the map area (Figures 27.2 and 27.3). The north block lies north of Highway 7 and encompasses most of the map area. As shown in Figure 27.3, this block is dominated by northwest- and northeast-striking structural trends. The second block lies in the south-east corner of the map area, and is dominated by east- to northeast-striking trends (Figure 27.3). A complex fault zone, the Moira Lake fault zone (Figure 27.3), separates the two structural blocks. This fault zone is discussed in greater detail in the section on structural geology.

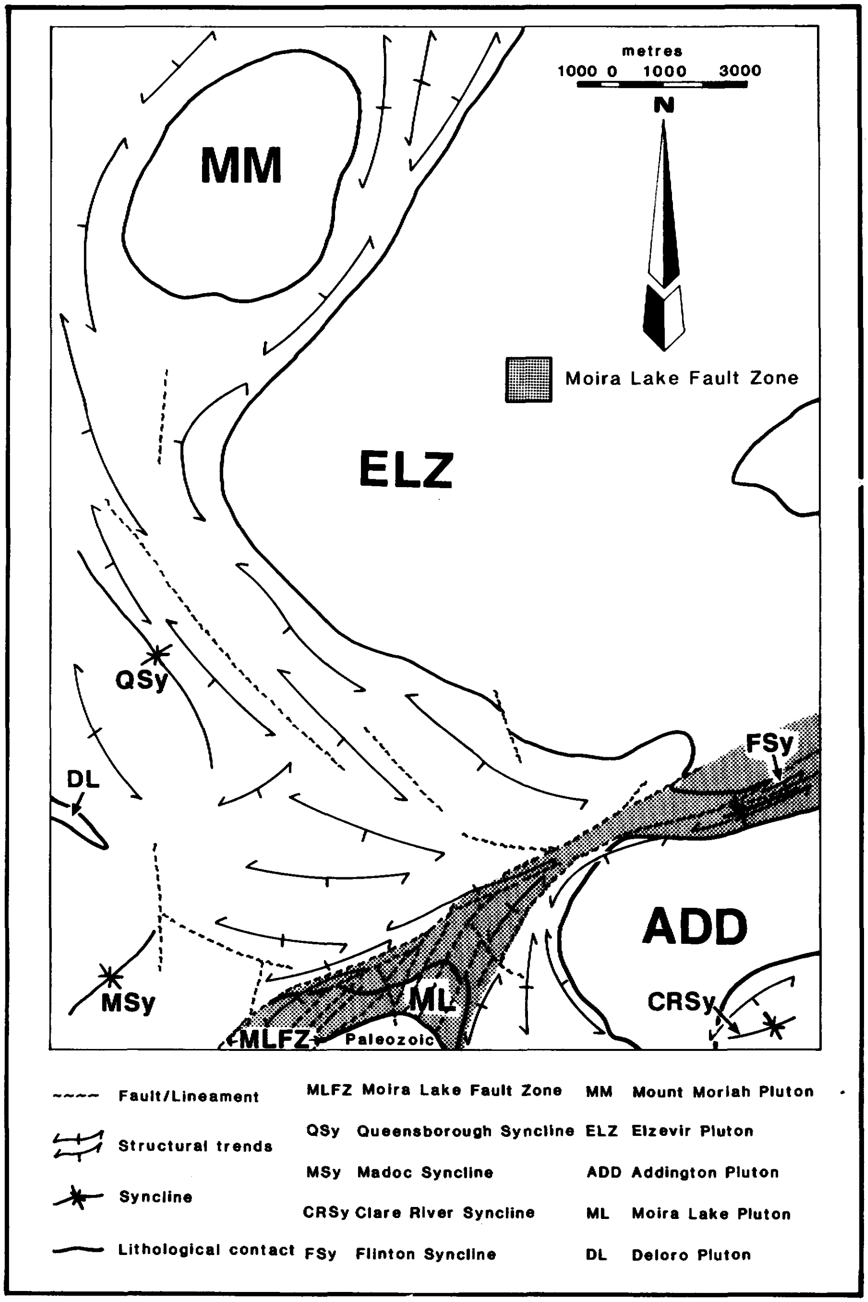

Figure 27.3. *Major structural elements in the Elzevir map area.*

The oldest rocks in the map area are a package of supracrustal rocks, which form part of the Grenville Supergroup. Mafic volcanic rocks and minor mafic pyroclastic and volcaniclastic rocks form the base of this supracrustal sequence, and are overlain by siliceous clastic and carbonate metasediments. The supracrustal rocks were intruded by ultramafic and mafic plutonic rocks, including pyroxenite, gabbro, diorite (Lingham Lake, Kaladar and Skootamatta complexes), by a large body of granodiorite tonalite rocks (Elzevir pluton), and by granitic plutons (Addington, Moira Lake and Deloro plutons). In the northwest part of the map area, syenitic and monzonitic rocks of the Mount Moriah syenite intruded the Grenville Supergroup subsequent to the peak of regional metamorphism, at about 1085 Ma.

In the east-central part of the map area, siliceous clastic metasediments of the Flinton Group are exposed in fault contacts with the Elzevir and Northbrook plutons. Moore and Thompson (1980) have suggested that the Flinton Group is a younger supracrustal sequence that unconformably overlies the Grenville Supergroup. This relationship could not be confirmed by this study.

Regolith deposits and Early Paleozoic clastic and carbonate sediments overlie the Precambrian basement in the south-central and western parts of the map area. All rocks in the area were subsequently partly covered by Pleistocene sediments.

SUPRACRUSTAL ROCKS

Mafic metavolcanic rocks of the Tudor Formation (Lumbers 1967) crop out in a broad zone extending northwest-southeast in Tudor and Grimsthorpe townships, and wrap around the Mount Moriah syenite and the western margin of the Elzevir pluton (Figure 27.2). They also crop out in the eastern part of the map area in the Kaladar complex. The metavolcanic rocks are fine- to medium-grained, black to greenish amphibolites, locally with subordinate quartz, chlorite and carbonate. Although generally massive, they are strongly foliated around the plutonic bodies, and locally they show fragmental and pillowed textures. Tuffs are rare in the area, however, there are a number of mafic volcaniclastic horizons, generally of ash-sized material, intercalated with the flow rocks. Fine- to medium-grained gabbroic sills intrude the volcanic rocks, and in many parts of the area it is difficult to distinguish between these fine-grained intrusive rocks and flow rocks.

Overlying the metavolcanic rocks are siliceous clastic and carbonate metasediments of the Grenville Supergroup, which occur in three main zones in the map area: 1) to the southeast in the Clare River synform, 2) in a belt north and west of the Addington pluton, and 3) in the southwest and west part of the map area near Madoc and Queensborough (Figures 27.2 and 27.3).

The metasediments in the Clare River syncline consist of dark, well-layered, fine-grained mafic volcaniclastic rocks; amphibole- and biotite-rich, fine-grained, dark grey metawacke; rusty schist; and medium-grained, whitish, calcitic and dolomitic marble.

To the north and west of the Addington pluton, the sedimentary sequence consists of fine-grained mafic and intermediate volcaniclastic metasediments. South of Highway 7, the volcaniclastic metasediments grade, without apparent disconformity, into metaconglomerates, metalitharenites, metawacke and minor phyllite. Further south, these siliceous clastic metasediments grade into medium- to coarse-grained, white, fairly pure dolomite and subordinate calcite marble. However, along Highway 7 to the east, the volcaniclastic metasediments grade into the overlying dolomite and calcite marbles.

Near Madoc in the western part of the map area, metaconglomerates and metawackes are overlain by dark grey, fine-grained calcitic marble and minor greyish, whitish, buff, fine- to medium-grained calcite and dolomite marble (Madoc syncline of Hewitt 1968). Dark grey, aphanitic rocks that crop out northwest of the syncline have been previously mapped as fresh, intermediate to felsic volcanic rocks. These rocks were re-examined during the 1989 field season, and are considered to be, for the most part, clastic metasediments that have been silicified, probably by solutions originating from the roof of the Deloro pluton (*see* Paper 26, this volume). In addition, re-dolomitization, silicification and brecciation of dolomite and calcite marble in the area may reflect the same process (*see* Paper 26, this volume).

In the Queensborough area, siliceous clastic metasediments occur at the margin of the "Queensborough Syncline" (Hewitt 1968; *see* Paper 28, this volume). The core of the synform is occupied by dark grey, fine-grained, thinly bedded calcite marble. On the east limb of the synform are pale beige, silicified rocks, mapped by Hewitt (1968) as felsites. These rocks, as well as dolomitized, silicified and brecciated marble to the south and west of the synform, have been affected by solutions from the Deloro pluton, as were the rocks near Madoc.

Rocks correlative with the Flinton Group (Moore and Thompson 1980) crop out in the east-central part of the map area in the Flinton syncline (Figure 27.2). The rocks of the Flinton Group in this area consist of stretched quartzose conglomerate, meta-quartz arenite, metawacke and calc-silicate paragneiss. The paragneiss is interpreted to be a strongly deformed mafic volcaniclastic rock. In the map area, the Flinton syncline is fault bounded and no indication of an unconformity with the Grenville Supergroup was observed.

PLUTONIC ROCKS

The supracrustal rocks are intruded by a variety of plutons of which the oldest are mafic and ultramafic rocks. In the northwestern part of the area, medium-grained gabbro, diorite, quartz diorite, and subordinate tonalite, granodiorite and pyroxenite of the Lingham Lake complex intruded the metavolcanic rocks of the Tudor Group. In the north-central part of the map area, coarse- and medium-grained gabbro, diorite and minor pyroxenite of the Skootamatta complex are well preserved along the northwestern margin of the Elzevir pluton. In many areas, a transition can be observed between the less deformed mafic and ultramafic plutonic rocks of the Skootamatta complex and the highly strained equivalents of these rocks surrounding the Elzevir pluton further south (Figure 27.2). These highly strained rocks are layered to schistose, serpentinized and amphibole-plagioclase-rich rocks, in which remnant coarse-grained gabbroic textures are still recognizable. These highly strained rocks are interpreted as protomylonitized mafic plutonic rocks of the Skootamatta complex. Both relatively undeformed gabbroic rocks and more deformed mafic plutonic rocks were also observed in the Kaladar complex to the east, and are similar to rocks of the Skootamatta complex.

The mafic plutonic rocks are in turn intruded by granodioritic-tonalitic rocks of the Elzevir pluton (Figure 27.2). The core of the Elzevir pluton is a fairly uniform, medium-grained, grey to yellowish and pinkish, tonalite to granodiorite. Several large (tens to a few hundred metres) xenoliths of mafic plutonic and metavolcanic rocks crop out in the core of the pluton. The margin, as noted above, shows complex relationships with the mafic plutonic rocks of the Skootamatta complex and the surrounding volcanic rocks.

Several granitic bodies, probably coeval with the granodiorite-tonalite plutons, also occur in the map area (Figure 27.2). The Addington pluton crops out in the southeast corner of the area, and consists mainly of pink to pinkish biotite granite and leucocratic granite, typically lineated. In the south-central part of the area, the Moira Lake pluton (Figure 27.2) is a pale pinkish, fine-grained granite composed essentially of quartz and feldspar. In the west-central part of the area, the eastern arm and several small apophyses of the Deloro pluton crop out, and consist of pink, fine- to medium-grained granite and porphyritic granite.

The Mount Moriah syenite, a subcircular to oval body of potassic syenite to monzonite, crops out in the northwestern part of the area (Figure 27.2). The rocks are equigranular, medium to coarse grained, and pink-mauve to purplish in colour. Biotite and amphibole-rich syenite phases can be traced on a detailed scale. The shape of the pluton and the freshness of the rocks suggest a syn- to late-metamorphic intrusion of this body.

Rare, dark diabase dikes and unmetamorphosed pegmatite dikes intrude the Precambrian rocks throughout the map area.

POST-GRENVILLE ROCKS

Overlying the Precambrian rocks, in physiographic depressions or on slopes, are discontinuous patches of unmetamorphosed, coarse, siliceous, clastic sediments. The sediments consist of reddish-brown, coarse, polymictic, clast-supported conglomerates. Locally, conglomerates rich in quartz clasts and with fragments ranging from a few centimetres up to two metres are present. The matrix, where observed, is fine grained and reddish-yellowish in colour. These deposits are similar to paleoregoliths present beneath Paleozoic strata in the same area (Di Prisco 1986, 1987).

Middle Ordovician rocks in the map area include greenish and reddish, immature sandstones and conglomerates of the Shadow Lake Formation and limestone and minor dolostone of the Gull River and Bobcaygeon formations. The Paleozoic rocks occur mainly in large outliers in the western half of the map area (Figure 27.2), but small (1 to 2 m wide) remnants of Paleozoic sediments occur throughout the area.

STRUCTURE AND METAMORPHISM

Two major structural blocks occur in the map area (Figure 27.2). The northern block lies north of Highway 7, and encompasses most of the map area. As shown in Figure 27.3, it is dominated by northwest- and northeast-striking structural trends. The two synforms present in the northern block also have northwest- or northeast-trending axes. The second block underlies the southeastern corner of the map area, and is dominated by east- to northeast-striking trends (Figure 27.3).

The north and south structural blocks are separated by a complex fault system, the Moira Lake fault zone. In the map area, this fault zone has a length of 17 km and is up to 1.5 km wide (Figure 27.3). The highest strain occurred in the south block, where the granitic rocks of the Moira Lake pluton and the meta–quartz arenite and metawacke of the supracrustal sequence are mylonitized. The mylonitized zone is up to 600 m wide and is discontinuous. The mylonitized rocks are very fine grained, usually light pink, yellow and white in colour, and more rarely, dark grey. They have a "floury" texture, and a faint pseudolayering. No kinematic indicators were observed; however, large scale block displacements suggest sinistral movement along northeast- and north-northeast-striking axes (Figure 27.3). A pronounced northwest-trending fault cuts all older structures throughout the map area. Hewitt (1968) considered northwest-trending faults in the area to be post–Ordovician in age.

In general, most of the map area has been subjected to upper greenschist to lower amphibolite facies of metamorphism. In a few small areas, such as south of Cooper, lower greenschist facies conditions prevail. Metamorphic grade changes abruptly across several of the major faults.

ECONOMIC GEOLOGY

GOLD

The major deposits in the area have been described by Carter (1984) and Malczak et al. (1985). These deposits are hosted by quartz veins and were classified by Carter (1984) as "concordant to discordant quartz and quartz-ankerite vein deposits". Gold and silver are commonly accompanied by arsenopyrite, pyrite and chalcopyrite, and occasionally by pyrrhotite, tetrahedrite, bornite and galena. Typically the mineralization occurs along shear zones. The Barry occurrence and the James Joseph occurrence (Figure 27.2) are near the Moira Lake fault zone. Old trenches are common along this fault zone, and several quartz veins were sampled for gold assay during the present survey. The Moira Lake fault zone represents a favourable target for precious metal exploration. The Barry and James Joseph occurrences, as well as most of the quartz veins sampled, have an east-southeast trend. Similarly, the mineralized veins of the Sophia gold mine, west of Queensborough, strike northerly and northwesterly, paralleling the major northwest-trending fault which juxtaposes the mafic metavolcanic rocks and the marbles. This fault system, particularly where it cuts the metavolcanic rocks, is also a potential exploration target for gold.

IRON

Hewitt (1968) described the main features of the iron ore (magnetite and hematite) deposits mined at the turn of the century. They are located in the southwestern part of the map area, near the eastern margin of the Deloro pluton or its apophyses. The ore occurs principally in marbles which are locally silicified, and represent skarn deposits produced by fluids from the Deloro pluton. Easton (*see* Paper 26, this volume) evaluates the possibility for iron and base metal mineralization in the area surrounding the Deloro pluton.

PYRITE

Major pyrite deposits occur along the southern margin of the Queensborough syncline (Canadian Sulphur Ore Company, Madoc Township, Concession X, Lot 9; Blakely Pyrite Mine, Madoc Township, Concession XI, Lot 11) and in the western margin of the Clare River synform (Hungerford western extension pyrite occurrence, Hungerford Township, Concession XII, lots 21 and 22; Ontario Sulphur Mine, Hungerford Township, Concession XI, Lot 21). Carter (1984) classified these deposits as stratabound, sedimentary-hosted pyrite deposits. Detailed descriptions are found in Malczak et al. (1985). The ore occurs in siliceous clastic metasediments mapped as rusty schist (quartz-feldspar-muscovite-sericite-pyrite schist) which crops out near the noses of the synclines. Similar zones of rusty schist occur elsewhere in these two synclines and may warrant further exploration. In addition, zones of rusty schist were observed and sampled in the belt of mafic volcaniclastic metasediments east and south of the Mount Moriah syenite.

INDUSTRIAL MINERALS

Talc has been produced in the area since the 1880s. The first talc mine, the Henderson Mine (now Canada Talc Limited), was opened in 1896. Detailed studies and reviews of the talc deposits of the region are provided by Hewitt (1972), Dillon and Barron (1985), and LeBaron and van Haaften (1989).

The talc deposits occur in carbonate or ultramafic rocks. Carbonate-hosted talc is represented by the deposits of Canada Talc Limited west of the Moira Lake pluton (Hungerford Township, Concession XV, lots 14 and 15). Potential for this type of deposit exists all along the northern margin of the Moira Lake pluton in Hungerford and Madoc townships, where lenses of dolomitic marble are in contact with the pluton. Ultramafic rock-hosted talc occurs in several lenses around the southern and western margins of the Elzevir pluton. LeBaron et al. (1987) and LeBaron and van Haaften (1989) suggested, primarily on the basis of geochemical analyses, that the talc is the result of alteration of komatiite flows. No primary structures indicative of an extrusive (i.e., komatiite) origin were reported. The talc-rich zones, however, typically occur in areas of highly strained mafic and ultramafic plutonic rocks. Elsewhere along the margin of the Elzevir pluton, transitional phases and less strained plutonic rocks are present, suggesting that most of this marginal zone consists of variably deformed, mafic and ultramafic plutonic rocks. Thus, field observations suggest that the talc is likely to be the result of alteration of strongly deformed, ultramafic plutonic lenses within larger mafic plutonic bodies and that the protolith was not a komatiite. This hypothesis does not alter the basic model of talc genesis for ultramafic-hosted talc deposits presented by LeBaron et al. (1987), because the geochemistry of ultramafic plutonic rocks is similar to the geochemistry of ultramafic volcanic rocks. The possibility of finding economic deposits of high quality talc along the margin of the Elzevir pluton and in lensoid mafic plutonic bodies west of the pluton remains strong and warrants additional exploration.

Actinolite, which can be an alteration product of serpentine, can be used as a substitute for asbestos. Because of this, demand for actinolite has increased in recent years. An actinolite deposit has recently been discovered in serpentinized, strained gabbroic rocks near the western contact of the Elzevir pluton

(Figure 27.2). Additional occurrences of serpentinized gabbro were identified during the present field work. These serpentinized rocks, present within 1 to 1.5 km of the western margin of the Elzevir pluton, are favourable targets for actinolite exploration.

Only one fluorite occurrence (Hill occurrence, Lot 1, Concession V, Madoc Township) is present in the map area. However, south and west of the map area, many deposits of fluorite occur. Detailed descriptions of these vein deposits are found in Guillet (1964). Fluorite occurs with sulphates, carbonates and occasionally with sulphides. The mineralized veins occur in northwesterly trending faults which cut both Precambrian and Paleozoic rocks. Exploration of the northwesterly trending faults could lead to discoveries of new fluorite deposits.

MARBLE

The western and southern parts of the map area have long been the centre for a marble quarrying industry (Hewitt 1964; Hewitt and Vos 1972; Derry, Michener, Booth & Wahl and Ontario Geological Survey 1988). In the Madoc and Queensborough synclines, dolomitic marble has been quarried principally for terrazzo chips. In the southern structural block, high purity dolomitic and calcitic marbles crop out in several zones, with the highest quality zone occurring in a belt, about 1 km wide, along the northern and western margins of the Addington pluton (P.S. LeBaron, Resident Geologist's office, Tweed, 1989).

BUILDING STONE

LeBaron et al. (1989) describe several sites of potential building stone in the map area. In addition, several other potential sites occur along major roads in the granitic rocks of the Elzevir and Addington plutons.

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28. 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. In addition, graphite, copper, zinc, mica, marble for building stone, and marble for lime production have come from Grenville marbles (Hewitt and Vos 1972; Storey and Vos 1981a, 1981b; Carter 1984; Malczak et al. 1985).

Mineral production from clastic metasedimentary rocks of the Grenville Supergroup has consisted mainly of pyrite for production of sulphur and/or sulphuric acid from stratabound lenses of pyrite such as those of the Blakely and Canadian Sulphur Ore Company mines in the field area, the Bannockburn pyrite mine in northern 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 also hosted by clastic and carbonate metasediments, commonly in association with volcanic rocks (Carter 1984; Malczak et al. 1985).

At present, marbles are used for filler, chips (for concrete facing and similar uses), golf sand, chicken grit, mortar and white bricks. Talc is produced from dolomitic marble at Madoc, and at Haley Station, dolomitic marble is used for the production of magnesium.

The author began his studies in 1987 in the Belmont–Madoc Township area in order to gain a preliminary insight into the stratigraphy and petrography of the metasedimentary rocks and the mineralization environments associated with them. The area was selected because it is underlain by rocks of low metamorphic grade and because the calcitic and dolomitic marbles of Belmont Lake and the stromatolitic dolomite on Big Island of Belmont Lake, Belmont Township seemed to be at or near the base of the thick marble sequence in the region of interest. In 1988, field work concentrated on the Belmont Lake area (Meyn 1988).

Field work in 1989 was concentrated on the sedimentary rocks of the "Queensborough Syncline" of Hewitt (1968) thought to be at the base of the

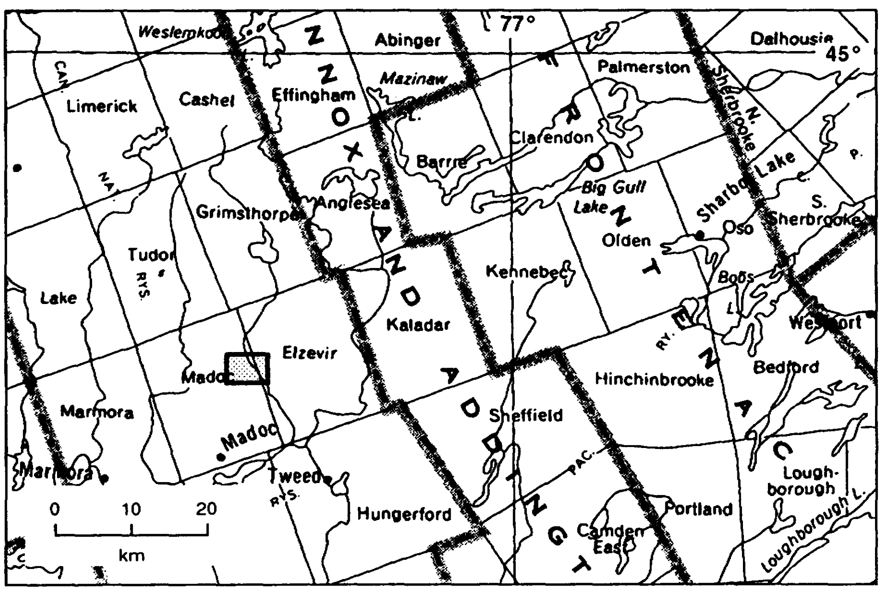

Figure 28.1. *Location map of the study area.*

sedimentary sequence in east-central Madoc Township. The field area is located about 7 km northeast of the village of Madoc, and 2 km southwest of the hamlet of Queensborough (Figure 28.1) and includes all of the Ontario Base Map sheet 10 18 3050 49350. The former Canadian Sulphur Ore Company and Blakely pyrite mines lie in the area. Just to the north lies the former Sophia (diamond) gold mine. The area also includes the "Queensborough Acid Volcanic Centre" of Hewitt (1968).

This field area is also part of the Elzevir Area, i.e., the west half of the Kaladar 1:50 000 sheet (31 C/11) mapped at 1:20 000 by G. Di Prisco (*see* Paper 27, this volume). Field work was conducted just to the west of the Elzevir area by R.M. Easton (*see* Paper 26, this volume).

Beavon spent several years in the late 1960s and early 1970s in the area, working for several exploration companies, in particular for Syngenore Explorations Limited, on the so-called Sager claims. In the process of the work he produced a geological map of the claims at the scale of 1:4800. This map was never submitted as part of any assessment work, but it was made available to the Tweed office of the Ministry of Northern Development and Mines and the author by Gordon and Albert Sager of Madoc Township.

MINERAL EXPLORATION

In the early 1900s the area was the centre of considerable mining activity. Pyrite for the production of sulphuric acid was produced from the Canadian Sulphur Ore Company and the Blakely pyrite mines. Gold was produced from the Sophia (diamond) Mine just to the north of the area mapped this summer. Details of the history of these mines can be found in Malczak et al. (1985).

Roofing granules were produced from several felsite quarries in Madoc Township. Two of these quarries, in Lot 8, Concession VIII, and Lot 9, Concession X, are located in the field area (Hewitt 1968).

From the 1930s to the present day, members of the Sager family, in particular Earl Sager, have kept exploration for base metals and gold active in the area. Over the years several mining companies have had options on the Sager claims and each did a variety of work. Many exploration pits and trenches occur in the area and numerous holes were diamond drilled over the last few decades. The Sager claims are currently optioned to Faith Mines Limited, a subsidiary of Arbor Resources Inc.

Local borrow pits have provided sand and gravel for residents and township road construction.

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).

In the last two decades, Beavon (unpublished), Sangster (1970), Verschuren (*in* Carter 1984; Malczak et al. 1985), Carter (1984) and Malczak et al. (1985) examined the area from various aspects, however, no detailed stratigraphic or sedimentological study has been conducted.

The stratigraphic sequence in the area of investigation, as it is understood today, consists of mafic metavolcanic rocks at the base, overlain by a sequence of rocks of intermediate to felsic composition classified as either metavolcanic or metasedimentary rock. This sequence in turn is overlain by an upper sequence of thick marble. The whole package has been intruded by felsic plutons and by late diabase dikes.

The mafic volcanic rocks at the base of the sequence were found to contain considerable amounts of gabbro, and are more extensively exposed both to the east in Elzevir Township and where they have been mapped and described by LeBaron et al. (1987), LeBaron (1988) and by Di Prisco (*see* Paper 27, this volume).

The origin of the "Queensborough Syncline" and the "Queensborough Acid Volcanic Centre" is not well understood. Strong alteration, such as silicification, and strong rusty weathering of pyrite-bearing rocks make identification of the rocks difficult. Thus, the limited outcrop and strong faulting in various directions complicate the stratigraphic correlations and sedimentological and/or volcanological studies. Many of the altered rocks, however, could be either volcanic or sedimentary in origin.

It is possible, also, that metamorphism has destroyed primary sedimentary and volcanic features. According to Sampson (1972), the metamorphic grade increases southward from the hamlet of Cooper, north of the map area, and reaches upper greenschist transitional to amphibolite grade in the centre of the "Queensborough Syncline" in the map area.

During the 1989 field season, the author concentrated his efforts on the study of two rock units, namely the "felsites" and the "rusty schists". These rock units are described below.

FELSITE

The terms felsite and felsite breccia have been used by many workers in the area. Miller and Knight (1914) studied these rocks and appear to have recognized igneous textures in thin section and conclude that the felsites are intrusive in origin. They also recognized brecciation of the felsite near the Blakely and the Canadian Sulphur Ore Company workings.

Hewitt (1968) described the felsite as a "fine-grained, buff-coloured rock composed of angular quartz and feldspar, rhyolite fragments, and some carbonate. It is an acid volcanic fragmental intrusive rock that cuts the marble".

Sangster (1970), based largely on work by Beavon (unpublished), saw the felsite as an intrusive or extrusive unit that possibly shows some flow banding but no chilled contacts against adjacent rocks.

Verschuren (*in* Carter 1984, p.223-232; *in* Malczak et al. 1985, p.96-100) does not use the term felsite and presumably groups the felsites of other authors with his felsic metavolcanics. He interprets essentially all of the non-carbonate rocks in the vicinity of the Blakely pyrite and Canadian Sulphur Ore Company mines as volcanic. He does not mention an intrusive relationship for any of these rocks.

Based on his field investigations, the author believes that the term felsite as used in Madoc Township probably includes various rock types such as massive or fragmental felsic volcanic rocks, felsic volcaniclastic rocks and massive arenites. No felsites of obvious intrusive origin have been found by the author who, so far, has identified eight types of felsites with several subtypes.

Many and possibly all of the felsites seem to be highly silicified rocks and their protolith may no longer be identifiable with certainty. Easton (Ontario Geological Survey, personal communication, 1989; *see* Paper 26, this volume) suggests that the silicification may have been caused by the Deloro intrusion interpreted by him to shallowly underlie the rocks exposed in the present and neighbouring areas. Easton (*see* Paper 26, this volume) uses the term "porcellanite" for the strongly silicified rocks.

RUSTY SCHIST

Rusty schist is also a term used by many of the authors that have worked in the area. Miller and Knight (1914) state:

"The rusty schists, or pyritous slates, are perhaps the least extensive of any of the sediments... They occur in disconnected beds rarely exceeding 100 feet in width... They are fine-grained, grey to black in colour, and possess a slaty cleavage in places. Their composition is variable, and they include quartzose and feldspathic facies with iron pyrites, and in places, pyrrhotites disseminated through them. In addition to iron pyrites, graphite occurs in fine flakes, and sometimes predominates over any other mineral giving the rock its dark colour." and they conclude: "The chemical composition of the rusty schists points to a sedimentary origin."

Hewitt (1968) does not mention rusty schists in his report nor are they shown on his map. Presumably they are included in the various stratigraphic units in which they occur.

Verschuren (*in* Malczak et al. 1985, p.100) states:

"The rusty schist is a grey to black, fine-grained, strongly foliated unit composed of variable amounts of quartz, sericite, pyrite and graphite. Zones of disseminated graphite and disseminated and banded pyrite occur parallel to the foliation... The rusty schist is generally narrow and discontinuous and conforms to local structural trends..."

The essence of the two quotations above is that these rusty schists may be black slates but they may also include quartzose and feldspathic rocks and that they are generally narrow, discontinuous lenses conformable to local structure. This means that any of the local volcanic or sedimentary rocks may, with enough sulphides added, become, and be labelled, a rusty schist.

This summer's field work essentially confirms the above general descriptions. When mapping any rock that has a moderate gossan on it or is stained deep black from sulphide weathering it is essentially impossible to obtain a fresh sample for petrographic investigation by just using a geological pick. Measuring structural trends in such gossans is also very difficult. What the work so far has revealed is that deep rust stain, reflecting pyrite (sulphide) weathering is present to various degrees in many of the rock types in the area. Aside from the mined pyrite lenses at the Canadian Sulphur Ore Company and the Blakely mines, there are rusty zones in several of the different types of felsite, in a conglomerate, in a garnet amphibolite schist, in addition to several outcrops so small and so badly weathered that they could only be mapped as rusty schist. As more of the units are mapped out in detail, the various lenses of rusty schist may be assigned to a particular stratigraphic unit.

Economically, the most important rusty schist is the pyritiferous black shale-slate that is closely associated with the pyrite lenses at the Canadian Sulphur Ore Company Mine. These rocks are seen in the mine dump but were not seen in outcrop. Miller and Knight (1914) also mention quartzite and quartzose phases in close association with the pyrite lenses at the Canadian Sulphur Ore Company Mine. These phases are also seen in samples in the mine dump.

STRUCTURAL GEOLOGY

Limited outcrop and the small size of the area investigated to date do not allow for a reliable interpretation of the structural geology of the area. The reader, therefore, is referred to Di Prisco (*see* Paper 27, this volume) for an account of the structural geology of the region. Some observations and thoughts on the structure, however, are presented as follows.

The author recognized sheared fault contacts between metasedimentary and metavolcanic rocks near the Madoc–Elzevir Township boundary. The shear zones trend northwest, are subparallel to the contact of the rock units and have been observed over a width of several hundred metres. Transport along them appears to be dextral.

The "Queensborough Syncline" (Hewitt 1968) may be maintained as a working concept but preliminary indications from the few areas with somewhat better exposure, are that the structure of the sedimentary sequence is considerably more complex than that of a simple syncline.

Verschuren (*in* Malczak et al. 1985, Fig.12, p.97) interpreted the area in terms of lens-like bedding and gentle folds. Beavon (unpublished) shows numerous faults of different ages, direction, and amount of movement distributed throughout the area and consequently shows fault blocks, not one of them larger than a few hundred metres. Where exposure permits detailed work, the author recognized that the fault blocks are maximally only a few tens of metres in their largest extent.

ECONOMIC GEOLOGY

In the past, the area has seen production of pyrite, gold (just outside the field area), and stone for roofing granules. There is currently no mineral production in the area with exception of the quarrying of sand and gravel for local needs.

There is potential for the discovery of precious metals and base metals. Malczak et al. (1985), in their description of the Blakely pyrite mine, quote V.P. Verschuren reporting a 15 cm wide drill hole intersection by Syngenore Explorations Limited which assayed 297.1 ounces silver/ton, 0.46 ounce gold/ton, 2.15 percent copper, 5.40 percent lead, and 3.79 percent antimony. A grab sample by Verschuren assayed 1.3 ounces silver/ton, 0.03 ounce gold/ton, 0.34 percent antimony, 0.205 percent arsenic, and 8.96 percent zinc.

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29. Exploration Targets in the Madoc Fluorite Area, Southern Ontario

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INTRODUCTION

The work reported here is a continuation of a study (Williams and Thompson 1986; Thompson and Williams 1987, 1988) of the structural and stratigraphic setting of fluorite veins in the Madoc area (Figure 29.1) and concludes the geophysical component of the study. The fluorite veins occur above and below the Precambrian–Paleozoic unconformity, and their localization has been influenced by normal faults. Earlier work in the project, including geological mapping and geophysical surveying, has concentrated on locating faults and determining how they offset the stratigraphic units.

In 1989, geophysical field work was carried out in Hungerford Township at the Thomasburg and Tweed sites (Thompson and Williams 1987; Thompson 1989), in order to evaluate their exploration potential. The results for the Thomasburg site include previously unreported data acquired during the fall of 1988.

STRUCTURAL GEOLOGY

Veins occupy fractures belonging to two joint sets, one striking approximately 115° and the other striking approximately 140°. The pattern of mineralized fractures postulated by Thompson and Williams (1988) is presented here in revised form as Figure 29.2. Incorporated in Figure 29.2 are the locations of possible fractures deduced from a study by Lalonde (1974) of the fluorine content of groundwater in the Madoc area.

GEOPHYSICAL SURVEYS

The selection of the Thomasburg site (Figure 29.2) was based on the location of a southeasterly projection of a mineralized fracture zone and on the high

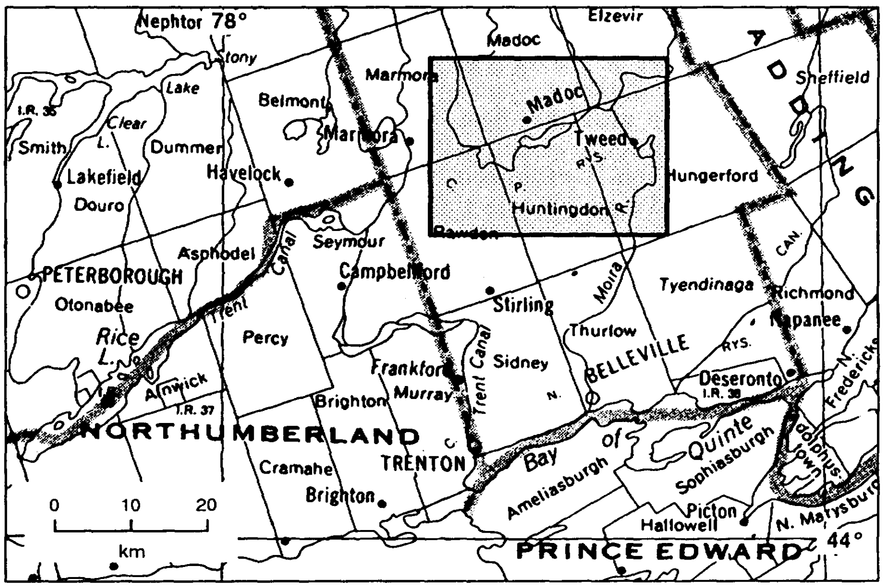

Figure 29.1. *Location map for the Madoc Area, Southern Ontario.*

CANADA ONTARIO Mineral Development Exploration Minérale

This project A.1.4 is part of the five-year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

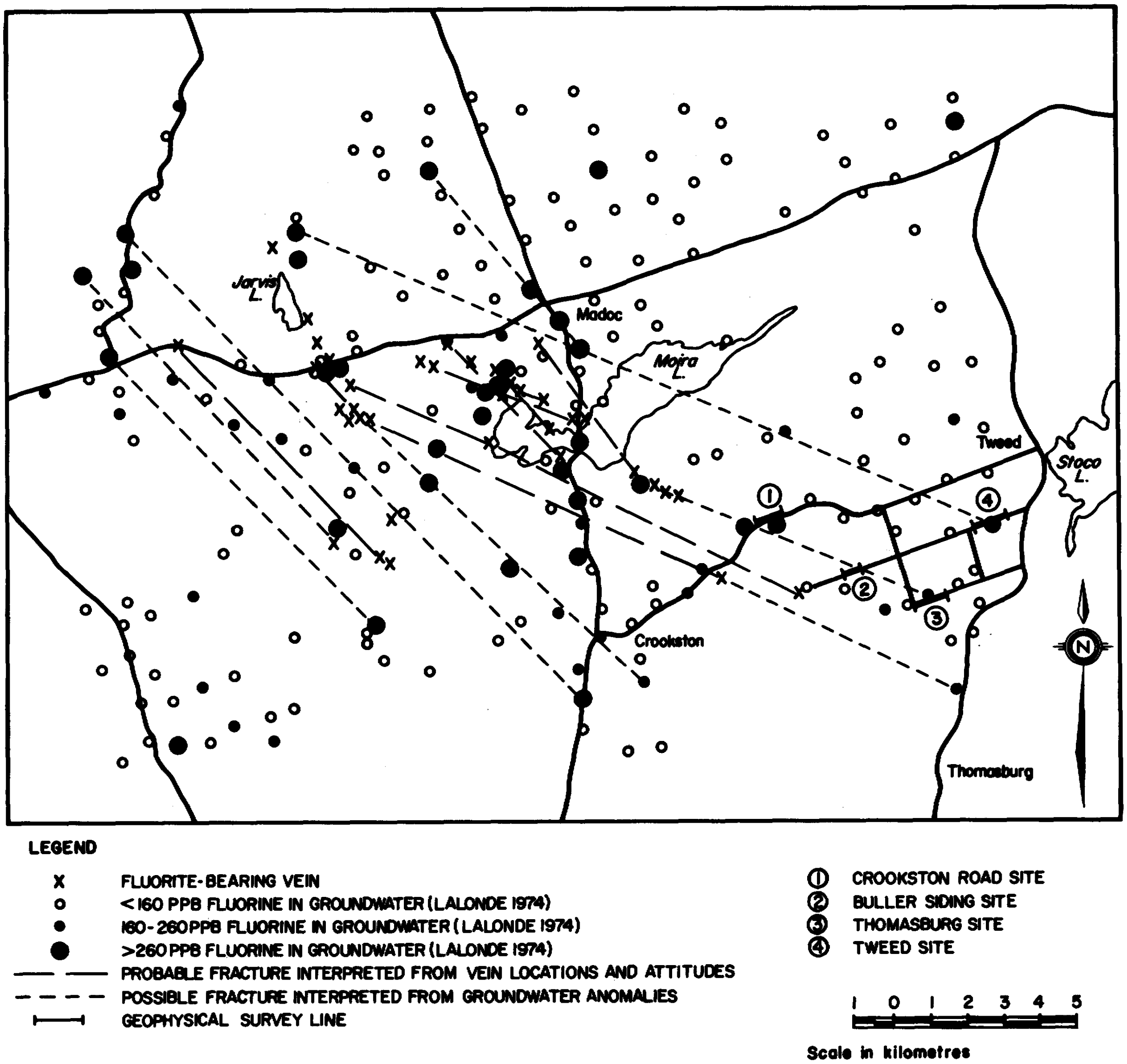

Figure 29.2. *Map of the study area showing fractures occupied by fluorite-bearing veins.*

fluorine content of the groundwater (Lalonde 1974). The survey line extended for 1 km along the Concession road 8, from the Old Thomasburg Road eastward across lots 3, 4, and 5. Seismic, magnetic, resistivity (the inverse of conductivity), alpha radiation, and elevation surveys were completed during the fall of 1988 and the summer of 1989. The seismic work included several test lines in different locations to determine the seismic velocities of local Precambrian and Middle Ordovician bedrock. Several auger holes were drilled to verify depths to bedrock.

The selection of the Tweed site (Figure 29.2) was based on high fluorine concentrations (1700 ppb) in the groundwater (Lalonde 1974) and on the location of a possible fracture zone characterized by the occurrence of groundwater with high fluorine concentrations at several localities. The survey line extended for 1 km along the Concession road 9, from a stream eastward across lots 7 and 8. Seismic, magnetic, resistivity (the inverse of conductivity), alpha radiation, and elevation surveys were completed during the summer of 1989 and several auger holes were drilled to verify depths to bedrock.

