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Insights into the Tectonic and Metamorphic Architecture of the Composite Arc Belt and the Frontenac–Adirondack Belt near Perth, Ontario, Grenville Orogen: A Geological Guidebook

2017

ONTARIO GEOLOGICAL SURVEY

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Insights into the Tectonic and Metamorphic Architecture of the Composite Arc Belt and the Frontenac–Adirondack Belt near Perth, Ontario, Grenville Orogen: A Geological Guidebook

by

R.M. Easton

2017

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Abstract

The Perth map area is located within the Mesoproterozoic Grenville Province. The map area straddles 2 major tectonic divisions of the Central Metasedimentary Belt: Sharbot Lake domain and Frontenac terrane. The 5 to 10 km wide Maberly shear zone, a *circa* 1162 million-year-old deformation zone, forms the boundary between the 2 divisions and is well exposed within the Perth map area. Approximately 45% of the map area consists of Paleozoic sandstones and limestones that overlie the Precambrian basement.

The Frontenac terrane consists of marble, quartzite and paragneiss, which were metamorphosed to granulite facies at *circa* 1168 Ma, coincident with emplacement of monzonite, syenite and diorite plutons of the Frontenac intrusive suite. Frontenac intrusive suite plutons younger than *circa* 1164 Ma occur in both Frontenac terrane and Sharbot Lake domain, indicating that the 2 terranes had been amalgamated together by that time. In contrast, Sharbot Lake domain is a marble-dominated terrane, although amphibolite, derived from mafic metavolcanic rocks, is abundant along parts of the Maberly shear zone and in the northwestern part of the domain. The supracrustal rocks of Sharbot Lake domain were intruded at *circa* 1225 Ma by large gabbroic intrusions of the Lavant intrusive suite and, at least in the southeast, by plutons of the Frontenac intrusive suite. Between 1090 and 1065 Ma, both the Frontenac terrane and the Sharbot Lake domain were intruded by monzonite, syenite and granite plutons of the Kensington–Skootamatta intrusive suite.

Current mineral production from the Perth map area consists of aggregate extraction from quarries in the Paleozoic March and Oxford formations, with past extraction also from the Covey Hill and Nepean formations. Historic mineral production and advanced exploration activities in Precambrian rocks included graphite and vermiculite from marbles, mica and feldspar from granitoid pegmatite veins; and mica and apatite from pyroxenite pods and/or veins. The latter have the potential to host rare earth mineralization. Relatively pure calcite and dolomite marbles occur in both Sharbot Lake and Frontenac terranes and are suitable for a variety of industrial uses.

A day-long field excursion providing an overview of the Precambrian geology of the Perth map area is included in this report. The majority of the stops focus on the tectonic, magmatic and metamorphic history of the Maberly shear zone. Within Frontenac terrane, stops focus on the evidence for higher metamorphic pressures than previously known, the character of the early Frontenac intrusive suite (*circa* 1190–1178 Ma) rock units in the map area, and metasomatic mica-apatite-pyroxenite rocks. This report complements the geological map, report and data publications for the Perth map area, which will be released as separate products. The combination of road-accessible stops included in this guidebook is designed to illustrate important aspects of the geology, stratigraphy and geological evolution of this segment of the Grenville Province.

Insights into the Tectonic and Metamorphic Architecture of the Composite Arc Belt and the Frontenac–Adirondack Belt near Perth, Ontario, Grenville Orogen: A Geological Guidebook

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2017

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Introduction

PREFACE

This field trip guidebook was prepared for a 1-day pre-meeting field trip (Trip A-1) held in conjunction with the Geological Association of Canada–Mineralogical Association of Canada (GAC–MAC) Annual Meeting hosted in Kingston, Ontario from May 14 to 17, 2017. The reasons for preparing this geological guidebook were many, and included the fact that the author had just completed 2 summers of mapping in the Perth map area (Easton 2015, 2016a, 2016b) and that this meeting was a prime opportunity to showcase some of the findings from that field work (Project Unit 15-014) to a broad audience. Furthermore, the proximity of Perth to Kingston, and the fact that no one had run a field trip that examined the geology of the Perth map area in detail for over 50 years, also contributed to the decision to prepare this guidebook. Finally, 2017 represented the 50th Anniversary of the release of a classic geological field trip guidebook for the Grenville Province in Ontario that arose from a joint Geological Association of Canada–Mineralogical Association of Canada–Mineralogical Association of America held in Kingston in August to September 1967 (Jenness 1967). Although no stops from this 1967 guidebook were located in the Perth map area, the route from Kingston to Perth utilized during the 2017 field trip retraced part of the route of one of the 1967 field trips.

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.

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

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 (*see* 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 %

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. 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. Geochemical data related to the field trip are included in Appendix 1. Complete geochemical data related to the Perth mapping project can be found in Easton (2018a).

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.

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 both the Composite Arc Belt and the Frontenac 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). 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
- alkalic suites: Nepheline Syenite suite (1160–1050 Ma), Frontenac suite (1180–1150 Ma), Kensington–Skootamatta suite (1085–1070 Ma).

