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**Ontario Geological Survey
Open File Report 6331**

**Tectonic and Metamorphic
Architecture of the
Northeastern Composite Arc
Belt and the Central
Metasedimentary Belt
Boundary Tectonic Zone,
Grenville Orogen:
A Geological Guidebook**

2017



ONTARIO GEOLOGICAL SURVEY

Open File Report 6331

Tectonic and Metamorphic Architecture of the Northeastern Composite Arc Belt and the Central Metasedimentary Belt Boundary Tectonic Zone, Grenville Orogen:
A Geological Guidebook

by

M. Duguet and R.M. Easton

2017

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Abstract

This geological guidebook summarizes the results of 5 years of mapping and geochronological studies conducted by the Ontario Geological Survey from 2011 to 2015 in the Mesoproterozoic Grenville Province. The area was last mapped in the late 1970s at 1:100 000 scale, and very few geological field trips have ever been conducted in the area. The field trip area is located in the northeastern part of the Central Metasedimentary Belt in Ontario, and includes 3 main geological domains: the Mazinaw domain, the Black Donald domain and the Bancroft terrane. Each of these domains can be subdivided into smaller subdomains.

Three day-long field excursions are included in this guidebook. Day 1 focusses on the Black Donald domain, which is characterized by a distinctive lithotectonic package containing abundant garnetiferous migmatites and which was subjected to Shawinigan orogenic (*circa* 1190–1130 Ma) magmatic, metamorphic and deformational events. Day 2 focusses on the Mazinaw domain, which has many similarities to the Mazinaw domain rocks exposed in the Cloyne–Plevna area, albeit at much high metamorphic grades. Day 2 also includes a field trip stop in the Flinton Group near Renfrew. Finally, Day 3 focusses on the geology of the Cobden map area. The first part of Day 3 focusses on metasomatic and Late Syenite suite intrusive rocks present in Bancroft terrane to the west of the Ross fault. The second half of Day 3 focusses on the lower grade marbles and gabbros present to the east of the Ross fault, as well as the northernmost slivers of Mazinaw domain rocks preserved along the west side of the Ross fault north of Renfrew.

Tectonic and Metamorphic Architecture of the Northeastern Composite Arc Belt and the Central Metasedimentary Belt Boundary Tectonic Zone, Grenville Orogen: A Geological Guidebook

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**Ontario Geological Survey
Open File Report 6331
2017**

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Introduction

PREFACE

This geological guidebook summarizes the results of 5 years of mapping and geochronological studies conducted by the authors for the Ontario Geological Survey from 2011 to 2015 in the Mesoproterozoic Grenville Province. The areas covered by the guidebook were last mapped in the late 1970s at 1:100 000 scale (Lumbers 1982a, 1982b, 1982c, 1982d), and very few geological field trips have ever been conducted in the area. The field trip area is located in the northeastern part of the Central Metasedimentary Belt in Ontario, and includes 3 main geological domains: the Mazinaw domain, the Black Donald domain and the Bancroft terrane. Each of these domains can be subdivided into smaller subdomains, as described in greater detail throughout this guidebook.

As indicated in Figure 1, mapping was conducted in 7 different study areas. M. Duguet focussed on 1:20 000 scale mapping of high mineral potential areas along the boundary of the Bancroft terrane and the Black Donald and Mazinaw domains of Elzevir terrane (Project Units 11-003 and 13-014). R.M. Easton conducted 1:50 000 scale mapping of the Brudenell and Cobden national topographic system sheets 31 F/6 and 31 F/10 (Project Units 11-004 and 13-013, respectively). Maps for 4 of these 7 study areas have already been published (Duguet, Magnus and Ratcliffe 2014a, 2014b; Duguet, Dubé-Bourgeois and Ma 2016; Duguet, Ma and Whitney 2017), with work on the remaining 3 maps in progress. In addition, geochemical and other field and laboratory data for 4 of the areas are also available (Duguet 2014, 2016; Easton and Azar 2017; Azar 2015; Azar and Easton 2015). As part of the mapping studies, over 28 samples were collected for U/Pb geochronology, which resulted in over 40 separate new age determinations for the northeastern Central Metasedimentary Belt, as summarized in Appendix 1.

Chart A (back-pocket), provided with this report, contains the following elements.

1. Chart-Figure A-1: A simplified, combined geological map of the 4 areas for which 1:20 000 scale maps have been published (Duguet, Magnus and Ratcliffe 2014a, 2014b; Duguet, Dubé-Bourgeois and Ma 2016; Duguet, Ma and Whitney 2017), with the locations of field trip stops for Days 1 and 2 indicated.
2. Chart-Figures A-2 to A-6: Geological cross sections from 4 of the areas mapped by M. Duguet. These 5 cross sections are also available on the 1:20 000 scale geological maps for the areas (Duguet, Magnus and Ratcliffe 2014a, 2014b; Duguet, Dubé-Bourgeois and Ma 2016; Duguet, Ma and Whitney 2017).
3. Chart-Figure A-7: An image of the second vertical derivative of the residual magnetic field for the Renfrew area (from Ontario Geological Survey (2014a)), with the simplified geology from the published 1:20 000 scale maps superimposed.
4. Chart-Figure A-8: The geological history for the area for the time interval from 1200 to 1000 Ma is provided (note, this is a larger version of Figure 9).
5. Chart-Table A-1: A compilation of the geochronological data related to the Shawinigan Orogeny. All samples were analyzed as part of this study (Kamo 2013; Davis 2016). The locations of the samples are shown in Chart-Figure A-1.

Three day-long field excursions are included in this guidebook. Day 1 focusses on the Black Donald domain, which is characterized by a distinctive lithotectonic package containing abundant garnetiferous migmatites and which was subjected to Shawinigan orogenic (*circa* 1190–1130 Ma) magmatic, metamorphic and deformational events. Day 2 focusses on the Mazinaw domain, which has many similarities to the Mazinaw domain rocks exposed in the Cloyne–Plevna area, albeit at much high metamorphic grades. Day 2 also includes a field trip stop in the Flinton Group near Renfrew. Finally, Day 3 focusses on the geology of the Cobden map area. The first part of Day 3 focusses on metasomatic and Late Syenite suite intrusive

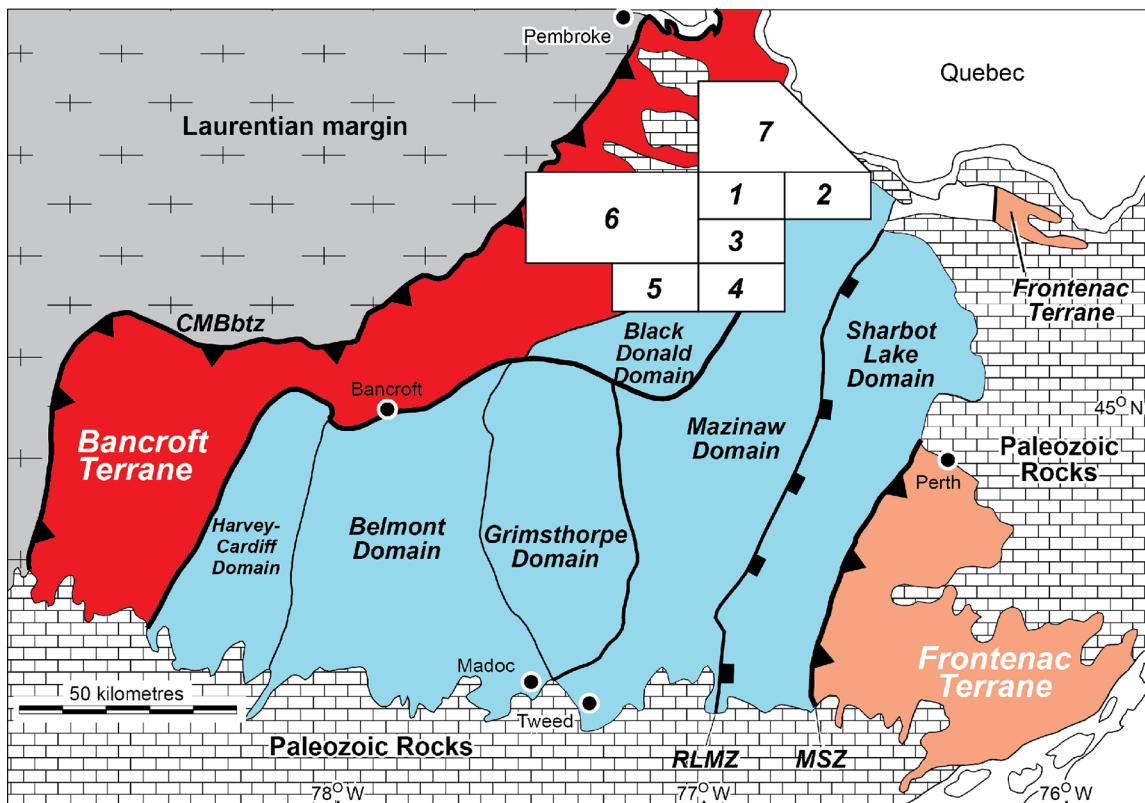
rocks present in Bancroft terrane to the west of the Ross fault. The second half of Day 3 focusses on the lower grade marbles and gabbros present to the east of the Ross fault, as well as the northernmost slivers of Mazinaw domain rocks preserved along the west side of the Ross fault north of Renfrew.

The field trip uses road-accessible outcrops. All of the road stops can be accessed using a two-wheel drive vehicle. Unless otherwise stated, all Universal Transverse Mercator (UTM) co-ordinates are provided using North American Datum 1983 (NAD83) in Zone 18.

SAFETY

Many of the field trip stops are located on highways that are especially busy during the summer season. Care should always be exercised when parking, exiting vehicles, and crossing the roads. Use of safety vests and/or bright clothing is recommended to improve your visibility to motorists.

Most of the trip routes are on Crown land or public roadways, but access is on or near private property for some routes. As in all such situations, please respect the property rights of others, in order to maintain good relationships with landowners so that future access for geologists is not adversely affected.



- | | |
|--|---|
| 1 Admaston area (P.3783) | 5 Centennial Lake area (in progress) |
| 2 Horton area (P.3784) | 6 Brudenell area (in progress) |
| 3 Mud Lake area (P.3785) | 7 Cobden area (in progress) |
| 4 Black Donald Lake area (P.3808) | |

Figure 1. Terrane and domain subdivisions of the Central Metasedimentary Belt (*modified from Easton 1992*) showing the location of the areas mapped at scales of 1:20 000 and 1:50 000 by the authors between 2011 and 2015. Numbers in brackets beside each area name refer to the published Preliminary Maps that are cited in the reference list; these areas are referred to often in this guidebook. Abbreviations: CMBbtz, Central Metasedimentary Belt boundary tectonic zone; MZ, Maberly shear zone; RLZ, Robertson Lake mylonite zone.

TERMINOLOGY

A number of terms used in this report are outlined below.

Rock Classification

Layering thickness terms used in this report are listed below. These terms apply to bedded, layered and gneissic rocks.

Very thinly layered	<3 cm
Thinly layered	3 to 10 cm
Medium layered	10 to 30 cm
Thickly layered	30 to 100 cm (1 m)
Very thickly layered	1 to 3 m
Extremely thickly layered	>3 m

Terminology for all plutonic rocks follows that of Streckeisen (1976) and LeMaitre et al. (2002).

Nomenclature for carbonate rocks (Table 1) is modified from Storey and Vos (1981) and is weighted toward a field-based system and modal mineralogy. It is parallel to the terminology applied to unmetamorphosed chemical sedimentary rocks (Soller 2004). In principle, in most metamorphic environments, marble is derived from limestone and dolostone; and carbonate-silicate and calc-silicate rocks are derived from carbonate-bearing mudstones, sandstones, tuffaceous and evaporitic sedimentary rocks and marlstones. For practical field purposes, the reaction of a metacarbonate rock to the application of 10% HCl is an effective tool in determining the relative proportion of carbonate and noncarbonate mineralogy present (*see* Table 1).

For metamorphic rocks, mineral prefixes are listed in order of relative abundance, starting with least abundant first. Mineral abbreviations follow Whitney and Evans (2010). The following conventions are used regarding descriptive adjectives. A *gneissic granite* is a meta-igneous rock of granitic composition.

Table 1. Classification of rocks containing abundant carbonate minerals.

	Silica Content	Name (metamorphosed)	Name (unmetamorphosed)	Reaction to HCl
Part 1 – Silicate Content				
	>65%	Silicate rock	Silicate rock	Does not fizz
	30–65%	Calc-silicate rock	Calc-silicate rock	Typically does not fizz
	5–30%	Siliceous Marble	Siliceous limestone	Fizzes slightly to moderately
	0–5%	Marble (<i>see</i> Part 2)	Limestone or dolostone	Fizzes aggressively if calcitic, decreasing reactivity with increasing dolomite content
Part 2 – Carbonate Content				
Metamorphosed (Precambrian strata in map area)	Calcite Marble	Dolomitic Calcite Marble	Calcitic Dolomite Marble	Dolomite Marble
Unmetamorphosed (Paleozoic strata in map area)	Limestone	Dolomitic Limestone	Calcitic Dolostone	Dolostone
Reaction to HCl	Fizzes aggressively	Fizzes moderately	Fizzes slightly	Does not fizz, may fizz slightly when powdered
Mineralogical division	0–10% dolomite	10–50% dolomite	50–90% dolomite	90–100% dolomite
Geochemical division based on CaO/MgO ratio	Infinity to 24.4	24.4–3.95	3.95–1.67	1.67–1.4
MgO content (approximate)	0.0–2.2 wt %	2.2–10.9 wt %	10.9–19.7 wt %	19.7–21.0 wt %

A *granitic gneiss*, a *granite gneiss*, or a *gneiss of granitic composition* may be either a meta-igneous or a metasedimentary rock. Similarly, a *tonalitic gneiss* or a *tonalite gneiss* is a gneiss of tonalite modal composition, but may be of either meta-igneous or metasedimentary origin. A *gneissic meta-arkose* is a metasedimentary gneiss of overall granitic composition. The term metamorphic grade is used in the case where bulk-rock composition or other factors prevent a more detailed assignment of metamorphic conditions. Where metamorphic conditions can be outlined more precisely, the metamorphic facies terminology of Turner (1981) is used.

Many rocks in the Grenville Province were subjected to extreme ductile deformation and subsequently recrystallized, and can be described either as tectonites or gneissic mylonites. A number of field-based terms have been proposed to describe these gneissic mylonites (e.g., Davidson, Culshaw and Nadeau 1982; Hanmer and Ciesielski 1984), including the terms straight gneiss, block gneiss and porphyroclastic gneiss.

A migmatite is a heterogeneous rock composed of 2 or more components, one generally quartzofeldspathic in composition (leucosome or neosome) and the other more mafic in composition (paleosome or mesosome). Within the field trip area, such rocks are commonly layered and, in many instances, are formed by partial melting during high-grade regional metamorphism. Descriptive terminology for these rocks follows Sawyer (2008) and Mehnert (1971). Migmatites collectively display a wide variety of features depending on the degree of partial melting and deformation during development. The first-order division of migmatites, based on morphology and proportion of leucosome, results in 2 types: metatexite and diatexite. The division between the 2 types is based on the relative amount of melt (leucosome) in the rock. The Ontario Geological Survey uses a boundary of 20% leucosome between metatexite and diatexite, which is near the minimum value suggested by Sawyer (2008), but does not require the same precision in estimating leucosome content as the use of 16% would require. The 20% boundary also accounts for the fact that initial bulk-rock composition of the protolith is a factor in the amount of partial melt that can be produced and, thus, is better suited for a wide range of bulk-rock compositions.

Geochemical Methods and Terminology

Except where otherwise stated, all chemical analyses that appear in this report were done at the Geoscience Laboratories, Ontario Geological Survey, Ministry of Northern Development and Mines, Sudbury. Detailed analytical methods are described in Vander Voet and Riddle (1993). All chondrite-normalized rare earth element data or diagrams referred to or shown in this report use the normalizing values of Sun and McDonough (1989). With respect to assay data, the term “anomalous” is used in reference to background levels determined empirically by this study.

REGIONAL TECTONIC SETTING

Rocks of the Grenville Province in Ontario range in age from *circa* 2690 to 990 Ma. All rocks older than 1300 Ma are pre-Grenvillian, whereas those younger than 1300 Ma are Grenvillian. With respect to nomenclature, a variety of subdivisions are in use for the Grenville Province in Ontario, and fall into 2 broad groups: those that are lithologically based, commonly with a long history of usage (e.g., Wynne-Edwards 1972); and those that are more tectonic or interpretative in character, generally of more recent vintage (e.g., Rivers et al. 1989; Carr et al. 2000). Geological domains and their boundaries between the different types do not always coincide from one scheme to another (e.g., the Central Gneiss Belt contains para-autochthonous and allochthonous rocks); however, both approaches are valid, and usage is based on needs (e.g., lithologic- and historic-based terminology may be used more on detailed maps (<1:50 000 scale), tectonic-based terminology may be used on regional maps and in academic literature). Key divisions of the Grenville Province are listed in Table 2, and those related to the Central Metasedimentary Belt are shown in Figure 1.

Table 2. Key divisions and boundaries within the Grenville Province in Ontario.

Key Divisions		
Historic or Lithologic	Regional Tectonic	Local Tectonic or Historic
Grenville Front Tectonic Zone (GFTZ)	Para-autochthonous belt (Rivers et al. 1989) or Laurentian margin 1 (Carr et al. 2000)	Segments 1, 2, 3
Central Gneiss Belt (CGB) (Wynne-Edwards 1972; Easton 1992)	Para-autochthonous and/or allochthonous belt (Rivers et al. 1989), Laurentian margin 2 and 3 (Carr et al. 2000)	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) (Wynne-Edwards 1972; Easton 1992)	Composite Arc Belt (CAB) and Frontenac–Adirondack Belt (FAB) (Carr et al. 2000)	Bancroft, Elzevir, Frontenac terranes (Elzevir contains Anstruther, Belmont, Grimsthorpe, Mazinaw, Sharbot Lake domains), Adirondack Lowlands and Highlands
Important Boundaries		
Grenville Front (Wynne-Edwards 1972; Easton 1992)	North limit of Grenville metamorphism and penetrative deformation (locally migmatite front)	Grenville Front boundary fault (GFBF)
Allochthon Boundary Thrust (ABT) (Rivers et al. 1989)	Separates para-autochthonous and allochthonous rocks (Rivers et al. 1989; Carr et al. 2000)	a.k.a. central Britt shear zone, Shawanaga shear zone
Laurentian Margin–Composite Arc Belt boundary (Carr et al. 2000)	Composite Arc boundary zone (CABZ) (Carr et al. 2000)	Central Metasedimentary Belt boundary zone (CMBBZ), a.k.a. Central Metasedimentary Belt boundary tectonic zone (CMBbtz)
Composite Arc Belt—Frontenac–Adirondack Belt boundary (Carr et al. 2000)	Frontenac–Adirondack boundary zone (FABZ) (Carr et al. 2000)	a.k.a. Maberly shear zone, Sharbot Lake–Frontenac boundary

The southwestern end of the exposed Grenville Province consists of 2 main elements: the Central Gneiss Belt comprising rocks, dominated by continental-arc plutonic rocks, of the pre-Grenvillian Laurentian margin, and the Central Metasedimentary Belt (nomenclature *after* Wynne-Edwards 1972) comprising rocks that were accreted to that margin. The rocks observed on the field trip are situated in the Central Metasedimentary Belt, as well as belonging to the Composite Arc Belt.

The Central Metasedimentary Belt is dominated by supracrustal rocks, deposited between 1300 and 1200 million years ago, which were subsequently intruded by several plutonic suites (e.g., Lumbers et al. 1990; Easton 1992). Although age ranges are associated with these intrusive suites, the suites are not chronostratigraphic units. The plutonic suites fall into 4 groupings, as follows, using the terminology of Easton (1992), but with updated age ranges:

- arc-related intermediate composition suites: Dysart suite (*circa* 1340 Ma), Elzevir suite (1275–1250 Ma);
- granite-dominated suites: Methuen intrusive suite (1245–1220 Ma), Catchacoma suite (*circa* 1065 Ma);
- mafic-dominated suites: Killer Creek suite (1290–1275 Ma), Lavant suite (1245–1220 Ma); and
- other suites: Nepheline Syenite suite (1160–1050 Ma), Frontenac suite (1180–1150 Ma), Kensington–Skootamatta suite (1085–1070 Ma), Woermke intrusive syenite suite (1060–1030 Ma).

The Central Metasedimentary Belt can be divided into a number of lithotectonic terranes and domains (*see* Figure 1) (e.g., Moore 1982, 1994; Easton 1992; Easton and Davidson 1994) separated from one another by shear zones. The terrane classification provides a framework for describing regional variations in the geology of the Central Metasedimentary Belt. For clarification, a terrane is a fault-bounded package of rock that has a geologic and/or tectonothermal history distinct from adjoining geologic units. In contrast, a domain is a volume of rock, bounded by compositional or structural discontinuities, in which there is structural homogeneity. Usage within the Grenville Province has taken

the approach that terrane is the “larger” unit, which may be divided into domains (subterranees). Many, if not all, lithotectonic domains in the Central Metasedimentary Belt are fault-bounded and, thus, they could be termed subterranees.

Three main orogenic events have affected the rocks in the field trip area:

1. the Elzevirian Orogeny (1250 to 1200 Ma) (Rivers 1997, 2012),
2. the Shawinigan Orogeny (1190 to 1140 Ma) (Rivers 1997, 2012) and related magmatic pulse (Hynes and Rivers 2010), and
3. the Ottawa Orogeny (1090 to 1020 Ma) (Rivers 1997, 2012), which is sometimes divided into 2 pulses, with an early pulse from 1090 to 1050 Ma and a later pulse from 1050 to 1020 Ma (Rivers 2012).

Note that the intensity of each orogenic event may vary within the different terranes and domains located in the field trip area, as discussed in greater detail in subsequent sections of this guidebook.

General Lithostructural Architecture

The area covered by Days 1 to 3 of the field trip mainly includes rocks of the Black Donald domain and the Mazinaw domain, as well as some rocks that belong to the Bancroft terrane (*see* Figures 1 and 2). To the southwest, the Black Donald domain overlies the metavolcanic rocks of the Tudor and Kashwakamak formations of the Mazinaw domain, and possibly the Grimsthorpe domain, by a tectonic contact (Easton 2006) (*see* Figure 1). Conversely, to the northwest, the Black Donald domain is directly thrust upon the Bancroft terrane (*see* Duguet, Magnus and Ratcliffe 2014a).

To the east, the structural relationships are far more complex. The Mazinaw domain is compartmentalized into tectonic slivers stacked upon the units of the Black Donald domain. This structural pattern was acquired during a protracted sequence of polyphase deformational events of which a major regional shear zone, the Ross fault, played a central role (Figure 3) (Easton 2013; Duguet, Whitney and Ma 2014). However, to the southeast in the Black Donald Lake map area (*see* Figure 3), this relationship is reversed, with the Black Donald domain overthrust onto the upper units of the Mazinaw domain. The detailed structural history is outlined and discussed in “Structural Geology”.

This structural complexity and its organization in thrust sheets led the authors to divide the Mazinaw domain into subunits. The part of the Mazinaw domain on top of the Black Donald domain and below the Ross fault is named the western Mazinaw domain. The geological units above the Ross fault are part of the upper Mazinaw domain, whereas the units of this domain located below the Black Donald domain are named the lower Mazinaw domain. Although this classification is, for the moment, provisional and used in a purely descriptive way, it is based nonetheless on slight, but significant, differences between these structural units. For instance, the western Mazinaw domain contains Shawinigan-age intrusive rocks (*see* Chart-Figure A-1; Appendix-Table 1-4; Duguet, Magnus and Ratcliffe 2014a), that are absent from the upper and lower units of the Mazinaw domain. In contrast, rocks of the Flinton Group are restricted to the part of the Mazinaw domain located in the hanging wall of the Ross fault (upper Mazinaw domain). These subdivisions of the Mazinaw domain may also have a regional significance. Indeed, to the south in the Cloyne–Plevna area (Easton 2006), the Ross fault puts, in direct contact, the upper Mazinaw domain on top of the lower Mazinaw domain, with the western Mazinaw domain disappearing (R.M. Easton, OGS, unpublished data, 2016).

BLACK DONALD DOMAIN

Prior to the onset of this project, the Black Donald domain had received little attention. The area was covered by geological maps at a scale of 1:100 000 (Lumbers 1982b, 1982c; *see* Figure 2) and partly covered by compilation maps at a scale of 1:50 000 (Lumbers and Vertolli 2001). Other, geographically limited, studies were parts of mapping or thematic projects that focussed mainly on the Mazinaw domain (Karboski 1980; Easton 2006). The Black Donald domain is extensive in the Mud Lake, Black Donald Lake and Centennial Lake map areas (*see* Figure 1). Going north into the Admaston map area, however, the thickness of rock units of the Black Donald domain is significantly reduced or they pinch out entirely (*see* Chart-Figure A-1).

The nomenclature of “domain” assigned to the Black Donald domain is a fairly recent concept (Schwerdtner, Serafini and Burke 2004), but it is justifiable in a sense that, within the Elzevir terrane, the Black Donald domain contains distinct geological and structural features. This distinctiveness has been confirmed and strengthened by this study. Compared to other domains in the Central Metasedimentary Belt, which are mostly volcanic, volcanoclastic and plutonic dominated, the Black Donald domain is characterized by an abundance of metasedimentary rocks (in order of decreasing abundance: carbonates, calc-silicate rocks and siliciclastic rocks) deposited prior to 1223 Ma (the age of the oldest known intrusive rocks in the area, possibly belonging to the Lavant intrusive suite; *see* Appendix-Table 1-1). Moreover, the boundary between the Black Donald and the Mazinaw domains has been classically drawn at the limit of the disappearance of the larger Methuen intrusive suite plutons (e.g., Easton 2006). This is a recurrent pattern seen from the Horton and Admaston map areas in the north to the Black Donald map area to the south and farther west in the Centennial Lake map area.

The rock packages of the Black Donald domain are folded into a series of northeast-trending, northwest-verging antiforms and synforms in the Admaston, Centennial and Mud Lake map areas whereas, in the Black Donald map area, units of the Black Donald domain display a fan-like geometry with southeast-directed structures along the southeastern boundary with the Mazinaw domain and northwest-directed structures in the northwest. As pointed out by several authors (Karboski 1980; Easton 2006; Duguet, Whitney and Ma 2014), the presently observed map pattern is the result of several collinear superimposed folding and shearing events. These folds can be followed for at least 30 km along strike (*see* Chart-Figure A-7) and were recognized quite early on by Lumbers (1982b, 1982c). Some of these structures are also shear zone-bounded, which give the Black Donald domain an overall fold-and-thrust-belt pattern. Three of these lithostructural units can be delineated easily on the map of Lumbers (1982b). From east to west, they are an upper unit, an intermediate unit and a lower unit (*see* Figure 2). Rock units of the Black Donald domain, at least in the eastern part of the area, reached upper amphibolite- to granulite-facies metamorphism (Duguet, Whitney and Ma 2014), with widespread partial melting that affected the pelitic and semi-pelitic rocks within the supracrustal package.

General Stratigraphy

UPPER UNIT

The easterly upper unit is the most complex of the 3 units in Black Donald domain (*see* Figures 3 and 4; *see also* Chart-Figure A-1). The stratigraphic succession described herein for the upper unit shares strong similarities with the 2 other units of Black Donald domain, but the relative proportion of the different rock units varies greatly from one unit to another. Considering the importance of recumbent folding in the area (*see* “Structural Geology”), one must also bear in mind that the succession presented herein has only relative value.

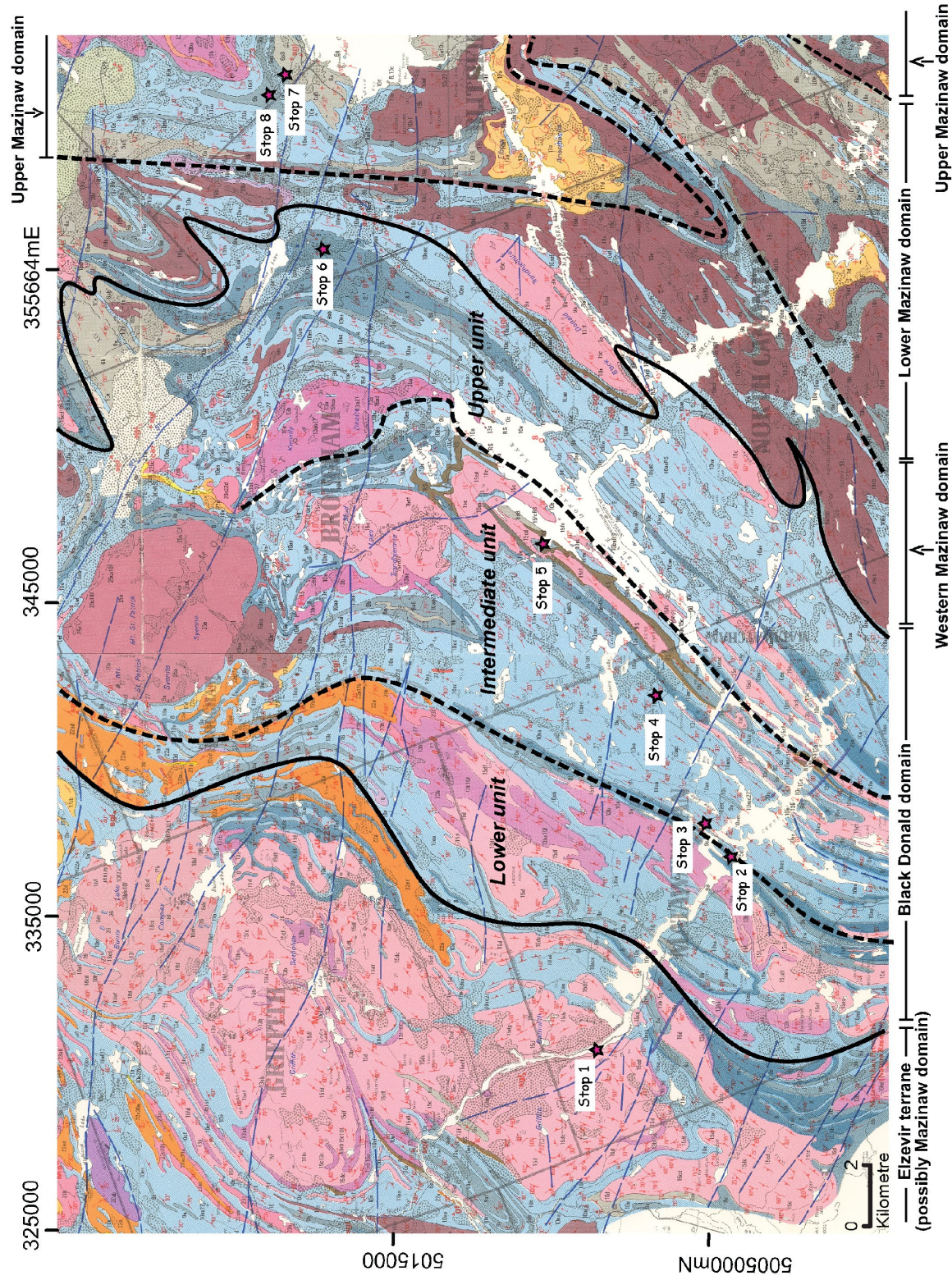


Figure 2. Geological map (after Lumbers 1982b, 1982c) encompassing the Brudenell, Centennial Lake, Black Donald Lake and Mud Lake map areas. The locations of field trip stops 1 to 8 are also shown. Solid black lines delineate domain boundaries. Dashed black lines represent the subunits within the domain.



Figure 2, continued. Legend for geological map (from Lumbers 1982c).

Table 3. Geological legend used for mapping the Admaston, Horton, Mud Lake, Black Donald Lake and Centennial Lake map areas.

PHANEROZOIC


CENOZOIC

QUATERNARY

PLEISTOCENE AND RECENT
 Sand, gravel, mainly glaciofluvial deposits; till, ground moraines and organic deposits
UNCONFORMITY

PALEOZOIC

UPPER ORDOVICIAN



32

Chemical Sedimentary Rocks (Gull River Formation and Bobcaygeon Formation):
 Finely crystalline limestone, lithographic limestone, dolostone, minor calcarenite and shale
UNCONFORMITY

PRECAMBRIAN

NEOPROTEROZOIC

31

Mafic Intrusive Rocks (Grenville Dike Swarm) (590 Ma): Gabbro, fine grained, black

MESOPROTEROZOIC

30

Late Tectonic Felsic Intrusive and Related Rocks (<1040 Ma)

29

Syntectonic Felsic Intrusive Rocks (circa 1070 to 1050 Ma)

28

Alkalic Mafic to Felsic Intrusive Rocks (circa 1090 to 1070 Ma)

INTRUSIVE CONTACT

27

Syntectonic Felsic Intrusive Rocks (1190 to 1130 Ma)

INTRUSIVE CONTACT

Amphibolite-Facies Metamorphism Between 1040 and 1020 Ma

26

Potassic-Carbonate Alteration (affecting units 2, 3, 18, 19 and 20)

Metasedimentary Rocks of the Flinton Group (<1155 Ma)

25

Upper Unit (possible equivalent of Fernleigh Formation)

24

Middle Unit (possible equivalent of Myer Cave Formation and Bishop Corners Formation)

23

Basal Unit (possible equivalent of Ompah Formation or Bishop Corners Formation)

UNCONFORMABLE CONTACT, TECTONICALLY MODIFIED

22

Felsic to Intermediate Intrusive Rocks

INTRUSIVE CONTACT

21

Intermediate to Felsic Intrusive Rocks, Hurds Lake tonalite (1211 Ma)

20

Mafic to Felsic Intrusive Rocks, Lavant Intrusive Suite (1223 to 1220 Ma)

19

Tholeiitic Mafic Rocks with N-MORB (western domain) to Back-Arc (eastern domain) Chemical Affinity

Table 3, continued.

INTRUSIVE CONTACT

18 Felsic Intrusive Rocks, Methuen Intrusive Suite (1250 to 1230 Ma)

INTRUSIVE CONTACT

17 Felsic to Intermediate Intrusive Rocks, Elzevir Suite (1270 to 1245 Ma) (units 17a, 17b, 17c)

17 Mafic Intrusive Rocks, Killer Creek Suite (1270 Ma) (units 17d, 17e, 17f)

17 Migmatitic Intermediate Intrusive Rocks (1285 Ma) (units 17g, 17h)

INTRUSIVE AND/OR TECTONIC CONTACTS

Greenschist- to Granulite-Facies Metamorphism Between 1240 and 1050 Ma

GRENVILLE SUPERGROUP

BANCROFT TERRANE

16 Calcitic Carbonate Metasedimentary Rocks

15 Migmatitic Felsic to Intermediate Gneiss

14 Amphibolites and Mafic Gneiss

TECTONIC CONTACT

BLACK DONALD DOMAIN

13 Calc-Silicate Metasedimentary Rocks (interbedded with units 9, 11 and 12)

12 Dolomitic Carbonate Metasedimentary Rocks

11 Calcitic Carbonate Metasedimentary Rocks

10 Tholeiitic Mafic Gneiss (arc tholeiite and back-arc affinity)

9 Migmatitic Felsic to Intermediate Gneiss

TECTONIC CONTACT

MAZINAW DOMAIN

8 Migmatitic Felsic to Intermediate Gneiss (western part) (partly derived from units 3, 4, 21 and 22)

7 Calc-Alkalic Felsic Metavolcanic Rocks (unknown affinity)

6 Dolomitic Carbonate Metasedimentary Rocks

5 Calcitic Carbonate Metasedimentary Rocks

4 Tholeiitic Mafic to Felsic Metavolcanic Rocks (Mazinaw Lake Formation and equivalent) (1250 to 1240 Ma)

3 Gneiss Derived from Calc-Silicate, Siliceous Clastic Metasedimentary Rocks and Calc-Alkalic Felsic Metavolcanic Rocks (locally interlayered with unit 2)

2 Transitional to Calc-Alkalic Mafic to Felsic Metavolcanic Rocks (Kashwakamak Formation and equivalents) (1280 to 1265 Ma)

1 Tholeiitic (N-MORB and E-MORB) Mafic Rocks (Tudor Formation and equivalents) (>1265 Ma)

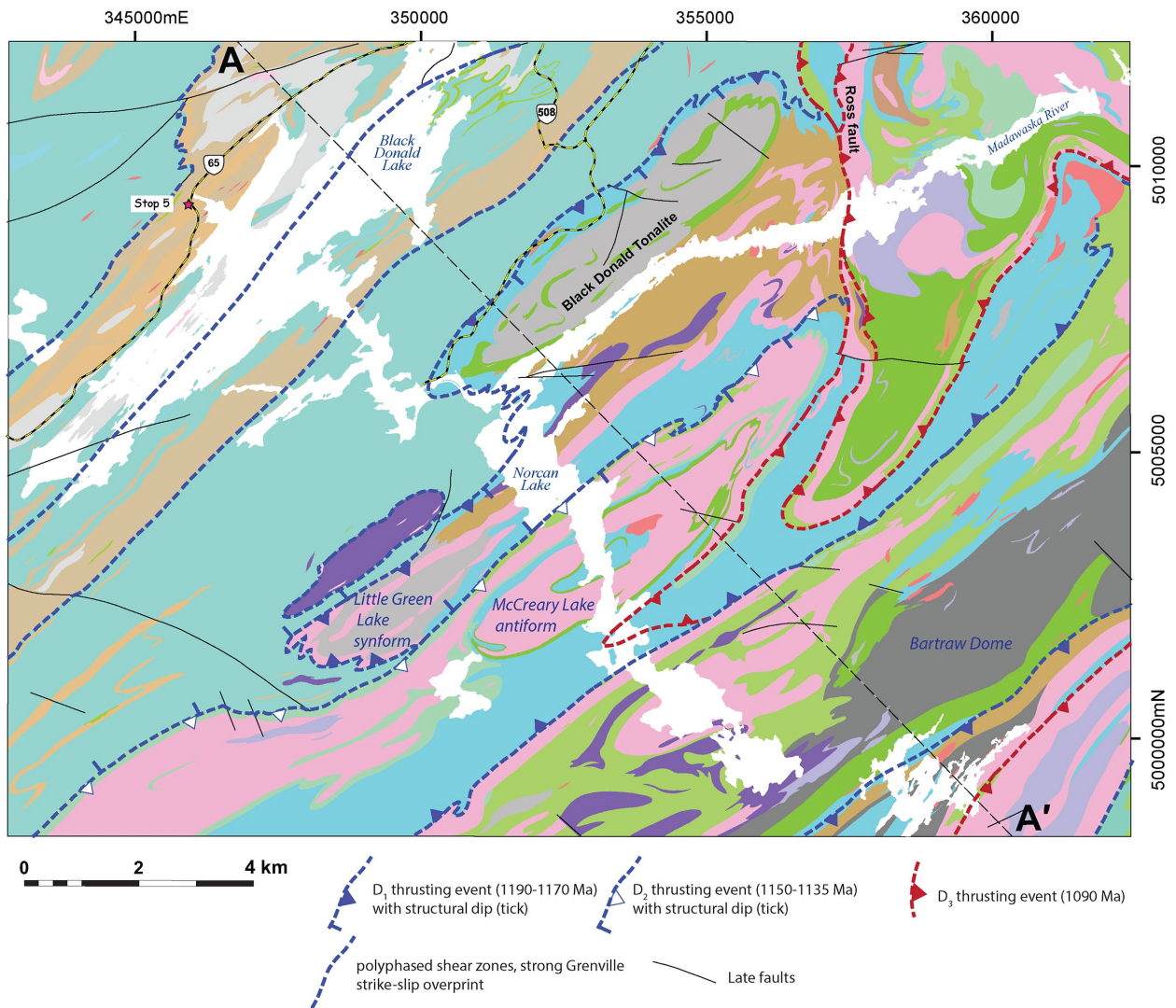


Figure 3. Simplified geological and structural map of the Black Donald Lake map area. This figure is a simplified version of Preliminary Map P.3808 (Duguet, Ma and Whitney 2017). For the legend, refer to Table 3. Line A–A' indicates the location of the geological cross section A–A' (see Chart-Figure A-2, back pocket) and on Duguet, Ma and Whitney (2017). The location of field trip stop 5 is also indicated.