Thomasburg Site Results

The results of all geophysical field work completed at the Thomasburg site are shown in Figure 29.3. Along the road surface profile, the two topographic highs have till (with some sandy topsoil) over the bedrock. A change in the bedrock seismic velocities indicates that a fault is located at 400 m to 450 m on the survey line, and separates a downfaulted block of limestone of the upper Gull River Formation on the west and Precambrian granitic rock on the east. Immediately to the east of the fault, the low

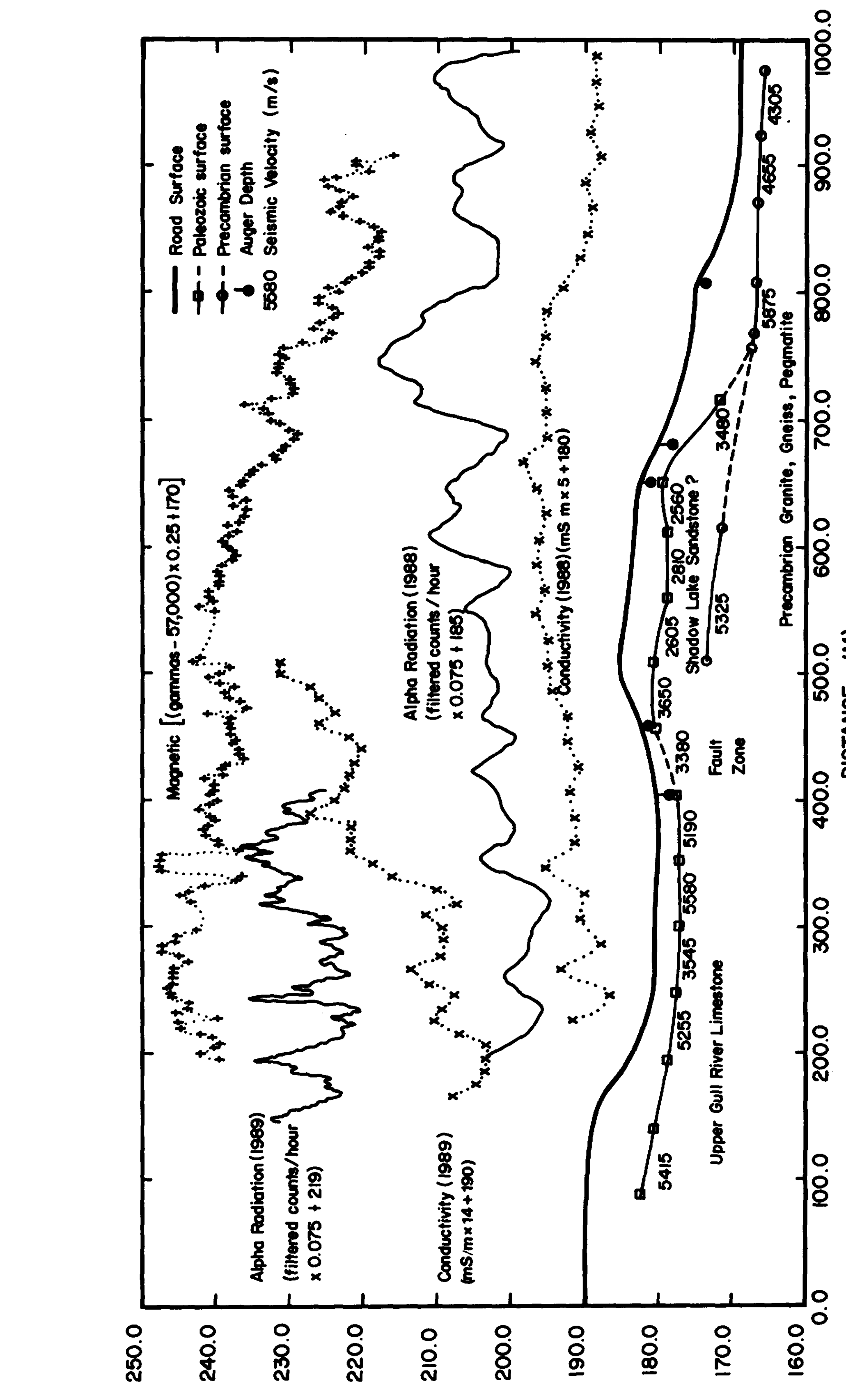

Figure 29.3. *Geophysical survey results for the Thomasburg site.*

bedrock velocities (2600 to 3600 m/s) indicate that the Precambrian granite is overlain by a thin layer of material, probably sandstone of the Shadow Lake Formation. It forms the bedrock topographic high at this location, and is evidently a small plateau.

The conductivity and alpha radiation profiles have anomalies at about 250 m and 350 m on the survey line. These indicate the possible presence of mineralized fractures, based on conclusions from previous work at the Buller Siding site (Figure 29.2, and Thompson and Williams 1987). The 1988 resistivity measurements were made using a Wenner spread of 20 m with 20 m separation between measurement points. Since the anomalies of interest were defined by only one data point, the west section of the line was repeated in 1989 with only 10 m of separation between measurement points. This survey confirmed the conductivity anomalies with more data points, although the overall conductivity level was different. The 1988 alpha particle measurements were made with a 4 m spacing between data points, and filtered by weighted averaging with a 4 m interval. To confirm the anomalies of interest, the west part of the line was repeated in 1989 with measurements made every 2 m and filtered by weighted averaging with a 2 m interval. This work verified the radiation anomalies and provided additional detail. The conductivity and alpha radiation anomalies may indicate a southeasterly extension of a mineralized fracture zone.

Tweed Site Results

The results of geophysical field work completed at the Tweed site are shown in Figure 29.4. The entire survey line is underlain by Precambrian granitic rock which varies from massive to gneissic to pegmatitic, resulting in considerable variation in the seismic velocities. At about 410 m and 650 m on the survey line there are sharp depressions in the granitic bedrock surface which suggest fracture zones in the granite. However, there is no evidence of a fault along the survey line.

The conductivity profile generally reflects the thickness of the overburden. However, the peak at about 120 m on the survey line could be an anomaly of interest. The alpha radiation profile has three anomalies of interest. One is at about 150 m on the survey line, and is spatially related to the possible conductivity anomaly. The second is at about 300 m, and the third at about 550 m. The groundwater sample with the very high fluorine content (Lalonde 1974) came from about 500 m. It is therefore possible that one or more of the alpha radiation anomalies indicate a mineralized fracture zone.

CONCLUSIONS

Several conclusions can be drawn from the geophysical work conducted in the past year:

1. Seismic, magnetic, and alpha radiation geophysical surveys can be used to locate faults in the Madoc area. The seismic method detects changes in bedrock velocity (and therefore in rock type) and changes in elevation of the bedrock surface. A change in rock type across a fault may also result in a change in the magnetic field. Alpha radiation anomalies over faults are a result of the channelling of radon generated at depth. A fault zone in a tectonically similar area near Montreal was mapped by measurement of soil radon (Abdoh and Pilkington 1989).
2. Seismic, conductivity, and alpha radiation geophysical surveys can be used to locate fluorite drill targets in the Madoc area. Changes in elevation of the bedrock surface, possibly resulting from the presence of a fracture zone, are detected by the seismic method. A conductive band in the bedrock may be the expression of a vein zone. High alpha radiation values have been reported from some of the abandoned fluorite mines of the Madoc area (Thompson and Williams 1987).
3. A number of fluorite exploration targets are thought to exist in the Madoc area based on the interpretation of probable fracture zones from known vein occurrences and possible fracture zones from fluorine groundwater geochemical data (Figure 29.2). Alpha radiation and conductivity surveys have detected anomalies of interest associated with two southeasterly trending exploration targets at the Buller Siding site (Thompson and Williams 1987) and the Thomasburg and Tweed sites (this study). The Buller Siding site is 2 km northwest of the Thomasburg site, and both are located on the more southerly exploration target. The Tweed site is on the more northerly exploration target. Also on the more southerly target is the Crookston Road site (Figure 29.2) (Thompson and Williams 1987), located 3 km northwest of the Buller Siding site, where only seismic and magnetic surveys have been done to date. Evaluation of any of the exploration targets should include geochemical work as Lalonde (1974) concluded that the fluorine, barium and zinc contents of soils are most useful for detailed surveys.

ACKNOWLEDGMENTS

The assistance of the members of the 1988 geophysical crew (Jonathan Rudd and Mark Stewart) and the 1989 crew (Seann Day and Shawn Donohue) is greatly appreciated.

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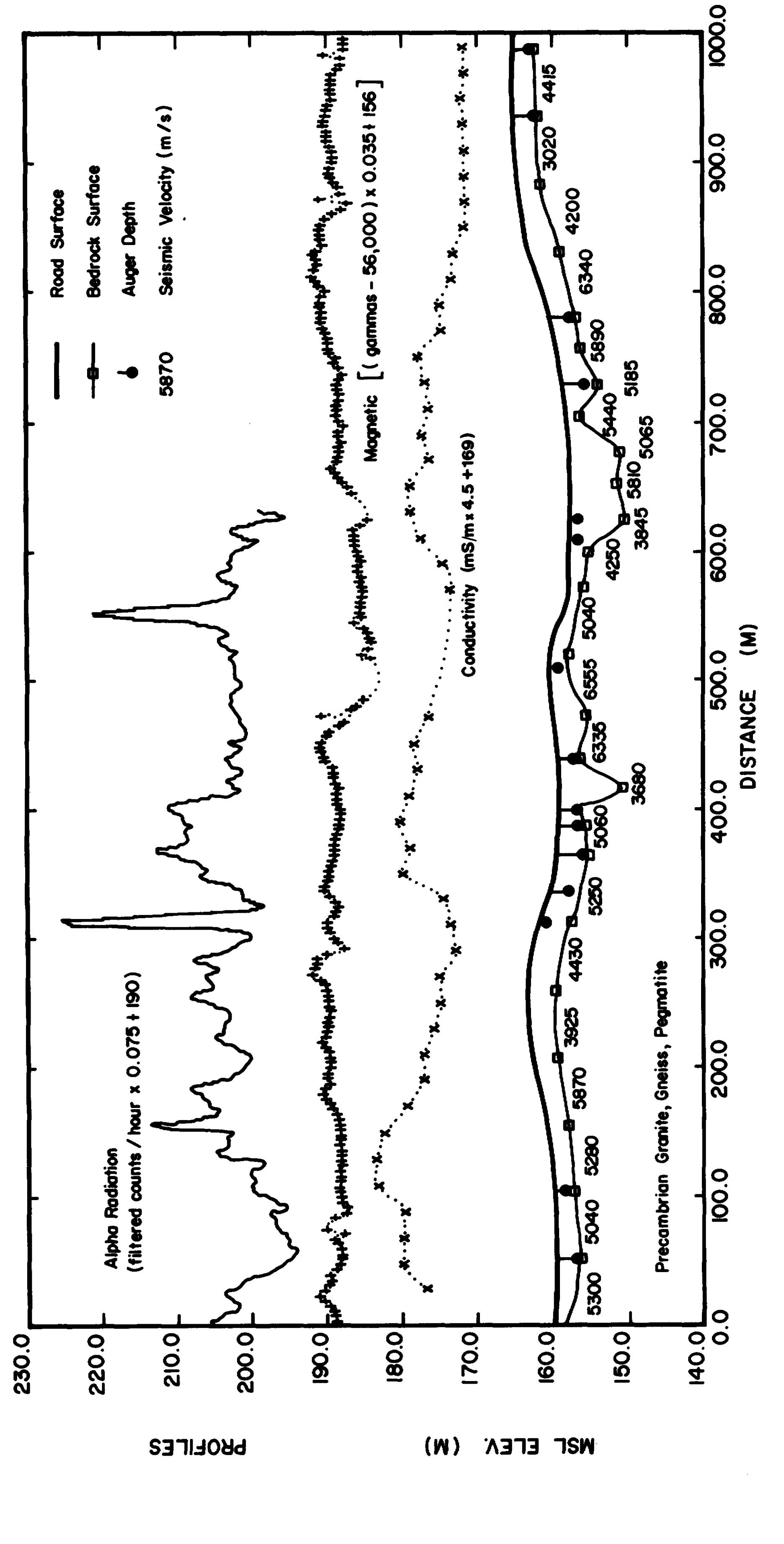

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30. Project Unit 88-32. Development and Implementation of a Computer-based Digital Mapping and Data Storage System

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INTRODUCTION

This paper reports on the progress achieved during the past year in the development of an integrated data base and cartographic software package for portable microcomputers. The project was initiated to take full advantage of recent advances in computer technology, which have resulted in powerful, durable, and inexpensive portable microcomputers and sophisticated software to utilize this power. The objective of the work, for which earlier results were reported by Brodaric and Fyon (1988), is to provide the geologist with the ability to store and analyze data and to expedite the construction of complex geological maps in the field and office.

This development of an integrated data base and cartographic software package has obvious similarities to the capabilities provided by Geographic Information Systems (GIS). However, it does not address the complex spatial analysis problems that are the realm of GIS systems. Rather, it is intended to provide an inexpensive, yet reliable and efficient, means of organizing, storing, analyzing and displaying geological data, and to facilitate the use of the data in more powerful analytical packages or by other users.

The software system consists of a relational data base (dBASEIII PLUS®) and computer-assisted drafting systems (CAD, AutoCAD (Release 10)®) package. These are fully integrated to allow either: 1) the input and storage of user-specified geological data and the simultaneous construction of a geological map, based on user-specified display data ("map configuration"); or 2) the input and storage of user-specified geological data for analysis or geological-map construction at a future date ("storage configuration"). Both configurations are designed to: 1) be portable and to function in the spectrum of field conditions, 2) facilitate archival data storage, 3) assist in the visual analysis of geological data, 4) expedite the generation of diverse types of geological maps, and 5) facilitate the export of data to more powerful GIS or other data base systems.

®AutoCAD and dBASE are registered trademarks of Autodesk, Incorporated and Ashton-Tate Company, respectively.

MAP CONFIGURATION

The "map configuration" goes beyond the basic cartographic presentation of data, using CAD systems, in that data are simultaneously stored in a relational data base, and used to construct a geological map. While all data displayed on the map are automatically stored in the data base, additional data—which either are not suitable (e.g., descriptive text) or not necessary (e.g., station or sample number, deformation intensity) for display—are also stored in the data base. All stored data are automatically assigned a geographic reference co-ordinate (Universal Transverse Mercator grid system or UTM) and are then linked to the station or outcrop from which the data were collected. The result is an exhaustive, relational data base, designed to fit the geologist's expertise and project emphasis. The spatial aspects of the geological map, such as the relative positions of display attributes and outcrop locations, are determined by the geologist, who positions the display data on the map at the time of data input. In this spatial aspect, the data input and cartographic construction sequence emulates that followed during the conventional preparation of a paper or mylar geological map, with the significant advantage that the data are also simultaneously stored for future analysis. Because of the integrated relational data base, complex types of data or data relationships can be identified later and displayed on specially constructed maps.

STORAGE CONFIGURATION

Although the "map configuration" allows the simultaneous storage of data and creation of a geological map, its implementation is not always possible or practical because of equipment restrictions or the nature of a particular geological survey (e.g., frequent moves of "fly camp"-type, short-duration projects). Hence, a "storage configuration" was also developed in which data are stored into a relational data base only—no CAD capabilities are attached. The intent of the "storage configuration" is to capture data in a format which allows for treatment by the CAD package at a future date. Because of the absence of cartographic capabilities, data are stored without a geographic reference co-ordinate (UTM), but are linked to the station or outcrop from which the data were collected.

TECHNICAL REQUIREMENTS

The technical characteristics of hardware requirements for the "map configuration" and the design of the accompanying data base were described previously (Brodaric and Fyon 1988). The data base design is critical because it represents the types of data that will be displayed by the CAD system and the types of data that are stored and, therefore, are available for subsequent analysis techniques. Because of the importance of the data base design, some aspects of the design philosophy require reiteration.

HARDWARE–MAP CONFIGURATION

To address the processing needs of the integrated CAD-relational data-base ("map") configuration, portable microcomputers with "80386" processors, 2 megabytes of memory, a 33-megabyte hard disk, high-resolution screen and a digitizing pad were employed. The high-resolution screen, larger memory and faster processor speeds of this system were required for adequate graphics and data base processing, while maintaining the ability to integrate with the in-house computer network. A dot-matrix printer allowed working maps to be printed as required, thereby eliminating the need to generate, by hand, paper versions of the evolving geological map. This hardware configuration operated successfully using both the conventional power supply and portable generators.

HARDWARE–STORAGE CONFIGURATION

Hardware requirements for the "storage configuration" are far less robust because graphics processing is not required. A variety of lap-top computers with "8088" processors were found to be adequate.

MODULAR DATA BASE DESIGN

Geological projects are conceptually and practically broken into several logical divisions (e.g., lithologic, alteration, structural, commodity aspects). A modular data base design has been adopted for which each such division has an equivalent, related data base file (e.g., structure, alteration, commodity), referred to as a module. These logical divisions and the types of data to be assigned to each are defined by the project geologist to fit his expertise and project requirements, prior to the onset of mapping. The project needs are then translated, using an auxiliary program, into both AutoCAD® prompts and dBASE III PLUS® data bases, depending on whether the "map configuration" or "storage configuration" is being used.

The actual data entry through AutoCAD® ("map configuration") or directly into dBASE® ("storage configuration") is routine, requiring minimal computer knowledge and experience. For data entry, the geologist is presented with a series of prompts, determined by the module selected (e.g., structure, alteration, commodity). The system was designed for flexibility in dealing with diverse geological problems, so the geologist completely tailors the input prompts and, therefore, the information to be stored in the data base and displayed on the map, if the "map configuration" is being used. This structure can be modified at any time, allowing the deletion of unwanted items and the addition of pertinent prompts. Changing the input prompts by means of an easy-to-use auxiliary program results in appropriate modification to the data base format, removing or adding the required space and data.

ENHANCEMENTS TO DATA ENTRY

During the past year, several aspects of data entry and data base design were refined. The definition and utilization of the data bases were made easier by assigning many user-required operations to menus. Error-checking capability, at the time of data input, was enhanced to ensure standardization of input data, which is particularly important where abbreviations are used to represent rock types (e.g., BSLT for basalt), alteration types (e.g., SIL for silicification), or structural data types (e.g., IFOL1 for earliest inclined foliation). Where possible, the abbreviations used had previously been established "in-house".

Enhancements were made to the subroutine which allows users to recall data from the data base and alter it through the interactive graphic (CAD) input mode, as well as performing global changes to the map and data base. For the "map configuration", data to be changed can now be selected: 1) individually, using a pointing device (e.g., mouse); or 2) globally, using a window area, combined with a conditional discriminator (e.g., within the indicated window area, change all IFOL1 determinations to IFOL2; or, within the indicated window area, change all 4b occurrences to 5c in all strings).

ENHANCEMENT TO MAP PRESENTATION

One minor, but significant, change has improved the quality of the final display map. In many projects, the basic data to be displayed on a map consist of: 1) outcrop shape and location, 2) lithologies, 3) structural measurements, 4) alteration types, and 5) commodity types. In the "map configuration", all outcrop attributes that are to be assigned to the data base must be entered individually, using the interactive graphics mode. If a particular attribute is also identified as one which is to be displayed on the map (e.g., alteration type), each data base entry of this attribute also appears on the map. The appearance of these identical attribute data on the map can result in clutter, particularly where several outcrops (stations), each displaying the same attribute data, occur in close proximity. This situation is not visually aesthetic, and the redundant data can actually obscure the presence of other different data attributes, by virtue of the sheer number of data crowded into a restricted area.

Conventionally, this situation is handled by linking a few display attributes to the relevant outcrops by lines. This approach can be emulated by erasing the redundant display attributes from the screen (i.e., erasing the attribute from the AutoCAD® drawing data base); however, if this erasure is done while operating the integrated "map configuration", the redundant attributes are also erased from the dBASE III PLUS®, relational data base. The result is a relational data base whose station data are incomplete, and this would affect subsequent data analysis. Accordingly, a "HIDE" command was introduced. Its effect is to erase the extra display attributes from the AutoCAD®-drawing data base and, hence, from the display screen and product map, but to leave the redundant attributes assigned to their relevant stations in the relational data base. In this way, a visually aesthetic map is achieved, but a comprehensive data base is preserved.

DATA BASE-TO-MAP CONSTRUCTION

The generation of a geological map, using data which were stored directly into the data base ("storage configuration"), is associated with some spatial difficulties. When data are entered and stored through the interactive graphics mode ("map configuration"), spatial co-ordinates (UTM co-ordinates) are automatically assigned and stored. These co-ordinates represent the absolute position of the outcrop (station) and each display attribute because the geographic base map is referenced to the UTM grid. However, spatial co-ordinates may not be available for data whose entry bypasses the interactive graphics mode, unless UTM co-ordinates are calculated and subsequently entered for each station. Even when the spatial co-ordinates for each station are available and entered into the data base, the co-ordinates of the relative positions of display attributes are still not available. Hence, a map produced directly from the data base, having minimal spatial co-ordinate information (station location), has all display attributes superimposed upon that single outcrop reference point. To overcome this clustering, subsequent editing is required to reposition the display attributes. This is a limitation of the direct-to-data base, data-entry approach. The availability of absolute spatial co-ordinate data, generated during data entry through the interactive graphics mode ("map configuration"), remains an attractive advantage of the "map configuration" over the direct-to-data base ("storage configuration") storage system.

SUMMARY

Field testing in 1989 demonstrated that the hardware and software configurations could operate under rigorous conditions. The ease of operation and the flexible data base design are regarded favourably by all geologists involved in the testing. More rigorous utilization of the stored data will be evaluated this fall and winter.

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31. Project Unit 88-20. Applications of Remote Sensing to Geology

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INTRODUCTION

Since 1987, the Ontario Geological Survey and the Ontario Centre for Remote Sensing have jointly investigated the integration of remote sensing into digital geoscience data bases. The initial phase of this investigation, reported in Mussakowski and Trowell (1988), tested the usefulness of remotely sensed data (LANDSAT 5 Thematic Mapper and airborne C-band radar (SAR)) in interpreting digital geological (bedrock geology, structural geology, total field aeromagnetic data and geochemistry) data bases from the Goudreau–Lochalsh area of the Michipicoten greenstone belt (Figure 31.1). This study continued in 1989, and new studies were started elsewhere in the Michipicoten and Mishibishu Lake greenstone belts.

CONTINUING STUDIES IN THE GOUDREAU-LOCHALSH AREA

The Goudreau–Lochalsh area was selected as the initial test area because of the availability of an extensive, recent, geological data base, which includes information on bedrock geology (Sage 1985, 1987), mineral deposits (Arias and Heather 1987; Heather and Arias 1987; Heather et al. 1988) and geochemistry (Fortescue and Stahl 1987). Information from studies continuing in 1989 (*see* Paper 17, this volume; *see* Paper 46, this volume) will be added to this data base.

As noted in Mussakowski and Trowell (1988), a common difficulty in using remote sensing data is that features interpreted from the data cannot be confirmed when checked in the field. The principal project activity in the Goudreau–Lochalsh test area during 1988-89 was attempting to locate, in the field, "lineaments"[1] that had been defined from examination of the remote sensing data.

[1]*"Lineament" is used as defined by O'Leary (1976): "A lineament is a mappable simple or composite linear feature of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differs distinctly from the patterns of adjacent features and presumably reflects a subsurface phenomenon."*

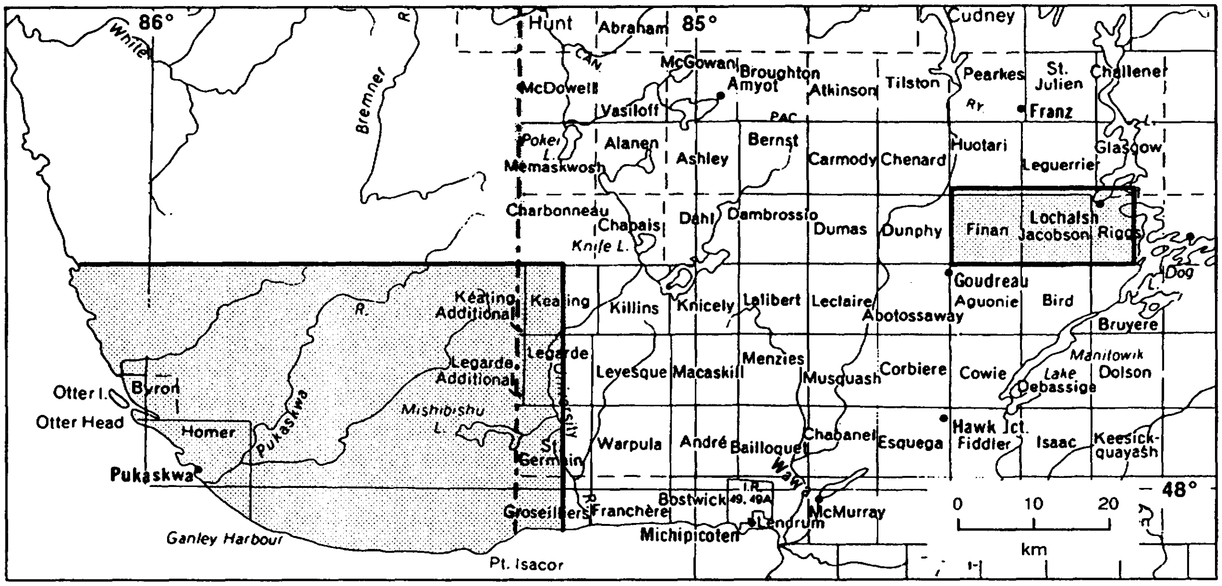

Figure 31.1. *Location map for the Goudreau-Lochalsh, Michipicoten-Mishibishu Lake and Iron Lake-Kabenung Lake areas.*

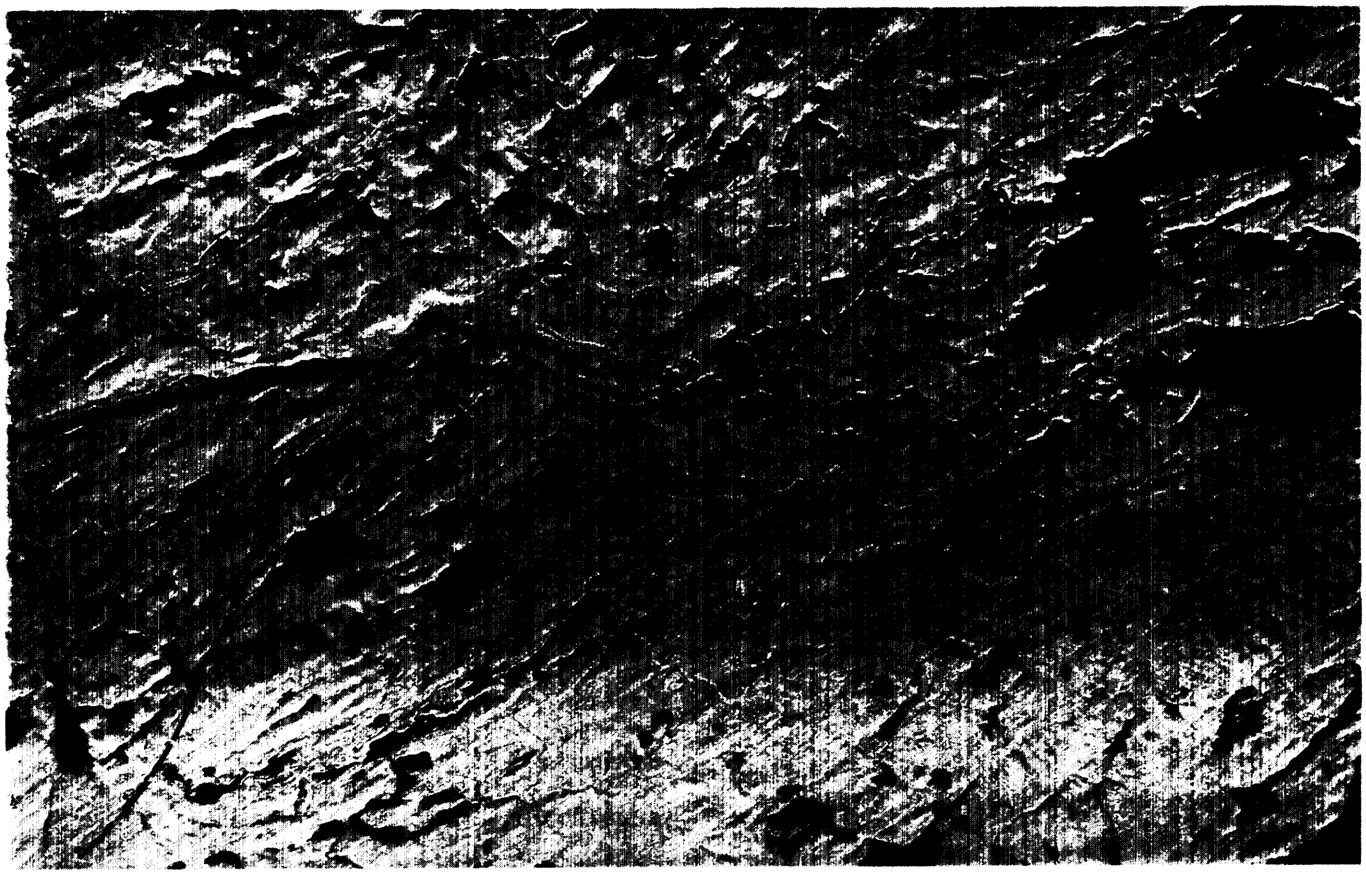

Photo 31.1. *Radar image showing lineament(s) that was investigated. Scale 1:50 000.*

Attempts in May 1989 to locate and define the northeast-striking lineament(s) shown in Photo 31.1 were hampered by limited accessibility. The lineament(s) was traversed, and one site on the lineament reached by helicopter. Steep-sided, incised valleys and sharply bounded, swampy areas and lakeshores result in pronounced topographic lows along the lineament(s). However, evidence of faulting, such as fault gouge, slickensides, and alteration in nearby rock outcrops, was not observed. Outcrops near suspected "fault" areas are very few, due to the extensive Pleistocene cover, and any local evidence of faulting was probably either deeply buried by glacial material or removed by glacial scouring.

Several other lineaments were investigated in September 1989. In most cases, no evidence of a lineament was observed either in the terrain or in outcrops close to these features. In a few cases, weakly developed, almost wispy, late, brittle fractures oriented parallel to the trend of the lineament were observed. One of these lineaments is apparently defined by both a topographic expression (a ridge of resistant mafic metavolcanics) and a ductile shear zone along the southern side of this ridge.

A few of the lineaments in the Goudreau–Lochalsh area correspond to weak magnetic trends noted in high resolution total field aeromagnetic maps (Barlow 1987, 1988; Ontario Geological Survey 1987). Subtle trends, not initially discerned on the grey scale contour aeromagnetic maps (Photo 31.2a), were enhanced by spatial filtering. This technique, which changes the orientation of the directional filter interactively on an image analysis system, can be used to enhance or suppress features such as diabase dikes and aeromagnetic trends (Photos 31.2b, 31.2c, 31.2d).

Spatial filtering is accomplished by the application of an appropriate "convolution matrix" (Lillesand and Kiefer 1987). Use of an asymmetric convolution matrix can develop a directional enhancement. The features which will be enhanced or suppressed can be varied by changing the orientation of the directional filter. For example, looking along the strike of the diabase dikes (Photo 31.2b) suppresses the dikes and enhances features oriented at an angle to them.

Testing of the remote sensing data for the Goudreau–Lochalsh area has led to the following

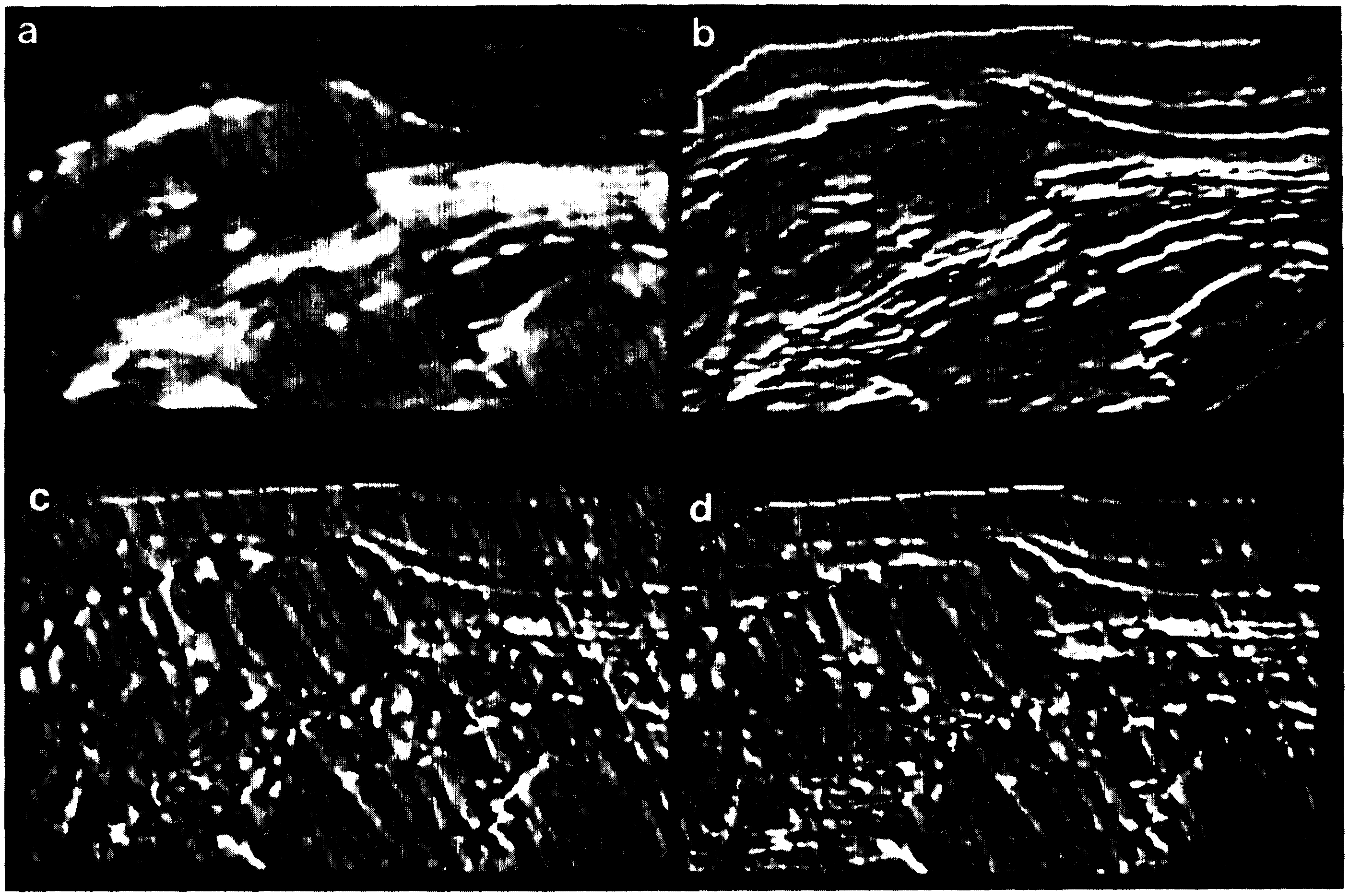

Photo 31.2. *Aeromagnetic data for the Goudreau–Lochalsh area. Scale 1:100 000.*

a. *Grey scale total field aeromagnetics.*

b. *Filtered aeromagnetics with effects due to diabase dikes eliminated.*

c. *Filtered aeromagnetics emphasizing east-west aeromagnetic pattern.*

d. *Filtered aeromagnetics emphasizing diabase dikes.*

empirical observations and conclusions about the available data and how it can best be interpreted:

1. A LANDSAT (bands 4, 5, 7) colour composite image was found to be best suited for terrain analysis of the vegetated landscape.
2. Considerable information can be extracted from interactive manipulation of the grey-scale digital aeromagnetic data (*see* Photos 31.2a-d).
3. Subtle features may sometimes be obscured by the digital integration used to produce a custom composite from individual data sets. Separate visual analysis of each data set is preferred.
4. The analysis of new geological information is best accomplished on merged data sets, upon which a high level of control has been established.
5. Optimum visual analysis of the remote sensing data was achieved on a full-scale hard copy or on a transparency on a projection system.
6. The aeromagnetic data proved to be the most valuable source for bedrock information because of its penetrative capability.

FUTURE STUDIES

MICHIPICOTEN–MISHIBISHU LAKE GREENSTONE BELTS

Future studies will concentrate on using techniques to enhance the data sets (Drury and Walker 1987, 1988; Aarnisalo 1984) and on interpretations of the regional structural geology (Kowalik and Glenn 1987).

Wide swath radar data are now available, from the Canada Centre for Remote Sensing, for all of the Michipicoten and Mishibishu Lake greenstone belts. These data include two east-west flight lines with a 68 km swath width, and one north-south line over Mishibishu Lake, extending from Lake Superior to the granitoid rocks north of the greenstone belt. These data will be digitally integrated with the composite of radar and LANDSAT data that has been prepared, and used in an interpretation of the structural geology of the area. This interpretation should be improved by comparison of the two radar data sets (Masuoka et al. 1988).

Recently acquired aeromagnetic data for the far western portion of the area will also be incorporated into the data base.

IRON LAKE-KABENUNG LAKE AREA

Data from recent geological mapping in the Iron Lake–Kabenung Lake area (Reilly 1988; Sage 1988) will be examined in a GIS (geographic information system) environment as the next phase of the study. Remote sensing data sets available for this area include a composite image of radar and first derivative aeromagnetic data, LANDSAT Thematic Mapper data, X-band radar data and a 10 m resolution panchromatic SPOT image.

The integration and assessment of all these data differs from the study of data from the Goudreau–Lochalsh area in that mapping of the Iron Lake–Kabenung Lake area is only partially complete. Interpretations of the remote sensing data could, therefore, be incorporated into strategies for future mapping in the area.

DIGITAL BASE MAPS

Resident Geologists maintain maps that show geology, the locations of mineral occurrences, drill holes and company properties, and an index to work reports. These maps are currently produced by hand, which is a time consuming and costly process. In an attempt to provide a faster and cheaper method of maintaining these maps, the authors have produced a digital base map from a geo-referenced LANDSAT Thematic Mapper image. This base map is currently being assessed by Resident Geologists in Wawa and Sault Ste. Marie.

SUMMARY

This project was initiated to assess the usefulness of remotely sensed, digital imagery in exploration for mineral deposits. Work to date has demonstrated that different geological data sets can be successfully merged with remotely sensed data bases, a necessary precursor to use of more powerful GIS systems. It has also demonstrated that remote sensing data provide important information to interpreting the geology of an area, particularly with respect to regional structure.

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Engineering and Terrain Geology Programs

32. Summary of Activities 1989, Engineering and Terrain Geology Section

Owen L. White

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The Engineering and Terrain Geology Section supported seven field crews during the 1989 season: four crews mapping Quaternary geology in northern and southern Ontario; two crews undertaking studies of rocks of Paleozoic age in southern Ontario; and one crew investigating buried aggregate deposits in southwestern Ontario. Also reported here are the results of an investigation of building stone resources in the Algonquin area and the drilling of an 8 cm diameter overburden hole in the Niagara area. Two crews investigating aggregate deposits in Sioux Lookout and Wawa were deployed late in the season and will have the results of their work reported at a later time.

The staff of the Quaternary Geology Subsection were involved in three mapping projects in southern Ontario and one in northern Ontario (under the Canada–Ontario Mineral Development Agreement (COMDA)) and were responsible for managing the drilling project in the Niagara area.

P.J. Barnett continued his investigations in the Barrie–Elmvale area by completing the mapping of the Elmvale area and beginning the Barrie area. In particular, these investigations covered the Bass Lake Moraine and the area south of the moraine to Lake Simcoe. Barnett is confident that the field evidence demonstrates that this moraine was not overridden after its formation. Many abandoned shoreline features recognized represent not only Main Algonquin and Nipissing Great Lakes but several upper and lower lake phases of glacial Lake Algonquin. Barnett's investigations in this area, both last year and this year, strongly suggest that a rethinking of many aspects of the glacial history of Ontario will be in order.

In southwestern Ontario, T.F. Morris continued his investigations in Essex County where the terrain is essentially a clay plain with very little relief. The glacial drift, ranging in thickness from 9 to 45 m, completely mantles the Middle Devonian sandstone, dolostone and limestone bedrock. Although most of the original glacial and proglacial landforms in the area have been appreciably modified by glaciolacustrine waters and processes, Morris has made use of aerial photography and subsurface drilling in selected sites to identify many of those modified landforms, including seven belts of recessional moraines, and several sand fans and eskers. These newly identified features are suggesting that an examination of the glacial history of the area may lead to a better understanding of groundwater resources, potential waste disposal sites and possibly some useful deposits of construction sand.

Morris has located three new organic sites, but only one radiocarbon date has been obtained to date. To conclude his summary report, Morris briefly notes other research activities in the Essex County which were underway at the University of Western Ontario and the University of Windsor.

R.I. Kelly continued his investigation of the Chatham–Wheatley area. Again, the terrain is essentially a flat plain which consists of glaciolacustrine and alluvial clays, silts and sands with some areas of water-modified clay till plain. The glacial deposits are thick and the Middle and Upper Devonian shales and limestones of the bedrock do not outcrop in the map area. Poorly defined, but distinct, recessional moraines have been recognized through the use of aerial photography and despite the reworking of the moraines by the postglacial lake waters. A large buried aggregate deposit at Pinehurst is the only major sand and gravel deposit known in the area. Other buried deposits may exist.

In northern Ontario, P.W. Alcock extended his mapping of the Sinclair Lake area into the adjoining Gowganda area. In the Gowganda area, the glacial materials and the surface of the terrain are very similar to that found in the Sinclair Lake area to the west. The drift is usually thin, but it can deepen to up to 30 m in thickness. Bedrock is frequently exposed at the surface. The one till identified in the area ranges up to 4 m in thickness but more commonly is 1 m or less. Weathering generally extends to a depth of 2 m below the surface. Glaciofluvial ice-contact and outwash deposits abound and include some large, coarse-grained eskers and kames. Topographic lows are occupied by glaciolacustrine fine sands with occasional laminated silts and clays. Parabolic sand dunes occur in Cockill and Lawson townships but are much less numerous and less well developed than the dunes in the Shining Tree area. Preliminary analytical results of till samples taken in the area indicate that surface till geochemical and mineralogical investigations and boulder tracing can be effective exploration tools in this area.

P.J. Barnett reports the results of a co-operative drilling venture with Ontario Hydro in the St. Davids Buried Gorge of the Niagara area. Good organic samples obtained before the sonic drilling was terminated at 62.9 m are presently being evaluated. Drilling continued with a rotary drill to a depth of 237.7 m where Queenston Shale bedrock was encountered.

Staff of the Paleozoic/Mesozoic Geology Subsection were active in Prince Edward County and on the Bruce Peninsula. G.H. McFall and A. Allam continued with their detailed investigations of the structural features of Prince Edward County and extended their land based studies by offshore side-scan sonar and magnetic surveys. These offshore studies were possible through the successful co-operation of staff from Ontario Hydro, the Ontario Ministry of the Environment and McQuest Marine Research and Development Company Ltd. together with Ontario Geological Survey personnel. The offshore studies showed that many onshore features identified and mapped by McFall and Allam continued into the lake.

Allam used seismic refraction techniques to investigate anomalous bedrock features in the eastern end of southern Prince Edward County. McFall investigated several normal and thrust faults in the Long Point area, determining their orientation, sense of movement and magnitude of throw wherever possible. Structural features were also examined in the Mountainview and Picton quarries. Widely spaced fractures and some minor folding were noted in the Mountainview Quarry. In the Picton Quarry, the presence of an ultramafic rock dike which has, after emplacement, been faulted and fragmented by later movements indicates a more active domain that has hitherto been understood.

In the Bruce Peninsula, D.K. Armstrong extended his investigations from the northern and central parts of the peninsula to the south and supplemented his earlier field mapping with stratigraphic drilling. As in the past, Armstrong was particularly concerned with the potential for the occurrence of building stone resources. The geologic formations encountered in this year's mapping ranged from the Upper Ordovician Georgian Bay Formation to the Upper Silurian Bass Island Formation. Armstrong has provided updated descriptions of all formations within the map area noting where the new information adds to or differs from that previously reported. Several formations on the Bruce Peninsula are quarried for either building stone, aggregate or lime production.

Building stone is also emphasized in the report by C. Marmont prepared as part of the COMDA studies. The Resident Geologist's staff at Dorset has investigated a variety of industrial minerals over the past four years but in 1989 major attention was given to the potential for building stone in the Algonquin District. Rock types considered were high-grade metamorphic gneisses, thinly splitting gneissic flagstone and massive multicoloured granite.

Field work in 1989 has shown that several sites, where joint density is low, are available for potential architectural stone production. Flagstone quarrying has gone on for many years in the area and resources in present quarries are capable of supporting additional production capacity.