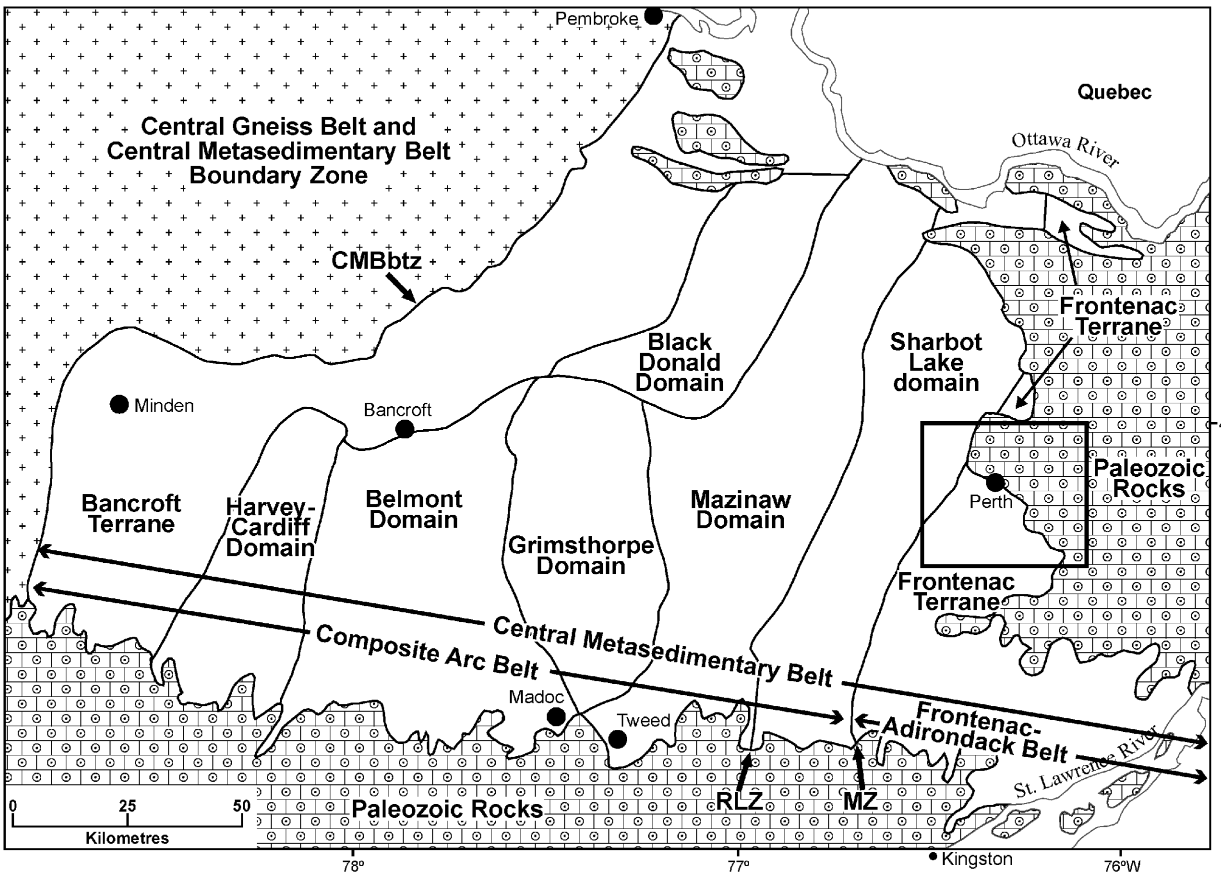

Figure 1. Terrane and domain subdivisions of the Central Metasedimentary Belt (*modified from* Easton 1992) showing the location of the Perth map area (boxed area). Abbreviations: MZ, Maberly shear zone; RLZ, Robertson Lake mylonite zone.

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

Historic or Lithologic	Regional Tectonic	Local Tectonic or Historic
Key Divisions		
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 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 (subterranes). Many, if not all, lithotectonic domains in the Central Metasedimentary Belt are fault-bounded and, thus, they could be termed subterranes.

Two main orogenic events have affected the Frontenac terrane and the Sharbot Lake domain:

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

Geological Setting

The Perth map area (NTS map area 31 C/16) (Figure 2) is bounded by latitudes 44°45′ to 45°00′N and longitudes 76°00′ to 76°30′W, encompasses approximately 1088 km^2, and includes all or parts of Bastard, Beckwith, Burgess, Dalhousie, Drummond, Elmsley, Kitley, Montague, North Crosby and South Sherbrooke townships. The cities of Perth and Smiths Falls are located in the map area; the city of Perth celebrated its bicentennial in 2016.

Previous mapping of the Precambrian geology of the area dates from the 1950s (Dugas 1950; Wilson and Dugas 1961). Paleozoic rocks cover approximately 45% of the Perth map area and were mapped last by Williams and Wolf (1984). Recent acquisition of high-resolution aeromagnetic data for the area (Ontario Geological Survey 2014a, 2014b) allows, in part, for tracing Precambrian units beneath Paleozoic cover rocks.

Two main lithotectonic subdivisions of the Central Metasedimentary Belt of the Grenville Province are present in the Perth map area, with Highway 7 approximately coincident with the boundary between the 2 subdivisions (*see* Figure 2). To the southeast are medium-pressure granulite- and upper amphibolite-