The lowermost package in the Black Donald domain is composed mostly of stromatic metatexite derived from sedimentary protoliths that range in composition from pelitic to psammitic, as well as local intercalated thin quartzite and quartzofeldspathic gneiss horizons. This package underwent subsolidus deformation near the contact with the Mazinaw domain. Garnet is abundant in both the leucosome and melanosome. Based on textural relationships, garnet crystallization is likely a peritectic product of the partial melting. Sillimanite clots are also present in the more pelitic-derived metatexite. In other rock types nearby (e.g., marble, gneiss, etc.), garnet-bearing granitic sills are also present. They have the same mineralogy and composition as the leucosomes in the metatexite. They are particularly abundant in the northern part of the Mud Lake map area (Figure 4) area and follow the general regional structural trend. These rocks are interpreted by the authors as sills that originated from the melting of the underlying metatexite. They constitute indirect evidence that the melt started to interconnect and migrate upward into the crust. Other evidence of melt migration is provided in the migmatite itself. For example, garnet crystals corroded by melt percolating into the melanosome are locally present. The melt migration can be traced over a distance of 10 to 100 cm and partly or entirely erases the metamorphic fabric. Texturally, these rocks qualify as diatexite. Some of these diatexites host biotite + potassium feldspar + sillimanite + spinel (hercynite) ± ilmenite assemblages with relicts of garnet and staurolite. In the Mud Lake map area, however, rocks with identical parageneses contain stable garnet.

This lowermost package of pelitic to psammitic stromatic metatexite is overlain by a texturally and compositionally heterogeneous calc-silicate package with minor calcite marble. The uppermost package consists of calcite marble with minor intercalated calc-silicate rocks and amphibolite, with the latter interpreted as synvolcanic sills. Despite the strong deformation, the contact between the 2 lowermost packages (i.e., metapelites and calc-silicates) seems to be transitional, with both rock types interlayered in the transition zone between the 2 packages. Similarly, the calc-silicate rocks also seem to gradually change upward into the uppermost calcite and dolomite marble unit. The interlayering of the 2 lowermost packages can be observed at the outcrop scale. One outcrop where this relationship can be viewed is located on Ferguson Lake Road (in the Mud Lake map area, UTM 355956E 5016445N, stop 6). At this section, the very bottom of the outcrop is occupied by garnet- and sillimanite-bearing metatexite. Similar metatexite occurs as rare thin layers in the overlying calcareous metasandstone. At the same outcrop, thin and scarce layers of medium-grained calcite marble are interlayered with the calc-silicate rocks. Other, less accessible, locations displaying these same characteristics are observed in the southwestern part of the Black Donald Lake map area.

Carbonate rocks (marbles) in the upper unit account for an average of 50% of the supracrustal rocks exposed on surface and become more abundant in the Black Donald Lake map area. They are mainly composed of medium- to coarse-grained, white to grey calcite marble. These calcite marbles are typically moderately to strongly layered, especially in zones of intense folding, which suggests a tectonic origin for this layering. On the other hand, in more impure marbles, phlogopite- and diopside-rich layers are interbedded with calcite-rich layers suggesting a strong primary compositional control. Interlayering of calc-silicate horizons is quite common and calc-silicate layers vary in thickness from 0.5 to 5 m. Dolomite marbles are present sporadically in thin layers interlayered with the calcite marbles. The dolomite marbles tend to be coarser grained and more massive, and display little to no layering. The carbonate rocks host numerous mafic gneiss and amphibolite masses, which are likely derived from hypovolcanic sills. The age of these mafic intrusive rocks is unknown, but they could be associated with the gabbroic Lavant intrusive suite, which, in the Sharbot Lake domain, has an age of *circa* 1224 Ma (Corfu and Easton 1997).

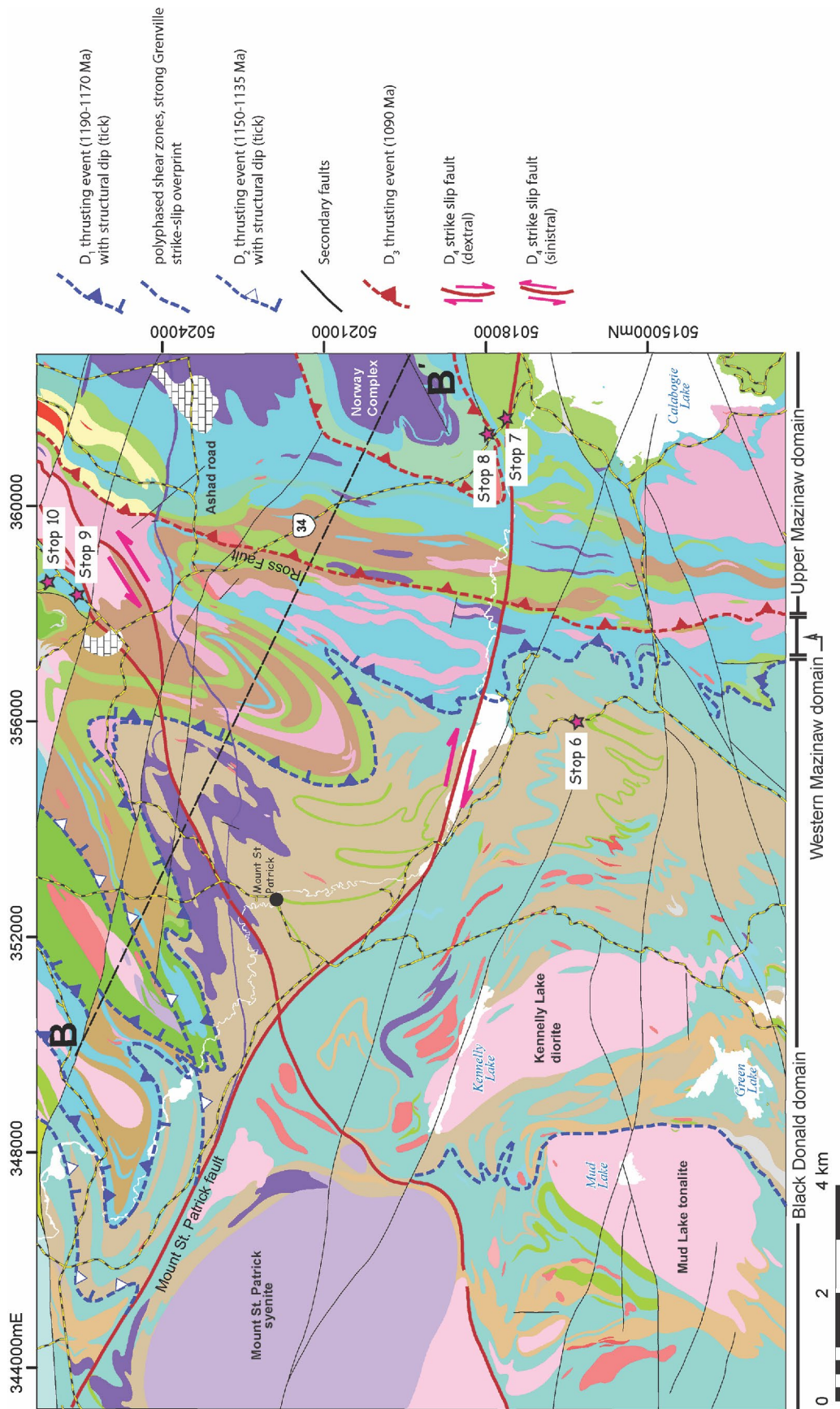


Figure 4. Simplified geological and structural map of the Mud Lake map area. This figure is a simplified version of Preliminary Map P.3785 (Duguet, Dubé-Bourgeois and Ma 2016). For the legend, refer to Table 3. Line B-B' indicates the location of the geological cross section B-B' (see Chart-Figure A-3, back pocket) and on Duguet, Dubé-Bourgeois and Ma (2016). The locations of field trip stops 6 to 10 are also indicated.

INTERMEDIATE UNIT

The intermediate unit is represented by a northeast-trending megasyntrope centred on Centennial Lake. This lithostructural unit continues along strike to the northeast in both the Mud Lake and Black Donald Lake map areas (*see* Duguet, Dubé-Bourgeois and Ma 2013; Duguet, Whitney and Ma 2014). The supracrustal rocks present in this syntrope differ little from their eastern counterparts (upper unit) in the Mud Lake map area (*see* Duguet, Dubé-Bourgeois and Ma 2013; Duguet, Whitney and Ma 2014). On the east flank of the syntrope, the same lithological succession is found again in the Centennial Lake map area, with, from bottom to top, migmatitic metapelitic and metapsammitic rocks, amphibolites, calc-silicate schists and gneisses, and calcite and dolomite marbles. Marbles predominate in comparison to the other rocks and mostly occupy the core of the syntrope. In the Black Donald Lake and Centennial Lake map areas, stromatic metatexite and calc-silicate rocks are exposed on the flanks of the megastructure. The stromatic metatexite unit decreases in abundance along strike to the southeast. It is also worth mentioning that this unit hosts abundant graphite mineralization that is associated with massive pyrite-pyrrhotite gneiss interlayered with the calc-silicate rocks and the paragneiss (*see* Duguet, Duparc and Mayer 2015). Distal parts of this mineralization also affected adjacent rocks, such as tonalite. These distal mineralization effects are usually represented in the field by rusty gneiss and schist, which were mapped as a separate unit of rusty schist (unit RS) by Lumbers (1982a, 198b, 1982c).

However, some notable differences are present in the Centennial Lake map area. The first is the presence of more abundant and continuous dolomite marble units. These dolomite marbles are clean, white to grey, coarse grained and massive. They commonly host pods or concretions of calc-silicate (mostly composed of tremolite) and/or quartz that are interlayered with the pure dolomite marble. As a first approximation, the dolomite marbles appear to be in stratigraphic contact with the siliciclastic units (metatexite and calc-silicate gneiss), even though the map-scale units in the northeastern part of the Centennial Lake map area seem to be encased in calcite marble. In the Mud Lake and Black Donald Lake map areas, amphibolites and mafic gneiss of probable intrusive origin were emplaced as sills parallel to the main layering present in the supracrustal rocks (Duguet, Whitney and Ma 2014). In the Centennial Lake map area, the abundance of amphibolite increases, and they form thicker bodies rather than the typical metre- to tens of metre-scale sills present in the Mud Lake map area. The amphibolites are locally garnet rich and are especially deformed along the shoreline of Centennial Lake east of the megasyntrope. A new unit, composed of metatextitic, fine-grained, light grey felsic gneisses was found interlayered with the other siliciclastic rocks present in the stratigraphically lower units of the Black Donald domain. These gneisses are magnetite rich and overlap a magnetic anomaly of regional extent (Ontario Geological Survey 2014b-m). This particular unit has not been reported before in the supracrustal rocks of the Black Donald domain, which tend to be non-magnetic, with the notable exception of the graphite-pyrrhotite schists. In stratigraphic contact with these felsic gneisses is a bimodal sequence of rocks not previously described in the Black Donald domain. On the outcrop scale, this bimodal sequence is characterized by alternating, mafic to intermediate layers and felsic layers, in equal proportion. Both layer types are themselves well layered, equigranular, and fine to medium grained. The layer types can be locally magnetic (magnetic susceptibility up to 32×10^{-3} SI units). Garnet can be quite abundant, especially in the felsic layers.

Strongly foliated, fine- to medium-grained, equigranular, light grey tonalitic gneisses are the main metaplutonic unit present. These tonalitic gneisses were, for the most part, mapped as intrusive rocks by Lumbers (1982b). Nonetheless, these tonalitic gneisses are difficult to distinguish from the locally garnet-bearing felsic gneisses in the map area, which display similar petrographic features. Moreover, sampling of both rock types in the Black Donald Lake map area indicates that both units have similar major element chemistry. Based on trace element data, some of the felsic gneisses have strongly fractionated rare earth element (REE) patterns with enrichment in light rare earth elements (LREE) similar to those found in the Black Donald Lake tonalite (Duguet, Whitney and Ma 2014). The trace element data suggest

an igneous origin for the garnet-free tonalitic gneisses. Grenvillian intrusive rocks in the eastern lithostructural unit are limited to the presence of late granitic pegmatites, emplaced mostly as sills, or more rarely as dikes.

LOWER UNIT

Of the 3 lithostructural units in the Centennial Lake map area, the lower unit appears to be the least lithologically complex, albeit this could simply reflect its relatively poor exposure compared to the other 2 units. In the case of the supracrustal rocks, the succession in the Centennial Lake map area is quite similar to that established farther east in the Black Donald domain (Duguet, Dubé-Bourgeois and Ma 2013). On the other hand, the amount of metaplutonic rock present in this lithostructural unit is much higher than the equivalent unit in the eastern Black Donald domain, which is composed almost entirely of supracrustal rocks. Moreover, the metaplutonic rocks in the west show features rarely observed in the metaplutonic rocks that have intruded the supracrustal rocks of the eastern Black Donald domain.

The flanks of the lower lithostructural unit are composed of a thin unit of highly sheared metatexitic, porphyro-granoblastic, garnet-bearing, light grey paragneiss and rare intercalated metapelite. Calc-silicate schists and gneisses are present only locally. Amphibolites become more abundant than in the east, and are associated both with the siliciclastic rocks and marbles, but they are also present as a larger unit located at the centre of the megastructure. Some amphibolites display trace element geochemistry and petrographic characteristics (e.g., local anomalous garnet content) identical to the ones of the amphibolites of the eastern lithostructural unit. It is likely that they are actually sills that intruded both the siliciclastic rocks and the overlying marble. Nonetheless, based on textural evidence, the amphibolites cropping out in the hinge of the megafold possess features difficult to reconcile with a solely plutonic origin. They are consistently very fine to fine grained over an extensive area, magnetic and strongly foliated. Whereas partial melting is mostly absent in the mafic intrusive rocks, it is commonly present in these amphibolites. The partial melting is expressed in the amphibolites by the presence of thin leucosomes parallel to the main foliation. Moreover, anastomosed calc-silicate veins, parallel to the foliation and composed of epidote and diopside, also occur in these amphibolites, and are associated with anomalous garnet content. This latter feature suggests that an alteration event, possibly synvolcanic, affected the mafic rock prior to metamorphism. Hopefully, pending geochemical data will provide additional information to help separate intrusive from extrusive mafic rocks in the Centennial Lake map area.

The core of the lower lithostructural unit is occupied by calcite marble identical to those classically described in the Black Donald domain (Easton 2006; Duguet, Dubé-Bourgeois and Ma 2013; Duguet, Magnus and Ratcliffe 2014a). A significant proportion of dolomite marble accompanies the calcite marble and is mostly located at the contact between the amphibolite to the east and the siliciclastic units to the west. In the nose of the fold (*see* Figure 19-1 in Duguet, Duparc, and Mayer 2015), a significant proportion of the dolomite marbles is highly silicified with anastomosed quartz veins representing, in some places, up to 70% of the rocks. The apparent thickness of this silicified zone is approximately 500 m. Where the alteration is less intense, quartz veins are mostly parallel to the layering in the dolomite marble, which is folded by, at least, 1 deformation event. Even though this deformational event seems to occur relatively early in the history of these units, it is unclear what processes caused this alteration. It is also uncertain whether or not the dolomitization of the rocks is coeval with their silicification. If the interpretation of the amphibolites as being metamorphosed volcanic rocks and/or hypovolcanic intrusions is accepted, then the setting here may be similar to the one described by Easton (2006), who reported dolomitization of marble units associated with the metovolcanic rocks of the Mazinaw Lake Formation.

MAZINAW DOMAIN

The Mazinaw domain has been the subject of many multidisciplinary studies over the past decades. Most of these studies have focussed solely on the southern portion of the Mazinaw domain (for the most recent work, *see* Easton 2006; Duguet, Gordon and Easton, 2010; Duguet and Gordon 2011; Cutts 2013; McCarron 2013). Very little was known of the northeastern extent of the Mazinaw domain in the area of the Ottawa River valley. Near Renfrew, the Mazinaw domain shares numerous similarities with its southern counterpart, such as a similar volcanic succession and the presence of rocks of the Flinton Group, which was first recognized in the area by Easton (2009). On the other hand, the northeastern part of the Mazinaw domain contains far more carbonate rocks than does its southern portion, which is mostly plutonic and volcanic dominated (Easton 2006).

Another major difference is in the age of the tonalite-trondhjemite-granodiorite (TTG) Elzevir intrusive suite rocks present in the northern Mazinaw domain. Apparently absent are rocks from 1270 to 1250 million years ago that are widespread in the southern part of the Mazinaw domain. Instead, the Elzevir intrusive suite is represented by younger tonalite intrusions, such as the Hurds Lake tonalite, which has an age of *circa* 1210 Ma (Kamo 2012, 2013). The Hurds Lake tonalite is emplaced at the interface between the lowermost volcanic and volcanoclastic rocks and the uppermost carbonate rocks. The older Elzevir intrusive suite rocks were interpreted as a relative basement for the supracrustal rocks in some parts of Mazinaw domain (Easton 2006) and their disappearance in the northern Mazinaw domain, in conjunction with a higher content of carbonate rocks, may be explained by the rocks in the north being at a higher stratigraphic level (Easton, Duguet and Magnus 2011).

General Stratigraphy

The eastern and northern parts of the Horton map area (Figure 5, right) are carbonate dominated and are composed mainly of calcite marble and minor calc-silicate gneiss, along with minor mafic and felsic gneiss possibly derived from volcanoclastic rocks. This mixed package of mafic and felsic gneiss and mafic schist can be traced along strike for over 10 km (*see* Figure 5). This unit was previously identified as a marker horizon in 2011 because of its anomalous garnet content in the both the mafic and felsic rocks (Easton, Duguet and Magnus 2011). Most of these mafic and felsic gneiss units display chemical characteristics similar to those documented for the Mazinaw Lake Formation to the south (Ayer 1979; Easton and Ayer 1994).

The western part of the Horton map area is characterized by a strong decrease in the volume of carbonate rocks. This trend of decreasing carbonate units continues west into the eastern Admaston map area, which is composed mainly of plutonic rocks consisting mostly of tonalitic gneiss, Methuen intrusive suite granitoids, amphibolites and minor carbonate units (*see* Figure 5). Based on chemistry, the amphibolites in the Admaston map area were split into 2 different formations (Duguet, Magnus and Ratcliffe 2014a). The lowermost mafic gneiss unit has chemical features (N-MORB to E-MORB) akin to the Tudor Formation (1279±3 Ma: Heaman et al. 1987), whereas the uppermost unit has a calc-alkalic to arc-tholeiite chemistry that could be equivalent to the Kashwakamak Formation (1276±2 Ma: Corfu and Easton 1995). It should be noted that this comparison is based solely on chemistry and relative stratigraphic position. The intense deformation and metamorphism in northern Mazinaw domain impairs our ability to properly determine an age for these formations.

To the northeast in the Horton map area, a highly deformed and metamorphosed package of calc-silicates, Methuen intrusive suite granitoids, fine-grained intermediate gneisses of calc-alkalic affinity, tholeiitic and calc-alkalic gabbroic intrusions, and minor calcite marble, structurally overlie the plutonic-dominated package. The bulk of these structurally overlying units is likely metasedimentary and

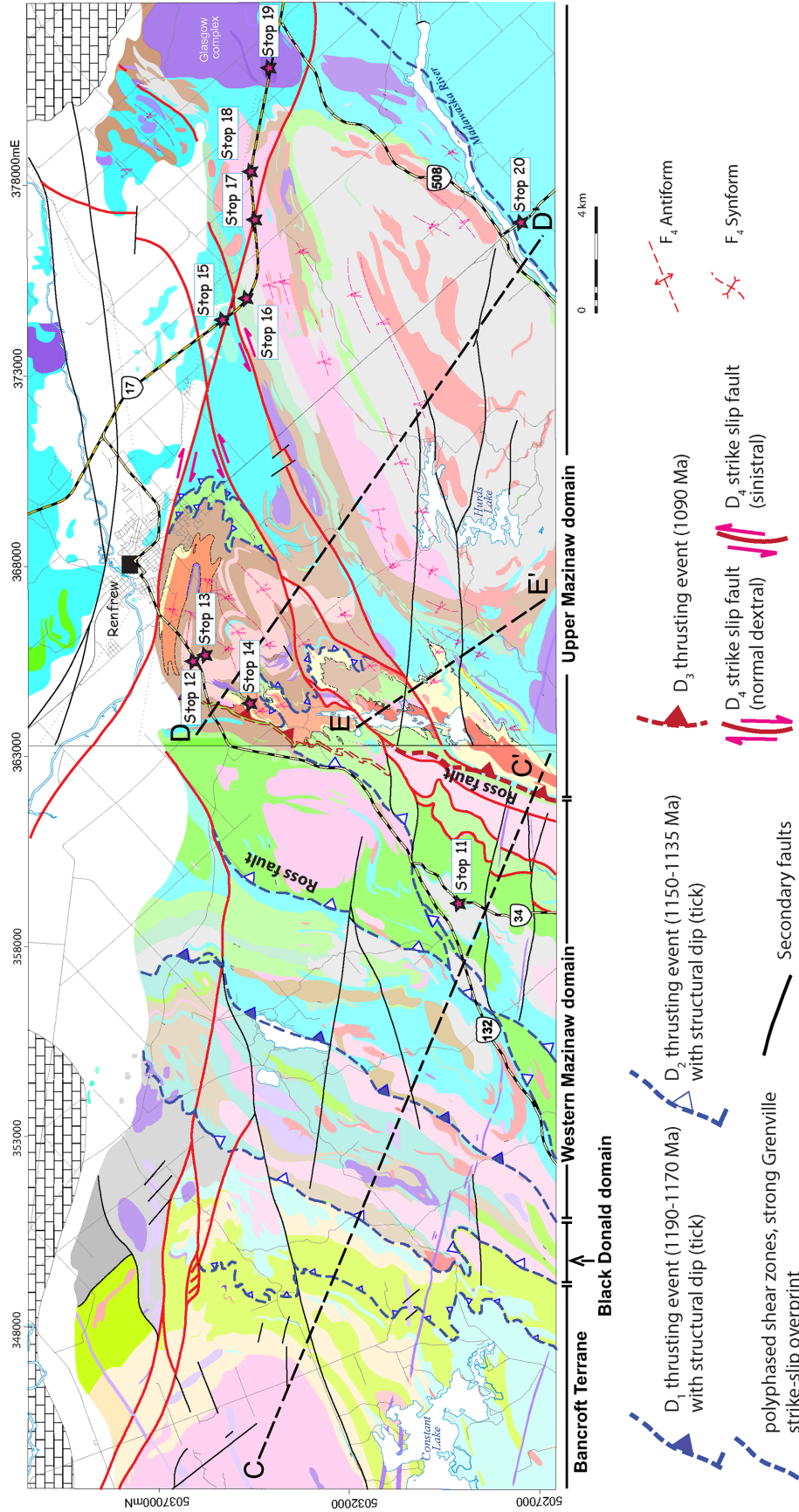


Figure 5. Simplified geological and structural map of the Admaston (left) and Horton (right) map areas. This figure is a simplified version of merged Preliminary Maps P.3783 and P.3784 (Duguet, Magnus and Ratcliffe 2014a, 2014b). For the legend, refer to Table 3. Lines C-C', D-D' and E-E' indicate the locations of the geological cross sections C-C', D-D' and E-E' (see Chart-Figures A-4, A-5 and A-6, respectively, back pocket) and on Duguet, Magnus and Ratcliffe (2014a, 2014). The locations of the field trip stops 11 to 20 are also indicated.

volcaniclastic in origin and are, in turn, overlain by thicker units of carbonate rocks farther to the northeast. The metasedimentary-dominated package was in part subjected to an intense potassium metasomatic event that was associated potentially with the Flinton Group unconformity and nearby Mississippi Valley–type (MVT) lead-zinc deposits (Duguet, Magnus and Ratcliffe 2012). The Flinton Group unconformity is also closely associated with a package of locally brecciated calcite and dolomite marbles. In the Horton map area, dolomite marbles are located mainly near the unconformity with the Flinton Group rocks and they can be traced as a mappable unit (Duguet, Magnus and Ratcliffe 2014b). Both the calcite and dolomite marbles are medium to coarse grained and white.

All of these units are unconformably overlain by rocks of the Flinton Group, which were deposited no later than 1157 ± 10 Ma (maximum age of deposition: Sager-Kinsman and Parrish 1993). Three belts of rocks assigned to the Flinton Group were identified in the field. They are all located along the southern join between the Horton and Admaston map areas (*see* Figure 5).

The southernmost belt of Flinton Group rocks overlies marbles and consists of metaquartzarenite, calcareous metaquartzarenite and biotite-sillimanite-bearing mylonitic schist. These rocks are, in turn, overlain by garnet-sillimanite-bearing mica schists. The second belt is located just north of the first and has the largest surface area of the 3 belts. The substrate to the second belt consists of the rock units present in the Admaston map area, in which carbonate rocks are a minor component. This second belt is composed of the 2 rock units previously described for the first belt, plus an upper unit composed of finely laminated calc-silicate rock. The northernmost belt is almost exclusively composed of finely laminated calc-silicate rocks, with minor meta-arenite. Of all of the Flinton Group rock types, the calc-silicate rocks are the most difficult to assign to the classic Flinton Group stratigraphy, or to differentiate into the different formations of the group. This is because they are very texturally and compositional similar to Grenville Supergroup calc-silicate rocks—a task made even more difficult by the degree of metamorphism and the intense deformation that these rocks have undergone. Partly because of poor exposure, Flinton Group strata could not be traced south of the Paleozoic rocks located north of Ashad Road (*see* Figure 4). Only the dolomite marble unit associated with the Flinton Group unconformity has been found to the south of Ashad Road.

In the Mud Lake map area (*see* Figures 1 and 4) is a unit composed of grey gneiss, with its likely protoliths showing a wide range in composition, including calc-silicate rocks, calcareous arkose, arkose and possibly intermediate volcaniclastic rocks. These gneisses underwent varied degrees of partial melting with some of them exhibiting a clear and abundant segregation of the melt, qualifying them as metatexite. This unit is well represented in the Horton map area where they are stratigraphically on top of mafic volcanic rocks that are geochemically akin to arc tholeiites (*see* Table 3, units 3 and 5). This relationship is less obvious in the Mud Lake map area and will need further work to be resolved.

A mafic volcanic rock unit crops out on the eastern side of the Mud Lake map area (stop 7). This unit is composed of fine-grained, nematoblastic, locally massive, dark bluish-grey amphibolite. Some layers of this unit have widespread epidote pods. Despite the pervasive strain and stretching, the shape of these epidote pods strongly suggests that they are former pillow selvages. The interpretation of this unit as volcanic in nature is strengthened by the presence of garnet-bearing schists interlayered with the mafic rocks. The gradational transition between the 2 suggests that the schists may represent metamorphosed synvolcanic alteration. The mafic volcanic unit was affected on its southern boundary by potassic metasomatism, which induced recrystallization of the calc-silicate pods. This metasomatism is likely the result of emplacement of the Calabogie syenite (1088 ± 2 Ma: Corriveau et al. 1990), located to the southeast near Calabogie Lake.

Farther south, in the Black Donald Lake map area (*see* Figure 3; *see also* Table 3, units 1 to 8), the rock units of the Mazinaw domain have the same characteristics as do those in the southern Mazinaw domain and, therefore, will not be discussed in detail, in part because the field trip does not cover that area. Nonetheless, interested readers can refer to Duguet, Whitney and Ma (2014) for further information about the Black Donald Lake map area and, for a comprehensive study of the Mazinaw domain, refer to Easton (2006).

PLUTONIC ROCKS

If supracrustal rocks in the Mazinaw and Black Donald domains show significant differences with respect to rock types and history, so do the plutonic rocks. Plutonism in the Mazinaw domain differs notably from that of the Black Donald domain in composition, age and timing. The Mazinaw domain experienced Elzevirian plutonism. This tonalite-trondhjemite-granodiorite arc-related plutonism spanned 70 million years from 1280 to 1210 Ma (*see* Appendix-Table 1-1) and was characterized by several magmatic pulses of different compositions. Shawinigan-age plutonism is very rare in the Mazinaw domain and so far has been observed only in the western Mazinaw domain near the tectonic boundary with the Black Donald domain. Unlike the Mazinaw domain, plutonism in the Black Donald domain started no earlier than 1223 Ma (oldest documented age on a plutonic rock in that area) and is dominated by plutonic rocks ranging in age from 1200 to 1135 Ma and likely related to the Shawinigan Orogeny (*see* Appendix-Table 1-4). Syn-orogenic Grenvillian plutonism (*see* Appendix-Table 1-5) affected both the Mazinaw and the Black Donald domains differently.

The description of the plutonic events in this section will be presented in chronological order from oldest to youngest regardless of their domain provenance. It should be remembered that the intrusive suites defined by Lumbers et al. (1990) and Easton (1992) were lithostratigraphic, not chronostratigraphic, units. Thus, slight differences in the age of plutons of these intrusive suites between their type areas and the field trip area, although noteworthy, do not negate lithological correlation with these suites. Appendix 1 provides summary tables of all of the geochronological data referred to in this guidebook. In the subsequent section, 2 geochronology methods are mentioned frequently: laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) and isotope dilution thermal ionization mass spectrometry (ID-TIMS).

Older Tonalite Suite and Killer Creek Suite (1285–1270 Ma) (part of unit 17)

These rocks constitute units 17g, 17h and 17d, 17e, 17f in Table 3. In Mazinaw domain, the oldest documented intrusive unit is located in the Black Donald Lake map area in the Bartraw dome (Duguet, Ma and Whitney 2017; *see* Figure 3). It is composed of an equigranular, medium-grey, metatextitic blue-grey gneissic tonalite. Migmatitic intrusive rocks, more dioritic in composition, are also present. This tonalite experienced a complex structural history (Duguet, Whitney and Ma 2014). Uranium-lead (U/Pb) geochronology on zircon by LA-ICP-MS (Davis 2015) produced 4 different $^{207}\text{Pb}/^{206}\text{Pb}$ ages of 1083 ± 36 Ma, 1201 ± 10 Ma, 1237 ± 11 Ma and 1285 ± 20 Ma (*see* Appendix 1). The oldest zircon population is characterized by low-uranium oscillatory zoned domains and is interpreted as a crystallization age. Based on textural evidence, the age of *circa* 1237 Ma was associated with crystallization of zircon after a period of zircon resorption (Davis 2015). The most likely interpretation is that the tonalite underwent partial melting at this time with dissolution and subsequent neocrystallization of zircon. It is also remarkable that this age corresponds within error to a widespread intrusive event in the Mazinaw domain involving several types of plutonic rocks (*see* Appendix-Table 1-1). The youngest population of zircon in this rock

is related to the Grenville Orogeny and displays textural features (e.g., low uranium with oscillatory and “fir-tree” zoning) compatible with a crystallization during a partial melting event.

In the Black Donald Lake map area, this metatextitic tonalite is associated closely, in the field, with gneissic anorthosite and anorthositic gabbros that are frequently infilled with tonalitic melt, likely derived from the nearby, migmatitic, 1285 million-year-old tonalite (*see* Appendix-Table 1-1). By comparison with similar rocks in adjacent areas (*see* Easton and de Kemp 1988; Easton, Ford and Cooke 1995) and because of the close relationship with the older tonalites, these gneissic mafic intrusive rocks have been assigned to the Killer Creek intrusive suite of which the emplacement age has been estimated as prior to 1270 Ma, based on field relationships in the Grimsthorpe domain (*see* Easton and Ford 1994a, 1994b).

Elzevir Intrusive Suite (1270–1245 Ma) (part of unit 17)

These rocks constitute units 17a, 17b and 17c (*see* Table 3). The most volumetrically abundant plutonic suite in the Elzevir terrane is the Elzevir intrusive suite. Defined by Easton (1992) and modified by Praasma, Wodicka and Easton (2000), the Elzevir intrusive suite is composed of high-aluminium gneissic tonalite, granodiorite and granite emplaced between 1270 and 1245 Ma. In the Black Donald Lake map area (*see* Figure 3), an elongated pluton named the Black Donald tonalite (Lumbers 1982b, 1982c) is exposed at the boundary between the Mazinaw and the Black Donald domains. The Black Donald tonalite intruded metatextitic metasedimentary rocks, marble and mafic gneiss (likely volcanic derived) of the Mazinaw domain (*see* Figure 3). Assigned originally to the Black Donald domain (Duguet, Whitney and Ma 2014), careful structural analysis indicates that the Black Donald tonalite is more likely affiliated with the Mazinaw domain. Although a synform centred on the Black Donald tonalite overthrusting the Black Donald domain was preferred, because of this structural complexity, several hypotheses can be considered regarding the geometry of the Mazinaw–Black Donald domains boundary in this area.

A granitic phase of the Black Donald tonalite sampled along the Madawaska River yielded a U/Pb age on zircon of 1247 ± 14 Ma (LA-ICP–MS, Davis 2015), which was interpreted as a crystallization age (*see* Duguet, Ma and Whitney 2017). Two other populations with concordant to near-concordant zircon populations clustered at 1156 ± 9 Ma and 1037 ± 14 Ma (*see* Appendix-Table 1-1) and were interpreted as metamorphic overgrowths formed during the Shawinigan and the Ottawa orogenies, respectively. The Griffith batholith, much farther west (*see* Figure 2), gave very similar emplacement ages at 1245 ± 5 Ma (by LA-ICP–MS on zircon, Davis 2016) on its southern part and at 1241 ± 2 Ma (ID-TIMS on zircon, Kamo 2016) on its northern part (*see* Appendix-Table 1-1). The 2 ages were performed on different phases of the Griffith batholith, namely an equigranular, medium-grained, light grey tonalite in the south, and a potassium feldspar megacrystic granite in the north. Shawinigan metamorphism also affected the Griffith batholith with an age of 1156 ± 26 Ma reported from a thick zircon rim (LA-ICP–MS, Davis 2016).

Methuen Intrusive Suite (1245–1220 Ma) (unit 18)

These rocks constitute map unit 18 (*see* Table 3). Similar to the older plutonic suites, the younger *circa* 1245 million-year-old Methuen intrusive suite granitoids are restricted to the Mazinaw domain and are apparently absent from the Black Donald domain. Defined by Easton (1992) and corresponding to the alaskite suite of Lumbers et al. (1990), these plutonic rocks are composed mainly of equigranular, medium-grained, migmatitic pink monzogranite and syenogranite (Easton 1992; Lumbers et al. 1990) chemically identical to F-III rhyolite (Leshner et al. 1986). This distinctive tholeiitic chemical affinity among the felsic intrusive rocks within the Central Metasedimentary Belt led Easton (2006) to interpret them as being emplaced in a rifted arc context. Methuen intrusive suite plutons recurrently are closely associated in the field with bimodal volcanic sequences assigned to the Mazinaw Formation. Both the

Methuen intrusive suite and Mazinaw Formation rocks show similar chemical affinities (Easton 2006; Duguet, Magnus and Ratcliffe 2014b; Duguet 2014), but ages from both the intrusive and volcanic equivalents come from a single location, which gave ages of 1246 ± 3 and 1240 ± 10 Ma for the Mazinaw Formation and the Abinger granite, respectively (*see* Easton 2006; Corfu and Easton 1995).

Methuen intrusive suite plutons are morphologically diverse, emplaced either as rounded-shape plutonic bodies or, more commonly, as thin elongated plutons parallel to the original stratigraphy. They are particularly abundant in the southern part of the field trip area both in the footwall and the hanging wall of the Ross fault. They become, however, marginally present in the northeastern and eastern parts of the study area (Horton map area; Duguet, Magnus and Ratcliffe 2014b). There, the largest granitic pluton of this suite occurs on the north side of the Hurds Lake tonalite and is oriented to the northeast (*see* Figure 5). A zircon from this pluton, analyzed by TIMS, yielded a minimum U/Pb age of 1229 ± 3 Ma (Kamo 2012). This age is younger than the typical age of *circa* 1245 Ma obtained for Methuen intrusive suite rocks in the southern Mazinaw domain, such as the Abinger and the Norway granites (Easton 2006; Corfu and Easton 1995), but it is consistent with ages of Methuen intrusive suite granitoid rocks present in the northwestern and western Central Metasedimentary Belt (*see* Easton and Kamo 2011; Kamo 2013). During the Grenville Orogeny, Methuen intrusive suite granites underwent partial melting to produce a significant amount of pegmatitic leucosomes, which are monzogranitic to syenogranitic in composition, and which are locally enriched in thorium and uranium. High concentration of these pegmatitic leucosomes in Methuen intrusive suite granite produces prominent uranium, thorium and potassium anomalies that are clearly visible on regional airborne gamma-ray radiometric maps (Ontario Geological Survey 2014n-s; *see also* Duguet, Dubé-Bourgeois and Ma 2016; Duguet, Ma and Whitney 2017).

Lavant Intrusive Suite (1245–1220 Ma) (units 19 and 20)

These rocks constitute map units 19 and 20 (*see* Table 3). Mafic intrusive rocks emplaced in the interval from 1245 to 1220 Ma are widespread in the Central Metasedimentary Belt where they are found in most of the terranes and domains. They are assigned to the Lavant intrusive suite, named after the largest of these plutonic bodies, the Lavant gabbro, which intruded supracrustal rocks of the Sharbot Lake domain (Easton 1992). Their composition generally ranges from gabbro and leucogabbro to diorite. Their chemical affinity is generally calc-alkalic, but significant parts of individual intrusions may display island arc tholeiite and alkalic chemical affinities (Figure 6) (*see also* Magnus 2013b; Duguet, Magnus and Ratcliffe 2014b; Azar 2015). Several isotopic studies conducted on these mafic intrusions (e.g., Chenaux, Raglan Hills, Glamorgan and Lavant gabbros) have shown that they came from a depleted mantle source with little to no crustal input (Gemmell 2009; Jessett 2010; Magnus 2013b; Azar 2015). In addition, detailed studies have shown that a single intrusion can be the result of individual multiple injections of magma of different compositions (Magnus 2013a, 2013b; Duguet, Magnus and Ratcliffe 2014b) and may, therefore, qualify as an intrusive complex.

