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Geology of the Canadian Shield in Ontario: An Update

2007

Ontario

ONTARIO GEOLOGICAL SURVEY

Open File Report 6196

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by

J.A. Percival, and R.M. Easton

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Miscellaneous Release—Data 216
Geology of the Canadian Shield in Ontario: An Update; by J.A. Percival and R.M. Easton. This release contains geological, geochronological, aeromagnetic, gravity and earthquake location data, as well as the location information for drill hole and geochemical data for the province of Ontario compiled from federal and provincial databases. The release also includes ArcExplorer™ project (.aep) files for viewing with ArcExplorer™ freeware, which is included with the release. These data are a joint release between the Ontario Geological Survey, the Geological Survey of Canada (released as Open File 5511), and Ontario Power Generation (OPG 06819-REP-01200-10158-R00). The data complement a hard copy report—Ontario Geological Survey, Open File Report 6196—which summarizes the advances made in our understanding of the geology of the Precambrian Shield in Ontario since 1992. A portable document format (*.pdf*) version of this report is included in this release. The files are on one CD-ROM.

Detailed contents of MRD 216 (*see* also detailed metadata listing in Appendix 1):

- Ontario Geological Survey 2006. 1:250 000-scale bedrock geology of Ontario. (MRD 126 – Revised)
- Ontario Drillhole Database; Ontario Geological Survey, Data Set 13.
- Canadian Geochronological Data Base (GEOCHRON_RO@gdress.ess.nrcan.gc.ca)
- PETROCH lithogeochemical data. Ontario Geological Survey, Open File Report 5855
- Canadian Earthquake Data Base (http://earthquakescanada.nrcan.gc.ca)
- Canadian Gravity Data Base (http://gdr.nrcan.gc.ca/gravity/can2k_bwf_e.php)
- Canadian Aeromagnetic Data Base (http://gdr.nrcan.gc.ca/aeromag/can200m_vg_e.php)

MRD 216 is available separately from Open File Report 6196.

Abstract

The report reviews advances in understanding the geology of the Canadian Shield in Ontario since the 1992 compilation provided in the Ontario Geological Survey *Geology of Ontario* special volume. New information includes data and interpretations produced during several recent major initiatives: Operation Treasure Hunt, Discover Abitibi, the Abitibi–Grenville and Western Superior Lithoprobe transects, Western Superior NATMAP transect, and many updated maps and data sets. In addition to a descriptive overview, associated digital data contain a set of digital geology and geophysical maps, along with distribution of point data from published databases of geochronology, lithogeochemistry, drill hole locations, and earthquake location-magnitude.

Two main geological provinces of the Canadian Shield are represented in Ontario. The Superior Province and autochthonous cover sequences underlie approximately 80% of the province of Ontario, distributed mainly across the north and northwest. The Grenville Province, exposed in the southeast, and its autochthonous cover, make up the remainder.

The Superior Province records about one billion years of geological history, from 3.6 to 2.6 billion years ago. Five microcontinental fragments evolved independently between 3.6 and 2.75 Ga, prior to a series of five discrete accretionary events between 2.72 and 2.68 Ga that assembled the continental and intervening oceanic crustal domains into a coherent Superior craton. The Northern Superior superterrane recorded 3.6 to 2.75 Ga events prior to 2.72 Ga collision with the 3.0 Ga North Caribou superterrane. Following rifting at 2.98 Ga, the Uchi margin of the North Caribou superterrane evolved in an upper plate setting before collision 2.72 to 2.70 billion years ago with the Winnipeg River terrane (<3.4 Ga), which trapped synorogenic English River turbidites in the collision zone. The Winnipeg River terrane was reworked in magmatic and tectonic events 2.75 to 2.68 billion years ago, including the central Superior orogeny (2.71-2.70 Ga) that marks accretion of the juvenile western Wabigoon terrane. In the south, the Wawa–Abitibi terrane evolved in a mainly oceanic setting until Shebandowanian collision with the composite Superior superterrane at 2.695 Ga. Synorogenic Quetico turbidites were trapped in the collision zone. The final accretionary event involved addition of the Minnesota River Valley Terrane (MRVT) from the south, and deposition and metamorphism of synorogenic turbidites of the Pontiac terrane during the Minnesotan orogeny (ca. 2.68 Ga). Seismic reflection and refraction images indicate north-dipping structures, interpreted as a stack of discrete, 10 to 15 km thick terranes. A slab of high-velocity material, possibly representing subcreted oceanic lithosphere, as well as Moho offsets, support a model of progressive accretion through plate-tectonic-like processes. Following stabilization in the Neoarchean, the craton was affected by emplacement of at least eleven dyke swarms (2.45-1.1 Ga), uplift of the Kapuskasing zone (ca. 1.9 Ga), ductile reworking of the northwestern margin (ca. 1.8 Ga), and attempted rifting (ca. 1.1 Ga). Minor seismicity occurs in the Lake Timiskaming seismic zone.

The Grenville Province contains rocks ranging in age from 2.69 to 0.99 Ga, metamorphosed between 1.08 and 0.99 Ga. It is bounded to the northwest by the subvertical Grenville Front. Within the Grenville Province, there is an overall, generally shallow (20-40°), southeasterly dip to both surface geological structures and seismic reflectivity within the crust, suggesting northward thrusting of deep-level crustal rocks. Abitibi–Grenville Lithoprobe seismic data suggests that the Superior Province continues at least 200 km southeast of the Grenville Front as a southward-tapering wedge in the Grenville lower crust.

Tectonic stability has prevailed since *circa* 1.0 Ga in most of the Grenville Province, when it is thought that a mountain range and plateau existed, similar to the modern-day Himalayas and the Tibetan plateau. The mountains were peneplained by the time of deposition of Paleozoic limestones at *circa* 0.42 Ga. Neoproterozoic and younger tectonic activity is limited to localized rifting at *circa* 0.59 Ga along the

Ottawa graben and along an east-trending corridor along the Mattawa, French and Pickerel rivers, and Lake Nipissing. In addition, subsequent rifting during the Jurassic, at *circa* 0.17 Ga, resulted in the formation of the Ottawa–Bonnechere graben system, as well as the localized injection of lamprophyric and kimberlitic dikes in the eastern Grenville Province in Ontario. In addition, emplacement of several mafic dyke swarms occurred prior to, during, and after the Grenville Orogeny. It has been suggested that significant neotectonic activity persists in the "Golden Horseshoe" area and along the north shore of Lake Ontario and the St. Lawrence River. At present, apart from localized, low-level seismicity in the "Golden Horseshoe" area near the subsurface trace of the Central Metasedimentary Belt boundary zone, there is no compelling evidence that significant neotectonic activity, has, or is, occurring in the Grenville Province.

Geology of the Canadian Shield in Ontario: An Update

J.A. Percival[1], and R.M.Easton[2]

Ontario Geological Survey
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[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8, joperciv@nrcan.g.c.ca

[2] Precambrian Geoscience Section, Ontario Geological Survey
Ministry of Northern Development and Mines, Sudbury, Ontario, Canada P3E 6B5, mike.easton@ontario.ca

Introduction

This report reviews advances in understanding the geology of the Canadian Shield in Ontario (Figure 1) developed since the major compilation provided in the Ontario Geological Survey's Special Volume 4, *Geology of Ontario* (Figure 2; Williams et al. 1992). Subsequent compilations were presented for Ontario (Eyles 2002), the Superior Province (Stott 1997; Card and Poulsen 1998), Superior Province geochronology (Skulski and Villeneuve 1999), the Grenville Province (Davidson 1998), the Abitibi–Grenville region of Ontario and Quebec (Ludden and Hynes 2000; Ayer et al. 2002), and the western Superior region of Ontario–Manitoba (Percival et al. 2006a). Much additional information has been acquired through Operation Treasure Hunt, Discover Abitibi (e.g., Ayer 2004), the Western Superior Lithoprobe and National Mapping Program (NATMAP) transects, and many updated maps and data sets (e.g., Rolandone et al. 2003).

Sources of Information

Geology of Ontario (Ontario Geological Survey 1992) and subsequent digital updates (Ontario Geological Survey 2006) provided an overview of bedrock geology, geophysics and tectonic assemblages (Figure 2) as well as glacial cover sequences. Several additional province-scale data sets are available at nominal cost through the Ontario Geological Survey. Aeromagnetic coverage has been upgraded in approximately 10 percent of the province over the past ten years and is available at http://www.mndm.gov.on.ca/mndm/mines/ogs/gpxatlas/pub_air/default_e.asp.
A geochronology database reporting U/Pb, Rb/Sr, Nd/Sm, K/Ar and Ar/Ar age data for rocks older than 1 Ma, current to 2001 (Easton 2001a), has been updated for this report and is available on the associated CD–ROM (OGS Miscellaneous Release—Data 216). A drill-hole database showing the location and additional information for 113,006 holes based on assessment files can be acquired at http://www.geologyontario.mndm.gov.on.ca/ (locations of holes drilled up to the year 2005 are provided in the Drill-Hole Database on the CD–ROM). A lithogeochemical database, containing over 31,500 major oxide and trace element whole rock chemical analyses, along with location information, is available at http://www.geologyontario.mndm.gov.on.ca/ (locations listed on the CD–ROM). The location of diabase dykes swarms is included in Buchan and Ernst (2004) and provided on the CD–ROM.

A large amount of information has been published in maps and reports of the Ontario Geological Survey (OGS) and Geological Survey of Canada (GSC), as well as in scientific journals. Some data is available only in Lithoprobe transect reports (available through http://www.lithoprobe.ca). Processed Lithoprobe seismic data for the Abitibi–Grenville (Calvert et al. 1995; Calvert and Ludden 1999), Sudbury, Kapuskasing and Western Superior transects are available at http://www.litho.ucalgary.ca/atlas/atlas.html.

Superior Province

The Superior Province makes up approximately 70 percent of the Canadian Shield in Ontario. It forms the core of the North American continent and is surrounded by provinces of Paleoproterozoic age on the west, north and east, and Mesoproterozoic age (Grenville Province) on the southeast (*see* Figures 1, 2). Tectonic stability has prevailed since *circa* 2.5 Ga in large parts of the Superior Province. Proterozoic and younger activity is limited to rifting of the margins, emplacement of several mafic dyke swarms,

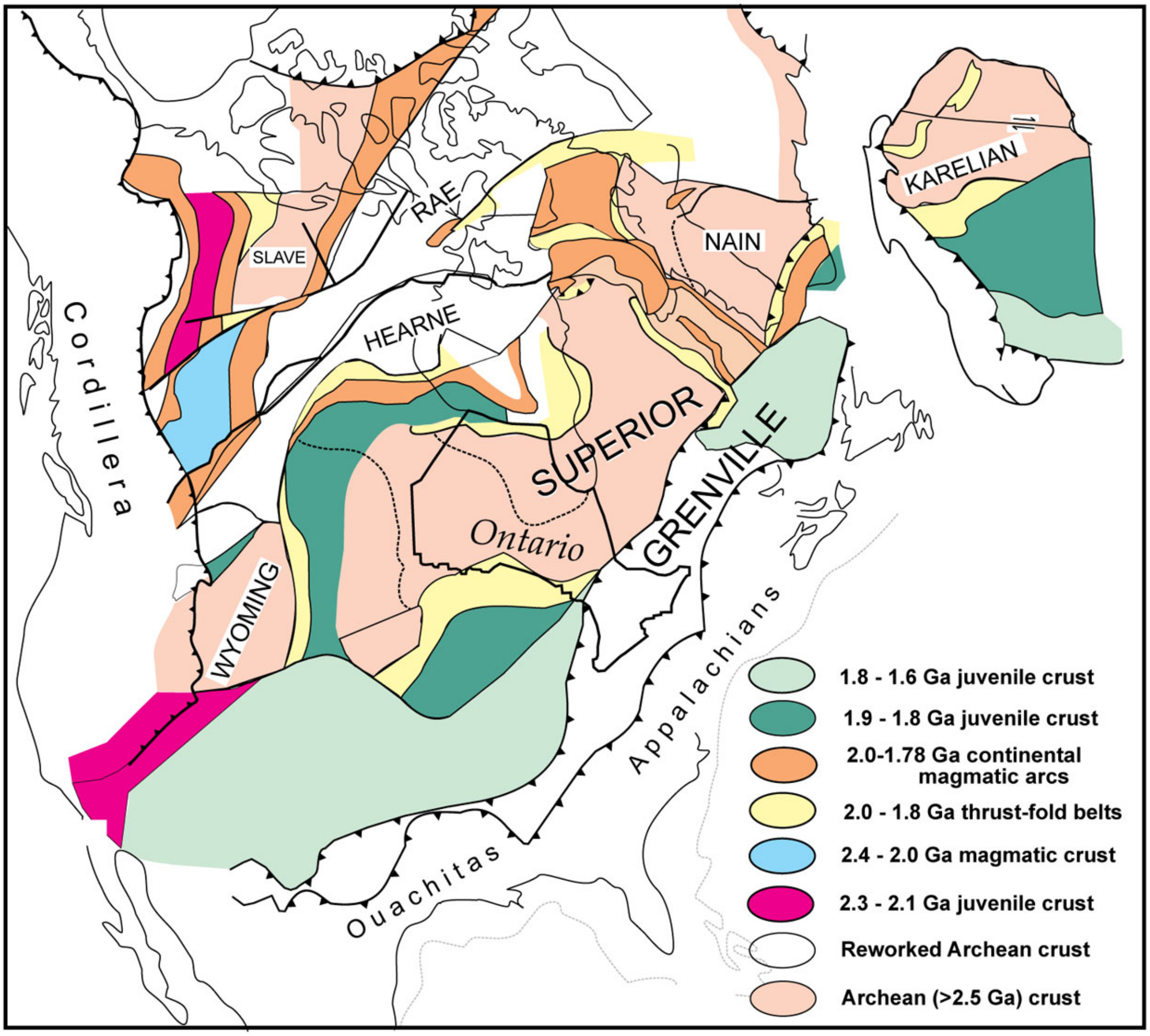

Figure 1. Tectonic map of North America, showing location of Ontario with respect to major geological provinces (*modified after* Hoffman 1989).

compressional reactivation and large-scale rotation at *circa* 1.9 Ga, as well as failed rifting at *circa* 1.1 Ga. With the exception of the northwestern Superior margin that was pervasively deformed and metamorphosed at approximately 1.8 Ga, the craton has escaped later ductile deformation.

Current views regard the Superior Province as a collage (*see* Figure 2) made up of small continental and oceanic plates (Card 1990; Williams et al. 1992; Stott 1997; Percival et al. 2004b, 2006a), with a complex history of aggregation between 2.72 and 2.68 Ga, followed by post-orogenic effects. Sedimentary rocks as old as 2.48 Ga uncomfortably overlie Superior Province granites, indicating that most erosion had occurred prior to *circa* 2.5 Ga.

The southern Superior Province (to latitude 52ºN) is a major source of mineral wealth, hosting active gold and base metal mining camps in the Timmins–Kirkland Lake and Red Lake areas. Owing to its potential for these and other commodities, the Superior Province attracts mineral exploration in both established and frontier regions.