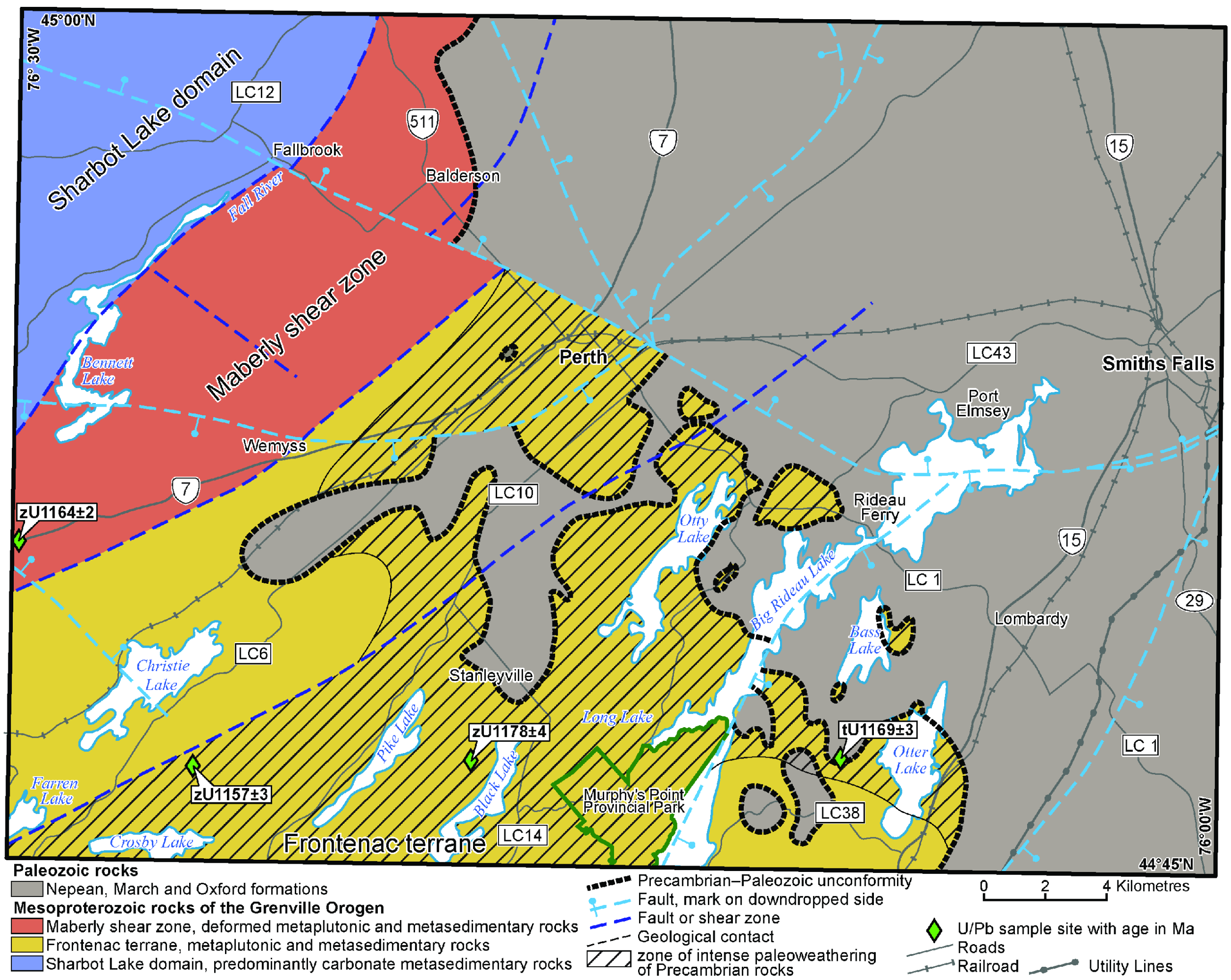

Figure 2. Major geological features present in the Perth map area. Geology is *modified from* Hewitt (1964b), Wilson and Dugas (1961) and Williams and Wolf (1984). Geochronological data: U/Pb zircon (zU) ages, in Ma, shown on the figure are *from* Davidson and van Breemen (2000); titanite age (tU) is *from* Mezger et al. (1993). The abbreviation "LC" designates Lanark County roads. *Modified from* Easton (2015, Figure 18.1).

facies rocks of the Frontenac terrane, whereas to the northwest are upper greenschist- to lower amphibolite-facies rocks of the Sharbot Lake domain (*see* Figure 2). They are separated by the Maberly shear zone that formed at *circa* 1160 Ma (Corfu and Easton 1997; Davidson and Ketchum 1993; Davidson and van Breemen 2000).

Detailed descriptions of the Frontenac terrane and Sharbot Lake domain can be found in Easton (1992) and Carr et al. (2000). The following brief summary is based on those sources. The Frontenac terrane consists of marble, quartzite and paragneiss, which were metamorphosed to granulite facies at *circa* 1168 Ma, coincident with emplacement of monzonite, syenite and diorite plutons of the Frontenac intrusive suite (Easton 1992; Corfu and Easton 1997). Frontenac intrusive suite plutons younger than *circa* 1164 Ma occur in both Frontenac terrane and Sharbot Lake domain, indicating that the 2 terranes were amalgamated to one another by that time. Argon–argon cooling ages on hornblende suggest that the Frontenac terrane was little affected by subsequent Grenville metamorphic events after *circa* 1120 Ma (Cosca, Sutter and Essene 1991). In contrast, the Maberly shear zone contains argon–argon cooling ages on hornblende of *circa* 1035 Ma (Cosca, Sutter and Essene 1991).

In contrast, Sharbot Lake domain is a marble-dominated terrane, although amphibolite, derived from mafic metavolcanic rocks, is abundant along parts of the Maberly shear zone and in the northwestern part of the domain. The supracrustal rocks of Sharbot Lake domain were intruded at *circa* 1225 Ma by large gabbroic intrusions of the Lavant intrusive suite (Corfu and Easton 1997) and, subsequently, at least in the southeast, by plutons of the Frontenac intrusive suite. Between 1090 and 1065 Ma, both the Frontenac terrane and the Sharbot Lake domain were intruded by monzonite, syenite and granite plutons of the Kensington–Skootamatta intrusive suite (Easton 1992).

Current mineral production from the Perth map area consists of aggregate extraction from quarries in the Paleozoic March and Oxford formations, with past extraction also from the Covey Hill and Nepean formations. Historic mineral production and advanced exploration activities in Precambrian rocks included graphite and vermiculite from marbles, mica and feldspar from granitoid pegmatite veins; and mica and apatite from pyroxenite pods and/or veins. Mineral potential related to these pyroxenite pods and/or veins has been discussed by Easton (2016b).

REGIONAL STRUCTURAL FEATURES AND THE PERTH MAP AREA

Some aspects of the geology of the Perth map area can only be understood within the context of the regional structural pattern, as indicated in Figure 2. Of particular significance are the packages of rocks present along the Sharbot Lake domain–Frontenac terrane boundary and the placement of this boundary.

In the southwest part of the Perth map area is a highly deformed northeast-trending belt, up to 10 km wide, of gabbroic and anorthositic rocks of the Lanark–Oso intrusion (Miller 1899; Wolff 1985) and surrounding migmatitic, granitoid-dominated orthogneisses. This belt pinches out between Fallbrook and Balderson (*see* Figures 2 and 3). From Highway 511 north of Perth to Carleton Place, a package of quartzite, migmatitic paragneiss and marble tectonic breccia occurs in the immediate footwall of the Maberly shear zone (*see* Figure 3). To the immediate north of the presently defined Maberly shear zone is the Wolf Grove structure (*see* Figure 3), which contains high metamorphic grade gneisses similar in age to rocks of Frontenac terrane (Buckley, Easton and Ford 1997; Corfu and Easton 1997). Marbles located between the Wolf Grove structure and the Maberly shear zone have been previously assigned to Sharbot Lake domain, in part because of their relatively purity and the presence of seawater geochemical signatures (Easton 1995). However, the presence of seawater geochemical signatures in relatively clean marbles in the Brooke belt of the western subdomain of Frontenac terrane, as discussed in “Marble Geochemistry and Stratigraphy”, allows for the possibility that the location of the Sharbot Lake domain–Frontenac terrane boundary might be better placed on the north side of the Wolf Grove structure, rather than in its current position subparallel to Highway 7 (*see* Figure 3).