Such compositionally heterogeneous bodies are well exposed in the Horton map area and seem to be restricted to the Mazinaw domain. An ovoid-shape bimodal intrusion, cropping out in the northeastern part of the Horton map area (Duguet, Magnus and Ratcliffe 2014b) and named the Glasgow complex, is composed of gabbro, diorite, syenite and monzonite. A diorite from this intrusion sampled along Highway 17 (*see* Figure 5: stop 19) yielded a zircon age of 1223 ± 1 Ma by U/Pb TIMS (Kamo 2012). Because of the age and its chemistry, this unit was assigned to the Lavant intrusive suite. This age is comparable to the U/Pb zircon ages of the Chenaux and Raglan Hills gabbros (1231 ± 2 Ma and 1229 ± 5 Ma, respectively: Pehrsson, Hanmer and van Breemen 1996) and the Lavant gabbro (1224 ± 2 Ma: Corfu and Easton 1997). The age for the Glasgow complex is older than previous workers had suggested based solely on field relationships (e.g., Lumbers 1982c). Another much larger intrusion, the Norway complex, displays similar petrographic features and is exposed on the south edge of the Horton map area

and on the eastern edge of the Mud Lake map area (*see* Figures 4 and 5). Because most of the Norway complex lies outside the boundaries of the various map areas shown in Figure 1, it was not mapped in detail. Nonetheless, chemistry from rocks sampled in the Horton map area show identical patterns to those seen for the Glasgow complex and suggests that both are part of the same intrusive suite (*see* Figure 6).

Another set of mafic intrusive rocks was discovered in the Mazinaw domain. They were mostly found in the Horton map area (Duguet, Magnus and Ratcliffe 2014b) and are characterized by thin elongated bodies parallel to the regional fabric and sills. Albeit closely associated with the Lavant intrusive suite intrusions in the field, these mafic intrusions are chemically distinguishable from the typical mafic Lavant intrusive suite rocks because they have a chemical affinity equivalent to back-arc basalts (back-arc field in the diagram of Cabanis and Lecolle 1989). Their age is unknown and they were grouped under unit 19 (*see* Table 3). For now, based on field relationships, it is believed that they were emplaced contemporaneously with the Lavant intrusive suite metagabbros.

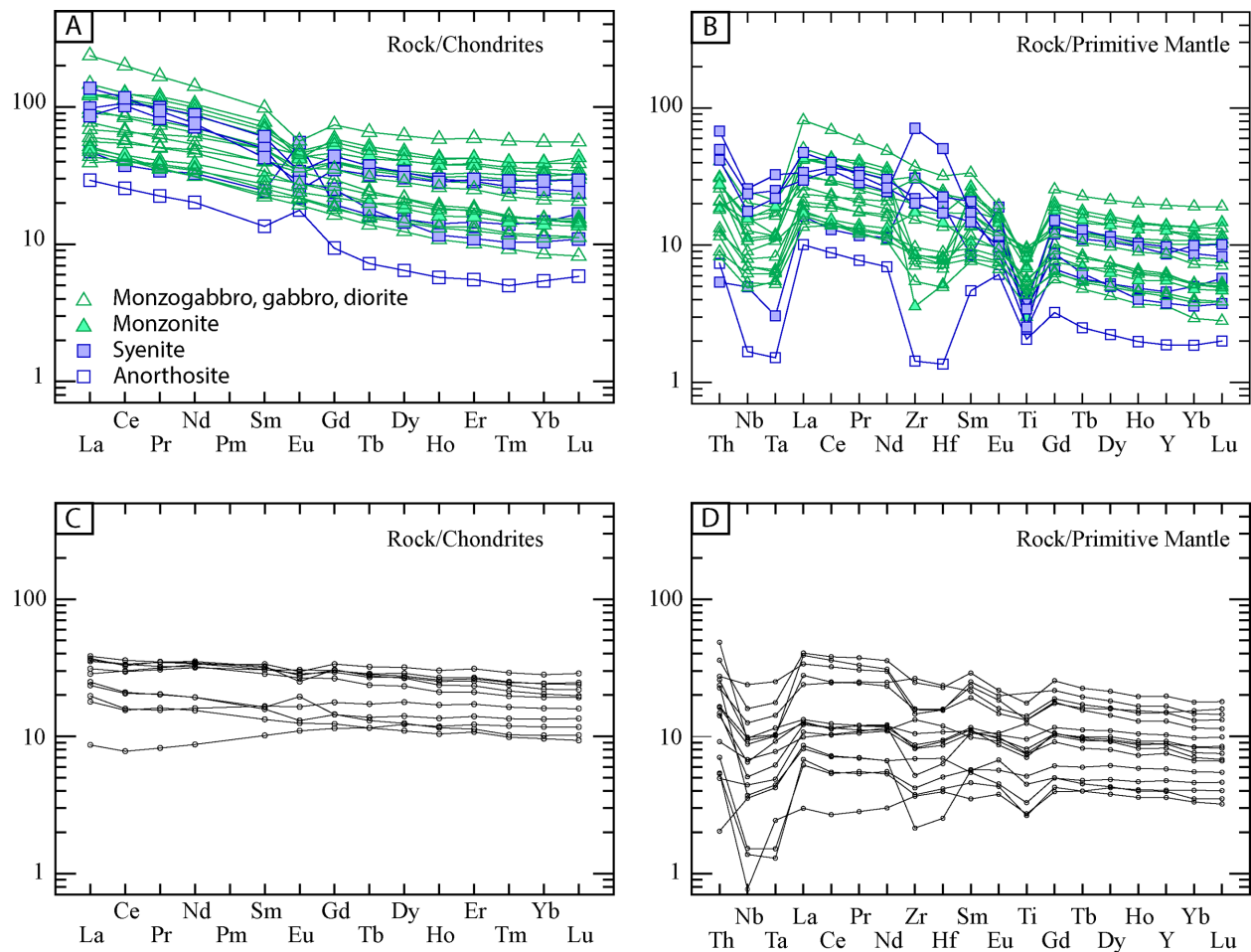


Figure 6. A) Chondrite-normalized rare earth element (REE) diagram for syenite-monzonite-gabbro of the Glasgow and Norway complexes. B) Primitive mantle-normalized incompatible elements diagram for syenite-monzonite-gabbro of the Glasgow and Norway complexes. C) Chondrite-normalized rare earth element (REE) diagram for unit 10 in the Black Donald domain. D) Primitive mantle-normalized incompatible elements diagram for unit 10 in the Black Donald domain. Normalizing factors of Sun and McDonough (1989) are used.

The Black Donald domain was also intruded by mafic bodies displaying chemical affinities akin to the Lavant intrusive suite. However, they are more homogeneous than their counterparts present in the Mazinaw domain with a clear lack of felsic members. In the Centennial Lake map area, an interesting feature of some of these mafic metaplutonic rocks is that their long axis is oblique in relation to the general trend of the megastructures. On a map pattern, this is particularly obvious for the body cropping out in the northern part of the lithostructural unit, which forms an angle of 30° with the overall azimuth of the belt (*see* Figures 3 and 2). Mafic metaplutonic rocks are represented by melanocratic, medium- to coarse-grained, locally plagioclase-phyric gneissic gabbro and diorite. The intensity of the foliation varies greatly from moderate to mylonitic.

Another type of mafic intrusive rock restricted to the Black Donald domain is represented by 1 to 10 metre-thick mafic sills. They are chemically distinct from the other mafic intrusive rocks assigned to the Lavant intrusive suite because their chemistry is characterized by slightly enriched flat REE profiles and are akin to arc tholeiites. They are usually highly deformed and metamorphosed, with garnet commonly being present. Field relationships suggest that part of these mafic rocks were also extrusive. For this reason, they were placed in map unit 10 (*see* Table 3), even though they may have been coeval with the Lavant intrusive suite metagabbros.

Young Tonalite-Granodiorite Suite (unit 21)

These rocks constitute map unit 21 (*see* Table 3). In the course of this mapping project, several U/Pb zircon ages were obtained from tonalite, granodiorite and granite intrusions that were initially thought to be Elzevir intrusive suite plutons. However, these intrusions gave surprisingly young ages clustered at *circa* 1210 Ma (*see* Appendix-Table 1-1). Thus, although lithologically similar to the Elzevir intrusive suite, their ages are much younger than typically found for the Elzevir intrusive suite.

The largest of these tonalitic bodies is the Hurds Lake tonalite, which is exposed in the Mazinaw domain in the Horton map area (*see* Figure 5; *see* Chart-Figure A-5) (Duguet, Magnus and Ratcliffe 2014b). This pluton, covering a significant part of the Horton map area, is likely a thin laccolith emplaced subparallel to the stratigraphy. Its current batholith-like shape is the result of subsequent deformation (*see* Chart-Figure A-5). A sample from the Hurds Lake tonalite yielded a U/Pb zircon TIMS age of 1211±1.4 Ma (Kamo 2012). This age is far younger than ages obtained from the Elzevir intrusive suite elsewhere in the Central Metasedimentary Belt, which typically range from 1270 to 1245 Ma (Easton 1992).

The age of the Hurds Lake tonalite gives credence to the hypothesis previously expressed concerning a younger age for tonalitic plutonism in this part of the Central Metasedimentary Belt (Easton, Duguet and Magnus 2011). In the Admaston map area, a porphyritic mylonitic granite also yielded a U/Pb TIMS zircon age of 1210±9 Ma (Kamo 2013). Rocks with ages at *circa* 1211 Ma (*see* Appendix-Table 1-1) also occur farther west, such as the tonalite dike that crosscut the Raglan Hills gabbro (*circa* 1229 Ma), which gave an age of 1213.4±5.4 Ma (Magnus 2013a). Furthermore, a potassium feldspar monzogranite from the Harvey–Cardiff domain (*see* Figure 1) gave an age of 1211.3±1.5 Ma (Easton and Kamo 2011). Because these younger tonalitic plutonic and related rocks are chemically undistinguishable from the older tonalitic suites, such as the Elzevir intrusive suite, additional geochronology will be required to further assess the regional distribution of this calc-alkalic plutonic event.

Based on petrographic similarities with tonalitic rocks, with ages of approximately 1210 Ma, and structural relationships with other units (Duguet, Magnus and Ratcliffe 2012), several tonalitic plutonic bodies were assigned to this younger suite of tonalite intrusions. Nevertheless, for the reasons mentioned previously in this section, such assignment of a pluton to one suite or another is subject to a high degree of uncertainty. The recurrence of this age of *circa* 1210 Ma, not only within the Mazinaw domain, but

possibly throughout the entire northern part of the Central Metasedimentary Belt, may lead to the creation of a new intrusive suite. Until now, such young tonalitic plutonism has not been found in the southeastern part of the Central Metasedimentary Belt. It is unclear if this absence is caused by a lack of data or if it reflects a different geodynamical setting and history of the southern Central Metasedimentary Belt. In light of these new data, one must also wonder about the temporal and geodynamical relationships of this plutonic event to younger (Shawinigan) and older (Elzevirian) tectonometamorphic events. The plutonic event at *circa* 1210 Ma is so close in age to both the Lavant intrusive suite and to the early Shawinigan tectonic cycle that it is uncertain if we are dealing either with an orogenic continuum or 2 separate tectonometamorphic events. However, because the tonalite intrusive event at *circa* 1210 Ma (e.g., Hurds Lake tonalite in the Mazinaw domain) has not been previously documented as being related to Shawinigan history, this would suggest an affiliation with the late stages of the Elzevirian Orogeny.

Shawinigan-Age Magmatism (*circa* 1150 Ma) (units 22 and 27)

These rocks constitute map units 22 and 27 (*see* Table 3). Shawinigan-age plutonism, previously unrecognized in this part of the Central Metasedimentary Belt, actually constitutes the bulk of the plutonic history of the Black Donald domain (*see* Appendix-Table 1-3). The composition of these Shawinigan-age plutons is varied, ranging from gabbro, diorite to syenite and monzonite. With respect to the syenite and monzonite plutons, because of their similar petrography and chemistry, their heterogeneous and locally very weak deformation, they were at first thought by the authors to be related to younger Kensington–Skootamatta suite (Corriveau et al. 1990; Easton 1992) which is also widespread in the area. On the other hand, Lumbers (1982b, 1982c) had assigned the syenite and monzonite plutons to be part of an undated older plutonic event (part of the “anorthosite suite”). Conversely, because of their composition and their more intense deformation, diorite and tonalite, such as the Kennelly Lake diorite or the Mud Lake tonalite (*see* Figure 4; Duguet, Dubé-Bourgeois and Ma 2016) were previously interpreted as being part of the Elzevir intrusive suite (Lumbers 1982b, 1982c).

In the Admaston map area, elongated intrusions straddle the major tectonic boundaries. They are commonly composed of equigranular, medium-grained, pink biotite monzonite and syenite elongated parallel to the northeast-trending thrust. One of these plutons crops out at the inferred boundary between the Mazinaw domain and the Black Donald domain (*see* Figure 5; *see also* Chart-Figure A-1). Composed mainly of monzonite and syenite, this intrusion is nonetheless more diverse in composition, including granodiorite and diorite. Near its margins, the intrusion is strongly deformed and, locally, the original protolith has been metamorphosed into a biotite-rich schist. Zircons from this intrusion yielded a U/Pb age of 1167 ± 13 Ma (LA-ICP-MS, Kamo 2013). This intrusion is similar in age and in composition to magmatism described farther to the southeast in the Frontenac terrane and the Sharbot Lake domain (Corfu and Easton 1997; Cutts 2013). The Shawinigan magmatism in the Black Donald domain differs from the Frontenac intrusive suite, however, in its trace element chemistry. On chondrite-normalized rare earth element (REE) plots, all samples display strong fractionation pattern with enrichment in LREE and depletion in heavy rare earth elements (HREE) (Figure 7). Monzonites are overall more enriched in REE (*see* Figure 7), barium and strontium than the syenites and diorites. These trace element chemistries are identical to those known for the Kensington–Skootamatta suite at *circa* 1080 Ma (Corriveau et al 1990), but also for the Chevreuil suite in Quebec at 1190 to 1160 Ma (*see* Corriveau 2013).

The syenite-monzonite plutons are not found in the Mud Lake and Black Donald Lake map areas. Instead, the dominant plutonic suite in those areas is composed of strongly deformed tonalite and diorite intrusions, the largest being the Kennelly Lake diorite and the Mud Lake tonalite (*see* Figure 4) (Duguet, Dubé-Bourgeois and Ma 2013). Within a single intrusive body, a significant range in both texture and composition is present. For instance, the southern portion of the Kennelly pluton is an equigranular, fine-grained, medium grey diorite, whereas the northern portion of the pluton is an equigranular, medium-

grained leucocratic hornblende tonalite. These plutonic rocks are also exposed in the northwestern corner of the Black Donald Lake map area along strike with the Mud Lake and the Kennelly plutons. The plutonic rocks also occur sporadically to the southeast of the Black Donald Lake map area, but only as diorite sills. They are geochemically comparable to calc-alkalic intrusive rocks observed in modern active margins, with a strong fractionation pattern, with a strong enrichment in LREE (Figures 8B and 8D) and prominent negative niobium and tantalum anomalies. Geochronology (U/Pb) on zircon by ID-TIMS initially gave ages for the Kennelly Lake diorite scattered between 1157 and 1132 Ma (Kamo 2014). Such a widespread range of ages is usually diagnostic of either the presence of inherited zircons or a post-emplacement tectonometamorphic overprint or both. Consequently, the sample was reprocessed using LA-ICP-MS. These subsequent U/Pb analyses on 20 out of 22 spots agree within error, giving an average $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1190 ± 6 Ma (Davis 2016). This age is much older than the ID-TIMS age, but is equivalent to a U/Pb LA-ICP-MS age of 1187.1 ± 2.4 Ma (Geospec Consultants 2013) obtained from a migmatitic mafic gneiss in the Admaston map area (Bancroft terrane) that was interpreted as the timing of migmatization.

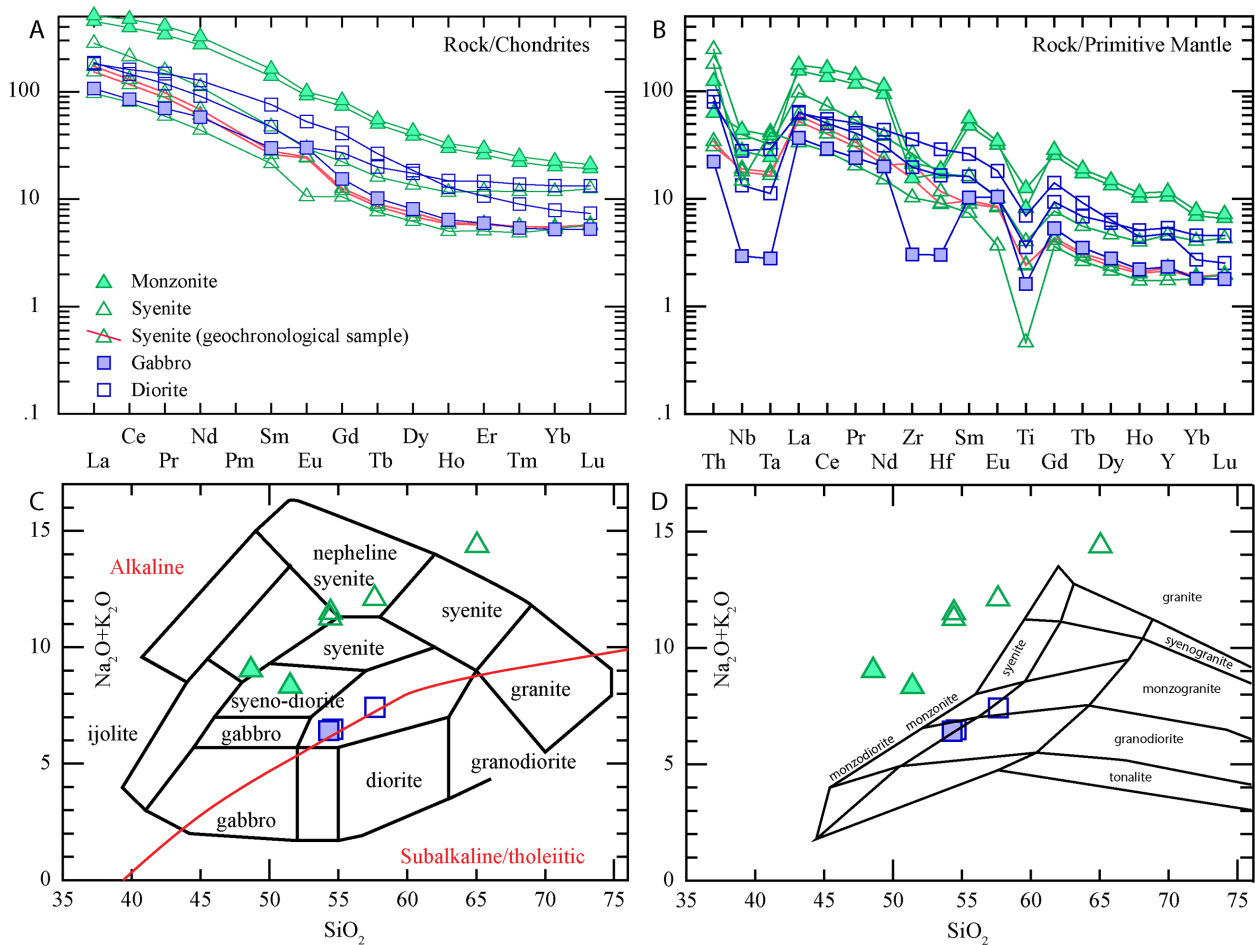


Figure 7. A) Chondrite-normalized rare earth element (REE) diagram for syenite-monzonite-gabbro from the Admaston map area. B) Primitive mantle-normalized incompatible elements diagram for syenite-monzonite-gabbro of the Admaston map area. C) SiO_2 versus total alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) plot for syenite-monzonite-gabbro from the Admaston map area. D) SiO_2 versus total alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) granite classification diagram for syenite-monzonite-gabbro of the Admaston map area. Normalizing factors of Sun and McDonough (1989) are used in Figure 7A and 7B.

In the Centennial Lake map area, within the Black Donald domain, another type of bimodal intrusive rock is exposed within the lower unit (*see* Figure 2). The most abundant type is characterized by a well-foliated, equigranular, fine- to medium-grained, light grey granodiorite to tonalite. The less abundant dioritic facies contains hornblende, whereas the granodioritic to tonalitic rocks rarely have any. When both metaplutonic types are tightly interlayered, they look very similar to some of the rocks of the bimodal sequence described in the intermediate unit. In the lower unit, both types of metaplutonic rocks are typically magnetic, with magnetic susceptibility values ranging from 10 to 82×10^{-3} SI units. The age of these plutons is unknown, but, based on chemical similarities (*i.e.*, calc-alkalic affinity) with the 1190 million-year-old Kennelly Lake diorite, they are provisionally assigned to the Shawinigan magmatic cycle. On the other hand, their petrographic and magnetic features contrast strongly with those of the Kennelly Lake diorite (Duguet, Dubé-Bourgeois and Ma 2016) or the coeval Mud Lake tonalite, both of which tend to be non-magnetic. Another peculiarity concerning the tonalitic unit is that it locally displays a strongly fractionated rare earth element pattern akin to those seen in adakite.

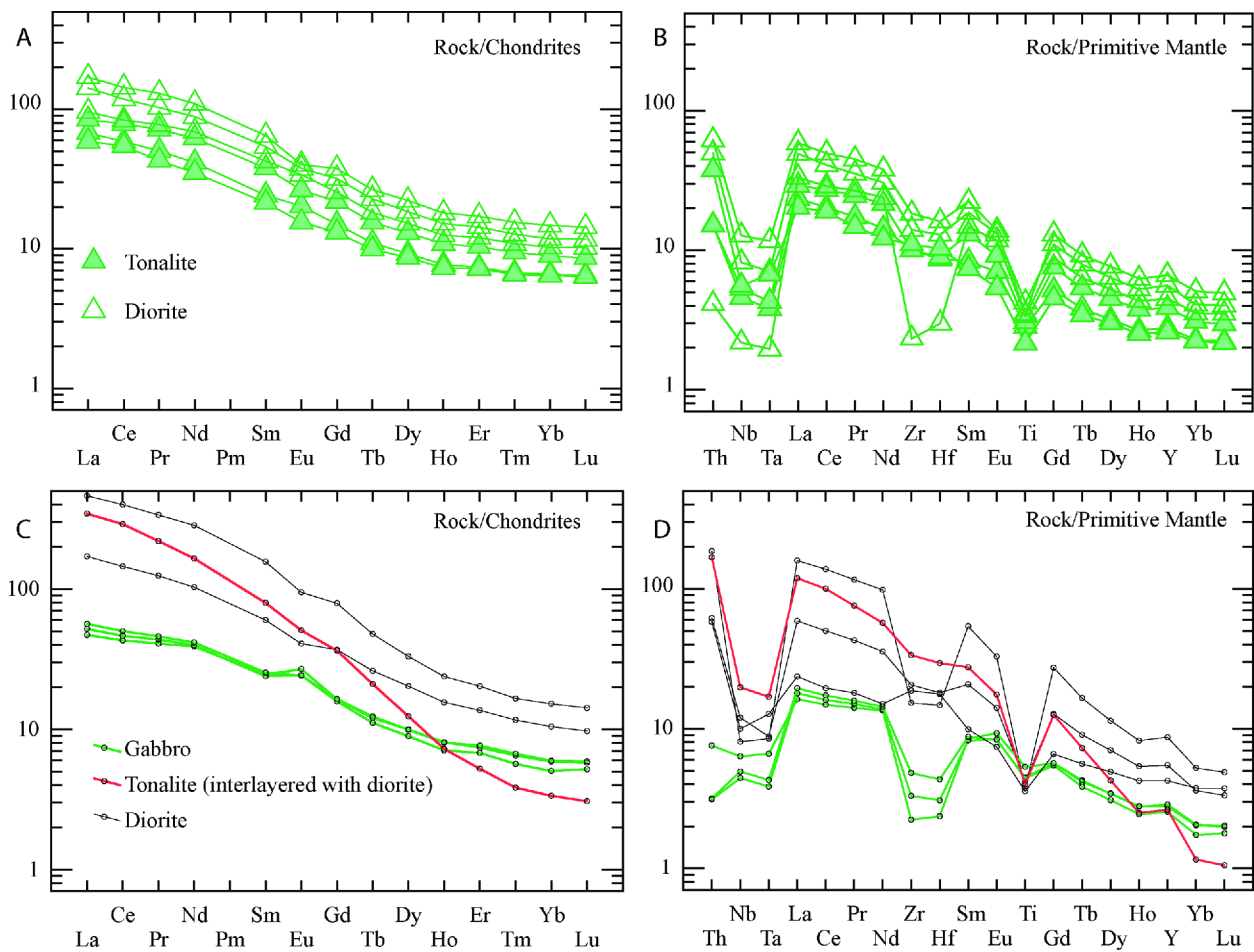


Figure 8. **A**) Chondrite-normalized rare earth element (REE) diagram for the Mud Lake tonalite and the Kennelly Lake diorite (Mud Lake map area). **B**) Primitive mantle-normalized incompatible elements diagram for the Mud Lake tonalite and the Kennelly Lake diorite (Mud Lake map area). **C**) Chondrite-normalized rare earth element (REE) diagram for gabbro, diorite and tonalite of the intermediate unit (Centennial Lake map area). **D**) Primitive mantle-normalized incompatible elements diagram for gabbro, diorite and tonalite of the intermediate unit (Centennial Lake map area). Normalizing factors of Sun and McDonough (1989) are used.

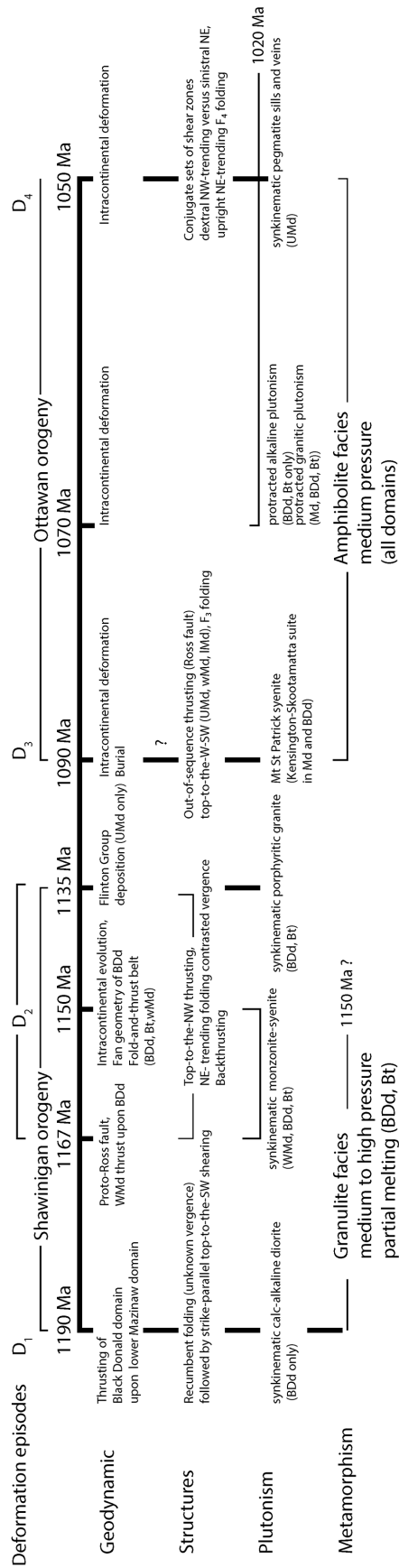


Figure 9. Summary of regional plutonic and tectonometamorphic events, resulting from the Shawinigan Orogeny and Ottawa Orogeny (both of which are part of the Grenville Orogeny), in the northeastern Central Metasedimentary Belt (from Duguet 2017). Abbreviations: BDd, Black Donald domain; Bt, Bancroft terrane; LMD, lower Mazinaw domain; Md, Mazinaw domain; UMd, upper Mazinaw domain; WMd, western Mazinaw domain. See Appendix-Tables 1-4, 1-5, 1-6 and 1-7 for complete geochronological constraints used to produce this figure. Chart-Figure A-8 is a larger version of this figure (see back pocket).

Shawinigan-age plutonism in the Bancroft terrane and the Black Donald domain lingered until *circa* 1135 Ma. A synkinematic intrusion, located in the western part of the Admaston map area, was also sampled for geochronology. It consists of a highly strained porphyroclastic mylonitic granite in which the fabric was acquired during crystallization. Zircons from this sample yielded an age of 1135 ± 3 Ma (ID-TIMS, Kamo 2013). The geochronological data and significance of this sample will be discussed further in “Structural Geology”.

All of the above-mentioned ages (*see* Appendix-Table 1-4) provide strong evidence for a protracted orogenic event (Figure 9) in the northeastern Central Metasedimentary Belt from 1190 to 1135 Ma, prior to terminal Grenville collision (Ottawan Orogeny) at *circa* 1090 Ma. They also call for several remarks.

- With ages spanning from 1190 to 1167 Ma, diorite, tonalite and biotite monzonite are similar in age and petrography to the monzonite-diorite-gabbro plutons in the Chevreuil suite in Quebec (Wynne-Edwards et al. 1966; Corriveau and van Breemen 2000; Hynes and Rivers 2010).
- The age range of this tectonometamorphic event falls within that of the previously defined Shawinigan Orogeny (cf. Corriveau and van Breemen 2000; Carr et al. 2000; Hynes and Rivers 2010; Rivers 2012).
- The Mazinaw domain, the Black Donald domain and the Bancroft terrane were all regionally affected by the 1190 to 1130 Ma event, both in terms of deformation and plutonic activity.
- These ages also raise the question of the geographic extension of this event within the Central Metasedimentary Belt in Ontario, as this Shawinigan-age event has not been identified in domains of the Elzevir terrane farther to the south.

Grenvillian Magmatism

Grenvillian magmatism is also widely represented within the Mazinaw and Black Donald domains (*see* Appendix-Table 1-5). The oldest Grenvillian intrusion identified in the Mud Lake map area is the Mount St. Patrick syenite (*see* Figure 4), which intruded supracrustal rocks of the Black Donald domain. This ovoid-shaped intrusion is interpreted as being of similar age to the Calabogie syenite in the Mazinaw domain, which has a U/Pb zircon age of 1088 ± 2 Ma (Corriveau et al. 1990). This assessment is based on strong petrographic, magnetic, radiometric and geometric similarities between the 2 intrusions. The Calabogie syenite belongs to the Kensington–Skootamatta suite (Corriveau et al. 1990; Easton 1992). Whole-rock chemistry on the Mount St. Patrick syenite confirmed its affinity with the Calabogie syenite (Duguet 2016). Two facies were identified in the field. The first facies, located on the margin of the pluton, is a gneissic, fine-grained beige syenite. The second facies is a coarse-grained, porphyritic light grey syenite. The potassium feldspar phenocrysts commonly range in size from 1 to 5 cm and the interstitial mineral phases are either biotite or pyroxene. The porphyritic facies is the dominant one, with a gradational transition from the rim toward the centre of the intrusion from strongly aligned potassium feldspar phenocrysts to randomly oriented crystals.

Alkalic mafic intrusions composed of gabbro and pyroxenite are also abundant in the Admaston and Mud Lake map areas. They are represented by several small intrusions in the Black Donald domain, but more commonly occur as sills and dikes. Others were found within the Mount St. Patrick syenite where they seem to be part of the intrusion. Despite the absence of geochronology on these rocks, the lack of deformation, their chemistry and their close spatial association in the field with syenites of the Kensington–Skootamatta suite led us to classify these alkalic mafic intrusive rocks as contemporaneous with the felsic intrusive rocks of the Kensington–Skootamatta suite. Farther west in the Brudenell map area, the Woermke gabbro shares the same petrologic, and some of the chemical, characteristics as the rocks in the Admaston map area. The Woermke gabbro has a U/Pb TIMS zircon age of 1073 ± 3 Ma

(Easton 2012; Kamo 2012). It is likely coeval with a mafic dike swarm recognized by Easton (2012) in the Brudenell and Cobden map areas (Easton 2012, 2014).

Younger intrusive rocks (1050–1020 Ma; *see* Appendix-Table 1-5) consist of porphyritic monzogranite and quartz syenite. These intrusions occur mostly as tight networks of sills and veins, but, if this network is dense enough, it can result in mappable intrusions. The grain size in these veins and sills is highly varied, ranging from pegmatitic (the most abundant) to medium grained. Such intrusions are abundant in the Horton map area (Mazinaw domain), especially in and around the Hurds Lake tonalite. Some of the pegmatites intruding the Hurds Lake tonalite are magnetite rich and are clearly visible on maps showing the second vertical derivative of the residual magnetic field (Ontario Geological Survey 2014h-m). The pegmatites are known historically to host uranium-thorium mineralization (Easton, Duguet and Magnus 2011; Duguet, Magnus and Ratcliffe 2014b) and molybdenum-rich skarns (Lentz 1996). Immediately to the east, close to the Ross fault, a significant number of these veins and sills are boudinaged, although internally undeformed. Their emplacement is coeval with a major tectonic event that affected the Mazinaw domain.

It is also noteworthy that the pegmatite sills and veins hosted in Flinton Group metasedimentary rocks have a different mineralogy than those intruding other types of host rock. The latter sills are muscovite and tourmaline bearing. It is possible that some of these pegmatites were actually derived from the partial melting of some tourmaline-rich Flinton Group rocks. Another cluster of these intrusions is present in the Black Donald domain, just east of the Mount St. Patrick syenite where they intrude carbonate rocks and the northern edge of the Kennelly Lake diorite (Duguet, Dubé-Bourgeois and Ma 2013). Graphic texture is common in these pegmatitic quartz syenites. These felsic intrusions are also magnetite bearing and are likely responsible for the molybdenite-hosted skarn mineralization present in the Mud Lake map area.

Structural Geology

The structural pattern in the field trip area is the result of a succession of orogenic events that spanned approximately 300 million years. Three major orogenies, either resulting from an active plate margin setting or from continent–continent collision, shaped the Central Metasedimentary Belt. The oldest, the Elzevirian Orogeny is poorly understood, but occurred during the assembly of the Composite Arc Belt, and culminated between 1245 and 1220 Ma, mostly in an arc and back-arc setting (Carr et al 2000).

ELZEVIIRIAN OROGENY (1290–1200 Ma)

Within the field trip area, no major or minor structural features, such as folds and foliation, could be assigned with a reasonable certainty to the Elzevirian Orogeny, although the presence of layering in marbles cut by the Chenaux gabbro (1231±2 Ma: U/Pb zircon, ID-TIMS, Pehrsson, Hanmer and van Breemen 1996) has been suggested previously to be the result of Elzevirian metamorphism and deformation (Easton and Davidson 1994). The mostly likely explanation for the lack of such structural features partly lies in the subsequent intense deformation and metamorphism that affected the area in several pulses after 1210 Ma (*see* Figure 9), which include events related to both the Shawinigan and Ottawa orogenies that are described next in greater detail. Although structures related to the Elzevirian Orogeny may be difficult to locate, the orogeny is well documented by a complex plutonic history consisting of multiple plutonic events and a migmatization event that occurred at *circa* 1245 Ma in the Bartraw dome (*see* “Plutonic Rocks”).

SHAWINIGAN OROGENY (1190–1130 Ma)

Within the field trip area, the oldest recognized structural features that can be tied to the Shawinigan Orogeny (1190–1135 Ma; Carr et al. 2000) include the overthrusting of the Black Donald domain on top of the Mazinaw domain. This event also created the general structural architecture of the area and occurred at *circa* 1167 Ma, but possibly may have started as early as 1190 Ma (*see* Figure 9). In addition, many emplacement and metamorphic ages between 1200 and 1135 Ma have also been reported from the northernmost Mazinaw domain (Kamo 2013, 2014, 2015, 2016; Davis 2014, 2015, 2016).

The oldest deformational event recognized in the field trip area is a folding event (F_1). The F_1 folding event is characterized by megascopic recumbent tight to isoclinal folds likely coeval with the development of a regional foliation. They occur both in the Black Donald and the western Mazinaw domains. In the Black Donald Lake map area, the initial vergence of these folds is obscured as a result of the strong overprint of subsequent deformation events. On the other hand, within the Mud Lake map area (Duguet, Dubé-Bourgeois and Ma 2016), the original vergence of such F_1 folds in the Black Donald domain (*see* Chart-Figure A-2) may have been directed southeast. Also in the Mud Lake map area, compelling evidence for early folding is seen in the second vertical derivative of the residual magnetic field (Ontario Geological Survey 2014h-m; *see also* Duguet, Dubé-Bourgeois and Ma 2016) where F_1 fold hinges are distorted and wrap around later fold hinges.

In the Black Donald Lake map area, F_1 structures are also present. At the map scale, refolded F_1 hinges are more apparent in the Mazinaw domain than the Black Donald domain (Duguet, Ma and Whitney 2017). Because of better stratigraphic markers, this pattern was observed most clearly in the western Mazinaw domain just south of the Madawaska River (*see* Figure 3). Karboski (1980) provided a very detailed and comprehensive study of the sequence of folding and the fold geometries in the Black Donald Lake map area, which was confirmed and refined by this study (Duguet, Ma and Whitney 2017). The presence of F_1 folding was mostly established by formation of a type 3 fold interference pattern because of late F_2 folding (*see* this section therein) (Ramsay 1967; Thiessen 1986; Thiessen and Means 1980). For instance, in this aspect, the McCreary Lake antiform (Karboski 1980; *see* Figure 3; *see* Chart-Figure A-2) provides a perfect example of a F_1 fold refolded by a F_2 fold (Karboski 1980; Duguet, Whitney and Ma 2014; Duguet, Ma and Whitney 2017).

The earliest non-coaxial deformational event that affected the area is characterized by a belt-parallel top-to-the-southwest shearing. So far, this event has been recognized only in rock units present in the western Mazinaw domain and the Black Donald domain; this event seems to be absent in the Mazinaw domain east of the Ross fault. This non-coaxial deformational event was coeval with a major regional metamorphic event ranging from upper amphibolite to granulite facies that reached partial melting conditions in several rock types (e.g., gneissic tonalite, monzogranite and metapelite) (*see* Duguet, Dubé-Bourgeois and Ma 2013; Duguet, Whitney and Ma 2014). The associated partial melting event was identified first in the Mud Lake map area (*see* Duguet, Dubé-Bourgeois and Ma 2013, 2016). The locus of this event is along the boundary between the Mazinaw domain to the east and the Black Donald domain to the west (*see* Figure 4). It resulted in suprasolidus and subsolidus deformation of leucosomes and melanosomes of the stromatic metatexite (*see* Table 3, unit 9) and their associated granitic sills. Foliation planes associated with this event contain a composite stretching and mineral lineation striking to the northeast. Rocks with the highest proportion of melt are located along the boundary between the Mazinaw and Black Donald domains. In this stromatic metatexite unit, the proportion of leucosome can attain up to 60 volume % in some places. It is unlikely that such high melt content was generated *in situ*. Rather, it is more likely that this shear zone channelized and facilitated the migration of melt produced at lower structural levels.