D.G. Vanderveer continued his investigation of buried aggregate deposits in southwestern Ontario through detailed studies in McGillivray Township, Middlesex County. Electromagnetic conductivity surveys were run in the vicinity of a newly discovered aggregate deposit overlain by 2 m or more of glacial drift. The surveys, in and around the McGillivray Township pit, indicated the presence of a zone of lower conductivity which was confirmed later, by a series of 20 cm boreholes up to 6 m deep, as a coarse sand and gravel deposit. The electromagnetic survey techniques used at the operating pit, were then applied in locations with similar geological conditions. Encouraging results were obtained in a number of these areas and test pitting will follow to obtain samples for evaluation.

33. Project Unit 88-04. Quaternary Geology of Essex County, Southern Ontario

T.F. Morris

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INTRODUCTION

Quaternary geological mapping of Essex County (Figure 33.1) was initiated in the summer of 1988 and continued in 1989. Mapping west of longitude 82°52'30"W to the Detroit River and between latitudes 41°40'35"N and 42°20'00"N was completed in 1989. This area is covered by 1:50 000 scale NTS map sheets Essex (40 J/2), Belle River (40 J/7), Pelee Island (40 G/15), Middle Island (40 G/10) and Amherstburg (40 J/3).

Vagners (1972a, 1972b) previously mapped the Quaternary geology of Essex County defining the distribution of surface deposits. The current mapping project will refine this work and result in a report defining the distribution and origin of surface and subsurface materials and landforms.

Remote sensing techniques (black and white aerial photographs at a scale of 1:10 000 and 1:50 000, infrared images at a scale of 1:15 000 and Landsat imagery), differences in surface materials, drilling, and material exposures (man-made and natural) were used to identify landforms. The origin of materials was determined by examining their sedimentology, stratigraphy and distribution. Laboratory analyses of materials (including petrology, grain size, carbonate content, clay mineralogy, geochemistry and heavy minerals) will assist in the separation and characterization of units.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The study area is primarily an extensive clay plain with little relief (Chapman and Putnam 1984). The exception to this is the area north and west of Leamington and north and east of Colchester where the land surface rises up to 50 m above lake level. Depth to bedrock varies between 9 m and 45 m (Vagners et al. 1973a, 1973b) although a section within a quarry east of Amherstburg revealed a dome of limestone subcropping to within 3 m of the surface. Bedrock crops out on Middle Sister Island, North Harbour Island, the Chicken Islands (F. Krestle, personal communication, 1989), East Sister Island, Hen Island, Middle Island and the northwestern and southeastern corners of Pelee Island.

The Middle Devonian Sylvania Formation sandstone and Amherstburg and Lucas Formation dolostones and limestones of the Detroit River Group underlie the southern half of Essex County and the east bank of the Detroit River. The limestones of the Dundee Formation and the shales of the Hamilton

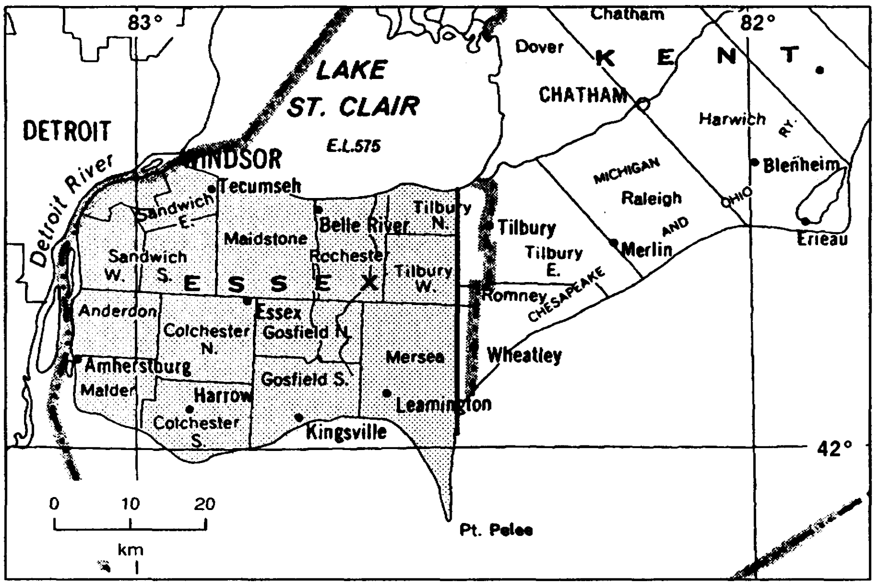

Figure 33.1. *Location map of the study area.*

Group underlie northern Essex County, Point Pelee and Pelee Island (Telford and Russell 1981). The Silurian Bass Islands Formation dolostone underlies the area along the north shore of Lake Erie, northwest of Colchester and may outcrop on the south shore of East Sister Island.

OBSERVATIONS ON THE GLACIAL GEOLOGY

Burial, partial burial and modification of glacial and proglacial landforms (by silty clay till and glaciolacustrine clays, glaciofluvial and beach sands, and glaciolacustrine and lacustrine processes) make it very difficult to identify and define the occurrence and distribution of glacial and proglacial landforms. Remote sensing imagery was used initially to identify glacial and proglacial landforms. These landforms were further identified through field mapping, a drilling program and by the sedimentology of material in the landforms as revealed in man-made and natural exposures.

Pebble fabric in tills, indicator erratics (tillite and jasper conglomerate) throughout Essex County, paleocurrents in proglacial subaqueous fans, the distribution of the recessional moraines and one set of striae aligned at 240° (observed on limestone in quarries east of Amherstburg) all indicate ice flowing south from the Lake Huron Basin.

Large grooves and flutes occur on outcropping bedrock at four locations on Pelee Island, and one location on each of East Sister, Hen and Middle islands. Striae and grooves located at South Bay, Pelee Island and East Sister Island indicate at least two flow directions: one set orientated at 190° to 225°, cut by a second set orientated at 264° to 275°. Striae and grooves on Hen and Middle islands are aligned in one direction only at 230°. These striations and "p" forms align with those on Kelly Island, although the "p" forms are less well developed.

Seven belts of recessional moraine were identified as lighter tones on remote sensing imagery obtained in the early spring. The lighter tones are due to enhanced early spring surface drainage facilitated by subtle rises in the landscape and presence of coarser material on the rises. A drilling program undertaken in the spring of 1989 showed that a number of ridges in Essex County are clay cored and are of glacial origin.

Additional evidence supporting these ridges as recessional moraines are 1) striae orientated at 240° observed on the floor of quarries east of Amherstburg indicating ice flow perpendicular to the recessional moraines located in southwestern Essex County; 2) a moraine aligned northwest-southeast through Detroit appears to be a continuation of a buried recessional moraine in northern Essex County; and 3) stratified clays and sands proximal to recessional moraines indicate material flows away from an ice front: these materials were observed in drill core and exposures.

Lighter tones on remote sensing images indicate the presence of several north-south orientated sand fans in the southern third of the map area. The lighter tones are probably due to enhanced spring drainage facilitated by the sand constituting the fans and by the topographic relief associated with some of these fans.

Sand associated with some of these fans is exposed at the surface. In other fans, sand is buried under silty clay till and glaciolacustrine clay. Buried sand has been identified in Lake Erie bluff sections and in drill core.

Determining the distribution of these exposed and buried sand bodies was accomplished by an Ontario Geological Survey drilling program and additional drilling records from the Ontario Ministry of Transportation and private engineering firms. These controlled drill records were combined with water well records and surface information.

These sand fans are interpreted to be proglacial subaquatic in origin on the basis of sedimentological and stratigraphic observations. These observations indicate that these proglacial subaquatic fans were probably formed during more than one "fan building" event.

Five eskers, three buried, extend generally north-south across the study area. In at least three instances these terminate at subaquatic fans. Buried eskers were first identified as lighter tones on remote sensing images. Drilling and water well records confirmed the presence of buried sand at two of the proposed esker locations. The surface eskers were identified by their morphology, material and sedimentological characteristics.

Three organic sites were located in Essex County. The oldest is in a man-made excavation at 216.4 m above sea level. Wood, shells and peat are contained in beach sands and glaciolacustrine clays. The second site is located 210.3 m above sea level. Cedar wood within beach sands was radiocarbon dated at 10 000±200 BP. A third organic site is located on Pelee Island and consists of peat directly overlying glaciolacustrine clay and underlying 4 m of beach sand.

RELATED RESEARCH

Several related Quaternary geological mapping projects within Essex County and the surrounding area have recently been completed or are in progress. These include a) a BSc thesis on the lithology, structure and stratigraphy of the upper clayey diamicton from three boreholes drilled in the Courtright–Port Lambton area (Ansell 1988); b) a BSc thesis examining heavy minerals from till samples collected in Kent and Essex counties (Arroyes 1988); c) an MSc thesis on the Bedford Formation and overlying Quaternary sediments in the Lake St. Clair region (G. Brown, University of Western Ontario, personal communication, 1989); d) an Ontario Geological Survey mapping project in the Chatham–Wheatly area (*see* Paper 34, this volume) and e) an isotope study of groundwater in southern Ontario (M. Sklash, University of Windsor, personal communication, 1989).

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34. Project Unit 88-47. Quaternary Geology of the Chatham–Wheatley Area, Southern Ontario

R.I. Kelly

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INTRODUCTION

The Chatham–Wheatley area is situated between latitudes 42°30′N and 42°00′N and longitudes 82°00′W and 82°30′W (Figure 34.1). The area is portrayed on the Wheatley (40 J/1) and Chatham (40 J/8) National Topographic System (NTS) maps at a scale of 1:50 000.

Quaternary geological mapping in the Chatham–Wheatley area was previously undertaken by Fitzgerald (1979), Sado (1981) and Kelly (1988). Additional mapping was conducted by the author, assisted by Cindy Styles, in the area covered by the Chatham map sheet, during the summer of 1989. Emphasis was placed on the collection of surface information and on the examination of sediments exposed in excavations, aggregate pits and along the banks of the Thames River. Examination of sediments was conducted to examine stratigraphic relationships and sedimentological characteristics of the exposed Quaternary deposits.

PHYSIOGRAPHY

The map area lies within the physiographic regions of the St. Clair Clay Plain and the Bothwell Sand Plain (Chapman and Putnam 1984). The St. Clair Clay Plain has been subdivided by these authors into the Essex Clay Plain, Lambton Clay Plain, Chatham Flats and St. Clair Delta. The Lambton Clay Plain is the only subregion not within the map area.

The Essex Clay Plain is essentially a low relief till plain smoothed by the action of glacial lakes which covered the area following final glacial retreat. The Essex Clay Plain occupies the southern portion of the map sheet.

The Chatham Flats, located between Lake St. Clair and Chatham is composed of glaciolacustrine and alluvial deposits. This area represents an abandoned lake plain with numerous alluvial features. The alluvial sediments were deposited by streams and rivers which crossed the glaciolacustrine plain and entered high-level postglacial lakes which occupied the Lake St. Clair basin.

The delta at the mouth of the St. Clair River occupies the extreme northwestern corner of the map area. Although most of the delta is marshland, some areas have been reclaimed and are farmed.

The second physiographic region, the Bothwell Sand Plain, is dominated by glaciolacustrine, alluvial and deltaic deposits. In some areas, eolian action has reworked the surface sand sediments into small

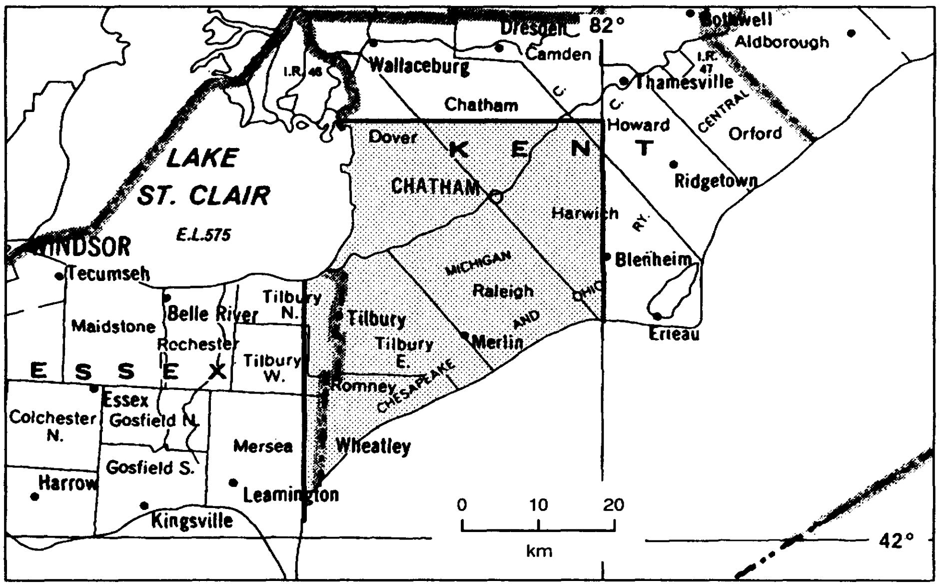

Figure 34.1. *Location map of the study area.*

dunes. This region covers much of the northeastern part of the map area.

The economy of the area is based primarily on agriculture. The warm climate, long growing season and fertile soils allow for the production of a wide variety of tender fruits and vegetables in addition to more traditional crops.

BEDROCK GEOLOGY

The Chatham–Wheatley area is underlain by Middle and Upper Devonian shales and limestones. Middle Devonian limestone of the Dundee Formation subcrops in the southwestern corner of the region near the town of Wheatley and further east near the hamlet of Port Alma. Shales and limestones of the Middle Devonian Hamilton Group overlie the Dundee Formation. The Hamilton Group subcrops over much of the western part of the map sheet and also in the extreme eastern part. The youngest rock unit in the area is the Upper Devonian Kettle Point Formation. The black shale of this formation covers most of the eastern portion of the map area. Throughout the area, the bedrock is overlain by thick deposits of Quaternary sediments. No bedrock outcrops are known to exist in the map area.

QUATERNARY GEOLOGY

The oldest glacial sediment exposed in the area is a clast-poor, grey, silty to clayey-silt till. This unit is present over much of the southern part of the map area. Pebble fabrics and shear structures indicate that this till was deposited by ice which advanced south-southeast from the Huron basin. This unit was previously described north of the Chatham–Wheatley area by Fitzgerald (1977, 1979), but was attributed to deposition by ice advancing out of the Erie basin.

A second till, thought to be of slightly younger age than the aforementioned unit, is found only along the extreme southern margin of the map sheet. Previously described by the author (Kelly 1988), this till is proposed to have been deposited by glacial ice advancing northwestward out of the Erie basin. This unit was previously ascribed to the Port Bruce Stadial and correlated with the Port Stanley Till (Sado 1981).

Retreat of the ice front left a number of small recessional moraines throughout the area. Many of these moraines are poorly defined, in part, because of partial burial and reworking by glacial lake waters. The largest and most distinct, the Blenheim Moraine, is thought to have been deposited in an interlobate position between the Huron and Erie ice lobes. A narrow ridge extending from Blenheim to just north of Wheatley is proposed to have been deposited by Erie ice. This ridge was previously described by Taylor (1913). A number of rather indistinct ridges associated with Huron ice retreat are found in the vicinity of Tilbury and north of Blenheim. A low relief ridge extending from Merlin to northeast of Charing Cross, known as the Charing Cross Moraine, was previously noted by Chapman and Putnam (1984).

Following retreat of the ice front from the area, a series of proglacial lakes covered southwestern Ontario. In the Chatham area a number of poorly defined shorelines were noted. The highest level shorelines ring the Blenheim moraine and have been related to Lake Warren levels (Chapman and Putnam 1984). A series of other low level shorelines, which ring the Lake St. Clair basin, were noted at 192 m, 184 m, 180 m and 177 m. Whether these shorelines represent a series of regressive lake levels is unclear at this point. In the western part of the map area fine-grained, shell-rich, glaciolacustrine sediments were found overlying sandy, glaciolacustrine sediments. This fine-grained glaciolacustrine unit could be traced eastward to Chatham where it was found to underlie sand-rich deltaic deposits. The sequence of sediments would seem to indicate a regressive glaciolacustrine sequence (the lowermost sands) followed by a glaciolacustrine transgression (the clay-rich sediments) which in turn was followed by a final glaciolacustrine regression. A late transgressive event in the Erie basin has been suggested by Barnett (1985) and Coakley (1989).

Into these low level lakes an early Thames River deposited sediments which formed broad, thin, deltaic deposits (Chapman and Putnam 1984). These deposits form the surface of the Bothwell Sand Plain (Chapman and Putnam 1984) and cover much of the area east of Chatham.

In the Chatham area the Thames River has two associated terraces at 180 m and 177 m, with the 180 m level being most pronounced. Alluvial deposits associated with the proto-Thames River are small. Other alluvial deposits are found in association with the smaller streams which cross the area. These deposits are most easily recognized on air photos. The texture of these deposits is variable and reflects the parent materials which the streams are eroding. A peculiar archeological feature of some alluvial deposits is their usage by early Indians as burial grounds, landfill and encampment sites. Eolian processes have modified the surface sediments of some sand-rich areas into small dunes. These dunes are often parabolic or ribbon shaped.

ECONOMIC GEOLOGY

The Chatham–Wheatley area is for the most part devoid of large, good quality aggregate deposits. Remaining surface deposits of sand and gravel are restricted to a narrow, thin beach deposit which parallels Highway 3 and the Lake Erie bluff.

A large body of buried aggregate located at Pinehurst, southeast of Chatham, is the only major source where aggregate is currently being extracted in the area. Previous drilling and this mapping project indicate the potential for other buried aggregate bodies. Additionally, buried aggregate bodies which are uneconomical to extract may provide important supplies of potable water.

Oil and gas production in the map area has continued since the last century. Recent discoveries of oil near Wheatley and Paincourt have sparked renewed interest in the area. The apparent success of this activity seems likely to ensure the continuation of exploration and drilling for years to come.

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35. Project Unit 86-13. Quaternary Geology of the Barrie and Elmvale Area

P.J. Barnett

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INTRODUCTION

During this past summer, geological field mapping of the Quaternary geology of the eastern half of the Elmvale (NTS 31 D/12) map sheet was completed and mapping in the eastern half of the Barrie (NTS 31 D/5) map sheet began (Figure 35.1). The Elmvale study area is bounded by latitudes 44°30′ and 44°45′N and longitudes 79°30′ and 79°45′W, and includes parts of Orillia, Medonte, Oro, Matchedash, Tay and Flos townships. The east half of the Barrie area is defined by latitudes 44°15′ and 44°30′N and longitudes 79°30′ and 79°45′W, and includes parts of Oro, Vespra, Innisfil and Essa townships. Competent field assistance during the summer was provided by Diana Babuin.

GEOLOGY

The physiography and general geology of the map area has been described previously by the author (Barnett 1986, 1988). This past summer the area around, and including, the Oro Moraine or Bass Lake Kame Moraine, (sometimes referred to as the Oro sandhills) was investigated as well as the area south of the moraine toward Lake Simcoe.

The Oro Moraine (Chapman and Putnam 1943) or the Bass Lake Kame Moraine (Deane 1950) was considered by Deane to be an end moraine with ice on the northern side only. Gravenor (1957) suggested that this moraine was interlobate in origin and that it had been overridden by ice from the Lake Simcoe basin. Chapman and Putnam (1966, 1984) and Terasmae (1980), later supported the interlobate origin.

The main supply of sediment to the moraine was from the ice on the southern side (within the Lake Simcoe basin). Sediment was fed to the moraine via two main conduits (now eskers), one at the extreme eastern end of the moraine and the other on the southern side approximately 5 km northeast of Edgar. Deposition of stratified sediments occurred in closed and open conduits, and as subaqueous fans within the interlobate zone. There appears to have been three main stages in the formation of the moraine as the interlobate gap successively widened.

The well-developed kettled surface of this moraine and the absence of subglacially deposited till above the stratified sediments indicates that the moraine has not been overridden as suggested previously by Gravenor (1957) and supported by several other workers (Chapman and Putnam 1984;

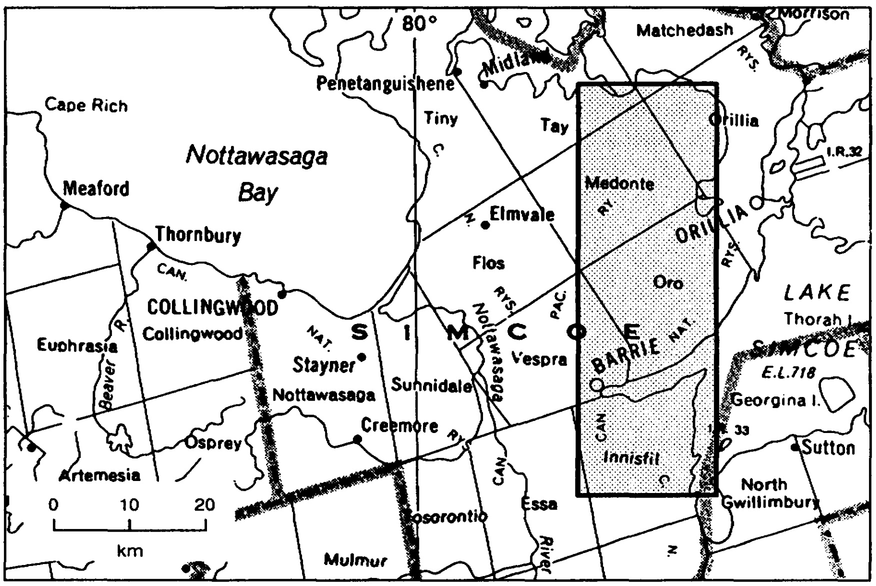

Figure 35.1. *Location map of the study area.*

Finamore and Bajc 1984). Sand and gravel deposits buried beneath the till plain east of Bass Lake are believed to be older and not part of the interlobate moraine. The Bass Lake Kame Moraine appears to be almost entirely confined to the east half of the Elmvale (NTS 31 D/12) map sheet. The extent of the Bass Lake Moraine or what is referred to as the Oro Moraine by Chapman and Putnam (1984) is delineated on Map P.2715 accompanying their monograph.

South of the Oro Moraine, the dominant mappable surficial sediment is till or a unit dominated by till-like debris flows (flow tills) interstratified with sand, silt, and occasionally clay. The debris flow unit is often associated with low relief sinuous ridges interpreted by Deane (1950) to be ice block ridges resulting from stagnating ice.

Several abandoned shoreline features; bluffs, beach bars and spits, mark the former positions of water level in the Lake Simcoe and Georgian Bay basins. The Main Algonquin shoreline is best developed and is usually marked by a substantial shore bluff and large beaches and spits. The Main Algonquin shoreline appears to be the result of a major transgression that resulted in extensive erosion of pre-existing sediments and the formation of the extensive boulder lags and very large spits in the area mapped. This shoreline rises in elevation from about 240 m above sea level (asl) near Barrie to about 260 m asl in the vicinity of Coldwater, as noted by Deane (1950). Successively lower phases of Lake Algonquin are recorded by a series of small shore bluffs and beach bars cut into the edges of the Simcoe Uplands. The Nipissing Great Lakes are recorded by shoreline features in the vicinity of Coldwater.

Several well-formed spits and shore bluffs occur at elevations above the Main Algonquin level and appear to mark the shorelines of at least two large lakes. These levels occur just above 270 m asl and 290 m asl in the vicinity of Gilchrist in the Barrie map area. High level shoreline features, some 30 m above the Main Algonquin level, were also observed in the Elmvale map area near Warminster and Prices Corners. Shorelines above the Main Algonquin level have been reported previously (Finamore 1981; Chapman and Putnam 1984) and have been suggested to have been related to Early Lake Algonquin or Lake Schomberg. Further study is needed into these high level shorelines and lake level history in the Lake Simcoe and Georgian Bay basins.

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36. Project Unit 86-20. Quaternary Geology of the Gowganda Area

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INTRODUCTION

Quaternary geological mapping and sampling was conducted in the Gowganda map sheet area (scale 1:50 000; NTS 41 P/10). The study area is bounded by latitudes 47°30'N and 47°45'N and longitudes 80°30'W and 81°00'W (Figure 36.1).

The project objectives are to determine the distribution and stratigraphy of the Quaternary sediments and to expand the geological data base of the area. This will be of use in mineral exploration, forestry and land use planning. Airphoto interpretation, map compilation and analysis of geochemical data are currently in progress.

Previous Quaternary geological mapping, at a scale of 1:50 000, surficial till sampling and overburden trenching have been undertaken in the Shining Tree (Finamore 1986) and Sinclair Lake map areas (Alcock 1987, 1988) to the west.

QUATERNARY GEOLOGY

The area investigated contains a surficial sedimentary sequence representing the last major, late Wisconsinan ice advance, and postglacial glaciofluvial, glaciolacustrine and eolian activity.

Glacially streamlined and striated bedrock outcrops demonstrate that the last dominant ice movement was towards 150° to 200° azimuth in the western part of the study area and 145° to 180° azimuth in the eastern part. Ice flow directions were strongly controlled by the rugged local bedrock topography. Minor late-glacial shifts in ice direction are indicated by a few examples of striations which crosscut at small angles. No clear evidence of an earlier ice advance to the southwest, such as that documented by Veillette (1986) in the Timmins, Matheson and Lake Timiskaming areas and by Alcock (1988) in the Shining Tree and Sinclair Lake areas, was found.

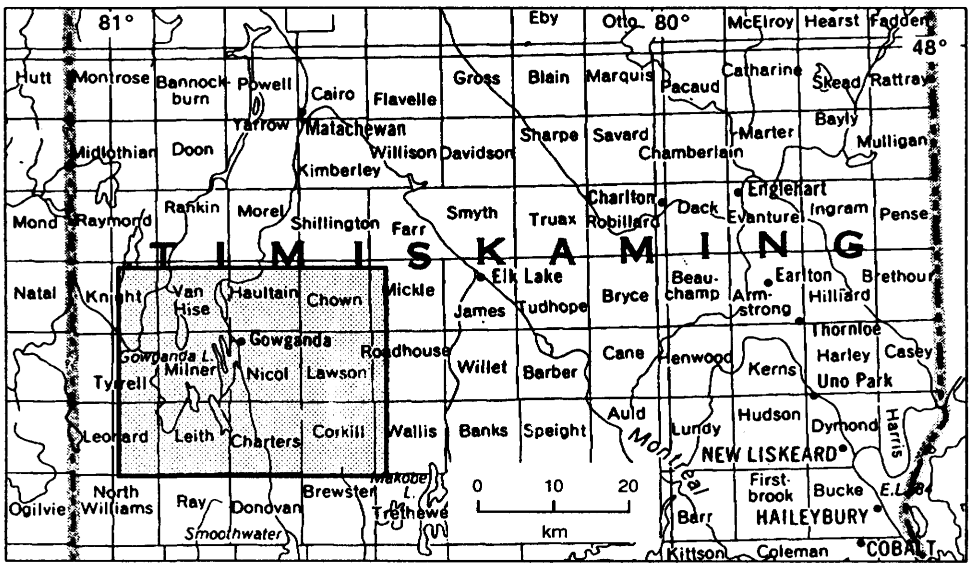

Figure 36.1. *Location map for the Gowganda area.*

This project A.4.1 is part of the five-year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

Drift thickness ranges from less than 1 m to more than 30 m in areas of ice-contact sediments. Large areas of essentially bare bedrock occur on ridges and other topographic highs, as well as preferentially near eskers and meltwater channels. It is likely that meltwaters eroded the overburden cover along their flow paths both beneath and in front of the ice.

One till sheet was found over the study area. It forms a patchy veneer (less than 1 m) over extensive areas of bedrock but locally ranges up to 4 m or more in thickness in lee-side or valley bottom locations. The till commonly consists of pebbly to bouldery sand with few fines present. Facies interpretation of the till was hampered by the extremely coarse texture and strong degree of surface weathering. Most till exposures indicate that subglacial deposition predominated. The composition of the surface till often strongly reflects the local bedrock. All till at surface has been affected by soil-forming processes, oxidation and translocation of matrix carbonate and iron to a depth of at least 1 to 2 m.

Glaciofluvial ice-contact deposits consist of cobbly to bouldery sand and gravel and occur as eskers, kames, crevasse fills and other hummocky and kettled stagnant ice features. Large, single ridge eskers, with individual sections up to several kilometres in length, occupy the edges of major valleys. Compound or distributary esker complexes occur in other topographic lows. Sections of the eskers were eroded by later proglacial meltwater activity. Locally, small kames are found in valley bottoms among drift-veneered bedrock knobs.

A halt in ice retreat is represented along the southern boundary of the map area by the Sultan Scarp. This discontinuous, north-facing, ice-contact slope separates ice-contact deposits to the north from proglacial outwash deposits to the south. At this ice halt position, the eskers terminate in broad, coalescing fans of bedded outwash sands and gravels. These fans represent deposition in subaerial and subaqueous environments.

Glaciofluvial outwash deposits, consisting of pebbly to cobbly sand, flank the esker systems and occur as gently undulating plains with some kettles. Minor outwash deposits occur as terraces in local valleys.

Glaciolacustrine deposits in the Gowganda area consist of fine sand, silty fine sand and occasional rhythmically laminated silt and clay. Extensive tracts of glaciolacustrine deposits occupy topographic lows near the south end of Duncan Lake, Wapus Creek, Firth Lake and along Bear River in Corkill and Lawson townships. Deposits of silty sand border the fans of outwash sand and gravel at the esker termini and blanket till and glaciofluvial sediment.

Abandoned shoreline features, consisting of ridges or bluffs less than 2 m high, occur occasionally on the outwash fans. The shoreline features were probably formed in temporary proglacial ponds or lakes.

Eolian deposits consist of well-sorted, thinly bedded fine sand which commonly occur as parabolic dunes. Small dune fields occur in southern Corkill Township and in Lawson Township, 2 km south of Longpoint Lake. The dunes are located on and southeast (down-paleowind direction) from parent deposits of fine-grained glaciofluvial and glaciolacustrine sands. These dune fields are much less extensive and more poorly developed than in the Shining Tree area to the west and northwest.

Organic material, including peat, mud and muck, occur as deposits up to a few metres in thickness. Organic deposits are found in bogs and swamps occupying local topographic depressions and along meandering streams and rivers.

Recent alluvial deposits consist of sand, silt, rare gravel and some organic material. They are found along larger watercourses which cut through glaciofluvial and glaciolacustrine deposits. Alluvial deposits are present along sections of Wapus Creek, Calcite Creek, Bear River, and Montreal River in central Charters Township. Most deposits are of very restricted areal extent and thickness and grade laterally into organic deposits.

Man-emplaced deposits consist of rock debris, tailings and fill. Piles of rock debris are found near former mining operations and at numerous small adits throughout the study area. Tailings are present in infilled lake basins near the former silver mines. Considerable quantities of fill have been placed within the town of Gowganda and along Highway 560 but are too small to be mapped at 1:50 000 scale.

APPLIED QUATERNARY GEOLOGY

A till sampling program was carried out to supplement the geochemical data base developed for the Shining Tree area. Its purpose is to determine how overburden sampling can be effectively used as a mineral exploration technique in the project area. A total of 33 samples of weathered surface till were collected in the study area. Geochemical analyses were performed on the -0.063 mm (-230 mesh) fraction for a suite of elements including Ag, As, Au, Ba, Bi, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, Pb, Pd, Pt, Sb and Zn. Six samples of till were collected for heavy mineral concentrate (specific gravity greater than 3.3) preparation, gold grain counts, heavy mineral grain counts and geochemical analysis.

Preliminary results indicate that surface till geochemical and mineralogical sampling and boulder tracing are effective exploration methods in those areas with till at or near surface. Results from surface till samples collected up to several hundred metres down-ice of known gold occurrences in the Shining Tree area indicate gold grains are present in the sand-sized heavy mineral fraction. In addition, anomalous gold geochemical values occur in the silt and clay fraction of these samples.

Geochemical results are pending for samples taken near and down-ice of silver deposits in the Gowganda area. Previous studies in the Cobalt area (Boyle 1968) indicate sampling of thin till should be an effective exploration method for silver.

Soil geochemical sampling would not be effective in those areas where non-locally derived glaciofluvial, glaciolacustrine or eolian sediment forms the surficial material.

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37. Project Unit 89-54. Record of an Overburden Drill Hole in the St. Davids Buried Gorge, Niagara Falls

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INTRODUCTION

In the spring of 1989, a borehole was drilled at Niagara Falls, Ontario in co-operation with Ontario Hydro (Figure 37.1). The major objective was to obtain a continuous core of as much of the sediments infilling the St. Davids Buried Gorge as possible, and in particular, to obtain samples of the organic bearing beds reported earlier by Spencer (1907). A sonic drill was used in order to achieve the objective.

Ever since Sir Charles Lyell first recognized the buried valley between The Whirlpool and the embayment in the escarpment at St. Davids in 1841, supposing it to be a preglacial Niagara River (Lyell 1845), curiosity as to its origin and the composition of the infilling sediments has existed. Spencer (1881) originally suggested the channel was interglacial. Later, however, Spencer (1887) suggested it was preglacial but cut by local drainage only and not part of the Erigan River system.

In 1905, the Geological Survey of Canada drilled a borehole (affectionately known as "Spencer's Well") into the buried valley fill. This borehole, drilled to a depth of 268 feet (81.7 m) (Spencer 1907), encountered remains of white spruce wood at 186 feet (56.7 m) and "angular gravel with earthy binding" at 239 feet (72.8 m) below the surface (possibly a remnant of a buried soil).

Hobson and Terasmae (1969) tested Spencer's theory of the buried valley in the St. Davids–Whirlpool area, using seismic surveys, and a drilling and sampling program. In one of their boreholes, borehole 5, the presence of pollen and plant macrofossils in stratified silt, clay and sand was found in the interval between 106 and 183 feet (32.3 to 55.8 m) below the surface. Cold climatic conditions were inferred from the pollen assemblage and a late mid-Wisconsinan age assigned to the nonglacial beds (Hobson and Terasmae 1969). The buried gorge itself was suggested to have been cut either during the last interglacial, the Sangamonian, or earlier (Hobson and Terasmae 1969). Karrow and Terasmae (1970) also reported on the pollen-bearing sediments of the St. Davids Buried Gorge. Feenstra (1981) has summarized the above findings in greater detail, including his additional findings and those of others.

RESULTS AND FINDINGS TO DATE

The sonic borehole terminated at a depth of 62.9 m due to penetration difficulties below 44 m. The organic-bearing unit of Spencer's was encountered and

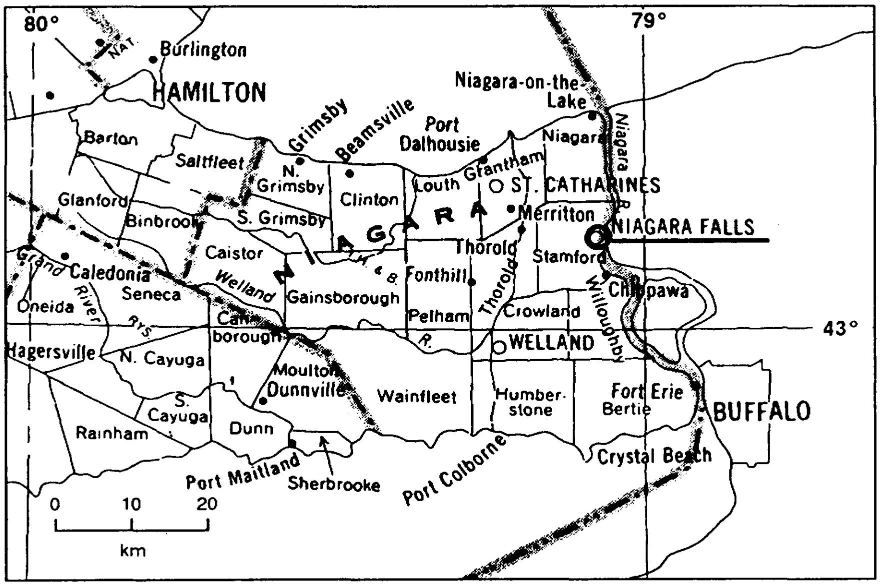
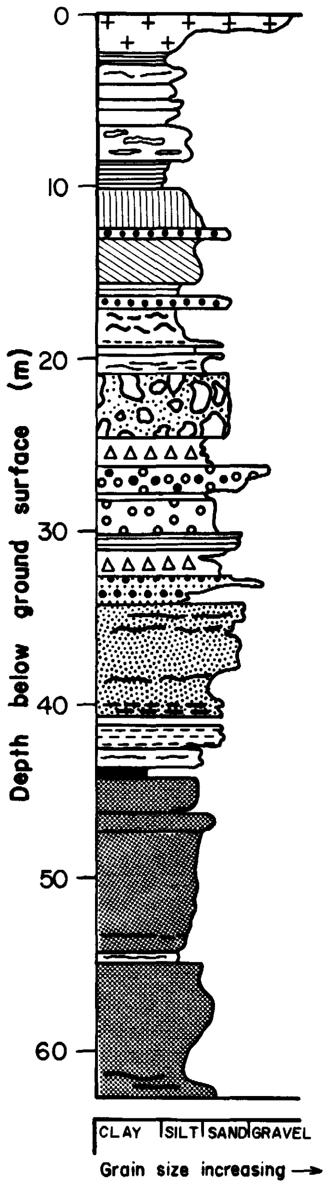


Figure 37.1. *Location map of the study area.*



Description	Interpretation
Angular boulder - cobble gravel and disturbed clayey silt	Fill
Reddish brown silt to very fine sandy silt, with thin discontinuous clay laminations - contains occasional beds of poorly-sorted, massive, pebbly, sandy silt diamicton	Proglacial Lake Sediments - debris flows or flow tills
Reddish grey, dense, massive, stony, sandy silt diamicton	Subglacial Deposits - till
Interbedded dark reddish grey, clayey silt and sandy silt diamictons, grey silt and reddish brown dirty pea-to-cobble-sized gravel layers	Subglacial Conduit Deposits - debris flows, meltwater deposits and deformation till
Grey, interbedded, silty very fine sand and very fine sandy silt, with occasional thin beds of organic detritus Concentrations of organic detritus	Non-glacial Fluvial Deposits

Figure 37.2. *Lithologic log of OGS-89-13, St. Davids Buried Gorge, Niagara Falls, Ontario.*

good samples recovered. A graphic log of the sediments in the borehole and a preliminary interpretation of their origins is presented in Figure 37.2. The graphic log is based on descriptions of the sediments at the drill site and on subsequent examination of the core during sampling in the laboratory.

The sediments consisted of an upper unit of stratified silt and very fine sand with occasional clay laminations. Near the base of this unit several thin diamicton layers (less than 0.5 m) occur. The diamicton units are massive, poorly sorted, gritty, sandy silt with subrounded pebbles and are interpreted as flow tills. The upper unit overlies approximately 4 m of massive stony sandy silt interpreted as subglacially deposited till. The till overlies about 8 m of thinly bedded diamicton interstratified with dirty silty gravels and gravelly sands. Most diamicton units appear to be debris flows, however, evidence of subsole deformation is present in two of the thicker layers which are likely deformation till. Deposition appears to have occurred subglacially in a large cavity which periodically closed allowing the base of the glacier to deform and deposit the till layers. The remaining sediment consists of interbedded silts and very fine sands containing thin beds and laminations of organic detritus.

Samples were taken from the cores for determination of physical and chemical properties. Organic-bearing sediments were sampled for pollen and plant macrofossil content. Wood fragments were collected from several horizons for dating.

Palynological analysis of six point samples from a 50 cm interval approximately 44 m below the surface was undertaken by J.H. McAndrews. He reports (J.H. McAndrews, Royal Ontario Museum, written communication, 1989) that "*Pinus*, mostly the small *P. banksiana* type, and *Picea* were the dominant tree pollen followed by the herbs Cyperaceae and Gramineae." The assemblage suggested to him a subarctic forest-tundra dominated by sparse spruce. The pine pollen was probably derived either from contemporary jack pine growing in the southeastern United States or recycled from glacier ice (McAndrews 1984). The "pollen assemblage is similar to other mid-Wisconsinan assemblages as well as the proglacial zone 1p of McAndrews and Jackson (1988)". Processing of samples is continuing and the correlation of the sediment sequence to the known stratigraphy of the immediate area (Feenstra 1981) is in progress.

Drilling continued at the site with a rotary drill to a depth of 237.7 m. Bedrock (Queenston Shale), was encountered at a depth of 183.6 m or at an elevation of 2.1 m below mean sea level (Branko Semec, Ontario Hydro, personal communication, 1989). Only a few samples were obtained from the lower units of sediments infilling the St. Davids Buried Gorge.

The assistance of Branko Semec, Ontario Hydro; J.H. McAndrews, Royal Ontario Museum; and of my colleagues A.F. Bajc, and B.H. Feenstra, Resident Geologist, London, Ministry of Northern Development and Mines is much appreciated. Al Coutie and Dave Koudy, Ontario Hydro provided valuable assistance in the smooth running of the drilling operations.

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38. Project Unit 88-19. Delineation of a Buried Aggregate Deposit in McGillivray Township, Middlesex County, Southwestern Ontario

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INTRODUCTION

A detailed electromagnetic conductivity survey of buried aggregate resources located in McGillivray Township, Middlesex County, was undertaken in 1989 (Figure 38.1). The purpose of the survey was to delineate the distribution and depth of burial of the sand and gravel horizons.

McGillivray Township and the London area of southwestern Ontario are increasingly facing a shortage of coarse aggregates. Existing resources within McGillivray Township consist predominantly of sand. Few of the licenced pits in the township have an adequate supply of gravel to meet local demands for coarse aggregates. The surrounding townships are experiencing a similar shortage of coarse aggregates. Aggregate producers in the London area are increasingly searching for additional resources of coarse aggregate to meet existing and future demands as growth in the London area continues. Coarse aggregates of high quality might also be expected to find a market in the aggregate-starved Sarnia area, 75 km to the west.

The study area is located 20 km northwest of London and covers a 45 km^2 area along the eastern edge of McGillivray Township, encompassing concessions 1, 2, and 3 (Figure 38.2). The study area is bounded on the east by King's Highway 4 and Middlesex County Road 22, on the south by King's Highway 7, and on the north by Huron County Road 5, all of which provide general access to the area. Access within the area is by Middlesex County Road 24, running from east to west, and by McGillivray Concession Road 2 which transects the area from north to south. Numerous other township roads cross the study area in a general eastward direction. A Canadian National Railways (CNR) line crosses the south part of the area in a southwest to northeast direction, and an abandoned CNR track, with rails and ties removed, provides a north-oriented trail near the eastern margin of the study area. The Huron water supply line, an underground pipeline supplying drinking water to the city of London, crosses the southern part of the study area in a northwest to southeast direction.