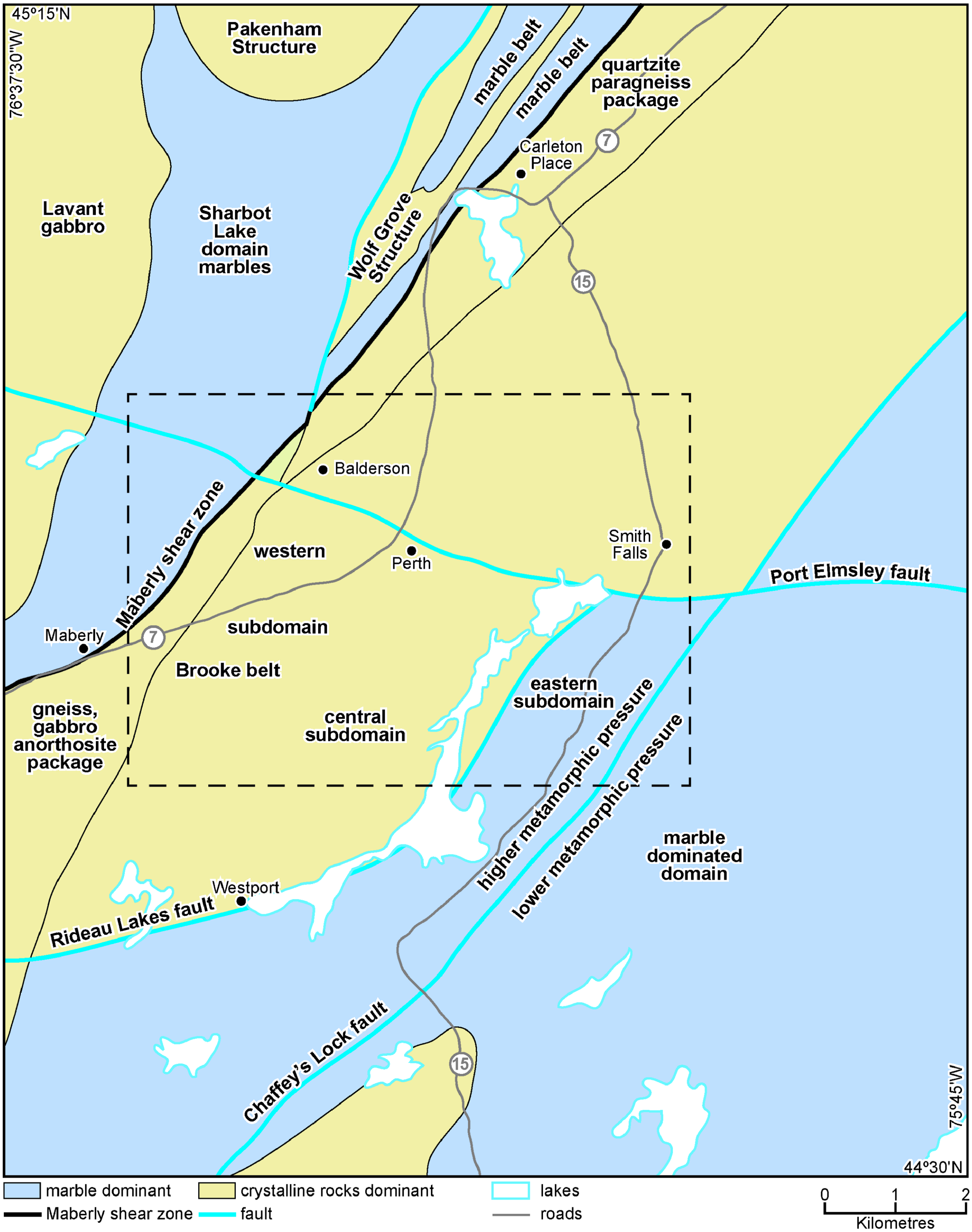

Figure 3. Major Precambrian geological features present in eastern Ontario. Plutonic rocks of the Frontenac suite and the Precambrian–Paleozoic unconformity are not shown for the purpose of clarity. Outline (dashed black line) indicates the location of the Perth map area. *See* text for details.

Easton (2015, 2016a) divided Frontenac terrane in the Perth map area into 3 subdomains (Figure 4). From west to east, these are the western, central and eastern subdomains. As discussed in more detail in "Conditions of Regional Metamorphism", a significant metamorphic pressure change occurs along a north-northeast-trending fault located southeast of Smiths Falls (*see* Figure 3). This fault also appears to separate rocks of the 3 subdomains in the Perth map area from a large marble-dominated belt present in Frontenac terrane to the east and southeast of the Perth map area (*see* Figure 3).