This southwest-directed shear event was reworked by subsequent northeast-trending upright to northwest-directed folding events, which locally induced reversal of the shear sense indicators (namely, giving a shear sense to the northeast) in the inverted flanks of the folds. At the outcrop scale, shear criteria observed on injected leucosomes on the normal flank of the folds gave a consistent shear sense to the southwest. On inverted flanks, the shear sense observed on the same injected leucosomes gave an opposite top-to-the-northeast shear sense. Metamorphic conditions for a metatextitic metapelitic rock were estimated at 815°C and 9.5 kilobars (Steer 2015) by the average P - T mode in Thermo-Calc Software.

As mentioned previously, the contact between the Black Donald domain to the north and the Mazinaw domain to the south, located southward of the Centennial Lake map area is tectonic (Easton 2006). A reconnaissance excursion along this contact confirmed that the rocks (i.e., mafic volcanic rocks of the Kashwakamak Formation) are highly sheared and bear a composite stretching and mineral lineation plunging to the northeast. These lineation trajectories are very similar to the ones associated with the along-strike top-to-the-southwest shearing farther north. Work on oriented samples confirmed the presence of top-to-the-southwest kinematics along the contact between the upper Black Donald domain and the underlying Mazinaw domain and, therefore, is likely related to the top-to-the-southwest shearing parallel to the general strike of the belt found in the Mud Lake map area (Duguet, Dubé-Bourgeois and Ma 2013).

The chronological relationship between the collinear top-to-the-southwest shearing and the F_1 folding event remains uncertain. Nonetheless, despite local reversal of shear sense because of later folding events, these top-to-the-southwest kinematics were also found recurring in the Black Donald Lake and Centennial Lake map areas. This suggests that F_1 folding had little to no effect on the geometry of this shearing event and, therefore, the shearing occurred either during or after the F_1 folding. In the case of a post-shearing F_1 folding (folding and shearing being collinear), one would expect shear sense reversal from one flank to another. Such a pattern has not been observed in the field. However, the validity of this interpretation remains difficult to test directly in the field because of the extensive area of marbles that are present. Most of these marbles lack tectonic layering and are texturally equigranular, granoblastic and medium to coarse grained. Macroscopically, shape fabric is commonly weak to almost non-existent in the marbles. These textural features suggest that grain boundary diffusion may have been the dominant mechanisms of the deformation. Marbles experiencing high-grade metamorphism (amphibolite to granulite facies) either during or after deformation will behave quite differently from adjacent quartzofeldspathic rocks, potentially leading to the absence of a strong shape fabric.

Another line of evidence suggesting that top-to-the-southwest shearing occurred after the F_1 folding event comes from map patterns. In the Mud Lake map area (Duguet, Dubé-Bourgeois and Ma 2016), the cross section (*see* Chart-Figure A-3) shows that a marble-dominated F_1 recumbent fold of the footwall is truncated by the thrust plane suggesting that the thrusting event reworked the previous F_1 fold. The F_1 folding event is followed by an out-of-sequence thrusting event that placed a sheet of western Mazinaw domain rocks over rocks of the Black Donald domain. This thrusting event took place before refolding and is likely responsible for the top-to-the-southwest shearing.

In the Mud Lake map area (Duguet, Dubé-Bourgeois and Ma 2016), a garnet-bearing injected leucosome was sampled for geochronology. This dike is similar in composition to the leucosomes of the adjacent stromatic metatexite (unit 9, Duguet, Dubé-Bourgeois and Ma 2016) it intrudes and is very likely part of the same partial melting event. The dike crosscuts metatextitic paragneiss of the Black Donald domain and, thus, was a good candidate to give a lower bracket for the migmatization age and the top-to-the-southwest shearing. Individual ages on zircon grains were discordant and fell along a short mixing line from 1210 to 1000 Ma. A U/Pb zircon ID-TIMS age of 1169±3 Ma on a single, near-concordant zircon was interpreted as a minimum age of crystallization (Kamo 2014). In order to evaluate the presence of inherited and magmatic zircon populations, the sample was reprocessed using LA-ICP-MS (Davis 2016). Monazite was examined as well as zircon. Ages from monazite and zircon grains gave ages

of 1200 ± 5 Ma and 1192 ± 8 Ma, respectively. Both ages overlap within error and are interpreted to reflect the crystallization age of the dike. Spot analyses on zircon cores confirmed the presence of Archean and Mesoproterozoic inheritance. Analyses performed on the rims of monazite grains showed a clear Grenvillian orogenic overprint. These monazite and zircon ages are comparable to the age of a migmatitic mafic gneiss in the Admaston map area (1187 ± 2.4 Ma, U/Pb on zircon by LA-ICP-MS; Geospec Consultants 2013; Duguet, Magnus and Ratcliffe 2014a), and the age of 1190 ± 6 Ma reported for the Kennelly Lake diorite (Davis 2016). These ages, along with field relationships, establish clearly that the earlier tectonic event was coeval with partial melting of the supracrustal rocks and calc-alkalic plutonism (*see* “Plutonic Rocks”), and that both are related to the early phases of the Shawinigan Orogeny (*see* Figure 9). It also confirms that the regional foliation in the Black Donald domain and parts of Mazinaw domain was acquired at this time and possibly earlier.

The F_1 folding event and the top-to-the-southwest shearing are refolded by a second major tectonic event. In the Admaston and northwestern Mud Lake map areas (*see* Figures 5 and 4, respectively; *see* Chart-Figure A-4), this tectonic event is characterized by northeast-trending, northwest-directed overturned to inclined F_2 folds, which, when observed at map scale, clearly reworked earlier structures. In contrast to the F_1 folding and the D_1 shearing events, which appear to be diachronous, the F_2 folds are associated with a second generation of thrust faults with consistent top-to-the-northwest shearing. Mylonitic foliation related to this event bear a southeast-plunging composite stretching and mineral lineation that is particularly dominant in the western two thirds of the Admaston map area (Duguet, Magnus and Ratcliffe 2014a).

At the contact between the Bancroft terrane and the Black Donald domain in the southwestern part of the Admaston map area, this event was coeval with felsic plutonism, which included the emplacement of coarse-grained to pegmatitic, porphyritic (alkali-feldspar-phyric), white to pink syenogranite to monzogranite. These granitoid rocks were emplaced as small laccoliths and sills near or into the thrust shear zone plane and were strongly deformed during their crystallization. Numerous shear criteria from these intrusions gave a consistent top-to-the-northwest shear sense (Photo 1). In places, mylonitic foliation is characterized in the field by the alternation of monomineralic bands composed of varied proportions of alkali-feldspar and quartz. This texture indicates that this fabric was likely acquired at the suprasolidus stage when the granitoid rocks were emplaced parallel to the main deformational fabric. One of these granitoids was sampled for geochronology. The sample was an intensely strained porphyroclastic mylonitic granite, indicating that the fabric was acquired during its crystallization. Conspicuous shear criteria gave a top-to-the-northwest shear sense (Duguet, Magnus and Ratcliffe 2012). Zircons extracted from this sample yielded an upper intercept age of 1135 ± 3 Ma (U/Pb ID-TIMS, Kamo 2013), which is interpreted as the crystallization age. Two fractions of titanite from the same sample yielded $^{206}\text{Pb}/^{238}\text{U}$ ages of 1115 ± 3 Ma and 1070 ± 2 Ma (Kamo 2013).

In the north-central part of the Mud Lake map area, F_2 folds display a different geometry, one that is characterized by an upright axial plan. In that area, a synform–antiform pair prominent in the second vertical derivative of the residual magnetic field (Ontario Geological Survey 2014h-m) refolds an early tectonic contact superimposing units from the western Mazinaw domain upon units of the Black Donald domain (*see* Chart-Figure A-3; Duguet, Dubé-Bourgeois and Ma 2013). The synform portion of this remarkable structure was previously recognized by Quinn, Wilson and Leech (1956) and Lumbers (1982c).

In the Black Donald Lake map area, F_2 folds also trend northeast, but display a contrasted vergence to those in the Mud Lake map area. To the northwest in the Black Donald domain, the F_2 folds are directed northwest, whereas they are directed southeast at the contact, in the southeast, between the Black Donald domain and the Mazinaw domain *sensu lato*. This southeast vergence remains constant farther south and west into the Centennial Lake map area. On the other hand, farther north in the Mud Lake and Admaston map areas, structures at the eastern contact between the Mazinaw domain and the Black Donald domain adopt an overall northwest-directed vergence. This change of polarity of the structures along strike could result in several ways, some involving inheriting the shape of the footwall geometry, which would constrain the geometry of newly created structures. Herein, a two-step process is favoured, in which the change of polarity from southeast-directed to northwest-directed is the result of a later deformational event. In this scenario, the southeast-directed structures would be primary and coeval with the D_2 shearing and folding event. The later deformation is responsible for the change of polarity to the northwest along strike as described in “Ross fault”. In the Black Donald Lake map area, most of the F_2 folds display a double plunge, either to the northeast on their northeastern periclinal termination or to the southwest on their southwestern periclinal closures. As mentioned in the previous description of F_1 folding, these F_2 folds are responsible for a type 3 fold interference pattern (Ramsay 1967) in the Black Donald Lake map area. Two megascopic folds, the Little Green Lake synform to the northwest and the McCreary Lake antiform to the southeast, are good examples of this F_2 folding (*see* Figure 3; *see* Chart-Figure A-3).



Photo 1. Shear bands in a synkinematic potassium feldspar porphyritic syenogranite give a top-to-the-northwest shear sense (vertical surface). Stylus is 96 mm long. Admaston map area. UTM 347401E 5029067N (NAD83, Zone 18).

OTTAWAN OROGENY (1090–990 Ma)

Ross Fault

In the southern part of the field trip area, in the Admaston, Mud Lake and Black Donald Lake map areas in particular, the Mazinaw domain is separated from the Black Donald domain to the west by a major tectonic boundary first described by Easton (2013) and Duguet, Whitney and Ma (2014). This tectonic boundary was initially named the Ross fault in the Cobden map area (Easton 2013), and a complex shear zone in the Black Donald Lake map area was termed the western Madawaska shear zone. It is now recognized that these 2 structures are likely part of the same fault system; consequently, herein only the term Ross fault will be used to discuss this complex structure.

The Ross fault can be traced over 55 km from the Ottawa River (Cobden map area) in the north to the Black Donald Lake map area in the south. In the Cobden map area, the Ross fault trends almost due north and dips shallowly to the east.

This structural pattern stays consistent along strike in the Admaston–Horton, Mud Lake and Black Donald Lake map areas. The Ross fault forms a prominent lineament on both the total magnetic field and second vertical derivative of the residual magnetic field maps of the area (Ontario Geological Survey 2014h-m). In the Cobden map area, the area west of the fault is characterized by a higher magnetic background in the total field, and by prominent northwest-trending linear features in the first vertical derivative magnetic data. In contrast, the area east of the fault is characterized by a lower total magnetic signature and minimal internal magnetic structure, consistent with the abundance of marbles with low magnetic susceptibility (typically $<0.5 \times 10^{-3}$ SI units) east of the fault (Easton 2013).

The Ross fault also marks a change in the Bouguer gravity field (Ontario Geological Survey 1999), with the area east of the fault having higher gravity values than the area to the west. Similarly, in the first vertical derivative of the Bouguer gravity field, a northeast-trending gravity high, noted by Easton, Duguet and Magnus (2011) and which corresponds to anomaly 24 in Dufréchoy and Harris (2013), is truncated against the Ross fault north of Foresters Falls. Also, the Ross fault is located near or parallel to a large north-trending gravity lineament identified by Dufréchoy and Harris (2013, their Figure 7). Thus, the Ross fault is both a significant geological and geophysical feature. The extension of the Ross fault to the south into the Admaston map area can be still followed on the second vertical derivative of the total magnetic field (Ontario Geological Survey 2014h-m). There, the geophysical signature gets blurred and difficult to interpret. Moreover, the position of the northern Ross fault does not match along strike with its southern counterpart, located a couple of kilometres to the east.

Cross sections drawn for the Admaston and Mud Lake map areas provide some insight on this apparent contradiction. In the Admaston map area (*see* Chart-Figure A-4), the Ross fault is actually represented by D₁ thrust reworked by a D₂ top-to-the-northwest thrusting event. On the other hand, in the Mud Lake and Black Donald Lake map areas (*see* Chart-Figures A-3 and A-2, respectively, back pocket), the Ross fault is better described as an out-of-sequence thrust affecting units belonging to the Mazinaw domain both in the footwall and the hanging wall. Both structures merge in the Mud Lake map area where the latter out-of-sequence thrust clearly reworked the previous polyphase D₁ and D₂ Ross fault seen in the Admaston map area. These contrasted features strongly supports that the Ross fault is better described as a polyphase array of shear zone.

In the Admaston–Horton and Mud Lake map areas, the main north-striking foliation along the Ross fault contains a composite stretching and mineral lineation with an average orientation of 10° and with a shallow plunge to the northeast. These lineation trajectories suggest a significant amount of strike-parallel displacement along to the Ross fault. In the Mud Lake map area, sporadic sinistral shear senses were described in mylonitic gabbroic sills (Duguet, Dubé-Bourgeois and Ma 2013). Conversely, in the

southern Mud Lake and the Black Donald Lake map areas, numerous stretching lineations are oriented between 35 and 50° and show a much steeper plunge to the northeast. In sections perpendicular to the foliation and parallel to the lineation, rare top-to-the-southwest shear criteria were found, mostly in Ottawa pegmatitic sills. These lineations are particularly well represented in the highly deformed Elbow Lake anorthosite (*see* Duguet, Whitney and Ma 2014).

It is difficult to reconcile the 2 sets of lineation with a single deformation event. This interpretation is strengthened by the fact that the foliation bearing the steeply plunging lineation is clearly of second generation (*see* Duguet, Whitney and Ma 2014). In the Black Donald Lake map area, shear criteria along the Ross fault are rare and inconclusive. This is partly the result of the lack of good marker units, as most of the rocks along the fault are marbles, amphibolites or anorthosite. However, the structures (i.e., foliation and lineation) described in this paragraph suggest a polyphase structural history for the Ross fault. It is also likely that at least one of the events associated with the northeast-plunging (50°) lineation was a top-to-the-southwest thrusting event (“top” is used here in its structural sense, not stratigraphic).

The southern termination of the Ross fault was found in the Black Donald Lake map area. In the southwestern corner of the Black Donald Lake map area, as the contact with the Ross fault is approached, map units with D₁ and D₂ southeastern-directed structures are progressively overturned to the northwest. The change in geometry also affects foliation trajectories and F₁ and F₂ fold axes, which are rotated from southwest trending in the southeastern part of the Black Donald Lake map area to north trending at the contact with the Ross fault. This change in vergence is well illustrated in the interpretative cross section for the Black Donald Lake map area (*see* Chart-Figure A-2; Duguet, Ma and Whitney 2017). This northwest vergence remains constant along strike when heading northward into the Mud Lake, Admaston–Horton and Cobden map areas. Thus, the Ross fault can be clearly described as a D₃ structure since it reworks earlier structures related to the Shawinigan Orogeny.

Numerous northeast- to north-trending upright to northwest-directed folds in the respective map areas have been interpreted as being coeval with this D₃ motion along the Ross fault. In the Black Donald map area, because of their similar geometry and orientation, these F₃ folds are barely distinguishable in the field from their F₂ counterparts. Only where these F₃ folds are in close proximity to the Ross fault could clear overprinting and geometrical relationships be established. Such north-trending upright to west-directed F₃ folds were described in the southeastern Mud Lake map area where they affected previously mylonitized Methuen intrusive suite granites present in the hanging wall (Duguet, Dubé-Bourgeois and Ma 2016) (*see* Chart-Figure A-3). In addition, different geometries and clear overprinting relationships made it possible to assign some northeast- to east-trending upright folds in the southwestern Admaston map area near Constant Lake (*see* Figure 5) to the F₃ folding event. There, F₃ folds overprint a D₂ top-to-the-northwest thrust fault.

In the Black Donald Lake map area, the map pattern also shows that the Ross fault was subjected to a younger folding event (Duguet, Ma and Whitney 2017). This folding event (F₄) is characterized by northeast-trending upright to northwest-directed folds, of which the best example is a synform–antiform pair located between the McCreary Lake antiform and the Bartraw dome (*see* Chart-Figure A-2).

Elsewhere, these structural features are nearly identical in orientation and style to those described for both F₂ and F₃ folds, and only the late D₃ Ross fault made it possible to assign this folding event to a D₄ event. Therefore, the map units of the Bartraw dome constitute a structural window with a lower and older unit. This interpretation is in accordance with the older age of *circa* 1285 Ma obtained from the migmatitic tonalite (unit 17gh) exposed within this window. Moreover, it should be noted that the term “dome” refers here to the ellipsoidal and elongated shape of the structure. This morphology results from a rather complicated interference pattern resulting from several folding events (likely up to 4). Whichever hypothesis is considered for the structural features present in the Bartraw dome, they all involved multistage folding. For that reason, migmatitic doming (e.g., metamorphic core complex) or a single-stage structural antiform were ruled out as possible mechanisms of formation of the Bartraw dome.

Late Strike-Slip Tectonism

The upper Mazinaw domain in the Horton map area underwent a major sinistral strike-slip deformational event that was responsible for the formation of shear zones associated with northeast-trending upright to northwest-verging folds in the area (Easton, Duguet and Magnus 2011). This strike-slip event is coeval with the emplacement of pegmatitic syenite and syenogranite bodies (Easton, Duguet and Magnus 2011). For example, on the north side of the Hurds Lake tonalite in the Horton map area, a northeast-trending sinistral shear zone separates a carbonate-dominated eastern domain from a plutonic and siliciclastic-dominated western domain. This shear zone continues farther south into the Admaston map area where its orientation becomes subparallel (northerly) to the Ross fault. The shear sense criteria along this shear zone in the Admaston map area gives a consistent sinistral southeast-side-up shear sense that is particularly well developed in the mica schists of the Flinton Group (stop 14). Several second-order sinistral shear zones are also present to the northwest in the western part of Horton map area.

Considering the maximum age of Flinton Group deposition is bracketed between 1157 Ma (Sager-Kinsman and Parrish 1993) and 1131 Ma (Geospec Consultants 2012), this strike-slip event is likely related to the Ottawa Orogeny. Metamorphic conditions were estimated on Flinton Group samples from the Horton map area, using the average P - T mode in Thermo-Calc Software, at 660°C and between 6.3 and 7.4 kilobars (Campbell 2013). These pressure-temperature (P - T) estimates are lower than those calculated for the Shawinigan D₁ top-to-the-southwest thrusting event. Because the mineralogical assemblages are synkinematic, these pressure-temperature conditions likely reflect the conditions when the sinistral shearing occurred. It should be noted also that these pressure-temperature conditions fall in the range of those obtained by McCarron (2013) for Flinton Group rocks farther south in the Mazinaw domain.

On the other hand, sinistral strike-slip shear criteria become rare heading south along the Ross fault. Because of their very close proximity in the Horton map area, originally it had been assumed that this sinistral event might have been one of the major episodes of movement along the Ross fault. Despite a lack of good deformation markers to the south, mostly because of the nature of the rocks there, one would have expected, nonetheless, to find a greater number of these sinistral shear criteria along the Ross fault. Instead, more sinistral shear criteria were found farther west in the Mud Lake map area near the antiform centred on the Mount St. Patrick village (*see* Figure 4). Although one can argue that these sinistral movements might be partly related to the Shawinigan top-to-the-southwest shearing described earlier, this hypothesis cannot entirely account for some field observations. A significant portion of shear criteria observed in this area seems consistently sinistral from one flank to another of the antiform, which suggests that they were unaffected by the folding and, hence, postdated the folding.

Sinistral shear criteria are composed mostly of late oblique shear bands and asymmetric Grenvillian pegmatitic boudins. In some outcrops, this sinistral event overprints clearly an earlier dextral shearing. Examination of the second vertical derivative of the residual magnetic field (Ontario Geological Survey 2014h-m) also displays a clear northeast-trending discontinuity offsetting locally the high magnetic anomalies and crosscutting the antiform (*see* Duguet, Dubé-Bourgeois and Ma 2016). Along with field evidence, this discontinuity corroborates the hypothesis of a late shear zone in this sector. The geophysical expression of this shear zone is lost close to the Mount St. Patrick fault. Thus, the sinistral strike-slip event in the area is related to a northeast-trending shear zone that crosscuts both the Black Donald and the Mazinaw domains. It is likely the expression of a late intra-orogenic deformation event in an already well-structured nappe stack. Although Grenvillian in age and coeval with pegmatite plutonism, the relationships with the Ross fault remains unresolved.

The Horton and Admaston map areas also underwent another Ottawa ductile deformation event that, until now, has either been disregarded or unidentified. Northwest-trending shear zones are associated with this event in the field. If such structures were identified in previous mapping of the area (Lumbers

1982b, 1982c), then they were interpreted as resulting from Paleozoic faulting associated with the Ottawa–Bonnechere graben. Our field investigations, however, have shed new light on the nature and the age of this ductile deformation event.

In the north part of Horton map area, on a map scale, all of the northeast-trending structures are consistently transposed into a northwest trend (*see* Figure 5). This is particularly evident just south of Renfrew, where structures were bent clockwise as much as 90° from their initial orientation. North of Renfrew, however, the regional structures once again exhibit a regional northeast trend. Along Highway 17, localized northwest-trending shear zones that dip steeply to the northeast crosscut the earlier regional fabric (Duguet, Magnus and Ratcliffe 2012; Liu, Lin and Duguet 2013). Within the shear zone on Highway 17 at stop 17, asymmetric boudinage of pegmatite veins gives a dextral shear sense consistent with the clockwise rotation of the structures on a map-scale view. These pegmatite veins are clearly synkinematic with respect to this event because they show little to no internal plastic deformation (Liu, Lin and Duguet 2013). All of these observations cast doubt on these structures being active only during the Paleozoic. Rather, as discussed in greater detail by Liu, Lin and Duguet (2013), it is likely that these shear zones were contemporaneous with the Ottawa Orogeny and developed roughly perpendicular to the trend of the belt.

Another shear zone, the Mount St. Patrick fault, similar in orientation and kinematics to that present on Highway 17, transects the Mud Lake map area and continues to the northwest into the Brudenell map area (Easton 2012). This fault is a major topographic feature with a down-drop of several of hundred metres on its northeastern side. The Mount St. Patrick fault is also associated with second-order faults throughout the area. Some of these faults clearly influenced the deposition of Paleozoic limestone in the region, and these faults typically have been interpreted as coeval with the opening of the Ottawa–Bonnechere graben at *circa* 590 Ma. This association is conspicuous along Renfrew County road 508 just northeast of Calabogie Lake, where Paleozoic limestone is in direct contact with Grenville Supergroup rocks, separated only by a sliver of fault gouge. More evidence is found in the Brudenell area as well as at Lake Clear, where a small limestone basin is present in the hanging wall of the Mount St. Patrick fault (Lumbers 1982b, 1982c; Easton 2012). However, the history of some of these faults might have started much earlier than the Paleozoic (*cf.* Easton 2012). Traces of ductile deformation near the main fault of this set, going through Calabogie Lake and up to the northeast edge of the Mount St. Patrick syenite, have been found in the Mud Lake map area. Near this fault, mylonitic foliation is reworked by drag folds, giving a dextral sense of shear. Similar kinematic criteria are also found on the southern edge of the Mount St. Patrick syenite and may be coeval with this event (Duguet, Dubé-Bourgeois and Ma 2013). On a map scale, the regional fabrics near this major structure are bent counterclockwise into a northwest trend (*see* Figures 4 and 11).

Further studies are needed in order to decipher the relative timing between the late ductile deformational event and the sinistral strike-slip deformation event. Such structures cutting at high angle the general trend of the earlier structures are observed in younger orogens, such as the Himalayas, where they have been recently described and discussed (*cf.* Rivers 2012). Even though the dextral shearing seems to rework the sinistral one, the geometrical relationship is similar to either a S-C system or, more likely, to a conjugate set. The synkinematic pegmatitic plutonism shared by both make the hypothesis that they operated in unison is a very credible idea that deserves to be pursued further.

DISCUSSION

Structural analyses coupled with geochronology show that the units of the Black Donald domain were thrust upon the Mazinaw domain sometime after 1190 Ma (age of a major plutonic and tectonometamorphic event) and very likely before 1167 Ma (age of the synkinematic syenite-monzonite plutons) (*see* Appendix-Table 1-4).

The structural relationships and kinematics associated with this D₁ event remains for the moment highly speculative. The thrusting of the western Mazinaw domain upon the Black Donald domain occurred prior to 1167 Ma and possibly during the subsequent top-to-the-southwest event. The D₂ event was synchronous with plutonism and took place no later than 1135 Ma. Most of the prominent structural features, such as the fold-and-thrust belt and the fan-like geometry of these units, were likely acquired at that time. Despite some differences, the Black Donald domain shares far more similarities (e.g., type and age of metamorphism, age of plutonism, structural history, etc.) with the Sharbot Lake domain and the Frontenac terrane than with most of the domains in the Elzevir terrane. Nonetheless, the Black Donald domain has distinctive features (e.g., chemistry of the felsic plutonism), which make it difficult to directly correlate the Black Donald domain with similar domains and/or terranes in the Central Metasedimentary Belt.

This short discussion on domain boundaries would be incomplete without addressing briefly the possible regional significance of the Ross fault. As a major structure more than 50 km in length, it obviously had a significant impact on the tectonic history of the Mazinaw domain. It may be noteworthy that Flinton Group rocks present in the Horton map area are exposed in the hanging wall of this structural discontinuity (Duguet, Magnus and Ratcliffe 2014a, 2014b). As described in earlier sections, the Ross fault is a polyphase structure with a different history in the Cobden and Admaston–Horton map areas as compared to the Black Donald Lake map area. In the Admaston–Horton map area, the main event is characterized by sinistral top-to-the-northeast shearing. This tectonic episode has not been recognized in the Mud Lake map area (Duguet, Dubé-Bourgeois and Ma 2013) and has not been found to date in the Black Donald Lake map area. In the Black Donald Lake map area, the dominant shearing event is a top-to-the-southwest event. The youngest rocks of the Mazinaw domain, the Flinton Group (maximum age of deposition *circa* 1130 Ma: Duguet, Magnus and Ratcliffe 2014b), are widely affected by the sinistral top-to-the-northeast shearing. It is very likely that this event is related to the Ottawa orogeny, whereas the top-to-the-southwest shearing does not seem to be younger than *circa* 1169 Ma (Shawinigan Orogeny).

The relationship of the Ross fault with the previously established domain boundaries is also highly complex. The Ross fault does not always match the location of the presumed domain boundaries. For example, the Ross fault crosscuts rock units in the Mazinaw domain in the Admaston–Horton map area and in the southern Black Donald Lake map area, but, in the southern Mud Lake map area, the Ross fault juxtaposes rocks units of the Mazinaw domain to the east with those of the Black Donald domain to the west. However, this complexity may only be superficial because Mazinaw domain rock units in the footwall of the Ross fault in the Admaston and Mud Lake map areas could be interpreted as thrust slices of Mazinaw domain rocks beneath the thrust plane. Using recently acquired aeromagnetic data (total field, first and second vertical derivative: Ontario Geological Survey 2014a, 2014h-m), the Ross fault is coincident with a conspicuous linear magnetic high that extends from the Cobden map area south to the Black Donald Lake map area. This geophysical lineament is only locally interrupted or blurred by more complex geology, most notably in the Admaston map area. In the Cobden map area, the Ross fault also coincides with the boundary between a Bouguer gravity high east of the fault (Easton 2013). A similar relationship is seen again in the Admaston–Horton, the Mud Lake and the Black Donald Lake map areas. In summary, the Ross fault displays many of the features that we can expect to find associated with a domain and/or terrane boundary. To fully understand its regional significance, additional work is warranted.

ROAD LOGS

Note: Caution should be taken when parking vehicles on the shoulders of the highways and when examining outcrops located along the field trip route. All UTM co-ordinates are provided in NAD83, Zone 18.

DAY 1. MAZINAW AND BLACK DONALD DOMAINS

Start at the junction of Highway 41 and Matawatchwan Road (Renfrew County 71) on the west side of the bridge on Highway 41 on the west side of Griffith. Turn onto Matawatchwan Road and head south.

Pull off onto the shoulder of Matawatchwan Road by long roadcut (UTM 330366E 5008314N). Mazinaw domain, map units 17a and 20 (*see* Table 3).

Stop 1. Griffith batholith, Mazinaw domain

The outcrop is located on the east side of the Griffith batholith as defined by Lumbers (1982b), which crops out in both the Brudenell and Centennial Lake map areas. The Griffith batholith occupies the core of a north-trending, 20 km long, antiformal structure. In contrast to previous work, our mapping has shown that the Griffith batholith in the Centennial Lake map area consists of only 40 to 50% tonalitic rocks, with the remainder being granitic rocks of the Methuen intrusive suite (Duguet, Duparc and Mayer 2015). Because of the abundance of Methuen intrusive suite granitoids and neighbouring supracrustal rocks similar in composition to those present in the Mazinaw domain, this antiformal structure was provisionally assigned to the Mazinaw domain. Nonetheless, it must be borne in mind that Methuen intrusive suite granitoids occur in other domains in the Central Metasedimentary Belt, thus, further work is needed to confirm assignment to the Mazinaw domain.

Most of the outcrop is an equigranular, medium-grained, light grey metatextitic tonalite. The tonalite is interlayered with an equigranular, fine- to medium-grained, melanocratic gneissic gabbro. Field relationships suggest that the gabbro intruded the tonalite. Some granodioritic to monzogranitic veins emplaced locally in tension gashes crosscut both the tonalite and the gabbro. Two geochronology samples were collected from this outcrop. The tonalite yielded an emplacement age of 1245 ± 5 Ma (U/Pb zircon, LA-ICP-MS, Davis 2016). A metamorphic overprint was also identified at 1158 ± 26 Ma (U/Pb zircon, LA-ICP-MS, Davis 2016). The gabbro yielded an age of 1157 ± 7 Ma, which was interpreted as a metamorphic age (U/Pb zircon, ID-TIMS, Kamo 2016).

Return to vehicles and continue south. Drive to junction of Matawatchwan Road and Centennial Lake Road (Renfrew County Road 65). Turn left onto Centennial Lake Road heading east-southeast.

Pull off onto the shoulder of Centennial Lake Road (UTM 336358E-5004002N). Black Donald domain, map unit 10, and possibly units 13 and 20 (*see* Table 3).

Stop 2. Migmatitic amphibolite and marble, Black Donald domain

The roadcuts on both sides of the road average of 2 m high and are approximately 80 m long. This stop is located at the contact between 2 lithostructural map units of the Black Donald domain. The roadcut is composed mainly of an intensely deformed, metatextitic, sequence of well-layered amphibolites, some of which are calcareous. To the east, these gneisses are in contact with calcite marble, where skarn alteration is present. The northeast-trending, near-vertical foliation, contains a mineral lineation that dips shallowly to the northeast. The protolith of the amphibolite is ambiguous. Near the eastern edge of the outcrop is a unit of massive, medium- to coarse-grained, porphyritic mafic gneiss that was likely derived from boudinaged of mafic sills. However, elsewhere in the outcrop, some of the amphibolites contain compositional layering that is not reconcilable solely with a intrusive origin.

Garnet is a peritectic phase of the partial melting and is ubiquitous throughout the outcrop in both amphibolites and coarser grained mafic rocks interpreted as sills. The mafic gneisses are intruded by synkinematic felsic sills composed of porphyritic granite in which sinistral shear criteria were observed. These shear criteria are tentatively assigned to an early Shawinigan orogenic event at *circa* 1190 Ma.

Return to vehicles. Continue and then pull off onto the shoulder of Centennial Lake Road east of Centennial Lake Bridge (UTM 337300E 5004741N). Black Donald domain, map units 11 and 13 (*see* Table 3).

Stop 3. Interlayered marble and calc-silicate rocks, Black Donald domain

This 200 m long exposure is one of the few locations where the interlayering between marble and calc-silicate rocks of the Black Donald domain, as well as the abrupt stratigraphic transition between the underlying calc-silicate unit and the overlying calcite marble, can be observed. It is located on the western flank of a 20 km long synform that trends to the northeast (*see* Figure 3). The outcrop on the northwestern side of the road is composed dominantly of calc-silicate rocks interbedded with the occasional marble layers. A pegmatite sill and a pegmatite dike crosscut the main fabric and are undeformed. The outcrop on the southeastern side reverses this pattern, with calcite marble becoming dominant compared to the calc-silicate rock. Two Z-folds, up to 10 m in size, are visible on each side of the road. A third fold is likely present in between the 2 sides of the road along the trace of the roadbed. The average axial plane of these folds is oriented 245° and dips 35° to the northwest. The average axis plunges shallowly (between 5 and 10°) to the northeast. It is unclear whether these folds are first- or second-generation folds.

Return to vehicles. Continue and then pull off onto the shoulder of Centennial Lake Road (UTM 341369E 5006177N). Black Donald domain, map units 11 and 10 (*see* Table 3).

Stop 4. Marble, calc-silicate rocks and mafic intrusions, Black Donald domain

This 170 m long road section is located on the eastern flank of the regional fold structure noted in stop 3. The section is composed mostly of medium- to coarse-grained, nearly pure calcite marble and minor calc-silicate rocks that were intruded by at least 2 generations of mafic intrusions. The first generation of mafic intrusive rock is characterized by fine- to medium-grained, medium to dark bluish-grey amphibolite. They are mostly sills emplaced parallel to the main layering in the marbles. The larger sills are strongly and asymmetrically boudinaged (Photo 2), whereas the smaller ones are stretched and/or disrupted along the

main fabric to form isolated pods in the marbles (Photo 3). These amphibolitic sills are also locally garnet bearing, with the garnets being partially or totally retrogressed. A second generation of mafic intrusive rock crosscuts both the marbles and the first-generation mafic sills. An example of this second-generation mafic intrusive rock can be observed on both sides of the road and is a dike ranging in thickness from 5 to 100 cm (Photo 4). This dike is very fine grained, is similar in colour to the mafic sills, and displays locally a weak foliation.

In terms of structure, the road section is characterized by a northeast-trending foliation shallowly dipping to the southeast at an average of 30°. Boudinage is responsible for the observed dip variation along the outcrop, which can range between 10 and 55°. Folding is present also in the marbles. It is characterized by S- and M-folds on a scale of tens of centimetres. The axial plane of the folds trends to the northwest and dips 25 to 30° to the southeast. The apparent vergence of the folds in this outcrop is opposite to that observed previously at stop 3.

Return to vehicles. Continue and then pull off onto the shoulder of Centennial Lake Road (UTM 346239E 5009714N).

Black Donald domain, unit 13 (*see* Table 3).

NOTE: The section is on both sides of the road and is located on a long curve sloping down with low visibility. Pay extreme attention to the oncoming traffic.



Photo 2. Strongly boudinaged mafic sills within well-layered calcite marble at Stop 4. No scale. View to the southeast.



Photo 3. Isolated pods of amphibolite in a weathered, nearly pure white calcite marble at Stop 4. These pods likely resulted from the tectonic dismantlement of a mafic sill and/or dike. No scale. View to the southwest.



Photo 4. Stop 4. Outcrop view illustrating amphibolite boudins in marble that are crosscut by a younger mafic dike. No scale. View to the north.

Table 4. Whole-rock chemistry of the different rock types present at stop 5 (all values are in weight %).

Sample Number	Description	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI
13MD-170A	Massive, porphyro-lepidogranoblastic, fine-grained, dark greenish grey intermediate gneiss (melanosome)	49.02	0.55	18.54	11.30	0.16	8.03	5.68	3.10	2.38	0.05	1.00
13MD-172A	Massive, porphyro-lepidogranoblastic, fine-grained, dark greenish grey intermediate gneiss (melanosome)	55.99	0.78	16.36	10.53	0.08	6.03	4.76	2.14	2.48	0.23	0.69
13MD-172A1	Well-foliated, nemato-lepidonematoblastic, light grey green intermediate gneiss (melanosome)	59.89	0.47	15.91	6.31	0.08	3.84	6.06	4.02	1.98	0.07	1.00
13MD-172A2	Weakly foliated, porphyro-lepidogranoblastic, mesocratic stromatic metatexite (melanosome) derived from a psammite	58.43	0.72	15.97	9.84	0.07	5.72	4.57	2.37	2.03	0.19	0.64

Stop 5. Metatexite and amphibolite, Black Donald domain

This nearly 160 m long, structurally and lithologically complex outcrop is composed of a sequence of interlayered, thin- to medium-layered, intermediate metatextitic gneisses and amphibolites. Both rock types show a wide variety of textures, facies and bulk compositions. For example, a patchy to stromatic metatextitic medium to dark grey mafic to intermediate gneiss encompasses massive to weakly foliated boudins composed of leucosome-poor, garnet-rich, dark grey mafic to intermediate gneiss (Photo 5). The metatextitic gneiss tends to be garnet free in contrast to the high amount of garnet (up to 35%) in the more massive gneiss. In thin section, the mineralogical assemblage of the massive gneiss is plagioclase + quartz + biotite + green hornblende + garnet and biotite + green hornblende + plagioclase + garnet + quartz (the minerals are presented in order of most to least abundant).

The outcrop in its entirety was affected by polyphase deformation. The migmatitic foliation trending to the northeast and dipping to the southeast is folded by asymmetric folds. The axial plane of these folds trends to 55° with an average dip of 55°. The fold axes plunge shallowly to the northeast between 5 and 10°. These folds can be difficult to spot in the more massive gneiss or those gneissic units lacking well-developed compositional layering. Nonetheless, at least 3 folds, 5 to 10 m in size and observed across this outcrop, caused a strong crenulation lineation. A late event overprinted all of these structures and is characterized by an anastomosed network of granitic veins that are locally sheared. These veins likely intruded along a plane of deformation and are delineated by boudins. This boudinage event is relatively flat lying and is distinct from the earlier developed boudins of garnet-rich massive gneiss because these anastomosed deformation planes crosscut them. The geodynamic significance of this late event is not well understood and is open to debate.

Whole-rock geochemistry confirms the lithological complexity of this outcrop. Of the 2 main rock types, the garnet-bearing massive amphibolite unit exhibits the widest range in chemical composition. The amphibolite unit tends to be richer in iron, magnesium, manganese and aluminum than the layered gneiss, with silica contents of 49 to 60 weight % (Table 4). Trace element chemistry is also quite varied, likely the result of the protolith composition and subsequent modification during the partial melting processes (Figure 10). Because of this complicated history, the nature of the protolith is uncertain. Nonetheless, a sedimentary origin (calc-silicate) is favoured.