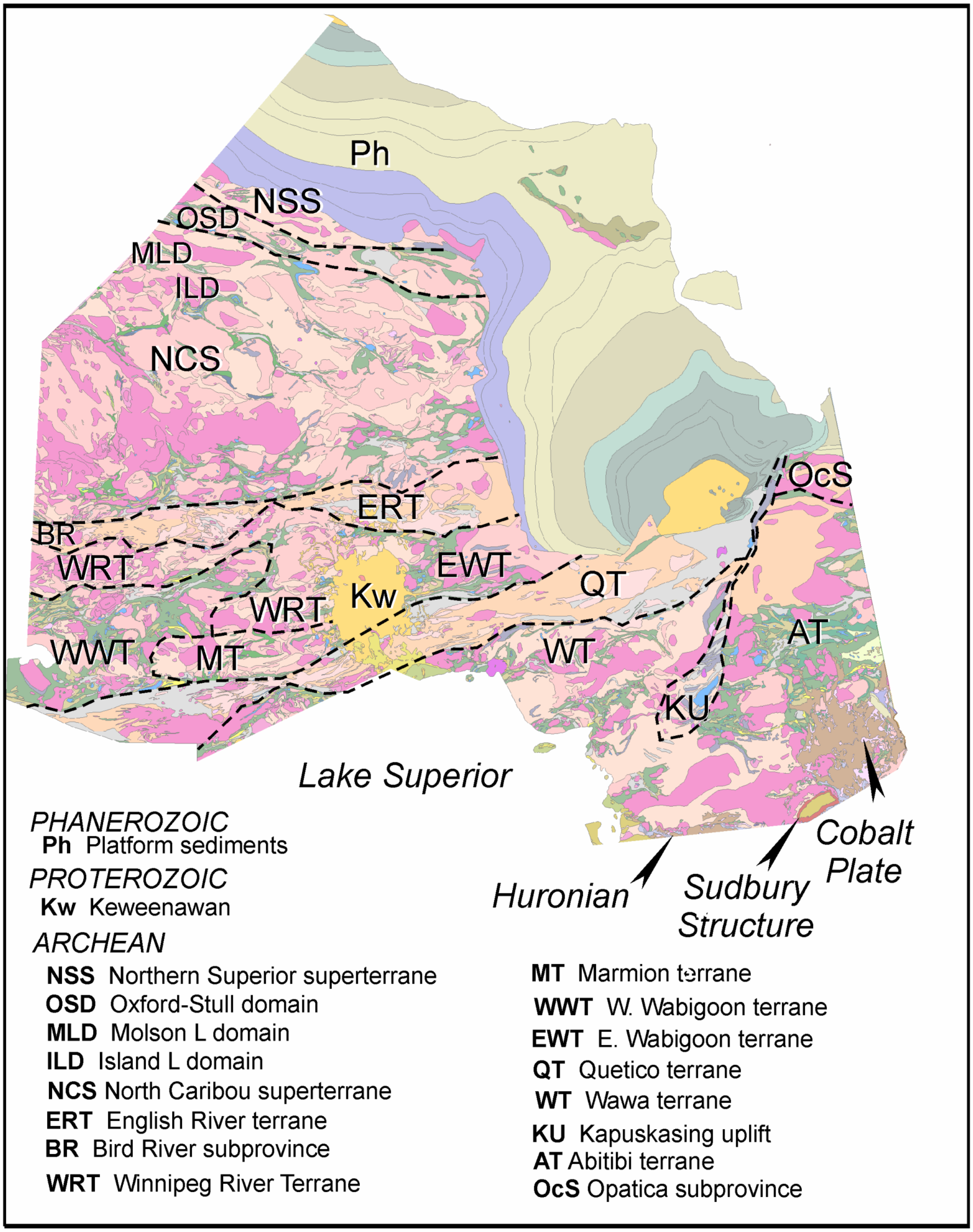

Figure 2. Geological map of Ontario (*modified after* Ontario Geological Survey 1992). For map legend, *see* Ontario Geological Survey 1992, Map 2545. Superimposed are subdivisions of the Superior Province modified after Percival et al. (2006a).

WESTERN REGION

Northern Superior Superterrane

Dominated by granitic and gneissic rocks, the poorly exposed Northern Superior superterrane at the northern fringe of the Superior Province (*see* Figure 2) has been recognized on the basis of fragmentary isotopic evidence from Ontario and Manitoba (Skulski et al. 1999). Supracrustal units in the Assean Lake complex of Manitoba include greywacke with detrital zircon ages up to 3.9 Ga, iron formation and mafic to intermediate volcanic rocks (Böhm et al. 2000, 2003). The ancient rocks have been strongly reworked by granitoid magmatism at 3.2 to 3.1, 2.85 to 2.81 and 2.74 to 2.71 Ga, representing evolution in a continental magmatic arc setting, followed by amphibolite-facies metamorphism at 2.68 and 2.61 Ga (Böhm et al. 2003). To the east in the Yelling Lake area of Ontario, magmatism at 2.85 to 2.81 Ga was followed by metamorphism and further magmatism at 2.74 to 2.71 Ga (Skulski et al. 2000). The Northern Superior superterrane is bounded to the south by the North Kenyon fault, which juxtaposes it with the Oxford–Stull terrane.

The Northern Superior superterrane is characterized by linear, west-northwest-trending aeromagnetic anomalies, truncated by prominent ductile shear zones in the eastern extension beneath Phanerozoic cover. The main trends are thought to correspond to Archean lithological units and structures, and the shears may be Neoarchean or Paleoproterozoic in age. Exploration targets for diamondiferous kimberlites have been identified in the Ontario–Manitoba border region through discovery of kimberlite indicator minerals in northeastern Manitoba (Nielsen 2002). Glacial cover is extensive in this region, with bedrock exposure limited to rare outcrops in river cuts.

North Caribou Superterrane

The North Caribou superterrane (Thurston et al. 1991) is the largest domain with Mesoarchean ancestry of the Superior Province (*see* Figure 2). This old basement consists of 3.0 Ga juvenile plutonic and minor volcanic belts (Stevenson 1995; Stevenson and Patchett 1990; Corfu et al. 1998; Hollings et al. 1999; Henry et al. 2000), upon which were deposited early rift-related (Thurston and Chivers 1990; 2.98 to 2.85 Ga) and younger (2.85-2.71 Ga) arc sequences. It has been severely reworked by continental arc magmatism at 2.75 to 2.70 Ga. The terrane has wide transitional margins in both the north and south. Parts of the terrane extend eastward beneath Phanerozoic cover in the Hudson and James Bay lowlands (Stott and Berdusco 2000). Glacial cover is widespread throughout this region, increasing in thickness toward the east, where exposure of bedrock is limited to outcrops on the shores of large lakes.

NORTHERN MARGIN: OXFORD–STULL DOMAIN

In the north, the Oxford–Stull Lake domain (*see* Figure 2) represents the largely juvenile, 2.88 to 2.73 Ga continental northern margin of the 3 Ga North Caribou superterrane that was tectonically imbricated with oceanic crustal fragments (Skulski et al. 2000; Corkery et al. 2000; Stone et al. 2004; Craven et al. 2004). The Oxford–Stull domain tectonostratigraphy (Corkery et al. 2000 and in prep.) includes 2.84 to 2.83 Ga tholeiitic and calc-alkaline arc volcanic rocks, which are unconformably overlain by <2.82 Ga sediments (Skulski et al. 2000). This package was juxtaposed on D_1 faults with submarine, depleted tholeiitic basalts of the Seller Lake assemblage prior to intrusion of 2.78 Ga tonalite (Corkery et al. 2000). Submarine arc volcanic rocks (2.738 Ga) covered the composite basement prior to D_2 deformation at *circa* 2.72 Ga (Lin et al. 2006) that may mark collision of the Northern Superior terrane (Skulski et al.

2000). Unconformably overlying the shortened continental margin collage is a 2.722-2.705 Ga successor arc of calc-alkaline to shoshonitic volcanic and associated sedimentary rocks (Oxford Lake assemblage; Brooks et al. 1982; Corkery and Skulski 1998; Corkery et al. 2000; Skulski et al. 2000; Stone et al. 2004; Lin et al. 2006). Synorogenic sedimentary rocks of the Cross Lake assemblage, which contain detrital zircons ranging in age from 2.704 to 3.65 Ga (Corkery et al. 1992; Corkery et al. 2000; Lin et al. 2006), lie unconformably on the older rocks. The entire collage is cut by northwest-trending, dextral shear zones (D_3; Osmani and Stott 1988; Lin and Jiang 2001; Lin et al. 2006; Parmenter et al. 2006), themselves cut by 2.692 Ga granite (Corkery et al., in prep.), providing a bracket of <2.704 to >2.692 Ga on D_3. Several small, syntectonic gold deposits and showings occur in association with faults such as the Wolf Bay–Stull–Wunnumin shear zone, particularly in the Little Stull Lake area (Jiang and Corkery 1998).

MUNRO LAKE AND ISLAND LAKE DOMAINS

The Munro Lake and Island Lake domains (*see* Figure 2) comprise plutonic rocks with several small supracrustal belts (Stone et al. 2004; Parks et al. 2006). In the Munro Lake domain, rift-related quartzite locally interbedded with komatiite overlies 2.883 to 2.865 Ga tonalite at Ponask Lake, Ontario (Stone et al. 2004). Tonalite and granodiorite plutons across the Munro and Island Lake domains have U/Pb ages ranging from 2.88 to 2.70 Ga, and have 3.05 to 2.71 Ga Nd model ages reflecting variable recycling of North Caribou-age crust (Stevenson and Turek 1992; Skulski et al. 2000).

The Island Lake domain includes 2.89, 2.85 and 2.74 Ga volcanic sequences in a series of structural panels (Parks et al. 2006). Diverse clastic sedimentary sequences were deposited synvolcanically at <2.84 to >2.744 Ga and post-volcanically at <2.71 Ga (Island Lake assemblage). All sequences have detrital zircon U/Pb ages that range from 2.938 to 2.711 Ga (Corfu and Lin 2000), consistent with North Caribou provenance. Penetrative deformation is slightly younger (ca. 2.695 Ga; Parks et al. 2006), followed by localized strain and shear-zone-hosted gold mineralization (ca. 2.658 Ga; Lin and Corfu 2002).

Numerous west-northwest-trending faults transect the region, and generally display evidence of dextral transcurrent displacement (Lin and Jiang 2001; Lin et al. 2006). The occurrence of coarse clastic sediments (Corkery et al. 2000) and alkalic volcanic rocks (Brooks et al. 1982) along some faults suggests that they were active during deposition of the Island Lake assemblage. Several small, syntectonic gold deposits and showings occur in association with faults such as the Wolf Bay–Stull–Wunnummin shear zone, particularly in the Little Stull Lake area near the Ontario–Manitoba border (Jiang and Corkery 1998). A high-grade metamorphic complex may exist south of the Wunnummin Lake shear zone, based on the high-relief aeromagnetic Bird’s eye pattern (Thurston et al. 1998).

CENTRAL NORTH CARIBOU SUPERTERRANE

The central North Caribou superterrane is dominated by tonalitic, dioritic, granodioritic and granitic plutons that crystallized between 2.745 and 2.697 Ga at depths ranging from 18 to 10 km (0.6 to 0.3 GPa) (Stone 1998; 2000; Corfu and Stone 1998a, 1998b). They range from polydeformed gneisses to massive and foliated plutons. Remnants of *circa* 3.0 Ga tonalite and supracrustal rocks are sporadically preserved through the younger magmatism (Krogh et al. 1974; Corfu and Ayres 1991; Henry et al. 1998; Whalen et al. 2003). The ancient crust was at least 35 km thick at 3.0 Ga based on paleopressure determinations (Percival et al. 2006b). Within the greenstone belts, thin packages of quartz arenite-carbonate-komatiite have variably been interpreted as platformal cover strata (Thurston and Chivers 1990; Thurston et al. 1991; Thurston 2002) and plume-related rift deposits (Hollings and Kerrich 1999; Hollings 2002; Percival et al. 2002a, 2006b). Evidence of early (>2.87 Ga) deformation is recorded in the North Caribou greenstone belt (Stott et al. 1989). The iron formation-hosted Musselwhite lode gold deposit may have formed during development of structures associated with pluton emplacements at 2.87 Ga, or during *circa* 2.7 Ga events (Fyon et al. 1992). Aeromagnetic patterns reflect sinuous greenstone belts and broad plutonic domains with little aeromagnetic relief. A crustal-scale synform has been suggested for the eastern Berens River arc based on seismic data (White et al. 2003). Hynes and Song (2006) concluded that the structure is more akin to that of divergent orogen geometry, in which the north-dipping reflectors would represent south-vergent thrusts. Extensive drift cover obscures large parts of the central North Caribou superterrane, particularly in the east.

Southern Margin: Uchi Domain

The Uchi domain (*see* Figure 2) preserves approximately 300 m.y. of tectonostratigraphic evolution along the southern margin of the North Caribou superterrane (Stott and Corfu 1991; Corfu and Stott 1993a, 1993b, 1996a; Hollings et al. 2000; Sanborn-Barrie et al. 2001, 2004). This well exposed region hosts some of the largest mineral deposits of the western Superior region, including the Red Lake gold camp. Aeromagnetic trends reflect the complex structural configuration of supracrustal rocks in a chain of greenstone belts separated by large lobes of plutonic material.

The stratigraphic record preserved in greenstone belts indicates a history of rifting beginning *circa* 2.99 Ga (Pirie 1982; Corfu and Wallace 1986; Corfu and Andrews 1987; Tomlinson et al. 1998; Sanborn-Barrie et al. 2004; Percival et al. 2002a, 2006b; Bailes et al. 2003; Sasseville et al. 2006), followed by a protracted history of continental arc magmatism at 2.94 to 2.91, 2.90 to 2.89, 2.85 and 2.75 to 2.72 Ga (Stott 1996; Beakhouse et al. 1999; Henry et al. 2000; Hollings et al. 2000; Rogers et al. 2000; Rogers 2002; Young 2003; Sanborn-Barrie et al. 2004). These rocks host both world-class gold deposits (*see* Harris et al. 2006) and massive sulphide mineralization (Nunes and Thurston 1980; Rogers 2002).

Several deformation events are recognized within the greenstone belts, including pre-2.74, 2.73, 2.72 and 2.70 Ga events that have produced composite, steep, east-trending fabrics (Parker 2000; Sanborn-Barrie et al. 2001, 2004; Dubé et al. 2004; Rogers 2001; Young et al. 2006; Harris et al. 2006). Structures identified on seismic profiles have been interpreted as extensional in origin (Calvert et al. 2004). Multiple ages of gold mineralization are indicated, with the main stage associated with D2 structures prior to 2.712 Ga and late-stage gold localization after 2.701 Ga (Corfu and Andrews 1987; Dubé et al. 2004). Coarse clastic sedimentary rocks generally represent the youngest strata along the southern margin of the North Caribou superterrane. Where dated, these sequences contain detrital zircons as young as 2.703 Ga, and may be facies equivalents of the marine greywacke turbidites of the English River Subprovince to the south (e.g., Devaney 1999; Stott 1996).

NORTH CARIBOU – ENGLISH RIVER BOUNDARY

Over 450 km of strike length, the east-trending Sydney Lake–Lake St. Joseph (SL-LSJ) fault separates rocks of the North Caribou margin to the north, from metasedimentary schists and migmatitic rocks of the English River terrane to the south. The steeply dipping, 1 to 3 km wide, brittle-ductile fault zone is estimated to have accommodated about 30 km of right-lateral transcurrent displacement and 2.5 km of south-side-up movement (Stone 1981). To the north, parallel faults of similar character and relative age dissect the southern North Caribou margin.

In several areas, immature sedimentary sequences occur to the north of the SL-LSJ fault, where their metamorphic grade is lower than that of similar units to the south, consistent with post-metamorphic, south-side-up displacement. Where crossed by seismic line 1a, the fault is imaged as a steeply north-dipping discontinuity with normal geometry (White et al. 2003). Bethune et al. (2000, 2006) studied the Miniss River fault, which is cut and offset by the extension of the SL-LSJ fault in the region of the seismic profile. An age of approximately 2.68 Ga for movement on the Miniss fault (Bethune et al. 2006) also provides a maximum age for the time of dextral displacement on the SL-LSJ fault. Hrabi and Cruden (2006) inferred a still younger age of <2.646 Ga for brittle movement.

English River Terrane

The English River terrane (*see* Figure 2) is distinguished from adjacent regions by supracrustal rocks of metasedimentary origin, high metamorphic grade, and a prominent east-trending structural grain (Breaks 1991). Based on the turbiditic nature of its chemically immature greywackes, the setting of the English River has traditionally been considered as a fore-arc basin (Langford and Morin 1976) or accretionary prism (Breaks 1991), although more recently Pan et al. (1999) inferred a back-arc setting. Detrital zircon studies indicate that the sediments were deposited after arc activity in adjacent volcanic belts had ceased (Corfu et al. 1995; Davis 1996a, 1996b, 1998), close to the time of collisional orogeny, thereby implying an origin as a syn-orogenic flysch basin. The small Melchett Lake greenstone belt in the central English River terrane comprises a juvenile, calc-alkaline volcanic sequence (ca. 2.723 Ga: Corfu and Stott 1993a, 1996a; Davis et al. 2000), possibly correlative with the Lake St. Joseph assemblage.

The main protolith to metasedimentary schist, migmatite and derived diatexite is greywacke, with some oxide-facies iron formation. Detrital zircons indicate a maximum depositional age between 2.713 Ga (southern margin; Stott et al. 2002), and 2.705 Ga (Corfu et al. 1995). A lower bracket on depositional age is provided by cross-cutting, 2.698 Ga, pre-metamorphic diorite-granodiorite bodies (Corfu et al. 1995).