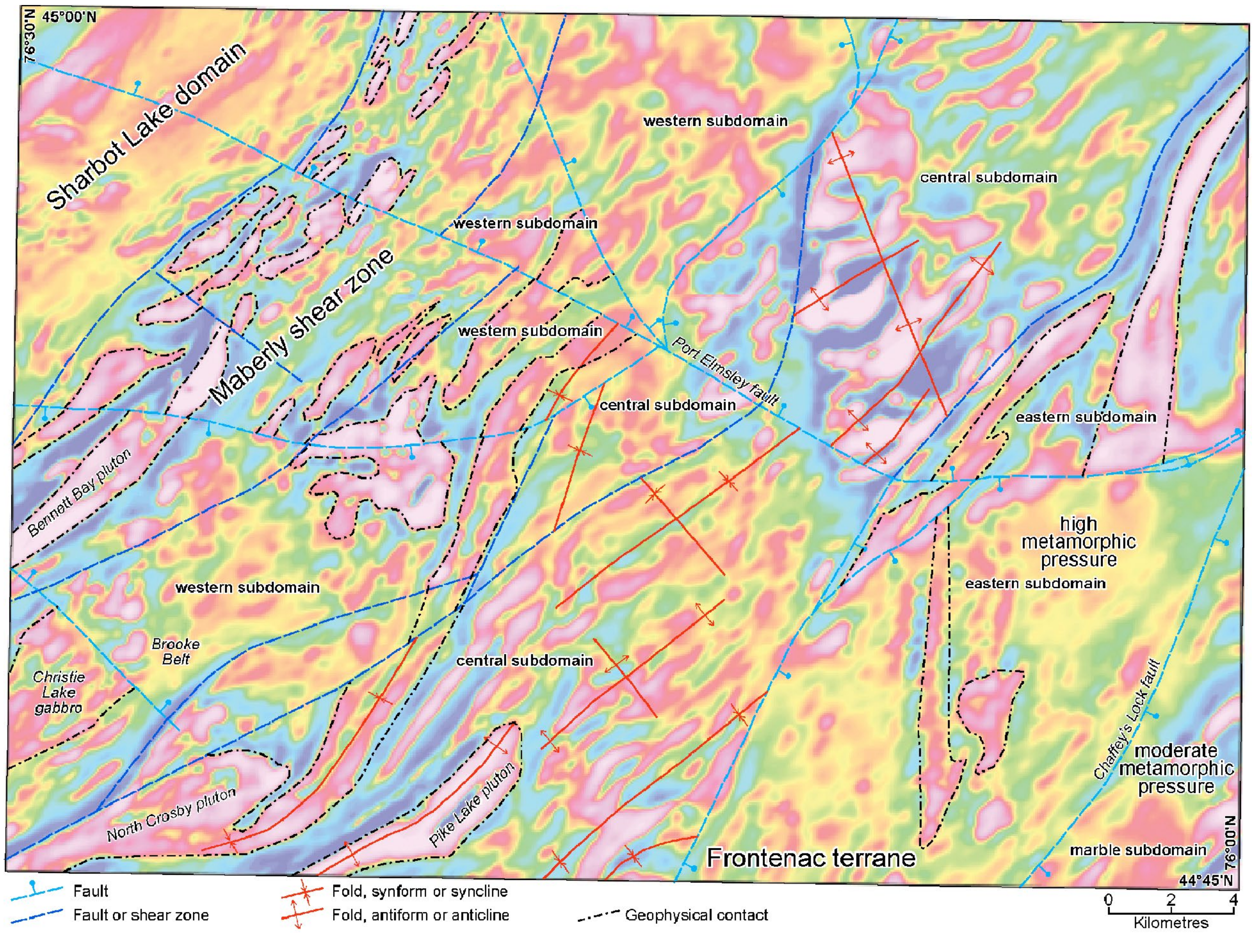

Figure 4. Major Precambrian geological features present in the Perth map area, superimposed on an image of the first vertical derivative of the total magnetic field (data *from* Ontario Geological Survey 2014a, 2014b). *See* text for details on the characteristics of the subdomains present in Frontenac terrane. Geographic features, downdropped fault indicators and the Precambrian–Paleozoic unconformity shown in Figure 4 are omitted for clarity. *Modified from* Easton (2015, Figure 18.2).

FRONTENAC TERRANE

Subdomain Characteristics

The western subdomain consists of both felsic and mafic Frontenac suite intrusions that are rimmed by migmatitic, compositionally varied, quartzofeldspathic gneisses that are commonly cut by smaller irregular bodies and sills of Frontenac suite intrusive rocks. It is not clear if these smaller intrusive bodies are simply sheet-like injections of magma emplaced during deformation, or if they represent cupolas or roof-pendants of a larger intrusive body at depth. Thin slivers of marble separate the plutonic-gneiss units from one another. To some degree, the western subdomain has many of the characteristics of the plutonic-gneiss units present in the Maberly shear zone, but is less deformed.

Frontenac suite intrusions in the western subdomain consist of pre- to syntectonic (e.g., Pike Lake pluton, 1178±4 Ma), syntectonic (e.g., Bennett Bay pluton, 1164±2 Ma) and posttectonic (e.g., North Crosby pluton, 1157±3 Ma) intrusions (all ages *from* Davidson and van Breemen 2000). This relative age range is also observed in the smaller Frontenac suite intrusions. Older intrusions, especially the smaller bodies, appear to be more quartz rich (quartz syenite, quartz syenite) than the younger intrusions (syenite, monzonite). The margins of some of the pre- to syntectonic intrusions, including some intrusions that are only 50 m wide, are intrusion breccias, consisting of both coeval mafic rocks and mafic xenoliths. The presence of these intrusion breccias, especially phases that exhibit magma-mingling textures, such as ball-and-pillow structures, suggests that there was an early phase of Frontenac suite mafic magmatism that has not been previously recognized.

The central subdomain, located between Black Lake and Big Rideau Lake, is characterized by a dome-and-basin–folded geometry (*see* Figure 4) and represents the middle part of the stratigraphic sequence described by Wynne-Edwards (1967) in the Westport area (Table 3), which is located directly to the south.

The eastern subdomain, located east of Big Rideau Lake, is dominated by marbles. A prominent feature of the eastern subdomain is a linear, north-trending, 1 to 2 km wide, magnetic high (*see* Figure 4). The source of this magnetic high has yet to be determined, as it is almost entirely located beneath Paleozoic strata.

Marble Geochemistry and Stratigraphy

Mapping and geochemical sampling during the 2015 and 2016 field seasons revealed differences in the character of the marbles present in the 3 subdomains of Frontenac terrane, as follows.

1. Eastern subdomain marbles are predominantly dolomite and dolomitic calcite marbles with minor silicate impurities, some interbedded quartzite, and minor interlayered paragneiss or plutonic rocks. They also contain weak cerium anomalies and Y/Ho values >35, both suggesting partial preservation of seawater geochemical signatures. The low total rare earth element abundance and cerium anomalies in these samples is also an indication of the relatively purity (i.e., lack of clay minerals) of many of these samples.
2. Central subdomain marbles are predominantly calcite marbles, typically with 10 to 20% silicate minerals, commonly diopside and phlogopite. Marble tectonic breccias are observed in many parts of this subdomain. These samples contain no cerium anomalies. Some samples have moderate total rare earth element contents (70 to 150 ppm) and rare earth element patterns similar to the post-Archean Australian Shale composite (Taylor and McLennan 1985) that cannot be related directly to silicate mineral content.