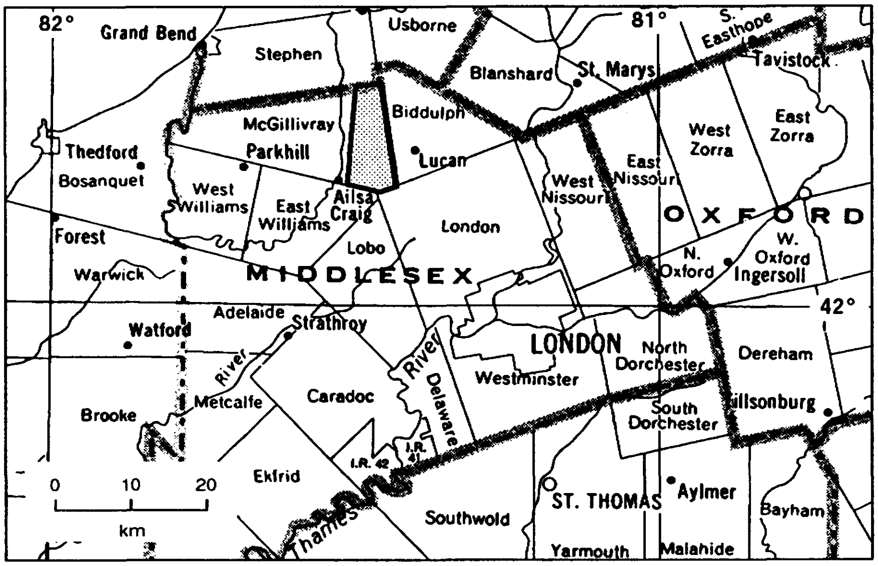


Figure 38.1. *Location map for the McGillivray Township survey area.*

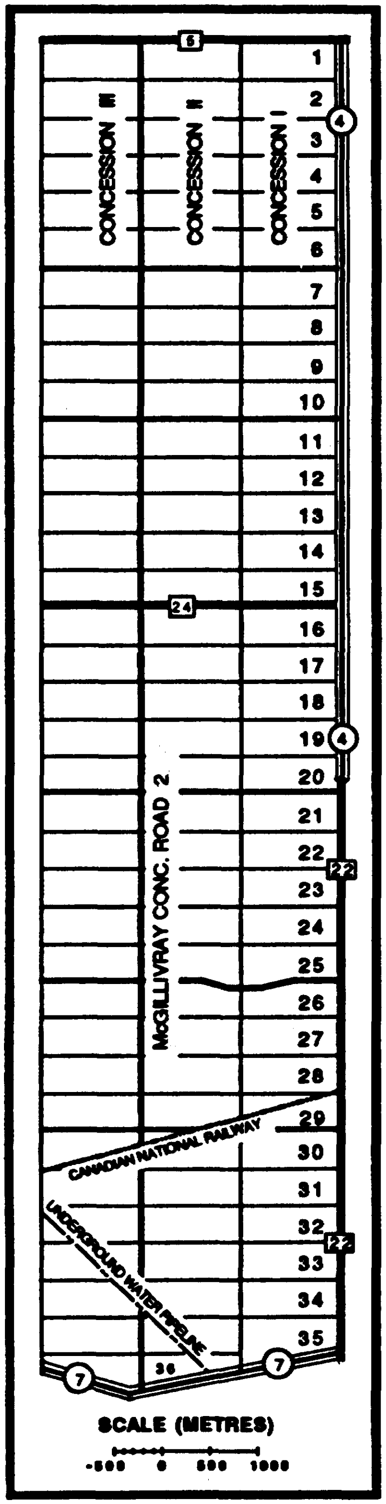


Figure 38.2. *Lot and concession map of study area, McGillivray Township.*

GENERAL GEOLOGY

Mapping of the study area includes a provincial physiographic study by Chapman and Putnam (1984) and more detailed Quaternary geology mapping by Karrow (1977) and Sado and Vagners (1975). The topography of the study area consists of a flat land surface that becomes gently rolling in the vicinity of the Seaforth Moraine to the east and the Centralia Moraine to the northeast. The predominant surface material in the area is a clayey silt till (Sado and Vagners 1975). In the northern part of the study area, Karrow (1977) has mapped this unit as Rannoch Till. The area is dissected by the Little Ausable River and poorly incised by tributaries of the Ausable River. Alluvium deposits, consisting predominantly of silt and occasionally organics or sand and gravel, occur within some of these channels (Sado and Vagners 1975). The bedrock surface is essentially flat lying (Sado and Jones 1980a) with a minor dip to the southwest and is buried under 35 to 50 m of glacial drift in the area (Sado and Jones 1980b). Bedrock consists of limestones of the Middle Devonian Dundee Formation.

A general inventory of the aggregate resources of McGillivray, East Williams and West Williams townships is presently in preparation (Ontario Geological Survey, in preparation). Aggregate Resources Inventory Papers for the surrounding townships of Lobo, Biddulph and London have been published by the Ontario Geological Survey (1981, 1982, 1983). An evaluation of aggregate suitability in East and West Williams townships has been conducted by Deike (1982).

PROJECT OBJECTIVE

This project was to concentrate on the delineation of the buried aggregate resources along the eastern edge of McGillivray Township, during the 1989 field season. This work was to consist of an initial review of a buried aggregate deposit that had been discovered by a local farmer during drainage improvements on his farm. Test lines were to be run across this area, using procedures established by the author during field work in 1988 (Vanderveer, in preparation; Vanderveer and Szoke 1988), to evaluate the applicability of electromagnetic conductivity to the delineation of the McGillivray deposit. If the test lines were successful in identifying the location of known aggregates, then an electromagnetic conductivity (EM) survey to delineate this deposit and a search for additional aggregate materials were to be undertaken.

SURVEY METHODOLOGY

An investigation of the known buried aggregate deposit, now operated under licence by the Township of McGillivray for aggregate extraction, revealed that the aggregate occurs under 2 m or more of glacial till. The underlying sand and gravel materials consist of cobble- to boulder-sized gravel with a matrix of predominantly coarse sand and occurs below the water level. A minor amount of fines in the silt- to clay-size range are intermixed in the matrix or as coatings on the coarse gravel to boulder-sized fraction.

Trial surveys were conducted using the EM31® and the EM34-3® conductivity meters. For more information regarding the methodology of EM surveys, the reader is referred to McNeill (1980). These trial runs were concentrated on the area adjacent to the licenced pit and consisted of spot profiles and selected east-trending test lines which ran across Lot 33, Concession 1, and Lot 33, Concession 2, and included the licenced pit area. The five spot profiles were generated with the EM31® and EM34-3® operated in both the horizontal and vertical dipole modes and the EM34-3® operated with each of the 10, 20, and 40 m intercoil spacings. Three of the spot profiles were generated adjacent to the extracted area for cross correlation with nearby stratigraphic exposures. The two other spot profiles were generated at increasing distances with the farthest profile centred approximately 400 m west of the pit. Readings derived from the three east-oriented test lines were generated using the EM31® and the EM34-3®. The EM34-3® was operated with an intercoil spacing of 20 m and readings for both instruments were taken in horizontal and vertical modes. The readings for the EM31® were taken at stations established using the EM34-3® which preceded the EM31® by a minimum of 40 m to prevent any instrument cross interference. These three transects provided profiles of conductivity that show the location of the buried aggregates as zones of low conductivity. This is demonstrated by the profiles for Line 1230 North (Figures 38.3a and 38.3b). The horizontal conductivity readings for the EM34-3 in the immediate vicinity of shallow-buried aggregates was in the range of 6 to 10 millimhos per metre (mmhos/m). Farther away, readings were 14 to 18 millimhos per metre, with the highest readings occurring in the vicinity of the Seaforth Moraine where the till was expected to be thickest and where gravels are less likely to occur. The EM34-3® vertical readings were generally lower than those for the horizontal dipole. Both of the EM31® readings were generally higher than the corresponding readings by the EM34-3®, with the EM31® vertical readings generally being the highest, indicating an overlying mantle of conductive till. The lower vertical values with the EM34-3® provide an indication that the aggregate unit was of substantial thickness and perhaps quite extensive across the area, although more deeply buried in areas farthest from the active pit area.

Following the conclusion that electromagnetic conductivity could be used effectively to locate zones of buried aggregates in the vicinity of the existing pit, a grid was established and a survey implemented. McGillivray Township Concession Road 2 was selected as a reference base line from which stations along grid lines would be established in an easterly and westerly direction such that lots within concessions 1, 2, and 3 of McGillivray Township could be covered. The intersection of this Concession Road 2 with King's Highway 7 was chosen as the zero-line position, and lines were then located to the north of this position. The grid lines were initially established at 250 to 300 m intervals and then later at 400 m intervals. An EM survey along these lines was conducted using the EM34-3® operated with a 20 m intercoil spacing and readings taken for both the horizontal and vertical dipoles. A total of 40 grid lines,

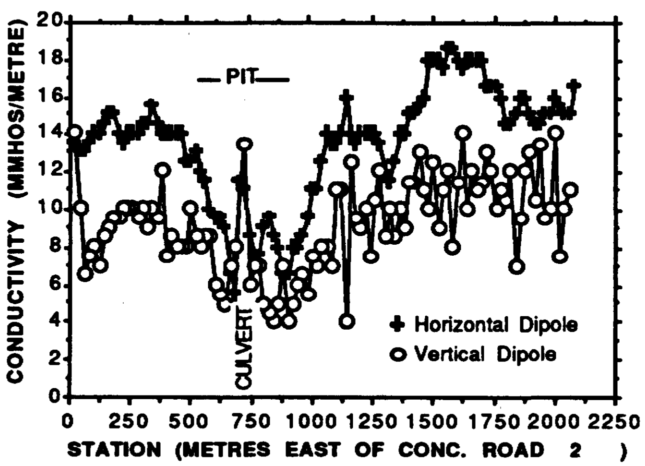


Figure 38.3a. *EM34-3® conductivity profiles, Line 1230 North.*

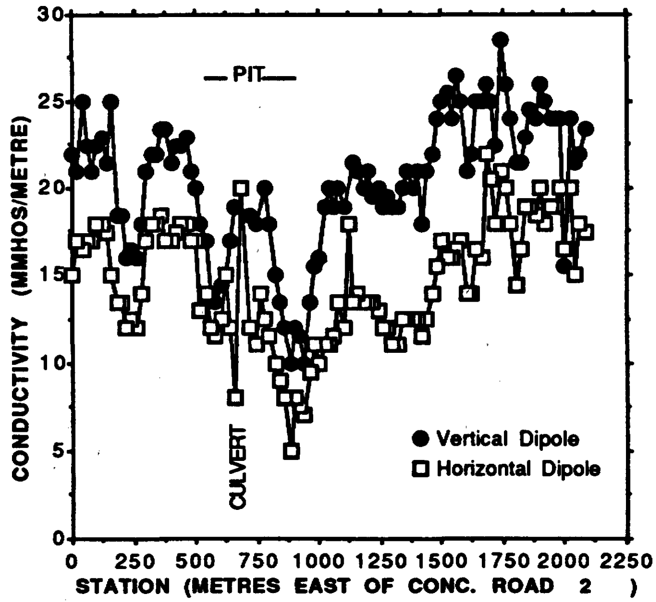
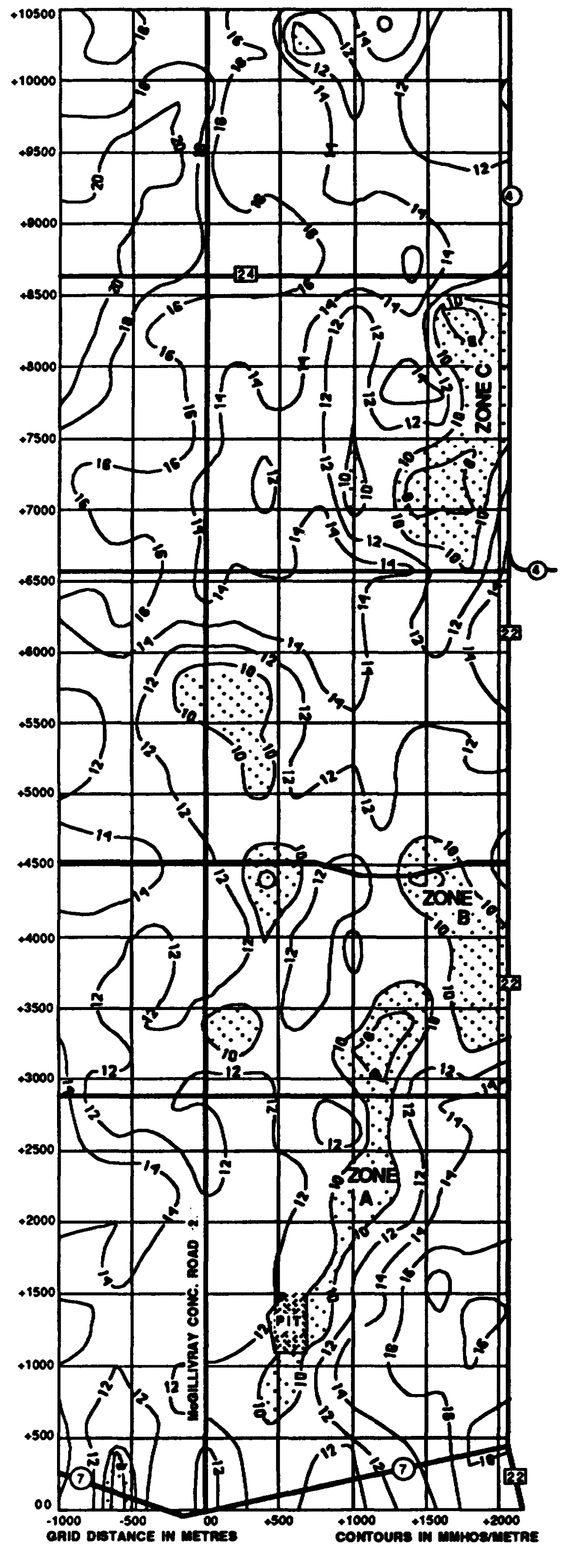


Figure 38.3b. *EM31® conductivity profiles, Line 1230 North.*



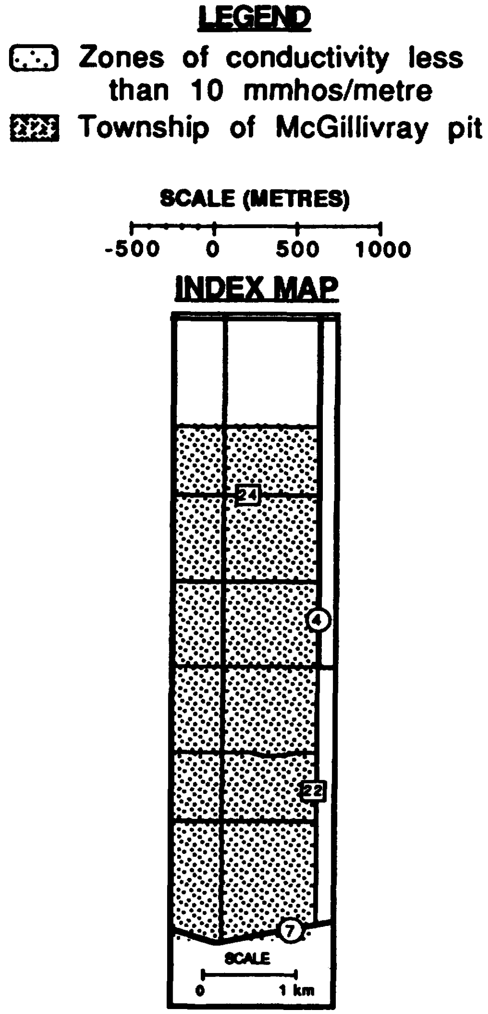


Figure 38.4. *Contoured EM34-3® data, McGillivray Township study area.*

each averaging just over 3 km in length, were surveyed, covering an area of approximately 45 km^2.

STATISTICAL TREATMENT OF DATA

The EM readings for each line of data were entered into separate Excel® spreadsheets on a Macintosh SE® computer. On a regular basis as sections of the area were completed, these data were combined into a singular spreadsheet which was then used to create a grid file for contouring using MacGridzo®. The grid file was contoured and contour labels were added. The resultant file was combined with a compiled base-map file that included the location of roads, a reference grid and other features.

PRELIMINARY RESULTS

Figure 38.4 shows the southern two thirds of the study area and the resultant contoured data for the horizontal dipole of the EM 34-3® operated with a 20 m intercoil spacing. The location of the Township of McGillivray pit is highlighted to show the location of known buried aggregates. The pit occurs along the west edge of a north-northeast-trending band—ZONE A—of conductivities of 10 millimhos per metre or less. This band of lower conductivity extends for over 3.5 km and has a width of generally less than 300 m. Drilling was conducted within ZONE A using a truck-mounted solid-stem auger. This drill unit is equipped to drill to a maximum depth of 6.5 m. A total of 14 holes were drilled and, within the area of lower conductivity, coarse sand and gravel was intersected between 3.5 and 5.0 m. Very little penetration into the aggregate materials was possible with this drill unit because of the stony nature of the gravel and the presence of water occurring approximately 4 m below the ground surface.

A number of other zones of low conductivity have been identified to the west and north of ZONE A. These two zones—ZONE B and ZONE C—are located to the northeast, and extend into Biddulph Township. ZONE C extends to the north-northeast and into the area of a licenced pit from which sand and gravel is being extracted from beneath more than 10 m of glacial till. This pit occurs along the western flank of the Seaforth Moraine where the till is expected to be thicker. Landowners to the west of King's Highway 4 and in the area of these two zones report encountering sand and gravel in shallow holes which also suggests the presence of buried aggregates in these areas.

FURTHER WORK PLANNED

Future plans include the digging of a number of test pits using a large excavator with a minimum 6.0 m depth of reach both within the zone that was drilled and within the other areas of lower conductivity. This will determine the depth of burial of aggregates suspected to underlie these areas and provide adequate samples for testing of aggregate quality.

CONCLUSIONS

The EM survey conducted within McGillivray Township has been successful in outlining a substantial deposit of buried aggregates contiguous with aggregates located within the licenced pit. It has also identified a number of other zones of lower conductivity that are being investigated for aggregate potential. Gravel was the material most commonly encountered during drilling operations. If this trend continues during the testing of the other identified zones, then this survey will have provided a preliminary delineation of the single largest discovery of sand and gravel in southwestern Ontario in recent years.

ACKNOWLEDGMENTS

The co-operation of numerous landowners is gratefully acknowledged, without whose permission to access their private properties our surveys would not have been possible. The author wishes to thank Bern Feenstra (Resident Geologist, Southwestern District, London) for his assistance and in particular the assistance of Kay Kennes (Assistant, Southwestern District Resident Geologist's Office, London). The Ministry of Transportation is thanked for the use of the auger-drill rig. Also, the drilling crew consisting of John Black, Ron Hill and Marie-Josee Charron. Joel Mejilla, Richard Weiner and Kelvin Antoniuk, capable assistants on the project, are thanked for their contributions.

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39. Project Unit 88-36. Detailed Structural Geology Investigations of Prince Edward County, Southern Ontario

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INTRODUCTION

Detailed mapping of the structural features in the southern part of Prince Edward County has been undertaken by the Ontario Geological Survey as its contribution to a multiyear program investigating neotectonics in eastern Canada. This research is being co-ordinated with the Multi-Agency Group for Neotectonics in Eastern Canada (MAGNEC). Other agencies involved in the MAGNEC projects in Ontario include: the Atomic Energy Control Board, the Geological Survey of Canada, the Ontario Centre for Remote Sensing and Ontario Hydro.

The Ontario Geological Survey's contribution to this research is centred on the field identification of geologic features which may indicate neotectonic movement; particularly features that can be clearly demonstrated to have occurred since deglaciation (approximately 12 000 years ago in the Prince Edward County area). In bedrock, these features include faults, stress relief features (pop-ups), domes and offset strata along adjacent bedding planes.

Activities in 1989 concentrated on the southern part of Athol and South Marysburgh townships, Prince Edward County (Figure 39.1). Located south of the town of Belleville, the study area encompasses approximately 100 km^2 and is bounded by the Lake Ontario shoreline, latitude 43°56′N, longitude 77°12′ and longitude 77°03′W. In addition to detailed field mapping, this years activities included side-scan sonar and offshore magnetic surveys of the lake bottom to the south of the study area, and detailed geophysical surveys over selected structural features within the study area. Field mapping was extended outside the detailed study area to provide a regional framework for the study. Activities outside the study area included the documentation of structures in the Picton and Mountainview quarries (UTM 329750E 4879750N and UTM 311500E 4882900N) and the examination of bedrock out-

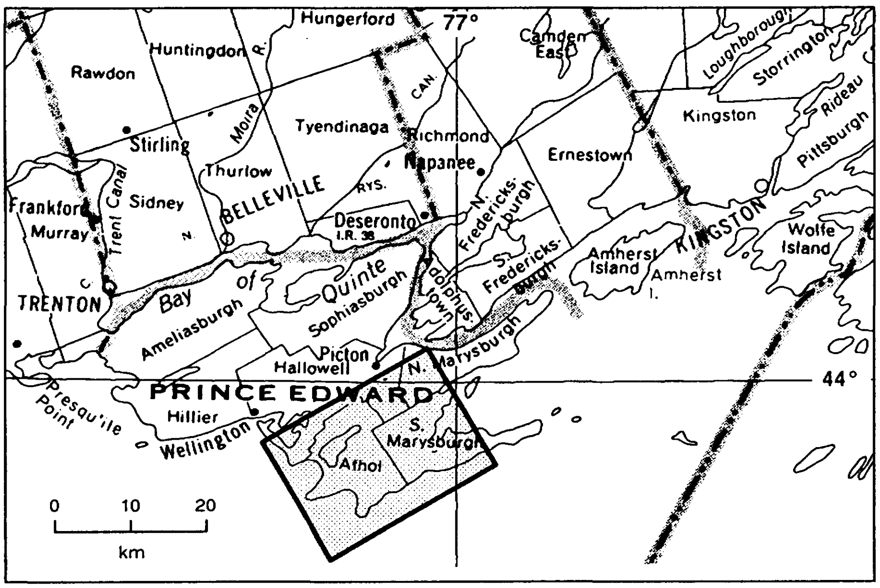

Figure 39.1. *Location map for Prince Edward County.*

crops along Long Point to the east of the study area. Resource assistance for this work was supplied by Ontario Hydro, McQuest Marine Research and Development Company Ltd., and the Great Lakes Division, Ontario Ministry of the Environment.

GENERAL GEOLOGY

Paleozoic strata exposed in the southern part of Prince Edward County are the Middle Ordovician Verulam and Lindsay formations. These overlie the Ordovician Bobcaygeon and Gull River formations (Simcoe Group), which in turn overlie Precambrian basement rocks (Grenville Province). At some locations a thin veneer of clastic material separates the Paleozoic from the Precambrian rocks. Total Paleozoic cover in the Belleville area amounts to approximately 210 m (Carson 1981) but is probably thicker in the study area due to its downdip location relative to Belleville. Regional mapping of the area by Carson (1981) suggests that the Paleozoic stratigraphy is relatively simple. Detailed mapping was subsequently undertaken in adjacent eastern Ontario, east of the Frontenac Axis (Williams et al. 1985) which extends northwest from Gananoque to Westport. This work included a redefinition of the Bobcaygeon–Gull River Formation contact and suggests that Carson's (1981) interpretation of the Paleozoic stratigraphy in the Belleville area requires further revision.

The Verulam Formation, as most recently defined by Williams et al. (1985), consists of an interbedded microcrystalline to coarse-crystalline limestone with up to 15 cm thick interbeds of dark grey calcareous shale. The Lindsay Formation, as recently redefined by Russell and Telford (1983), has two members. There is a lower unnamed member consisting of microcrystalline to coarse-crystalline fossiliferous limestone with undulating shaly partings, and an upper member termed the Collingwood Member which is a black to dark brown, calcareous, organic-rich shale and limestone unit. The Collingwood Member has not yet been identified within the study area.

GEOPHYSICAL SURVEYS

Side-scan sonar and offshore magnetic surveys were conducted by McQuest Marine Research and Development Company Ltd. Seismic refraction surveys within the study area were carried out by A. Allam.

SIDE-SCAN SONAR SURVEY

Observations of the lake bottom south of the study area were made using side-scan sonar equipment. Five traverses were made across the eastern arm of the Picton fault where it extends into Lake Ontario. Offshore, as on land, the fault occupies a broad, sediment infilled valley bounded by bedrock outcrops on either side. The presence of pop-ups in the offshore region was confirmed. Records from traverses approximately parallel to the southeast shoreline show two, possibly more, pop-ups that are collinear with those documented on land (McFall et al. 1988).

MAGNETIC SURVEYS

Magnetic surveys were conducted in conjunction with the side-scan sonar surveys. Very large magnetic anomalies were measured to the west-central area of the southern shoreline of the study area less than 1 km offshore of the Gull Bar (UTM 331900E 4858150N), and at several locations along Long Reach and Adolphus Reach.

SEISMIC REFRACTION SURVEYS

Many of the bedrock structural features scattered throughout the study area are partially or completely blanketed by Quaternary and Recent deposits making direct observation difficult. Several obscured structural features were examined using single channel refraction seismic surveys. These include a potential fault and an area of possible folding or doming of the strata.

The presence of a structure extending east-northeast from UTM 324250E 4859400N to UTM 327550E 4861300N is suggested by the collinearity of:

1. the southeastern shoreline of Salmon Point
2. the abrupt linear termination of the Soup Harbour swamp
3. a gentle 1.2 m change in elevation of the bedrock surface
4. a change in the general character of the eastern arm of the Picton Fault from swampy treed land to generally well-drained farm- and pastureland

The possible presence of a fault was tested with a perpendicular survey line along King's Crossroad at UTM 326900E 4860800N. The data from this survey is presently being processed prior to interpretation.

Semicircular structures suggestive of folds or domes are seen on 1:10 000 false-colour infrared aerial photographs covering an area of approximately 60 000 m^2 centred around UTM 335100E 4861750N. Transverse and longitudinal geophysical transects were conducted across the possible fold traces. The interpretation of this structure is pending final processing of the geophysical data collected by this survey.

FIELD MAPPING

The best exposures of the Paleozoic bedrock in the study area occur along the Lake Ontario shoreline. These exposures are naturally occurring and exhibit little disturbance from man's activities. A stereographic examination of aerial photographs of the shoreline regions of Prince Edward County was conducted by Creasy (1976) who identified a number of unusual structural features. In the present study, detailed mapping of the bedding attitudes, joints and fracture systems was carried out in order to evaluate the regional structural framework. Man-made exposures, such as abandoned pits or quarries, excavated cattle ponds, roadcuts, and bulldozer-cleared bedrock outcrops were also examined in detail. Several faults were observed in the cliff exposures along the north side of Long Point and the orientations, dips and sense of movement were documented. Most of the exposures are only accessible by boat. One exception to this is a normal fault that is well exposed on the beach at Point Traverse (UTM 350450E 4867250N). The fault strikes 120/80SW with the southwest block displaced downwards 40 cm relative to the footwall. The fault zone is weathered with no apparent infilling material. Slickensides are not common but where observed are near-vertical. Ductile deformation of the adjacent strata has occurred on both sides of the fault plane for a distance of about 20 cm.

A conjugate pair of low-angle reverse faults, striking 315/17NE and 144/19SW respectively, were observed where a prominent lineament observed on the aerial photographs intersects the cliff, about 3 km west of Point Traverse (UTM 347600E 4866800N). Slickensides perpendicular to the strike of the fault plane were observed in outcrop. It is difficult to determine the offset, as good marker horizons are rare. It was estimated, on the basis of apparently similar strata across the fault, that the displacement may be 2.25 m in the reverse direction. A conjugate fault was observed about 10 m to the east. It has the same strike but dips in the opposite direction. Unlike the normal faults described above, deformation of the adjacent bedding occurs within 30 to 40 m of the structure in the form of gentle warping of the otherwise flat-lying beds.

Strike-slip faults, which strike 273°, occur in two closely spaced and highly fractured zones near Point Traverse (UTM 3499000E 4867400N). The faults are marked by calcite veins and the strike-slip motion is suggested by a general lack of dip separation across the fault and the presence of horizontal slickensides on the fault surfaces. The faults are open and the infilling calcite is mostly euhedral, commonly with well-developed crystal terminations. This suggests that deposition of the calcite occurred after the strike-slip motion, perhaps during a later period of extension.

Previously it has been suggested (McFall et al. 1988) that not all of the open fractures observed in the study area were formed by dissolution alone and that some may have opened in response to changes in regional stress. The latter mechanism for producing open fractures is supported by the preserved slickenside surfaces and the presence of euhedral calcite within the openings of the strike-slip faults. Field observations also confirm the presence of mesoscopic scale faults in the southern part of Prince Edward County which includes the study area.

PICTON QUARRY

The Picton Quarry is located 4 km to the northeast of the town of Picton, in Sophiasburgh Township, Prince Edward County (UTM 329750E 4879750N). Owned and operated by the Lake Ontario Cement Company Ltd., the quarry extends 55 m into the bedrock exposing both the Lindsay and Verulam formations in cross section. The central part of the quarry is cut by a 40 m wide zone of very closely spaced fractures that includes faults, veins of calcite, and an ultramafic dike. To either side of this zone, the fractures are well developed but widely spaced. The fracture orientations are mostly in the 085/77S and 299/88NE directions. The ultramafic dike is up to 32 cm wide, intrudes a 125 cm wide zone of intensely fractured limestone, and strikes 090/76S. A large fault, which strikes 238/78NW, appears to transect the dike. Sub-horizontal slickensides on the fault surfaces suggest strike-slip movement but it is not known whether the dike or the fault is displaced as the area of intersection is not exposed.

Barnett et al. (1984) conducted paleomagnetic and K-Ar age-dating studies on the dike rock and concluded that intrusion occurred in the Jurassic (173 Ma) during which rejuvenated basement structures may have served as conduits for deep seated magmatism. They suggest that rejuvenation was probably a distal expression of continental rifting prior to the opening of the North Atlantic.

MOUNTAINVIEW QUARRY

The Mountainview Quarry is located 17 km to the northwest of the town of Picton, in Ameliasburgh Township, Prince Edward County (UTM 311500E 4882900N). Owned and operated by the H.J. McFarland Construction Company Ltd., the quarry exposes an 8 to 10 m vertical section of the Lindsay Formation. Fractures are widely spaced and generally not well developed in the quarry. A gentle concentric fold and a "kink-band", both formed by brittle deformation, were documented.

CONCLUSIONS

The presence of a variety of faults, some with evidence of two or possibly more periods of movement, and the observation of both ductile and brittle deformation suggests that the tectonic history of Prince Edward County is more complex than previously believed. The above observations indicate that periodic rejuvenation of structures probably occurred between the late Ordovician and the Jurassic. The presence of neotectonic features (McFall et al. 1988) suggests a more recent period of instability. Ongoing stress relief is indicated by the presence of earthquake activity related to some of the major structures which cut the eastern end of Lake Ontario and Prince Edward County. There is a potential for future movement as many of the observed structures have apparently not "healed".

The presence in southern Ontario of neotectonic features has important implications for the construction of major engineering structures. A clear understanding of these features, the stresses which formed them and how they will act in the future will permit a more accurate assessment of their behaviour than was available in the recent past.

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40. Project Unit 88-2. Paleozoic Geology of the Southern Bruce Peninsula

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INTRODUCTION

The Paleozoic strata exposed in the southern part of the Bruce Peninsula was mapped during the summer of 1989. This was the final year of a three-year geological mapping project covering the entire Bruce Peninsula. Results of previous field mapping seasons in the northern and central portions of the Bruce Peninsula are summarized respectively by Armstrong (1987) and Armstrong (1988), and preliminary geology maps for these areas are forthcoming. In addition to field mapping, a drilling program was conducted in the central and northern parts of the Bruce Peninsula during the spring of 1989. This report summarizes the preliminary findings of both the field and drilling investigations of 1989.

The objective of the Bruce Peninsula Paleozoic mapping project is to produce 1:50 000 scale geological maps of the peninsula, incorporating updated stratigraphic terminology, new outcrop exposures and new subsurface information. A lithostratigraphic approach was used to aid in the delineation and evaluation of potential resources such as building and crushed stone.

LOCATION

The 1989 map area (Figure 40.1) includes the southern Bruce Peninsula between latitudes 44°30'N and 44°45'N, and from the Lake Huron shore in the west to longitude 80°52'30"E, east of Owen Sound. This area is covered by 1:50 000 scale NTS map sheets of Wiarton (41A/11) and part of Owen Sound (41A/10). The map area can be accessed via highways 6, 10, 21 and 26, and is readily accessible by a network of public roads and by the Bruce Trail.

GENERAL GEOLOGY

The Paleozoic units exposed on the southern Bruce Peninsula are listed in the stratigraphic column in Figure 40.2. They range in age from the Upper Ordovician Georgian Bay Formation to the Upper Silurian Bass Island Formation. The stratigraphic nomenclature used in this study is modified after previous investigators in this area (Williams 1919; Caley 1945; Bolton 1953, 1957; Liberty 1966; Sanford 1969; Liberty and Bolton 1971) and includes consideration of more recent mapping by the Ontario Geological Survey in the adjacent geographic areas

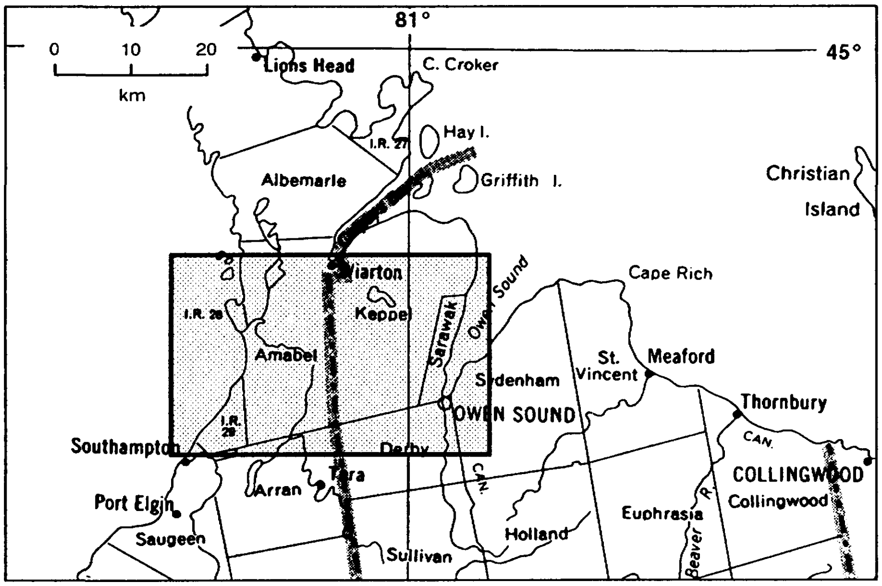

Figure 40.1 *Location map for the Southern Bruce Peninsula area.*

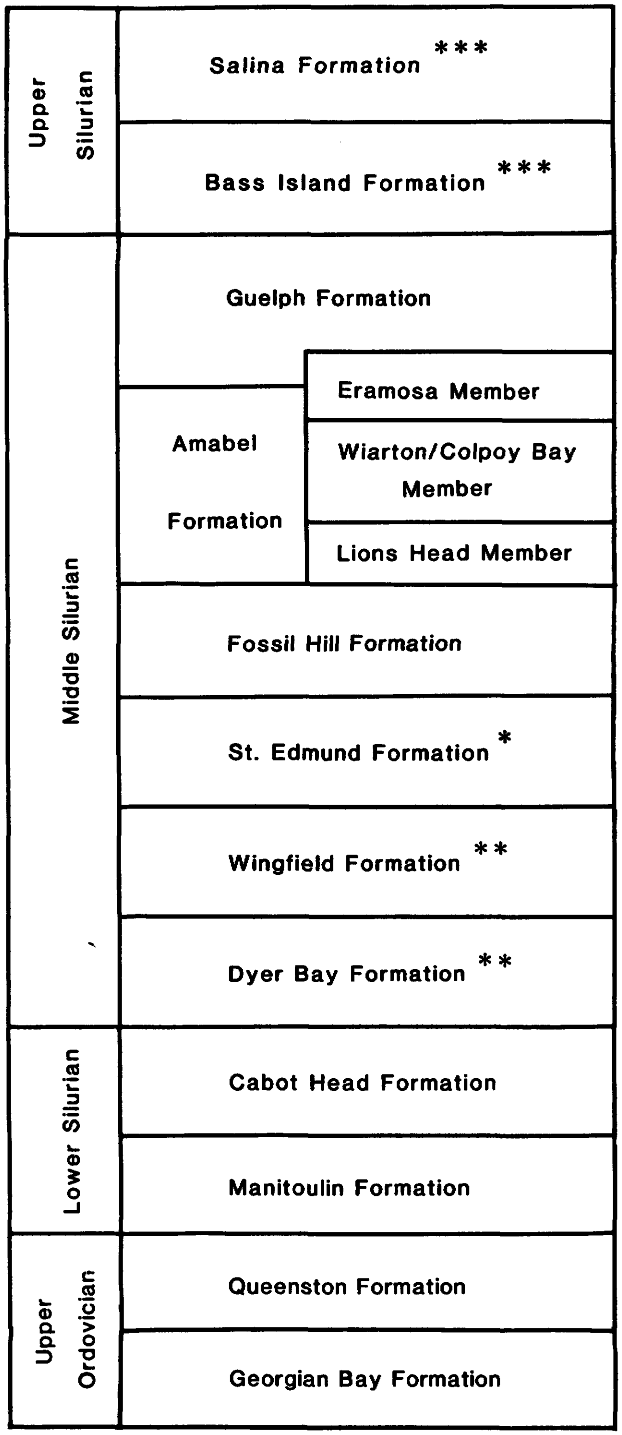

Figure 40.2 *Stratigraphic nomenclature of Paleozoic strata exposed on the southern Bruce Peninsula (modified after Bolton 1957; Sanford 1969; Liberty and Bolton 1971).*

Notes:

- * not present in the map area
- ** pinched out by south end of map area
- *** not exposed in the map area (subcrops beneath surficial sediments)

of Manitoulin Island (Johnson and Telford 1985) and the Collingwood area (Telford 1976). Revisions to the stratigraphic column (Figure 40.2) with respect to the nomenclature used by previous workers are discussed by Armstrong (1987).

The thick-bedded dolostones of the Amabel Formation form the white cliffs of the Niagara Escarpment along the eastern margin of the Bruce Peninsula. The units below the Amabel Formation, consisting of interbedded shales and carbonates, are exposed in a generally narrow outcrop belt beneath, and east of, the escarpment. Resistant limestone and dolostone beds and units in this lower sequence form subordinate escarpments beneath the main Niagara Escarpment. The dolostones of the Amabel and Guelph formations underlie a broad belt from the Niagara Escarpment west to the Lake Huron shore. The two uppermost formations listed in Figure 40.2, the Salina and Bass Island formations, are not actually exposed on the Bruce Peninsula; however, they have been interpreted by Liberty and Bolton (1971) to subcrop beneath Quaternary deposits in the southwestern part of the map area.

The Quaternary geology of the southern Bruce Peninsula has been investigated by Sharpe and Jamieson (1982) and Feenstra (1979). Quaternary deposits vary in thickness in the map area and are up to 60 m thick in the southwest part. The Arran drumlin field covers most of the central and southwestern parts of this map area. A sandy plain covers much of the western shore, where dunes have been developed, and extends inland from Sauble Beach to Hepworth. Glacial lake levels are indicated by bluffs cut into surficial sediments along the present western shore, and by raised cobble beaches which occur along the eastern shore.

1989 FIELD MAPPING

Each of the formations exposed in the southern Bruce Peninsula map area are described below in ascending stratigraphic order. This report highlights significant new finds and observations. Formation thicknesses, as exposed in this map area, are compared with those encountered in drill hole OGS-82-4, drilled by the Ontario Geological Survey in 1982, near Isaac Lake, approximately 6 km northwest of Wiarton (Johnson et al. 1985).

GEORGIAN BAY FORMATION

The Upper Ordovician Georgian Bay Formation, consisting of green shales with interbedded limestones, and calcareous siltstones, is poorly exposed along the western shore of Owen Sound. The most significant outcrop of this unit in the map area occurs on the southern shore of Gravelly Bay (UTM 507140E 4949500N). Here, thin grey-green bioclastic limestone beds are interbedded with ripple cross-laminated calcisiltites. Typical fossils include cephalopods, bryozoans, brachiopods and pelecypods.

The Georgian Bay Formation is approximately 100 m thick in drill hole OGS-82-4 (Johnson et al. 1985). The upper contact of the Georgian Bay Formation with the Queenston Formation is not exposed in the map area. This contact is commonly taken at the base of the lowest significant red shale bed.

QUEENSTON FORMATION

The Upper Ordovician Queenston Formation consists of green and red shale with subordinate interbeds of siltstone, limestone, and dolostone and is approximately 60 m thick in drill hole OGS-82-4 (Johnson et al. 1985). Approximately 10 m of green shale with limestone interbeds occurs in the middle of the formation in the southern half of the Bruce Peninsula (Johnson et al. 1985; Armstrong 1988). There appears to be very little lithologic difference between the green interval of the Queenston Formation and the Georgian Bay Formation, except that the Queenston shales (both red and green) in the map area tend to be more calcareous than those of the Georgian Bay Formation.

A concentration of limestone beds in the green shale interval of the Queenston Formation locally forms an escarpment. This is well exposed at Sutton Point (UTM 506450E 4946650N) and north of the map area at Big Bay (UTM 503060E 4960250N). These limestone beds may correlate with those exposed to the north on Cape Croker (Armstrong 1988).

The sharp upper contact of the Queenston Formation with the Manitoulin Formation is exposed on the northeastern side of Owen Sound (UTM 505650E 4936800N) and north of Owen Sound at the Indian Falls Conservation Area (UTM 503500E 4940800N).

MANITOULIN FORMATION

The Lower Silurian Manitoulin Formation, consisting of thin-bedded dolostone, calcareous dolostone, and minor limestone, is exposed at Owen Sound (UTM 505650E 4936800N, and UTM 503850E 4934700N), north of Owen Sound at the Indian Falls Conservation Area (UTM 503500E 4940800N), and in a relatively continuous escarpment along the western shore of Owen Sound, northward from the village of Hogg (UTM 505525E 4947500N). Scattered bedding plane outcrops of this formation are exposed on a 2 to 4 km wide plain between this escarpment and the main Niagara Escarpment to the west. In the map area, the maximum thickness of this formation in outcrop is approximately 10 m at the Indian Falls Conservation Area (UTM 503500E 4940800N) and in a roadcut (UTM 506900E 4952200N) 1.5 km east of Kemble. Its upper contact, however, is not exposed. In drill hole OGS-82-4 the Manitoulin Formation is 12.5 m thick (Johnson et al. 1985).

Lithologically, the Manitoulin Formation in this map area differs only slightly from its exposures in the central Bruce Peninsula (*see* Armstrong 1988). The main difference is that low-angle cross-stratified beds in the middle of the formation, which occur in the central part of the Bruce Peninsula, are thinner and less significant in this map area.

The lowest 1 to 2 m of the Manitoulin Formation are more bioturbated, argillaceous, and calcareous than the upper part. The basal 1 m is locally an argillaceous limestone. The upper few metres tend to contain more chert and silicified fossils, sometimes in bioclastic lag beds. Hardgrounds (early-cemented surfaces) are visible in the upper beds of this formation in a roadcut at Owen Sound (UTM 503850E 4934700N).