Metamorphic conditions have been determined on garnet-, orthopyroxene- and garnet-, sillimanite-bearing assemblages in several areas of the English River terrane. Peak conditions varied from middle amphibolite facies near the margins, to interior upper amphibolite (650-750ºC at ca. 0.5 MPa; Pan et al. 1999) and granulite facies (750-850ºC at 0.6-0.7 MPa; Pan et al. 1999). Peak metamorphic conditions likely coincided with widespread generation of migmatite and diatexite, at 2.691 Ga (Corfu et al. 1995). Elevated temperatures may have been attained through addition of mantle-derived magmatic heat (Breaks 1991), an inference supported by the near-isobaric cooling paths (Hynes 1997). The main tectonothermal event was followed by a second thermal pulse at 2.669 Ga (Pan et al. 1999), intrusion of *circa* 2.65 Ga pegmatites (Corfu et al. 1995; Smith et al. 2004) and growth of hydrothermal minerals (Pan et al. 1999).

The dominant east-trending structural grain of the terrane reflects upright to north-vergent F_2 folds of an earlier foliation, which is defined in many areas by migmatitic layering (Breaks 1991; Hrabi and Cruden 2001, 2006). The early foliation appears to be a composite fabric that includes primary layering and at least one set of early folds and axial planar foliation. It is particularly well expressed in the Lac Seul area (Sanborn-Barrie 1988), where early (F_1?), large-scale, north-trending, west-vergent folds were delineated (Hynes 1997). D_1 deformation preceded emplacement of the Fletcher Lake batholith (Hrabi et al. 2000), but most strain coincides with or postdates formation of migmatitic layering after 2.69 Ga.

Models for the tectonic history of the English River terrane have generally focused on specific elements of its history, for example its depositional setting or tectonometamorphic evolution. The immature, turbiditic character of the sediments derived from the recently active arc on the North Caribou margin, and the association in time with its deformation support a depositional setting in a syn-orogenic basin. Whether the basin evolved from a fore-arc trench setting (cf. Langford and Morin 1976; Breaks 1991) is addressed by seismic reflection profiles, which should image sedimentary panels dipping northward beneath the North Caribou superterrane. Although observed seismic dips are appropriate, the generally seismically featureless English River terrane does not appear to project to the north. However, a possible Moho-penetrating structure (suture 1 of White et al. 2003) that dips north could mark the ancient plate boundary.

Several authors have remarked on the rapidity of burial and heating of sediments, and both folding and thrusting have been invoked to account for crustal thickening (Corfu et al. 1995; Hynes 1997; Pan et al. 1999). More remarkable, however, is heating of the rocks from surface conditions to about 800ºC within a *circa* 15 m.y. interval (2.705-2.691 Ga). Peak metamorphism was followed by an extended period of burial, as reflected by isobaric cooling, additional metamorphic pulses (i.e., 2.685, 2.67 Ga), sustained magmatism to 2.65 Ga, and relatively young U/Pb (2.69-2.64 Ga; Corfu et al. 1995) and Ar (2.66-2.4 Ga; Hanes and Archibald 2001) cooling ages. These observations have been interpreted in terms of late-stage (2.5-2.4 Ga) exhumation of the high-grade rocks along brittle structures such as the SL-LSJ fault (Hanes and Archibald 2001). Gravity (Nitescu et al. 2003), seismic reflection (White et al. 2003) and seismic refraction (Kay et al. 1999b; Musacchio et al. 2004) profiles collectively indicate that the Moho beneath the combined English River–Winnipeg River terrane is elevated by about 8 km over that in adjacent regions. A late to post-tectonic adjustment of this style could account for metamorphic pressure estimates up to 0.3 GPa higher within the English River terrane, as well as the slow cooling history. The interpretation of reflection profile 1 of White et al. (2003) supports a component of normal movement on the SL-LSJ fault, in addition to a major dextral strike-slip component (cf. Stone 1981; Stott 1996).

ENGLISH RIVER – WINNIPEG RIVER BOUNDARY

This boundary separates dominantly metasedimentary rocks of the English River terrane from mainly metaplutonic rocks of the Winnipeg River terrane to the south. Metamorphic grade is generally high and metamorphic isograds transect the lithological boundary. Between the two terranes lies the metavolcanic Bird River Subprovince in eastern Manitoba and its narrow eastward extension, the Separation Lake greenstone belt (Breaks 1991). These belts consist dominantly of mafic rocks. Ages of the largely juvenile supracrustal units range from *circa* 2.78 to 2.73 Ga (Timmins et al. 1985).

Ductile deformation involving thrust, high-angle reverse and both dextral and sinistral transcurrent movement (Hynes 1998) obscure original contact relationships within the boundary zone. However, depositional contacts have been inferred between English River clastic rocks and both volcanic strata of the Separation Lake belt (Hrabi and Cruden 2006) and gneissic tonalitic basement to the east (Sanborn-Barrie 1988). The Separation Lake belt appears to be in tectonic and intrusive contact with granitic rocks of the Winnipeg River terrane to the south (Blackburn and Young 2000).

The boundary zone is a focus for emplacement of *circa* 2.646 Ga rare metal pegmatites (Larbi et al. 1999; Smith et al. 2004), including the Tanco and Separation Rapids fields (Blackburn and Young 2000).

Winnipeg River Terrane

The Winnipeg River terrane is a collective term used to describe the plutonic domain exposed north and east of the western Wabigoon volcanic domain. It consists of two main elements: 1) the Winnipeg River Subprovince proper (Beakhouse 1991), a >500 km long terrane composed of Mesoarchean metaplutonic rocks variably intruded by Neoarchean plutons; and 2) a largely Neoarchean plutonic domain, formerly referred to as the central Wabigoon granitoid complex (Percival et al. 2002b, 2004a; Percival and Helmstaedt 2004) and Wabigoon diapiric axis (Edwards and Sutcliffe 1980; Thurston and Davis 1985), which contains scattered remnants of Mesoarchean crust and isotopic evidence for recycling of 3.4 to

3.0 Ga crust (Tomlinson and Percival 2000; Tomlinson et al. 2004; Whalen et al. 2002, 2004a). With inheritance dating back to *circa* 3.4 Ga (Henry et al. 2000; Tomlinson and Dickin 2003), the Winnipeg River terrane stands apart from the Northern Superior and North Caribou superterranes to the north and the Marmion domain to the south (described below). It also carries a distinct record of magmatic and structural events (Percival et al. 2004a; Melnyk et al. 2006), typically characterized by amphibolite to granulite facies metamorphism (Corfu 1988).

The Mesoarchean history of the Winnipeg River terrane has remained cryptic because of extensive overprinting by Neoarchean magmatism and deformation. Tonalitic rocks are the oldest units recognized, and include both gneissic (e.g., 3.17 Ga Cedar Lake gneiss (Corfu 1988); 3.32-3.05 Ga Tannis Lake gneiss (Davis et al. 1988; Melnyk et al. 2006)) and foliated varieties (e.g., 3.04 Ga Lac Seul tonalite; Krogh et al. 1976). Some of these old rocks show still older Nd isotopic signatures, with model ages in excess of 3.4 Ga (Henry et al. 2000; Tomlinson and Dickin 2003) and zircon inheritance. Similar isotopic signatures characterize younger (2.88, 2.84 and 2.83 Ga) tonalitic rocks, reflecting the antiquity of the basement (Beakhouse and McNutt 1991; Beakhouse et al. 1988). Mafic volcanic belts older than *circa* 3.0 Ga (Davis et al. 1988) and newly recognized *circa* 2.93 and 2.88 Ga intermediate volcanic rocks in the eastern Savant–Sturgeon greenstone belt (Sanborn-Barrie and Skulski 1999; Sanborn-Barrie et al. 2002) are also considered part of the Winnipeg River terrane. Two early deformation events are interpreted to have occurred between *circa* 3.1 and 2.85 Ga (Melnyk et al. 2006), with evidence for early metamorphism at *circa* 2.92 Ga.

Significant pulses of Neoarchean tonalite-granodiorite magmatism occurred at between 2.715 and 2.705 Ga, followed by emplacement of granites at *circa* 2.70 to 2.69 Ga (Beakhouse 1991; Beakhouse et al. 1988; Cruden et al. 1997, 1998; Corfu 1988, 1996). A complex structural-metamorphic history characterizes the Winnipeg River terrane during the Neoarchean. Metasedimentary rocks exposed in the Cedar Lake dome contain detrital zircons as young as 2.72 Ga, indicating that rocks now at amphibolite to granulite facies had been deposited after 2.72 Ga (Melnyk et al. 2006). The supracrustal rocks and older gneisses were folded (D_3) between 2.717 and 2.713 Ga, prior to syntectonic injection of 2.713 to 2.707 Ga tonalite and granodiorite sheets accompanying D_4 horizontal extensional deformation (Melnyk et al. 2006). Upright folding during D_5 deformation took place after 2.705 Ga, and younger upright F_6 folds indicate a period of north-trending compression associated with emplacement of granite and granodiorite between 2.695 and 2.685 Ga (Melnyk et al. 2006). Late pegmatites and granites intruded during a dextral transpressive (D_7) regime (Melnyk et al. 2006).

The eastern part of the Winnipeg River terrane represents a broad (200 km wide) transverse corridor of granitoid rocks separating the volcanic-dominated eastern and western Wabigoon domains (*see* Figure 2). Small, east-trending greenstone belts have ages >3075 to 2703 Ma (Davis et al. 1988; Tomlinson et al. 2002, 2003). Dated granitoid units have yielded ages in the range 3075 to 2680 Ma (Davis et al. 1988; Whalen et al. 2002) and some of the oldest rocks have ε_{Nd} values of -1 to + 1, suggesting derivation from even older crustal sources (Tomlinson et al. 2004). At least five generations of Neoarchean structures (D_1-D_5) have been recognized in complex tonalitic gneisses (Brown 2002; Percival et al. 2004a), although the dominant tonalite-granodiorite suite (2.723-2.709 Ga; Whalen et al. 2002) has only S_3 foliation, F_4 folds and D_5 shear zones.

MARMION TERRANE

The Marmion terrane, formerly included as part of the south-central Wabigoon Subprovince, is now recognized to consist of 3.01 to 2.999 Ga Marmion tonalite basement (Davis and Jackson 1988; Tomlinson et al. 2004), upon which several small greenstone belts formed between 2.99 and 2.78 Ga (Stone et al. 2002; Tomlinson et al. 2003). In contrast to Winnipeg River-type crust with 3.4 Ga ancestries to the north, the Marmion terrane appears to have been juvenile at 3.0 Ga. It has been proposed to have accreted to the Winnipeg River terrane by *circa* 2.92 Ga (Tomlinson et al. 2004) or may have formed by magmatic addition to juvenile crust at the Winnipeg River margin. The Marmion terrane has experienced little, if any, Neoarchean (i.e., 2.745-2.72 Ga) magmatic activity, in contrast to the eastern Winnipeg River terrane to the north, and to the Wabigoon terrane to both the west and east (described below).

The eastern Winnipeg River and Marmion terranes are characterized by steeply dipping structures at surface and subhorizontal reflectivity at depth. Lithoprobe Line 1, which crosses these domains, shows several 10 km scale, gently north-dipping crustal panels, including a lower-crustal, high-velocity (Musacchio et al. 2004) layer of mafic composition that terminates as one of two mantle reflectors along the line (White et al. 2003). This feature is interpreted as a subcreted fragment of oceanic crust (White et al. 2003).

WINNIPEG RIVER – WABIGOON TERRANE BOUNDARY

The southern boundary of the Winnipeg River–Marmion terrane may have originated as a Mesoarchean rift margin, evolved into a Neoarchean continental margin arc, been involved in a collisional orogeny, followed by significant strike-slip displacements. Its history may extend over 300 m.y.

The earliest manifestation of activity in this zone is deposition of a substrate of *circa* 2.93 to 2.88 Ga mafic and felsic volcanic rocks (Skulski et al. 1998) that represents depositional basement to well-preserved rift to drift deposits of the Jutten assemblage. The Jutten comprises a lower sedimentary unit containing detrital zircons with ages between 3.4 and 2.9 Ga (Davis and Moore 1991; Sanborn-Barrie et al. 2002), and an upper tholeiitic volcanic sequence. The mafic rocks have ε_{Nd} values of +0.5 to +2.0, reflecting a continental rift environment (Sanborn-Barrie and Skulski 2006). Their depositional age is bracketed between 2.88 and 2.75 Ga (Sanborn-Barrie and Skulski 2006).

Evidence for the existence of restricted oceanic basins is preserved in juvenile magmatic rocks (2.77-2.72 Ga) of the western Wabigoon (Blackburn et al. 1991; Ayer and Davis 1997) and eastern Wabigoon (Stott et al. 2002) domains, although the width of the putative ocean is undefined. A period of continental arc magmatism in the Winnipeg River terrane (2.72-2.70 Ga; Corfu 1988, 1996; Whalen et al. 2002; Melnyk et al. 2006), is attributed to north - and eastward subduction of oceanic rocks (Sanborn-Barrie and Skulski 2006) followed by D_1 deformation at 2708 to 2701 Ga. Post-2.704 Ga regional deformation (D_2) across the Wabigoon outlasted deposition of syncollisional coarse clastic sedimentary overlap sequences (i.e., Crowduck and Ament Bay assemblages; Fralick 1997; Ayer and Davis 1997; Sanborn-Barrie and Skulski 2006). Late faults with both strike-slip and dip-slip motion define the present terrane boundary (Gower and Clifford 1981). For example, Bethune et al. (2006) studied the Miniss River fault and determined an early history of ductile oblique sinistral movement at *circa* 2.685 Ga, followed by brittle reactivation.

Wabigoon Terrane

The Wabigoon terrane has long been recognized as a composite terrane comprising volcanic-dominated domains with a central axis of variable-age plutonic rocks (Davis and Jackson 1988; Percival et al. 2002b). Current understanding is that it consists of distinct western and eastern domains, separated by domains with Mesoarchean ancestry (described above): the eastern Winnipeg River terrane and Marmion domain (Tomlinson et al. 2002, 2004). Areas dominated by metavolcanic rocks display sinusoidal aeromagnetic patterns produced by the complex structure of supracrustal units, interacting with oval shapes derived from lobate plutons. Seismic sections image an overall gently north-dipping reflectivity consisting of stacked panels on the order of 10 to 15 km thick down to the top of the Moho at a depth of ~35 km. The tectonic characteristics and significance of the western and eastern Wabigoon terrane are outlined below.

WESTERN WABIGOON TERRANE

The western Wabigoon terrane is dominated by mafic volcanic rocks with large tonalitic plutons (Blackburn et al. 1991). Volcanic rocks range in composition from tholeiitic to calc-alkalic, and are interpreted to represent ocean floor or plateau and arc environments, respectively (Ayer and Davis 1997; Ayer 1998a; Ayer and Dostal 2000; Wyman et al. 2000). Most of the preserved volcanic rocks were deposited between *circa* 2.745 and 2.72 Ga (Corfu and Davis 1992), with rare older rocks, such as the Fourbay assemblage (2.775 Ga: Davis et al. 1988) of oceanic plateau affinity (Sanborn-Barrie and Skulski 1999) and minor younger (2.713-2.70 Ga) volcanic-sedimentary sequences. Plutonic rocks range from broadly synvolcanic batholiths composed of tonalite-diorite-gabbro (ca. 2.735-2.72 Ga; Davis and Edwards 1982; Corfu and Davis 1992; Whalen et al. 2004a), to younger granodiorite batholiths and plutons (ca. 2.710 Ga; Davis and Edwards 1986; Sanborn-Barrie 1988; Davis and Smith 1991; Melnyk et al. 2006), monzodiorite plutons of sanukitoid affinity (ca. 2.698-2.690 Ga; Stern and Hanson 1991; Ayer 1998b; Stevenson et al. 1999), and plutons and batholiths of monzogranite (2690-2660 Ma; Sanborn-Barrie 1988; Melnyk et al. 2000). Immature clastic metasedimentary sequences are preserved in narrow belts within volcanic sequences. They are commonly younger than the volcanic rocks, as illustrated by local unconformable relationships (Fralick 1997) and geochronological constraints indicating deposition between *circa* 2.711 to <2.702 Ga (Davis 1996a, 1996b, 1998; Fralick and Davis 1999). Virtually all carry ancient (>3 Ga) detrital zircons indicating ancient source regions. At least two phases of deformation affected supracrustal rocks of the western Wabigoon terrane (Blackburn et al. 1991; Edwards and Stauffer 1999), with apparent diachroneity in the onset of deformation from *circa* 2.709 Ga in the Lake of the Woods area (Davis and Smith 1991; Ayer and Davis 1997; Melnyk et al. 2006), to *circa* 2.700 Ga in the Sioux Lookout–Savant area in the east (Sanborn-Barrie et al. 1998, 2002; Sanborn-Barrie and Skulski 2006). These events involved at least local tectonic inversion, through thrust imbrication (Davis et al. 1988) and possible formation of nappe-like structures (Poulsen et al. 1980).