Table 3. Proposed Grenville Supergroup stratigraphy in the Westport area (*modified from* Wynne-Edwards 1967, p.112) and possible equivalent units in the Perth map area. All supracrustal units of the Grenville Supergroup are older than 1178±4 Ma, the age of the oldest Frontenac suite pluton in the Perth area (Davidson and van Breemen 2000).

Westport Area	Perth Area	Comment
Upper major marble (unit 4)	eastern subdomain marbles with minor quartzite, commonly cut by white quartz monzonite to quartz syenite veins	Relatively clean dolomite and dolomitic calcite marbles
	central subdomain, impure marbles and interlayered quartzofeldspathic paragneiss and calc-silicate paragneiss	Impure marbles, would correspond to lower major marble (unit 2) of Wynne-Edwards (1967)
Thin quartzite and quartzose gneiss interlayered with migmatitic quartzofeldspathic gneiss (unit 3 upper)	central subdomain, includes minor interlayered impure marble, marble tectonic breccia and quartzite	Approximate stratigraphic position of sample CL-1, with a maximum age of deposition of 1306±16 Ma (Sager-Kinsman and Parrish 1993)
Migmatitic quartzofeldspathic gneiss, garnet-bearing gneiss, cordierite-garnet gneiss, quartz-biotite-feldspar and quartz-biotite-feldspar-diopside gneiss (unit 3 lower)	central subdomain, core of structural domes	May include rocks of both units 1 and 3 of Wynne-Edwards (1967). Rb/Sr whole-rock age of 1204±72 Ma by Krogh and Hurley (1968)
Lower major marble (unit 2)	western subdomain, mainly the Brooke marble belt	Relatively clean marbles
Migmatitic quartzofeldspathic gneiss and pyroxene granulite associated with gneissic quartz monzonite and quartz syenite (unit 1)	western subdomain and southwestern central subdomain	Found primarily as slivers between Frontenac suite plutons (e.g., between Pike Lake and North Crosby plutons)

3. Western subdomain marbles show a variety features. Those within a northeast-trending belt, herein referred to as the Brooke belt, located between Brooke and Christie Lake and up to 2 km wide, are relatively clean calcite marble and minor interlayered dolomitic calcite marble, with weak cerium anomalies. Some of the Brooke belt marbles also have moderate total rare earth element contents (70 to 150 ppm) and rare earth element patterns similar to the post-Archean Australian Shale composite that cannot be related directly to silicate mineral content. Elsewhere in the western subdomain, impure marbles and marble breccias are present.

Wynne-Edwards (1967) proposed that a stratigraphic succession existed within the Grenville Supergroup rocks of the Westport area, which is located directly to the south. His proposed succession and its possible correspondence to rock units in the Perth map area are shown in Table 3. Supracrustal units (and subdomains) apparently young from west to east across the Perth map area, similar to the observation made by Wynne-Edwards (1967) for the Westport area. Supracrustal rocks in the western subdomain of the Perth map area possibly correspond to the lower major marble unit (*see* Table 3), whereas those in the eastern subdomain appear to correspond with the stratigraphically higher major marble unit of Wynne-Edwards (1967). Correlation of supracrustal units in the central subdomain is more problematic (*see* Table 3). The gneissic units seem to match reasonably well with the major gneiss unit of Wynne-Edwards (1967), but the presence of more than one marble unit is required, neither of which readily match the characteristics of either major marble unit of Wynne-Edwards (1967).

Protolith of the Paragneisses

Dark-coloured, feldspathic paragneiss, with and without garnet, is abundant in the central subdomain (map unit 3 of Wilson and Dugas 1961). Primary depositional features in these rocks have been destroyed during metamorphism making protolith identification difficult. The paragneiss units, especially near their contact with marble belts, are spatially associated with, and interlayered with metamorphosed quartz arenites (*see* Appendix 1: analyses 12 and 13), likely derived from clean sandstones. This association suggests a likely sedimentary protolith for the feldspathic paragneiss units.

Table 4. Comparison of the geochemistry of the aluminous and the non-aluminous feldspathic paragneiss samples from the Frontenac terrane, Perth area. Note the generally higher calcium and potassium, and lower iron contents of the low-Al pelites. All analyses were performed at the OGS Geoscience Laboratories, Sudbury. The UTM co-ordinates are provided using NAD83 in Zone 18.

Sample Number	15RME-0420	16RME-0456	16RME-0558	16RME-0222	16RME-0225	16RME-0230
Type	Aluminous	Aluminous	Aluminous	Low-Al	Low-Al	Low-Al
SiO_2	57.17	57.66	62.71	73.40	61.67	61.21
TiO_2	1.49	1.55	1.55	0.98	1.16	0.90
Al_2O_3	**20.76**	**20.46**	**17.09**	9.90	13.17	15.02
Fe_2O_3	9.41	9.29	6.98	6.80	5.52	3.59
MgO	3.69	2.76	3.31	1.82	3.71	1.78
CaO	1.05	0.77	1.21	**2.56**	**3.01**	**4.21**
Na_2O	3.69	1.25	1.48	0.62	3.10	2.82
K_2O	3.55	5.04	4.91	2.88	**6.17**	**5.84**
P_2O_5	0.06	0.11	0.04	0.07	0.12	0.09

Preliminary geochemical data originally presented in Easton (2016a) (e.g., *see* Appendix 1: analyses 5 to 10) indicated that the feldspathic paragneiss rocks were not especially aluminous or quartz-rich (<17 weight % and <65 weight % Al_2O_3 and SiO_2, respectively), and they plot as pelites or calc-pelites using the CaO–Al_2O_3–Na_2O+K_2O classification diagram of Easton (1997). The moderate alumina and silica contents of these rocks would explain the general absence of aluminosilicate minerals in these rocks.