CABOT HEAD, DYER BAY AND WINGFIELD FORMATIONS

The Lower Silurian Cabot Head Formation, and Middle Silurian Dyer Bay and Wingfield formations are respectively shale, dolostone, and shale-dominated units. Approximately 1.7 km north of this map area (UTM 504000E 4956700N), along the road south of Big Bay, these formations are exposed, with the overlying Fossil Hill and Amabel Formation (Lions Head Member), in a series of disconnected outcrops. The Wingfield and Dyer Bay formations pinch out to the south as they are progressively cut by a regional unconformity at the base of the overlying Fossil Hill Formation. Near the southern boundary of this map area, in the roadcut (UTM 504870E 4930500N) beside the Inglis Falls Conservation Area, both of these units were completely eroded and the Fossil Hill Formation directly overlies the Cabot Head Formation.

The Cabot Head Formation, consisting mostly of red and green shales, is poorly exposed in the map area. This formation is approximately 25 m thick in drill hole OGS-82-4 (Johnson et al. 1985). The upper contact of this formation with the Dyer Bay Formation is best exposed 2.6 km north of this map area in Gleason Brook (UTM 492720E 4956650N) at Oxenden.

The Dyer Bay Formation, consisting of thin-bedded, grey, sparsely to moderately fossiliferous dolostones and argillaceous dolostones, is not well exposed in the map area. The formation is approximately 5 m thick in drill hole OGS-82-4 (Johnson et al. 1985). Just 2.6 km north of the map area, almost the entire Dyer Bay interval (approximately 4 m thick) is exposed in Gleason Brook (UTM 492720E 4956650N) at Oxenden. In the map area, this formation is best exposed in two outcrops north of Owen Sound (UTM 502500E 4941750N, and UTM 502350E 4937280N), where it is unconformably overlain by the Fossil Hill Formation. Although dominantly bioturbated, this formation also exhibits horizontal and low-angle cross-stratified beds and soft-sediment deformation structures.

The Wingfield Formation, consisting of interbedded green shale and ripple cross-stratified grey to grey-brown, thinbedded dolostone, is approximately 5 m thick in drill hole OGS-82-4 (Johnson et al. 1985). The shaly interbeds cause this unit to weather recessively and result in poor exposures. It is not exposed in the map area. However, in an outcrop 1.7 km north of the map area (UTM 504000E 4956700N), on the hill south of Big Bay, it is partially exposed between overlying and underlying units which restrict its thickness to less than 2 m. It is not present in the southern half of the map area due to its erosion prior to Fossil Hill Formation deposition.

FOSSIL HILL FORMATION

The Middle Silurian Fossil Hill Formation is exposed at a number of localities in the map area where it locally forms a subordinate escarpment beneath the main Niagara Escarpment. This formation consists of fossiliferous (brachiopods, various corals and stromatoporoids) thin- to medium-bedded dolostone. In the map area it is less than 4 m thick, its approximate thickness in drill hole OGS-82-4 (Johnson et al. 1985). The Fossil Hill Formation thins to the south and is only 1.7 m thick at the Inglis Falls roadcut (UTM 504870E 4930500N). This thinning is presumably due to its unconformable upper contact with the Amabel Formation.

AMABEL FORMATION

The Middle Silurian Amabel Formation, an entirely dolostone unit, has been subdivided by previous workers (Liberty and Bolton 1971) on the Bruce Peninsula into three members (*see* Figure 40.2). Recent investigations (Armstrong 1987; Armstrong and Meadows 1988; Armstrong 1988) indicate that the uppermost of these, the Eramosa Member, should be re-assigned to the overlying Guelph Formation. This uncertainty in its stratigraphic placement is indicated in Figure 40.2 and the Eramosa Member is discussed as a separate unit below.

Excluding the Eramosa Member, the Amabel Formation consists of three lithofacies which make up two members, the Lions Head and the Wiarton/Colpoy Bay members. In drill hole OGS-82-4, these two members constitute approximately 25 m in thickness (Johnson et al. 1985). The three lithofacies, denoted A, B and C, are described by Armstrong (1988).

The Lions Head Member ranges from 3 to 5 m in thickness in this map area. Although its lower contact is sharp, it is only clearly exposed as unconformable in the southern part of the map area, at the Inglis Falls roadcut (UTM 504870E 4930500N) and in a roadcut 1 km to the north (UTM 504225E 4931400N). The Lions Head Member typically consists of thin-bedded, fine-crystalline, non-biohermal lithofacies A dolostone. However, in this map area, small (1 m thick by 2 m wide) bioherms occur locally in the middle to upper part of this member. The best exposure of the Lions Head Member bioherms is in a roadcut (UTM 505350E 4954400N) 2.2 km north of Kemble. The upper contact of the Lions Head Member with the Wiarton/Colpoy Bay Member is gradational and these two units appear to be in part lateral equivalents.

The Wiarton/Colpoy Bay Member of the Amabel Formation consists of two lithofacies, B and C (Armstrong 1988), which are both typically thick- to massive-bedded dolostones. Lithofacies C is fossiliferous and biostromal or biohermal and tends to occur in more lensoidal or irregular bedding than the non-biohermal lithofacies B. Lithofacies C tends to occur in the upper part of the Wiarton/Colpoy Bay Member and is locally difficult to distinguish from lower Guelph Formation bioherms.

There are a number of relatively accessible exposures of the Amabel Formation in this map area, most of which typically expose the upper Lions Head Member to middle Wiarton/Colpoy Bay Member interval. The most notable outcrops are at Inglis Falls Conservation Area (UTM 505150E 4930200N), and in roadcuts at Springmount (UTM 501125E 4933650N), on the northeast side of Pottawatomi Conservation Area (UTM 501760E 49350050N), 2.2 km north of Kemble (UTM 505350E 4954400N), and just east of the map area 0.6 km east of Bothwell's Corner (UTM 510250E 4936050N).

ERAMOSA MEMBER

Armstrong and Meadows (1988) and Armstrong (1988) identified four constituent lithofacies and four subunits within the Eramosa Member in the outcrops and quarries in the Oliphant Road area northwest of Wiarton. Essentially, the Eramosa Member consists of thin-bedded, fine-crystalline, bituminous dolostone. Beds within the Eramosa Member may also be laminated, biostromal, or consist of limestone.

The stratigraphy of the Eramosa Member composite section (approximately 15 m thick) in the Oliphant Road area (*see* Armstrong and Meadows 1988) appears to be continuous into the northern part of the map area to at least as far southeast as Mountain and Francis lakes. Similar Eramosa Member stratigraphy is also exposed in scattered outcrops in the central part of the map area, from west of Hepworth, south to Park Head, and southeast to Shallow Lake and Cruickshank. An east-west zone of Guelph Formation biohermal lithofacies trending from Sauble Falls to south of Clavering and Mountain Lake appears to separate these two areas.

The Guelph Formation biohermal lithofacies is interpreted to be in part equivalent with, and in part overlying, Eramosa Member strata. In the map area, this relationship is exposed in a creek (UTM 483250E 4945350N) 3.8 km southeast of Sauble

Falls, and on the ridge (UTM 498325E 4947850N) between Mountain and Francis lakes.

In the central part of the map area, near Hepworth, Park Head and Shallow Lake, much of the Eramosa Member interval is limestone instead of dolostone. The best exposures of the Eramosa Member limestone are in the Sauble River (UTM 485300E 4942150N) 4 km west of Hepworth and beside Shallow Lake (UTM 491700E 4937925N) 2.5 km east of Park Head.

Thin-bedded slightly bituminous dolostone exposed in the North Spey River (UTM 506800E 4927750N), 2.1 km south of Rockford, near the southern boundary of the map area, is probably assignable to the Eramosa Member. No exposures of the laminated Eramosa lithofacies were found south of the Owen Sound Ledgerock Quarry at Cruickshank. This may be due to the thicker drift cover in the southern part of the map area.

GUELPH FORMATION

The Middle Silurian Guelph Formation is the highest stratigraphic unit exposed on the Bruce Peninsula. Previously, it has not been subdivided into formal members on the Peninsula, however, three main lithofacies, denoted A, B and C, were identified and described by Armstrong (1988).

In the southern Bruce Peninsula map area, the biohermal lithofacies (lithofacies C) occurs in two zones. The first, and stratigraphically lowest of these zones (it may in part be upper Amabel Formation), occurs south and east of Cruickshank and south and west of Owen Sound. The roadcut on highways 6 and 10 at Rockford (UTM 506500E 4929800N) is a good example of these lower bioherms, with an abundant, varied, and very well preserved fauna. The second biohermal zone trends from the western shore of the Bruce Peninsula south of Oliphant to Sauble Falls and southeast of Boat Lake to south of Clavering and Mountain Lake. Excellent, very fossiliferous bedding plane exposures occur on Lonely Island (UTM 477280E 4951200N) just south of Oliphant. There is no discernable preferred primary orientation of bioherms in either zone.

Non-biohermal lithofacies A is apparently the stratigraphically highest Guelph Formation strata exposed in the map area. It is sucrosic, light tan-grey, tabular bedded, with strata-bound moldic porosity. Although some of this porosity is fossil-moldic, much appears to be small burrows.

The upper contact of the Guelph Formation with the Upper Silurian Salina Formation is covered by overburden, so the total thickness of the Guelph Formation is unknown in this map area.

SALINA AND BASS ISLAND FORMATIONS

The Upper Silurian Salina and Bass Island formations are not exposed in the map area and have been interpreted (Liberty and Bolton 1971) to subcrop beneath the thick Quaternary deposits in the southwestern corner of the map area. The Salina Formation in this area is described by Liberty and Bolton (1971) as consisting of interbedded grey dolostone, green shale, brown dolostone, and red shale. They describe the Bass Island Formation as consisting of brown fine-crystalline dolostone.

1989 DRILLING PROGRAM

During the spring of 1989, three holes were drilled in the northern and central Bruce Peninsula areas. The objectives of this drilling program were to: 1) obtain unweathered samples of the Guelph Formation for aggregate testing; and 2) to investigate the relationship between the Guelph and Amabel formations. Each drill hole was located as far west as possible in order to maximize the intersected stratigraphy. The base of the Fossil Hill Formation was selected as target depth to provide a datum.

The three drill holes, denoted OGS-89-1, OGS-89-2, and OGS-89-3, are respectively located just north of Pike Bay (UTM 474170E 4969990N), at Pine Tree Harbour (UTM 461500E 4991850N) 4.3 km southwest of Miller Lake, and at the St. Edmunds Township Landfill (UTM 448680E 5007010N) approximately 4 km south of Tobermory. Their total drilled depths are 79.9 m, 106.7 m, and 122.56 m, respectively. Downhole geophysical logs were obtained for OGS-89-2 and OGS-89-3.

Preliminary lithologic logging results document the southward pinch-out of the St. Edmund Formation, the variable faunal content and thickness of the Fossil Hill Formation, the virtual disappearance of the Wiarton/Colpoy Bay Member in OGS-89-3, and the change in character of the Eramosa Member.

ECONOMIC GEOLOGY

Quarrying has been an important part of the Bruce Peninsula economy since the turn of the century. A number of dolostone units, including the Manitoulin, Amabel and Guelph formations, have been quarried for building stone, aggregate and lime.

Currently, the Manitoulin Formation is quarried for aggregate at E.C. King's Sarawak Quarry (UTM 504700E 4949150N) approximately 13 km north of Owen Sound. The Wiarton/Colpoy Bay Member of the Amabel Formation is quarried for crushed stone at the new Sutherland Quarry (UTM 500750E 4947500N) 7 km northwest of Owen Sound and at E.C. King's Sydenham Quarry (UTM 511100E 4934700N) just east of the map area. The Eramosa Member is quarried for building stone in the southern part of the Bruce Peninsula at the McCartney Quarry (UTM 492150E 4949600N) 5 km southeast of Wiarton and at the Owen Sound Ledgerock Quarry (UTM 496550E 4937150N) 0.5 km southwest of Cruickshank.

The Guelph Formation was quarried in this map area presumably for building stone in two small inactive quarries, 2.3 north of Allenford (UTM 487375E 4933800N) and on the northeast side of Alvanley (UTM 490400E 4931700N). Although the Guelph Formation is quarried in southern Ontario for lime and construction aggregate, it remains an untested potential resource on the Bruce Peninsula.

The only sphalerite occurrence found in the map area is as fracture- and pore-fillings in coral-rich beds immediately above Eramosa Member strata 5.5 km southeast of Wiarton (UTM 493200E 4949800N).

The only producing oil or gas field on the Bruce Peninsula was the now abandoned natural gas field at Hepworth. This field produced gas from the Ordovician Simcoe Group (Liberty and Bolton 1971) from 1901 to approximately 1935 (Bailey Geological Services and Cochrane 1984).

STRUCTURAL GEOLOGY AND KARST

Joints are well developed on the Bruce Peninsula, especially in the dolostone units. Joints can be grouped into four main orientations which are, in order of significance, 70° to 80°, 150° to 160°, 90° to 100°, and 350° to 10°. In grass-covered fields with less than 1 m of overburden, joint patterns are visible as greener grass stripes. This is presumably due to water retention in the joints during dry spells.

The joint openings are commonly dissolution enhanced up to 20 cm wide. The widest and deepest (3 m or more) solution enhanced joints occur on the east side of the peninsula on the top of the Niagara Escarpment. Karst features on the Bruce Peninsula, such as dissolution enhanced joints, were the subject of an investigation by Cowell (1976) and subsequent publication by Cowell and Ford (1980).

A pop-up in thin-bedded dolostones of the Lions Head Member was discovered just north of the map area, 1.4 km east of Lake Charles (UTM 500350E 4956050N). The pop-up, which outcrops on either side of a road, is approximately 1 m high, trends approximately 140°, and is up to 600 long.

ACKNOWLEDGMENTS

The author greatly appreciated the assistance of Alexis Anastas during the field season. The author would like to thank the Chippewas of Saugeen Band for permission to enter the Chief's Point and Saugeen Indian Reserves (Indian Reserves 28 and 29). The author also appreciates the continued assistance of the various quarry operators on the Bruce Peninsula and especially those who granted permission to visit the quarries in this year's map area: the McCartney Quarry, Owen Sound Ledgerock Quarry, Sutherland Quarry, and E.C. King's Sarawak and Sydenham quarries.

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41. Project Unit 87-56. Building Stone in the Algonquin Resident Geologist's District

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INTRODUCTION

This report describes field work conducted in 1989, the final year of a four-year program to evaluate the industrial minerals and building-stone potential of the Algonquin Resident Geologist's District. In the first three years of this program, field work has concentrated on the evaluation of:

1. calcitic marble as a filler material, for metallurgical applications, as a neutralizing agent, and as agricultural lime (Marmont 1988a)
2. anorthosites and pegmatites as sources of feldspar for the glass, ceramics, filler, and abrasives industries (Marmont 1988b)
3. gneisses (multicoloured, patterned, or "veined" granites) as potential dimensional stones (Ministry of Northern Development and Mines 1989)

Field work in 1989 has focussed almost exclusively on building stone. The study area encompasses that served by the Dorset Resident Geologist's Office, which extends from Georgian Bay, in the west, to the Ottawa River, in the east, and from the French River and Lake Nipissing, in the north, to Bala and Pembroke in the south. This area—the Algonquin District—is underlain by gneisses of high-metamorphic grade and appears to have the potential to supply mill blocks of attractive, multicoloured granites as well as thinly splitting, gneissic flagstones.

PREVIOUS WORK

Other workers who have described building stones in the Algonquin District include Parks (1912), Goudge (1938), Satterly (1943), Hewitt (1964a, 1964b, 1967), Martin (1983), Verschuren et al. (1986), and Fouts and Marmont (in press).

The Algonquin District is best known for its flagstone, most of which is produced "on demand" from small quarries. This flagstone is extensively used as interior and exterior wall veneer, for fireplace surrounds, and for patios and walkways. The best known quarry is the Mill Lake Stone Quarry, at Parry Sound, which has been in operation for many decades. Flagstone in the Algonquin District was most recently studied by Fouts and Meadows in 1987 (Fouts and Marmont, in press); that study formed the basis for the field work on flagstone resources reported here.

Many of the gneisses are massive, rather than thin splitting, and are potential sources of architectural stone, suitable for monuments and for sawing into thin panels and tiles for cladding modern buildings. For this use, it is essential that large mill blocks (15 to 25 t) can be quarried. Patterned gneisses or "multicoloured granites", notably from India and Brazil but also from Sweden, South Africa, and Minnesota, have become increasingly popular over the last few years. The National Art Gallery in Ottawa makes excellent and extensive use of such a gneiss from Tadoussac, Quebec, attesting to the merits of patterned granite. There are no current producers of architectural stone in the Algonquin District, although the existence of a past producer in Sundridge has recently come to light (*see* below).

CURRENT PROGRAM

1989 FIELD WORK

During the 1989 field season, the building-stone study comprised three components.

1. Reconnaissance

Areas of the Algonquin District not previously reconnoitred were traversed. These include terrain north, east, and southeast of Algonquin Provincial Park. At the time of writing, reconnaissance was continuing in the southern and southwestern parts of the Algonquin District. The survey involves the examination of roadside and readily accessible, prominent outcrops primarily to ascertain the density of joints and fractures (a low density is essential for a prospective architectural stone). Sites suitable for flagstone extraction were also investigated.

At the time of writing, no new sites had been identified which would be suitable for architectural stone, because most outcrops are too heavily jointed. The identification of broad areas with flagstone potential, related to major ductile shear zones (Fouts and Marmont, in press), appears to be valid.

CANADA ONTARIO Mineral Development Exploration Minérale

This project A.2.4 is part of the five-year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

2. Detailed Studies

Some areas of extensive outcrop containing attractive rock types with moderate joint density had been identified during previous work (Verschuren et al. 1986; Ministry of Northern Development and Mines 1989). These areas were traversed in detail in an attempt to identify specific outcrops with low joint density. One site near Powassan and two near Killbear Point Provincial Park (Ministry of Northern Development and Mines 1989) appear to warrant investigation as prospective sites for architectural stone.

The existence of a former dimensional stone quarry in Sundridge has recently come to light. This quarry is currently owned by Ross McBride of Sundridge, who reports that it was owned and operated by Angus Buchanan in the early 1920s. The remnants can be seen of a horse-powered winch which was used with a derrick to move mill blocks. The stone was used as setts for the Yonge Street streetcar tracks in Toronto. When these were removed, the stone was recovered and used for walkways at the McMichael Canadian Art Collection in Kleinburg, and at many other locations in Metropolitan Toronto and elsewhere. The quarry is located on the east side of a small hill in the southern portion of the Powassan Batholithic Complex. The granite is pink, with rods of biotitic material (an L-tectonite). It is medium grained, and has a sugary texture. Angus Buchanan's tombstone in the Sundridge Cemetery is made of a polished slab of this granite, which reveals a cataclastic texture with rounded feldspar crystals up to one centimetre in diameter. The granite has the important quality of being readily split into rectangular blocks.

3. Quarry Visits

Martin (1983) lists several dozen sites in the Algonquin District from which stone has been quarried. Some of these were investigated by Fouts and Meadows (Fouts and Marmont, in press). Most are small quarries that supplied local houses with flagstone or ashlar. Some are wayside quarries, opened to supply crushed aggregate for highway construction. There appears to be a potential to extract considerable tonnages of flagstone, veneer, landscaping stone and, possibly, dimensional and architectural stone from some of these sites.

ONGOING WORK

Field work was continuing at the time of writing. The extraction of small blocks from three or four of the most prospective sites is planned, to be sawed and polished into 12 inch tiles. Compilation of the results of the four-year program will be undertaken during the winter, in preparation for publication in 1990.

CONCLUSIONS AND RECOMMENDATIONS

Several sites have been identified which appear to have potential as sources of architectural stone. The stone is attractive and distinctive, and the outcrops contain joint spacings in excess of two metres, which should permit the extraction of a reasonable proportion of 20 t blocks. These sites warrant evaluation by experienced quarry operators. As well, many sites would permit extraction of 5 to 15 t blocks, which might be of use to certain operators with smaller equipment and specific needs.

The potential for increased flagstone quarrying has been discussed by Fouts and Marmont (in press). There are several small or inactive quarries which could be developed more fully and serve the lucrative Toronto and southern Ontario markets. This would also require astute advertising and marketing strategies, and reliable supply and distribution. Distribution would be simplified by the ready accessibility of most parts of the Algonquin District and the presence of good transportation routes to southern Ontario.

ACKNOWLEDGMENTS

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Geophysics/Geochemistry Programs

42. Summary of Activities 1989, Geophysics/Geochemistry Section

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INTRODUCTION

During the 1989 field season, the Geophysics/Geochemistry Section undertook nine projects; one compilation project, one research project and seven regional mapping projects. These projects were distributed throughout northern and southern Ontario and involved geophysical and geochemical mapping, and research studies of both bedrock and Quaternary materials.

GEOPHYSICS PROGRAM

Five airborne electromagnetic-magnetic surveys, covering areas of high mineral potential, were initiated for completion in 1989 (*see* Paper 43, this volume). A total of approximately 78 000 line-kilometres were surveyed in the Sturgeon Lake–Savant Lake, North Swayze–Montcalm, Shining Tree, Batchawana and Rainy River areas. The results of two AEM surveys were released in June 1989. The Tashota–Geraldton–Longlac area consisted of 90 maps (81 259 to 81 348) while the Detour–Burntbush–Abitibi area was covered by 88 maps (81 171 to 81 258).

An overburden sounding research program began during the summer season to investigate current methods and potential improvements for imaging the subsurface overburden stratigraphy in various areas of southern Ontario (*see* Paper 44, this volume). An improvement in methods would be a valuable asset for projects requiring a detailed cross section of overburden materials. Projects involving subsurface construction engineering, environmental engineering and groundwater investigations currently rely on drilling technology for almost all data collected. Supplementary techniques such as shallow seismic reflection and electromagnetic sounding are being tested in a variety of Quaternary stratigraphic sequences as a first stage. A case history study on groundwater exploration is also currently under way.

A project has been initiated to create a single continuous Master Aeromagnetic Grid for the province of Ontario (*see* Paper 45, this volume). The digital aeromagnetic data set in non-gridded form, from 41 surveys, has been provided by the Geological Survey of Canada (GSC) which is also participating in this project. The entire data set will be levelled using an 812.2 m reference grid. A grid cell size of 200 m will be generated using the minimum curvature algorithm. A data base containing all the levelled aeromagnetic data in a flight line archive format will also be generated for users. From this newly created data base, colour total field magnetic maps, enhanced, processed derivative maps and shaded relief maps will be produced as a contribution to the Geology of Ontario volume which is to be published by the Ontario Geological Survey.

GEOCHEMISTRY PROGRAM

During June 1989, a small-scale regional geochemical survey based on lake sediments and waters was completed in a 500 km^2 area in the vicinity of Murray Lake situated 65 km northeast of Wawa, Ontario (*see* Paper 46, this volume). The purpose of regional geochemical surveys of this type is to provide verified geochemical information which is of direct importance in mineral exploration. The Murray Lake area is of particular interest at this time because it lies to the east of the Goudreau Lake area in which new gold deposits are currently being developed. Like the Goudreau Lake and Magpie River geochemical surveys which were completed in 1987 and 1988, the Murray River survey represents a portion of the regional geochemical coverage of the entire Wawa greenstone belt.

During August and September 1989, lake sediment and water sampling (905 samples) required for a regional geochemical survey of a portion of the Batchawana greenstone belt was completed in the 730 km^2 Hanes Lake Area (*see* Paper 47, this volume). This represents the third phase of a three-year project carried out as part of the Canada–Ontario 1985 Mineral Development Agreement (COMDA). The aim of this project is to provide a regional geochemical map of the entire Batchawana greenstone belt using a standardized methodology. When completed, this geochemical data base will be suitable for image processing of geochemical patterns.

43. Project Units 89-48 to 52. Recent Airborne Electromagnetic-Magnetic Surveys in Northern Ontario

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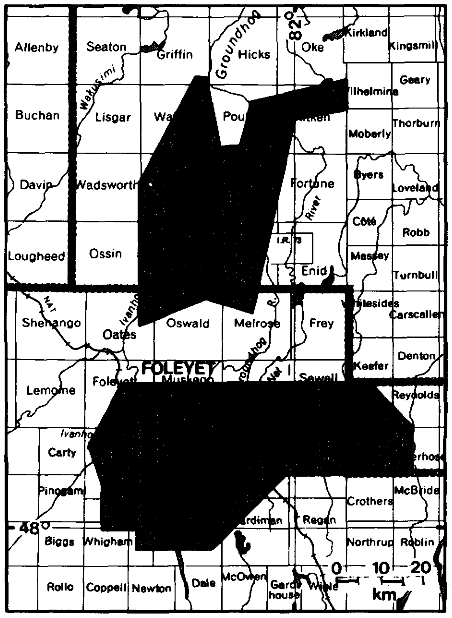
INTRODUCTION

The field survey portions of five Airborne surveys were completed during 1989. In all, approximately 77 765 line-kilometres of electromagnetic and magnetic survey data were acquired during the year. The results of these surveys, which were carried out over five areas (North Swayze–Montcalm, Figure 43.1A; Shining Tree, Figure 43.1B; Rainy River, Figure 43.1C; Sturgeon Lake–Savant Lake, Figure 43.1D; and Batchawana, Figure 43.1E), will be released in the summer of 1990.

To date, approximately 132 500 line-kilometres of data have been acquired, compiled, and released under the Airborne Geophysics Survey Program over four areas of Northern Ontario: Timmins, Wawa, Detour–Burntbush–Abitibi and Tashota–Geraldton–Longlac (Ontario Geological Survey 1988a, 1988b, 1989a, 1989b). The airborne survey program is being financed through the Northern Development Fund and managed by the Ontario Geological Survey.



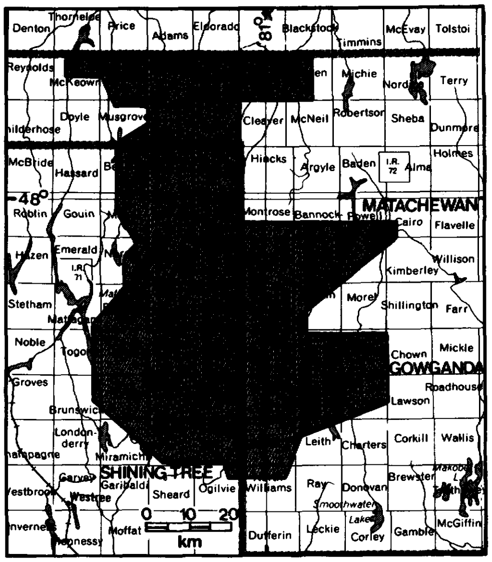
LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

Figure 43.1A. *Location map for the North Swayze–Montcalm AEM survey.*

This project is part of the five-year 1987 Airborne Geophysical Survey Program for Northern Ontario which is funded by the Northern Development Fund.

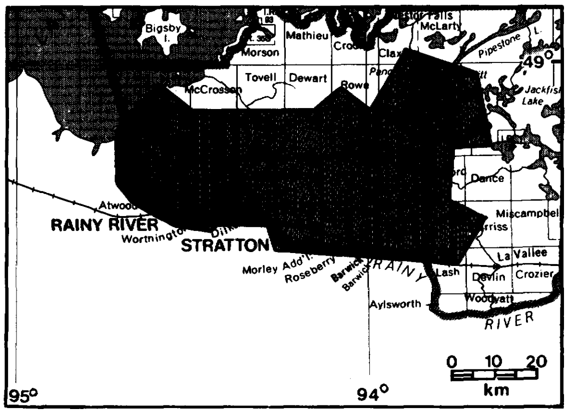
SURVEY INSTRUMENTATION

The GEOTEM® system, owned and operated by Geoterrex Limited of Ottawa, was used to acquire the electromagnetic data over the North Swayze–



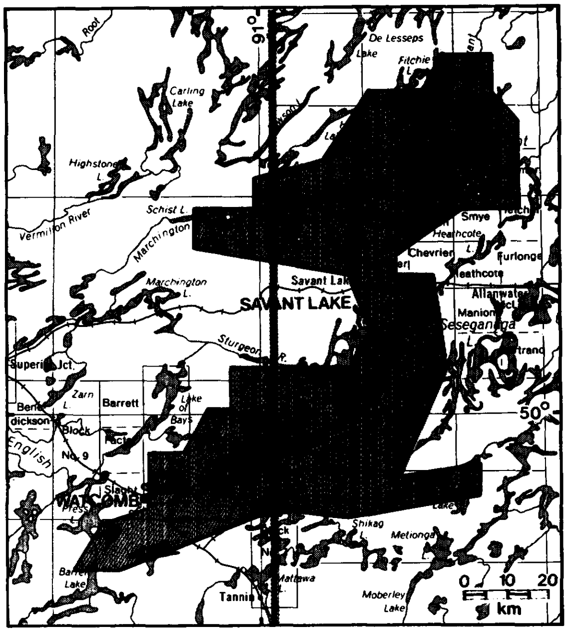
LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

Figure 43.1B. *Location map for the Shining Tree AEM survey.*



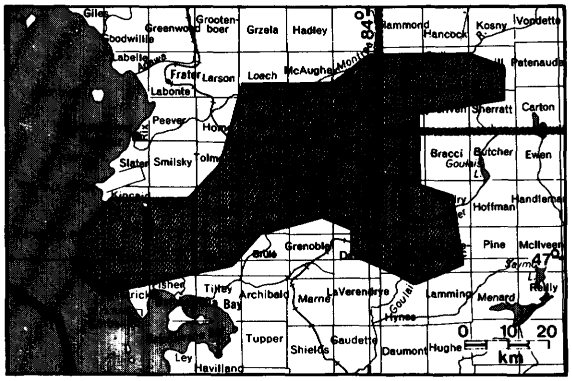
LOCATION MAP Scale: 1:1 584 000 or 1 inch to 25 miles

Figure 43.1C. *Location map for the Rainy River AEM survey.*



LOCATION MAP Scale: 1:1 584 000
or 1 inch to 25 miles

Figure 43.1D. *Location map for the Sturgeon Lake–Savant Lake AEM survey.*



LOCATION MAP Scale: 1:1 584 000
or 1 inch to 25 miles

Figure 43.1E. *Location map for the Batchawana AEM survey.*

Montcalm, Shining Tree and Rainy River areas. The survey platform was a CASA C212-200, twin turboprop short takeoff and landing (STOL) aircraft having a six-strand, three-turn, horizontal transmitter loop installed around the extremities of the plane and a sensor mounted in a towed bird. A Scintrex single-cell, split-beam, cesium vapor magnetometer was mounted in a stinger on the tail of the aircraft. Instrument configuration within the craft consisted of the digital receiver and transmitter circuits, a microprocessor and tape drive for data storage, as well as the magnetometer console and positioning equipment.

The primary electromagnetic field about the aircraft is created by a series of discontinuous sinusoidal (half sine) current pulses which are fed through a three-turn loop. The duty cycle is composed of 1050 μs of "on time" followed by 2280 μs of "off time" which is utilized to sample the resulting transient produced by the ground response which is induced by the time-varying primary field. During the "on time", the peak current through the loop is 600 A resulting in a dipole moment of 4.5×10^5 Am^2. The receiver sensor coil is mounted vertically, with the axis in the direction of flight, in a bird which is suspended on a 135 m cable approximately 40 m above the ground when the aircraft survey altitude is 120 m.

The transient resulting from the ground response is sampled six times a second over twelve gates whose centres and gate widths can be software selected over the entire range of "off time". Postflight processing normally reduced the noise level to about a 20 ppm envelope. The effective exploration depth as established at the Night Hawk test range is approximately 300 m.

The AERODAT system, owned and operated by Aerodat Limited, was used to acquire electromagnetic and magnetic data over the Sturgeon Lake–Savant Lake and Batchawana areas. The survey platform consisted of an Aerospatiale AS 350D helicopter. Both the transmitter and receiver coils are mounted in a tubular bird which is towed below the helicopter, approximately 30 m above the ground. A Scintrex single-cell, split-beam, cesium vapor magnetometer was towed below the helicopter and above the EM bird approximately 40 m above the ground. Each Tx-Rx coil pair is separated by a 7 m distance. The coil orientations consist of two coaxial (horizontal dipole) and two coplanar (vertical dipole) coil-pairs operating at 935 and 4600 Hz and 4175 and 33 000 Hz, respectively.

Inphase and quadrature responses are measured with a resolution of better than 0.1 ppm with an electronic time constant of 0.1 second and sampling rate of 10 readings per second. The moment of the coaxial transmitters is about 130 Am^2 and the 4175 and 33 000 Hz coplanar transmitters are 50 Am^2 and 20 Am^2, respectively. The noise level, excluding spherics, is less than 1 ppm under normal survey conditions. The instrument configuration within the helicopter consists of receiver and transmitter consoles, a digital data acquisition system, magnetometer console, and various positioning equipment.

The primary electromagnetic field about the bird is created by a continuous sinusoidal waveform, and the secondary field is measured in the presence of the primary field by a phase component measuring system. The intensities of the inphase and quadrature components of the secondary field are measured continuously during flight at pre-described frequencies and coil orientations and are given as fractions of the primary field strength. The effective exploration depth as established at the Night Hawk test range is approximately 150 m.

RESULTS

The maps are prepared with a photomosaic base at a scale of 1:20 000 using Ontario Ministry of Natural Resources 1:15 840 and 1:20 000 scale aerial photography. The photos were laid down using a Universal Transverse Mecator projection format constructed from scaling down 1:50 000 topographic maps.

The flight lines, anomalies, and magnetic contours were superimposed on this base and appropriate legend information was attached. Digital profiles of every flight line were constructed with standard presentation schemes and microfilmed for permanent storage.

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——1988b. Airborne electromagnetic and total intensity magnetic survey, Wawa area, Districts of Algoma, Sudbury and Thunder Bay; Ontario Geological Survey, Maps 81 003 to 81 034, scale 1:20 000.

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——1989b. Airborne electromagnetic and total intensity magnetic survey, Tashota-Geraldton-Longlac area, District of Thunder Bay; Ontario Geological Survey, Maps 81 259 to 81 348, scale 1:20 000.

44. Overburden Sounding Research—Groundwater Studies

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INTRODUCTION

An overburden sounding research program was initiated during the summer field season and continued into the fall of 1989, with the intention of developing improved geophysical techniques to map subsurface Quaternary sequences. Areas of particular application for these technigues are groundwater studies, the exploration for sand and gravel, and various waste disposal and subsurface pollution mapping problems. The variety and suitability of geophysical equipment manufactured in Canada is currently improving, however, there is a distinct lack of case histories and practical examples which demonstrate the cost effective retrieval of information with the mapping of unconsolidated materials deposited on the bedrock surface. This is particularly true in south-central and southwestern Ontario where overburden thicknesses may average 30 m and reach extended depths of several hundred metres.

The field work was carried out over the summer and fall of 1989 in Markham township (Figure 44.1) along a section of Bruce Creek (lots 19 and 20, Concession V) and was directed at mapping the gravel bar potential within, and around the flood plain area of the creek. It was reasoned that the presence of gravel bars and lenses of moderate areal extent would be a likely source for pottable groundwater. This is a resource which, according to local well records of the area, is difficult to develop in sufficient quantity by random drilling alone.

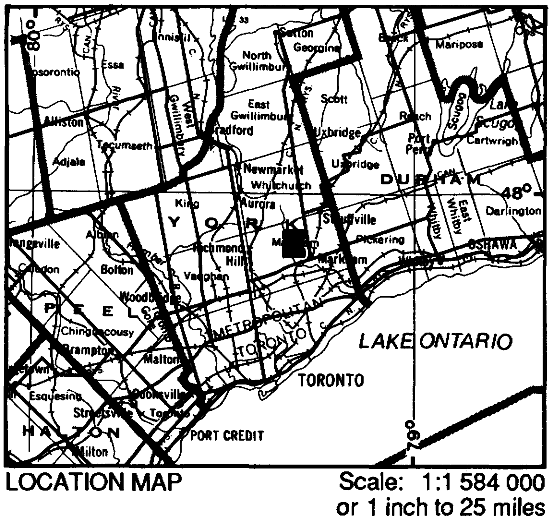

Figure 44.1. *Location map of the study area.*

The study area is accessable by Major Mackenzie Drive, just west of Kennedy Road. As the methods and equipment were continually under modification, the proximal location of the study area proved to be convenient. As well, the area has a relevant hydrogeological problem with challenging surface and subsurface conditions for geophysical mapping.

SURVEY EQUIPMENT

The initial survey equipment used included an S2-Echo shallow reflection seismograph manufactured by Scintrex Limited, cables and 100 Hz aluminum marsh geophones by Mark Products Limited, and a specially designed energy source prototype similar to the one described by Pullan and MacAulay (1987). The Geonics Limited EM-34 ground conductivity meter was deployed in the sounding mode and an EM-39 was used to log the conductivity of several overburden test holes which were prepared for the research project by the Engineering and Terrain Geology Section in the spring of this year. The holes are lined with polyvinyl chloride (PVC) pipe so that they can be reopened for future work. The inside diameter of the pipe is approximately 10 cm so that larger logging tools can be used.

SURVEY METHODS

The conceptual approach taken was initially based on the results of two boreholes (Figure 44.2). The holes are approximately 1 km apart in a northerly direction with one hole on each side of Bruce Creek. They were drilled as near the survey grid (Figure 44.3) as conditions in early spring would permit. When presenting the geological and conductivity logs of both boreholes superimposed, it is evident that stratigraphic correlations over this relatively short distance requires more detailed information of the subsurface. The stratigraphy of the Quaternary sediments in the area reflects a complex glacial history typical of an interlobate moraine enviroment. Consequently, simple interpretation models derived for

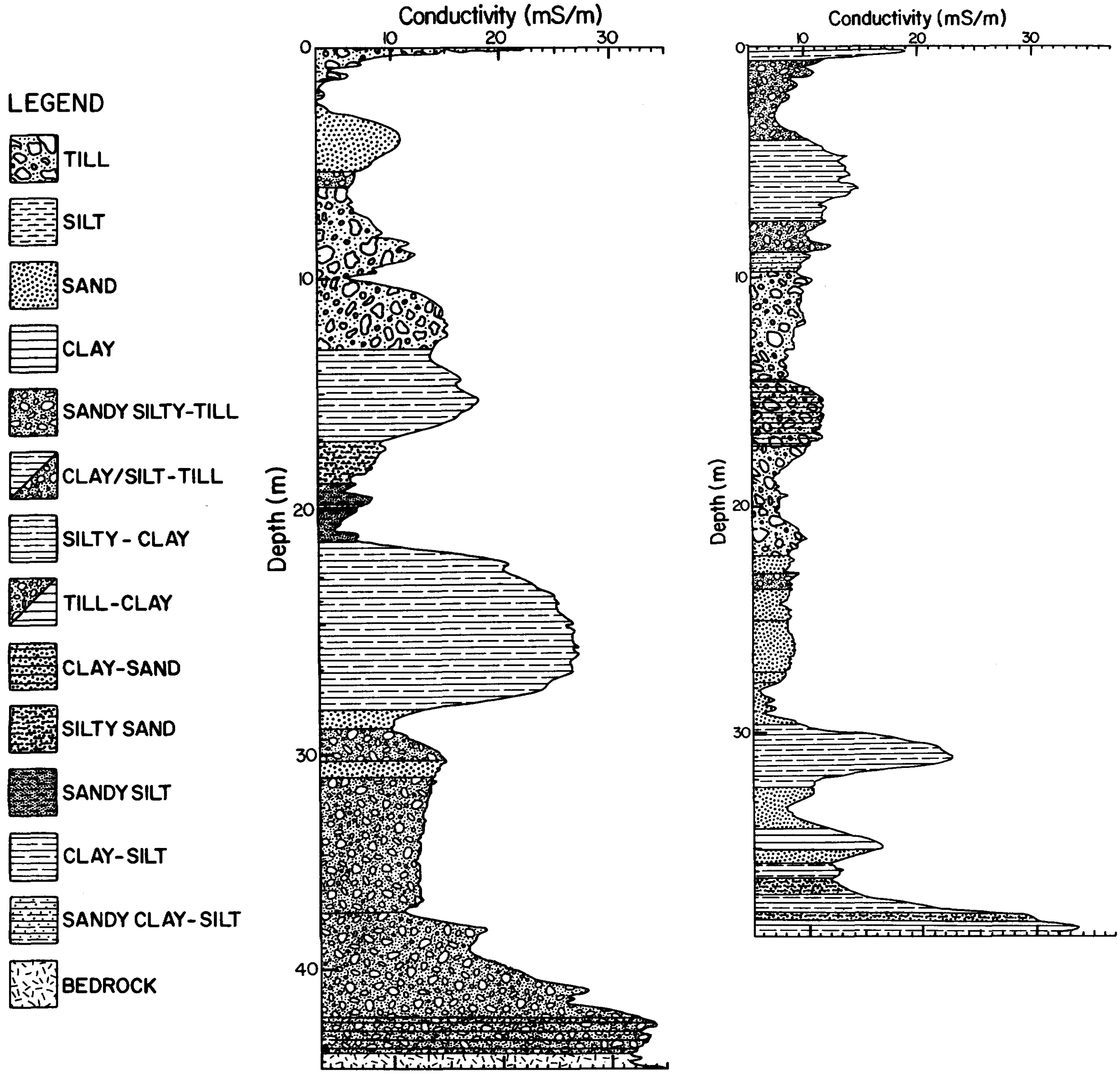

Figure 44.2. *Geological and conductivity logs superimposed (boreholes separated by approximately 1 km).*

the area must be capable of providing key information on the geometry of gravel lenses. This is neccessary so that the hydrological potential of the gravel lenses can be prioritized before drill testing.

The survey area proved to be challenging and a substantial effort was put forth before a modest level of mapping capability could be achieved. Due to an attenuating subsurface and variable surface coupling characteristics, it was necessary to develop a special energy source together with flexible signal processing software for seismic reflection surveying. The development of the software was necessary so that the high frequency components of the signal, which describe the key stratigraphic reflectors, could be distinguished and separated from the predominantly lower frequency components for effective mapping presentations. The electromagnetic application has also required the development of inversion routines which can facilitate interactive modelling of the survey data.

A survey grid was developed in a section of the creek where the flood plain was wide enough to permit reasonable line length for seismic reflection and electromagnetic surveying. Seismic reflection data was accumulated in two dimensions (four transect lines and two cross lines) using an optimum offset technique developed by Hunter et al. (1982). This method consists of accumulating several spreads of

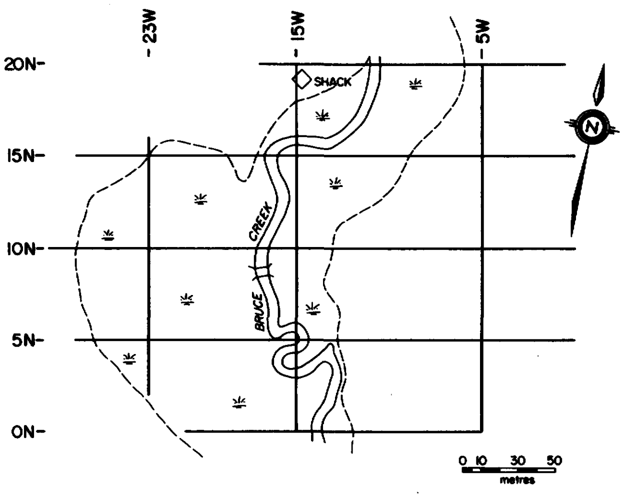

Figure 44.3. *Detailed plan of the grid system.*

refraction data taken with progressively wider offsets to determine the optimum window between the ground roll and the wide angle zone. The horizontal distance at the surface between the energy source and the recording geophone (called the optimum offset) that best permits the bedrock reflector to be recorded, is thus established. Optimum offsets of 25 m and 30 m were used with a geophone interval of 2.5 m over a 12 phone spread. A 100 ms record length consisting of 1024 data points was used (Nyquist Frequency approximately 5000 Hz). This allowed the highest desired frequencies from incoming signals of 1000 Hz to be sampled at least five times. An analogue filter was set to pass frequencies between 150 Hz and 1000 Hz and provided some damping of predominant lower frequencies which have peak power in the neighbourhood of 100 Hz. A 60 Hz notch filter was used although the area was found to be unusually devoid of power line noise. It was found that the combination of surface and subsurface conditions in the area rapidly attenuated acoustic energy and therefore maximum gain settings had to be deployed consistently throughout the area.