The recently studied Sturgeon–Savant greenstone belt consists of several tectonostratigraphic packages (Sanborn-Barrie et al. 2002), including the previously described Jutten assemblage. The Fourbay assemblage of basaltic rocks with minor dacite (ca. 2775 Ma; Davis et al. 1988) has field, geochemical and isotopic characteristics consistent with an oceanic plateau origin. A younger arc sequence, the Handy Lake and South Sturgeon assemblages, comprises calc-alkalic basalt, andesite and dacite. The arc appears to have been active mainly from 2745 to 2735 Ma (Davis et al. 1985; Sanborn-Barrie and Skulski 1999; Sanborn-Barrie et al. 2002). The 2735 Ma Lewis Lake batholith (Whalen et al. 2004b) may have provided the heat source for seawater convection and massive sulphide mineralization in the Sturgeon Lake camp (Galley et al. 2000). Younger (ca. 2718 Ma; Davis et al. 1988), high Fe, Ti basalt and minor dacite of the central Sturgeon assemblage represent a rifted arc sequence. Associated sedimentary rocks contain both arc (2745-2730 Ma) and continental (3.1-2.8 Ga) detritus based on SHRIMP U/Pb zircon analyses (Skulski et al. 1998). Two younger sedimentary sequences complete the stratigraphic record of the Sturgeon–Savant greenstone belt: 1) greywacke – iron formation (ca. 2.705 Ga) of the Warclub assemblage; and 2) sandstone and arkose (<2.698 Ga) of the synorogenic Ament Bay assemblage (Sanborn-Barrie et al. 2002). Two sets of ductile structures postdate <2.704 Ga rocks: 1) north-trending upright F_1 folds; and 2) east-trending upright D_2 folds and penetrative foliation. Pre-D_1 folds have been inferred locally (Sanborn-Barrie et al. 1998).

EASTERN WABIGOON TERRANE

The eastern Wabigoon terrane is a composite terrane with greenstone belts and intervening granitoid plutons that show variable Mesoarchean (Winnipeg River and Marmion) and oceanic affinity (*see* Figure 2). The supracrustal rocks have been divided into several assemblages based on lithology, age and geochemical character (Stott and Davis 1999; Tomlinson et al. 2000; Stott et al. 2002). In the northwest part of the belt the Toronto and Tashota assemblages (3.0-2.92 Ga) may represent a continental margin sequence built on the Winnipeg River terrane. The central part of the belt is dominated by rocks of oceanic affinity including tholeiitic juvenile pillowed basalt of the 2.78 to 2.738 Ga Onaman and Willet assemblages and the overlying calc-alkalic 2.725 to 2.715 Ga Metcalfe–Venus assemblage (Stott et al. 2002). Across the southern part of the eastern Wabigoon domain, the calc-alkalic Elmhirst–Rickaby assemblage (2.78-2.74 Ga) is possibly built on Marmion-age substrate (Tomlinson et al. 2004). Unconformably overlying clastic rocks (Albert–Gledhill and Conglomerate assemblages) were deposited after *circa* 2.71 Ga. At least two deformation events affected the eastern Wabigoon domain: east-striking D_1 structures (<2.706 Ga) and east-striking, dextral transpressive D_2 shear zones (Stott et al. 2002). The Deeds Lake pluton (2.694 Ga) provides a lower limit on the age of D_2 deformation (Stott and Davis 1999).

Seismic reflection profiles have provided images of the crustal structure beneath the central and eastern domains. Both profiles image crust with steeply dipping structures and reveal subhorizontal reflectivity at depth. Lithoprobe Line 1, crossing the Marmion and north-central domain, shows several 10 km scale, gently north-dipping crustal panels, including a lower-crustal, high-velocity (Musacchio et al. 2004) layer of mafic composition that terminates as one of two mantle reflectors along the line (White et al. 2003). This feature is interpreted as a subcreted fragment of oceanic crust (White et al. 2003). To the east, the eastern Wabigoon domain shows north-dipping crustal reflectors, similar to those across the Marmion and eastern Winnipeg River terrane, with prominent south-dipping features at the southern margin of the belt, corresponding to the Paint Lake fault. The electrical structure of the mantle, imaged with magnetotelluric techniques, shows prominent east-trending conductivity anisotropy, interpreted as graphite films reflecting a tectonic fabric (Craven et al. 2001). Similar strong east-trending anisotropy in the upper mantle is detected seismically through shear-wave splitting experiments (Kay et al. 1999a; Kendall et al. 2002; Sol et al. 2002).

Two general models have been proposed for formation of the Wabigoon terrane: 1) an ensialic rift setting (Blackburn et al. 1991; Cruden et al. 1998; Devaney 2000); and 2) an oceanic setting followed by accretion to ancient continental rocks of the Winnipeg River terrane (Davis and Smith 1991; Corfu 1996; Percival et al. 2004a; Sanborn-Barrie and Skulski 2006; Melnyk et al. 2006).

WABIGOON–QUETICO BOUNDARY

The Quetico boundary with the western Wabigoon terrane is well defined as the Seine River–Rainy Lake fault, whereas east of Lake Nipigon the boundary with the eastern Wabigoon appears to be an imbricate zone with an earlier history of structural telescoping (Devaney and Williams 1989; Tomlinson et al. 1996). The Wabigoon–Quetico interface is also marked sporadically by coarse clastic rocks (<2.692 Ga) of the Seine assemblage (Fralick and Davis 1999) that were deposited in transtensional basins (Blackburn et al. 1991) or delta fan environments (e.g., Fralick et al. 2006). As much as 100 km of dextral strike-slip displacement has been estimated for the Quetico fault (Mackasey et al. 1974), although current interpretations involve considerably less offset.

Quetico Terrane

The Quetico terrane consists dominantly of greywacke, derived migmatite and granite. No stratigraphic sequence has been established within the steeply dipping, polydeformed and variably metamorphosed sedimentary succession; however, younging directions are dominantly to the north (Percival 1989). Depositional age constraints indicate slightly older ages for the northern Quetico (<2.698 to >2.696 Ga; Davis et al. 1990) than for the south (<2.692 Ga; Zaleski et al. 1999). A prominent linear easterly aeromagnetic grain is given by alternating sedimentary units and granitic sheets. Irregular patterns in the belt interior correspond to dominant plutonic and migmatitic units. Incomplete seismic reflection images indicate overall gently north-dipping reflectivity and crustal thickness on the order of 35 km.

Several plutonic suites cut metasedimentary units, including early (2.696 Ga) tonalite (Davis 1996b). An early (D_1) deformation event predated emplacement of a chain of Alaskan type mafic-ultramafic intrusions in the northern Quetico (e.g., Pettigrew 2004; Pettigrew and Hattori 2006), which are associated with alkalic plutons including nepheline syenite and carbonatite. These rocks, derived from metasomatized mantle, have ages in the range 2.69 to 2.68 Ga (Lassen 2004) and geochemical affinities with the Archean sanukitoid suite (cf. Stern et al. 1989; Stevenson et al. 1999; Lassen 2004). Two subsequent deformation events (D_2, D_3) were followed by low-pressure, high-temperature metamorphism that reached upper amphibolite and local granulite facies at *circa* 2.67 to 2.65 Ga (Pan et al. 1994, 1998) in the central region and greenschist facies at the margins (Percival 1989). Coeval, crust-derived granitic plutons and pegmatites, include *circa* 2.67 Ga peraluminous granite and *circa* 2.65 Ga biotite granite (e.g., Southwick 1991).

Tectonic models for the Quetico terrane have favoured forearc settings (e.g., Langford and Morin 1976; Percival and Williams 1989; Williams 1991; Fralick et al. 2006). Depositional ages of *circa* 2.698 to 2.690 Ga overlap those of late arc magmatism in the Wabigoon. The dominantly sanukitoid plutons of this age may have been triggered by slab breakoff, following collision between the Wawa–Abitibi terrane and the amalgamated superterrane to the north.

QUETICO–WAWA BOUNDARY

The curvilinear Quetico–Wawa boundary separates Quetico metasedimentary rocks from the dominantly volcano-plutonic Wawa–Abitibi terrane to the south. Stratigraphic linkages between terranes are evident as common metasedimentary assemblages in the low-grade metamorphic rocks of the McKellar Harbour area (Fralick et al. 2006) and in amphibolite-facies rocks of the Manitouwadge area to the east (Zaleski et al. 1999). Superimposed dextral transpressive shear zones active at *circa* 2.685 Ga define the boundary in several areas (Corfu and Stott 1986, 1996b).

Wawa Terrane

Most workers accept a correlation between the Wawa and Abitibi terranes across the transverse Kapuskasing uplift structure (*see* Percival and West (1994) for a review). Within the Wawa terrane, small remnants of Mesoarchean crust occur in the form of sporadic, *circa* 2.92 Ga tonalitic gneiss (Moser 1994) and 2.89 to 2.88 Ga volcanic rocks of the Hawk assemblage (Turek et al. 1992). An oceanic setting is indicated by the Hemlo–Black River (2.775 Ga), Wawa (2.745 Ga) and Greenwater and Manitouwadge assemblages (2.72 Ga), the latter with significant massive sulphide mineralization (Sage et al. 1996a, 1996b; Williams et al. 1991). Polat et al. (1998, 1999) reported a variety of oceanic magma types from the Schreiber belt, and interpreted the belt as a tectonic mélange (Polat and Kerrich 1999, 2001).

Relatively late-stage volcanism at *circa* 2.695 Ga took place during D_1 thrusting. Subsequent calc-alkalic to alkalic magmatism (ca. 2.689 Ga Shebandowan assemblage (Corfu and Stott 1996b)) and associated coarse clastic sedimentation (Timiskaming type; <2.689 Ga) was followed by emplacement of sanukitoid plutons (2.65-2.68 Ga) and dextral transpressive D_2 deformation. These *circa* 2.685 to 2.68 Ga tectonic events were termed the Shebandowanian phase of the Kenoran Orogeny (Stott and Corfu 1991).

KAPUSKASING UPLIFT

The Kapuskasing uplift represents a 500 km long, northeast-trending, fault-bounded structure characterized by prominent positive gravity and aeromagnetic anomalies that divides the Superior Province into eastern and western halves (Percival and West 1994). Amphibolite- to granulite-facies tonalite gneiss, paragneiss, mafic gneiss and anorthosite (2.765-2.66 Ga), exposed in east-northeast-trending, moderately dipping units, represent mid to lower crustal levels (8-11 kbar; Mader et al. 1994) of the Abitibi–Wawa and Quetico belts that can be traced down-dip on seismic reflection profiles to 25 to 35 km depths (Percival and West 1994). Following an extended period of high-grade metamorphism (Krogh 1993; Moser et al. 1996), deep crustal levels were exposed through uplift events in the Neoarchean (Krogh and Moser 1994), and by east-directed thrusting and sinistral transcurrent motion during the Paleoproterozoic (Percival and McGrath 1986; Percival and Peterman 1994; Halls and Zhang 2003). Brittle structures such as the Ivanhoe Lake fault zone may have accommodated up to 27 km of northwest-trending shortening at approximately 1.9 Ga (Percival and West 1994) and crustal thickening to more than 50 km, in contrast to regional *circa* 40 km values (Percival and West 1994). Some faults are transected by 1.89 and 1.1 Ga alkalic complexes, which have local Nb, REE and phosphate mineralization (Sage 1991). Recent work suggests that the Kapuskasing structure accommodated a 20º counterclockwise rotation of the western Superior with respect to the east (Halls 2004; Halls and Davis 2004).

Seismicity maps (Ontario Geological Survey 2007) indicate some activity associated with the northern Kapuskasing uplift. It may be localized by the intersection of faults related to the Kapuskasing uplift and Lake Timiskaming rift structures.

EASTERN REGION

Abitibi Terrane

Large parts of the Abitibi terrane in Ontario are poorly exposed as a result of subdued topography and extensive glacial lake clay deposits. The region hosts some of the richest mineral deposits of the Superior Province, including the giant Kidd Creek massive sulphide deposit (Hannington et al. 1999) and the large gold camps of Ontario and Quebec (Robert and Poulsen 1997).

Views of the tectonostratigraphic evolution of the Abitibi terrane have changed markedly, from the allochthonous terrane concept introduced in the early 1990s (cf. Jackson and Fyon 1991; Jackson et al. 1994; Desrochers et al. 1993), to a more traditional autochthonous stratigraphic framework supported by detailed geochronology (e.g., Heather 1998; Ayer et al. 2002; Mueller and Mortensen 2002; Ayer 2004). In eastern parts of the belt the basement appears to have been ocean floor, whereas in the west, evidence from zircon inheritance suggests an older (ca. 2.9 Ga) sialic substrate, possibly connected in the subsurface to the Mesoarchean terrane exposed in the Wawa terrane to the west of the Kapuskasing zone (Ketchum et al. in press). Stratigraphic complexities are explained in terms of evolution of oceanic geodynamic settings from plateau, to arc and rift environments (e.g., Thurston 1994; Bédard and Ludden 1997; Kerrich et al. 1999; Wyman et al. 1999, 2002).

The Abitibi terrane has been subdivided into three domains with overlapping tectonostratigraphic histories. In the northern Abitibi, exposed in Quebec, volcanic assemblages are mainly 2.735 to 2.72 Ga (Ludden et al. 1986; Chown et al. 1992; Legault et al. 2002) and associated with layered intrusions. The central zone is dominated by plutonic rocks (Chown et al. 2002). Volcanic rocks of 2.71 to 2.695 Ga and their associated mineral deposits are restricted to the southern Abitibi of Ontario and Quebec (Dimroth et al. 1984; Daigneault et al. 2002). In addition, the southern Abitibi has relatively young sedimentary-volcanic deposits including greywackes (ca. 2.69 Ga) of the Porcupine Group (Bleeker and Parrish 1996) and conglomeratic and alkaline volcanic rocks (2.677 to 2.673 Ga) of the Timiskaming Group (Davis 2002).

PALEOPROTEROZOIC AND MESOPROTEROZOIC ASSEMBLAGES

Post-Archean sequences within the boundaries of the Superior Province include diabase dyke swarms, volcano-sedimentary cover sequences, mafic intrusions and alkalic rock-carbonatite complexes.

Southern Province

The Southern Province represents the oldest passive margin sequence built on the margin of the Superior Province (Bennett et al. 1991; Long 2004). It consists of two main parts: the Penokean fold belt in the west; and flat-lying to gently folded rocks of the Cobalt embayment to the east. The timing of breakup at the southern Superior margin is constrained by the age of sporadic basal volcanic sequences (2.475 Ga; Krogh et al. 1984), layered mafic intrusions such as the East Bull Lake intrusive suite (e.g., James et al. 2002; Easton et al. 2004), and the radiating, 2.471 to 2.445 Ga Matachewan dyke swarm (Fahrig 1987; Phinney and Halls 2001). Granitic intrusions, including the Skead and Murray (2.477 Ga; Krogh et al. 1996) plutons and the two phases of the Creighton (2.415 and 2.376 Ga; Smith 2002) pluton, were emplaced into basal volcanic units of the Elliot Lake Group. In addition, plutonic rocks of this age have been found in the Grenville Province east of Sudbury in Street, Henry and Loughrin townships (Corfu and Easton 2001; Easton 2003b), and thin slivers of mafic and felsic metavolcanic rocks, likely part of the Huronian Supergroup, also occur along the Grenville Front to the east of Sudbury (Easton and Murphy 2002; Easton 2003b). Thick overlying clastic sedimentary and carbonate units comprise three additional groups deposited prior to emplacement of 2.22 Ga Nipissing diabase sills: the Hough Lake, Quirke Lake and Cobalt groups of the Huronian Supergroup (Bennett et al. 1991).

In the Penokean fold belt early deformation predated emplacement of the 2.22 Ga Nipissing gabbro suite (Card 1978). The subsequent Penokean orogeny produced east-trending, upright to north-verging folds and associated faults, with tectonic transport toward the north (e.g., Jackson 2001, and references therein). Metamorphic grade is low to the north of the Murray fault and reaches amphibolite facies to the south, implying substantial post-metamorphic reverse movement on the structure. In the Cobalt embayment deformation is limited to open folds and metamorphic grade is very low (Card 1978).