From stop 5, continue east on Centennial Lake Road toward Calabogie. Turn left onto Ferguson Lake Road and continue for 2.3 km. Park on the shoulder of the road where it is safe to do so (UTM 355956 5016445N).

Black Donald domain, map units 9, 13, 27 and 29 (*see* Table 3).



Photo 5. Close-up of the massive facies at stop 5. This leucosome-poor, garnet-rich, dark grey mafic to intermediate gneiss is part of a weakly foliated boudin. The hammer is 40 cm long. View to the southwest.

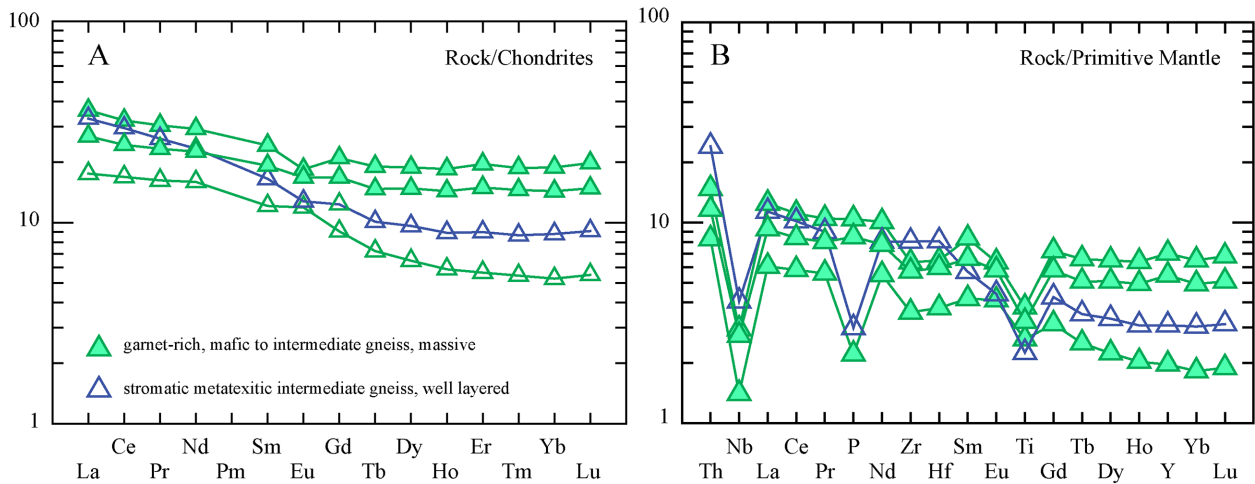


Figure 10. A) Chondrite-normalized rare earth element (REE) for the different rock types from the outcrop at stop 5. B) Extended incompatible element (spider) diagrams for selected rock types from the outcrop at stop 5. Normalizing factors of Sun and McDonough (1989) are used.

Stop 6. Metatexite and garnet leucosome veins, Black Donald domain

The relatively new roadcut (summer 2014) spans more than 260 m and consists of 2 main outcrop areas. Although still well within the Black Donald domain, this outcrop is closer to the boundary with the Mazinaw domain to the east. It is mainly composed of intermediate gneiss of tonalitic composition (grey, fine to medium grained, locally garnet bearing) that likely was derived from calcareous siliciclastic rocks that are locally interlayered with medium- to coarse-grained calcite marble. The gneisses were intruded by deformed garnet-bearing granite sills and veins that are interpreted as injected leucosomes. Texturally, these white granite veins are fine to medium grained and locally porphyroclastic (potassium feldspar phenocrysts). The garnets are part of the assemblage because they are automorphic, euhedral and randomly scattered in the veins. Some garnet porphyroblasts have tails of biotite that formed during recrystallization. These garnets are considered to be the peritectic product of the melting process that formed the leucosomes and were subsequently carried along with the melt. On the southern edge of the roadcut section, a pegmatite dike crosscuts the main foliation at high angle.

The calc-silicate unit overlies a blastomylonitic patchy to stromatic metatexite. The metatexite, metapelitic in composition, can be seen in a few places at the base of the outcrop. Unfortunately, the best exposure of this unit was removed when the road was reconstructed in 2014. Nonetheless, plenty of blocks of this unit are present downslope in the ditch. The neosome of this migmatite is mostly a strongly deformed medium bluish-grey melanosome interlayered with internally undeformed but boudinaged equigranular, fine-grained white leucosome (Photo 6). Within the melanosome, pre- to syn-kinematic blasts of garnet and sillimanite are abundant. Their size ranges anywhere between 0.2 and 3 cm. Garnet displays asymmetric recrystallization tails. Biotite-sillimanite shear bands and boudinaged leucosome are also common. Sillimanite tends to form pods elongated along the mylonitic foliation. This pelitic member is part of the lowermost unit described in the Black Donald domain (Duguet, Ma and Whitney 2017).

Key observations regarding the structural framework of the Black Donald domain in this part of the field trip area are present in both outcrops. The foliation in the first outcrop trends northeast and dips 55° to the southeast. This foliation contains a northeast-trending composite stretching and mineral lineation that is especially conspicuous in the garnet-bearing leucosome. Within these leucosomes, evidence of a non-coaxial deformation event is abundant. Asymmetric boudinage of these granitic veins and asymmetric recrystallization tails around potassium feldspar porphyroclasts give a consistent top-to-the-southwest shear sense. On the northern edge of the first outcrop, a northwest-verging metre-scale Z-fold is present (Photo 7). The second outcrop is located about 50 m northward along the road. It is lithologically identical to the first outcrop, but has structural differences. Here, the foliation is still northeast bearing, but is now near vertical. Shear criteria identical to those previously described give a sinistral sense of shear. This shear sense reversal from one outcrop to the other is interpreted to be the consequence of post-shear folding. This hypothesis is strengthened by the presence of the fold mentioned above (*see* Photo 7). If correct, the first outcrop would constitute the normal flank of the fold, whereas the second outcrop would be the inverted flank. This pattern has been found consistently in the course of mapping in the field trip area and is characteristic of the sequence of deformation events present in this part of the Black Donald domain.

Turn vehicles around, retrace route back to Centennial Lake Road and continue east toward Calabogie. Turn left on to Norton Road (Renfrew County Road 34). After 1.2 km, pull off and park on the shoulder of the road and proceed to the outcrop (UTM 361433E 5017514N). Since stop 6, the route has crossed the Ross fault and are now in the Mazinaw domain and from now on all the remaining stops of Day 1 are located within the Mazinaw domain, map unit 2 (*see* Table 3).

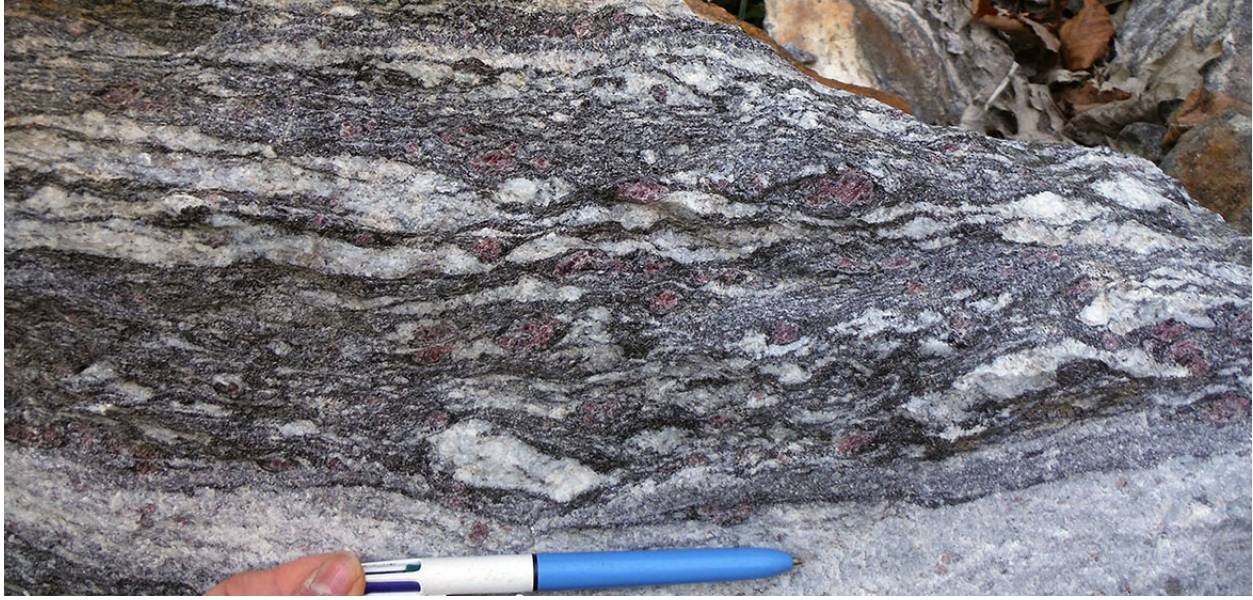


Photo 6. Stop 6. Photograph of a block of the lowermost unit (metapelite) showing textural relationships between partial melting and deformation. Note that the melanosome displays evidences of shearing. The leucosomes are also asymmetrically boudinaged, but internally free of deformation. Pen is 14 cm long.



Photo 7. Stop 6. Metre-scale Z-fold refolding an earlier foliation. View to the southwest.

Stop 7. Mafic fragmental rock and amphibolite, Mazinaw domain

The outcrop can be subdivided into 2 rock types: a fragmental mafic unit composed of strongly stretched epidote-plagioclase pods overlies massive dark grey to black amphibolites. The uppermost fragmental unit is interpreted as a strongly deformed flow-top or pillow breccia of a mafic flow. This outcrop constitutes the only clear evidence in the field trip area of the volcanic nature of these amphibolites. This outcrop is also rare in that it provides a perfect three-dimensional view of the ellipsoid of deformation. Also, it illustrates perfectly the partitioning of deformation between 2 units of different competency and rheology: the rheologically weakest unit (uppermost fragmental unit) is the most deformed. Examination of the 3 sections (roughly parallel to the Z–Y, X–Z and Y–X planes of the ellipsoid of deformation) on the outcrop indicates that the fragmental unit was deformed under a constrictional regime (Photos 8 and 9). On the top of the outcrop, the composite mineral and stretching lineation is shallowly plunging to the northeast, which is parallel to the average stretching lineation in the field trip area. It is likely related to the top-to-the-southwest trusting of the Ross fault.

Based on chemistry, the lowermost massive mafic gneisses have been assigned to the calc-alkaline Kashwakamak Formation of Mazinaw domain (Figure 11). The massive amphibolites display evidence of a late post-deformation alteration event that is characterized by presence of pods and veins. These pods and veins are composed of undeformed, coarse-grained, pink syenite. Quartz veins are also associated with this alteration event. In some places, these syenitic and quartz veins induced an alteration halo in the host rock resulting in pervasive crystallization of epidote and pyroxene (Photo 10).

Return to vehicles. Continue north on Norton Road (Renfrew County Road 34) for 800 m and park on the shoulder of the road (UTM 361103E 5017803N).
Mazinaw domain, map unit 4 (see Table 3).

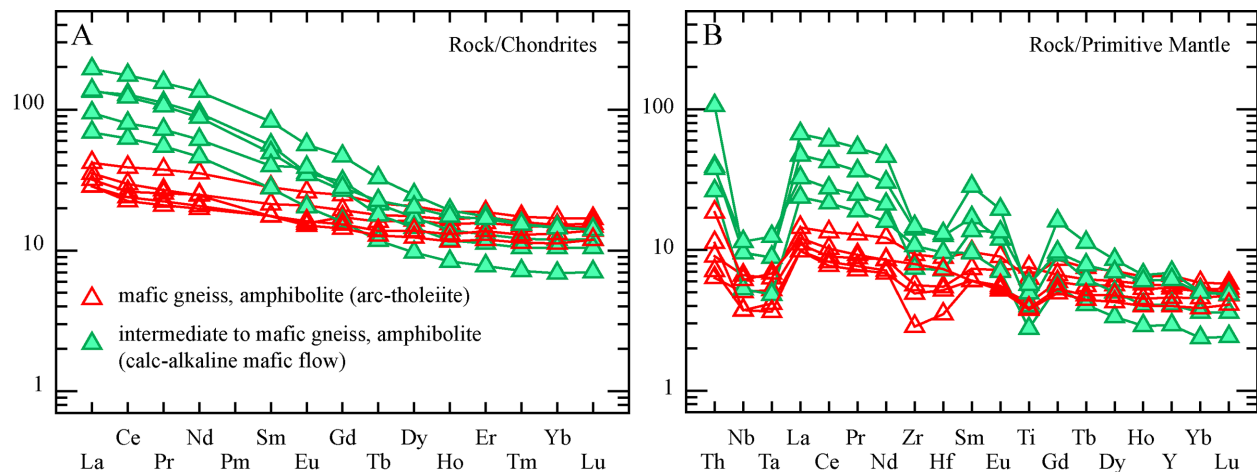


Figure 11. A) Chondrite-normalized rare earth element (REE) for the different lithological types of the Kashwakamak Formation, Mazinaw domain. The samples from stop 7 belong to the arc-tholeiite group. B) Extended incompatible element (spider) diagrams for the different lithological types of the Kashwakamak Formation, Mazinaw domain. Normalizing factors of Sun and McDonough (1989) are used.



Photo 8. Highly strained epidote pods interpreted as pillow selvages in mafic volcanic rocks at stop 7. Section X–Z of the ellipsoid of deformation. Hammer handle (upper left atop outcrop) is 40 cm long. View to the east.



Photo 9. Highly strained epidote pods interpreted as pillow selvages in mafic volcanic rocks at stop 7. Section Y–Z of the ellipsoid of deformation. View to the northeast.



Photo 10. Syenitic pod within amphibolite at stop 7. Note the greenish alteration halo in the host rock. The pen is 14 cm long. View to the east.

Stop 8. Amphibolite and felsite, Mazinaw domain

This outcrop exposes a sequence of amphibolite and minor interlayered pink felsic gneiss. These rocks are assigned to the bimodal Mazinaw Lake Formation (Ayer 1979; Easton 2006). The felsic gneisses show a wide range of textures. They can be fine grained, well layered and light grey or medium grained, gneissic and pink. The pink facies tends to be richer in silica than its grey counterpart and has a geochemical signature similar to that of Methuen intrusive suite granites. Both felsic facies show an unfractionated to slightly fractionated rare earth element profile (Figure 12) akin to F-III rhyolites (Leshner et al. 1986).

This outcrop displays similar structural characteristics to the previous stop. However, one difference is the presence of garnet-bearing blastomylonitic schists interlayered with amphibolites. These schists are thinly layered with alternating leucocratic and melanocratic layers. In thin section, the garnet-bearing schist is composed of alternating hornblende-rich and quartzofeldspathic layers. Garnet and biotite are ubiquitous throughout the entire thin section, with tourmaline and apatite as accessory phases. The garnet-bearing schists are interpreted to have resulted from the metamorphism of an altered mafic volcanic rock, possibly originally tuffaceous or volcanoclastic. The garnet porphyroblasts are elongated and boudinaged along the main elongation direction. Despite the strong deformation, shear criteria provide contradictory shear sense on the outcrop with a slight majority giving a top-to-the-northeast shearing. On the other hand, recrystallization tails around garnet blasts and pods are symmetric and indicate a strong coaxial component to the deformation. This shear sense is difficult to reconcile with regional events identified in the Horton map area and may be either the expression of the strong coaxial component of the deformation, or possibly a reverse flow within the shear zone.

Return to vehicles. Continue north on Norton Road (Renfrew County Road 34). At the junction of Norton and Whelan roads, turn right onto Whelan Road and head north. After 1.5 km, park on the shoulder of the road (UTM 358762E 5025791N). Mazinaw domain, map units 5, 20 and 21 (see Table 3).

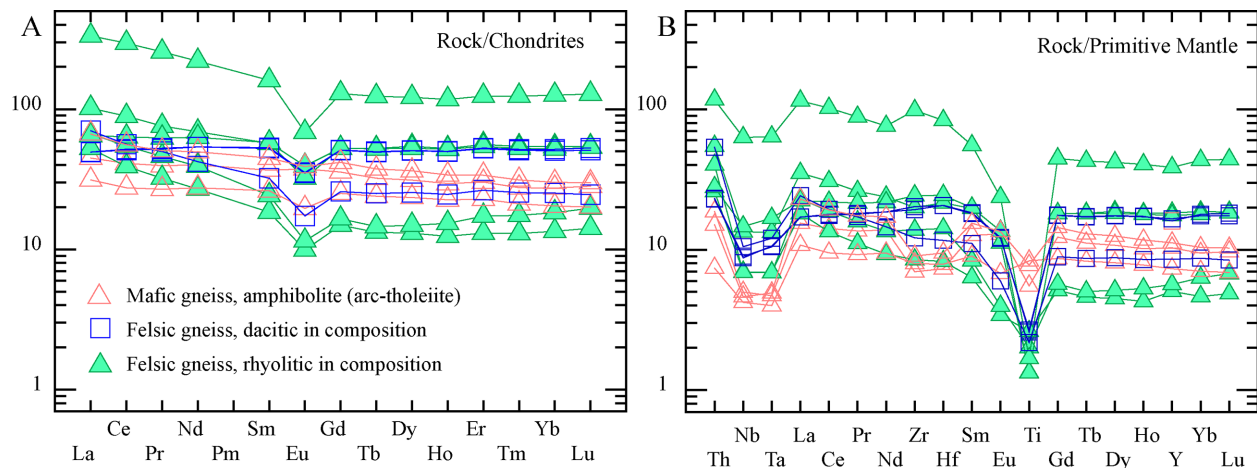


Figure 12. A) Chondrite-normalized rare earth element (REE) for the different lithological types of the Mazinaw Lake Formation, Mazinaw domain. B) Extended incompatible element (spider) diagrams for the different lithological types of the Mazinaw Lake Formation, Mazinaw domain. Normalizing factors of Sun and McDonough (1989) are used.

Stop 9. Refolded mylonites, Mazinaw domain

This outcrop is approximately 30 m long and is characterized by a refolded mylonitic package of interlayered calcite marble, amphibolite and tonalite sills. Metre-scale boudinage is also present.

900 m north of stop 9, an optional stop can be made to examine an amphibolite unit.

Continue north from stop 9 for 1.2 km on Whelan Road (Renfrew County Road 34). Park on the shoulder of the road (UTM 358565E 5026980N). Mazinaw domain, map units 5 and 21 (*see* Table 3).

Stop 10. Polyphase deformed mylonites, Mazinaw domain

This outcrop illustrates the polyphase deformation present in western Mazinaw domain. It is composed of a mylonitic package of interlayered calcite marble and tonalite sills refolded by west-verging folds. The axial plane of these D₂ folds trends to the northeast and dips from 45 to 50° to the southeast. The main foliation locally hosts a southeasterly plunging stretching lineation. On sections perpendicular to the foliation and the lineation, intrafolial isoclinal folds can be observed. Their axes are parallel to the stretching lineation. Some of these intrafolial folds could actually be sheath folds.

Return to vehicles. Continue north from stop 10 for 2.1 km on Whelan Road (Renfrew County Road 34). Park on the shoulder of the road (UTM 359103E 5028943N). Mazinaw domain, map unit 21 (*see* Table 3).

Stop 11. Deformed porphyritic granodiorite, Mazinaw domain

This outcrop, approximately 30 m long, features a mylonitic porphyritic granodiorite. This granodiorite has a U/Pb TIMS zircon age of 1210±9 Ma (Kamo 2013). Thus, it belongs to the same plutonic event as the Hurds Lake tonalite farther to the east. The granodiorite in this outcrop underwent polyphase deformation and at least 2 events can be seen in this outcrop. The first event was responsible for the development of the mylonitic foliation, which trends northeast and dips 40° to the southeast. This mylonitic foliation contains a stretching lineation that plunges to the southeast; the lineation is defined by elongated feldspar and quartz grains. The mylonitic foliation is sometimes not well defined and can be hard to spot, which is likely because of the constructional shape of the ellipsoid of deformation in this area. On sections parallel to the stretching lineation and perpendicular to the foliation, rare shear criteria can be observed and give a top-to-the-northwest sense of shear. A discrete second deformation event is characterized by a 30 cm wide dextral shear zone that crosscuts the previous fabric at a high angle. This shear zone trends southeast and dips 70° to the northeast.

END OF DAY 1 STOPS.

DAY 2. MAZINAW DOMAIN

Drive south of Renfrew along the Highway 132. Stop 12 is at UTM 365311E 503553N. Mazinaw domain, map unit 26 (*see* Table 3).

Stop 12. Potassium alteration zone

This outcrop and others nearby are part of a 12 km² high potassium anomaly located in the northwest corner of the Horton map area (Duguet, Magnus and Radcliffe 2014b; Ontario Geological Survey 2014n-s). The rocks in the area of the anomaly were previously mapped as syenite by Lumbers (1982b). Nonetheless, gamma-ray scintillometer measurements, initially reported by Easton, Duguet and Magnus (2011), and subsequent geochemical analyses indicate K₂O contents of up to 11.5 weight %, which is 2 to 3 weight % higher than the K₂O contents present even in even the most ultrapotassic syenite. Such high K₂O contents are more typical of alteration zones present in a wide variety of mineralized systems, including porphyry copper, iron oxide-copper-gold (IOCG), orogenic gold, and sedimentary-exhalative (SEDEX) systems.

The potassium alteration affects all rock types ranging from gabbro, granites of the Methuen intrusive suite and calc-silicate rocks, but can vary in intensity. It is usually characterized by an intense, texturally destructive replacement of the protolith resulting in light to medium pink fresh surfaces (Photo 11A). Some of these altered rocks adopt a more greenish colour when calc-silicate minerals are present in greater amounts. Where less intensely altered, alteration of the protolith is characterized by the presence of light pink veins, mostly composed of potassium feldspar, that parallel the main fabric in the rock (Photo 11B). On a map scale, the potassium alteration zone seems to parallel the regional foliation. It is also affected by the northeast-trending upright folding event.

Two representative samples from the potassium-rich zone are presented in Table 5. These 2 samples are also calcium- and CO₂-rich compared to typical syenitic rocks, although it is unclear if the calcium and CO₂ contents were primary features of the rock or were also the result of the hydrothermal event that introduced potassium.

Table 5. Selected chemistry of 2 samples from the potassium alteration zone, stop 12, Day 2. Data are from the Geoscience Laboratories, Ontario Geological Survey (UTM co-ordinates provided in NAD83, Zone 18).

Sample Number	Easting (m)	Northing (m)	CaO (wt %)	K ₂ O (wt %)	SiO ₂ (wt %)	CO ₂ (wt %)	Sr (ppm)
11MD047A	367601	5033210	5.86	11.50	52.56	3.91	394
11MD120A	365949	5034178	5.13	10.14	57.47	0.82	192

Abbreviations: ppm, parts per million; wt %, weight percent.

In thin section (Photos 11C and 11D), pervasively altered samples 11MD047A and 11MD120A display a granoblastic texture with a groundmass composed mostly of orthoclase (65%). Two mineral assemblages have been observed: 1) orthoclase + biotite + diopside + hornblende + magnetite and 2) orthoclase + biotite + calcite + hornblende + titanite + magnetite (the minerals are presented in order of most to least abundant). Quartz is absent in both assemblages. Considering the intense deformation and metamorphism that the Horton map area has undergone, it is unlikely that these assemblages reflect the primary alteration mineralogy.

The geological context of this intense potassium alteration zone is still a mystery. One reason for this is the intense metamorphism and polyphase deformation that affected the Horton map area during the Grenville Orogeny. Two main hypotheses are considered herein. First, as previously noted, potassium alteration is an ubiquitous feature related to magmatic-driven mineralizing systems. However, at present, no pluton large enough to generate a large regional hydrothermal system has been identified in the immediate vicinity of the alteration zone. Even if one considers that a pluton was in the alteration zone and was subsequently completely obliterated by the metasomatic event, it would have had to be considerably smaller than either the Hurds Lake tonalite or the Glasgow complex. Yet, these 2 much larger bodies induced only limited hydrothermal activity in their country rocks, mostly limited local fentization and/or albitization. The lack of an identifiable plutonic source makes a magmatic-related hydrothermal deposit model from either a porphyry copper or IOCG system an unlikely source.

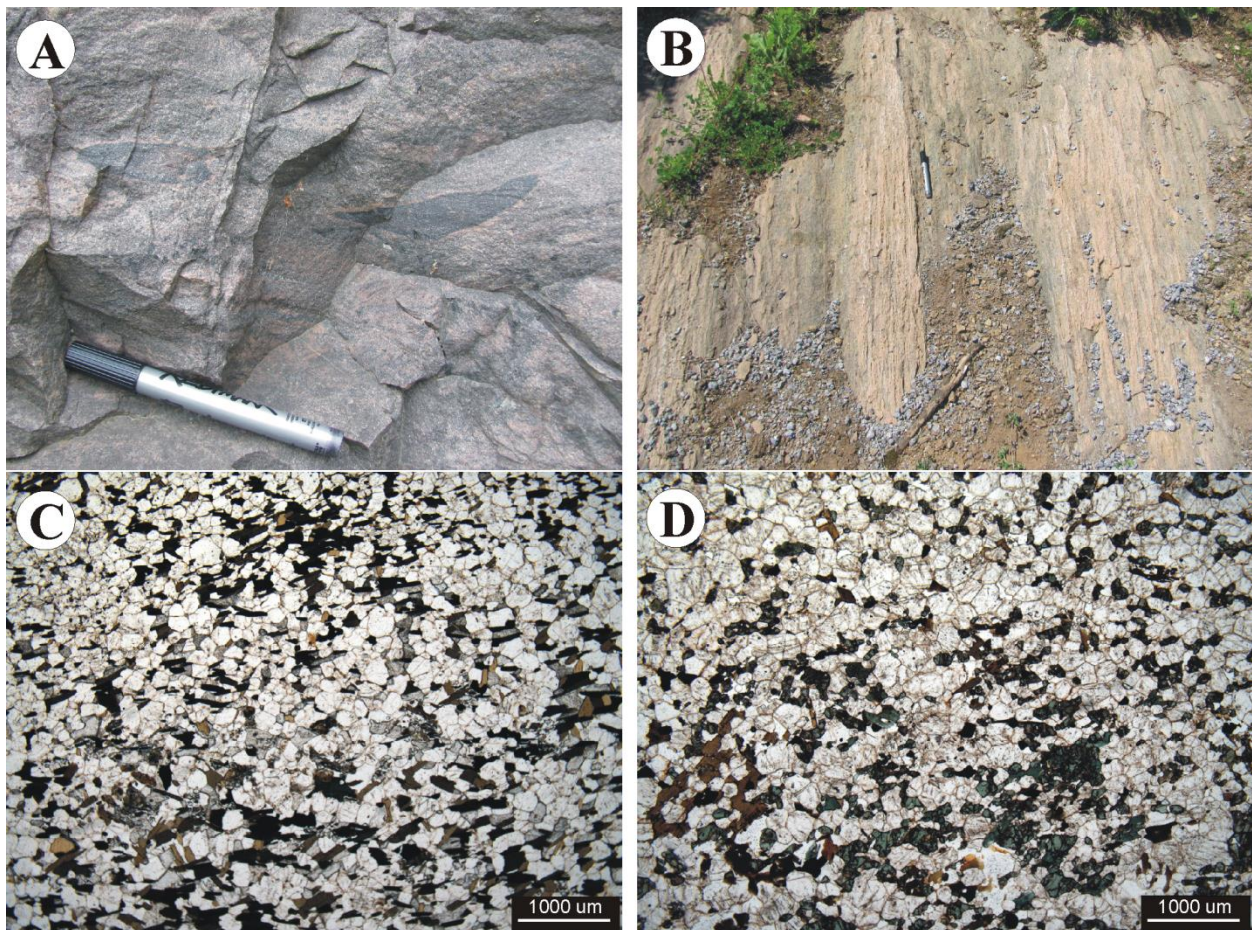


Photo 11. **A)** Rocks of unknown affinity affected by pervasive potassium alteration. Alteration halos are present around mafic “enclaves” which may be the unaltered protolith. The marker is 16 cm long. UTM 366028E 5032764N (NAD83, Zone 18). **B)** Potassic alteration veins parallel to the main foliation. The marker is 16 cm long. UTM 365487E 5035312N. **C)** Photomicrograph of sample 11MD047A in plane-polarized light showing the texture and the mineral assemblage of a pervasively potassium altered rock. **D)** Photomicrograph of sample 11MD120A in plane-polarized light showing the texture and the mineral assemblage of a pervasively potassium altered rock.

Second, the alteration zone occurs in proximity to the Renprior zinc-lead occurrence and the Flinton Group unconformity, which suggests a model involving hydrothermal circulation in a sedimentary basin. The Renprior zinc-lead occurrence is located at the southeastern edge of the potassium alteration zone and is 500 m distant from the zone. Moreover, the Flinton Group unconformity in the southwestern part of the Horton map area is geometrically associated with the only continuous dolomite marble unit in the Grenville Supergroup rocks in the Horton map area. It is possible that complete dolomitization of an original calcite marble substrate by intense fluid circulation resulted from a hydrothermal system that developed either during, or shortly after, deposition of Flinton Group rocks. Similar relationships between unconformities, Mississippi Valley-type (MVT) or SEDEX-type zinc-lead mineralization, and pervasive potassium alteration by saline brines have been described elsewhere (e.g., Cooke et al. 1998). Further work is needed to assess the setting of this potassium alteration and its relationships with zinc-lead sulphide mineralization. If they are indeed genetically linked, then identifying regional potassium alteration may be a useful tool for zinc-lead exploration within the Central Metasedimentary Belt.

Return to vehicles. Turn from Highway 132 south onto Opeongo Road and drive 200 m south to visit stop 13, which is optional (UTM 365487E 5035312N).

The stop is on a curve, so take precautions when parking and viewing the outcrop. Mazinaw domain, map unit 26 (*see* Table 3).

Stop 13. Potassium alteration zone, mafic protolith

This outcrop shows another example from the potassium alteration zone described at stop 12. Here, the alteration affects a probable mafic protolith. Some unaltered pods can be seen in the outcrop (*see* Photo 11A).

If stop 13 is visited, turn around, drive back to Highway 132 and continue west on Highway 132. If proceeding directly from stop 12, then continue west on Highway 132. After approximately 600 m, turn left onto Ferguslea Road and continue west on Ferguslea Road. After 1.2 km, park on the shoulder of the road opposite a long series of low outcrops on the south side of the road (UTM 364167E 5034102N). Mazinaw domain, map unit 23 (*see* Table 3).

Stop 14. Flinton Group metasandstone

This small outcrop is composed mostly of metasandstone intruded by muscovite-tourmaline-bearing granitic sills and veins parallel to the main foliation. This light to medium grey, fine- to medium-grained metasandstone unit has been assigned to the basal unit of the Flinton Group. The main foliation trends to the northeast and dips shallowly to the southeast. A mineral stretching lineation trends northeast. In thin section, this metasedimentary rock has a lepidogranoblastic texture characterized by the alternation between quartzofeldspathic and mica-rich layers. The overall mineralogical assemblage is quartz + plagioclase + orthoclase + muscovite + biotite + garnet + tourmaline + ilmenite. Garnet crystals are likely porphyroclasts. They are stretched and occasionally fractured along the main foliation. Tourmaline, which is an ubiquitous mineral in most Flinton Group rocks (Easton 2006, 2009), is an abundant accessory phase in this rock. Mica-fish of biotite and shear bands of muscovite give a sinistral (top-to-the-northeast) sense of shear. The same sinistral shear sense can be deduced macroscopically from the asymmetric boudinage of the granitic sills and veins emplaced parallel to the main fabric.

To establish a maximum deposition age of the sample, geochronology on 110 detrital zircons was carried out by LA-ICP-MS (Geospec Consultants 2012). The U/Pb results are presented as a density probability plot in Figure 13. The zircon $^{207}\text{Pb}/^{206}\text{Pb}$ ages vary between 1013 and 1676 Ma, but the majority (106 of 110) are between 1013 and 1255 Ma. The youngest detrital zircon at 1013 Ma can be considered a maximum estimate for the depositional age of this unit, assuming that these grains are not metamorphic in origin (a distinct possibility in this sample). The probability density plot (see Figure 13) indicates there are possibly 3 age modes recorded in this sample: 1) 1024.2 ± 7.0 Ma, 2) 1131 ± 8 Ma (shown, but not labelled on Figure 13) and 3) 1207.5 ± 4.8 Ma. Two zircon crystals exhibiting cores with overgrowths have cores with older ages (1246 and 1208 Ma) surrounded by younger rims (1039 and 1053 Ma): the latter could indicate the time of zircon growth during metamorphism.

After stop 14, return to Renfrew via Highway 132 and make your way through town to Highway 17. Proceed east on Highway 17. Pull over onto the shoulder and park (UTM 374332E 5034648E). **Note: The shoulder here is wide, but there is a low rise to the west along the highway that partially limits visibility.** Mazinaw domain, map unit 6 (see Table 3).

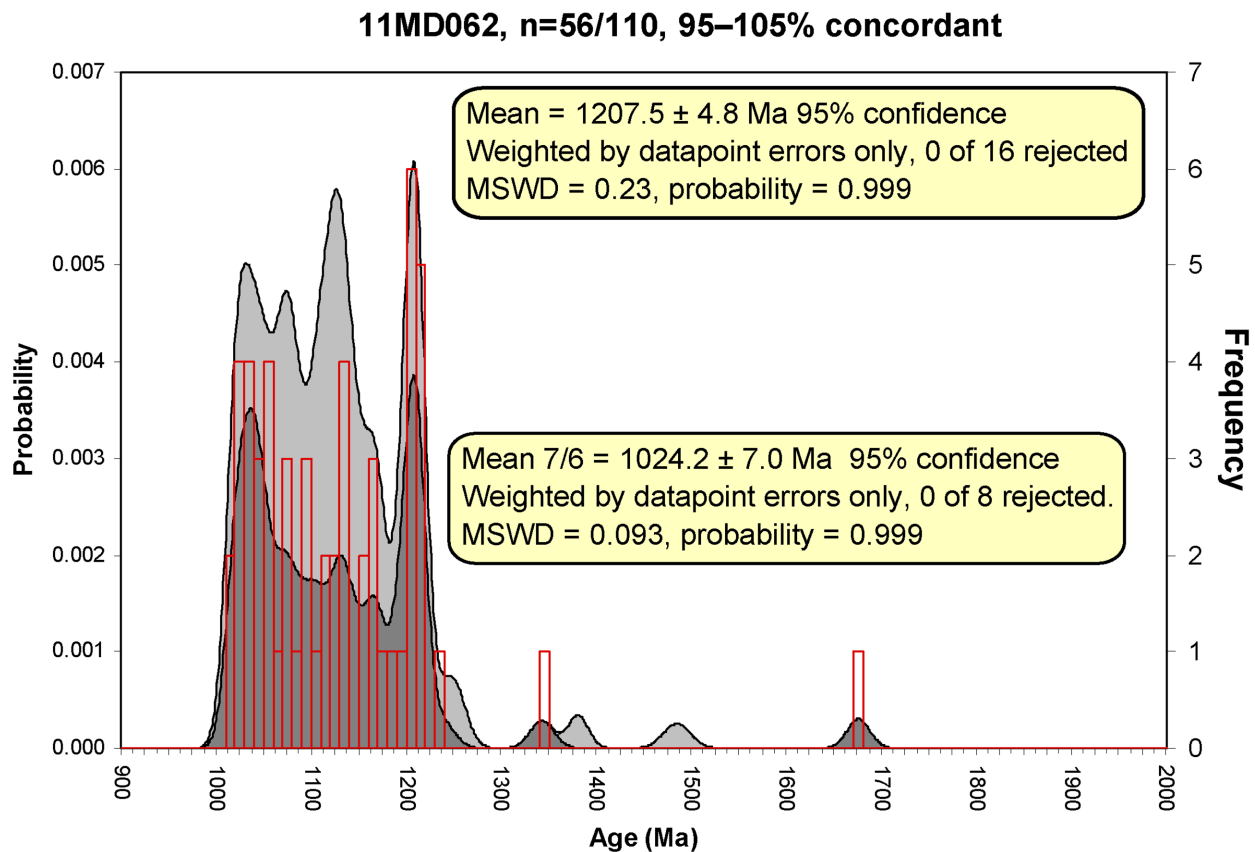


Figure 13. Density probability diagram for 110 detrital zircons extracted from sample 11MD062A, stop 14 (figure modified from Geospec Consultants 2012).

Stop 15. Dolomite marble

This section of outcrop is about 100 m in length and close to 4 m high. It is composed mostly of white, medium-grained dolomite marble hosting pods composed mainly of coarse-grained phlogopite, tremolite, diopside, tourmaline (W. Bleeker, GSC, personal communication, 2017) and minor garnet. It is unclear whether these pods result from a skarn or are the result of metasomatism associated with the Flinton Group unconformity (Duguet, Magnus and Ratcliffe 2012). Pink staining in the outcrop is related to hematite infiltrating along fractures, and is distinct from the development of metasomatic pink calcite rocks that are observed at stops 22 and 23 (Day 3) The foliation strikes to the northeast and dips to the northwest.

Return to vehicles. Return to Highway 17 and east on Highway 17 eastbound for approximately 800 m. Pull over onto the shoulder and park beside a 3 to 4 m high outcrop that is mostly obscured by cedars and pines (UTM 374868E 5033993N).
Mazinaw domain, map units 3, 5 and 29 (*see* Table 3).

Stop 16. Felsic gneiss and calcite marble

The east part of the outcrop consists of intermediate gneiss cut by a syenogranite pegmatite vein that is non-radiogenic. A small impure marble outcrop with abundant phlogopite is exposed in part of the outcrop (UTM 374836E 5034005N). The east end of the outcrop area (UTM 374775E 5034060N) is the best location to view the interlayered felsic and garnet-bearing mafic gneiss that make up the bulk of the outcrop area. These gneisses are likely metasedimentary derived. The foliation strikes northeast and dips to the northwest ($230^{\circ}/70^{\circ}$).

Return to vehicles. Continue east on Highway 17, pull over and park on the shoulder of the road prior to the start of the guardrails, approximately 700 m southeast of Goshen Road. Proceed cautiously along the shoulder of the road to the long roadcut (UTM 376548E 5033688N).
Mazinaw domain, map units 4, 5, 18, 21 and 29 (*see* Table 3).

Stop 17. Structural history, amphibolite, marble, skarn rocks, gneiss

Caution: This portion of the Highway 17 is wide and very busy. For safety reasons, field trip attendees will stay at all times behind the guardrail. No crossing will be tolerated.

This section crops out for over 1 km on both sides of the Highway 17. For safety reasons, only the southern section will be visited. However, it is a key outcrop from which a significant part of the structural history of the Horton map area can be seen.