The same coverage was obtained with the EM-34 equipment using a 10 m station spacing for three coil separations and two coil configurations (horizontal and vertical coplanar). At each station the centre point between the transmitter and receiver was used. This enabled a one-dimensional inversion to be carried out utilizing the six measured parameters at each station together with the related seismic information at the same station. The equipment was moved along the line, one coil separation

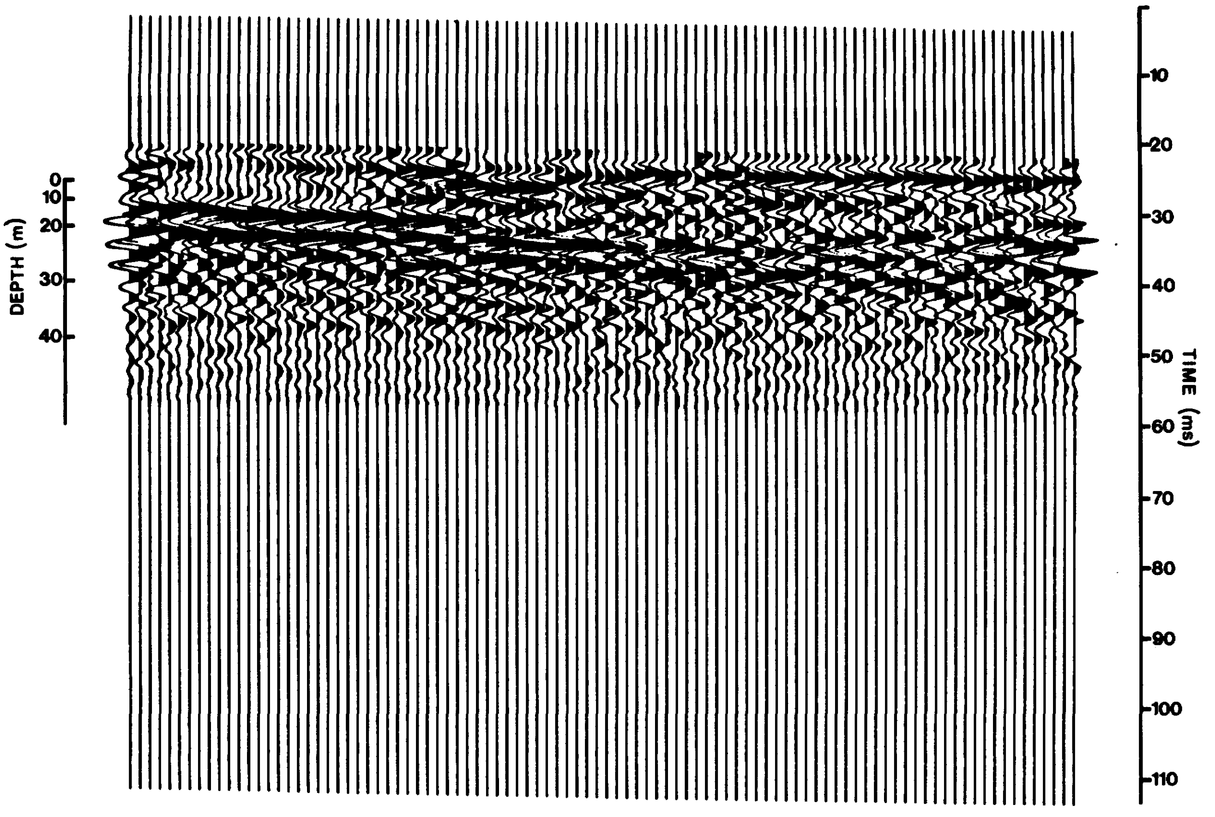

Figure 44.4. *Siesmic reflection section 5 north.*

at a time, and changed for the return traverse. Care was taken to align the coils precisely and maintain chained separations as these are the main sources of noise encountered with this equipment.

DATA PROCESSING AND MODELLING OF FIELD DATA

Seismic reflection records were first static corrected and then filtered with a bandpass of 300 Hz to 800 Hz. Filter characteristics were optimized by using data from several consecutive spreads over the closest borehole and computing average power spectrums of sections after filtering. The performance of the filter was then increased to lift the relevant high frequency reflectors from the original record. The appropriate filter parameters were thus determined by matching progressive results to the geological and conductivity log. Clay layering within the section seemed to exhibit the best reflection properties as well as the highest conductivity contrasts. This observation will be verified by future work. The bedrock reflector (*see* Figure 44.4) is not always clear. The borehole logs indicate that this is most likely due to aliasing effects produced by complex, thin reflecting layers near the overburden–bedrock interface. The filter used to prepare the seismic section had near symmetrical 100 Hz rollon and rolloff widths to -60 dB. Some ringing of the filter was observed when applied to the records and caused some superposition of false events on the negative side of the first arrival. These are muted from the beginning of each trace to provide a normalized starting point for

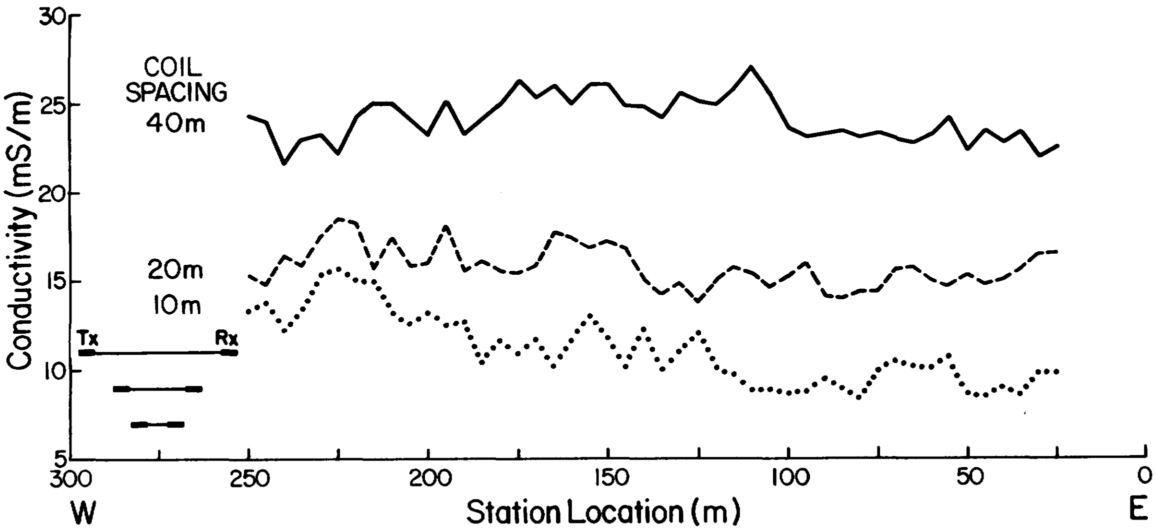

Figure 44.5a. *Vertical dipole EM-34 data with single point anomalies removed (line 5N).*

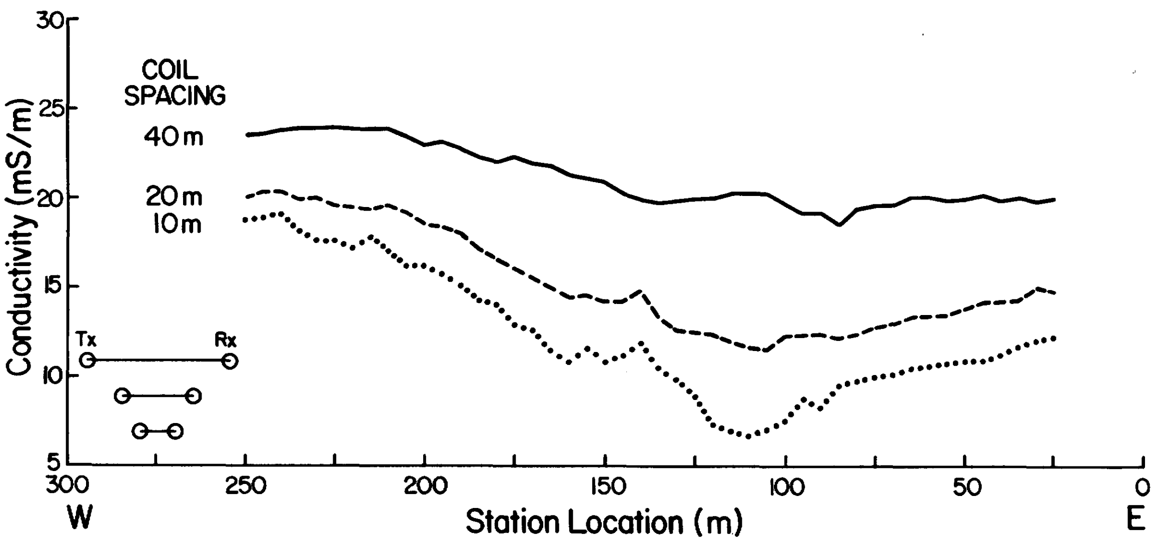

Figure 44.5b. *Horizontal dipole EM-34 data with single point anomalies removed (line 5N).*

the traces which comprise the seismic section. Plotting of the section was carried out on a Calcomp model 1077 pen plotter to produce a publication quality section.

The EM-34 sounding data was first processed by removing obvious single point anomalous readings (Figures 44.5a and 44.5b); then the profiles were filtered using a recursive low pass filter to smooth the data in preparation for inversion (Figures 44.6a and 44.6b). A one-dimensional inversion routine using a singular value decomposition method (Daniels 1978) and an algorithm for approximating the conductivity at low induction numbers by utilizing the first quadrature term from the half space formula (McNeill 1980) was written and applied to each set of records at 10 m intervals. A two-layer model was used as a first approximation, and the depth to the second layer was fixed using the depth to bedrock as calculated from the seismic reflection section. Using the six measurements at each station meant that the inversion matrix was twice overdetermined so that reasonable statistical error for the inversion could be calculated. In Figure 44.7a the result of allowing the first and second layer resistivities to optimize is presented. A second run (Figure 44.7b) had both an average resistivity for the second layer and the depth to the second layer fixed while the first layer resistivity was allowed to vary. The latter assumption is

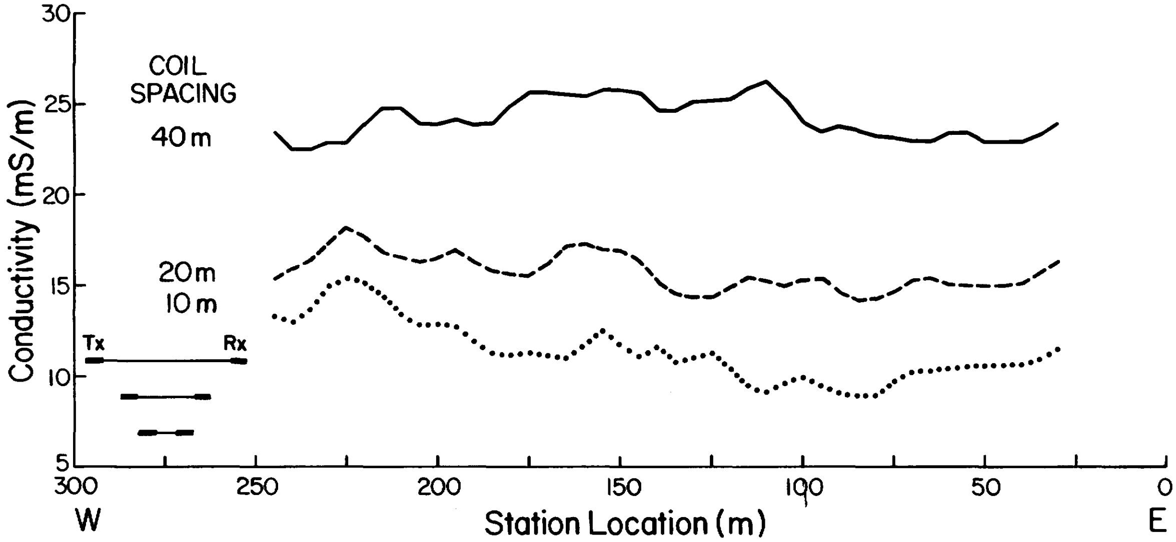

Figure 44.6a. *Vertical dipole EM-34 data with filter applied (line 5N).*

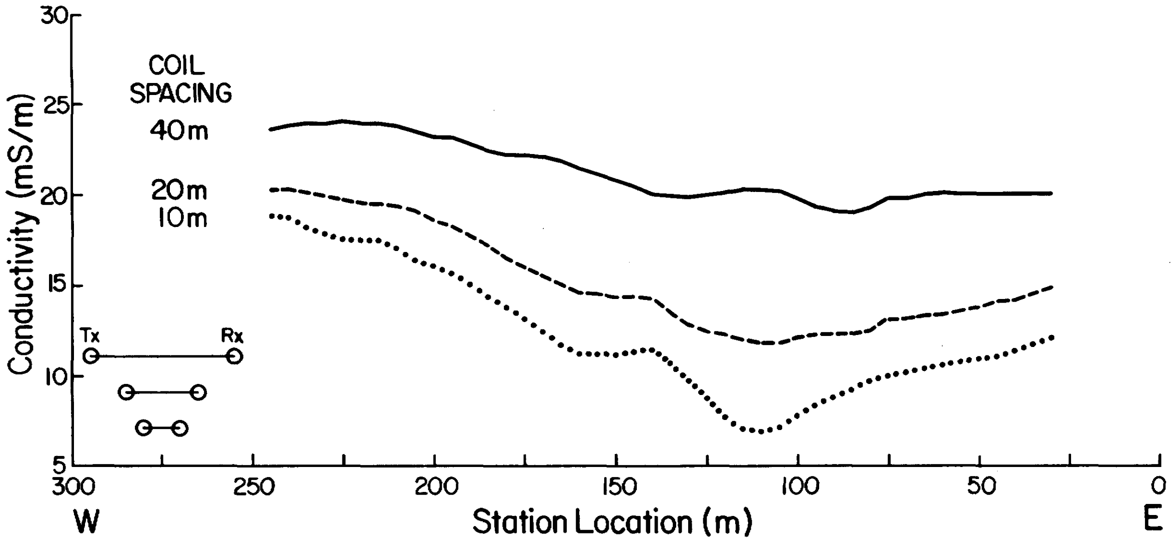

Figure 44.6b. *Horizontal dipole EM-34 data with filter applied (line 5N).*

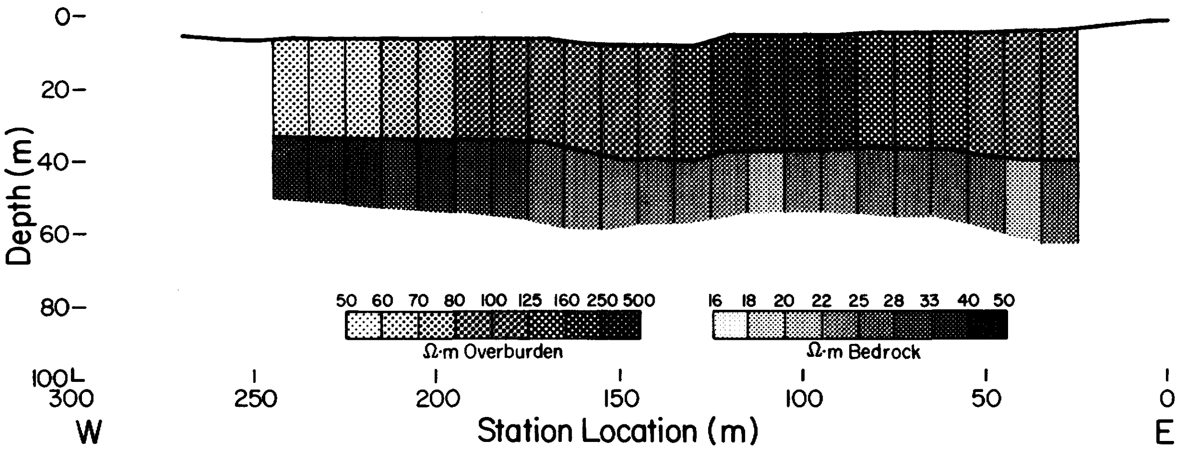

Figure 44.7a. *Two-layer model with depth to second layer fixed (line 5N).*

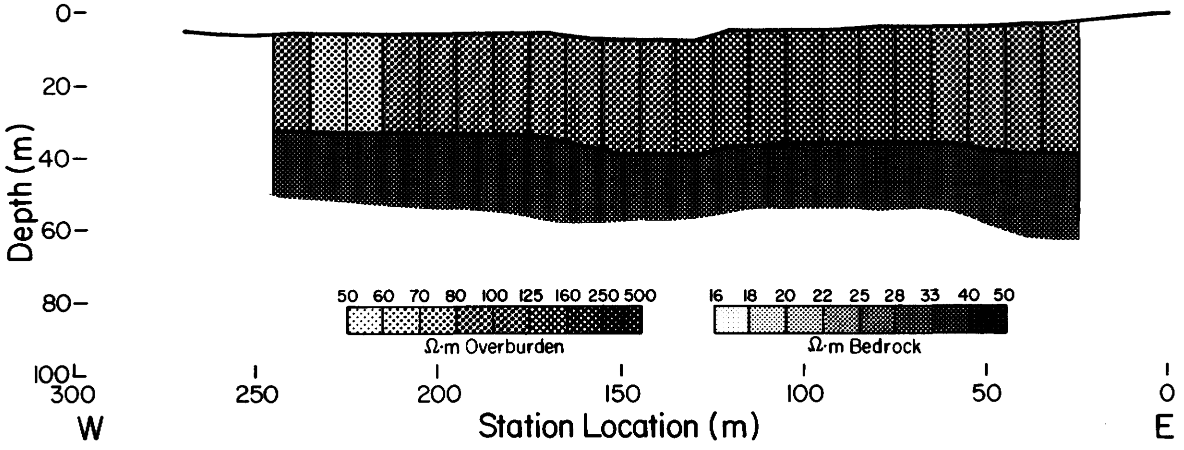

Figure 44.7b. *Two-layer model with depth to second layer and second layer resistivity fixed (line 5N).*

based on a model composed of flat lying, uniformly resistive bedrock.

PRELIMINARY INTERPRETATION

The combination of high resolution shallow seismic reflection and electromagnetic sounding provides an effective approach for overburden mapping because the reflectors are markers which define the geometry of subsurface layering while electromagnetic measurements give focussed clues to the composition of the layers. Figures 44.7a and 44.7b clearly show that an area of higher average resistivity exists near station 100 using two modelling assumptions, and that this area is also represented in the seismic section as a lensoidal feature devoid of strong reflectors. The evidence points to a substantial zone of resistive gravel and/or sand centred to the east of Bruce Creek. As well, both ends of the line show areas of lower average resistivity for the overburden layer which is more typical of a higher composition of silts, clays and tills. This environment could be reasoned to be less permeable on average than the subsurface near the creek. As Bruce Creek has a substantial year-round flow rate, it is further reasoned that recharge rates in the vicinity of the interpreted aquifer could provide an adequate source of pottable water.

FUTURE WORK

Further work on this site is planned in the coming months. Gravity measurements will be done to determine if a low density zone is associated with the area immediately east of the creek. As well, it is planned to measure streaming potentials (Ahmad 1961) by self potential methods arising from the underground movement of water. As this paper was being written, a co-operative project was underway with the shallow seismic reflection group at the Geological Survey of Canada to evaluate vertical siesmic profiling (VSP) techniques in boreholes for establishing interval velocities for the stratigraphic units.

ACKNOWLEDGMENTS

The authors are extremely grateful to A.W. Stollery for permission to use his property for this research study and to access it on a regular basis. To J.A. Hunter and S.E. Pullen of the Geological Survey of Canada we are indebted for all tutoring and continuing support for seismic reflection methods. Likewise, we are grateful to N. Keehn, R. Huxter, B. Felix, P. Mark, and A. Nakashima for their assistance in computer programming, plotting, and field work. Appreciation is also extended to C. Baker of the Engineering and Terrain Geology Section for his support in Quaternary Geology and in overburden drilling technology.

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45. Project Unit 88-25. Single Master Aeromagnetic Grid and Magnetic Colour Maps for the Province of Ontario

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INTRODUCTION

At the Ontario Geological Survey (OGS), plans are at an advanced stage for the production of a complete, concise and state-of-the-art review volume on the geology of Ontario. The volume's geophysical contribution will consist largely of Bouguer gravity maps, total field aeromagnetic maps, and computer processed filtered and derivative maps, all at a scale of 1:1 000 000. At this scale the entire province of Ontario can be represented by four map sheets, for easy viewing.

Currently, the digital aeromagnetic data for this province is available at a grid spacing of 812.8 m, from the Geological Survey of Canada (GSC). The data base at this grid spacing is considered coarse for any meaningful geological interpretation and therefore total field maps and computer processed enhanced products created from it will be suitable only for a regional to semi-regional exploration-mapping function. However, to make the current 812.8 m aeromagnetic data base more useful for detailed lithologic, structural and third dimension interpretation, the current data base must be refined and reprocessed.

The state-of-the-art data processing and modern geophysical techniques have been applied to the existing GSC 812.8 m grid data base. From this we have created a single master aeromagnetic super grid for the entire province of Ontario at a chosen uniform grid spacing of 200 m. From the super grid we will generate a set of 1:1 000 000 colour maps, comprising the total magnetic field and its daughter products. Once the super grid has been finalized it will also be used to prepare a separate data base containing all of the levelled aeromagnetic data in a flight line archive format for easy accessibility by the OGS client group.

In summary, these tasks have been completed by taking digitized analog and digital aeromagnetic data from 41 surveys and levelling it to a reference grid prior to the creation of the final data base, master grid, processed products and maps.

The work under this project will be performed under contract by Paterson, Grant and Watson Limited of Toronto. Technical specifications and supervision will be provided by the staff of the OGS and the GSC.

DATA

A total of 41 aeromagnetic surveys have been incorporated in this compilation. Of these, 32 were acquired in analog form and the remaining 9 in digital form. Figure 45.1 is an index map of the 41 surveys used that cover the province. Table 45.1 gives some of their technical specifications. The analog survey data were provided by the GSC in the form of values digitized from 1:50 000 scale contour maps at the contour line—flight line intercept points, and sorted into blocks on a 1:50 000 sheet basis (measuring 1/2° longitude by 1/4° latitude). The digital survey data were provided by the GSC in a flight line archive format, sorted by contiguous survey blocks. The much denser sampling of the digital survey data along the flight lines resulted in many more data points for a given length of line, as compared to the analog data. The roughly 8 million points in the final data base is divided equally between analog and digital data.

DATA ORGANIZATION

The first step in creating the master grid was to sort the blocks of analog data back into their contiguous survey areas. This was done by digitizing the survey boundaries and placing each block in the correct survey area based on the location of its midpoint. The result for one survey is shown in Figure 45.2. The breaks in the flight path mark the 1:50 000 sheet edges.

Once the analog data had been sorted into surveys, a 200 m grid of each survey was created. These were then systematically compared to the published contour maps, using an imaging workstation, to locate and correct any digitizing errors that might have been incorporated in the raw data base. The GSC had already made a first pass at error correction during preparation of their 812.8 m grid. However, the resolution needed for this project required a second pass. A workstation-based editing tool was used that allows windows showing a zoomed image, profiles of the magnetic data along flight

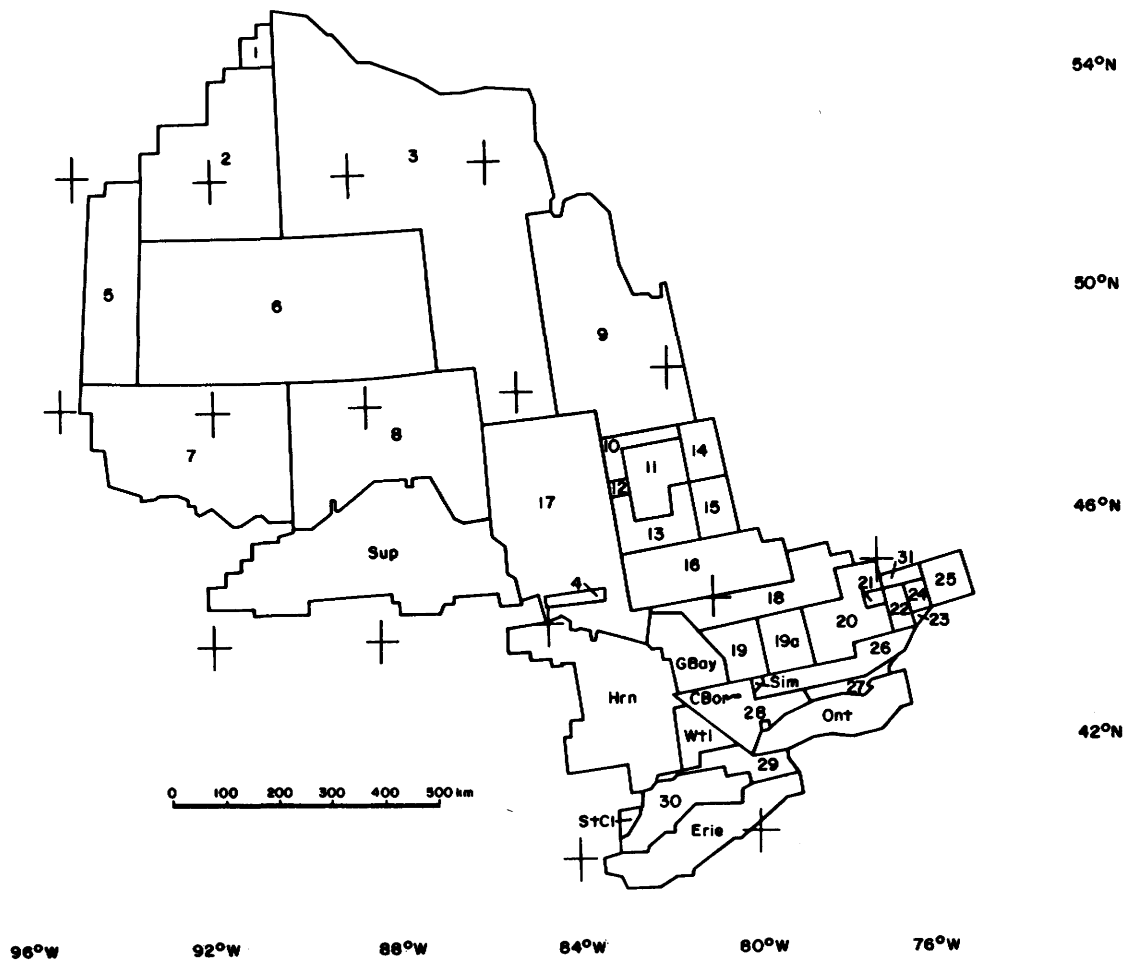

Figure 45.1. *Index map showing GSC aeromagnetic surveys incorporated in the Ontario master grid. Refer to Table 45.1 for more details.*

lines, and the data file itself to be displayed concurrently. Any errors that are located are corrected interactively and the data file updated. Most of the errors corrected consisted of line segments where the contour intervals had been incorrectly digitized. Some location errors also required correction. A similar analysis of the grids created from the digital surveys did not reveal any data errors, as might be expected. Each of the 41 survey grids were then plotted as a 1:250 000 colour map, so as to maintain a hard copy record of the corrected but unlevelled data.

Table 45.1 indicates that the data were measured at a mean terrain clearance of either 500 feet (150 m) or 1000 feet (300 m). All of the lower altitude data were restored, by upward continuation, to a common datum of 1000 feet above ground prior to levelling.

LEVELLING

The levelling procedure used in this project makes use of the existing GSC regional scale grid (812.8 m cell size) as a reference datum. This grid had been produced by taking the same data sets and fitting the survey blocks together by the classic method of adjusting (e.g., raising, tilting) the survey blocks to match at the seams. This method works well for the longer wavelengths in the data, but does not always provide a good match in the high frequencies along the seams. Such a method would not have been tenable for this project, where 200 m resolution of the grid is required. The classical method also tends to build a very long wavelength error into the levelled grid resulting from the subjective nature of the survey block adjustment process. This should not be a major problem in Ontario, given that most of the survey blocks are quite large. The long wavelength

TABLE 45.1. GSC AEROMAGNETIC SURVEYS IN ONTARIO.

ANALOG DATA

#	SURVEYOR	YEAR	ALTITUDE	FLT. DIRECTION
1	Canadian Aero	1963	1000 feet	N-S
2	Lockwood Survey Corp.	1965-66	1000 feet	N-S
3	Lockwood Survey Corp.	1966-68	1000 feet	N-S
4	Aeromagnetic Survey Ltd.	1954-56	500 feet	N-S
5	Spartan Air Services Ltd.	1965	1000 feet	N-S
6	Spartan Air Services Ltd.	1959-60	500 feet	N-S
7	Spartan Air Services Ltd.	1960-61	1000 feet	N-S
8	Spartan Air Services Ltd.	1960-62	1000 feet	N-S
9	Spartan Air Services Ltd.	1963-64	1000 feet	N-S
10	Spartan Air Services Ltd.	1963-64	1000 feet	N-S
11	Dominion Gulf	1947-49	1000 feet	N-S
12	Aero Photo Inc.	1959-60	1000 feet	N-S
13	Aero Photo Inc.	1959-60	1000 feet	N-S
14	Dept. of Mines & Technical Services	1948	300 m	N-S
15	GSC	1959-60	1000 feet	N-S
16	GSC	1959-60	1000 feet	N-S
17	Spartan Air Services Ltd.	1962-63	1000 feet	N-S
18	Dept. of Mines & Technical Services	1959-60	300 m	N-S
19	Dept. of Mines & Technical Services	1949	1000 feet	N-S
19a	Dept. of Mines & Technical Services	1949	1000 feet	N-S
20	Dept. of Mines & Technical Services	1947-48	1000 feet	N-S
21	Dept. of Mines & Resources	1947	1000 feet	N-S
22	Dept. of Mines & Resources	1947-48	1000 feet	N-S
23	Energy, Mines & Resources	1979	300 feet	E-W
24	Dept. of Mines & Technical Services	1949	300 m	N-S
25	Dept. of Mines & Technical Services	1959-60	300 m	N-S and E-W
26	Aero Services Corp.	1950-53	150 m	N125°E
27	Spartan Air Services Ltd.	1969-70	150 m	E-W
28	Aero Services Corp.	1950-53	150 m	N125°E
29	Spartan Air Services Ltd.	1969-70	1000 feet	E-W
30	Lockwood Survey Corp.	1954-55	1000 feet AMSL	E-W
31	Dept. of Mines & Technical Services	1950	500 feet	E-W

DIGITAL DATA

SURVEY	SURVEYOR	YEAR	ALTITUDE	FLT. DIRECTION
Camp Borden (CBor)	GSC	1985	300 m	E-W
Lake St. Clair (StCl)	GSC	1986	300 m	E-W
Lake Erie (Erie)	GSC	1984-85	300 m	E-W
Georgian Bay (GBay)	GSC	1985-86	300 m	N-S
Lake Huron (Hrn)	GSC	1986	300 m	E-W
Lake Ontario (Ont)	GSC		300 m	E-W
Lake Simcoe (Sim)	GSC	1985	300 m	N-S
Lake Superior (Sup)	GSC	1987	300 m	N-S
Waterloo (Wtl)	GSC	1986	300 m	E-W

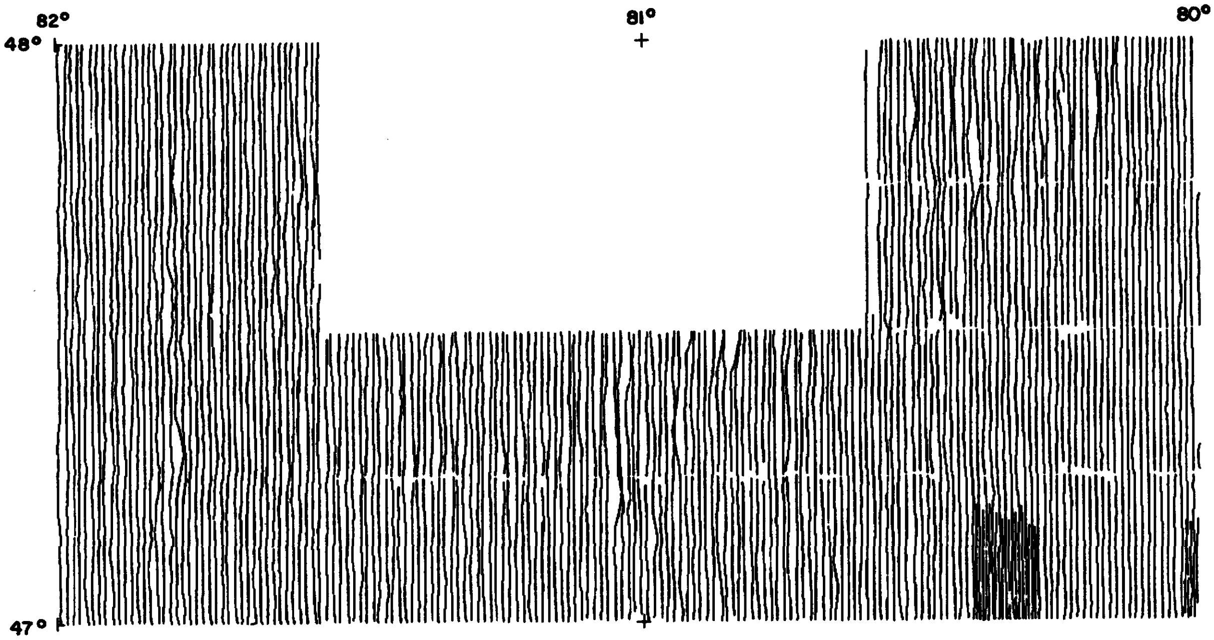

Figure 45.2. *Digitized flight path of analog survey 13.*

errors in the blocks, if real, would reflect sources located below the Curie point isotherm, which are not physically possible. This point should be kept in mind though, if the final grid is to be used in crustal studies.

The levelling method for this project takes the 812.8 m regional grid and assumes that it has been levelled correctly in the long wavelength along the survey boundaries. Effectively, the unlevelled survey grids have been draped into the regional grid to produce a levelled grid such that the seams are invisible but the higher resolution of the fine gridding interval is maintained.

The long wavelength levelling error was determined by comparison of the unlevelled data with the regional grid. It was then removed to create the levelled master grid. The error component was studied to ensure that no geological signal was removed from the data. This procedure has the advantage of matching exactly, in a regional sense, the published 1:1 000 000 series of maps of the GSC, thereby facilitating consistent interpretation of the data at all scales.

Any spurious high frequency effects that remain at the seams would be due to systematic noise such as position error, and would require manual correction prior to the application of this levelling method. A by-product of this process is that line-to-line noise in the data is removed if it is of a sufficiently long wavelength to be comparable with the levelling error.

The following example illustrates the results of the procedure. Figure 45.3 shows portions of three adjacent analog surveys (numbers 1, 2 and 3) from northwestern Ontario. The boundaries between surveys are obvious. Note that the join along one seam has flight lines sitting end-to-end while the other seam has the flight lines lying parallel. The three or four single-line, north-south anomalies are probably errors in the original data compilation. They can be observed in the published GSC contour maps.

The data sets from three surveys were subjected to the levelling procedure described above. Figure 45.4 shows the three levelled surveys as a single, contiguous grid. The seams are virtually invisible. There is a significant reduction in emphasis of the single-line anomalies. Absolutely no smoothing or special treatment at the seams was applied to improve the appearance of the map. Note that the contour interval is 5 nT whereas the data was originally digitized from 10 nT contours.

GRIDDING

The grid shown in Figure 45.3 was created with a bi-directional gridding algorithm that first splines down the flight lines and then perpendicular to them. Figure 45.4 shows the same levelled data set gridded using a minimum curvature algorithm. The latter is a true two-dimensional gridding program that interpolates each grid cell from a minimum curvature surface that passes through all the data. It produces a smoother looking map than the bi-

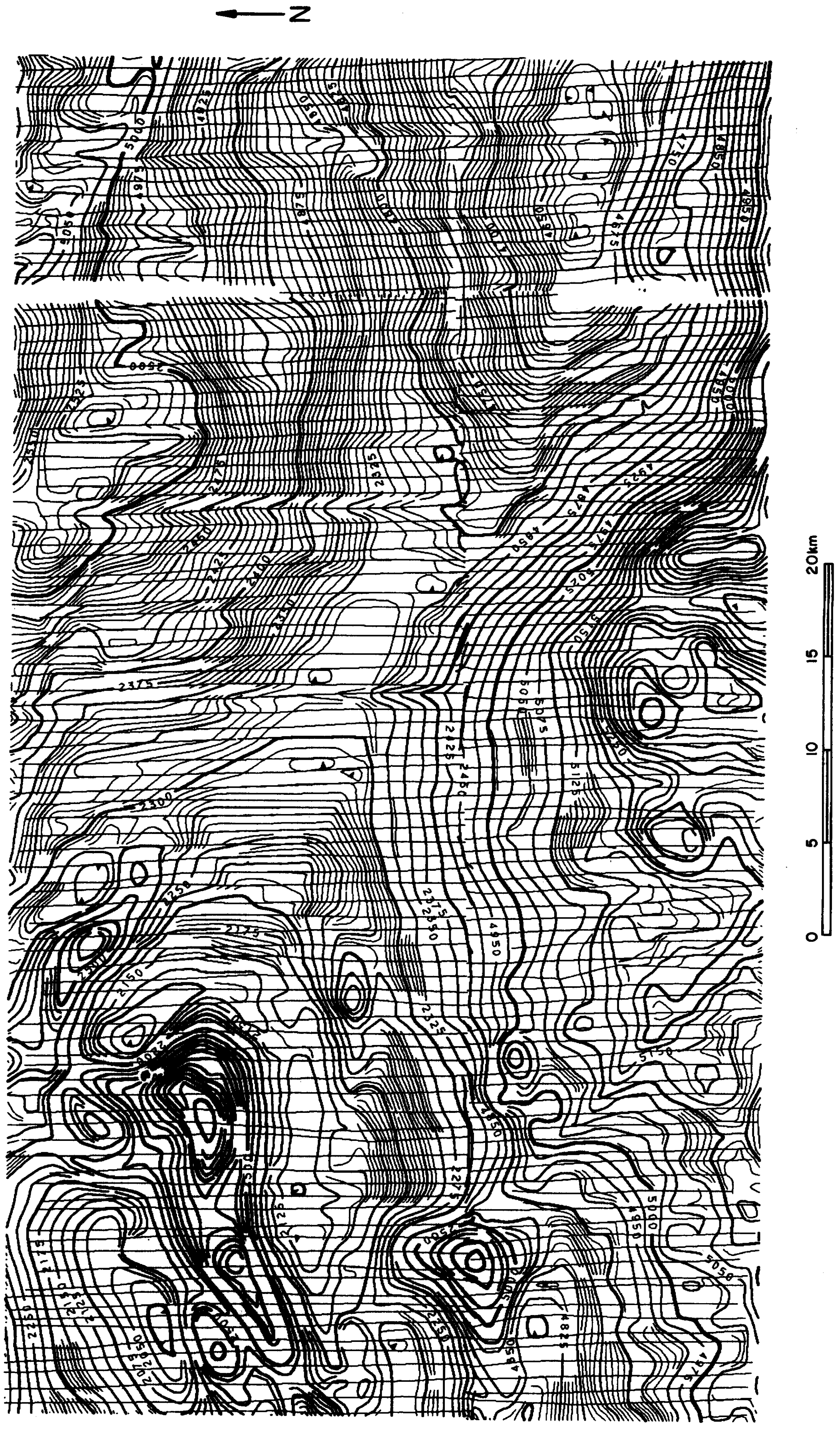

Figure 45.3. *Contours of unlevelled aeromagnetic data and flight path for portions of analog surveys 1, 2 and 3. Base contour interval = 5 nT.*

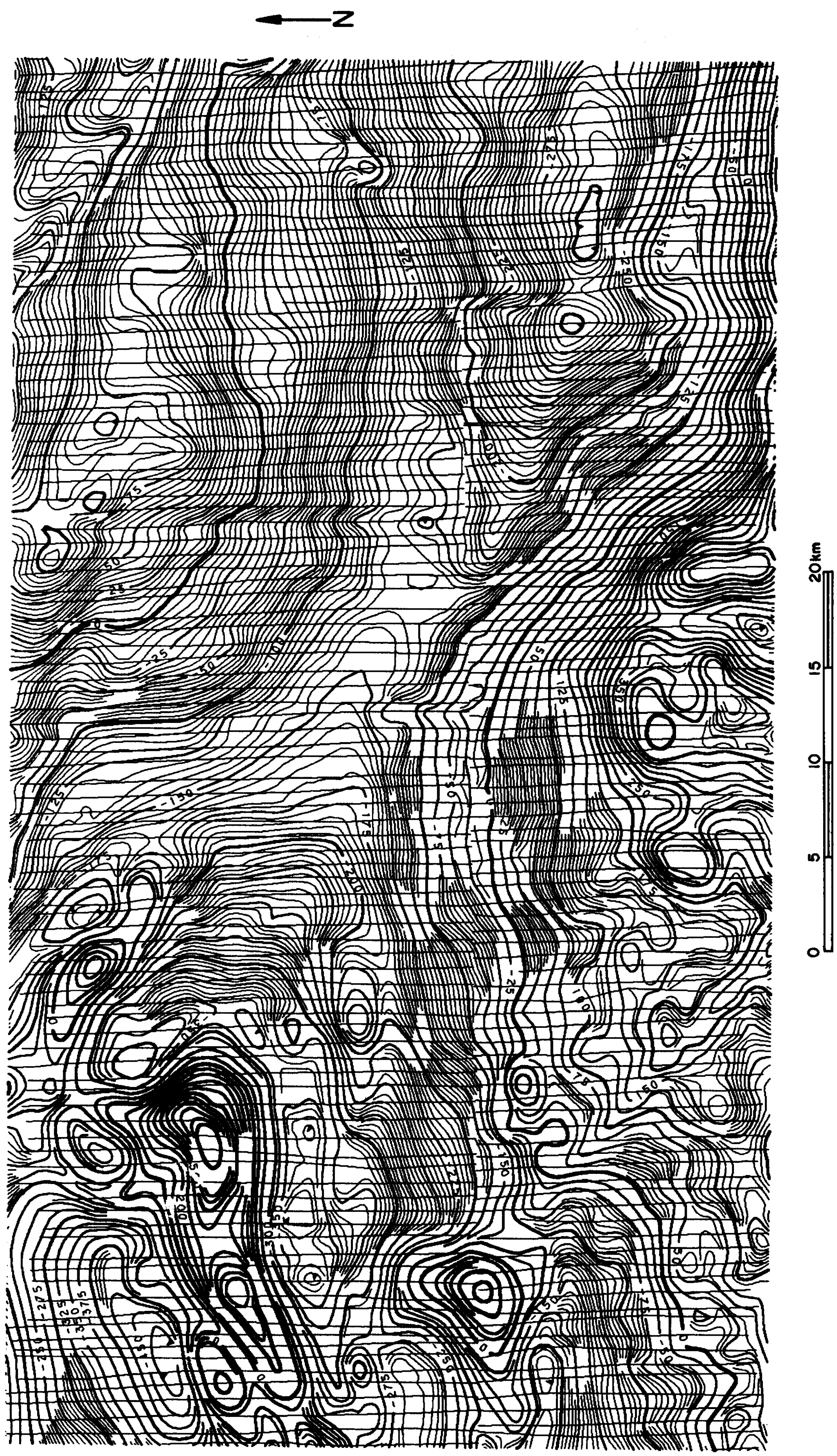

Figure 45.4. *Contours of levelled aeromagnetic data and flight path for portions of analog surveys 1, 2 and 3. Base contour interval = 5 nT.*

directional gridding process. The minimum curvature gridding method is the method of choice by the GSC for treating their aeromagnetic data, and was required, justifiably, to be used in this project to create the master grid. A very efficient version of the algorithm was developed for this application.