SUDBURY STRUCTURE

Situated on the southern edge of the Superior Province, the Sudbury Intrusive Complex (1.85 Ga) represents one of the most richly mineralized bodies of the Canadian Shield. Current thinking regards the intrusion to have been generated through crustal melting (Mungall et al. 2004) in response to meteorite impact (Ames 1999; Rousell et al. 2002, 2003; Therriault et al. 2002; Ames et al. 2005). The Sudbury structure (Dressler et al. 1991) consists of a differentiated sill of gabbro-norite, with granophyric top, sporadic basal ultramafic pods and dykes extending radially out into the country rock (Dressler et al. 1991). Large nickel-platinum group element (PGE) deposits, distributed around the perimeter of the intrusion (Wodicka and Card 1995), are localized primarily in the sublayer at the base of the sill (Naldrett 2003). Structurally above the intrusion is the Onaping breccia (Ames 1999) and clastic sedimentary units of the Whitewater Group. Sudbury breccias are zones and dykes of shattered country rock that extend tens of kilometres into surrounding areas (Scott and Spray 2000; Rousell et al. 2003). Detailed seismic reflection surveys in conjunction with magnetotelluric and drill-hole data have defined the subsurface distribution of major units (Milkereit et al. 2000; Boerner et al. 2000).

PROTEROZOIC GEOLOGY OF THE LAKE SUPERIOR AREA

Units of Paleoproterozoic and Mesoproterozoic age are common in the Lake Superior area (Sutcliffe 1991). Most prominent are *circa* 1.1 Ga volcanic, sedimentary and intrusive rocks related to the mid-continent rift system.

Distal units of the Animikie Group, exposed mainly in northern Wisconsin, Michigan and Minnesota, form part of the Penokean orogen. In Ontario these are the gently dipping and virtually unmetamorphosed Gunflint and Rove formations, deposited between 1.88 Ga (Fralick et al. 2002) and 1.777 Ga (Heaman and Easton 2005).

Sporadic Mesoproterozoic intrusions also occur in the area, and include the 1.537 to 1.547 Ga English Bay granite-rhyolite complexes (Davis and Sutcliffe 1985; Heaman and Easton 2005, 2006), as well as the 1.599 Ga Pillar Lake gabbro and associated 1.590 Ga Pillar Lake syenite (Heaman and Easton 2005, 2006). Rocks of Geon 15 age are unusual in North America, and the tectonic setting of these intrusions is unclear. Hollings et al. (2004) have suggested that they may represent part of the dominantly Geon 14 anorogenic granite province that is widespread further south.

Sedimentary rocks of the Sibley Group form an approximately 420 m thick red bed succession in the Lake Nipigon area. Detrital zircon data from sandstones of the lower and upper Sibley Group indicate maximum depositional ages of 1634 and 1670 Ma, respectively, with a predominance of Geon 17 and Geon 18, not Archean detritus (Heaman and Easton 2005, 2006). Data from the middle to upper Sibley Group indicates a maximum depositional age of 1450 Ma, and contains Geon 15 and 17 detritus, but no Geon 18 grains (Heaman and Easton 2005, 2006). Sibley Group rocks are cut by Logan and Nipigon sills dated at 1.115 and 1.114 to 1.110 Ga, respectively (Davis and Sutcliffe 1985; Heaman and Easton 2005, 2006).

The Mesoproterozoic Keweenawan Supergroup (1.008-1.005 Ga; Davis and Sutcliffe 1985; Davis and Green 1997) occurs in and around the mid-continent rift. The aborted intracontinental rifting event resulted in an approximately 2000 km long belt of basaltic and related rocks up to 30 km thick, deposited in half grabens (Sutcliffe 1991). Related intrusive rocks are widespread in the Thunder Bay–Lake Nipigon area, in the form of thick Logan and Nipigon diabase sills and dykes (1.115 to 1.110 Ga, Heaman and Easton 2006). Ultramafic intrusions, some hosting PGE mineralization, were emplaced between 1.24 and 1.107 Ga (Heaman and Easton 2006). In addition, alkalic rock complexes, such as the Coldwell Complex, as well as several alkalic rock - carbonatite complexes, were also emplaced during this event. The Lake Nipigon area has been the focus of intense research over the past several years as a result of the Lake Nipigon Region Geoscience Initiative (e.g., Rayner 2004). One of the outcomes of the initiative has been recognition that the rifting event began at approximately 1.14 Ga, based on the ages of the Inspiration sills along the northwest shore of Lake Nipigon, some of the Pigeon River dykes, and the

Great Abitibi dyke (Heaman and Easton 2005, 2006; Easton 2005a). Peak magmatic activity in the Lake Nipigon area occurred between 1.115 and 1.110 Ga, with activity migrating southward to form the main Lake Superior basin between 1.110 to 1.105 Ga, then tailing off between 1.095 and 1.085 Ga (Heaman and Easton 2005, 2006; Easton 2005a).

Paleoproterozoic and Mesoproterozoic Mafic Dykes and Related Rocks

Numerous Proterozoic dyke swarms transect the Superior Province, particularly in the south (Table 1; Buchan and Ernst 2004). The Matachewan swarm is volumetrically significant, making up almost 5 percent of bedrock area in northeastern Ontario. Some nickel-copper mineralization is present in associated mafic sills within lower Huronian strata (e.g., James et al. 2002). Significant mineralization is associated with the Paleoproterozoic Nipissing magmatic event, in the form of vein silver deposits in sills of the Cobalt plate (Marshall and Watkinson 2000). Mineralization related to the Keweenawan event includes copper, gold in basalts and nickel-PGE showings in Logan sills in the Thunder Bay area. Alkalic intrusions of similar age host nickel-PGE mineralization, and carbonatites host numerous niobium-REE prospects (Sage 1991).

Table 1. Diabase dyke swarms of the Superior Province in Ontario (*after* Buchan and Ernst 2004).

Swarm	Age (Ga)	Area
Logan–Keweenawan	1.18-1.11	L. Superior
Abitibi	1.14	E-central Ontario
Sudbury	1.238	E-central Ontario
Mackenzie	1.267	NW Superior
Pickle Crow	1.88	NW Superior
Molson	1.884-1.877	NW Superior; Animikie
Fort Frances	2.076	SW Superior
Marathon	2.12	L. Superior
Biscotasing	2.167	E-central Ontario
Nipissing	2.22	E-central Ontario
Matachewan	2.473-2.446	Central Ontario

Grenville Province

The Grenville Province makes up approximately 20 percent of the exposed Canadian Shield in Ontario, but is also present in the subsurface from the Paleozoic–Canadian Shield boundary along the Trent–Severn waterway south to the United States border beneath lakes Erie and Ontario and along the St. Lawrence River. The Grenville Province in Ontario contains rocks ranging in age from 2.69 to 0.99 Ga, all of which have been subjected to Grenvillian metamorphism between 1.08 and 0.99 Ga. By definition, all rocks older than 1.3 Ga are pre-Grenvillian; those younger than 1.3 Ga are termed Grenvillian (Davidson 1998).

The Grenville Province (Figure 3) is bounded to the west and north against the Superior and Southern provinces by an orogenic front, known as the Grenville Front. For most of its length in Ontario, the Grenville Front is a near-vertical fault, termed the Grenville Front boundary fault that was in large part developed along rejuvenated older structures. Metamorphic grade increases abruptly across the Front, from greenschist facies in the adjacent Southern Province, to upper amphibolite facies in the Grenville Province, with migmatitic rocks commonly forming the hanging wall of the Front.

Within the Grenville Province, there is an overall, generally shallow (20-40°), southeasterly dip to both surface geological structures and seismic reflectivity within the upper crust, both providing evidence for northward vergence, and suggesting northward thrusting of deep-level crustal rocks over the Superior and Southern provinces. The Abitibi–Grenville Lithoprobe seismic data suggest that the Superior Province continues at least 200 km to the southeast as a southward-tapering wedge in the Grenville lower crust (White et al. 2000), disappearing approximately at the Central Metasedmentary Belt boundary zone.

Tectonic stability has prevailed since *circa* 1.0 Ga in most of the Grenville Province. At the end of the Grenville Orogeny (ca. 1.0 Ga), it is thought that a mountain range and plateau, similar to the modern-day Himalayas and the Tibetan plateau was present in the region occupied by the Grenville Province. This mountain range was peneplained by the time of the deposition of Paleozoic limestones at approximately 0.42 Ga, based on the presence of local outliers of Paleozoic rocks throughout the Grenville Province, and the fact that the Grenville Province forms the basement to all of the Paleozoic rocks in southwestern and eastern Ontario.

Neoproterozoic and younger tectonic activity is limited to localized rifting at *circa* 0.59 Ga along the Ottawa graben and along an east-trending corridor along the Mattawa, French and Pickerel rivers, and Lake Nipissing. In addition, subsequent rifting during the Jurassic, at *circa* 0.17 Ga, resulted in the formation of the Ottawa–Bonnechere graben system, as well as the localized injection of lamprophyric and kimberlitic dykes in the eastern Grenville Province in Ontario. In addition, emplacement of several mafic dyke swarms occurred prior to, during, and after the Grenville Orogeny (Table 2).

It has been suggested that there is significant neotectonic activity in the Grenville Province, particularly in the "Golden Horseshoe" area of Southern Ontario, and along the north shore of Lake Ontario and the St. Lawrence (Fakundiny et al. 2002; Mereu et al. 2002; Dineva et al. 2004; O'Dowd et al. 2004). At present, apart from localized, low-level seismicity in the "Golden Horseshoe" area near the subsurface trace of the Central Metasedimentary Belt boundary zone, there is no compelling evidence that significant neotectonic activity, has, or is, occurring in the Grenville Province.

Table 2. Diabase dyke swarms of the Grenville Province in Ontario (*after* Buchan and Ernst 2004).

Swarm	Age (Ga)	Area
Rideau	0.42?	St. Lawrence River
Grenville	0.59	Laurentian margin (L1, L2, L3) mainly Ottawa River, Nipissing–French River corridors
Frontenac	1.16	Frontenac–Adirondack belt
Sudbury	1.238	Laurentian margin (L1, L2) deformed segments only
Matachewan	2.473-2.446	Laurentian margin (L1) deformed segments only

SOURCES OF INFORMATION

The geology of the Grenville Province in Ontario has been reviewed by Easton (1992), Davidson (1995, 1998), Carr et al. (2000, 2004) and Davidson et al. (2002). Metamorphic history has been reviewed by Easton (2000a) and Easton and Berman (2004). Metallogeny has been reviewed by Easton and Fyon (1992) and Sangster et al. (1992). Easton and Carter (1995) and Carter et al. (1996) describe the character of the Grenville Province in the subsurface of southwestern Ontario.

Since 1992, compilation mapping has focused largely on the Composite Arc Belt, with 1:50 000 scale maps of the National Topographic System (NTS) sheets located in an area south of 45°00′N latitude to the Paleozoic unconformity, from 80°30′W to 76°30′W longitude, published by the Ontario Geological Survey between 1999 and 2002. In addition, 1:50 000 scale map coverage of the Georgian Bay shoreline, and as far east as the Highway 400/69 corridor, was released by the Ontario Geological Survey in 2004

(Culshaw et al. 2004). An updated version of a 1:50 000 scale map covering the River Valley intrusion (NTS 41I/09), released in 2001 (Easton 2001b), is scheduled for publication in 2007 (Easton in press).

New mapping by the Ontario Geological Survey between 1996 and 2005, at either 1:20 000 or 1:50 000 scale, was focused in the vicinity of the Grenville Front (Easton and Murphy 2002; Easton 2002; Easton 2003a, 2003b, 2006; Easton and ter Meer 2004). Mapping along the Grenville Front near Sudbury between 1996 and 2001, conducted by A. Davidson of the GSC, has been incorporated into a new map of the Sudbury area (Ames et al. 2005).

In terms of new geophysical data sets, it should be noted that Abitibi–Grenville Lithoprobe seismic data was available at the time of writing of the Grenville Province chapter in Geology of Ontario (White et al. 1994), but that this data has been subsequently re-evaluated (White et al. 2000), particularly with respect to the depth extent of the Grenville Front. Additional seismic data for three areas of the Grenville Province beneath the Paleozoic were acquired in 2000 as part of the Southern Ontario Seismic (SOS) project (Ouassaa et al. 2002, 2004), but so far has only been subjected to limited processing and interpretation. Publication of a high-resolution gamma-ray spectrometric survey of the Composite Arc Belt, which was available at the time of writing of the Grenville Province chapter in Geology of Ontario, occurred in 2004 (Carson et al. 2004). A new, high resolution aeromagnetic survey of the area west of Toronto (Geological Survey of Canada 1999) provides better resolution of the Central Metasedimentary Belt boundary zone in the Toronto area.

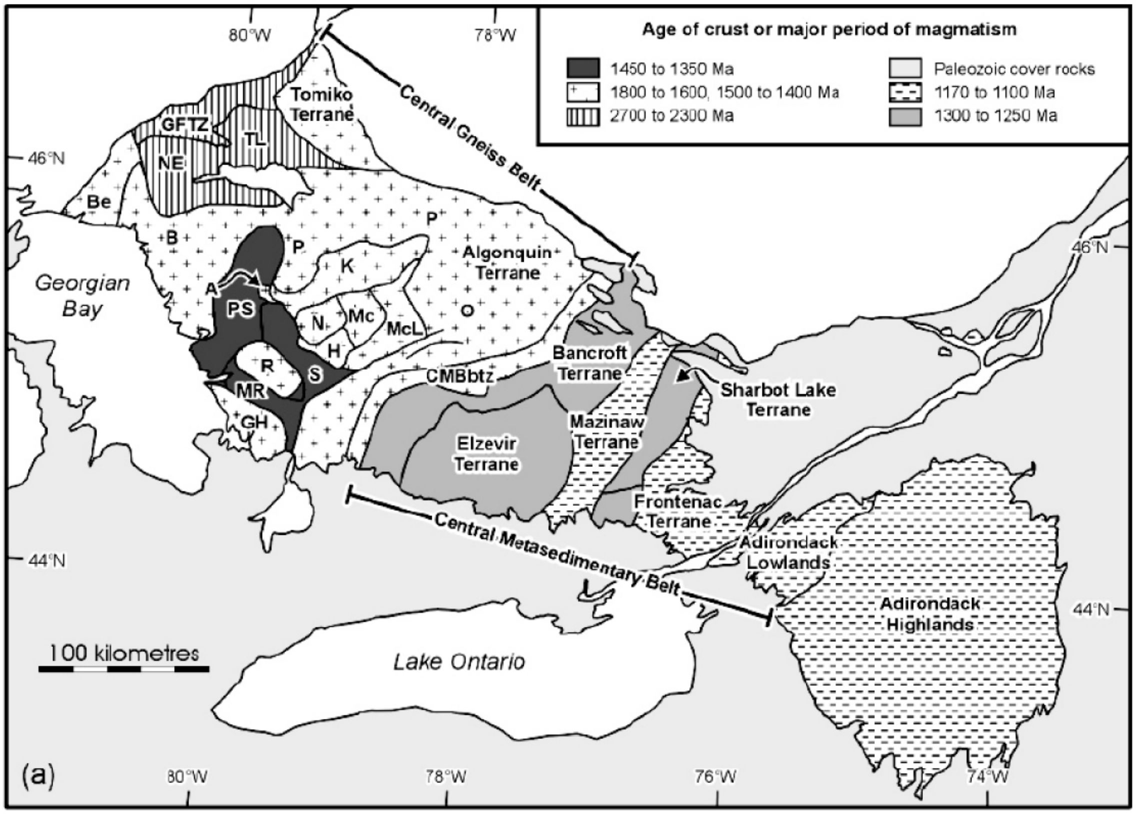

Figure 3. Major divisions and structures of southwestern Grenville Province showing definition of lithotectonic terranes, domains and crustal ages (*from* Easton 1992; *see also* Table 3). Abbreviations: A, Ahmic domain; B, Britt domain; Be, Beverstone domain (part of Killarney magmatic belt); CMBbtz, Central Metasedimentary Belt boundary thrust zone; GFTZ, Grenville Front tectonic zone; GH, Go Home domain; H, Huntsville domain; K, Kiosk domain; Mc, McCraney domain; McL, McLintock domain; MR, Moon River domain; N, Novar domain; NE, Nepewassi domain; O, Opeongo domain; P, Powassan domain; PS, Parry Sound domain; R, Rosseau domain; S, Seguin domain; TL, Tilden Lake domain.

SCOPE

This section focuses on developments in our understanding of Grenville Province geology in Ontario since the overview prepared for the Geology of Ontario volume (Easton 1992). Compared to the Superior Province, the scope of new developments is more limited, in part because:

a) the Grenville Province chapter was prepared two years after the Superior Province chapters and incorporated a large amount of unpublished data; and
b) there has been a significant decrease in the amount of research and mapping in the Ontario Grenville since 1992. This decrease is due to a combination of factors, including retirements from university and federal and provincial geoscience organizations of Grenville-focused researchers, and the end of research-funding linked to the Abitibi–Grenville Lithoprobe transect.