The southern section is composed mainly of highly deformed amphibolites with minor calcite marbles and mineralized skarn rocks. The western part consists mainly of partly metasomatized tonalitic and monzogranitic gneisses assigned to units 18 and 21 (*see* Table 3; also shown on Map P.3784: Duguet, Magnus and Ratcliffe 2014b), as well as migmatitic intermediate to felsic gneisses interlayered with the amphibolites. The dark bluish-grey amphibolites are fine to medium grained, strongly foliated and locally garnet bearing; these mafic rocks were assigned to unit 4 (*see* Table 3: also shown on Map P.3784: Duguet, Magnus and Ratcliffe 2014b). The minor exposures of marble are medium to coarse grained, white to pink and massive. Some have been altered into pink calcite-diopside skarns that host minor disseminated chalcopyrite mineralization. The migmatites display a wide variety of textures. Some of them are mylonitized stromatic metatexite. Others are closer to diatexite (but still with well-defined leucosome and melanosome) and are weakly deformed to undeformed. In thin section, both types are characterized by a porphyro-lepidoblastic melanosome composed of garnet + biotite ± cordierite ± plagioclase and a granoblastic leucosome mostly composed of quartz + potassium feldspar + plagioclase. Tourmaline is occasionally present as an accessory phase in the melanosome. A single sillimanite crystal was found in a leucosome and is probably relict. Geochemically, these rocks could be either volcaniclastic or sedimentary rocks (Figure 14), but, because of the strong deformation and partial melting, their protolith is difficult to establish. These gneissic rocks were widely affected by a late plutonic event represented by the intrusion of massive, pink, and coarse-grained to pegmatitic granites. These granites are either coeval with, or follow, a late deformational event, which is described below (Liu, Lin and Duguet 2013).

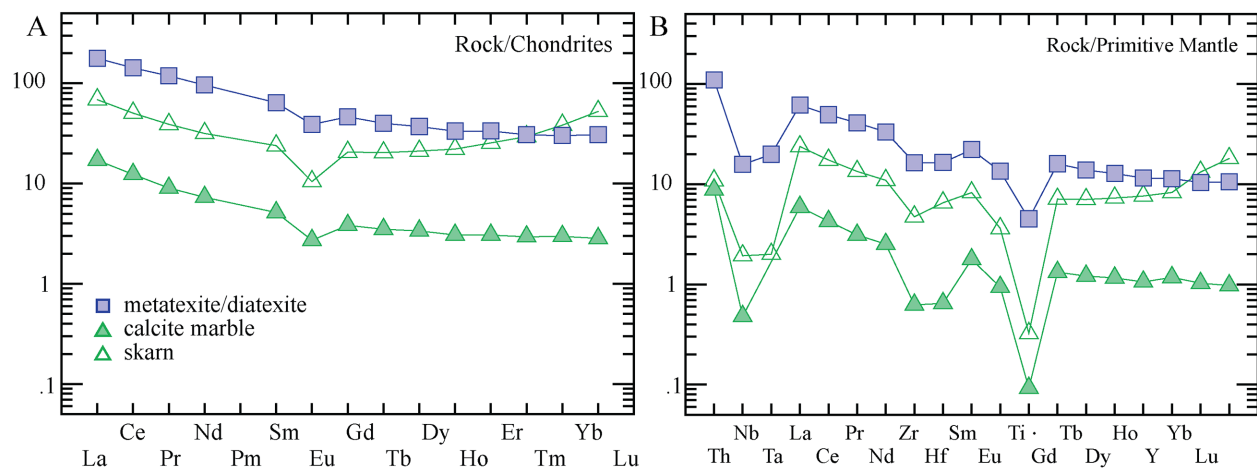


Figure 14. A) Chondrite-normalized rare earth element (REE) for the skarn, calcite marble and the migmatites from the outcrop at stop 17. B) Incompatible element (spider) diagrams the skarn, calcite marble and the migmatites from the outcrop at stop 17. Normalizing factors of Sun and McDonough (1989) are used.

In map-scale view, the rock units present throughout the entire outcrop section are exposed in an antiform. Gneissic granites of the Methuen intrusive suite occur on each side of the main amphibolite-dominated succession with the regional foliation dipping outward from the antiform core. On the western part of the outcrop, the foliation trends 100° and dips steeply to the southwest. On the eastern edge of the outcrop and on the north side of the road, the foliation trends to the northeast and is near vertical. A northwest-trending regional dextral shear zone crosscuts the antiform and is likely responsible for the distortion of the regional foliation observed at map scale. A 250 m long section of this outcrop was investigated as part of a BSc thesis project and focussed on the history of deformation (Liu, Lin and Duguet 2013).

At outcrop scale, 4 generations (G_1 to G_4) of deformation were recognized (Liu, Lin and Duguet 2013). The earliest G_1 deformation is responsible for the penetrative S_1 foliation. The G_2 deformation event is dominant in the section and is characterized by a rare subvertical S_2 foliation axial planar of upright isoclinal F_2 folds. This G_2 event is coeval with the sinistral shearing that extensively affected the Mazinaw domain in the Horton and Admaston map areas (Easton, Duguet and Magnus 2011; Duguet, Magnus and Ratcliffe 2012). The G_3 deformation event is characterized by dextral mylonitic shear zones associated with open-to-tight Z-folds that fold the S_{1-2} foliations. These metre-wide shear zones trend to the southeast (110°) and are near vertical. These shear zones contain a stretching lineation that is shallowly to moderately plunging to the east-northeast. This G_3 event is conspicuous on the north side of the highway and occurred during emplacement of the granite and pegmatite dikes and sills. Asymmetric boudinage of these granitic veins and sills, either internally plastically deformed or free of deformation, give a consistent dextral sense of shear. Nonetheless, these granitic intrusions clearly cut the S_{1-2} foliations at a high angle.

All the above fabrics were crosscut by brittle faults during G_4 deformation. This event is present in 4 late ductile-brittle faults that have similar strike and dip angles, approximately 025° and 40° southeast, respectively. A fifth fault dips at a steep angle to the west. Fault gouges and fault breccia are developed along these faults. Locally, the fault plane is mineralized with disseminated pyrite.

Return to vehicles. Continue east on Highway 17 for approximately 1.2 km. Park on the shoulder of the road (UTM 378003E 5033773N).
Mazinaw domain, map unit 18 (*see* Table 3).

Stop 18. Gneissic monzogranite, Methuen intrusive suite

This outcrop is mostly composed of an equigranular, medium-grained, pink gneissic monzogranite. It is part of a 14 km long, northeast-trending, cigar-shaped pluton occurring on the north side of the Hurds Lake tonalite. This intrusion is mainly composed of alkali-feldspar granite and syenogranite chemically identical to other granitic rocks of the Methuen intrusive suite (Easton 1992; Lumbers et al. 1990; Figure 15). This body is folded by regional northeast-trending upright folds. Partial fenitization of the gneissic monzogranite can also be observed in this outcrop. The pink unaltered gneissic monzogranite gradually changes over a few metres into a light green felsic gneiss. The metasomatism mostly affected the major element chemistry of the rock (Table 6), with little change in the trace elements (*see* Figure 15).

A zircon from this pluton has yielded a minimum age of 1229 ± 3 Ma (Kamo 2012). This age is younger than the typical age of *circa* 1245 Ma generally associated with the Methuen intrusive suite, but is similar to ages obtained from Methuen intrusive suite granitoid rocks present in the northwestern Central Metasedimentary Belt (Easton and Kamo 2011).

Return to vehicles. Continue east on Highway 17 for approximately 2.4 km and park on the shoulder of the road (UTM 380910E 5033190N). Stop is approximately 1 km east of the junction with Anderson Road.

Mazinaw domain, map unit 20 (*see* Table 3).

Table 6. Major element chemistry of an unaltered Methuen suite granite sample (11SM104A) and its hydrothermal counterpart (sample 11SM104B) on the same outcrop.

Sample Number	SiO ₂ (wt. %)	TiO ₂ (wt. %)	Al ₂ O ₃ (wt. %)	Fe ₂ O ₃ (wt. %)	MnO (wt. %)	MgO (wt. %)	CaO (wt. %)	Na ₂ O (wt. %)	K ₂ O (wt. %)	P ₂ O ₅ (wt. %)	LOI	Ba (ppm)
11SM104A	70.71	0.40	13.59	3.76	0.06	0.42	0.74	3.83	5.66	0.05	0.24	488
11SM104B	64.50	0.62	12.28	9.44	0.15	1.34	2.16	4.64	3.47	0.08	1.24	957

Abbreviations: ppm = parts per million; wt. % = weight percent.

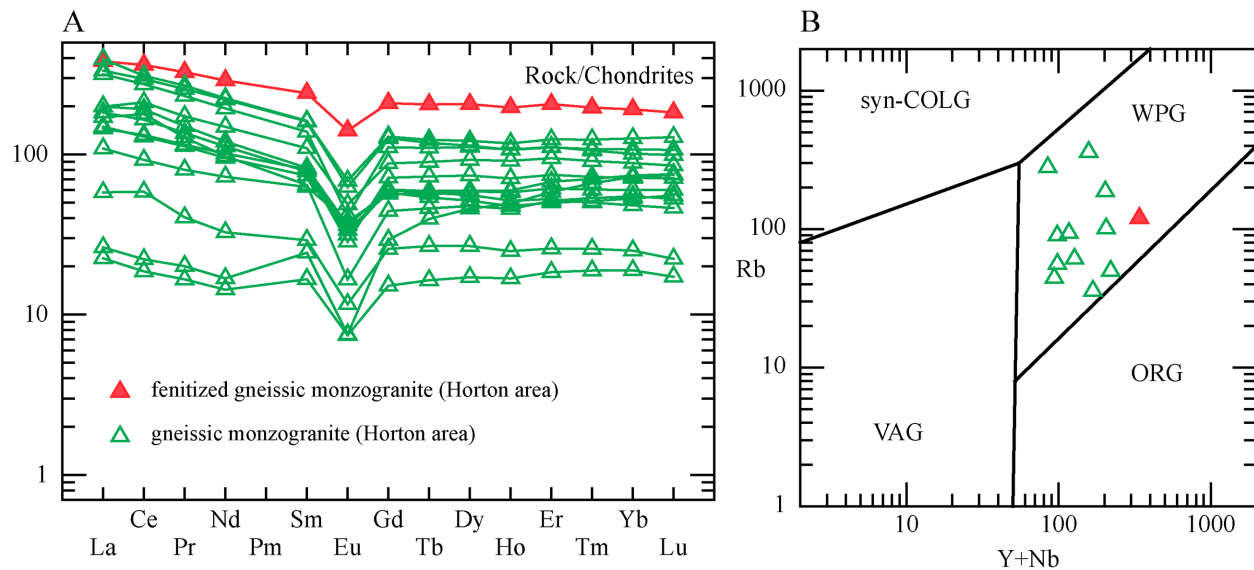


Figure 15. **A)** Chondrite-normalized rare earth element (REE) for the Methuen suite granite in the Mazinaw domain (Horton map area). Normalizing factors of Sun and McDonough (1989) are used. **B)** Discriminant diagram Rb versus (Y+Nb) from Pearce, Harris and Tindle (1984) for the Methuen suite granitoids of the Horton map area.

Stop 19. Diorite, Glasgow complex

This outcrop is composed of medium-grained, dark grey to black, gneissic gabbro to diorite. It is located on the southern edge of the Glasgow complex, which is a composite intrusion consisting of gabbro, diorite and syenite.

A sample from this outcrop yielded a zircon age of 1223 ± 1 Ma (Kamo 2012). This unit is tentatively assigned to the Lavant intrusive suite, but is at the younger age range of the suite. This is broadly comparable to the U/Pb zircon ages of the Chenux and Raglan Hills gabbros (1231 ± 2 Ma and 1229 ± 5 Ma, respectively: Pehrsson, Hanmer and van Breemen 1996) and the Lavant gabbro (1224 ± 2 Ma: Corfu and Easton 1997). The age on the Glasgow complex is older than previous workers had suggested based on field relationships, for example, Lumbers (1982b) suggested that it might have been similar in age to the Calabogie syenite (*circa* 1088 Ma: Corriveau et al. 1990).

Continue east on Highway 17 until the junction with Calabogie Road. Turn right onto Calabogie Road (Renfrew County Road 508) and proceed to Burnstown (approximately 9.8 km). At the road junction in Burnstown, turn left (south) onto Renfrew County Road 52. The outcrop is located just after the bridge over the Madawaska River. Mazinaw domain, map units 5, 6, 18, 20 and 21 (*see* Table 3).

Stop 20. Skarn, orthogneiss, amphibolite and marble of the Burnstown outcrop

This spectacular roadcut section, approximately 300 m in length, was rejuvenated by recent road construction. The roadcut is oriented at a high angle to the general northeast trend of the foliation and offers a perfect cross section of the rock sequence on the south side of the Madawaska River in an area of otherwise poor outcrop exposure. The roadcut is just south of the Madawaska River shear zone, a thrust fault with a dextral component. The roadcut exposes a sequence of deformed calcite and minor dolomite marbles, intruded by several sets of sills that range in composition from mafic to felsic. Table 7 presents the locations and descriptions of the different lithological units present along the exposed section.

The Burnstown outcrop is an historically well-known section that has been the subject of many studies over the past decades (Bartlett 1980; Dubé-Bourgeois 2013; Dubé-Bourgeois, Gall and Duguet 2013). Interest in this section was renewed by the discovery of rare earth element (REE) anomalies in some of the marbles by Duguet, Magnus and Ratcliffe (2012). A Bachelor of Science thesis focussing on the geochemistry and petrography of this outcrop was undertaken at the University of Ottawa by Vincent Dubé-Bourgeois: some of his results (Dubé-Bourgeois 2013) are included herein.

A summary of geochemical data related to the REE anomalies are presented in Table 8. The highest REE contents were found in what would seem, at first glance, to be regular marbles. In the case of the intrusive sills, geochemical and petrographic studies indicate that the sills have strong geochemical affinities with most of the known plutonic suites in the Horton map area. None of the REE patterns of the marble and calc-silicate rocks matches the REE patterns for the various mafic and felsic sills present in this outcrop (*see* Tables 8 and 7, respectively). For more details on the REE anomalies, *see* Dubé-Bourgeois (2013) and Dubé-Bourgeois, Gall and Duguet (2013).

Prior to this study, apatite was thought to be the primary phase containing the REE in the samples because of their high P_2O_5 content (*see* Table 8) and because it was the only microscopically visible REE-bearing mineral in the polished sections. Study with scanning electron microscopy (SEM), however, demonstrated that the REE are contained in monazite in the calcite marble unit and in allanite in the calc-silicate unit. Only minerals dominated by light rare earth element contents were detected during the SEM work, consistent with the whole-rock geochemistry results.

Previous work postulated that the marbles in the Burnstown outcrop were carbonatites (Bartlett 1980). Subsequently, Mitchell (2005) identified 2 main groups of metasomatic and magmatic carbonatites: primary carbonatite and pseudocarbonatite. Mitchell (2005) defined the first group as “calcite or dolomite carbonatite (or both)” that are primary and genetically related to nephelinite, melilitite, kimberlite and other mantle-derived magmas; and the second type is “carbothermal residua” derived from a wide variety of magmas. Mitchell (2005) defined “carbothermal” as a term referring to low-temperature fluids derived from a fractionated magma dominated by CO₂, but also containing fluorine and H₂O in varied proportions. Mitchell (2005) recognized 2 subgroups of “pseudocarbonatite”, both of which may be present in the Burnstown outcrop. The first is a potassic “carbonatite”, which occurs adjacent to potassic intrusions, such as the Mountain Pass intrusion in California that hosted the only past-producing REE mine in the United States. The other subgroup is an anatectite skarn. The description given by Mitchell (2005) of this type of pseudocarbonatite or skarn rock is consistent with many of the rocks described in the Burnstown outcrop (Dubé-Bourgeois 2013). Samples from the Burnstown outcrop match both subgroups, but most of the samples are most similar to the skarn subgroup.

As previously noted, the REE patterns in the rare earth element-rich marble and calc-silicate units do not show a match with any of the major intrusive rocks in the area (Figure 16). Even if the REE patterns of the tonalite sills in the Burnstown outcrop were similar to the nearby Hurds Lake tonalite, the low contents of barium, phosphorus and strontium of the Hurds Lake tonalite makes it an unlikely candidate as the source of the fluids that metasomatized the marbles and created the skarn rocks. Only 1 sill from the Burnstown outcrop (sample V6A, *see* Tables 7 and 8) could potentially be a source of metasomatizing fluids. This mafic sample has high contents of barium, phosphorus and strontium and a strongly fractionated REE pattern. This sill may be related to either the Woermke gabbro (Easton 2012) or the Calabogie syenite (Corriveau et al. 1990), as both these intrusions are characterized by light REE enrichment and elevated barium, potassium and strontium.

The samples with the highest total REE contents show broad geochemical similarities with the Calabogie syenite (emplaced at *circa* 1088 Ma: Corriveau et al. 1990). It is located approximately 12 km to the southwest of, and along strike with, the Burnstown outcrop, on the south side of the thrust fault present along the Madawaska River. Other, less well-studied syenite intrusions are located between the northeastern tip of the Calabogie syenite and the Burnstown outcrop (Lumbers 1982b). This geometric relationship suggests that the emplacement of these plutons may have been structurally controlled, as was the migration of the fluids responsible for the REE mineralization. These syenite-diorite-gabbro intrusions make the best candidate for the origin of the fluids causing the metasomatism and REE enrichment of the Burnstown outcrop.

It should also be noted that a relationship between syenite intrusion, related metasomatism and REE enrichment of adjacent marbles has been described by Easton (2012) and Easton and Clarke (2013), but for late syenite intrusions emplaced after 1050 Ma. A significant difference in the marbles described by Easton (2012) is that the REE are hosted primarily in REE-carbonate minerals and allanite, not monazite (*see* Easton and Clarke 2013).

END OF DAY 2 STOPS.

Table 7. Sample locations and descriptions from the Burnstown outcrop (data *from* Dubé-Bourgeois 2013).

Sample Number	Easting ^a (m)	Northing ^a (m)	Description (Hand Sample and Thin Section)	Interpreted Protolith; Geochemical Features
V1A	376661	5026866	Medium- to coarse-grained dolomite marble	Limestone
V1B	376668	5026858	Medium-grained porphyritic granite; feldspar, quartz with subordinate biotite, tremolite, pyrite, calcite	Limestone
V1C	376675	5026850	Medium- to coarse-grained calcite marble with minor silicate impurities	Limestone
V1D	376682	5026842	Medium-grained felsic gneiss; feldspar, quartz with subordinate biotite, tremolite, pyrite, calcite	Tonalite; REE pattern similar to the Hurds Lake tonalite
V2A	376697	5026822	Medium- to coarse-grained dolomite marble	Limestone
V2A-1	376715	5026797	Medium- to coarse-grained dolomite marble	Limestone
V2A-2	376698	5026819	Medium- to coarse-grained dolomite marble	Limestone
V2-1	376722	5026788	Medium-grained felsic gneiss; feldspar, quartz with subordinate biotite, tremolite, pyrite, calcite	Granite (now porphyroclastic)
V2-2	376697	5026822	Medium-grained gneiss; feldspar, quartz with subordinate biotite, tremolite, pyrite, calcite	Tonalite; REE pattern similar to the Hurds Lake tonalite
V3	376724	5026774	Hornblende-biotite-plagioclase schist to plagioclase-biotite-hornblende schist	Possible monzonite sill; REE pattern identical to syenite and monzonite of the Glasgow complex
V4A-1	376731	5026767	Calc-silicate rocks dominated by plagioclase feldspar, alkali feldspar, calcite, diopside	Skarn
V4A-2	376731	5026767	Calc-silicate rocks dominated by plagioclase feldspar, alkali feldspar, calcite, diopside	Skarn
V5A	376737	5026754	Calc-silicate rocks dominated by plagioclase feldspar, alkali feldspar, calcite, diopside	Skarn
V5B	376737	5026754	Medium-grained gneiss; feldspar, quartz with subordinate biotite, tremolite, pyrite, calcite	Monzogranite sill; REE pattern similar to Methuen suite
V6A	376748	5026736	Plagioclase-calcite ± hornblende granofels	Mafic sill, possibly Woermke-type type or metasomatized Glasgow complex gabbro
V6B	376754	5026724	Hornblende-biotite-plagioclase-garnet schist to plagioclase-biotite-hornblende schist	Skarn
V6C	376754	5026724	Plagioclase-calcite ± hornblende granofels	Skarn
V7B	376761	5026707	Medium- to coarse-grained calcite marble with minor silicate impurities	Limestone
V7C	376762	5026713	Hornblende-biotite-plagioclase schist to plagioclase-biotite-hornblende schist	Protolith unknown, possible skarn
V8A	376764	5026702	Biotite-plagioclase-quartz granofels	Monzogranite sill; REE pattern similar to Methuen suite
V8B	376764	5026702	Biotite-plagioclase-quartz granofels	Monzogranite sill; REE pattern similar to Methuen suite
V8C	376761	5026702	Mainly diopside (70–90%) and plagioclase	Skarn
V9A	376780	5026677	Hornblende-biotite-plagioclase schist to plagioclase-biotite-hornblende schist	Mafic sill (now amphibolite); REE pattern related to the Glasgow complex gabbro?
V9B	376780	5026677	Medium- to coarse-grained calcite marble with minor silicate impurities	Limestone
V10A	376793	5026660	Mainly diopside (70–90%) and plagioclase	Skarn (adjacent to mafic sills, such as V9B and V11A)
V11A	376800	5026653	Medium- to coarse-grained calcite marble with minor silicate impurities	Limestone
V11B	376819	5026623	Hornblende-biotite-plagioclase schist to plagioclase-biotite-hornblende schist	Mafic sill (now amphibolite); REE pattern related to the Glasgow complex gabbro?

^a UTM co-ordinates provided in NAD83, Zone 18.

Table 8. Selected geochemical data for the rare earth element-rich samples in the Burnstown outcrop. All analyses by the OGS Geoscience Laboratories, Sudbury, Ontario. Sample locations as UTM co-ordinates using NAD83 in Zone 18.

Sample Number	Rock Type	Easting (m)	Northing (m)	Total RRE (ppm)	P ₂ O ₅ (wt. %)	Zr (ppm)	Ba (ppm)	Th (ppm)	Sr (ppm)
V11A	Calcite marble	376800	5026653	1347.6	0.616	<6	305	0.32	372
V4A-1	Skarn	376731	5026767	608.0	0.073	49	1157	7.37	>1560
V7B	Calcite marble	376761	5026707	574.5	0.091	<6	>1740	0.17	>1560
V9B	Calcite marble	376780	5026677	549.4	0.046	<6	749	0.20	>1560
V6A	Mafic gneiss	376748	5026736	438.1	0.320	132	>1740	7.10	1541

Abbreviations: ppm = parts per million; wt % = weight percent.

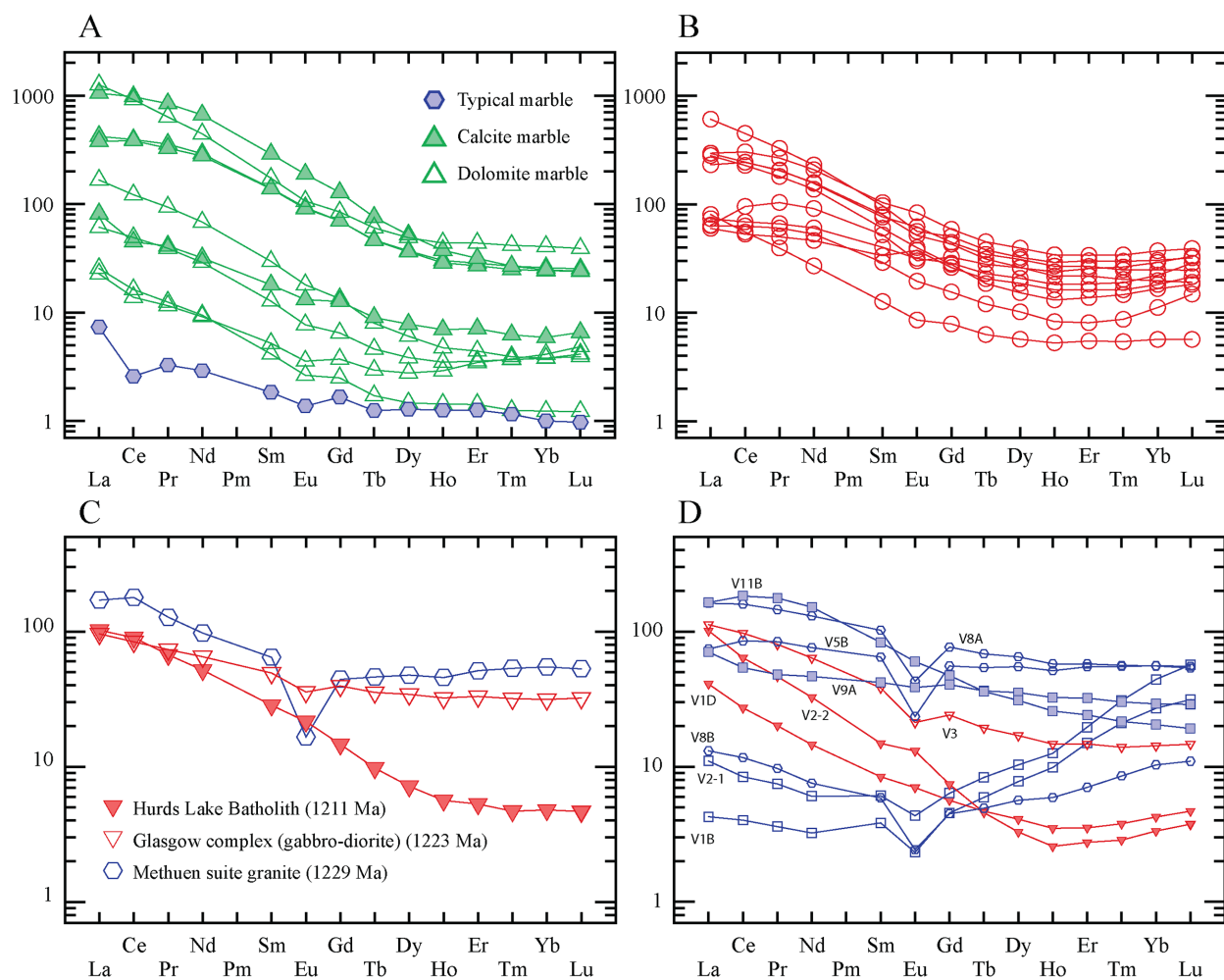


Figure 16. A) Chondrite-normalized rare earth element (REE) for the metasomatized marbles of the Burnstown outcrop compared with a typical unaltered marble of the Mazinaw domain. B) Chondrite-normalized rare earth element (REE) for the skarns of the Burnstown outcrop. C) Chondrite-normalized rare earth element (REE) of the main intrusive suite of the area. D) Chondrite-normalized rare earth element (REE) of the different intrusive sills of the Burnstown outcrop (labels indicate samples described in Table 7). Normalizing factors of Sun and McDonough (1989) are used.

DAY 3. GEOLOGY OF THE COBDEN MAP AREA

As noted by Easton (2013, 2014), the Cobden map area is split in two by a previously undocumented north-trending fault, which he termed the Ross fault (Figure 17). The two-thirds of the Cobden map area west of the Ross fault, referred to as the Bromley subdomain (*see* Figure 17), consists of high metamorphic grade paragneiss, orthogneiss and marble tectonic breccia, all of which are intruded and metasomatized by Late Syenite suite rocks (1090 to 1030 Ma). In contrast, the eastern one-third of the Cobden map area, referred to as the Ross subdomain (*see* Figure 17), is underlain by calcite and dolomite marble, which locally preserve relict stratigraphy. The marbles are intruded by the Chenaux gabbro (1231±2 Ma: Pehrsson, Hanmer and van Breemen 1996), which locally preserves primary mineralogy (*cf.* Azar 2015; Azar and Easton 2015). The Late Syenite suite and metasomatic rocks appear to be absent from the eastern one-third of the Cobden map area. Metamorphic grade is estimated to be lower amphibolite facies east of the Ross fault and upper amphibolite facies west of the fault.

Also present in the eastern one-third of the Cobden map area, adjacent to the Ottawa River, are several small areas of highly deformed, mafic and quartzofeldspathic gneiss that have a characteristic magnetic signature (Figure 18), and may be retrograded granulite-facies rocks. These areas of gneiss have a sheet-like geometry and may have been thrust on top of the marbles (*see* Figure 17). These rocks are

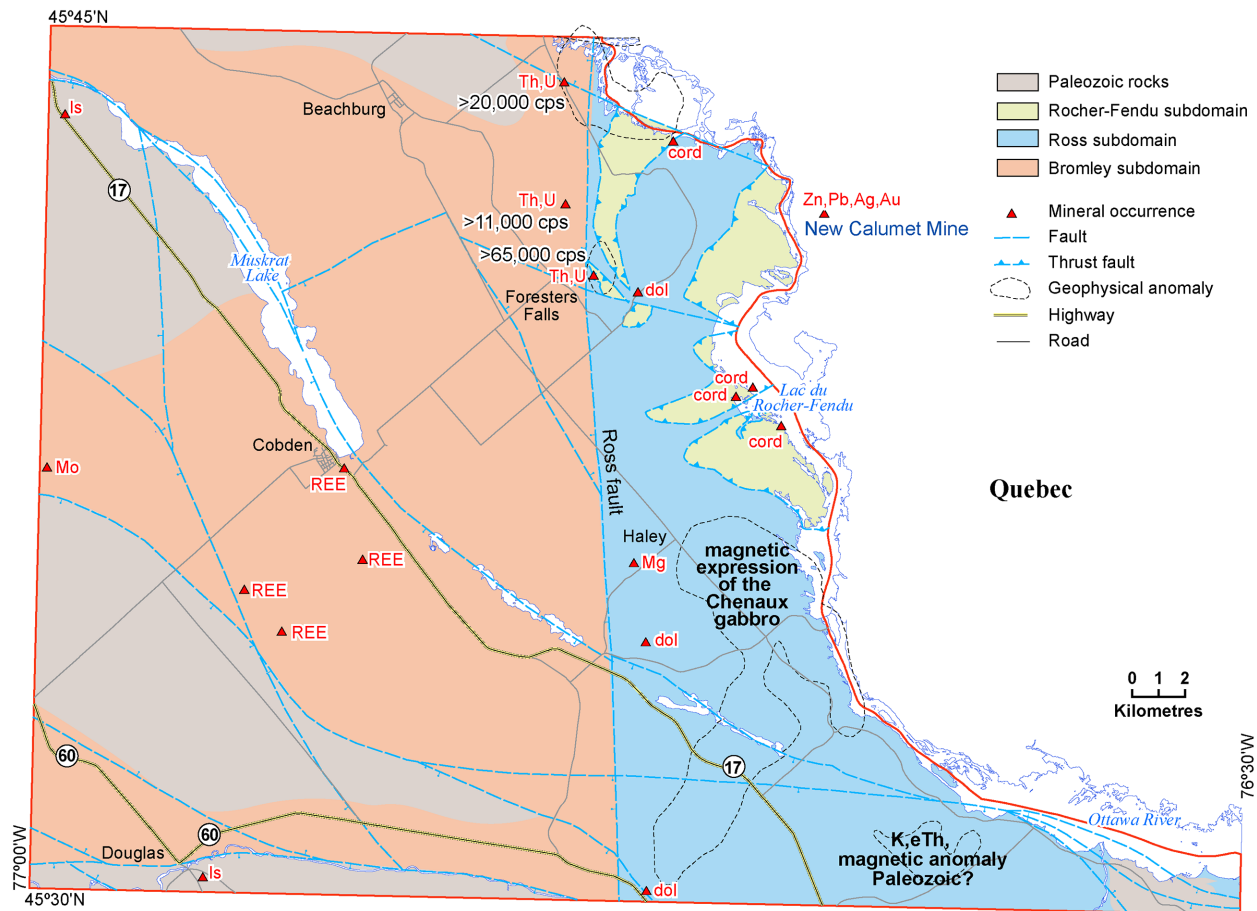


Figure 17. Simplified geological map of the Cobden map area showing the location of subdomains, major faults and significant mineral occurrences. Thin red solid line indicates the Cobden map area. Abbreviations: Ag, silver; Au, gold; cord, cordierite; cps, counts per second; dol, dolomite; eTh, equivalent thorium; K, potassium; Is, limestone; Mg, magnesium; Mo, molybdenum; Pb, lead; REE, rare earth elements; Th, thorium; U, uranium; Zn, zinc. Figure from Easton (2014).

more abundant on the Quebec side of the Ottawa River. They cannot be assigned to any terrane or domain in Ontario and are herein referred to as the Rocher–Fendu subdomain, named after Lac du Rocher–Fendu on the Ottawa River where they are well exposed. Rocks from the Rocher–Fendu subdomain have ages clustering at *circa* 1230 Ma (*see* Appendix-Table 1-2).

In addition to the Ross fault, the Cobden map area is also cut by several northwest-trending, dominantly vertical faults related to the Ottawa–Bonnechere graben system, which locally preserve Upper Ordovician limestones of the Gull River and Bobcaygeon formations on their down-dropped sides (*cf.* Russell and Williams 1985).

Geophysical Data

A high-resolution (200 m line-spacing) aeromagnetic and gamma-ray spectrometric survey was flown for the Ontario Geological Survey over much of Renfrew County, including the Cobden map area, during October 2013 (*see* Figure 18). The data from this survey were released in June 2014 (Ontario Geological Survey 2014a). Key observations from this data set related to the geology of the Cobden map area are as follows.

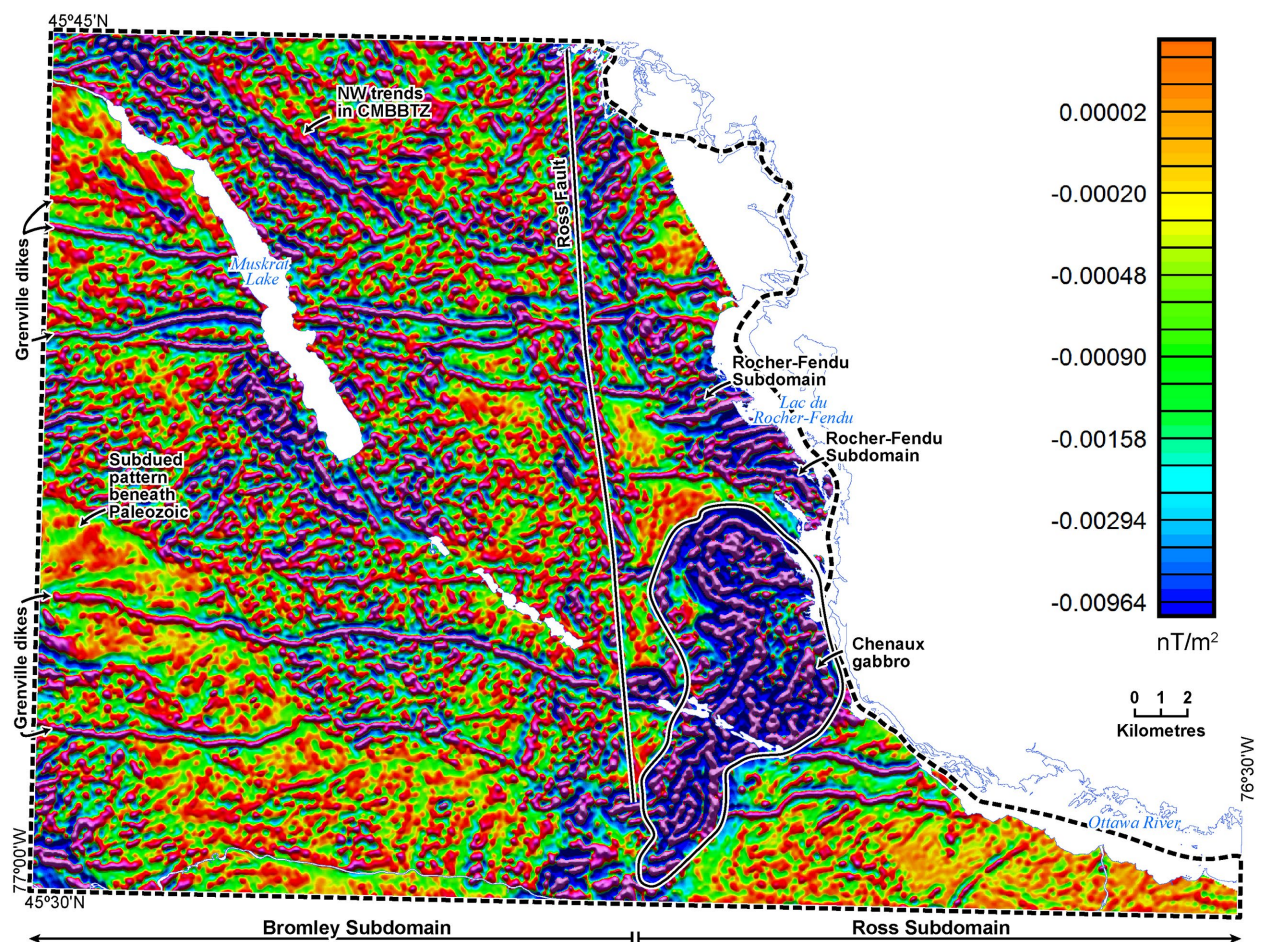


Figure 18. Map showing the second vertical derivative of the magnetic field for the Cobden map area, with key features indicated. Black dashed line indicates the Cobden map area. Magnetic data from Ontario Geological Survey (2014a), figure from Easton (2014).

Easton (2013) interpreted the Ross fault as a near-vertical fault based on the previous low-resolution (800 m line-spacing) aeromagnetic data (Ontario Geological Survey 1999), but the high-resolution data indicates that it may dip moderately to the east. Magnetic features present in the Bromley subdomain appear to continue for up to 500 m beneath mapped marbles belonging to the Ross subdomain (*see* Figure 18). It is not known if this indicates that the Ross fault is a thrust fault, or if it is simply an east-dipping normal fault.

Rocks of the Central Metasedimentary Belt boundary tectonic zone (CMBbtz) exhibit strong, linear northwest or north-northwest magnetic trends, for example, on the north side of Muskrat Lake north of Cobden (*see* Figure 18). These trends correspond to differences in surface geological units as mapped by Lumbers (1982a), and confirm the observation made by Easton (2013) that rocks of the CMBbtz underlie much more of the Bromley subdomain (i.e., occur farther south) than previously indicated.

The high-resolution data confirm the highly magnetic character of the Chenaux gabbro (*see* Figure 18). Immediately east of Haley, a prominent, 3 km long, north-northeast-trending magnetic high could be a subsurface dike or subsurface extension of the Chenaux gabbro beneath marbles exposed on surface. It is not known if this subsurface magnetic anomaly has any association with the observed hydrothermal alteration of the dolomite marbles at Haley.