The single master grid will be oriented in a Lambert Conformal Projection, with a central meridian of 92°W, standard parallels of 49°N and 77°N, and the origin of the grid being the equator (0°N) and 92°W. Each value in the data base is located in both this projection and by latitude and longitude. Prior to approval of the final single master grid, the data will be sent to the GSC for verification plotting. They will produce total field contour maps at the 1:50 000 scale in randomly selected areas to check the integrity of the grid, focussing particularly on the seams at survey boundaries.

From the master grid, enhanced products will be generated, namely, shaded relief and vertical derivative grids and 1:1 000 000 scale colour maps. These will be particularly useful for highlighting the near-surface geology of the province.

46. Project Unit 89-43. A Regional Geochemical Survey of the Murray Lake Area

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INTRODUCTION

During June 1989, a small-scale regional lake sediment and water geochemical survey was completed in the vicinity of Murray Lake. It covered a 500 km² area which is located 65 km northeast of Wawa, Ontario (Figure 46.1).

The purpose of this regional geochemical survey is to provide geochemical information pertinent to mineral exploration in the area. The Murray Lake area is of particular interest at this time because of its proximity to the Goudreau Lake area where gold deposits are currently being developed (Fortescue and Stahl 1987). The Goudreau Lake and the Magpie River geochemical surveys (Fortescue and Stahl 1987; Fortescue and Nakashima 1988), plus the Murray Lake geochemical survey represents a portion of the regional geochemical coverage of the Wawa greenstone belt.

As the regional geochemical coverage of the Wawa greenstone belt progresses, the different data bases can be combined. The resulting data set is suitable for detailed statistical analyses, image processing and incorporation into a Geographical Information System (GIS).

OBJECTIVES

The objectives of the regional survey are

1. to collect water and pre-Ambrosia lake sediment core material from all lakes and ponds accessible by helicopter in the 500 km² Murray Lake area
2. to provide in both hard copy and computer readable form, data for the pH, Ca and Mg content of the water samples and the levels of Ag, Al, As, Au, Ba, Be, Bi, Br, Ca, Cd, Co, Cr, Cu, Fe, Hf, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sr, Ta, Th, Ti, U, V, W and Zn, in the pre-Ambrosia Lake sediment core material collected from lake sample sites in the Murray Lake area
3. to provide a summary of the geochemical behaviour of elements which are of interest in min-

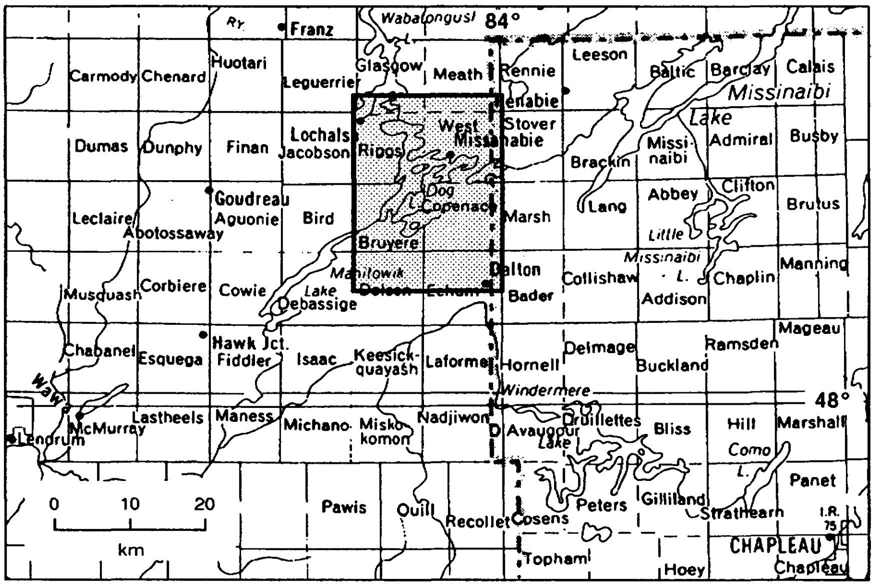

Figure 46.1. *Location map of the Murray Lake area.*

eral exploration in the Murray Lake area. This is achieved using univariate, bivariate and multivariate statistical analyses of the geochemical data obtained from the water and pre-Ambrosia lake sediment samples. Also, comparisons between the geology and lake sediment geochemistry of the area are proposed using multielement geochemical sections and geochemical signatures (*see* Paper 47, this volume).

4. to provide the geochemical data in a form that can contribute to an experimental, interdisciplinary, geoscience GIS project of the Wawa greenstone belt, now in progress at the Ontario Geological Survey. The project will include bedrock geology, Quaternary geology, geophysics, remote sensing and mineral deposit study data sets which can be utilized separately or as a combination of data sets.

GEOLOGICAL SETTING OF THE MURRAY LAKE AREA

The Murray Lake area covers almost all of Riggs, West, Bruyere and Copenace townships; the north half of Dolson and Echum townships; and, along its eastern margin, fractions of Stover, Marsh and Balder townships. The entire area is underlain by Precambrian greenstones and granitic rocks which together form a part of the complex Wawa greenstone belt.

The bedrock geology of the Murray Lake area has been summarized recently by Heather and Buck (1988). Parts of the area were mapped geologically on a 1:15 840 scale by Srivastava and Bennett (1978).

The bedrock geology of the Murray Lake area is complex and cannot be conveniently summarized here. The lithology of the area, as described by Heather and Buck (1988), is particularly complex. For example, mafic to intermediate metavolcanics, felsic to intermediate metavolcanics, metasediments and iron formation, plus external and internal granitoids, all occur within the Murray Lake area.

The structural geology of the area is complicated also. The area is crossed by several deformation zones in an east-west direction and by several major faults, such as the Meath Lake fault, which strike 320° to 350° (Heather and Buck 1988). Further information on the geology, and information on the metallogeny and mineral deposits in the area, can also be obtained from Heather and Buck (1988).

According to Gartner and McQuay (1979), the last glacial ice advance over the Murray Lake area was from the north-northeast. The retreat of this ice sheet is associated with the deposition of a thin mantle of stony sandy till over the bedrock. This till is usually 1 to 5 m thick.

Gartner and McQuay (1979) also reported sandy glaciofluvial deposits in several parts of the Murray Lake area. For example, areas of sandy glaciofluvial deposits were reported from (1) the southwest part of Riggs Township; (2) the northeast part of West Township; and (3) the eastern part of Dolson Township. In addition, these writers reported a relatively large area of ground moraine in the north-central part of Echum Township and the south central part of Copenach Township. Otherwise, the Murray Lake area is relatively free of substantial glacial cover.

In summary, the bedrock geology of the Murray Lake area is complex and varied. Except in the areas mentioned above, the Quaternary cover is relatively thin. From the viewpoint of regional geochemical mapping based on lake sediments, these geological conditions are favourable. Unfortunately, the presence of several large lakes in the Murray Lake area complicated the geochemical sampling. These complications are likely to make the interpretation of the geochemical map patterns more difficult when the geochemical map is completed.

FIELDWORK

In June 1989, a crew of three, using a float equipped Bell 206 helicopter, collected lake sediment and 1 L water samples from 487 sample points situated in lakes and ponds in the Murray Lake area. Core samples were collected and extruded on the float to provide pre-Ambrosia samples (*see* Fortescue 1988a). The rate of sampling was between 50 to 70 lake sediment cores and water samples per day.

In a field laboratory, a Fisher Acumet 925 pH meter was used to determine the pH of water samples after they had been chilled on arrival from the field.

SAMPLE INTENSITY

The area included in the Murray Lake regional geochemical survey was part of the area covered by a reconnaissance geochemical survey completed jointly by the Ontario Geological Survey and the Geological Survey of Canada (OGS–GSC 1979). During this particular OGS–GSC survey, the samples were collected at an average of 1 sample per 13 km^2 (5 square miles).

In the other regional geochemical surveys at Goudreau Lake (Fortescue and Stahl 1987) and Magpie River (Fortescue and Nakashima 1988), the sample density was 1 sample per 1.4 km^2 and 1 sample per 1.22 km^2 respectively. This compares with an average density of 1 sample per 0.97 km^2 in the Murray Lake regional geochemical survey area.

PRESENT STATUS

The field sampling program for the Murray Lake area was completed in June 1989. The water samples were submitted to the Geoscience Laboratories, Ontario Geological Survey, where the calcium and magnesium levels in all the water samples will be determined. The pre-Ambrosia lake sediment samples were delivered to the contractor, Chemex Labs Ltd, Mississauga, Ontario. They will complete a 35 element analyses for the lake sediment samples and quality control samples. All analyses should be complete by late 1989.

The geochemical data obtained from the Murray Lake survey will be released by the Ontario Geological Survey as soon as practicable. Any high element values discovered in the pre-Ambrosia material may be verified later using long cores and the technique described by Fortescue (1988b).

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47. Project 87-25. Regional Geochemical Mapping in the Batchawana Greenstone Belt

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INTRODUCTION

In 1987, 1988 and 1989, a geochemical mapping project was conducted in and around the Batchawana greenstone belt. The belt extends east for 100 km from the shore of Lake Superior and is located some 50 km north and east of Sault Ste. Marie (Figure 47.1).

The aim of the project is to provide a regional geochemical map of the entire Batchawana greenstone belt using a standardized methodology. When completed, this geochemical data base will be suitable for image processing of geochemical patterns. It will also provide a multielement, geochemical data base suitable for incorporation into a Geographical Information System of the type described by Ryghaug and Green (1988) and others.

Regional geochemical maps of the type described here are relatively new to Ontario. These maps are used in other parts of the world to enhance mineral resource appraisal processes as described by Plant and Slater (1986).

To date, in the Batchawana geochemical mapping project, a total of 2441 pre-Ambrosia lake sediment core and water samples have been collected within a 3175 km² area. The average sample density for the area currently mapped is 0.76 samples per square kilometre.

The area of the Batchawana greenstone belt previously mapped is indicated on Figure 47.2. The boundary delineating this year's field work in the Hanes Lake area is also indicated on Figure 47.2.

Details of the 1987 and 1988 Batchawana geochemical mapping projects have been described

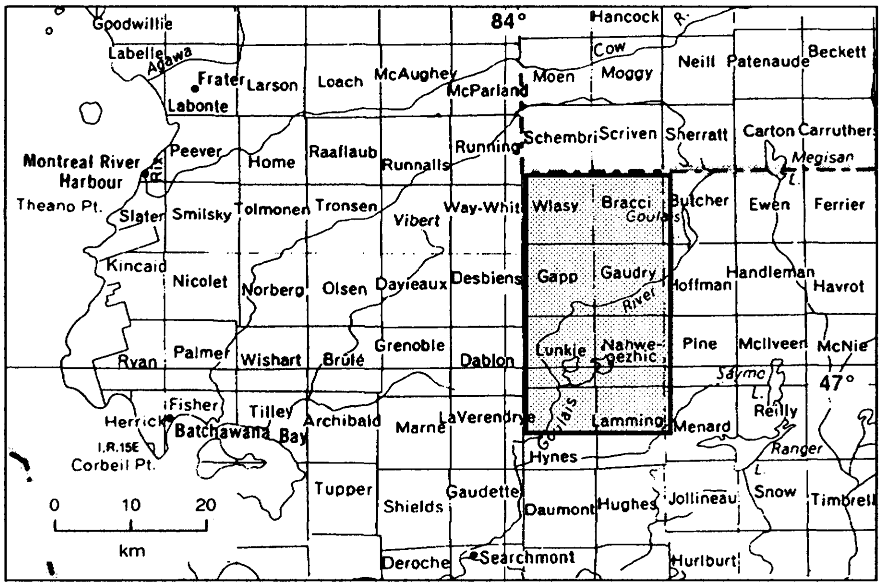

Figure 47.1. *Location map of the Batchawana area.*

This project A.8.1 is part of the five-year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

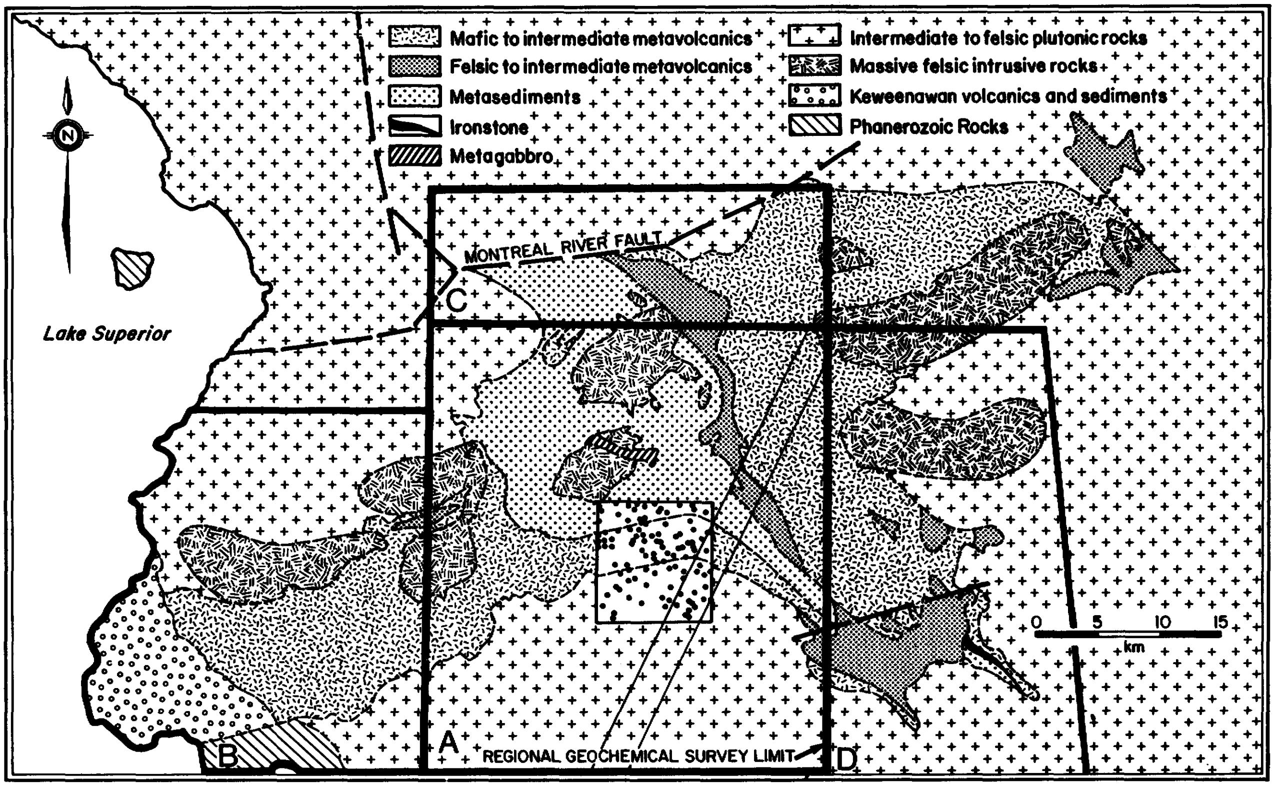

Figure 47.2. *Generalized geological map of the Batchawana synoptic project area showing limit of the regional geochemical survey and, as an inset, the sample density for lake sediments. The letters within the sampled area refer to the individual regional geochemical map sheets as follows: A—Trout Lake area, B—Pancake Lake area, C—Montreal River area and D—Hanes Lake area. The location of the geochemical/geological section is indicated on the Trout Lake sheet by the two parallel lines across the map.*

previously (Fortescue and Stahl 1987, 1988a). The Batchawana geochemical map series includes five map sheets. To date, field and laboratory work have been completed for three of these sheets (i.e., Trout Lake, Pancake Lake and Montreal River).

The sampling of a fourth map sheet, Hanes Lake, was completed in August and September 1989. The Trout Lake sheet is due for release in the winter of 1989 and the other three sheets by March 1991.

MARGINAL NOTES ON THE BATCHAWANA REGIONAL GEOCHEMICAL MAPS

The format for the marginal notes on the Batchawana series of geochemical maps has been standardized. In order to provide readers with an introduction to the organization of this standardized format, it has been summarized under six headings as follows:

1. a generalized description of the geology of the area, including a 1:50 000 scale coloured geological map with the geochemical sample sites indicated on it
2. a listing of the highest 100 lake sediment geochemical results for each of the 35 elements (Ag, Al, As, Au, Ba, Be, Bi, Br, Ca, Cd, Co, Cr, Cu, Fe, Hf, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sr, Ta, Th, Ti, U, V, W and Zn) included in the survey
3. a description of the performance of analytical methods used to obtain the geochemical data
4. a global level comparison of geochemical signatures (for 19 elements) between (1) lake sediments collected from the Trout Lake catchments underlain by a single lithology, and (2) a datum geochemical signature (based on 1688 lake sediments) obtained from more than one areas in the province
5. a regional level description of
   a. geochemical map patterns for elements of interest in mineral resource appraisal in the entire Trout Lake area
   b. results of principal components analysis for five Trout Lake area lake sediment data sets

c. two geochemical sections illustrating relationships between geology and lake sediment geochemistry
6. a detailed level description of the geochemistry of 52 "anomalous" results likely to be of particular interest in mineral resource appraisal. These values require verification by resampling as described by Fortescue (1988).

The marginal notes end with a summary and general conclusions.

GEOCHEMICAL SIGNATURES AND GEOCHEMICAL SECTIONS

The two concepts, geochemical signatures and geochemical sections, included in the marginal notes format summary require further elaboration. They are both relatively simple and effective ways of processing multielement regional geochemical data. Together they bring out relationships among the element patterns which might otherwise be difficult to envisage. In order to illustrate this, simple examples of their application to the Trout Lake geochemical data base are provided here.

Geochemical signatures and geochemical sections are currently used by geochemists making regional geochemical maps based on other sample media (e.g., stream sediments; Plant et al. 1980; Simpson et al. 1989). As far as we know, the project described here is the first time they have been applied to pre-Ambrosia lake sediments.

AN EXAMPLE OF A PRE-AMBROSIA LAKE SEDIMENT GEOCHEMICAL SIGNATURE

During the preliminary stage of the investigation of a multielement geochemical data set, it is important to discover how much the abundance of the elements determined in a sample (or samples) differ from the normative for the same elements in samples of the same media collected across the province.

The geochemical signatures for the Batchawana greenstone belt data are constructed in two stages. In order to provide a datum signature for pre-Ambrosia lake sediments, the median values for 19 selected elements in a large (*circa* 1600 sample) population were calculated after the values for each element had been normalized using the Clarke Index-I transform (symbolized by the letter K) (Fortescue 1985). This normalization process reduces the variability of the data between elements, and the selection of median values provides a measure of central tendency in the population unaffected by extreme values.

To plot the datum signature, the median values are ranked in ascending order and plotted on semilog paper as a series of steps, one for each element (Figure 47.3). Almost all the Clarke Index-I values for these 19 elements lie in the range from 0.1 K to 10 K.

Because of the ranking procedure, the datum signature approximates to a straight line. The sequence of elements in the signature reflects the abundance of elements in a mix of all the lithotypes found in greenstone belts from which the samples were collected. The datum signature provides a basis for comparison with other signatures obtained from single samples, or populations of samples, associated with particular geological features of the area.

The dashed line on Figure 47.3 illustrates this point. In general, it shows the pre-Ambrosia lake sediments from catchments entirely underlain by the Algoma plutonic domain are relatively low in Mn, Fe, V, Ca, Cu and Zn, and high in Ti, Al, Ba, Th, U and La. These results are expected on the basis of elementary geochemistry. Also, the results indicate for the catchments underlain by the Algoma plutonic domain in the Trout Lake area, the geochemistry of pre-Ambrosia lake sediment mimics the geochemical composition of the bedrock. Similar geochemical relationships to the datum signature were found for geochemical signatures obtained for the other common rock types in the area.

It was concluded the datum geochemical signature based on Clarke Index-I values, when combined with signatures obtained from samples derived from catchments underlain by specific lithotypes, provides a useful introduction to the interpretation of the geochemical mapping results. In particular,

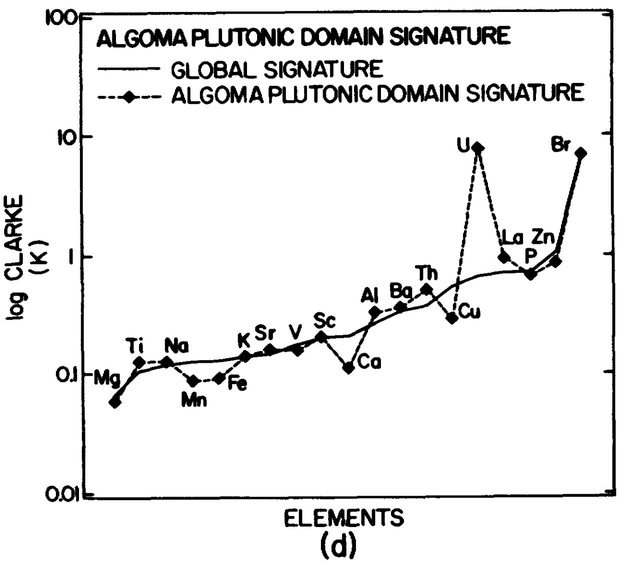

Figure 47.3. *A 19 element geochemical signature for pre-Ambrosia lake sediments, from catchments underlain entirely by the Algoma plutonic domain in the Trout Lake area. The element symbols refer to the pre-Ambrosia lake sediment datum (solid line) and the results from the Algoma plutonic domain (dashed line). For further explanation see text.*

the Clarke Index-I geochemical signatures focusses attention on the close relationship between litho-geochemistry and pre-Ambrosia lake sediment geochemistry. This is of fundamental importance to the regional geochemical mapping of areas covered by glacial deposits.

Once this type of general geochemical relationship has been firmly established, geochemical signatures can be examined in detail in order to discover more subtle geochemical relationships. These subtle relationships may relate to information of direct importance in mineral exploration, i.e., the presence of alteration or mineralization in catchment areas covered with glacial drift.

A MULTIELEMENT GEOCHEMICAL SECTION FROM THE TROUT LAKE AREA

The traditional role of geochemical mapping has been to locate "geochemical anomalies" which may lead directly to mineralization. We have shown that regional geochemical mapping, based on pre-Ambrosia lake sediments collected at a sample density of around one sample per square kilometre, can identify "geochemical anomalies" in areas where mineral showings have been, and in some cases have not been, reported (Fortescue and Vida, in press).

Recently, geochemists have identified a second, potentially more important, role for geochemical mapping; the identification of "geochemical provinces". Such provinces may, or may not, coincide with metallogenic provinces (Plant et al. 1989) and may have a large or relatively small extent. It is the geochemical provinces of small extent which are identified on individual geochemical maps sheets such as the Trout Lake sheet.

On the regional scale, multielement geochemical-geological cross sections aid in the identification of geochemical provinces. The sections may also relate geochemical data graphically to one or more types of rock and/or structure.

Geochemical sections on the Batchawana geochemical map series are based on sampling strips 5 km wide and are centered on the geological section under consideration. In Figures 47.2 and 47.5, the location of such a sampling strip is indicated on the Trout Lake map sheet area.

A regional geochemical-geological cross section is prepared as follows: (1) a line representing the desired geological section is drawn across the map in the location required; (2) a 5 km wide sampling strip is centred on the map trace of the geological section; (3) locations of all lake sediment sample points within the sampling strip are projected onto the trace of the geological section; (4) values for selected elements in the subset of lake sediments are transformed into Clarke Index-I units and are plotted using the intervals previously projected on to the map trace of the geological section; and (5) the geochemical-geological cross section is combined and labelled.

Figure 47.4 is an example of this procedure. It represents a geochemical-geological cross section across the Trout Lake Sheet mentioned above. The geological cross section included in Figure 47.4 shows the lake catchment areas selected are underlain by four different rock types. The geochemical section includes data for 10 trace elements in pre-Ambrosia lake sediments collected from these catchments. The spacing of the geochemical data points reflects the distribution of lake sediment sample sites within the sampling strip.

It is evident from Figure 47.4 that each element has a characteristic pattern along the geochemical section. For example, the Cu and Zn values in the sediment are relatively uniform along the entire section. The patterns for Sb is similar except for a single "isolated high" value occuring over the Algoma plutonic domain. The Mo pattern shows several relatively high values over the Algoma plutonic domain at the south end of the section and three high values within the mafic metavolcanics at the north end of the section. The latter may result from transport of Mo from areas of granitic rocks further north in the terrane covered with calcareous glacial drift.

In Figure 47.4, the elements As, Ag, Au and Cd are perceived to have a common pattern associated with the area of complex geology between the mafic metavolcanics and the Algoma plutonic domain. Several of these patterns appear to have been displaced to the south by glacial smearing. The U and La patterns probably reflect geological variations within the Algoma plutonic terrane.

Using the data base disk and a personal computer, geochemical sections of this type are relatively simple to draw. Consequently, in a detailed interpretation of the Trout Lake map data, many of these sections would be drawn parallel to each other. In this way the use of multiple sections facilitates the interpretation of the geochemical data and, at the same time, allows for the identification of isolated element values which do not fit into geochemical patterns.

GEOCHEMICAL SECTIONS AND GEOCHEMICAL MAP PATTERNS

Geochemical variations associated with particular elements within a given rock type revealed by geochemical sections may be later mapped as "geochemical provinces". This procedure is illustrated by two simple examples in Figure 47.5.

The first example is the U-rich area in the Algoma plutonic domain identified and discussed above. The second is a smaller cluster of high U values associated with the Grey Owl Lake stock which lies to the north of the Trout Lake sheet (Figure 47.5).

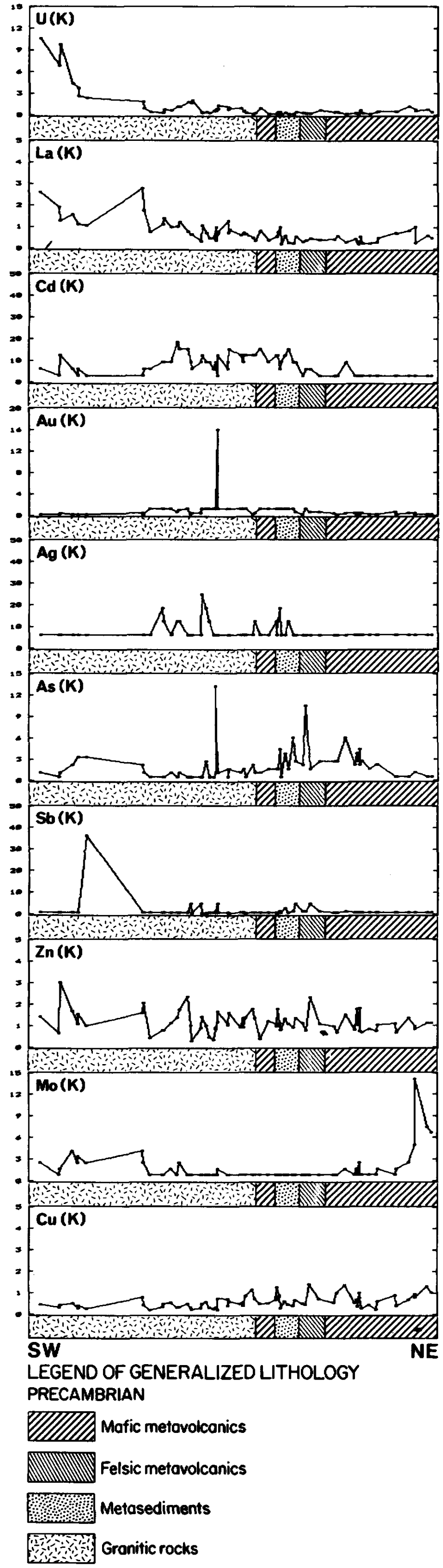

Figure 47.4. *A geochemical section diagonally drawn across the Trout Lake sheet (for exact location, see Figure 47.2 and Figure 47.5). Note the geological section which appears below each of the sets of element data and the spacing of the lake sediment data points which are projections from all sample sites within the sampling strip. For further explanation see text.*

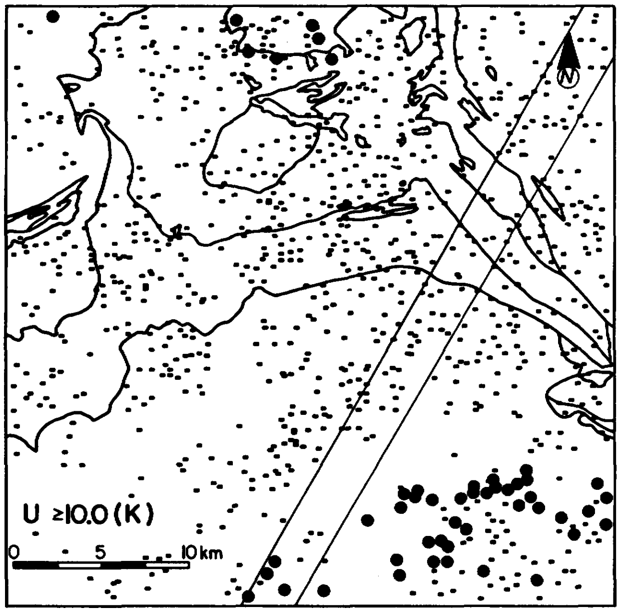

Figure 47.5. *A geochemical map of the Trout Lake area showing sample sites (rectangular dots) along with sample sites found to have uranium at a concentration greater, or equal to, 10 K (23 ppm) in pre-Ambrosia lake sediment (large round dots).*

It is concluded from these examples, and other similar cases not described here, that regional patterns on geochemical maps based on pre-Ambrosia lake sediments provide important information on the behaviour of trace elements within and between lithologies mapped by geologists. The detailed study of relationships of this type, on the basis of regularly spaced geochemical-geological cross sections placed within a geochemical map, may provide information pertinent to the mineral resource appraisal process.

PROJECT PROGRESS IN 1989

TROUT LAKE GEOCHEMICAL MAP SHEET

The Trout Lake geochemical map is the first full-scale example of a new regional geochemical map format developed by the writers at the Ontario Geological Survey. The format was developed from a prototype described by Fortescue and Stahl (1988b).

The Trout Lake regional geochemical map covers a 1225 km^2 area in the central part of the Batchawana greenstone belt (Figure 47.2). This regional geochemical information will be released in two parts: (1) a hard copy, coloured, geochemical map sheet with a 1:50 000 scale, and (2) a data disk which includes positional and geochemical data for the 946 water and lake sediment samples collected from the Trout Lake area. Some highlights of the geochemical data base are tabulated on the map sheet together with the marginal notes. Together, they will provide an introduction to the regional geochemistry of the area.

HANES LAKE GEOCHEMICAL MAP SHEET

A total of 905 samples of pre-Ambrosia lake sediment core material were collected from the 730 km^2 Hanes Lake area during August and September 1989 (*see* Figure 47.1). The objectives of the Hanes Lake geochemical survey are

1. to collect water and pre-Ambrosia lake sediment core material from at least one point in all lakes and ponds accessible by a helicopter within the Hanes Lake area
2. to provide a geochemical map (and associated data disk) for water pH, Ca and Mg, and levels of Ag, Al, As, Au, Ba, Be, Bi, Br, Ca, Cd, Co, Cr, Cu, Fe, Hf, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sr, Ta, Th, Ti, U, V, W and Zn in the pre-Ambrosia lake sediment samples collected from the entire area covered by the geochemical survey
3. to provide a summary of the geochemical behaviour of the elements (determined by the waters and lake sediment) in the marginal notes of the geochemical map similar to those described for the Trout Lake map sheet described above

On their arrival in Toronto, the water samples were sent to the Geoscience Laboratories of the Ontario Geological Survey for Ca and Mg determinations. The lake sediment samples, after being sequenced with quality control samples, were delivered to the contractor (Chemex Labs Ltd., Mississauga, Ontario) for sample preparation and chemical analyses.

Results from the chemical analyses are expected by March 1990 and the geochemical map will be released as soon as it is completed.

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Geoscience Laboratories Programs

48. Summary of Activities 1989, Geoscience Laboratories Section

Chris Riddle

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INTRODUCTION

The Geoscience Laboratories Section of the Ontario Geological Survey produces geoanalytical data in support of Mineral Resource Activity programs. A summary of analytical capabilities, "Analytical Capabilities and Services", was published in 1989 and may be obtained from the Laboratories Section.

The Laboratories Section also develops analytical methods for geoanalytical applications. This summary of activities highlights recent achievements in the Laboratory Section's three subsections.

To place these achievements in perspective, the interested reader is referred to the "Geoscience Laboratories' Manual".

A highlight of the year was the Symposium on Analytical Chemistry in the Mineral Industry, held in conjunction with the 72nd Annual Canadian Chemical Conference. The Geoscience Laboratories Section organized sessions on 1) sampling and quality control, and 2) inductively coupled plasma-mass spectrometry (ICP-MS); and presented two papers at the symposium. During the two-day meeting, papers on current topics of interest were presented to an audience of mineral industry laboratory scientists and technicians.

MINERAL SCIENCE SUBSECTION

Peter Lightfoot, Supervisor of the Mineral Science Subsection, has contributed to several co-operative projects with other Ontario Geological Survey (OGS) sections. These projects include temporal and spatial geochemistry of Archean volcanics from Wawa, petrogenetic studies of the Keweenawan basalt sequence, and studies of the Nipissing diabase and associated platinum group element mineralization. A review of flood basalt geochemistry based on work performed in conjunction with Richard Sutcliffe follows this summary (*see* Paper 49, this volume). Peter also published a new method for isotopic analysis of Nd (Lightfoot et al. 1989).

GRAIN-SIZE ANALYSIS

An automated technique for grain-size analysis is in routine use to analyze coarse-grained sediments.

MINERAL STUDIES

A Frantz isodynamic magnetic separator has been upgraded with the addition of a low-field attachment, and this has been used along with heavy liquids and a binocular microscope in the separation of phenocryst phases from medium-grained gabbroic rocks from the Nipissing diabase and Keweenawan magmatic provinces. Work has begun in the Laboratories Section to develop quantitative X-ray diffraction (XRD) techniques for the modal mineral analysis of rock powders and thin sections, and the determination of clay minerals. It is expected that the recently acquired XRD system, which is equipped with a Peltier-cooled silicon detector, will provide a significant increase in peak-resolution when compared to the existing, conventional XRD system equipped with a gas proportional counter.

In preparation for the installation of a fully equipped micromineralogical laboratory in the Mines and Minerals Research Centre, Sudbury (future home of the OGS), Hugh de Souza, the Laboratories Section Mineralogist, has undertaken a number of projects using the scanning electron microscope in the Department of Geology, University of Toronto, and the microprobe in the Department of Geology, University of Western Ontario.

FIELD SAMPLING GUIDE

A "Guide to Sampling for Geoanalysis" has been prepared in draft form and circulated to OGS field geologists for review. A final version will be published in 1990. The guide reviews aspects of sampling which have an impact on the significance of laboratory-produced data and which may therefore limit interpretations based on such data. Although primarily written for field assistants, the guide is intended for general use.

CHEMISTRY SUBSECTION

Chris Chan, Supervisor of the Chemistry Subsection, has continued to develop analytical methods involving the technique of flow-injection. In 1989, a semi-automated method for the determination of Bi was developed. The determination limit is 20 ppb, and up to 40 predigested samples can be analyzed per hour.

ROBOTICS

A Zymark Z100E robotic system is now providing routine digestion of rock-pulp samples for analysis by solution-based techniques (atomic absorption spectrophotometry (AAS) and inductively coupled plasma optical emission spectrometry (ICP-OES)). A mixed-acid attack, using HF, $HClO_4$, HNO_3 and HCl produces up to 40 sample solutions per day ready for analysis. A paper on this work was presented at the Canadian Mineral Analysts annual meeting in Timmins (Howlett, Chan and Heydon, in press).

SPECTROSCOPY SUBSECTION

David Boomer joined the Spectroscopy Subsection in 1989 as Supervisor. His 24 years of experience at the Ontario Ministry of the Environment have included use of all the spectroscopic systems currently in place at the Geoscience Laboratories Section. Will Doherty, ICP Scientist, has been contracted to undertake a two-year research project on ICP methods development.

DEVELOPMENTS IN ICP-MS

In conjunction with Peter Lightfoot, projects on the Keweenawan diabase and Nipissing diabase have generated data bearing on the origin of these magmatic provinces and the associated mineralization (Lightfoot and Naldrett 1989). Mineral phases separated from Nipissing samples were analyzed using ICP-MS to determine the rare earth element (REE), Th, Ta, Hf, U and Nb concentrations. These have been used to constrain partition coefficients and petrogenetic models.

The ICP-MS laboratory has advanced the development of new methods and the culmination of several years' work on the development of a method for the determination of REE and Y was published externally this year (Doherty 1989).

A new analytical package (Trace 5) was introduced. It provides high quality, sensitive determination of Hf (200 ppb), Ta (50 pbb), Th (100 ppb) and U (100 ppb) (determination limits in parentheses).

The result of instrument-design development work was presented by Will Doherty at the Symposium on Analytical Chemistry in the Mineral Industry. A blunted skimmer developed in the Laboratories Section has improved sensitivity and long-term instrument stability while providing substantial cost-savings.

DEVELOPMENTS IN ICP-OES

The Geoscience Laboratories Section purchased a new ICP-OES spectrometer system, developed in Ontario, following evaluation of a prototype instrument. The Plasmarray system, marketed by LECO Corporation, uses photodiode array detection with a novel optical path designed to produce high resolution spectra. It will be applied to the determination of analytes in samples with unusual matrices e.g., carbonatites. These samples pose considerable difficulty for the analyst due to complex interference patterns and the lack of available reference materials.

DEVELOPMENTS IN XRF (X-RAY FLUORESCENCE)

The transfer of the major element packages (M1, M2 and M3) to the Philips PW1400 spectrometer system has lead to improved precision in Si and P data as monitored through the Laboratories' Blind Duplicate Quality Control Program.

LOOKING AHEAD

One major activity of 1989 remains to be mentioned—the planning of the new laboratories for the Mines and Minerals Research Centre in Sudbury.

As a service group for the OGS, and other Ministry clients, the Laboratories Section must constantly strive to anticipate and prepare to meet future analytical requirements. The relocation exercise provides an opportunity to ensure that the new laboratory facility is able to meet these requirements.

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49. Precise Determination of Trace Element Abundances in Basalts from the Black Bay Peninsula and Mamainse Point Sections of the Keweenawan Volcanic Pile Using Inductively Coupled Plasma–Mass Spectrometry

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INTRODUCTION

Geochemical studies of thick, laterally continuous packages of young continental flood basalts (CFB) have provided:

1. an insight into the processes controlling the compositional variations in basaltic magmas (e.g., Cox and Hawkesworth 1984, 1985; Lightfoot and Hawkesworth 1988)
2. a method by which the stratigraphy of basalts may be correlated over wide lateral intervals (e.g., Devey and Lightfoot 1986)
3. the capability to correlate extrusive with intrusive magmatic activity
4. an approach to understanding the mechanism of segregation of magmatic nickel, copper and platinum group element (PGE) enriched sulphides (cf. Lightfoot et al. 1984)

In this summary we present preliminary field data, analytical methodologies and chemical data on the 3 km thick sequence of *circa* 1.1 billion year old basaltic rocks of the Black Bay Peninsula, Lake Superior, a part of the Osler sequence of the Keweenawan CFB province (Figure 49.1). We also include preliminary field information about a suite of samples from the 4 km-thick Mamainse Point sequence (Figure 49.1). These samples form the basis of our approach to understanding the petrogenesis of Keweenawan volcanics.

The narrow range in major and trace element concentrations within many volcanic suites requires the precise determination of the concentrations of petrogenetically significant elements (e.g., the rare earth elements (REEs), Y, Zr, Cs, Th, Ta, Hf, U, Nb, Rb and Sr) at natural abundance levels. In the past, this has generally been accomplished using a combination of X-ray fluorescence (XRF) and instrumental neutron activation techniques (INA). The detection limits for Rb and Nb by XRF techniques are close to the natural abundance levels of these elements in basic rocks; this level of precision is not sufficient to resolve very small differences in the concentrations and/or ratios of the trace elements. For this reason, an in-house inductively coupled plasma-mass spectrometry (ICP-MS) technique to determine the levels of all of the REEs (Doherty 1989), together with Y, Zr, Th, Ta, Hf, U, Nb, Sr, Rb and Cs, has been developed. These results are supported by major element data as determined by wavelength-dispersive XRF techniques, and data for Ba, Cr, Ni, Co, Zn, Cu, Sc and V as determined by atomic absorption and inductively coupled plasma-optical emission spectroscopy (ICP-OES) techniques.

The data determined in this study demonstrate the potential of the geochemical approach to the wider applications of understanding relationships in mafic rocks of older shield areas.

GENERAL GEOLOGY

BLACK BAY PENINSULA

The Black Bay Peninsula area was initially mapped by Tanton (1931), and subsequently mapped by McIlwaine and Wallace (1976) at a scale of 1:63 360. In the Black Bay Peninsula and St. Ignace Island area, the rift-related rocks consist predominantly of tholeiitic flows with minor interflow sediments and rhyolites. The flows overlie Archean basement, and the package thickens to the south of the Black Bay Peninsula (Cannon et al. 1989). Basaltic magmatism apparently commenced around 1109 Ma (Davis and Sutcliffe 1985) and terminated around 1086 Ma (Palmer and Davis 1987).