Analyses of additional feldspathic paragneiss samples (*see* Appendix 1: analyses 1 to 4), however, indicate that there are 2 types of pelites: the originally identified low-alumina pelites described in Easton (2016a), and an aluminous type, characterized by 17 to 21% Al_2O_3, as summarized in Table 4. Petrographic examination using transmitted light and scanning electron microscopy (SEM) indicates that the aluminous pelites contain corundum and/or aluminosilicate minerals, as might be expected given their alumina contents. The aluminosilicate is typically kyanite, with its identification based on its length-slow character, euhedral shape, and the presence of well-developed cleavage. Kyanite and corundum have not been previously reported from paragneiss from the Perth area.

Petrographic examination using transmitted light and SEM indicates 2 main mineralogical groups: potassium feldspar-oligoclase-quartz-garnet paragneiss (pelitic gneiss, e.g., *see* Appendix 1: analyses 1 to 7) and potassium feldspar-oligoclase-aegirine augite-quartz paragneiss (calc-pelitic gneiss, *see* Appendix 1: analyses 8, 9 and 10). Examination using SEM indicates that neither type contains any detrital zircon, although fine-grained (10 to 50 μm), typically thorium-poor, monazite is abundant. If zircon is present, it is observed as small (10 to 20 μm) homogeneous grains that are probably metamorphic in origin. These observations are consistent with derivation of the paragneiss units from mudstones rather than siltstones or sandstones.

Conditions of Regional Metamorphism

Frontenac terrane is generally regarded as a low-pressure granulite terrane with peak metamorphic conditions of approximately 5 kilobars and 760 to 790°C (e.g., Lonker 1980; Buckley, Easton and Ford 1997). To date, petrographic examinations using transmitted light and SEM have not been able to confirm that regional metamorphism in the Perth map area achieved true granulite-facies conditions, or occurred at low pressure (bathozone 4 to 5 of Carmichael 1978) (Figure 5).

The appearance of orthopyroxene in quartz-bearing rocks is the diagnostic mineral indicator for the transition from upper amphibolite-facies to granulite-facies conditions (e.g., Bucher and Frey 2002, p.244). Orthopyroxene has yet to be observed in any of the paragneiss units examined so far in the Perth map area. However, many of the paragneiss units have undergone partial melting, indicating high temperatures.

In addition, primary muscovite is absent, suggesting that most of the paragneiss units reached metamorphic conditions above the muscovite-breakdown reaction. Although the presence of cordierite has been reported by previous workers (e.g., Wilson and Dugas 1961), its presence has not been confirmed by the author. Bluish garnet gneisses that appeared to be cordierite bearing in the field turned out to be garnet-oligoclase rocks, with the blue observed in the field and in the hand sample likely the result of the presence of peristeritic feldspar. Thus, from a mineralogical standpoint, one can say that the area reached upper amphibolite- and, perhaps, granulite-facies conditions in terms of temperature, although granulite-facies metamorphism has yet to be confirmed.

Petrographic study suggests metamorphic pressures were at least 2 kilobars, and perhaps as much as 6 kilobars, higher than previously suggested. In the calc-silicate rocks and dolomite marbles in all 3 subdomains of Frontenac terrane, the common mineral assemblage is diopside + plagioclase ± scapolite ± chondrodite. This suggests pressures and temperatures greater than 8 kilobars and higher than 670°C, respectively (Bucher and Frey 2002, p.209), across the Perth map area. Phlogopite is common in the impure marbles of the central subdomain, but phlogopite can persist to high metamorphic conditions, so its presence is not diagnostic of peak metamorphic conditions (Bucher and Frey 2002, p.213). The

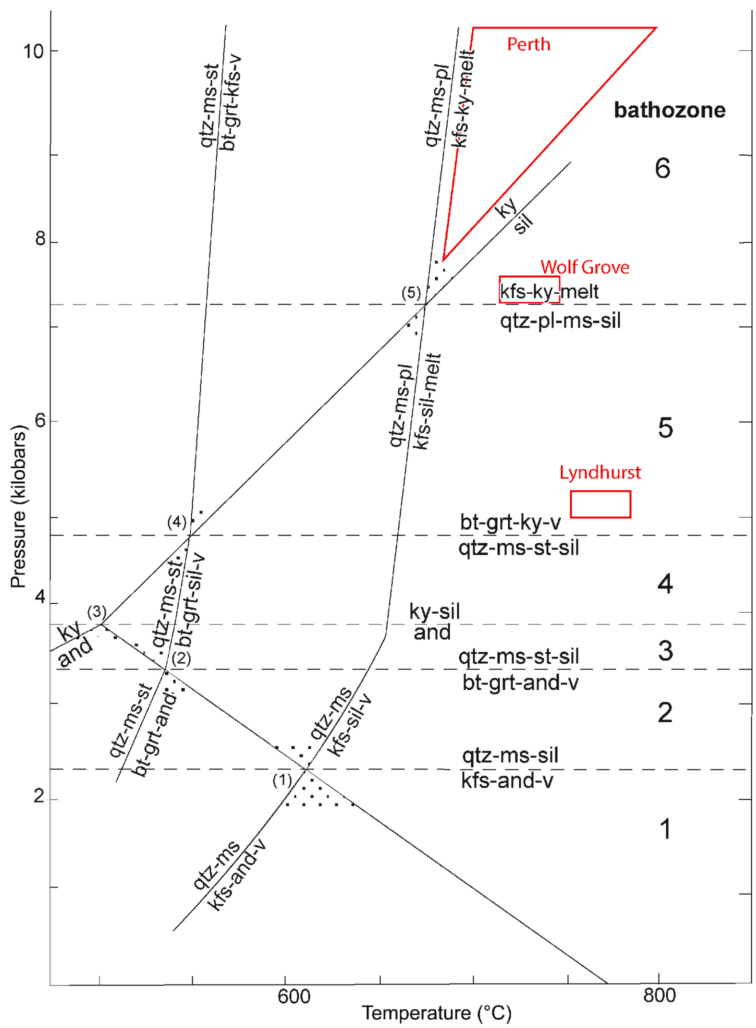

Figure 5. Pressure–temperature diagram showing the bathozones defined by Carmichael (1978) and possible pressure–temperature conditions of metamorphism in the Wolf Grove and Perth map areas. *See* text for additional explanation. Abbreviations: and, andalusite; bt, biotite; grt, garnet; kfs, potassium feldspar; ky, kyanite; ms, muscovite; pl, plagioclase; qtz, quartz; sil, sillimanite; st, staurolite; v, vapour phase.