The Cobden map area is cut by at least 7 major west-trending mafic dikes that are interpreted to be part of the Grenville dike swarm, which was emplaced at *circa* 590 Ma (Kamo, Krogh and Kumarapeli 1995). It is possible that these dikes may be associated with west-trending faults, although, if that is the case, movement along those faults would be mostly vertical, as the faults do not appear to laterally offset either Precambrian or Paleozoic strata. These dikes occur in 3 main corridors, approximately 10 km apart, containing dikes with strike lengths ranging from 3 to 17 km (*see* Figure 18). One corridor lies in the area of Haley Station (4 km southwest of Haley), another immediately north of Cobden, and the third is located just north of the northern boundary of the Cobden NTS map area north of Beachburg. The majority of these dikes occur beneath Paleozoic limestones, and have limited surface expression, although one of the dikes located east of Haley Station is overlain by a linear series of swamps. The dikes appear to cross the Ross fault without offset. The relationship between the dikes and the Rocher–Fendu subdomain is unclear, in part because of the higher magnetic character of that subdomain. In some instances, it appears that the dikes end at the subdomain boundary, but, in other instances, it appears that the dikes continue into the subdomain. Lumbers (1982a) mapped Grenville dikes within the Rocher–Fendu subdomain, suggesting that the dikes did intrude the subdomain.

Paleozoic strata in the Cobden map area are generally sufficiently thick ($\gg 100$ m) to subdue the magnetic character of the underlying Precambrian strata; this is particularly evident in the first vertical derivative (1VD) of the magnetic field. The only area where the Paleozoic strata may be thin (< 100 m) occurs north of Beachburg.

The high-resolution gamma-ray spectrometric data (Ontario Geological Survey 2014n) defines the same airborne gamma-ray spectrometric highs for uranium and thorium as those indicated by the data of Carson et al. (2004a, 2004b). Areas of active farming and/or areas underlain by Leda clay within the Cobden map area are characterized by potassium and equivalent thorium (eTh) highs in the high-resolution gamma-ray spectrometric data. These anthropogenic anomalies limit the use of the gamma-ray spectrometric data to distinguish rock units over most of the Cobden map area.

A subdued aeromagnetic signature coincides with an area of low potassium and low eTh in a 7 km² area in southeastern Ross subdomain (*see* Figures 17 and 18) bounded by the Castleford, Eady, Mullins and River roads. The reason for this anomaly is not readily apparent, but it could indicate an area underlain by Paleozoic limestone.

DAY 3. ROAD LOG: CIRCLE TOUR RENFREW–COBDEN–RENFREW

Note: Caution should be taken when parking vehicles on the shoulder of the highway and when examining outcrops located along Highways 60 and 653, on Renfrew County Road 61, and on other roads along the field trip route. All UTM co-ordinates are given in NAD83, Zone 18.

The Day 3 stops serve 2 main objectives. First, stops 21 to 29 in Bromley subdomain focus on the predominance of marble tectonic breccias in the subdomain, as well as the relationship between late syenite magmatism, metasomatism and the formation of calcite-diopside-apatite vein dikes along the Central Metasedimentary Belt boundary tectonic zone. Second, stops 30 to 32 in Ross subdomain illustrate the metamorphic contrast between Bromley and Ross subdomains, especially in terms of the differing degrees of preservation of carbonate rocks in each subdomain. Finally, if time allows, stops 33 to 36, located in a sliver of Mazinaw domain immediately west of the Ross fault, serve as a link to what was seen previously elsewhere in Mazinaw domain on Days 1 and 2.

Geological map references: Lumbers (1982a), Easton (2018).

- 0.0 km Start at the junction of Highway 60 and Renfrew County Road 20 (Bruce Street) in Renfrew. Head west on Highway 60 toward Douglas.
- 7.9 km Junction of Highway 60 and Renfrew County Road 61, stay straight on Highway 60.
- 19.9 km Pull off onto the shoulder of Highway 60 by long roadcut on both sides of the highway (UTM 349220E 5041800N).

Stop 21. Marble tectonic breccia

Marble tectonic breccias are common throughout the Bancroft terrane, especially in proximity to the Central Metasedimentary Belt boundary tectonic zone. Roadcuts on both sides of the road show a typical example, which contains a variety of fragment types and sizes in a matrix of white, coarse-grained calcite. Fragments constitute approximately 10 to 15% of the rock mass. Mafic fragments predominate and are tabular, angular, and locally show evidence of earlier folding. Also present are blocks of a medium-grained granitoid with coarse quartz grains. Calcite is beige weathering and somewhat finer grained where it has been dolomitized, likely by fluids moving through the rock during the Paleozoic, as the Precambrian–Paleozoic unconformity is present only a few hundreds of metres south of this outcrop.

Return to vehicles and continue west on Highway 60 into Douglas.

- 20.6 km Junction of Highway 60 and Renfrew County Road 5 in Douglas. Turn right and take Highway 60 north.
- 25.0 km Pull off onto the shoulder of Highway 60 opposite long roadcut on the west side of the road. Roadcut is on a curve so park safely taking the curve into account (southern end of outcrop is UTM 345761E 5044447N). Start at the main part of the outcrop just north of the guardrail and move south along the outcrop.

Optional Stop. Marble tectonic breccia and gneiss, Bromley subdomain

Roadcuts on the west side of the road show another example of a marble tectonic breccia; however, the marble tectonic breccia here has features common to both of the breccias observed at stops 21 and 22. As at stop 21, the typical matrix is white, coarse-grained calcite, with approximately 20%, dominantly tabular and angular, previously folded mafic fragments (Photo 12). Some parts of the marble tectonic breccia have been partly metasomatized, however, which results in the development of coarse pink calcite grains, the appearance of apatite and/or scapolite, and the alteration of the mafic fragments to diopside and scapolite (Photo 13). This transformation is only present locally in this roadcut—a near-complete transformation is present at stop 22.

Moving southward along the outcrop, there is a large pod or lens of medium-grained, sugary textured, grey to dark grey, compositionally layered, not obviously migmatitic gneiss that is cut by thin concordant and discordant syenite veins (Photo 14). This gneissic lens is in sharp contact with the adjacent marble breccia (Photo 15).

Return to vehicles and continue north on Highway 60.

26.5 km Pull off onto the shoulder of Highway 60 by long roadcuts on both sides of the road. Roadcut is on a curve so park carefully and safely (UTM 344426E 5045006N).



Photo 12. Marble tectonic breccia at optional field trip stop on Highway 60 north of Douglas. View to the west.



Photo 13. Marble tectonic breccia at optional field trip stop on Highway 60 north of Douglas. Outcrop face above hammer is white and typical of most marble tectonic breccia units. The breccia beside and to the right of the hammer is variably metasomatized, which resulted in the development of pink calcite and alteration of the mafic fragments to scapolite and diopside (note lighter colour of fragment immediately to the upper right of the hammer head). Hammer handle is 30 cm long. View to the west.



Photo 14. Fine- to medium-grained gneiss present in a large lens near the southern part of the outcrop at the optional field trip stop on Highway 60 north of Douglas. Note concordant syenite veinlets (lighter colour). Hammer handle is 30 cm long. View to the west.



Photo 15. Sharp contact between gneiss shown in Photo 14 (left) and marble tectonic breccia (right) in the southern part of the outcrop at the optional field trip stop on Highway 60 north of Douglas. Hammer handle is 30 cm long. View to the west.

Stop 22. Pink marble breccia, Bromley subdomain

This is an extremely complicated outcrop with large exposures on both sides of the highway. From north to south, on the west side of the highway, 5 main rock units are exposed. At the south end is a medium-grained, intermediate to mafic gneiss (dioritic?) cut by fine- to medium-grained red-pink syenite veins; minor diopside skarn and skarn-carbonate rock is present also. Moving north, there is a band of diopside skarn rock and metasomatized pink marble breccia. The marble breccia is an orange to pink to grey coarse-grained calcite-diopside-mica rock and green pyroxene skarn rock; locally, coarse pyroxene-calcite-apatite-scapolite-sulphide veins are present along with some lenses of mafic gneiss. Next are near-vertical, 3 to 4 m wide, discordant veins of fine- to medium-grained, vari-textured, pinkish pyroxene syenite that cut mafic gneiss, which is layered, equigranular, and locally metasomatized (Photo 16). The mafic gneiss is interlayered with pink carbonate rock and coarse pyroxene-calcite veins (Photo 17). The north end of the west roadcut is dominated by pink metasomatized marble breccia. It is an orange-pink-grey coarse-grained calcite-diopside-mica rock, with fine-grained dark green mafic fragments (pyroxenite) that are angular, tabular, and previously folded. Large lenses of mafic gneiss are present locally.

The outcrop on the east side of the highway shows the same succession of rock types, with the exception of the mafic gneiss at the extreme south end of the west outcrop. The pink metasomatized marble breccia is spectacularly exposed in the east side outcrop (Photos 18, 19 and 20).

28.1 km Junction of Highway 60 and Cobden Road. Turn left onto Highway 60 and head west toward Eganville.

32.6 km Pull off onto the shoulder of Highway 60 by long roadcut on the north side of the road (UTM 339600E 5046090N).



Photo 16. Irregular pink syenite veins cutting layered mafic to intermediate gneiss at stop 22. Outcrop on west side of highway. Scale card is 15 cm long. View to the west.



Photo 17. Coarse-grained orange-pink-white calcite vein cutting layered mafic to intermediate gneiss at stop 22. Outcrop on west side of highway. Scale card is 15 cm long. View to the west.



Photo 18. Coarse-grained orange-pink-white calcite marble tectonic breccia with mafic and other fragments at stop 22. Outcrop on east side of highway. No scale. View to the east.



Photo 19. Coarse-grained orange-pink-white calcite marble tectonic breccia with a large layered mafic gneiss fragment at stop 22. Outcrop on east side of highway. Scale card is 15 cm long. View to the east.



Photo 20. Large syenite fragment with biotite-diopside reaction rim in coarse-grained orange-pink-white calcite marble tectonic breccia at stop 22. Outcrop on east side of highway. Scale card is 15 cm long. View to the east.

Stop 23. Syenite and late calcite vein, Bromley subdomain

This roadcut consists predominantly of a compositionally heterogeneous pink, vari-textured pyroxene syenite, with grey fine-grained phases and locally pyroxene-rich phases. It is cut by a large subvertical zoned calcite veins (Photo 21), typical of the calcite-vein dikes common from Bancroft to the Ottawa River in the Bancroft terrane adjacent to the Central Metasedimentary Belt boundary tectonic zone. The syenite–vein contact on the east side of the vein consists mainly of red apatite and diopside, whereas the same contact on the west side of the vein consists of scapolite, apatite, amphibole and diopside.

Return to vehicles. Turn around and retrace route back on Highway 60 to junction with Cobden Road.

- 37.1 km Junction of Highway 60 and Cobden Road. Continue straight onto Cobden Road heading east toward Cobden.
- 39.0–39.5 km Road rises steeply, and crosses the Precambrian–Paleozoic unconformity.
- 39.5 km Pull off onto the shoulder of Cobden Road by low, long roadcut on the south side of the road after the crest of the hill. Park well past the crest of the hill and examine outcrops on both sides of the road (UTM 345695E to 345845E, 5048160N to 5048295N).

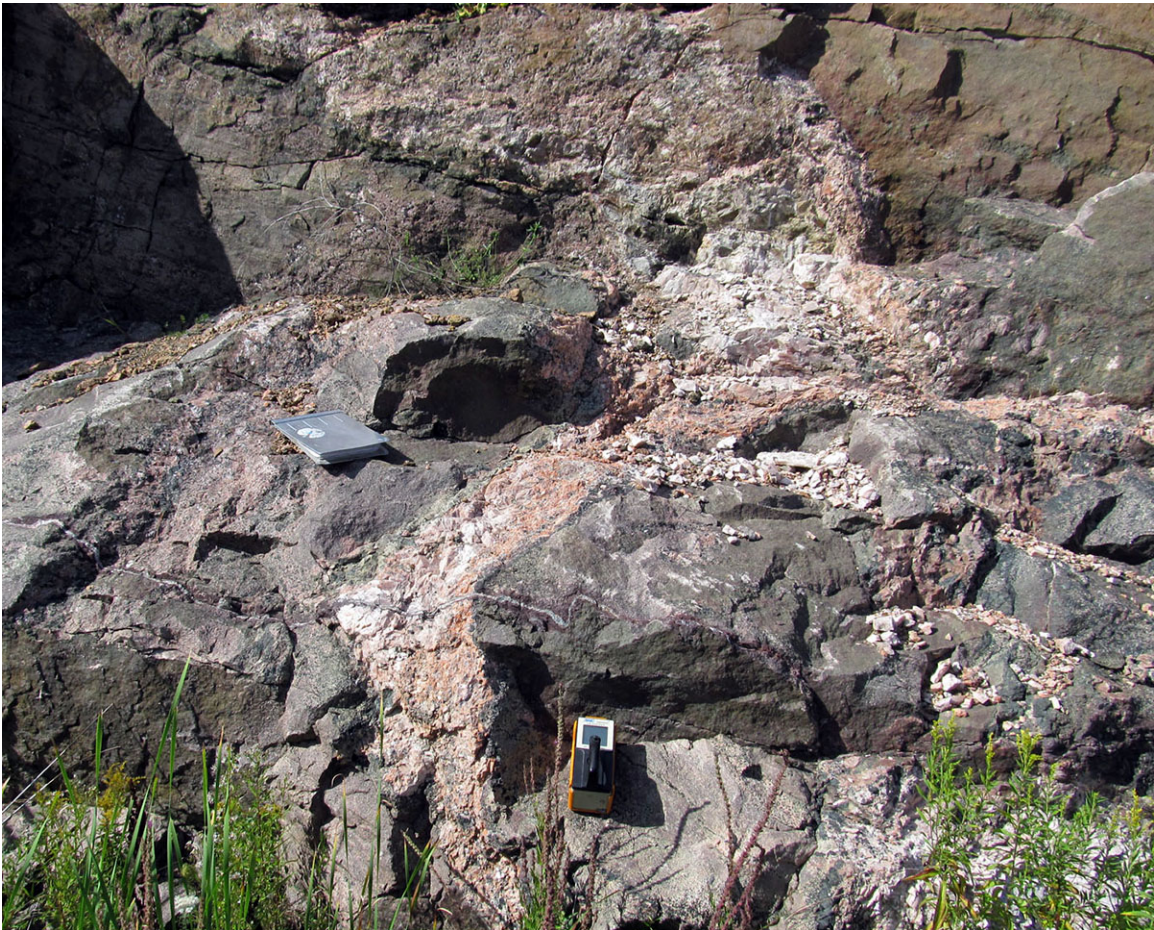


Photo 21. Zoned calcite vein cutting vari-textured syenite that includes grey fine-grained phases and pyroxene-rich phases, stop 23. Outcrop on north side of Highway 60. View to the north. Back of scintillometer (yellow-black) is 15 cm square.

Stop 24. Paleozoic rocks

The lowermost beds in this outcrop consist of grey, thin- to medium-bedded lithographic to fine-grained limestone of the Gull River Formation. Bedding in the limestone dips shallowly (3–4°) to the east. Moving east and up section, the limestone becomes interbedded with brown cross-bedded calc-arenite and bioclastic (crinoid) beds. The latter are more typical of the Bobcaygeon Formation, but, at this outcrop, the complete transition from the Gull River Formation into the Bobcaygeon Formation cannot be seen. Barnes (1967) recovered Rockland-age (*circa* 460 to 454 Ma) conodonts from this outcrop. This outcrop area was described also by Bleeker et al. (2011) as their Stop 3-2.

Near the top of the exposed section, on the north side of the road, are linear (two-dimensional) constructional bedforms. Barnes (1965, 1967) interpreted these features as paleo-spur and grove structures. Bleeker et al. (2011) noted that these bedforms are oriented approximately parallel to the axis of the structural embayment that preserves these strata. To form these bedforms, it is necessary to first erode a lithified coarse-grained seafloor and then colonize it with microbes; the latter produced carbonate mudstone to form the rounded tops observed at the present day (Bleeker et al. 2011). Bleeker et al. (2011) speculated that storm and/or tsunami events may have been responsible for the erosion, as there is no evidence for subaerial exposure of the limestone at the time of its deposition.

Based on the subdued nature of the total aeromagnetic field beneath this large regional outlier of Paleozoic rocks, the Paleozoic section may be on the order of 400 m thick in this area.

Return to vehicles. Continue east on Cobden Road.

42.8 km Junction with Barr Line. Continue east on Cobden Road heading east toward Cobden.

43.8 km Pull off onto the shoulder of Cobden Road by low, long roadcut on the north side of the road (either UTM 349005E 5051160N or UTM 348900E 5051070N).

Optional stop. Marble tectonic breccia, Bromley subdomain

The roadcuts on the north side of Cobden Road consist of marble tectonic breccias, with a variety of dark green and rusty paragneiss fragment, as well as one large block of granodiorite. Metasomatism is less intense than at the optional stop on Highway 60, but, nonetheless, there is local pink metasomatized marble breccia, as well as pyroxene skarn rock and pyroxene-rich veins.

44.8 km Pull off onto the shoulder of Cobden Road opposite low, long roadcut on the north side of the road (UTM 349590E 5051692N).

Stop 25. Quartz syenite, Bromley subdomain

The east and west ends of this outcrop area expose a pink, lineated, medium- to coarse-grained quartz syenite with scattered dark green pyroxene. Texture is varied throughout the rock, especially at the west end, with vari-textured pyroxene (Photo 22). The centre part of the outcrop consists of calc-silicate gneiss and mesocratic biotite paragneiss along with coarse-grained pyroxene skarn rock and veins.

The syenite is typical of the Late Syenite suite present near the Central Metasedimentary Belt boundary tectonic zone, which form more irregularly shaped and more compositionally heterogeneous bodies than do the syenites of the Kensington–Skootamatta suite (*circa* 1070 Ma). Because the syenite here is foliated, and possibly older than non-foliated syenites in the area, it was sampled in 2014 for U/Pb zircon geochronology (Photo 23). It yielded a concordant U/Pb TIMS age of 1080.5 ± 0.5 Ma (Kamo 2015) (Figure 19). This age makes it one of the oldest of the late syenites and is comparable in age to some of the older intrusions of the Kensington–Skootamatta suite.

- 48.3 km Junction of Cobden Road and Behm Line, turn right and head south on Behm Line.
- 50.5 km Junction of Behm Line and Patterson Road, continue south on Behm Line.
- 50.6 km Pull off onto the shoulder of Behm Line by low, long outcrops on the west side of the road (UTM 353455E 5052310N). Stop is on the west side of Behm Line.



Photo 22. Vari-textured syenite at stop 25 on the north side of Cobden Road. Marker is 14 cm long.



Photo 23. Geochronology sample site in syenite at stop 25, north side of Cobden Road. Hammer handle is 55 cm long. View to the north.

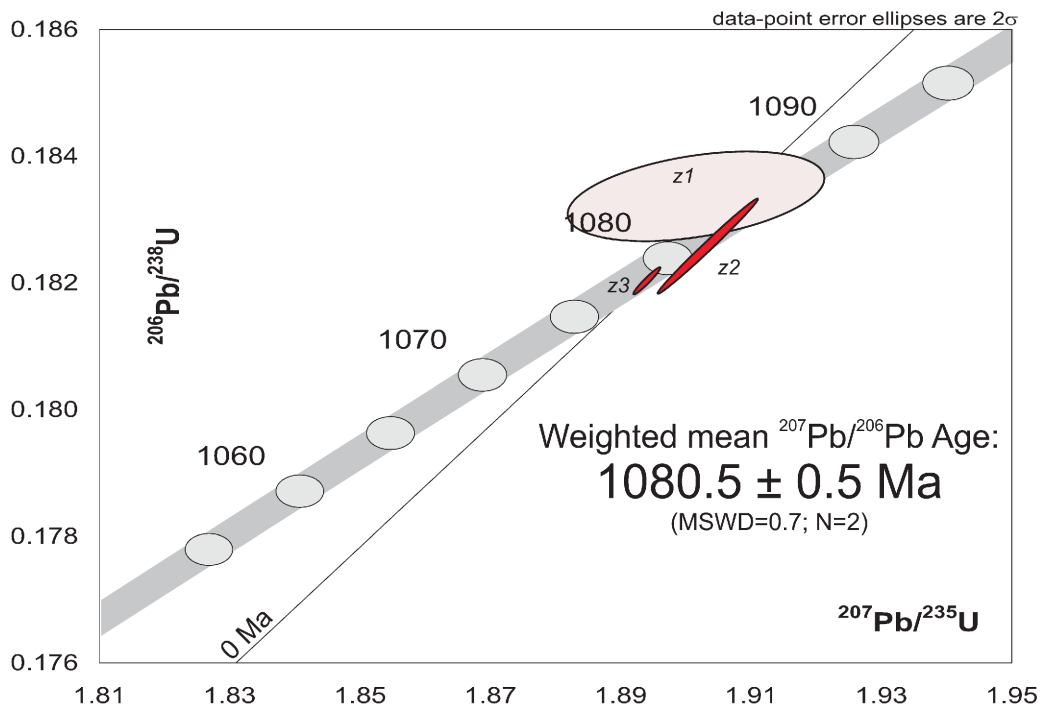


Figure 19. Concordia plot for geochronology sample 13RME-0073 collected from the syenite at stop 25. Figure from Kamo (2015).

Stop 26. Lake Clear-type syenite, Bromley subdomain

The large area of flat, rounded outcrops on the west side of the road are dominated by pink-green, pyroxene syenite that is vari-textured (Photo 24), as well as locally containing diopside-calcite clots (Photo 25). This vari-textured syenite is informally termed “Lake Clear-type syenite”, as it is similar to a large intrusion of syenite with similar features exposed farther to the west on the northeast shore of Lake Clear. The Lake Clear-type syenite cuts a slightly older leucosyenite to quartz syenite (*see* Photo 24), similar to that seen at the last stop (stop 25). The leucosyenite to quartz syenite is exposed also in small outcrops on the east side of the road, opposite the main outcrop area.

Return to vehicles and continue south on Behm Line.

52.6 km Pull off onto the shoulder of Behm Line by roadcut on the west side of the road (UTM 354570E 5050931N).



Photo 24. Outcrop area near the south end of stop 26 showing textural variations in the syenite present in this outcrop area. To the left is a pyroxene-rich, vari-textured syenite, to the right is a pyroxene-poor leucosyenite. The leucosyenite may be coeval with the syenite seen at stop 25. Hammer handle is 33 cm long.



Photo 25. Outcrop area at stop 26 showing a large coarse-grained feldspar and calcite clot in a pyroxene-rich, vari-textured syenite. Such calcite and/or feldspar clots and short veinlets are common in vari-textured syenites of the Lake Clear type. Hammer handle is 33 cm long.

Stop 27. Lake Clear–type syenite, calcite veins, apatite crystals, Bromley subdomain

Outcrops are present on both sides of the road; however, the large, higher exposure at the south end of the outcrop area on the west side of the road is the best spot to observe several large diopside-alkali feldspar-calcite-red apatite veins that cut classic Lake Clear–type vari-textured pyroxene syenite. Some calcite veins are locally alkali feldspar-rich (Photo 26). The largest vein has a coarse-grained diopside margin. Apatite is found in the more calcite-rich parts of the vein (Photos 27 and 28). These calcite-diopside veins are probably similar in age to the calcite vein observed at stop 23.

- 54.1 km Behm Line curves east into Rox Siding Road, continue east toward Highway 17.
- 55.5 km Junction of Rox Siding Road and Highway 17. Turn left onto Highway 17 heading north.
- 57.3 km Junction of Highway 17 and Kohlsmith Road. Turn right onto Kohlsmith Road heading east.
- 57.8 km Pull off onto the shoulder of Kohlsmith Road by long roadcuts on both sides of the road at the crest of the hill (UTM 355758E 5052516N). The best exposures of the calcite vein at this stop are on the north side of the road.



Photo 26. Stop 27. Large pink alkali-feldspar crystals in a calcite vein on the east side of Behm Line. Pen is 14 cm long.



Photo 27. Stop 27. Large red apatite crystals in a calcite vein on the west side of Behm Line. No scale.



Photo 28. Stop 27. Large red apatite crystals in a calcite vein on the west side of Behm Line. Green crystals are diopside; white material is calcite. Pen is 14 cm long.

Stop 28. Gneiss, calcite vein with apatite and fluorite crystals, Bromley subdomain

The outcrop consists of very thin-layered, grey, highly flattened, intermediate gneiss (Photo 29); typical of gneisses of the Central Metasedimentary Belt boundary tectonic zone. If these gneisses are part of the Central Metasedimentary Belt boundary tectonic zone, they are approximately 10 km south of where the boundary has traditionally been placed. One reason for this discrepancy is that many previous workers based the position of the boundary on the distribution of carbonate rocks, with the thought being that all carbonate rocks are part of the Central Metasedimentary Belt. However, as seen in many of the Day 3 stops, the calcite veins and metasomatized pink calcite rocks are atypical of the marbles found in the Central Metasedimentary Belt, and have crosscutting, almost igneous-like, relationships to their host rocks. Consequently, they are not a reliable indicator of whether one is in the Central Metasedimentary Belt or the Central Metasedimentary Belt boundary tectonic zone.

Also of interest in this outcrop is a larger, irregular, mineralogically diverse crosscutting alkali feldspar-diopside-hornblende-fluorite-green apatite-calcite vein (Photos 29 and 30). This vein differs from many of the others observed as part of Day 3 stops in that it is rich in fluorite and contains both red and green apatite crystals. Veins west of Highway 17 rarely contain fluorite and typically contain red apatite crystals. Veins east of Highway 17 toward the Ottawa River contain fluorite and are typified by green apatite crystals. Fluorite in the vein is not obvious on the weathered surface, but is readily apparent when the calcite part of the vein is broken open.

Return to vehicles and continue east on Kohlsmith Road.

- 61.2 km Junction of Kohlsmith Road and Mineview Road. Turn right and head southeast on Mineview Road.
- 61.5 km Pull off onto the shoulder of Mineview Road by long roadcuts on both sides of the road just south of the junction with Acres Road (UTM 360420E 5052280N).



Photo 29. Stop 28. Wedge-shaped, white calcite vein cutting irregularly layered gneiss of the Central Metasedimentary Belt boundary zone in an outcrop on the north side of Kohlsmith Road. Vein is subhorizontal, in the centre of the photograph and thickens to the right. No scale.



Photo 30. Stop 28. Close-up showing mineralogy of calcite vein exposed on north side of Kohlsmith Road. White material is calcite; pink phases are alkali feldspar; black material is hornblende. Hammer handle is 33 cm long.

Stop 29. Marble tectonic breccia, Bromley subdomain

This stop is located approximately 800 m northwest of the boundary with Mazinaw domain and 2.8 km northwest of the Ross fault. Marble tectonic breccia was exposed in 3 separate outcrop areas exposed at this road junction, but recent construction work has reduced the 2 southern outcrop areas to block rubble. Nonetheless, the textures and features of the breccia can still be seen in these blocks. The marble tectonic breccia here is somewhat different from the others observed at stops on Day 3 in that it contains mainly fine-grained quartzofeldspathic fragments that likely represent disrupted siliciclastic and calc-silicate sedimentary beds originally present in the limestone before metamorphism and deformation (Photo 31). Subrounded mafic fragments are also present, but they are less abundant than those observed at other stops on Day 3. No evidence for metasomatism, either in the form of pink calcite or coarse diopside is present.

Return to vehicles and continue southeast on Mineview Road.

- 64.3 km Approximate location of Ross fault, now entering Ross subdomain.
- 64.8 km Junction of Mineview Road and Magnesium Road, turn left and head east on Magnesium Road.
- 65.0 km Pull off onto the shoulder of Magnesium Road by long roadcut on the south side of the road by dolomite marble outcrop (UTM 362683E 5050055N). Cross the road and walk back to the outcrop on the north side of the road to view the calcite marbles (UTM 362636E 5050038N).



Photo 31. Stop 29. Marble tectonic breccia in outcrop on the east side of Mineview Road south of Acres Road.

Upper) Mafic block in marble tectonic breccia with surrounding calcite showing non-coaxial flow around the block, with flow-folds in the downstream eddy on the corner of the rotating boudin, the latter arrested at approximately 90°. The long dimension of the image is about 1.5 m. Photo courtesy of W. Bleeker, Geological Survey of Canada, Ottawa.

Lower) Note the presence of tabular, angular quartzofeldspathic fragments that likely represent metasedimentary rock layers that have been tectonically disrupted. Hammer handle is 33 cm long. View to the east.

Stop 30. Layered calcite and dolomite marbles, Ross subdomain

The outcrop on the north side of Magnesium Road exposes very thin- to thin-layered, medium-grained calcite marble with alternating white and dark grey layers (Photo 32). Layered marbles are typical of Ross subdomain, in contrast to Bromley subdomain, which is characterized by an abundance of marble tectonic breccia. Note that this location is only 3 km from stop 29 and approximately 300 m east of the Ross fault. The outcrops on the south side of Magnesium Road are massive blue-grey dolomite marble and calcitic dolomite marble. At the west end of the outcrop, the marble is cut by a 30 cm thick quartz-tourmaline vein.

Dolomite marbles constitute 30 to 40% of the marbles present in Ross subdomain, in contrast, dolomite marbles are almost absent in Bromley subdomain. Geochemical data from calcite and dolomite marbles of the Ross subdomain indicate that they are characterized by the presence of rare earth element patterns with negative cerium anomalies (Figure 20). Negative cerium anomalies in limestones are interpreted as indicating deposition in a marine environment with a minimal input of continental clastic debris (cf. Easton 1995). Forrester (2015) has also found that the calcite and dolomite marbles of the Ross subdomain also preserve strontium isotopic signatures that may reflect Mesoproterozoic seawater contents.

- 65.4 km Entrance to former magnesium metal mining operation. Continue east on Magnesium Road.
- 65.9 km Pull off onto the shoulder of Magnesium Road opposite Haley Industries. Examine roadcut on the north side of Magnesium Road (UTM 363432E 5050698N).

Return to vehicles and continue northeast on Magnesium Road.



Photo 32. Stop 30. Thin-layered calcite marble of Ross subdomain, north side of Magnesium Road. No scale. View to the north.

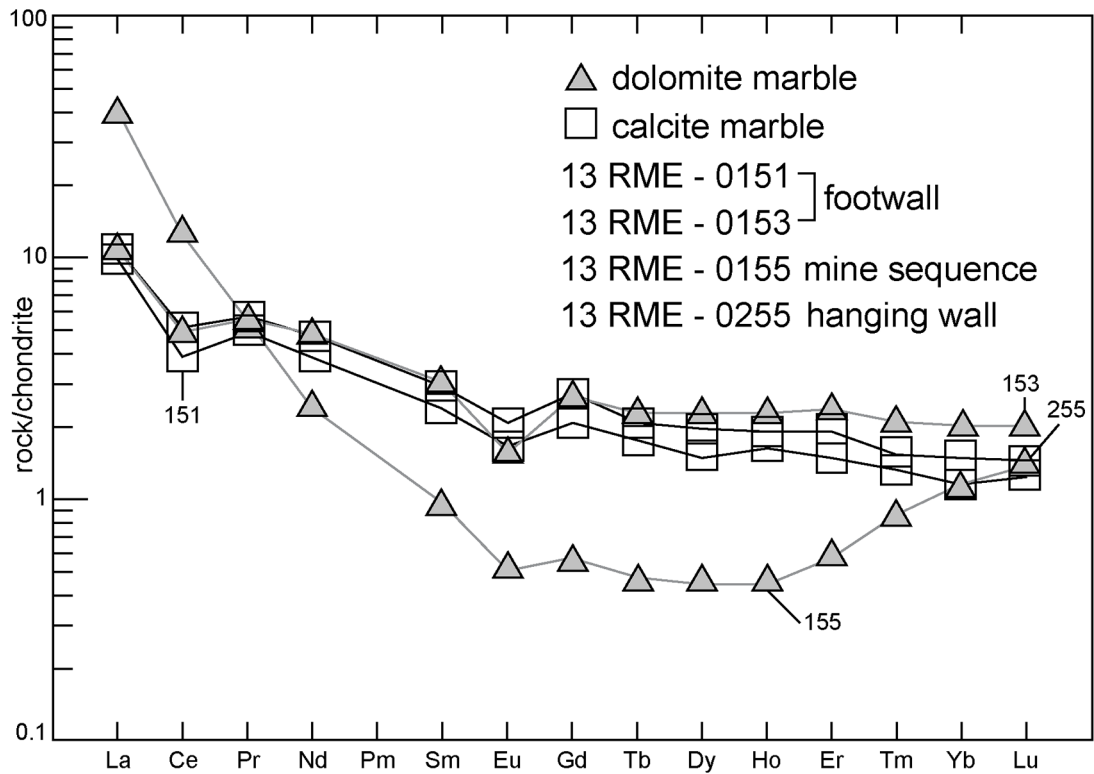


Figure 20. Representative rare earth element (REE) analyses of calcite and dolomite marbles from the area east of the Ross fault, including samples from the former Haley magnesium metal plant. The negative cerium (Ce) anomalies in 3 of the 4 samples are indicative of deposition in seawater (cf. Easton 1995). Samples 13RME-0151 and 13RME-0153 are from stop 30. Sample 13RME-0155 is from stop 31. Normalizing factors used are from Sun and McDonough (1989). All analyses are listed in Easton and Azar (2017). Figure from Easton (2014).

Stop 31. Hydrothermal altered dolomite marble (magnesium metal feedstock), Ross subdomain

This roadcut is approximately 80 m long with vertical faces up to 4 m high. Most of the outcrop is coarse-grained, massive dolomite marble. At the west end, there are 1 to 2 m thick tremolite marble layers. At the east end, there are tremolite-quartz pods and clots in the dolomite marble.

As noted at stop 30, marbles in Ross subdomain show apparent seawater rare earth element (REE) signatures. The only marbles not showing this signature are the dolomite and tremolite marbles found adjacent to the former magnesium metal plant at Haley (Dominion Magnesium Ltd., later Chromasco Ltd., later Timminico Ltd., MDI31F10SW00002). These magnesium-rich, and commonly silica-rich, marbles are characterized instead by very low total REE contents, and concave patterns where lanthanum, cerium, praseodymium, ytterbium and lutetium are high, and samarium, europium, gadolinium and terbium are low (*see* Figure 20). This unusual pattern is interpreted to be the result of post-depositional alteration of the original carbonate rock in a high-fluid flow regime, which likely introduced silica into the system and which also removed elements, such as zinc and some of the rare earth elements. Whether or not this hydrothermal alteration is related to a nearby subsurface aeromagnetic anomaly related to the Chenaux gabbro (Easton 2014) remains to be determined. Thus, the marbles (e.g., those at stop 31) that served as feedstock for magnesium metal production may be extremely unusual. Exploration for similar magnesium feedstock needs to focus not only on the presence of dolomite marbles, but also on the REE geochemistry of those dolomite marbles.

Return to vehicles and continue northeast on Magnesium Road.

- 67.6 km Junction, Magnesium Road and Queen Line. Turn right onto Queen Line and head south.
- 70.7 km Junction, Queen Line and Highway 653. Turn right onto Highway 653 heading west.
- 71.0 km Pull off onto the shoulder of Highway 653 just before Helmer Lane. Examine roadcuts on both sides of the road. Outcrop on south side of Highway 653 (UTM 367320E 5048355N). Outcrop on north side of Highway 653, east side of Helmer Lane (UTM 367302E 5048370N).

Stop 32. Coarse-grained, bronzite-bearing Chenaux gabbro, Ross subdomain

The Chenaux gabbro consists of gabbro, metagabbro, olivine-bearing gabbro and minor troctolite (Figure 21) with preserved primary igneous textures, and has recently been studied in detail by Azar (2015) (*see also* Azar and Easton 2015). Metagabbros show partial to complete replacement of clinopyroxene by hornblende and minor scapolite alteration of plagioclase. The olivine-bearing leucogabbros and troctolites show complicated multishelled corona textures along olivine–plagioclase interfaces. Minor titaniferous magnetite mineralization is found along the northern contacts of the intrusion and much of the intrusion contains elevated iron, titanium and vanadium. The oxide mineralization is magmatic and primary. Minor sulphide-bearing zones were found associated with dikes crosscutting the intrusion, but all have low or undetectable concentrations of nickel, copper and platinum group elements (PGE) (Azar 2015).

The Chenaux gabbro intrusion is cut by the east-trending Muskrat fault, where the block to the north is downthrown relative to the southern block (*see* Figure 21). Much of gabbro is massive, but tectonic foliation is well developed at the centre of the intrusion and along the southern contacts of the body. Primary igneous layering recorded in the Chenaux gabbro intrusion strikes southeast to southwest (Azar 2015; Azar and Easton 2015). The intrusion is interpreted to have formed within a primitive island arc,

which is supported by the iron-tholeiitic and calc-alkalic geochemical trend of the various mafic units (Azar 2015). An alternative environment may be a back-arc basin as suggested for many other gabbroic bodies with the Central Metasedimentary Belt (cf. Pehrsson, Hanmer and van Breemen 1996).

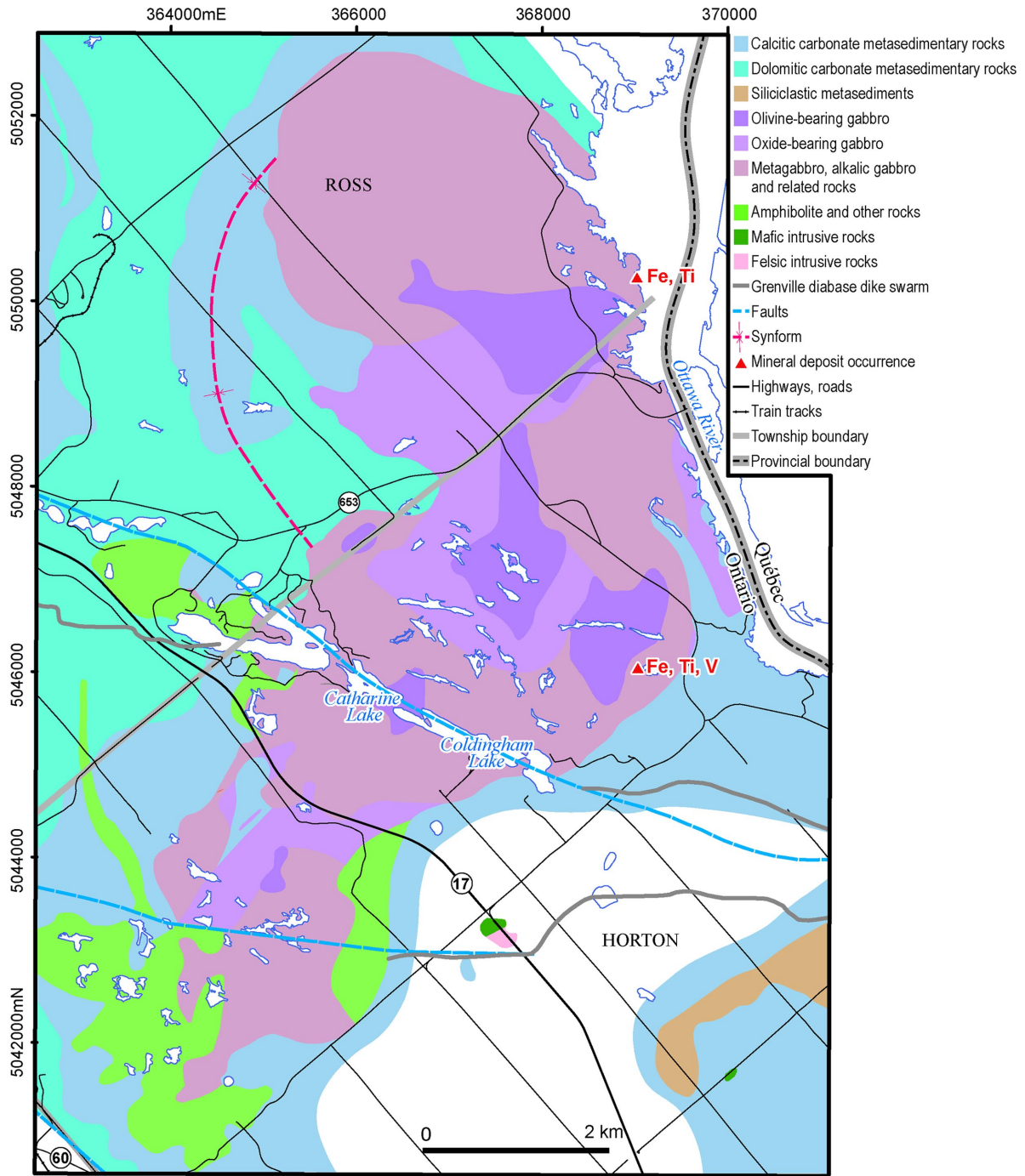


Figure 21. Geological map of the Chenaux gabbro intrusion in the northeastern Central Metasedimentary Belt, Grenville Province, showing the main units within the gabbro as well as the location of previously identified mineral occurrences. Chenaux gabbro subdivisions are from the Cobden area study; regional geology and faults are *from* Lumbers (1982b). Figure *from* Azar (2015).