New developments fall into three main areas:

a) better understanding of the regional geology because of additional U/Pb geochronology;
b) better understanding of the geology and geological history of specific terranes and/or domains because of additional geologic mapping; and
c) better tectonic models of the region, because of integration of the seismic data acquired during Abitibi–Grenville Lithoprobe (White et al. 1994, 2000) and finite-element modeling history of orogenic belts, conducted by C. Beaumont and co-workers at Dalhousie University (e.g., Willett et al. 1993; Ellis and Beaumont 1999; Ellis et al. 1998; Culshaw et al. 2004).

New developments will be discussed under two broad headings: “Regional Advances”, which relates to those developments of regional significance, and “Local Advances”, which relates to improved understanding of specific terranes and domains.

SUBDIVISIONS OF THE GRENVILLE PROVINCE

A variety of subdivisions are in use for the Grenville Province in Ontario, and fall into two broad groups, those that are lithologically-based, commonly with a long history of usage (e.g., Wynne-Edwards 1972; Moore and Pride 1979; Moore 1982; Easton 1992; Easton and Davidson 1994), and those that are more tectonic or interpretative in character, generally of more recent vintage (Rivers et al. 1989; Carr et al. 2000). Boundaries between the different types do not always coincide (e.g., the Central Gneiss Belt of Wynne-Edwards (1972) contains para-autochthonous and allochthonous polycyclic rocks of Rivers et al. (1989). Both approaches are still in use, with usage based on need. For example, the lithologic- and historic-based terminology is used more on maps (<1:50 000 scale), whereas the tectonic-based terminology is used more on regional maps and in academic literature. Key divisions are listed in Table 3 and shown in Figures 3 and 4.

The lithologically based subdivision into terranes and domains, but which also includes age, structural and geophysical characteristics, was the framework used for the *Geology of Ontario* overview. The tectonic-based subdivision, first proposed by Rivers et al. (1989), achieved widespread acceptance in Quebec shortly after its introduction, but was less widely accepted in Ontario, in part because the locations of some of the significant boundaries utilized in the classification, such as the Allochthon Boundary Thrust, were not resolved until recently (e.g., Ketchum and Davidson 2000).

The Carr et al. (2000) classification is the scheme used in this review (*see* Figure 4), and incorporates the broad regional tectonic divisions proposed by Rivers et al. (1989), while retaining the terrane and domain subdivision of Easton (1992) on a local scale. An updated classification of the subsurface Grenville terranes present in southwestern Ontario (Easton 1992; Easton and Carter 1995), consistent with Carr et al. (2000), was presented by Easton (2000c).

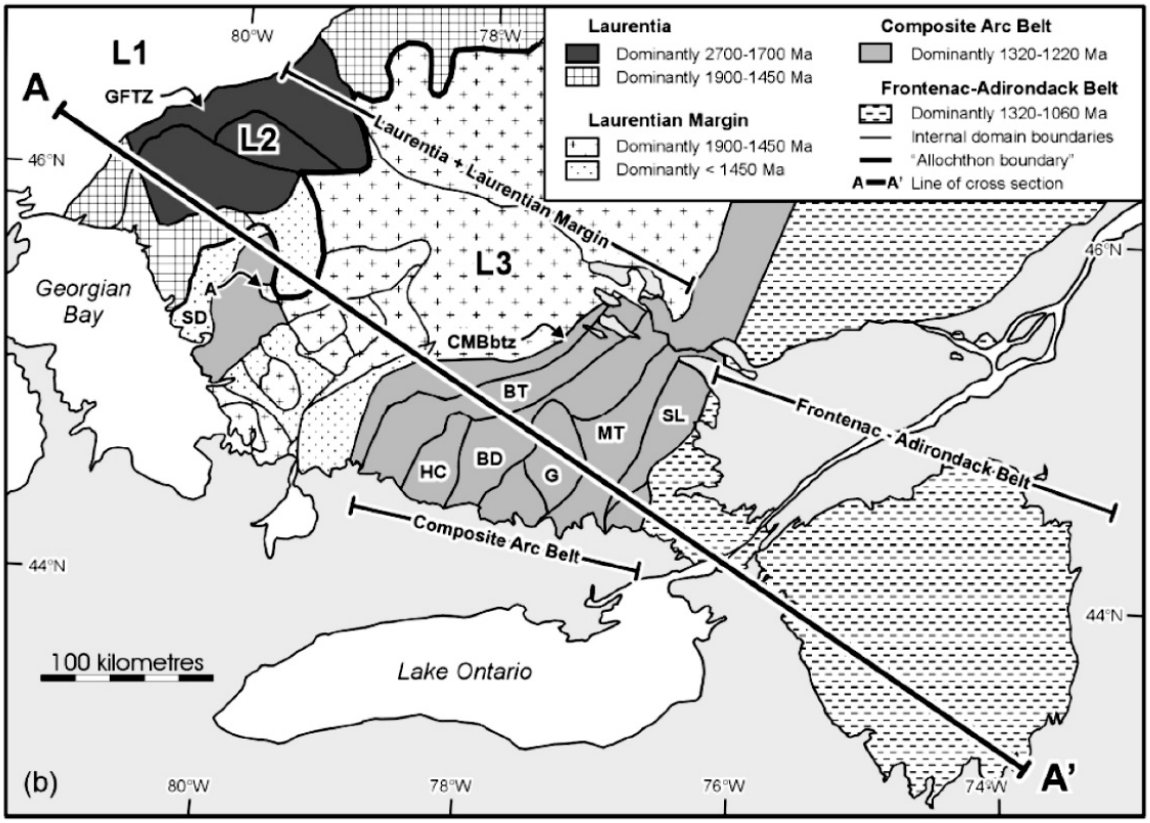

Figure 4. Nomenclature of the southwestern Grenville Province used in this paper including the tripartite divisions of (1) Pre-Grenvillian Laurentia and its margin (L1, Laurentian foreland northwest of the Grenville Front; L2, Archean crust with 1740 and 1450 Ma plutons; and L3, 1800 to 1680 Ma supracrustal rocks with *circa* 1450 Ma continental arc granitoids); (2) Composite Arc Belt; and (3) Frontenac–Adirondack Belt (*after* Carr et al., 2000, as described in Table 3). Abbreviations: A, Ahmic domain; BD, Belmont domain; BT, Bancroft domain; CMBbtz, Central Metasedimentary Belt boundary thrust zone; G, Grimsthorpe domain; GFTZ, Grenville Front tectonic zone; HC, Harvey Cardiff arch; MT, Mazinaw terrane; SD, Shawanaga domain; SL, Sharbot Lake domain.

Table 4 outlines the key geological events with respect to the Ontario Grenville Province, and the presence or absence of these events within the main tectonic entities of the Ontario Grenville Province. There are a few significant differences between the Grenville Province in Ontario when compared to Quebec and Labrador. These include:

a) For example, massif anorthosites anorthosite-mangerite-charnockite-granite (AMCG) suite, so common in Quebec, Labrador and the Adirondack Highlands, are absent from Ontario. Why this is so is unknown.

b) Younger plutonic rocks, i.e., less than 1.02 Ga, such as those found in eastern Quebec and Labrador, are absent. This could be related to distance from the suture zone of the orogen.

c) The Grenvillian rocks of the Composite Arc Belt are almost entirely restricted to Ontario. This distribution greatly increases the mineral potential of the Ontario Grenville for some mineral commodities.

Table 3. Key divisions of the Grenville Orogen in Ontario.

Historic/Lithologic	Regional Tectonic	Local Tectonic/Historic
Grenville Front Tectonic Zone (GFTZ)	Para-autochthonous belt or Laurentian margin 1	Segments 1, 2, 3
Central Gneiss Belt (CGB)	Para-autochthonous and/or allochthonous belt, Laurentian margin 2 and 3	Parry Sound, Algonquin, Tomiko, Beaverstone terranes Britt, Fishog, Go Home (lower), Go Home (upper), Huntsville, Kiosk, McCraney, McClintock, Moon River, Nepewassi, Novar, Powassan, Shawanaga, Sequin, Tilden Lake domains
Central Metasedimentary Belt (CMB)	Composite Arc Belt (CAB) and Frontenac–Adirondac Belt (FAB)	Bancroft, Elzevir, Mazinaw, Frontenac terranes, Elzevir contains Anstructher, Belmont, Grimsthorpe, Sharbot Lake domains), Adirondack Lowlands and Highlands
	Important Boundaries	
Grenville Font	North limit of Grenville metamorphism and penetrative deformation (locally migmatite front)	Grenville Front boundary fault (GFBF)
Allochthon Boundary Thrust (ABT)	Separates para-autochthonous and allochthonous rocks	a.k.a. central Britt shear zone, Shawanaga shear zone
Laurentian Margin –Composite Arc Belt boundary	Composite Arc boundary zone (CABZ)	Central Metasedimentary boundary zone (CMBBZ), a.k.a Central Metasedimentary Belt boundary thrust zone (CMBbtz)
CAB/FAB boundary	Frontenac–Adirondack boundary zone (FABZ)	a.k.a. Maberly shear zone, Sharbot Lake–Frontenac boundary

Table 4. Key events in and around the Grenville Province of Ontario.

Orogenic Events (Grenville Province and eastern North America)	Magmatic Events (Laurentian Margin)	Magmatic Events Composite Arc Belt, Frontenac–Adirondack belts
~2.68-2.64 Ga Archean plutonism and migmitization south of 2700 Ma Abitibi greenstone belt	Laurentian Margin 1 and 2	
~2.475-2.375 Ga Huronian plutonism (e.g., River Valley intrusion) coincident with Huronian volcanism	only in Laurentian 1 (GFTZ)	
~2.21 Ga Nipissing magmatism	only in Laurentian 1 (GFTZ)	
~1.85 Ga Sudbury event	no effects observed?	
~1.835 Ga Penokean orogen	Not present?	
~1.74 Ga Killarney magmatic belt plutonism and volcanism, ~1.70 Ga regional metasomatism	only in Laurentian 1 (GFTZ)	
~1.68 Ga Trans-Labradorian batholith emplacement and regional metamorphism in Labrador	Hiatus?	
~1.54-1.49 Ga plutonism and felsic volcanism in eastern Grenville in Quebec	Hiatus?	
~1.49-1.35 Ga Eastern-Granite rhyolite province event in central US; granuite facies metamorphism in Britt domain	Laurentian 1, 2 and 3 (may be 2 distinct events, Geon 14 and Geon 13)	Basement to FAB and/or CAB forms in this period?
~1.25 Ga domain amalgamation in Composite Arc Belt	~1.25 Ga mafic and felsic magmatism in Laurentian Margin 2	~1.25 Ga mafic and felsic plutonism, FIII rhyolite volcanism
~1.16 Ga CAB and FAB linked together, distal effects observed in Laurentian Margin?	Hiatus	~1.180-1.150 Ga Frontenac suite (mainly in FAB)
~1.145-1.085 Ga Midcontinent Rift magmatism, AMCG suite magmatism in Quebec Grenville and in Adirondacks	Hiatus crustal heating and softening	Hiatus
~1.07-1.04 Ga northwest directed thrusting, high-grade metamorphism, orogen-wide penetrative deformation	Hiatus	~1.085-1.070 Ga Kensington–Skootamatta suite plutons in CAB/FAB
~1.04-0.99 Ga continued thrusting, localized metamorphism and deformation, particularly along tectonic boundaries or in specific domains (Mazinaw)	Hiatus	~ pegmatite dikes along CABZ, possibly in GFTZ also

Note: Abbreviations: AMCG = anorthosite-mangerite-charnockite-granite; CAB = Composite Arc Belt; CABbz = boundary between Composite Arc and Frontenac–Adirondack belts; FAB = Frontenac–Adirondack Belt; GFTZ = Grenville Front Tectonic Zone.

REGIONAL ADVANCES

Advances in mapping and stratigraphic techniques in gneiss terranes have been two-fold since *Geology of Ontario*. First, is the recognition that deformed mafic dykes can serve as important regional markers and mapping tools, as elegantly demonstrated using the Sudbury dyke swarm by Bethune (1997) and Ketchum and Davidson (2000). Second, the use of "gneiss associations", which consist of a combination of lithologic units, dyking relationships, and plutonic and metamorphic history, have proven to be a useful mapping tool in several parts of the Ontario Grenville (Culshaw et al. 1988, 2004; Easton 2003b).

Although the Ontario Grenville Province remains one of the best-dated parts of the Canadian Shield, data distribution is erratic, with some terranes/domains being well studied, whereas others are bereft of data. Two significant advances have been made in terms of understanding the geochronology of the Grenville Province on a broad scale. First, is the recognition by Krogh (1997), that dating regional, protracted, high-grade metamorphic events can be problematic, as the ages recorded may show a continuum of ages, rather than a single, well-constrained peak. The abundance and timing of fluid circulation during metamorphism may be one reason for this effect (Krogh 1997), with the result that some phases (e.g., monazite) may be affected more than others (e.g., zircon). Consequently, interpreting geological histories using a mixture of U/Pb bearing minerals can be difficult. Within the Adirondacks, application of the ion-microprobe (SHRIMP) for single-grain U/Pb geochronology has resulted in significant changes to the tectonic picture for that area. For example, several Geon 12 plutons were identified in the Adirondack Lowlands in the 1990s using U/Pb multi-grain geochronology (McLelland et al. 1992), which suggested a linkage of the Adirondack Lowlands (FAB), and perhaps part of Frontenac terrane (FAB), with Elzevir terrane (CAB). Subsequent work has revealed that these Geon 12 ages were the result of inherited cores (McLelland et al. 1997a, 1997b; 2001; Wasteneys et al. 1999), and that all the plutons were emplaced at approximately 1.16 Ga, similar in age to the Frontenac intrusive suite that occurs throughout FAB (Davidson and van Breemen 2000a, 2000b).

Preparation of a geological cross-section (Carr et al. 2000) designed to be self-consistent with the seismic data for the Grenville Province (White et al. 2000) has led to two significant advances. First is the recognition that the Grenville Front does not likely extend to the Moho, as was previously suggested by Green et al. (1988), but more likely soles out into a mid-crustal decollement that underlies most of the Grenville Province. Second is one of the first attempts to construct a tectonic model for the whole of the western Grenville Province (Carr et al. 2000, 2004) since Wynne-Edwards' (1976) millipede model. Previously, models had focused either solely on the Laurentian margin (e.g., Culshaw et al. 1997) or on the Central Metasedimentary Belt, with or without the Adirondacks (e.g., Brown et al. 1975; Windley 1986; McLelland et al. 1996).

Mapping and new geochronology of the Laurentian margin (L1, L2) indicate a significant pulse of mafic and felsic magmatism occurred in that region at *circa* 1.27 to 1.24 Ga, coincident with the Sudbury dyke swarm in the Superior Province (Easton and Ketchum 2002; Easton and Kamo 2003; Easton 2002, 2006). The abundance of this mafic and felsic material increases toward the Quebec border, suggesting that if it is related to a plume event, then the plume centre might lie between the younger Grenville allochthons of western Quebec. This magmatism is coincident with the main period of magmatic activity present in the Composite Arc Belt; however, the tectonic linkage between the two events remains problematic.

It has become clearer that different tectonic regimes have been repeated in space and time in the Grenville Province. For example, at one time, as late as the 1980s, all of the tonalite plutons of the Composite Arc Belt, on the basis of petrography and chemistry, were grouped together as one, broadly coeval suite. Subsequent U/Pb geochronology revealed at least 3 ages of tonalite plutonism, at ~1.34, 1.27 and 1.25 Ga. Thus, petrographically and geochemically similar looking rocks might not be the same age.

The relationship of the Midcontinent Rift to Grenville Province evolution has long been a topic of speculation (e.g., Gordon and Hempton 1986), and is gradually being elucidated. It is now clear that the time period encompassed by the Midcontinent Rift, i.e., 1.145 to 1.085 Ga, is a period of tectonic quiescence in the Grenville orogen, although it does coincide with emplacement of AMCG magmas in the Frontenac–Adirondack belt and throughout the eastern Grenville Province in Quebec and Labrador. Carr et al. (2000) suggested that much of the ductile style of tectonism seen in the Laurentian margin portion of the Grenville Province of Ontario, and the prolonged metamorphism (1.08 to 1.04 Ga) there, can be attributed to heating of the crust in this region by the plume associated with the Midcontinent Rift, immediately prior to Grenvillian thrusting and deformation.

Finite-element modeling of orogen evolution is playing an increasingly important role in the development of tectonic models for the western Grenville Province, particularly the area underlain by the Laurentian margin (e.g., Culshaw et al. 2004).