Osler group tholeiitic flood basalts underlie much of the Black Bay Peninsula and are described by McIlwaine and Wallace (1976). They consist of massive simple-type flows and highly amygdaloidal compound-type flow units (e.g., Lightfoot 1985). Columnar jointing, ropy flow tops, pahoehoe structures and pipe amygdules are locally observed in these rocks.

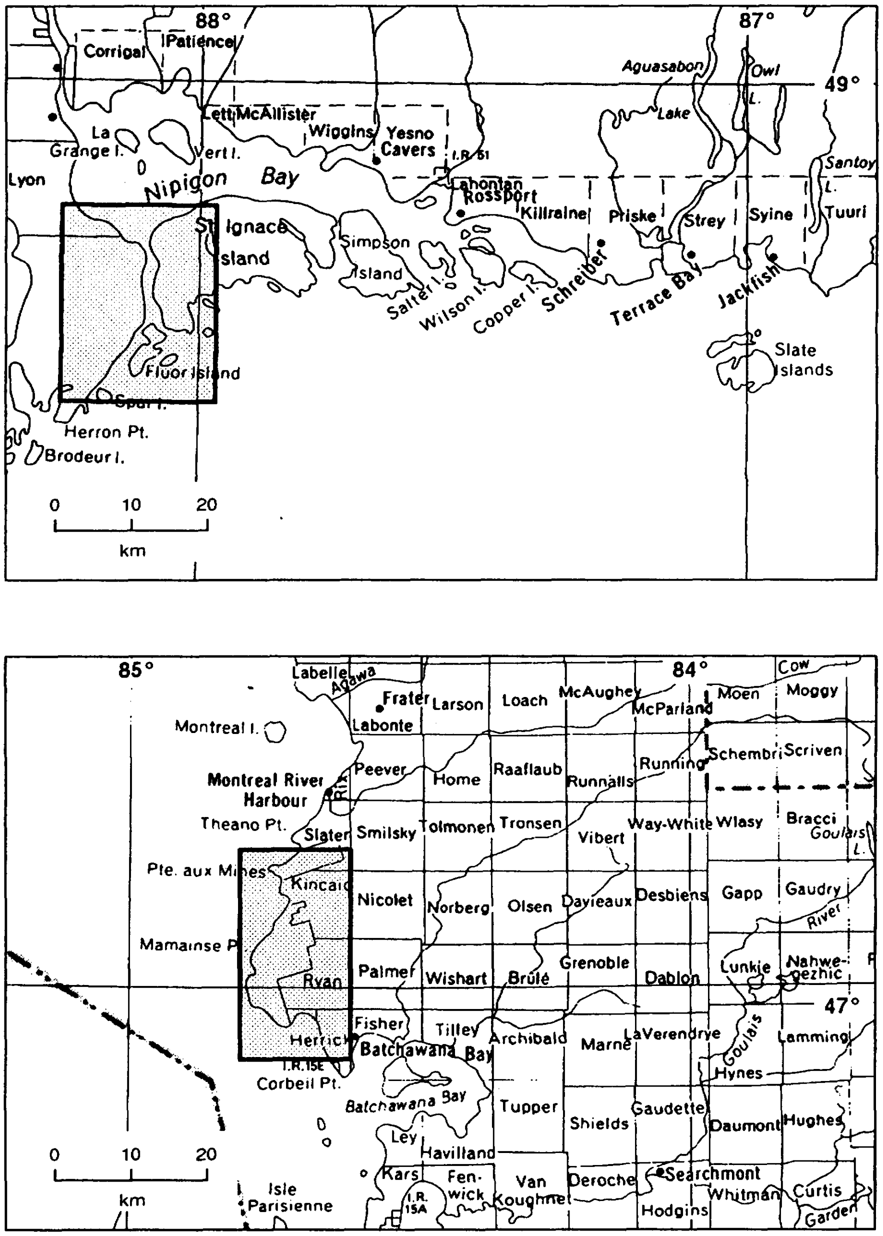

Figure 49.1. *Maps showing locations of study areas.*

The red quartz-feldspar porphyry at the base of the sequence is apparently a flow (McIlwaine and Wallace 1976). Porphyritic felsic volcanics occur in the vicinity of Agate Point, but the porphyries of Fluor Island are apparently intrusive (McIlwaine and Wallace 1976), and crosscut the tholeiitic basalt sequence. The volcanics are crosscut by the Moss Lake gabbro to the southwest.

There is no geological evidence for major faulting parallel to the strike of the flows, although we cannot be sure that faults are absent between the Black Bay Peninsula, Fluor Island and Puff Island sections (Figure 49.2). For the sake of discussion, we presume that the vertical sequence of samples reflects the compositional variation in successively erupted flows of basalt.

There are a number of large basic intrusions associated with the Black Bay Peninsula and St. Ignace Island basaltic flows, and Sutcliffe and Smith (1988) point out that the geological setting is very similar to the Tertiary volcanic centres of western Scotland. Little work has been performed on the basic intrusions to evaluate their potential as hosts for nickel, copper and platinum group element mineralization, and Sutcliffe and Smith (1988) suggest that these intrusions should receive further attention.

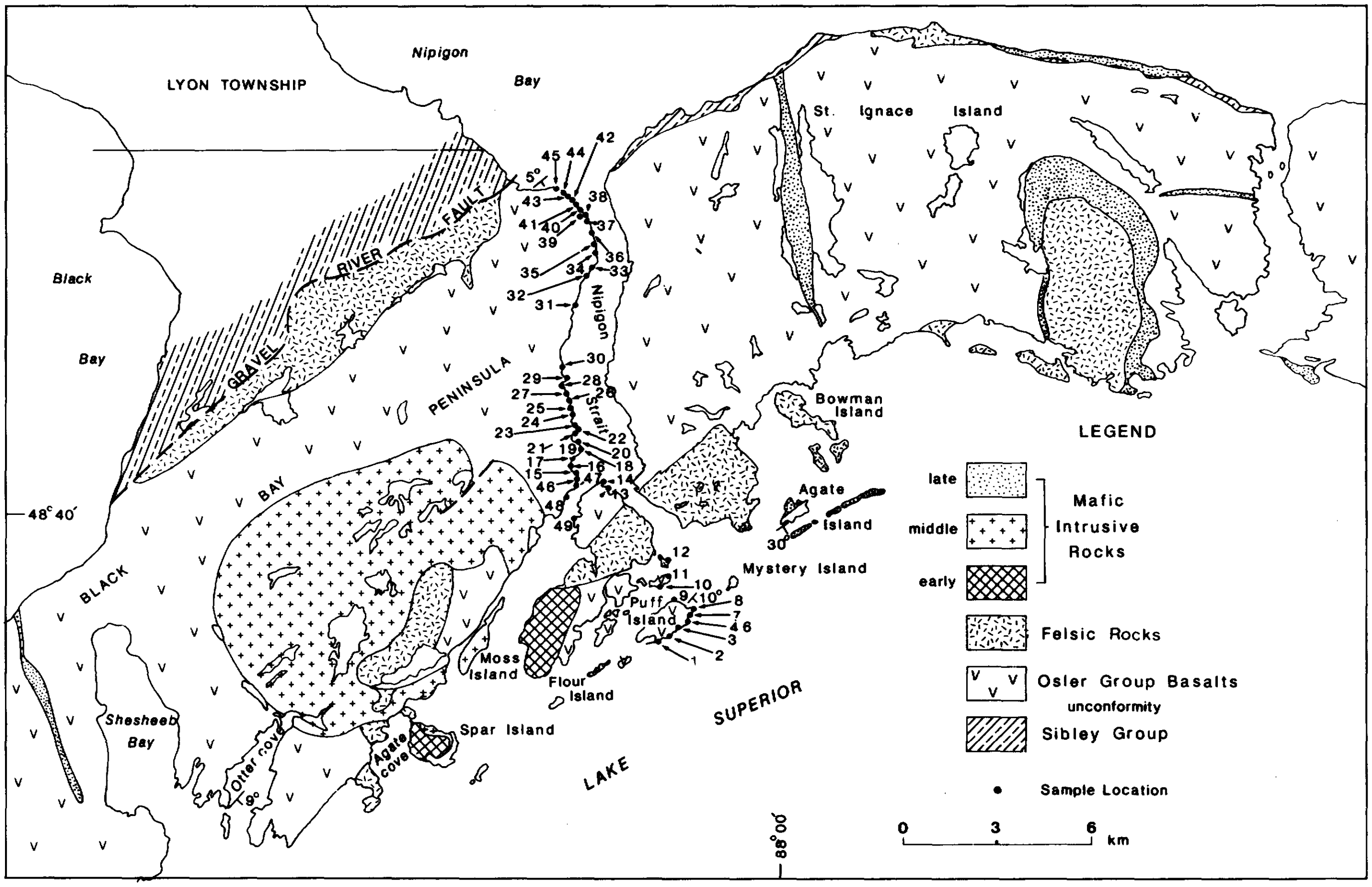

Figure 49.2. *Geological map of the Black Bay Peninsula and St. Ignace Island, showing the general geology and the location of basalt samples in the volcanic sequence.*

MAMAINSE POINT

The Mamainse Point area lies at the eastern end of Lake Superior. A thickness of about 5 km of the Mamainse Point Formation is exposed in shore and highway sections (Annells 1973; Giblin 1969a-d). The Mamainse Point Formation consists of picritic basalts and olivine- and feldspar-phyric tholeiitic flood basalts with minor felsic intrusive bodies and conglomeratic sediments (Berg and Klewin 1988; Annells 1973; Thompson 1954). The sequence rests unconformably on Archean basement, and is crosscut by a number of faults, the largest of which appears to cross Hibbard Bay parallel to the strike of the flow sequence (Figure 49.3).

These flows have been the subject of a number of extensive geochemical investigations (Massey 1980a, 1980b, 1982, 1983; Berg and Klewin 1988) which have indicated that much of the variation in the volcanic pile can be explained by a combination of fractional crystallization, dynamic partial melting and crustal contamination. These studies have, however, left a number of unresolved issues, not least of which include: 1) the relationship of these rocks to the Osler group; 2) the relationship between picritic, basaltic and evolved members of the suite; and 3) the source of the magmas, and the mechanism of liquid evolution.

FIELD PROGRAM

A total of 49 samples of basalt were collected through the exposed portion of the Osler basalt sequence of the Black Bay Peninsula, of which seven were a check on the degree of alteration of the basalt and lateral flow homogeneity. In a comparative study, 108 samples were collected through the Mamainse Point sequence of basalts and rhyolites to look at interflow variation on a detailed scale; 10 of these samples were collected vertically through a single flow unit and three laterally along a single flow to document intraflow homogeneity.

The freshest material was collected and the upper and lower zeolitic portions of flows were avoided as far as possible. All samples were cleaned of weathered surfaces and the larger zeolite filled amygdules (>0.5 mm) were removed. Sample locations are shown on Figures 49.2 and 49.3.

SAMPLE PREPARATION, ANALYTICAL TECHNIQUES AND QUALITY CONTROL

Samples were crushed using steel jaws, and then ground in a 99.8 percent pure, alumina planetary mill (note: this mill may introduce up to 0.25 percent Al_2O_3 during grinding). Major and selected trace element values were determined by conventional XRF and atomic absorption techniques in the

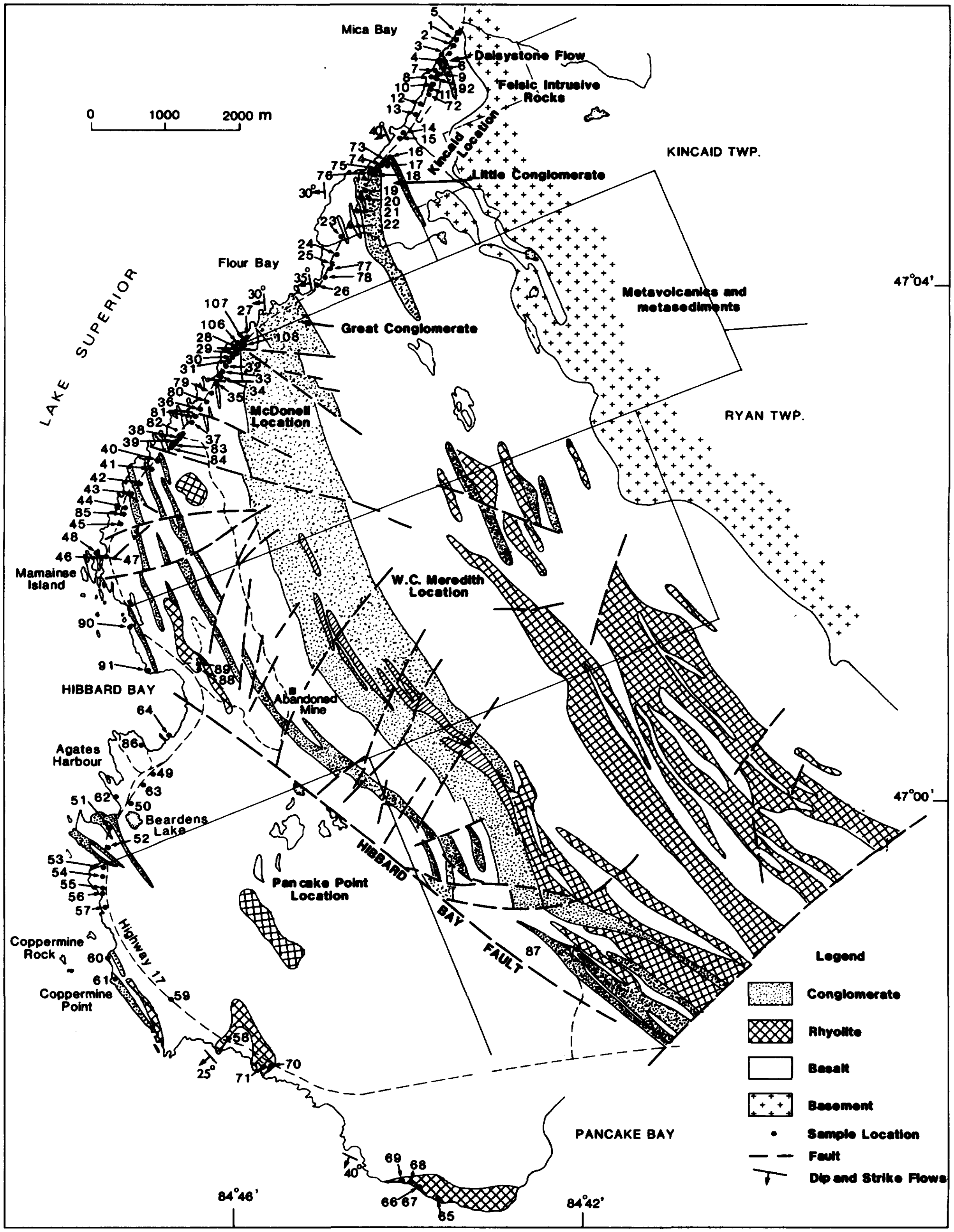

Figure 49.3. *Geological map of the Mamainse Point sequence, showing the general geology, and the location of basalt and rhyolite samples collected from the volcanic sequence.*

Geoscience Laboratories, Ontario Geological Survey, Toronto.

An ICP-MS based procedure for the accurate (±2 to 4 percent) and precise (±2 to 4 percent relative standard deviation) determination of Rb, Nb, Sr, Zr, Cs, Hf, Ta, Th, U, Y and the REEs in rocks has been established. The solubility problem associated with solutions containing Hf, Ta and Nb was solved by developing a stabilization technique utilizing hydrofluoric acid which allows the simultaneous determination of all the target elements in a single sample preparation. The analysis of trachytic and rhyolitic materials required the development of a combination of fusion and acid digestion techniques to open up the acid insoluble Zr phase. This allows for the accurate determination of Hf and the heavy REEs, which might otherwise be retained in insoluble phases such as zircon.

Determinate error associated with the ICP-MS instrumental effects are compensated for by the use of a dual internal standardization scheme (Doherty 1989). An investigation into the instrumental factors affecting the determinate error demonstrates the versatility of the correction procedure, and therefore its suitability for reliable use in a routine analytical laboratory setting.

Quality control measures taken during the course of this study include the analysis of basaltic standards (UTB-1, the University of Toronto basalt standard; BHVO-1, a USGS international reference standard; and in-house reference materials) and the introduction of duplicate samples in the analytical scheme. Table 49.1 provides data on the accuracy and precision of the analytical scheme based on multiple analyses of a standard. It should be noted that precisions quoted in Table 49.1 for elements determined by the ICP-MS technique are significantly better than those achieved by XRF and INA techniques, and that the 95 percent confidence limits are an order of magnitude smaller than the range in compositions found in the basalt sequence.

Software was developed to model the geochemical effects of Rayleigh fractional crystallization, batch melting and mixing of magmas; the programs are based on the algorithms of Allegre and Minster (1978). Distribution coefficient data are taken from Henderson (1982).

THE BLACK BAY PENINSULA SEQUENCE

GEOCHEMICAL STRATIGRAPHY

Geochemical variations are described in a stratigraphic context; the calculation of position within the sequence is based on: 1) the fact that the sample profile was collected perpendicular to the strike of the flow package, and 2) the average dip of the basalts is ten degrees.

We have investigated the degree of variation within a single flow located at the top of the sequence, and note that the compositional variability within this flow is small compared to the sequence as a whole. For example, in Figure 49.4, the group of seven samples collected at 3000 m above the base of the sequence have La/Sm ratios ranging from 2.4 to 2.7 and Gd/Yb ratios ranging from 1.7 to 1.9. This compares with La/Sm ratios of 2.0 to 6.2 and Gd/Yb ratios of 1.5 to 4.6 for the entire sequence. On these grounds, we suggest that the geochemical variations found are largely produced by processes other than alteration, and that flows are homogenous on the kilometre scale.

Variations in selected major and trace element concentrations and ratios are illustrated in Figure 49.4, where the vertical axis shows the relative positions of the samples in the 3000 m-thick basalt stratigraphy, and the horizontal axis shows the trace element concentrations and ratios. It is the concentrations and, more importantly, the ratios of these trace elements which permit us to split the stratigraphy into suites, each characterized by a particular magma type.

The plots indicate that the stratigraphic succession can be broadly subdivided into three groups of flows, here termed flow suites; these are the "Lower", "Central" and "Upper" flow suites. Although there are five samples which have not yet been fit into these three groups, the general subdivision holds true for the majority of samples. The lower 750 m of stratigraphy (Lower suite) is characterized by relatively high Mg-number (0.58 to 0.66) and Gd/Yb ratio (3.2 to 4.5), and low Th concentration (1.5 to 2.5 ppm) and La/Sm ratio (2.0 to 3.5), which contrasts strongly with the Central and Upper suites. Within the Lower suite, there is little variation in Mg-number or Th concentration, but La/Sm and Gd/Yb ratios appear to decrease very slightly. The Central flow suite is less primitive than the Lower suite (Mg-number = 0.62 to 0.42), has higher Th concentrations (8.0 to 2.0 ppm), and higher La/Sm ratios (6.0 to 3.0), but lower Gd/Yb ratios (2.2 to 1.5). There is a gradual change in the concentrations and ratios upwards through the sequence as Th, La/Sm and Gd/Yb progressively fall. Stratigraphically, there is an apparent interdigitation of Lower and Central suite flows between 500 and 800 m; this may reflect the eruption of both types of magma in this time interval. The Upper flows are more like the Central flows in their Gd/Yb and La/Sm ratios, but they clearly define a separate cycle of progressively changing flow compositions. Mg-number varies from 0.3 to 0.6, Th concentration ranges from 0.25 to 5.5 ppm, and there is a gradual decline in La/Sm (4.5 to 2.5) and Gd/Yb (2.5 to 1.5) ratios upwards through the sequence from 2500 to 3000 m above the base.

The two main breaks in the stratigraphy between 900 and 1100 and 2000 and 2500 m result from

TABLE 49.1. ANALYTICAL RESULTS FOR STANDARD REFERENCE MATERIALS AND PRECISION LEVELS FOR MAJOR AND TRACE ELEMENTS DETERMINED IN THIS STUDY. EXPECTED UTB-1 VALUES FROM LIGHTFOOT ET AL. (1987). EXPECTED BHVO-1 VALUES FROM GLADNEY AND ROELANDTS (1988). THE PRECISION OF 1σ IS BASED ON MULTIPLE ANALYSES OF THE IN-HOUSE BASALTIC REFERENCE STANDARDS (FOR MAJOR ELEMENT OXIDES, Ni, Cu, Cr, Co, Sc, V AND Ba), AND BHVO-1 (FOR THE REEs, Th, Ta, Hf, U, Y, Nb, Zr, Rb AND Sr).

Element/Oxide	Precision (1σ)	UTB-1 observed	UTB-1 expected	BHVO-1 observed	BHVO-1 expected
SiO_2 (wt. %)	0.3	49.7	49.6	nd	ns
TiO_2	0.03	3.09	3.09	nd	ns
Al_2O_3	0.14	13.5	13.5	nd	ns
Fe_2O_3	0.20	15.3	15.2	nd	ns
MgO	0.09	4.0	4.5	nd	ns
MnO	0.01	0.22	0.21	nd	ns
CaO	0.09	8.70	8.50	nd	ns
Na_2O	0.19	2.69	2.83	nd	ns
K_2O	0.03	1.32	1.30	nd	ns
P_2O_5	0.02	0.68	0.74	nd	ns
LOI	0.40	0.20	na	nd	ns
Ni (ppm)	4.4	nd	ns	nd	ns
Cu	1.4	nd	ns	nd	ns
Cr	6.6	nd	ns	nd	ns
Co	1.4	nd	ns	nd	ns
Sc	5	nd	ns	nd	ns
V	10	nd	ns	nd	ns
Zn	5.8	nd	ns	nd	ns
Ba	13	nd	ns	nd	ns
Rb	0.8	33.5	35	9.8	11
Sr	4	329	311	416	403
Y	0.8	44.6	41.0	26.2	27.6
Zr	3.5	207	200	183	179
Nb	0.5	18.6	15.3	22.5	19
Th	0.05	4.0	4.4	1.16	1.08
U	0.05	0.6	1.0	0.40	0.42
Ta	0.05	1.01	1.03	1.30	1.23
Hf	0.12	5.31	5.1	4.84	4.38
La	0.30	26.9	26.7	15.5	15.8
Ce	0.8	63.3	65.0	38.8	39
Pr	0.16	nd	na	5.88	5.7
Nd	0.8	36.8	32.0	25.3	25.2
Sm	0.21	8.06	8.0	6.38	6.2
Eu	0.10	2.66	2.40	2.15	2.06
Gd	0.16	8.41	na	6.39	6.4
Tb	0.04	1.29	na	0.98	0.96
Dy	0.20	8.18	na	5.43	5.2
Ho	0.03	1.64	na	1.03	0.99
Er	0.11	4.50	na	2.64	2.4
Tm	0.02	0.64	na	0.33	0.33
Yb	0.06	3.96	4.00	2.02	2.02
Lu	0.01	0.61	0.62	0.29	0.29

Notes: nd: not determined
ns: not shown
na: not available

lack of exposure. These breaks may correspond to faults, the interpretation of the changing geochemical variations must, therefore, be made with caution. However, it is evident that the geochemical signatures of the three suites are quite distinctive, and there is no evidence for fault repetition of a portion of the stratigraphy. The appearance of trachytic rocks close to the 2000 m level (some of which are flows) raises an important question regarding the relationship of basaltic and trachytic magmas and the degree of interaction between these components.

PETROGENESIS

The distinctions between the three suites are most clearly illustrated in Figure 49.5, which shows the variation in La/Sm versus Gd/Yb. This plot is

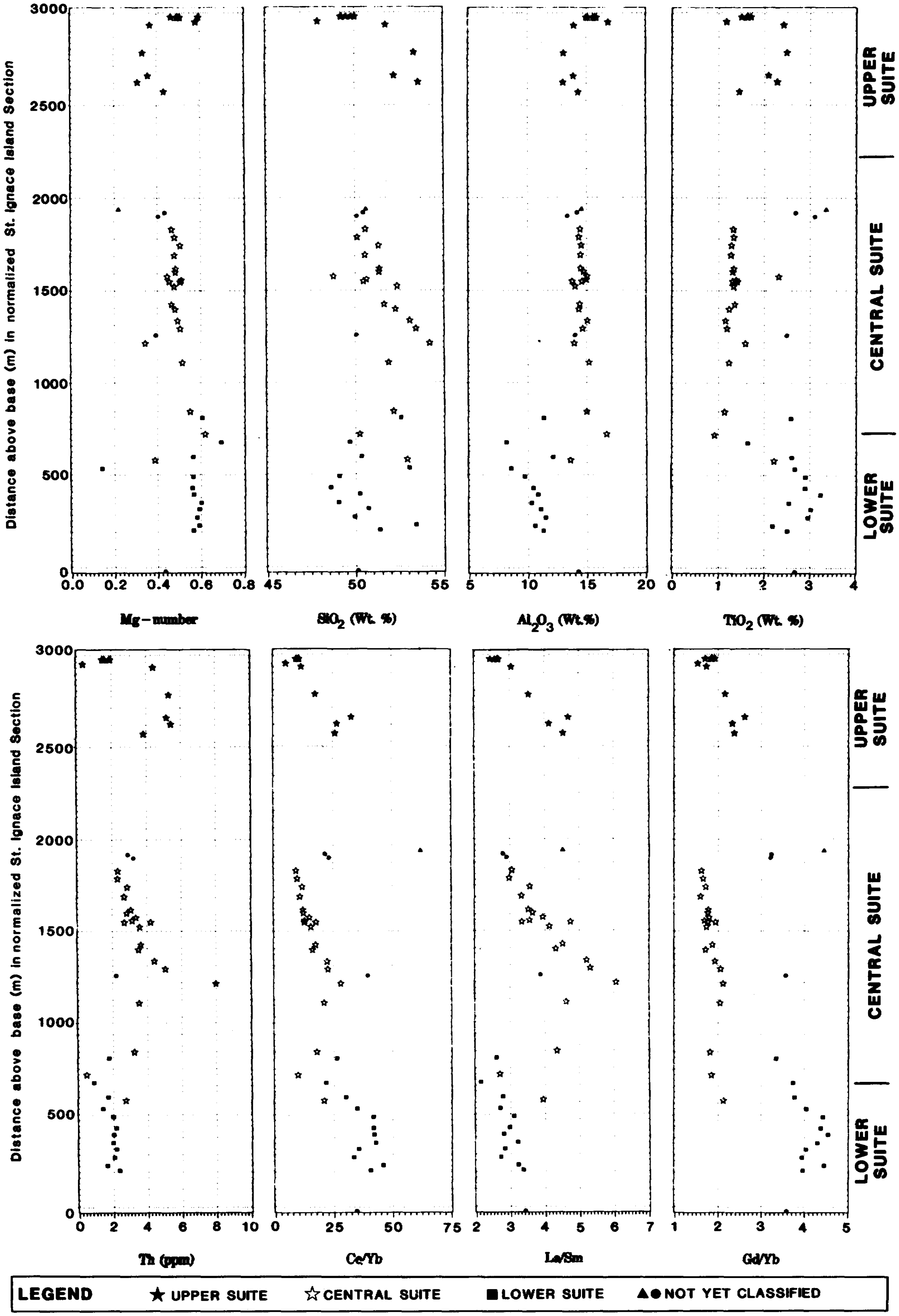

Figure 49.4. *Stratigraphic geochemical variations through the sequence of tholeiitic basalts on the Black Bay Peninsula.*

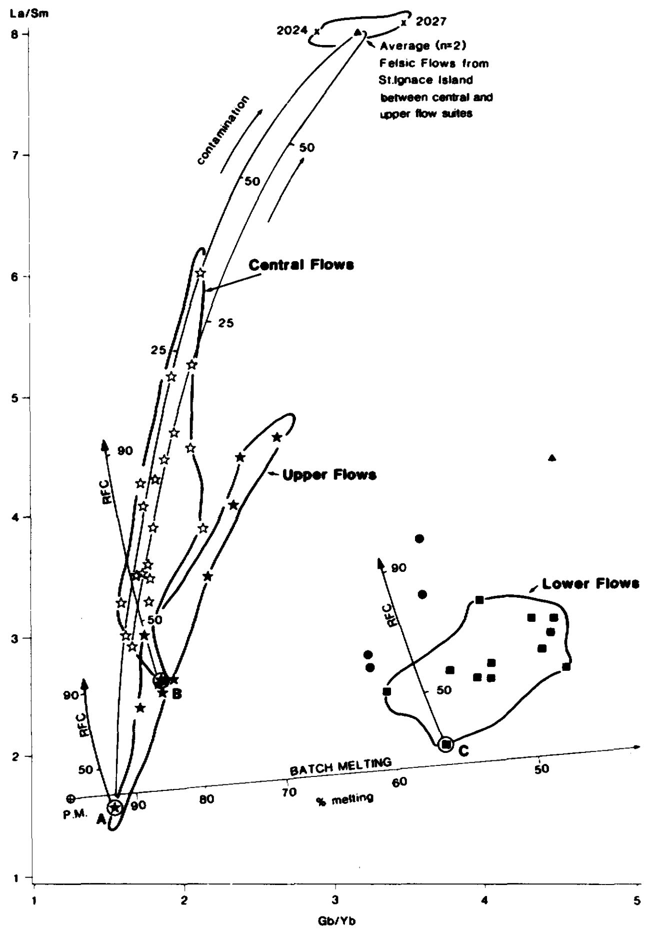

Figure 49.5. *Variation in La/Sm versus Gd/Yb in tholeiitic flows from the Black Bay Peninsula suites. Fields are shown enclosing the "Lower", "Central" and "Upper" suites. Five samples have not yet been allocated to any single suite. The variations are modelled in terms of batch melting (see text), Rayleigh fractional crystallization of a gabbroic mineral phase extract, and mixing of more primitive magma with a magma whose composition is represented by the average of samples from two felsic flows from St. Ignace Island (88ARS-2024 and 88ARS-2027). Tick-marks on modelled trends show: 1) the percentage of melting of a primitive mantle source; 2) the percentage Rayleigh fractional crystallization (RFC) of magmas represented by samples A, B and C (the extract consists of: 10 percent olivine, 60 percent plagioclase, 30 percent augite; the distribution coefficients are from Henderson 1982); and 3) the percentage contribution of felsic magma to primitive basaltic magmas from the "Central" and "Upper" flow suites.*

particularly useful as it demonstrates clearly the variations in the slopes of the REE patterns between La and Sm, and Gd and Yb. The Central and Upper flow suites are quite distinctive compared to the Lower flow suite in that they have much higher Gd/Yb ratios. The levels of Yb and Al_2O_3 are generally lower (Figure 49.4), but Ce/Yb ratios, TiO_2 levels and Mg-numbers are generally higher in the Lower than in the Central and Upper flow suites. The higher Mg-numbers suggest a lesser degree of evolution, and the low Al_2O_3 and high TiO_2 levels indicate the possibility that garnet was involved in the petrogenetic scheme. A simple batch melting program (Lightfoot, in-house software) was used to illustrate the effects of melting on a primitive garnet lherzolite mantle source (50 percent olivine, 30 percent orthopyroxene, 10 percent clinopyroxene and 10 percent garnet) assuming that all phases contribute equally to the melt and utilizing distribution coefficients from Henderson (1982). The resultant trajectory (shown in Figure 49.5) illustrates that the Lower flow suite might be related to the overlying flows by a partial melting mechanism. We cannot conclusively demonstrate the importance of this mechanism until the complete trace element data set is interpreted and Nd isotope data are available.

The flows of the Central and Upper suites define tight trends on the La/Sm versus Gd/Yb plot which pass close to the composition of primitive mantle at the lower end, and extend towards the compositional field of crustal materials at high La/Sm levels. It is evident from Figure 49.5 that the fractional crystallization of a gabbroic mineral phase extract (Lightfoot, in-house software) is incapable of producing the compositional spectrum of the Central or Upper flow suites, as the modelled trajectories do not fit the observed data trends. Batch melting is also ruled out, as the observed variation in La/Sm ratio is considerably larger than that of the Gd/Yb ratio, whereas the melting model involving a garnet lherzolite source produces a wide range in Gd/Yb ratio with little change in La/Sm ratio. A particularly improbable mantle mineralogy would be required to explain these variations.

The trajectory of the Central suite data, on the plot of La/Sm versus Gd/Yb, passes close to the composition of felsic flows (dacites) located along strike of the trachytes (and above the Central suite in the Black Bay Peninsula section). It is suggested that the addition of material, compositionally similar to the rhyolites, to mantle-derived Central suite magmas may explain the compositional variation in the Central suite (a similar mechanism may explain variations in the Upper suite). We successfully simulated this process using a mixing program (Lightfoot, in-house software) (Figure 49.5). We also note that there is no substantial change in Mg-number as the La/Sm ratio increases, but that SiO_2 content correlates positively with La/Sm ratio (Figure 49.4), and that the Th/Yb ratio and Ce, Rb, U and Ba concentrations all correlate positively with La/Sm ratio. As the felsic flows have high large-ion lithophile element concentrations and SiO_2 contents, but the addition of this material to the Central suite magmas will not produce a significant change in Mg-number, we suggest that the remaining major and trace element data are consistent with this mechanism.

The similarity of the compositions of the felsic flows to the compositions of crustal materials is quite striking, and we suggest that these flows may be derived by melting of the crust by basaltic magmas. These melts migrated to the surface either without significant degrees of interaction with the basaltic magma, or assimilating crustal material as they passed through the feeder conduits. It is important to note that La/Sm ratio and SiO_2 content decline upwards through the Central suite, suggesting a decline in the degree of assimilation of the crust or crustal melts upwards through the stratigraphy. As Mg-number does not vary significantly through this sequence, we suggest that temperature-controlled assimilation of crustal material (Huppert and Sparks 1985) is not a key petrogenetic process, as this would result in a positive correlation between Mg-number and La/Sm ratio. For a similar reason, assimilation coupled to fractional crystallization (AFC) (e.g., DePaolo 1981) is unlikely as there would be a negative correlation between Mg-number and La/Sm ratio. Rather, we suggest two possible alternative mechanisms.

1. The magma underwent equilibrium crystallization during ascent, where phenocrysts were neither lost from nor gained by the magma. The amount of crystallization may have been linked to the degree of crustal assimilation, where the latent heat of *in situ* equilibrium crystallization produced a commensurate amount of assimilation of the crust (cf. Devey and Cox 1987). In this model, the earlier magmas underwent greater degrees of equilibrium crystallization, whereas later magmas underwent lesser amounts of equilibrium crystallization. The degree of crystallization may be related to the residence time of the magma in the feeder conduit or magma chamber.
2. Mixing between basaltic and rhyolitic magmas (derived by melting of the upper crust) might explain the observed variations.

Presently, we favour the former process, although we do not have strong petrographic evidence for phenocryst enrichment in the lower part of the Central flow suite. However, we note that a mechanism of this type explains the continuous change in magma composition in a more satisfactory way than the mixing model.

CONCLUDING REMARKS

1. An inductively coupled plasma-mass spectrometric technique has been developed which permits the determination of the REEs, Y, Zr, Nb, Rb, Cs, Sr, Th, Ta, Hf and U in a single solution. For basaltic rocks, we are confident that the results are accurate, and indicate that the precision and detection limits are more appropriate to this type of study than those of XRF or INA analysis.
2. Systematic variations in the compositions of basalts from the Black Bay Peninsula provide important new information about the sources and evolution of these magmas, permit comparisons between extrusive and intrusive magmatic activity, and may ultimately yield information of value in the exploration for magmatic nickel, copper and platinum group element enriched sulphide mineralization in the Keweenawan.
3. Preliminary results indicate that there were at least two different magma types; one of them is quite undifferentiated and mafic (the Lower suite), whereas the other types are more differentiated and have a wider compositional range which may have been produced by crustal contamination (the Central and Upper suites).

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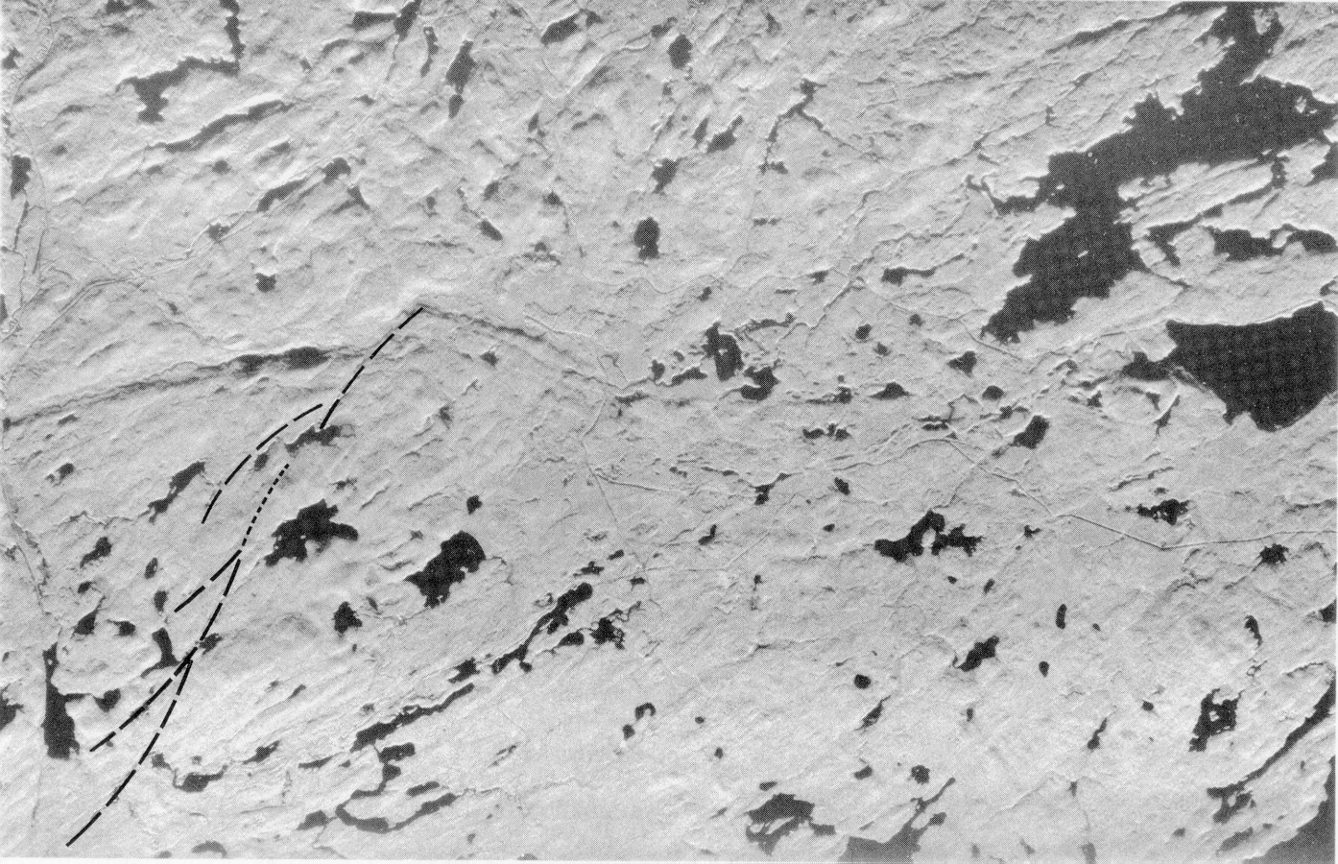

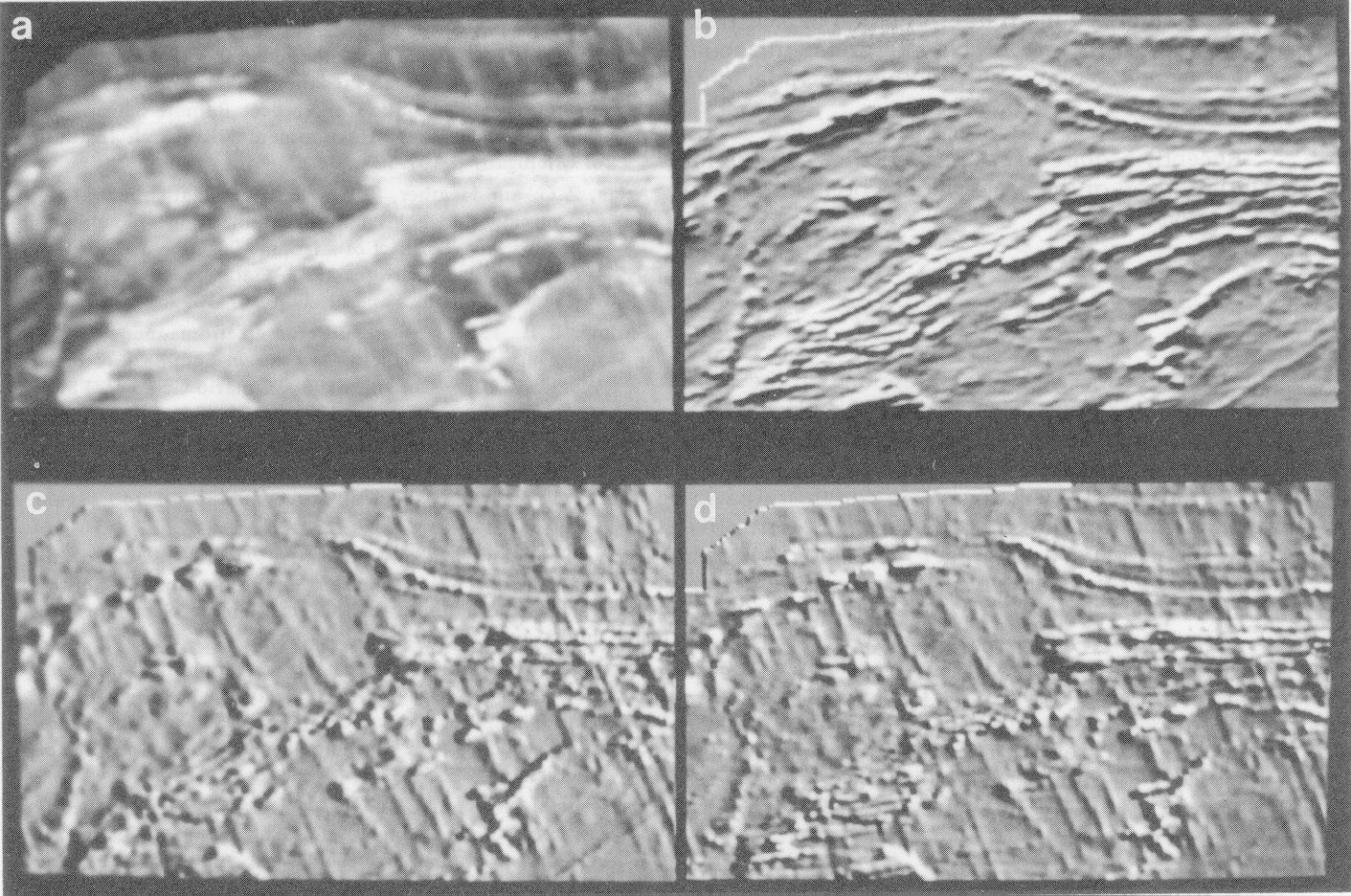
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