This outcrop on the north side of Highway 653 and on the east side of Helmer Lane shows some of the better preserved rocks of the Chenaux gabbro. It consists of coarse- to very coarse-grained pyroxene leucogabbro with dark plagioclase (Photo 33). There are local amphibole rims around some pyroxene grains, as well as many large bronzite crystals (*see* Photo 33). The coarse-grained gabbro is cut by fine- to medium-grained vari-textured gabbro that forms dike-like bodies up to 30 cm wide in the coarse-grained pyroxene gabbro (Photo 34). This outcrop is the likely location of the geochronology sample of the Chenaux gabbro collected by Pehrsson, Hanmer and van Breemen (1996), who reported an upper intercept U/Pb TIMS age of 1231 ± 2 Ma for the Chenaux gabbro. The sample also contained some inherited zircons approximately 1321 million years old.

The outcrop opposite, on the south side of Highway 653 is approximately 70 m long with vertical faces up to 3.5 m high. It also consists mainly of coarse- to very coarse-grained pyroxene leucogabbro with dark plagioclase, local amphibole rims on the pyroxene rains, as well as minor fine-grained patches.

Return to vehicles and continue west on Highway 653.

- 75.3 km Entrance to dolomite marble quarry on the right (north). Continue west on Highway 653.
- 75.6 km Roadcut on the north side of Highway 653 consists of thin-layered calcite marble of the Ross subdomain, similar to that observed at stop 30. (Photo 35).
- 76.3 km Junction of Highway 653 and Magnesium Road. This junction also approximates the location of the Ross fault. We now cross over from Ross subdomain to the east into a thin sliver of Mazinaw domain rocks to the west.
- 76.8 km Junction of Highway 653 and 17. Continue straight (west) across Highway 17 and continue heading west, now along Renfrew County Road 61. As an alternative, you can turn left onto Highway 17 and head south toward Renfrew.
- 79.8 km Pull off onto the shoulder of Renfrew County Road 61 by large roadcut on the west side of the road (UTM 361386E 5045100N).



Photo 33. Stop 32. Close-up of coarse-grained gabbro showing large bronzite crystals. Pen is 14 cm long.



Photo 34. Stop 32. Coarse-grained gabbro in the lower left and bottom of the photograph is cut by finer grained gabbro present in the upper right of the photograph below the hammer. Hammer handle is 33 cm long. View to the northeast.



Photo 35. Thin-layered calcite marble from outcrop on the north side of Highway 653. No scale.

Stop 33. Gneissic granodiorite, Mazinaw domain

As noted, the Ross fault was crossed before reaching Highway 17; this location is part of an approximately 3.5 km wide sliver of Mazinaw domain rocks located between the Bromley subdomain and the Ross fault. The next 4 stops will look at rocks of the Mazinaw domain. Roadcuts on both sides of the road, approximately 95 m long and up to 4 m high, expose typical monzogranitic gneiss of the Mazinaw subdomain (Photo 36), possibly belonging to the Methuen intrusive suite. The monzogranite at this locality may have been alkali-feldspar megacrystic; however, the megacrysts are now mostly flattened. Methuen intrusive suite rocks have not yet been reported from Ross subdomain.

80.1 km Pull off onto the shoulder of Renfrew County Road 61 opposite roadcut on the east side of the road (UTM 361366E 5044815N).



Photo 36. Stop 33. Close-up of monzogranitic gneiss typical of this outcrop. Pen is 14 cm long.

Stop 34. Garnet gneiss, Mazinaw domain

The stop is an approximately 23 m long roadcut on the east side of the road, and is up to 3 m high. It consists of medium-grained, garnet-biotite amphibolite (andesite?) (Photo 37), with minor interlayered grey intermediate gneiss with quartz stringers. Some of the garnets are large. This outcrop, as well as the next outcrop along the road, and the outcrops by stop 35 are part of a package of metasedimentary and metavolcanic gneisses exposed in this part of Mazinaw domain. Return to vehicles and continue south-southwest on Renfrew County Road 61.

80.3 km Pull off onto the shoulder of Renfrew County Road 61 opposite roadcut on the east side of the road (UTM 361324E 5044608N).



Photo 37. Stop 34. Close-up of intermediate gneiss containing garnet at this stop. Pen is 14 cm long.

Stop 35. Calc-silicate gneiss and quartzite, Mazinaw domain

This stop focusses on the south end of an approximately 150 m long set of discontinuous outcrops exposed on the east side of Renfrew County Road 61. Outcrops at the north end consist of an approximately 7 m wide band of very thin-layered, biotite-diopside mafic gneiss that is interlayered with quartzose and calc-silicate gneiss similar to that which is exposed in the south end of the outcrop area.

The outcrop of interest consists of white weathering, thin- to very thin-layered, buff quartzose sandstone and buff weathering calc-silicate gneiss; the latter fizzes slightly with hydrochloric acid when powdered. The quartzose gneiss (Photo 38) was sampled for detrital zircon study, in part to compare with a quartzite sample from Ross subdomain. The sample from this outcrop yielded young ages of 1057 ± 12 Ma for zircon ($n=19$) (Figure 22) and 1041 ± 8 Ma for monazite (Figure 23) (LA-ICP-MS, Davis 2015). Older zircon grains of 1234 Ma, 1275 Ma and 1422 Ma, likely detrital in origin, were also reported (Davis 2015). The age of metamorphism given by the zircon is similar to a metamorphic age of 1054 ± 3.2 Ma obtained from a leucogabbroic gneiss in the Hurds Lake area (Kamo 2012), albeit on the east side of the Ross fault.

The quartzite sample from Ross subdomain recorded a different history than stop 35. It had a dominant detrital population at 1268 ± 21 Ma ($n=13$), as well as metamorphic zircons at 1088 ± 38 Ma (Davis 2015).

Return to vehicles and continue south-southwest on Renfrew County Road 61.

- 83.7 km Junction of Renfrew County Road 61 and Highway 60. Turn left onto Highway 60 and head east toward Renfrew.
- 84.3 km Pull off onto the shoulder of Highway 60 by long roadcuts on both sides of the road. Cross the road and examine the west end of the north roadcut (UTM 361375E 5041175N).



Photo 38. Stop 35. Close-up of quartzose metasedimentary rock sampled for geochronology at this locality. No scale, but beds are 2 to 5 cm thick.

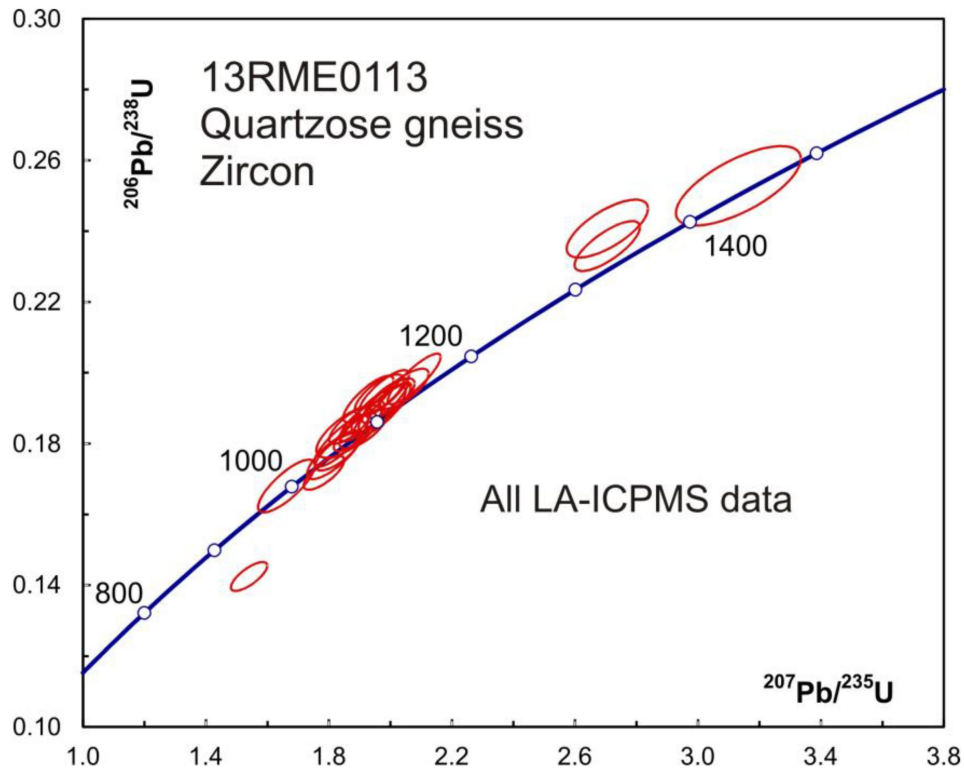


Figure 22. LA-ICP-MS analyses of detrital zircons from sample 13RME-0113 at stop 35. Note the presence of a few detrital grains; however, most zircons are metamorphic with an age peak at 1057 ± 12 Ma based on 19 grains. Figure from Davis (2015).

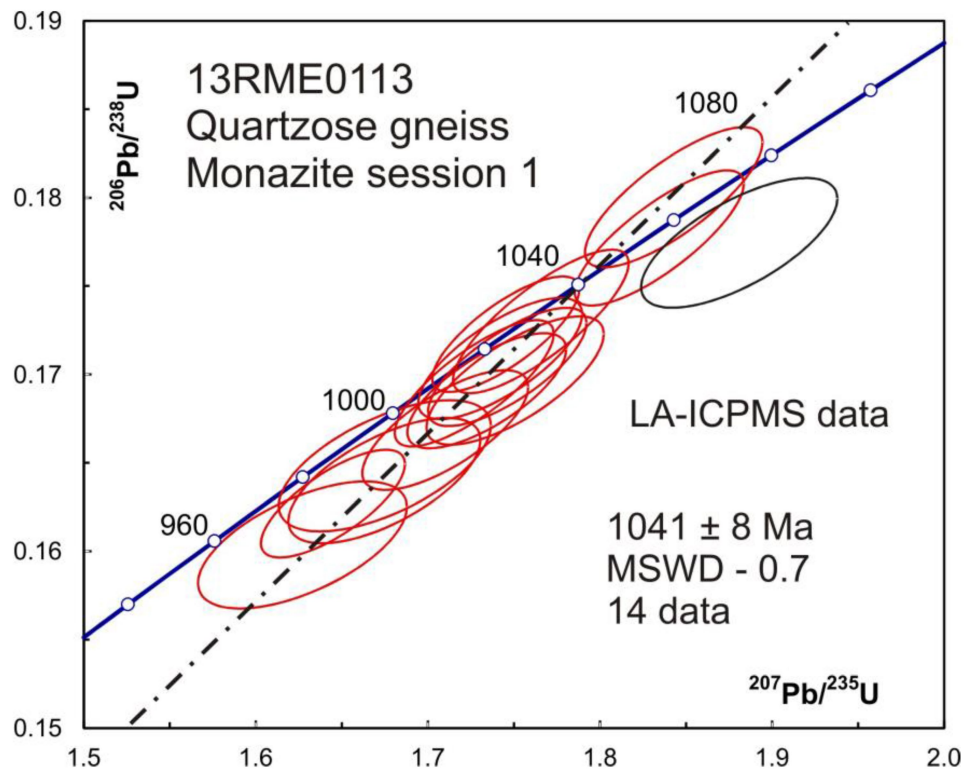


Figure 23. LA-ICP-MS analyses of monazite grains from sample 13RME-0113 at stop 35. All appear to be metamorphic, with an age peak at 1041 ± 8 Ma. Figure from Davis (2015).

Stop 36. Woermke-type mafic dike and intermediate gneiss (metavolcanic), Mazinaw domain

The majority of this outcrop consists of highly strained, very thin-layered, medium-grained, granular, dioritic to granodioritic gneiss (andesitic metatuff?), with pyroxene stringers and clots (Photo 39). Quartz clots and broken quartz stringers common.

At the north end of the roadcut on the north side of Highway 60 is a 10 m long, up to 1 m wide, metamorphosed, mafic dike that is discordant to fabric in gneiss (Photo 40), but which is metamorphosed itself. The fact that it is metamorphosed indicates that it is not a Grenville-swarm dike. Based on geochemistry and the fact that the dike is metamorphosed but not deformed, suggests that it is a Woermke-type dike, which has an age of *circa* 1073±3 Ma (Kamo 2012).



Photo 39. Stop 36. Close-up of intermediate gneiss (meta-andesite tuff?) at this locality. Pen is 14 cm long.

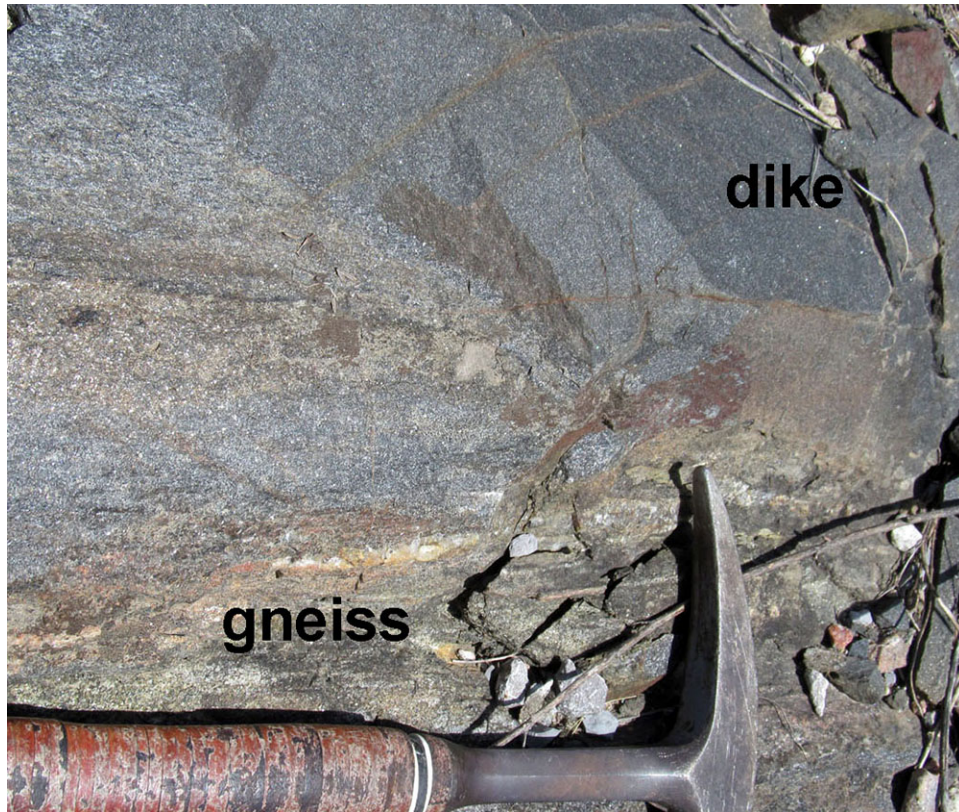


Photo 40. Stop 36. Contact between intermediate gneiss (meta-andesite tuff?) (lower part of outcrop) and grey, fine-grained dike (upper part of outcrop). Hammer handle is 33 cm long.

Return to vehicles and continue south-southwest on Renfrew County Road 61.

91.6 km Junction of Highway 60 and Renfrew County Road 20 (Bruce Street) in Renfrew.

END OF DAY 3 STOPS.

END OF ROAD LOGS; END OF FIELD TRIP.

Acknowledgments

S.L. Kamo and D.W. Davis of the Jack Satterly Geochronology Laboratory, University of Toronto, are thanked for their dedicated and meticulous study of the zircon, titanite and monazite grains separated from our many geochronology samples submitted as part of this 5-year study. P.S. LeBaron, of the Resident Geologist's Office, Ontario Geological Survey, Tweed, is thanked for serving as a driver and additional field trip safety officer when this trip was run as a post-meeting field trip for the Geological Association of Canada–Mineralogical Association of Canada (GAC–MAC) Joint Annual Meeting held in Kingston, May 14–18, 2017. The staff of the Rocky Mountain House in Renfrew provided excellent service to the field trip leaders and the field trip participants in May 2017. The authors also wish to thank all the participants of the GAC–MAC field trip for their discussion and active participation on the trip, and the guidebook has been improved as a result of these discussions.

Appendix 1.

Summary of Geochronological Data for the Northeastern Central Metasedimentary Belt

Appendix-Table 1-1. Summary of geochronological data for intrusive rock suites in the northeastern Central Metasedimentary Belt.

Age (in Ma)	Method	Mineral	Stratigraphic Unit and Sample Number	Interpretation	Source
1285±20 1237±11	U/Pb LA-ICP-MS	Zircon	Metatextitic tonalite, Bartraw dome 14KW-184A	Oldest population, 6 grains new growth, 10 grains	Davis (2015)
1274±14	U/Pb TIMS	Zircon	Metatextitic tonalite, Bartraw dome 14KW-184A	Upper intercept age, oldest grain 1251±4 Ma	Kamo (2016)
1247±14	U/Pb LA-ICP-MS	Zircon	Gneissic monzogranite, Black Donald intrusion, possible Elzevir intrusive suite 13SMA-141A	Age of emplacement, 12 grains	Davis (2015)
1245.6±2.3	U/Pb LA-ICP-MS	Zircon	Migmatitic tonalite gneiss 12SM-146	Age of emplacement, 60 grains, range from 1117 to 1321 Ma	Geospec Consultants (2013)
1245±5	U/Pb LA-ICP-MS	Zircon	Griffith batholith, metatextitic tonalite 15QD-001A	Age of emplacement	Davis (2016)
1241±2	U/Pb TIMS	Zircon	Griffith batholith, northern lobe, gneissic megacrystic tonalite 15RME-8008	Age of emplacement	Kamo (2016)
1231±2	U/Pb TIMS	Zircon	Chenaux gabbro, Ross subdomain	Age of emplacement, upper intercept age, inherited grain at 1321±2	Pehrsson, Hanmer and van Breemen (1996)
1229±5	U/Pb TIMS	Zircon	Raglan Hills gabbro	Age of emplacement, upper intercept age	Pehrsson, Hanmer and van Breemen (1996)
1229±3	U/Pb TIMS	Zircon	Methuen intrusive suite gneissic monzogranite 11SM-104	Minimum age of emplacement, intercept age 1230 ^{+30/-16} Ma	Kamo (2012)
1226±2	U/Pb TIMS	Zircon	Griffith batholith, gneissic gabbro 15MD-017A	Age of emplacement, metamorphism at <i>circa</i> 1160 Ma	Kamo (2016)
1225±3	U/Pb TIMS	Zircon	Griffith batholith, gneissic monzogranite, Methuen intrusive suite equivalent, 15QD-214	Age of emplacement, metamorphism at <i>circa</i> 1160 Ma	Kamo (2016)
1223±9	U/Pb LA-ICP-MS	Zircon	Methuen intrusive suite gneissic monzogranite, Brudenell map area 11RME-0119	Age of emplacement, 20 grains, minimum age of emplacement	Kamo (2013)
1208±3	U/Pb TIMS	Zircon	Gneissic diorite, Glasgow complex, 11SM-106	Age of emplacement, Concordia age	Kamo (2012)
1223±1	U/Pb TIMS	Zircon	Syn-folding garnet granite, Black Donald domain 14MD314C	Age of emplacement	Davis (2015)
1213±8	U/Pb LA-ICP-MS	Zircon	Tonalite that intruded Raglan Hills gabbro 11RME-0024	Minimum age of emplacement	Geospec Consultants (2013)
1213.4±5.4	U/Pb TIMS	Zircon	Hurds Lake tonalite, 11SM-012	Weighted mean age, minimum age of emplacement	Kamo (2012)
1210±9	U/Pb LA-ICP-MS	Zircon	Porphyritic granodiorite 11MD-248	Age of emplacement, 19 grains	Kamo (2013)
1206±2	U/Pb TIMS	Zircon	Lake Clear monzogranite	Minimum age	Lumbers et al. (1990); S.B. Lumbers and L.M. Heaman, unpublished data, 2007

Abbreviations: LA-ICP-MS = laser ablation inductively coupled plasma mass spectrometry; CA-TIMS = chemical abrasion thermal ionization mass spectrometry; TIMS = thermal ionization mass spectrometry.

Appendix-Table 1-2. Summary of geochronological data for rocks from the Rocher–Fendu subdomain.

Age (in Ma)	Method	Mineral	Stratigraphic Unit and Sample Number	Interpretation	Source
1232.8 ^{+3.9} / _{-2.7}	U/Pb TIMS	Zircon	Lapilli tuff, New Calumet Mine, Quebec	Age of deposition of tuff	Gauthier (2017)
1232±7 1213±8	U/Pb LA-ICP–MS	Monazite zircon	Gneissic diorite, Ontario 13RME-0175	Age of emplacement; zircon suffered minor lead loss giving slightly younger age	Davis (2015)
1227±15 1213±8 1230±3 1224±9	U/Pb TIMS	Monazite and zircon zircon monazite	Gneissic diorite, Ontario 13RME-0175	Age of emplacement; oldest concordant zircon, minimum age; 2 concordant monzonite grains	Kamo (2015)

Abbreviations: LA-ICP–MS = laser ablation inductively coupled plasma mass spectrometry; CA-TIMS = chemical abrasion thermal ionization mass spectrometry; TIMS = thermal ionization mass spectrometry.

Appendix-Table 1-3. Summary of detrital zircon ages and metamorphic ages from metasedimentary rocks in the northeastern Central Metasedimentary Belt. Most samples yielded only metamorphic ages.

Age (in Ma)	Method	Mineral	Stratigraphic Unit and Sample Number	Interpretation	Source
1268±21	U/Pb LA-ICP–MS	Zircon	Quartzose gneiss, Ross subdomain 13RME-0361	Near single-source detrital population based on 13 grains, metamorphic zircon growth at 1088±38 Ma	Davis (2015)
1223.7±25	U/Pb LA-ICP–MS	Zircon	Quartzose gneiss block in marble tectonic breccia near Palmer Rapids 12RME-0438	Near single-source detrital population with 74 grains giving 1223.7 Ma. Age range from 1097 to 1301 Ma	Geospec Consultants (2013)
1208±5 1131±8	U/Pb LA-ICP–MS	Zircon	Flinton Group quartzose gneiss, Horton map area, 11MD-062, stop 14	One grain at 1676 Ma, 3 grains at 1343, 1381, 1485 Ma, most grains 1013 to 1255 Ma; 3 population peaks, youngest is metamorphic	Geospec Consultants (2012)
1065±9 metamorphism only	U/Pb LA-ICP–MS	Zircon	Calc-silicate gneiss, Bancroft terrane, Brudenell area 13RME-1081	No detrital grains, uniform population of metamorphic zircon, 19 grains, titanite grains are on a chord (i.e., reference line) between 898 and 1762 Ma	Davis (2014)
1057±12 metamorphism	U/Pb LA-ICP–MS	Zircon	Quartzose gneiss, northern Mazinaw domain near Ross fault 13RME-0113, stop 35	Metamorphic age based on 19 grains. Only 3 detrital grains at 1231, 1275 and 1422 Ma. Might be 2 periods of metamorphic zircon growth at <i>circa</i> 1050 Ma that cannot be resolved	Davis (2015)

Abbreviations: LA-ICP–MS = laser ablation inductively coupled plasma mass spectrometry; CA-TIMS = chemical abrasion thermal ionization mass spectrometry; TIMS = thermal ionization mass spectrometry.

Appendix-Table 1-4. Summary of geochronological data for rocks of Shawinigan Orogeny age in the northeastern Central Metasedimentary Belt, includes both emplacement and metamorphic ages.

Age (in Ma)	Method	Mineral	Stratigraphic Unit and Sample Number	Interpretation	Source
1201±10	U/Pb LA-ICP-MS	Zircon	Metatextitic tonalite, Bartraw dome 14KW-184A	10 grains, age of metamorphism?	Davis (2015)
1200±5	U/Pb LA-ICP-MS	Monazite	Garnet-granite, remobilized leucosome 13MD-006C	Age of emplacement, 20 grains;	Davis (2016)
1192±8		Zircon		age of emplacement, 8 grains;	Davis (2016)
1169±3	U/Pb CA-TIMS	Zircon		minimum age of emplacement	Kamo (2014)
1190±6	U/Pb LA-ICP-MS	Zircon	Kennelly gneissic diorite 13MD-050A	Age of emplacement, population peak of 20 grains,	Davis (2016)
1132±2	U/Pb TIMS	Zircon		minimum age of emplacement, also grains at 1148±3 and 1157±12 Ma	Kamo (2014)
1189 ⁺³⁵ / ₋₁₁ 1181 ⁺⁶⁰ / ₋₁₈	U/Pb TIMS	Zircon	Deformed granite pegmatite dikes near Killaloe	Upper intercept ages give minimum age of emplacement of each dike	McEachern and van Breemen (1993)
1187.1±2.4	U/Pb LA-ICP-MS	Zircon	Mafic to intermediate migmatite 12SM-034	Age of emplacement based on population peak of 58 grains, grains range from 1087 to 1294 Ma	Geospec Consultants (2013)
1167±13	U/Pb LA-ICP-MS and TIMS	Zircon	monzonite to syenite 14SM-046	11 of 16 grains gave an age of 1167±13 Ma using LA-ICP-MS. TIMS gave a minimum age of emplacement <i>circa</i> 1160 Ma, but could be as old as 1180 Ma, partial resetting of titanite to 1115±3 Ma	Kamo (2013)
1158±26 metamorphism	U/Pb LA-ICP-MS	Zircon	Griffith batholith, metatextitic tonalite 15QD-001A	Age of metamorphism, thick rim, low U/Th	Davis (2016)
1157±7 metamorphism	U/Pb CA-TIMS	Zircon	Gabbro associated with Griffith batholith 15QD-001B	Age of metamorphism, small grains, low U/Th	Kamo (2016)
1156±9 metamorphism	U/Pb LA-ICP-MS	Zircon	Gneissic monzogranite, Black Donald intrusion, possible Elzevir intrusive suite 13SMA-141A	Age of metamorphism, 9 grains	Davis (2015)
1154±7 metamorphism	U/Pb TIMS	Zircon	Raglan Hills gabbro	Age of metamorphism, near-concordant grain	Pehrsson, Hanmer and van Breemen (1996)
1152±2 1141±1	U/Pb TIMS	Titanite	Marble tectonic breccia, 13-1, 13-2	Age of metamorphism	Mezger et al. (1993)
1150±5	U/Pb CA-TIMS	Zircon	Eleanor syenite 15RME-8009	Age of emplacement, alternatively emplacement at >1160 Ma and metamorphism at <i>circa</i> 1150 Ma	Kamo (2016)
1138±3 metamorphism 1101±11	U/Pb TIMS U/Pb LA-ICP-MS	Zircon	Methuen intrusive suite gneiss monzogranite, Brudenell area 11RME-0119	Maximum age of new zircon growth; age of new zircon growth, 10 grains	Kamo (2013)
1135±3	U/Pb TIMS	Zircon	Mylonitic quartz syenite 12LR-077B	Upper intercept age, best estimate of emplacement	Kamo (2013)
1133 zircon 1145 monazite <i>circa</i> 1000 monazite	U/Pb TIMS	Zircon, monazite	Granulite facies gneiss ~6 km southeast of Whitney	Other samples in Barry's Bay area give metamorphic ages of 1100, 1080–1060 and 1040 Ma	Carr and Berman (1997)
1107±16 1110±17	U/Pb CA-TIMS	Zircon	Elbow Lake anorthosite 13SMA-132A	Upper intercept age near-concordant grain	Kamo (2015)

Abbreviations: LA-ICP-MS = laser ablation inductively coupled plasma mass spectrometry; CA-TIMS = chemical abrasion thermal ionization mass spectrometry; TIMS = thermal ionization mass spectrometry.

Appendix-Table 1-5. Summary of geochronological data for rocks of the Late Syenite suite in the northeastern Central Metasedimentary Belt.

Age (in Ma)	Method	Mineral	Stratigraphic Unit and Sample Number	Interpretation	Source
1088±2	U/Pb TIMS	Zircon	Calabogie syenite, Kensington–Skootamatta suite	Age of emplacement	Corriveau et al. (1990)
1080.5±0.5	U/Pb CA-TIMS	Zircon	Foliated quartz syenite, 13RME-0073, stop 24	Age of emplacement	Kamo (2015)
1079±2	U/Pb TIMS	Zircon	Syenite pegmatite near Jewellville	Minimum age of dike emplacement	McEachern and van Breemen (1993)
1073±3	U/Pb CA-TIMS	Zircon	Woermke gabbro 11RME-0157	Age of emplacement	Kamo (2012)
1062 to 1033	U/Pb TIMS	Zircon	Lake Clear syenite	Age of emplacement, minor inheritance in some zircons	Childe, Mungall and Martin (2000)
1053±2	U/Pb TIMS	Zircon	Sullivan Island carbonatite complex	Age of emplacement	T.E. Krogh <i>cited in</i> Lumbers (1982d)
1054.5±1.5	U/Pb CA-TIMS	Zircon	Tory Hill Nepheline syenite 09RME-1035	Age of emplacement	Kamo (2012)
1048±2	U/Pb TIMS	Titanite	Pegmatite ACP-3	Age of emplacement	Mezger et al. (1993)
1043±4	U/Pb TIMS	Zircon	Foymount syenite	Age of emplacement	Lumbers et al. (1990); S.B. Lumbers and L.M. Heaman, unpublished data, 2007
1042±4 1043±6	U/Pb TIMS	Titanite	Pegmatite 18-1, 18-2	Age of emplacement	Mezger et al. (1993)
1042±3	U/Pb CA-TIMS	Zircon	Wolfe Nepheline syenite 11RME-0001	Age of emplacement	Kamo (2012)
1041±2	U/Pb TIMS	Zircon	Smart pegmatite	Age of emplacement	Lumbers et al. (1990); S.B. Lumbers and L.M. Heaman, unpublished data, 2007
1041±3	U/Pb TIMS	Titanite	Pegmatite ZR15	Age of emplacement	Mezger et al. (1993)
1033±7	U/Pb TIMS	Zircon	Meany pegmatite	Age of emplacement	Lumbers et al. (1990); S.B. Lumbers and L.M. Heaman, unpublished data, 2007
1033±1	U/Pb CA-TIMS and LA-ICP-MS	Zircon	Lorwell syenite 11RME-0075	Age of emplacement	Kamo (2013)

Abbreviations: LA-ICP-MS = laser ablation inductively coupled plasma mass spectrometry; CA-TIMS = chemical abrasion thermal ionization mass spectrometry; TIMS = thermal ionization mass spectrometry.

Appendix-Table 1-6. Summary of Ottawa Orogeny metamorphic ages from the northeastern Central Metasedimentary Belt.

Age (in Ma)	Method	Mineral	Stratigraphic Unit and Sample Number	Interpretation	Source
1109±19 1088±38	U/Pb LA-ICP-MS	Monazite zircon	Quartzose gneiss, Ross subdomain 13RME-0361	Average monazite age, metamorphic zircon growth at 1088±38 Ma	Davis (2015)
1083±36	U/Pb LA-ICP-MS	Zircon	Metatextitic tonalite, Bartraw dome 14KW-184A	5 grains, age of latest metamorphism	Davis (2015)
1078±2	U/Pb TIMS	Titanite	Methuen intrusive suite gneiss monzogranite, Brudenell area 11RME-0119	Titanite 1078, 1074 by TIMS 1017 by LA-ICP-MS	Kamo (2013)
1017±7 1074±7	U/Pb LA-ICP-MS U/Pb LA-ICP-MS	Zircon	Intermediate migmatite gneiss, Central Metasedimentary Belt boundary tectonic zone 13RME-1080	Age of crystallization, 33 grains	Davis (2014)
1066±14	U/Pb LA-ICP-MS	Zircon	Kennelly gneissic diorite 13MD-050A	Metamorphic grain, youngest grain in sample, low U/Th	Davis (2015)
1065±9	U/Pb LA-ICP-MS	Zircon	Calc-silicate gneiss, Bancroft terrane, Brudenell area 13RME-1081	uniform population of metamorphic zircon, 19 grains	Davis (2014)
1057±12	U/Pb LA-ICP-MS	Zircon	Quartzose gneiss, northern Mazinaw domain near Ross fault 13RME-0113, stop 35	Metamorphic age based on 19 grains	Davis (2015)
1054±3.2	U/Pb TIMS	Zircon	Leucogabbro, north side of Hurds Lake intrusion, 11SM-050	Weighted mean age, age of metamorphism	Kamo (2012)
1052±3	U/Pb TIMS	Zircon	Granite vein cutting fabric in Stafford thrust sheet, same outcrop as 14RME-0103	Age of dike emplacement, dike compositionally similar to 13RME-1079 which yielded a similar age	McEachern and van Breemen (1993)
1050±5 or 1036±12	U/Pb TIMS	Zircon	Granite boudin infill in Central Metasedimentary Belt boundary tectonic zone gneiss 13RME-1079	Maximum age of boudin emplacement either <i>circa</i> 1050 from 2 near- concordant grains or <i>circa</i> 1036 Ma from youngest grains	Kamo (2014)
1049±14	U/Pb LA-ICP-MS	Zircon	Syn-folding garnet granite, Black Donald domain 14MD314C	Age of metamorphism, 9 zircon grains;	Davis (2015)
1037±5	U/Pb LA-ICP-MS	monazite		age of metamorphism, 24 monazite grains	
1049±2	U/Pb TIMS	titanite	Griffith batholith, northern lobe, gneissic megacrystic tonalite 15RME-8008	Age of metamorphism	Kamo (2016)
1046±20 metamorphism	U/Pb TIMS	Zircon	Raglan Hills gabbro	Age of metamorphism, near concordant grain	Pehrsson, Hanmer and van Breemen (1996)
1044±23 1041±8	U/Pb LA-ICP-MS	Monazite	Quartzose gneiss, northern Mazinaw domain near Ross fault 13RME-0113, stop 35	run 2, 7 grains; run 1, 14 grains but more scatter, metamorphic zircon at 1057±12 Ma	Davis (2015)
1037±14	U/Pb LA-ICP-MS	Zircon	Gneissic monzogranite, Black Donald intrusion, possible Methuen intrusive suite 13SMA-141A	Age of metamorphism, 4 grains	Davis (2015)
1030±40	U/Pb LA-ICP-MS	Titanite	Porphyritic granodiorite 11MD-248	Age of metamorphism, 3 grains	Kamo (2013)
1024±7	U/Pb LA-ICP-MS	Zircon	Flinton Group quartzose gneiss, Horton map area, 11MD-062, stop 14	Age of metamorphism, 8 grains	Geospec Consultants (2012)
<i>circa</i> 1020	U/Pb TIMS	Titanite	Griffith batholith, gneissic monzogranite, Methuen intrusive suite equivalent 15QD-214	Age of younger metamorphic event	Kamo (2016)

Abbreviations: LA-ICP-MS = laser ablation inductively coupled plasma mass spectrometry; CA-TIMS = chemical abrasion thermal ionization mass spectrometry; TIMS = thermal ionization mass spectrometry.

Appendix-Table 1-7. Summary of young metamorphic and/or cooling ages from the northeastern Central Metasedimentary Belt.

Age (in Ma)	Method	Mineral	Stratigraphic Unit and Sample Number	Interpretation	Source
1006±3	U/Pb TIMS	Titanite	Lorwell syenite 11RME-0075	Cooling through titanite closure temperature	Kamo (2013)
1006±2	U/Pb TIMS	Titanite	Hurds Lake tonalite 11SM-0012	Cooling through titanite closure temperature	Kamo (2012)
1002±3	U/Pb TIMS	Titanite	Glasgow complex 11SM-0106	Cooling through titanite closure temperature	Kamo (2012)
1000±26	U/Pb LA-ICP-MS	Titanite	Migmatite, Central Metasedimentary Belt boundary tectonic zone 13RME-1080	Age of titanite and zircon closure in rock that crystallized at <i>circa</i> 1074 Ma	Davis (2014)
998±6	U/Pb TIMS	Titanite	Sullivan Island carbonatite complex	Cooling through titanite closure temperature	T.E. Krogh <i>cited in</i> Lumbers (1982d)
989±2	U/Pb TIMS	Titanite	Elbow Lake leucogabbro 14MD-134A	Cooling through titanite closure temperature	Kamo (2015)
988±2	U/Pb LA-ICP-MS	Titanite	Protomylonitic monzonite to syenite 14SM-046	Cooling through titanite closure temperature	Kamo (2013)
985±2	U/Pb TIMS	Titanite	Hurds Lake tonalite 11SM-012	Cooling through titanite closure temperature	Kamo (2012)
946±47	U/Pb LA-ICP-MS	Titanite	Calc-silicate gneiss, northern Bancroft terrane, Brudenell area 13RME-1081	Cooling through titanite closure temperature	Davis (2014)

Abbreviations: LA-ICP-MS = laser ablation inductively coupled plasma mass spectrometry; CA-TIMS = chemical abrasion thermal ionization mass spectrometry; TIMS = thermal ionization mass spectrometry.

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³ At the time this report was published (October 2017), this publication is “*in press*”.

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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 9	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 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.

ISSN 0826-9580 (print)
ISBN 978-1-4868-0375-0 (print)

ISSN 1916-6117 (online)
ISBN 978-1-4868-0376-7 (PDF)