LOCAL ADVANCES

Grenville Front Area (Laurentian Margin, L1 and Northern L2)

Apart from the Red Cedar Lake gneiss (Easton 1992), the extent of Archean rocks south of the Grenville Front was poorly constrained. Based on Nd and Pb model age mapping (Dickin 1998a 1998b; Holmden and Dickin 1995), and U/Pb geochronology (Chen et al. 1995; Ketchum cited in Easton 2003b; Easton and Kamo 2004), it is now clear that Archean rocks make up the bulk of the gneisses of the Nepewassi, Tilden Lake and Tomiko domains, even though Mesoproterozoic plutonic rocks cut the Archean gneisses in all three domains. In addition, Easton (2000b) suggested that in the River Valley area, a southward deepening Archean crustal section was present, consisting of Archean greywackes north of the Grenville Front, migmatitic equivalents of these greywackes immediately south of the Front, and mid-crustal granitoid rocks further south into Nepewassi domain. U/Pb ages suggest that the bulk of these gneissic rocks are 2.68 Ga in age, with migmatizaton occurring between 2.66 and 2.42 Ga. These ages are similar to those of the Levack gneiss complex north of Sudbury (Wodicka and Card 1995) and for parts of the Ramsey–Algoma granitoid complex (Prevec 1993). These U/Pb ages are younger than ages of 2.73 Ga reported from the Temagami greenstone belt immediately north of the Grenville Front (Bowins and Heaman 1991), and Easton (2000b) has suggested that the Grenville Front east of Sudbury may be subparallel to an Archean terrane boundary.

Mapping east of Sudbury, in Street, Henry, Loughrin and Dana townships (Easton and Murphy 2002; Easton 2003b, Easton and ter Meer 2004) has found that the Southern Province rocks can only be recognized within 1 to 3 km of the Grenville Front, and consist mainly of Nipissing gabbro intrusions and metamorphosed equivalents of the Stobie, Pecors and Ramsay Lake formations. An important observation is that Paleoproterozoic mafic rocks of the East Bull Lake and Nipissing intrusive suites are non-migmatitic, whereas Archean mafic rocks are invariably migmatitic. This suggests a significant metamorphic event affected the Archean rocks prior to 2.48 Ga.

Mapping in these same townships has indicated that the Grenville Front, *sensu stricto,* locally lies 1 to 2 km north of the Grenville Front boundary fault (GFBF) of Lumbers (1973). The boundary of Lumbers (1973) corresponds to the first appearance of migmatitic rocks. Detailed metamorphic and geochronology work north of the GFBF in Street Township by Murphy (2001), Easton and Murphy

(2002) and Corfu and Easton (2001) indicate the presence of a panel of Huronian Supergroup strata between the GFBF and the more northerly Ess Creek fault that were metamorphosed to amphibolite facies at 0.995 Ga, during the Grenville Orogeny. Similar relationships exist along the Front to the west of the River Valley (Easton 2003b). Although these new data do not shift the location of the Grenville Front in any significant fashion, it emphasizes that the criteria used to define the Front, be they structural, metamorphic, textural or geochronologic, do not always yield a unique result.

The River Valley intrusion, a mafic intrusive complex in the hanging wall of the Grenville Front, can be correlated geochemically and stratigraphically with other Paleoproterozoic mafic intrusions in the adjacent Southern Province, such as the East Bull Lake and Agnew Lake intrusions (James et al. 2002; Easton 2003b), as well as with equivalent rocks in the Baltic Shield (Easton 2005c). U/Pb geochronology (Heaman cited in Easton 2003b) has yielded a 2.475 Ga age for the intrusion, similar to other ages obtained from the East Bull Lake intrusive suite (Krogh et al. 1984). North of the Sturgeon River, large parts of the River Valley intrusion, and cross-cutting Sudbury dykes, are minimally affected by Grenville metamorphism (Easton 2003b). South of the Sturgeon River, however, the River Valley intrusion and Sudbury swarm dyke rocks are metamorphosed to upper amphibolite facies. Previous suggestions that the River Valley intrusion straddles the Front (e.g., Lumbers 1973) are incorrect, as first demonstrated by Davidson (1986), and confirmed by Easton (2003b). This disagreement in the location of the Front is due to the fact that the Front in the River Valley area is a 0.5 to 1 km wide, shallowly eastward dipping, anastomosing zone of mylonites. The River Valley intrusion north of the Sturgeon River hosts a major, contact-style, copper-PGE deposit, located along the northern margin of the intrusion, where it is in contact with granitic rocks 2.60 Ga in age (James et al. 2002; Easton et al. 2004).

Laurentian Margin (L2)

Mapping in the Tomiko domain, east and northeast of North Bay, was conducted to test suggestions that the domain has the potential to host Broken Hill-style lead-zinc mineralization (Easton 2003a, 2005b, 2006). This work has confirmed that quartzites in the domain were deposited post-1687 Ma (Easton and Kamo 2004), as first suggested by Krogh (1989), and prior to regional felsic plutonism at ca. 1.27 Ga. One surprise was that several lithologically different plutonic suites in Tomiko terrane all had similar anorogenic type chemistry, and were all emplaced between 1.27 and 1.25 Ga (Easton 2003a, 2006; Easton and Kamo 2004), similar to the previously reported age of 1.244 Ga (Lumbers et al. 1991) for the Mulock granite. Rocks of this age also occur in the Tilden Lake domain (West Bay granite, 1.235 Ga in Ketchum and Davidson 2000), and the Powassan batholith (1.27 Ga, Davidson and van Breemen 2001) may be part of the same magmatic event. Tomiko domain has had a complicated metamorphic history, with three separate events recognized in the field and petrographically, with metamorphic intensity increasing to the south. The only metamorphic age obtained so far indicates that the main, regional metamorphic event, which forms migmatitic sweats in quartzitic rocks, occurred at 1.04 Ga (Easton 2005a, 2006). Easton (2003a, 2006) has suggested that aluminosilicate-bearing gneisses in the domain may be the product of regional alteration rather than being metapelitic in origin. Easton (2003a, 2005a) has noted that parts of the Proterozoic supracrustal sequence in Tomiko domain resemble strata present in the Mazatal orogen in New Mexico.

Within Britt domain, a 1.45 Ga granulite facies metamorphic event has been recognized (Ketchum et al. 1994; Culshaw et al. 2004). This finding suggests that in addition to a major magmatic event throughout the Laurentian Margin at ca. 1.45, a significant metamorphic event may also have had regional extent.

Laurentian Margin (L3)

The central Britt shear zone (Davidson et al. 1982) is now known to be a significant tectonic feature, resulting from extensional activity along the Allochthon Boundary Thrust (Ketchum et al. 1998). Laurentian margin crust north of this boundary contains remnants of Sudbury swarm diabase dykes. Laurentian crust south of this boundary contains pods of coronitic metagabbro of *circa* 1.16 Ga age (Ketchum and Davidson 2000). Britt domain has been subsequently subdivided, with the southern Shawanaga domain being dominated by migmatitic gneiss, much of which may have formed at *circa* 1.34 Ga (Culshaw et al. 2004, and references therein). Culshaw et al. (1997, 2004) have suggested that the highly ("juicy") migmatitic character of most gneissic rocks in Shawanaga domain is the result of fluids from the Allochthon Boundary Thrust percolating upward and becoming trapped in the lowermost portions of the overlying thrust stack. Slagstad et al. (2004a, 2004b) provide data on the geochronology and geochemistry of metaplutonic rocks from Muskoka and Shawanaga domains.

Central Metasedimentary Belt Boundary Zone

Gauthier and Larivière (2005) have suggested that zinc mineralization in marbles in the Grenville Province may be in the form of zinc oxides (e.g., willemite, franklinite), rather than zinc sulphides (e.g., sphalerite). They have reported success in finding such oxides in carbonate rocks located in the Central Metasedimentary Belt boundary zone and the equivalent of northern Bancroft domain in western Quebec. Similar potential may exist in Ontario, particularly in the Renfrew area.

Composite Arc Belt

The Composite Arc Belt consists of several domains (*see* Table 3) characterized by volcanic-dominated supracrustal sequences deposited between 1.28 and 1.245 Ga, subsequently intruded by a suite of gabbroic and granitic plutons between 1.25 and 1.22 Ga. Some domains have a complex history (e.g., Mazinaw), consisting of early arc volcanism at 1.276 Ga, followed by bimodal, rifted arc volcanism at 1.245 Ga (Corfu and Easton 1995). Other domains, such as the carbonate-dominated Sharbot Lake domain, appear to have simple depositional histories (Corfu and Easton 1997). The Composite Arc Belt is thought to be the result of either dismemberment and tectonic rejuxtaposition of a single arc-system (e.g., Windley 1986), or a collage of several diverse arc segments (Easton 1992; Carr et al. 2000).

Little work has been conducted in the Composite Arc Belt since 1992. Mapping in the Puzzle Lake area (Easton 2001c) has refined the southern extent of the Robertson Lake mylonite zone, and the relationship of the Hinchinbrooke gneiss to Sharbot Lake domain. The Hinchinbrooke gneiss may be similar to the Pakenham gneiss in the northern Sharbot Lake domain (Praamsma et al. 2000), with both tonalitic gneiss bodies representing basement to the carbonate-dominated sequence that characterizes Sharbot Lake domain.

Geochemical studies of carbonate rocks in the Composite Arc Belt have been conducted in an attempt to better correlate marble belts between domains (Easton 1995). These studies found distinct differences between different domains, and between Grenville Supergroup and Flinton Group marbles (Easton 1995). Flinton Group carbonate rocks are enriched in strontium, perhaps reflecting the presence of early gypsum cements (Easton 1995). Within Sharbot Lake domain, calcite, and some dolomite marbles preserve marine cerium anomalies, whereas other dolomite marbles show more REE-enriched patterns, perhaps of hydrothermal origin.

Mapping in western Grimsthorpe domain (Easton 2004) indicates the presence of large-scale, carbonate and quartz vein systems in shear zones hosting gold mineralization in the area; these vein systems closely resemble those found in Archean greenstone belts. The timing of gold mineralization has been tightly constrained by field relations and U/Pb geochronology to 1.282 Ga, which is significantly older than other gold mineralization within the Composite Arc Belt, which is generally younger than 1.25 Ga (Easton and Kamo 2005). Easton and Kamo (2005) proposed a new, age-based classification for gold mineralization in the Composite Arc Belt, in contrast to previous, mineralogical or host-rock based classifications (e.g., Carter and Colvine 1985; Easton and Fyon 1992; Sangster and Bourne 1982; Sangster et al. 1992). Mapping in western Grimsthorpe domain also indicates that these alteration zones are truncated at the contact with the adjacent Belmont domain and that the Tudor gabbro may stitch the Belmont–Grimsthorpe boundary (Easton 2004). These observations would constrain amalgamation of the Belmont and Grimsthorpe domain to sometime between 1.27 Ga, the age of the youngest intrusive rocks in Grimsthorpe domain, and 1.25 Ga, the age of the Lavant and Methuen suite gabbroic and granitic plutons found throughout the Composite Arc Belt. Although an older Elzevirian orogeny that amalgamated the volcanic domains of the Composite Arc Belt (e.g., Moore 1982; Easton 1992), prior to emplacement of 1.25 Ga gabbro and granite stitching plutons (e.g., Easton and Davidson 1994), the Belmont-western Grimsthorpe domain boundary may be one of the few areas in the Composite Arc Belt where an Elzevirian age tectonic boundary has not been reactivated during younger Grenvillian tectonic events.

As outlined in Carr et al. (2000), the late history of Mazinaw domain is distinctly different from the rest of the Composite Arc Belt, in that it was strongly metamorphosed at *circa* 1.02 Ga, following deposition of the Flinton Group unconformably on the Grenville Supergroup. Flinton Group deposition is constrained to between 1.155 and 1.02 Ga (Sager-Kinsman and Parrish 1993; Corfu and Easton 1995). Hornblende Ar/Ar cooling ages in Mazinaw domain are *circa* 0.94 Ga (Cosca 1989), among the youngest in the Ontario Grenville, comparable only to those found in the hanging wall of the Grenville Front. This domain went from being high in the thrust stack at *circa* 1.15 Ga, perhaps at the same level as Frontenac domain, to being much lower in the thrust stack at *circa* 1.02 Ga. The process by which this occurred remains enigmatic.

Frontenac–Adirondack Belt

The northern edge of the Frontenac–Adirondack Belt in Ontario consists of a platformal sequence of marble, quartzite and calc-silicate rocks, deposited sometime after 1.3 Ga (youngest detrital zircons in quartzite, Sager-Kinsman and Parrish 1993) and prior to 1.18 Ga (oldest Frontenac suite plutons, Marcantonio et al. 1990). It has been subjected to low- to moderate-pressure granulite facies metamorphism at 1.168 Ga (Corfu and Easton 1997), coincident with an influx of Frontenac suite felsic and mafic plutons into the belt. It was subsequently intruded by the Kensington–Skootomatta suite of felsic plutons at *circa* 1.08 Ga (Corriveau et al. 1990).

Work on the northern edge of the Frontenac–Adirondack Belt has focused on the boundary with the Composite Arc Belt, locally termed the Maberly shear zone, combined with geochemical and geochronological studies of the plutons that apparently stitch this boundary (e.g., Easton and Davidson 1997). The geochemistry of the Frontenac and Kensington–Skootomatta suite plutons are broadly similar (Marcantonio et al. 1990; Lumbers et al. 1990; Davidson 1996). Consequently, geochronology has been critical in distinguishing these two suites of plutons (Davidson and van Breemen 2000a, 2000b). This has been complicated by the fact that some intrusions are composite. For example, the Mountain Grove intrusion consists of a northern segment composed of Lavant suite gabbro (1.25 Ga) and a more really extensive, southern segment of Frontenac suite biotite gabbro (1.16 Ga)(Davidson and van Breemen 2000a, 2000b). The work conducted since 1992 confirms that the Composite Arc Belt boundary zone was in place by 1.16 Ga, and that the boundary was stitched between 1.16 and 1.152 Ga by unmetamorphosed plutons of the Frontenac suite. In addition, it appears that the northern edge of the Frontenac–Adirondack Belt cooled quickly, perhaps at high crustal levels (Davidson et al. 2002), as it preserves hornblende Ar/Ar cooling ages of *circa* 1.125 Ga (Cosca 1989), which have not been reset by younger events.

As noted earlier, use of SHRIMP U/Pb geochronology has confirmed that plutons in the Adirondack Lowlands that previously yielded *circa* 1.2 Ga zircon ages, are actually 1.16 Ga Frontenac suite plutons containing inherited zircons (McLelland et al. 1997a, 1997b).

Phanerozoic Effects

Phanerozoic reactivation of the Shield is evident from sedimentary deposits that indicate basin subsidence. In southern Ontario much of this activity can be related stratigraphically to loading of the Appalachian margin (Johnson et al. 1992). Areas of nondeposition (structural arches) represent foreland bulges (e.g., Sanford et al. 1985).

Phanerozoic history may be also recorded in the low-temperature thermal history of Precambrian rocks without Phanerozoic cover. For example, the Sudbury complex underwent two heating-cooling cycles in the Late Silurian to Early Devonian and Permian to Jurassic in response to burial by, and removal of, sedimentary strata (Lorencak et al. 2004). These periods correspond to depositional pulses in preserved sedimentary basins. Similar results have been reported for the western margin of the Superior Province in southeastern Manitoba (R. Everitt, personal communication 2004).

Additional thermal disturbances have been related to migration of hot-spots associated with the emplacement of kimberlites and related rocks (e.g., Card et al. 1997).

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Appendix 1

Metadata listing for GIS files on OGS MRD 216.

Bedrock_Geology

Data Set Name	**Geology.shp**
Description	**Geology** polygon data of bedrock geology of Ontario.
Sources	Ontario Geological Survey 2006. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 (revised).
Source Comments	Data product is a revised and updated version of the Bedrock Geology of Ontario map that now replaces the digital data set previously released as MRD 126. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Area, Perimeter, PSMP_COMPI, Unit, Genuntnam, Rock_Type, Rock_Des, Strat, Eon, Era, Period, Epoch, Province, Tec_Zone, Bedsupdes
File Location	\Data\Bedrock_Geology\
File Type	Shape - polygon
Associated Files	.dbf, .prj, .sbn, .sbx, .shp, .lyr, .avl
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	To symbolize in ArcView or ArcMap use Geology.avl or Geology.lyr file located in same directory. There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**dykes.shp**
Description	**Dyke** Polyline data of Ontario.
Sources	Ontario Geological Survey 2006. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 (revised).
Source Comments	Data product is a revised and updated version of the Bedrock Geology of Ontario map that now replaces the digital data set previously released as MRD 126. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Dike_Unit
File Location	\Data\Bedrock_Geology\
File Type	Shape – Polyline
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**Faults.shp**
Description	**Faults** Polyline data of Ontario.
Sources	Ontario Geological Survey 2006. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 (revised).
Source Comments	Data product is a revised and updated version of the Bedrock Geology of Ontario map that now replaces the digital data set previously released as MRD 126. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Length, PSMP_unit, PSMP_COMP
File Location	\Data\Bedrock_Geology\
File Type	Shape – Polyline
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.

Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**Ironformation.shp**
Description	**Ironformation** Polygon data; iron formations of Ontario
Sources	Ontario Geological Survey 2006. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 (revised)
Source Comments	Data product is a revised and updated version of the Bedrock Geology of Ontario map that now replaces the digital data set previously released as MRD 126. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, IF_Unit
File Location	\Data\Bedrock_Geology\
File Type	Shape – polygon
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**Kimberlites.shp**
Description	**Kimberlites** Point data of kimberlite occurrences in Ontario.
Sources	Ontario Geological Survey 2006. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 (revised)
Source Comments	Data product is a revised and updated version of the Bedrock Geology of Ontario map that now replaces the digital data set previously released as MRD 126. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Kim_Unit, Dep_Name
File Location	\Data\Bedrock_Geology\
File Type	Shape – point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca

Base_data\cultural

Data Set Name	**250nts-sheet.shp**
Description	**250nts-sheet** Polygon data of National Topographical sheets (NTS) covering Ontario.
Sources	Ontario Geological Survey 2003. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126. ISBN 0-7794-5172-4
Source Comments	Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Tile, Name
File Location	\Data\Base_data\cultural
File Type	Shape - Polygon
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°N, 1st parallel 49°N, 2nd parallel 77°N, point of origin -92°W, Latitude of origin 40°N; NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**Lat_long.shp**
Description	**Lat_long** Polyline latitude and longitude grid over Ontario.
Sources	Ontario Geological Survey 2003. 1:250 000-scale bedrock geology of Ontario. Ontario Geological Survey, Miscellaneous Release—Data 126. ISBN 0-7794-5172-4
Source Comments	Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Latitude, Longitude
File Location	\Data\Base_data\cultural
File Type	Shape - Polyline
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**prov_boundary.shp**
Description	**Prov-boundary** Polyline data of Ontario provincial boundary.
Sources	Ontario Geological Survey 2003. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126. ISBN 0-7794-5172-4
Source Comments	Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Layer
File Location	\Data\Base_data\cultural
File Type	Shape – Polyline
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca

Data Set Name	**province.shp**
Description	**province** Polygon showing outline of province of Ontario.
Sources	Ontario Geological Survey 2003. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126. ISBN 0-7794-5172-4
Source Comments	Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Area, Perimeter, Province_, Province_1, FMF_Object, System_Cal, Geog_Unit_, Publish_DB, Ext_Effect, Effective_, Data_Sensi, ID
File Location	\Data\Base_data\cultural
File Type	Shape - Polygon
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**railroads.shp**
Description	**railroads** Polyline data of railroads in Ontario.
Sources	Ontario Geological Survey 2003. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126. ISBN 0-7794-5172-4
Source Comments	Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, DXF_Layer, DXF_Colour, DXF_Type
File Location	\Data\Base_data\cultural
File Type	Shape - Polyline
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**roads.shp**
Description	**roads** Polyline data of roads in Ontario.
Sources	Ontario Geological Survey 2003. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126. ISBN 0-7794-5172-4
Source Comments	Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, DXF_Layer, DXF_Colour, DXF_Type
File Location	\Data\Base_data\cultural
File Type	Shape - Polyline
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca

Data Set Name	**townships.shp**
Description	**townships** Polygon data of Ontario townships.
Sources	Ontario Geological Survey 2003. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126. ISBN 0-7794-5172-4
Source Comments	Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, System_ID, MNDN_Name, Admin_Type, Time_Stamp, MNR_Dist, RLTDIV_Nam
File Location	\Data\Base_data\cultural
File Type	Shape – Polygon
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca

Base_data\geographical

Data Set Name	**drainage.shp**
Description	**drainage** Polyline data of rivers and streams in Ontario.
Sources	Ontario Geological Survey 2003. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126. ISBN 0-7794-5172-4
Source Comments	Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Layer
File Location	\Data\Base_data\geographical
File Type	Shape - Polyline
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**lakes.shp**
Description	**lakes** Polygon data of rivers and lakes in Ontario.
Sources	Ontario Geological Survey 2003. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126. ISBN 0-7794-5172-4
Source Comments	Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Area, Perimeter, TB_LakeL_, Class
File Location	\Data\Base_data\geographical
File Type	Shape – Polygon
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca

Data Set Name	**majorlakes.shp**
Description	**majorlakes** Polygon data of Ontario's major lakes.
Sources	Ontario Geological Survey 2003. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126. ISBN 0-7794-5172-4
Source Comments	Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, Claimap_ID
File Location	\Data\Base_data\geographical
File Type	Shape - Polygon
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca

Drill_hole

Data Set Name	**Odh_all_drill_holes.shp**
Description	**Drill_hole** dataset of drill holes in Ontario; includes diamond, overburden, percussion, reverse circulation, underground and wedged diamond drill data.
Sources	Ontario Drill Hole Database, December 2005 Release, Ontario Geological Survey, Data Set 13, Revision 1. ODH data are compiled from assessment files. The ODH database was originally created from the archive of hard copy assessment files, then stored in Toronto but now housed at the Mines Library in Sudbury, they were converted to digital format in the Assessment File Research Image Database (AFRI) project.
Source Comments	This data was previously available as part of Data Set 13, Ontario Drill Hole Database. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, MNDM_ID, TWP_AREA, Type, CO_Name, Co_ID, MAP_SRC, RGP, NTS, AZ, DIP, Length, OVBDN, Year, AFRI_FID, CORE_LIB, Comments
File Location	\Data\Drill_hole
File Type	Shape – Point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**Diamond_drill.shp**
Description	**Diamond_drill** data from the Ontario Drillhole Database.
Sources	Ontario Drill Hole Database, December 2005 Release, Ontario Geological Survey, Data Set 13, Revision 1. ODH data are compiled from assessment files. The ODH database was originally created from the archive of hard copy assessment files, then stored in Toronto but now housed at the Mines Library in Sudbury, they were converted to digital format in the Assessment File Research Image Database (AFRI) project.
Source Comments	This data was previously available as part of Data Set 13, Ontario Drill Hole Database. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, MNDM_ID, TWP_AREA, Type, CO_Name, Co_ID, MAP_SRC, RGP, NTS, AZ, DIP, Length, OVBDN, Year, AFRI_FID, CORE_LIB, Comments
File Location	\Data\Drill_hole
File Type	Shape - Point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp

Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**overburden_drill.shp**
Description	**overburden drill** data from from the Ontario Drillhole Database.
Sources	Ontario Drill Hole Database, December 2005 Release, Ontario Geological Survey, Data Set 13, Revision 1. ODH data are compiled from assessment files. The ODH database was originally created from the archive of hard copy assessment files, then stored in Toronto but now housed at the Mines Library in Sudbury, they were converted to digital format in the Assessment File Research Image Database (AFRI) project.
Source Comments	This data was previously available as part of Data Set 13, Ontario Drill Hole Database. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, MNDM_ID, TWP_AREA, Type, CO_Name, Co_ID, MAP_SRC, RGP, NTS, AZ, DIP, Length, OVBDN, Year, AFRI_FID, CORE_LIB, Comments
File Location	\Data\Drill_hole
File Type	Shape – Point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**percussion_drill.shp**
Description	**percussion_drill** data from from the Ontario Drill Hole Database.
Sources	Ontario Drill Hole Database, December 2005 Release, Ontario Geological Survey, Data Set 13, Revision 1. ODH data are compiled from assessment files. The ODH database was originally created from the archive of hard copy assessment files, then stored in Toronto but now housed at the Mines Library in Sudbury, they were converted to digital format in the Assessment File Research Image Database (AFRI) project.
Source Comments	This data was previously available as part of Data Set 13, Ontario Drill Hole Database. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, MNDM_ID, TWP_AREA, Type, CO_Name, Co_ID, MAP_SRC, RGP, NTS, AZ, DIP, Length, OVBDN, Year, AFRI_FID, CORE_LIB, Comments
File Location	\Data\Drill_hole
File Type	Shape – Point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**reverse_circulation.shp**
Description	**reverse_circulation** data from from the Ontario Drill Hole Database.
Sources	Ontario Drill Hole Database, December 2005 Release, Ontario Geological Survey, Data Set 13, Revision 1. ODH data are compiled from assessment files. The ODH database was originally created from the archive of hard copy assessment files, then stored in Toronto but now housed at the Mines Library in Sudbury, they were converted to digital format in the Assessment File Research Image Database (AFRI) project.
Source Comments	This data was previously available as part of Data Set 13, Ontario Drill Hole Database. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, MNDM_ID, TWP_AREA, Type, CO_Name, Co_ID, MAP_SRC, RGP, NTS, AZ, DIP, Length, OVBDN, Year, AFRI_FID, CORE_LIB, Comments

File Location	\Data\Drill_hole
File Type	Shape – Point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**underground_drill.shp**
Description	**underground_drill** data from from the Ontario Drill Hole Database.
Sources	Ontario Drill Hole Database, December 2005 Release, Ontario Geological Survey, Data Set 13, Revision 1. ODH data are compiled from assessment files. The ODH database was originally created from the archive of hard copy assessment files, then stored in Toronto but now housed at the Mines Library in Sudbury, they were converted to digital format in the Assessment File Research Image Database (AFRI) project.
Source Comments	This data was previously available as part of Data Set 13, Ontario Drill Hole Database. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, MNDM_ID, TWP_AREA, Type, CO_Name, Co_ID, MAP_SRC, RGP, NTS, AZ, DIP, Length, OVBDN, Year, AFRI_FID, CORE_LIB, Comments
File Location	\Data\Drill_hole
File Type	Shape – Point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca
Data Set Name	**wedged_diamond.shp**
Description	**wedged_diamond** data from from the Ontario Drill Hole Database.
Sources	Ontario Drill Hole Database, December 2005 Release, Ontario Geological Survey, Data Set 13, Revision 1. ODH data are compiled from assessment files. The ODH database was originally created from the archive of hard copy assessment files, then stored in Toronto but now housed at the Mines Library in Sudbury, they were converted to digital format in the Assessment File Research Image Database (AFRI) project.
Source Comments	This data was previously available as part of Data Set 13, Ontario Drill Hole Database. Original projection: Geographic Coordinate System, GCS_North_American 1983.
Field Names	Fid, Shape, MNDM_ID, TWP_AREA, Type, CO_Name, Co_ID, MAP_SRC, RGP, NTS, AZ, DIP, Length, OVBDN, Year, AFRI_FID, CORE_LIB, Comments
File Location	\Data\Drill_hole
File Type	Shape – Point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp
Projection	Lambert conic conformal. Central meridian -92°N, 1st parallel 49°N, 2nd parallel 77°N, point of origin -92°W, Latitude of origin 40°N; NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca

Geochronology

Data Set Name	**geochronology.shp**
Description	**geochronology** data of Ontario clipped from national dataset of the Canadian Geochronology Knowledgebase.
Sources	From the Canadian Geochronology Knowledgebase, Geosciene Data Repository, National Resources Canada.
Source Comments	Original projection: Geographic Coordinate System, GCS_Clarke_1866 Datum: D_Clark_1866, Prime Meridian: 0, Angular unit: Degree
Field Names	Fid, Shape, Labno, Sampleno, Age, Err_ Plus, Err_Minus, Age_Method, Age_Interp, Age_Note, Age_Materi, Age_Techni, Age_Qualif, Geological, Prov, Latitude, Longitude, Location, Geologic_1, Rocktype, Rockdesc, Authors, Year, Title, Reference_, Compilatio, Objectid
File Location	\Data\geochronology
File Type	Shape – Point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp, .lyr .avl
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	To symbolize data, use geochronology.avl or geochronology.lyr file located in same directory. Email GEOCHRON_RO@gdress.ess.nrcan.gc.ca for information of end-users agreement on use geochronology data or visit website http://gdr.nrcan.gc.ca/index_e.php.

Petro_chemical2003

Data Set Name	**petrochemical.shp**
Description	**Location of petrochemical/ lithochemical** data of Ontario.
Sources	Haus, M. and Pauk, T. 1993. PETROCH lithogeochemical data; Ontario Geological Survey, Open File Report 5855, 18p.
Source Comments	Original projection: GCS_Assumed Geographic_1, D_North_American_1927 This is a location map only for the petrochemical dataset; for data analysis, please refer to Ontario Geological Survey, Open File Report 5855, 18p.
Field Names	Fid, Shape, Latitude, Longitude
File Location	\Data\petro_chemical2003
File Type	Shape – Point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp, .txt
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	There are legal constraints defining the use of this data. The complete and entire Electronic Intellectual Property Agreement may be viewed at: http://www.mndm.gov.on.ca/mndm/mines/ims/pub/digcat/licence_e.asp To purchase data, E-mail: pubsales.ndm@ontario.ca

Geophysics

Data Set Name	**earthquakes.shp**
Description	**earthquake location** data of Ontario.
Sources	http://www.earthquakescanada.nrcan.gc.ca
Source Comments	Original projection: GCS_Assumed Geographic_1, D_North_American_1927
Field Names	Fid, Shape, Latitude, Longitude
File Location	\Data\Geophysics
File Type	Shape – Point
Associated Files	.dbf, .prj, .sbn, .sbx, .shp, .txt
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	See website http://www.earthquakescanada.nrcan.gc.ca for information and agreement on use of Earthquake data.
Data Set Name	**OntarioGrav.tif**
Description	**Gravity anomaly** 2 km grid of Canada
Sources	Canadian Gravity Data Base (http://www.gdr.nrcan.gc.ca/gravity/can2k_bwf_e.php)
Source Comments	Original projection: Datum:WGS 84, Ellipsoid 84, Local datum transform WGS 84
Field Names	Non
File Location	\Data\Geophysics\
File Type	.tif (raster image)
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	See website http://www.gdr.nrcan.gc.ca/gravity/can2k_bwf_e.php for information and agreement on use of Gravity Data.
Data Set Name	**OntarioGrav1VD.tif**
Description	**First vertical derivative of gravity anomalies** 2 km grid of Canada
Sources	Canadian Gravity Data Base (http://www.gdr.nrcan.gc.ca/gravity/can2k_vg_e.php)
Source Comments	Original projection: Datum:WGS 84, Ellipsoid 84, Local datum transform WGS 84
Field Names	Non
File Location	\Data\Geophysics\
File Type	.tif (raster image)
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	See website http://www.gdr.nrcan.gc.ca/gravity/can2k_vg_e.php for information and agreement on use of Gravity Data

Data Set Name	**OntarioGrav1HG.tif**
Description	**Horizontal Gradient of gravity anomalies** 2 km grid of Canada
Sources	Canadian Gravity Data Base (http://www.gdr.nrcan.gc.ca/gravity/can2k_hg_e.php)
Source Comments	Original projection: Datum:WGS 84, Ellipsoid 84, Local datum transform WGS 84
Field Names	Non
File Location	\Data\Geophysics\
File Type	.tif (raster image)
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	See website http://www.gdr.nrcan.gc.ca/gravity/can2k_hg_e.php for information and agreement on use of Gravity Data
Data Set Name	**OntarioMag1VD.tif**
Description	**First vertical derivative of residual total magnetic field** 200 m grid of Canada
Sources	Canadian Aeromagnetic Data Base (http://www.gdr.nrcan.gc.ca/aeromag/can200m_vg_e.php)
Source Comments	Original projection: Datum:WGS 84, Ellipsoid 84, Local datum transform WGS 84
Field Names	Non
File Location	\Data\Geophysics\
File Type	.tif (raster image)
Projection	Lambert conic conformal. Central meridian -92°W, 1st parallel 49°N, 2nd parallel 77°N, latitude of origin 40°N; Prime Meridian – Greenwich (0.0), False_Easting: 0.000000, False_Northing: 0.0000000, NAD 83.
Notes	See website http://www.gdr.nrcan.gc.ca/aeromag/can200m_vg_e.php for information and agreement on use of Aeromagnetic Data

Metric Conversion Table

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	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	0.061 023	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	1.307 951	cubic yards	1 cubic yard	0.764 554 86	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	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	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 3	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 90**	t
CONCENTRATION					
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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