absence of cordierite noted in the previous paragraph is consistent with higher pressure conditions. Furthermore, 1 paragneiss sample (*see* Appendix 1: analysis 2) from the central subdomain contains the assemblage kyanite-garnet-biotite-rutile, indicating metamorphic conditions greater than 7 kilobars and higher than 675°C (Bucher and Frey 2002, p.235). This is confirmed by a second paragneiss sample (*see* Appendix 1: analysis 1) from the same subdomain that contains the assemblage andesine-quartz-garnet-corundum-rutile, as well as the rare zirconium-titanium silicate mineral srilankite. This assemblage could indicate metamorphic pressures as high as 11 to 14 kilobars and temperatures approaching 1000°C (Troitzch and Ellis 2004; Mouri, Guiraud and Osanai 2004). Neither kyanite or srilankite have been previously reported from Frontenac terrane.

Several samples of aluminous paragneiss from the central subdomain, including a sample from Stop 2, contain co-existing corundum-kyanite grains, as well as plagioclase-potassium feldspar coronas around kyanite. Whether or not these feldspar rims around kyanite are true coronas (resulting from a metamorphic reaction) or are the result of partial melting of the rock with the melt armouring the aluminosilicate grains remains to be determined. Where similar features have been previously described from the Bohemian massif (Stipska et al. 2010), they were interpreted to be the product of a decompression reaction at ~8.5 kilobars, and would imply higher peak *P–T* conditions, consistent with the srilankite-bearing sample. The presence of the assemblage corundum-quartz and co-existing corundum and kyanite in the aluminous paragneiss samples also suggests the presence of ultra-high temperatures (Mouri, Guiraud and Osanai 2004).

Peak metamorphic conditions from the Maberly shear zone have yet to be determined; however, high-pressure conditions are consistent with the presence of corundum in anorthositic rocks of the Lanark–Oso gabbroic anorthosite intrusion located west of the Perth map area (Miller 1899; Wolff 1985). The higher peak metamorphic conditions in the Perth map area suggest an eastward decrease in metamorphic pressure coincident with increasing distance from the Sharbot Lake domain–Frontenac terrane boundary. Fully resolving the metamorphic history of Frontenac terrane is beyond the scope of this project; however, university researchers are invited to pursue this subject further.

Uranium–lead (U/Pb) zircon geochronology by Corfu and Easton (1997) suggested the peak metamorphism occurred at 1168±3 Ma and new data acquired during this study appears to confirm that result, with sample 15RME-0420 yielding metamorphic zircon and monazite at 1166.1±1.1 and 1164±2 Ma, respectively (Kamo and Hamilton 2017) (Table 5). Titanite in the Perth map area appears to record a reheating event at *circa* 1100 Ma, with apatite recording a much younger event at *circa* 990-1000 Ma (*see* Table 5).

The high metamorphic pressures from the Perth area are consistent with data from Buckley, Easton and Ford (1997), who reported metamorphic conditions of 7.2 kilobars and higher than 718°C for gneisses from the Wolf Grove structure, located northwest of the Maberly shear zone, approximately 30 km northwest of the centre of the Perth map area (*see* Figure 3). This puts the Perth map area in bathozone 6, not bathozone 5, of the classification of Carmichael (1978) (*see* Figure 5). Bathozone 4 to 5 conditions, however, exist only 20 km south of the Perth map area near Lyndhurst, based on the data of Lonker (1980). This would require significant structural displacement between the Perth and Lyndhurst areas.

A possible candidate structure is the fault that trends north-northeast from Chaffey's Lock to Portland to Glen Elm just south-southeast of Smiths Falls (*see* Figure 3), herein termed the Chaffey's Lock fault. In the Perth map area, this fault is downdropped to the east, and places rocks of the Nepean Formation against rocks of the upper March and Oxford formations. This probably indicates no more than 100 m of post-Ordovician displacement across the fault. A difference of 2 kilobars between the Perth and Lyndhurst areas would involve at least a vertical displacement of 7 km (considering a lithostatic pressure for an average crustal density of 2.8×10^3 kg/m^3). It is not known if this displacement occurred rapidly during the Proterozoic, or if it occurred in several stages in both the Proterozoic and the Phanerozoic.

Table 5. Summary of geochronological constraints on Frontenac intrusive suite and their magmatic events in and around the Perth map area.

Age (in Ma)	Pluton or Stratigraphic Unit Name	Rock Type(s)	Comment	Source
1178±4 (zircon) 1174±2 (monazite)	Unnamed orthogneiss	Migmatite	Age or emplacement or onset of metamorphism sample 15RME-0247, just north of Stop 10 in Maberly shear zone	Kamo and Hamilton (2017)
1178±4	Pike Lake	Monzonite	In Perth map area	Davidson and van Breemen (2000)
1168±2	Wolf Grove complex	Migmatitic gneiss	In Carleton Place map area	Corfu and Easton (1997)
1168±2	Wolf Grove complex	Gneissic quartz syenite	In Carleton Place map area	Corfu and Easton (1997)
1167±2	Fall River augen gneiss	Augen gneiss, monzonite composition	In Maberly shear zone	Davidson and van Breemen (2000)
1166.1±1.1 (zircon) 1164±2 (monazite)	Paragneiss	Aluminous paragneiss	Age of metamorphism sample 15RME-0420, contains srilankite	Kamo and Hamilton (2017)
1164±2 (zircon) *circa* 1130-1100 (titanite) *circa* 990 (apatite)	Unnamed intrusion on County Road 6	Plagioclase-phyric alkalic gabbro	Zircon dates emplacement or early metamorphism, titanite and apatite record subsequent overprinting events, sample 16RME-0280, similar to dike at Stop 10, compositional similar rocks occur as migmatites in the contact strain aureole between the Pike Lake and Crosby plutons	Kamo and Hamilton (2017)
1164±2	Bennett Bay	Monzonite, syenite	In Maberly shear zone	Davidson and van Breemen (2000)
1162±7Ma *circa* 1100 (titanite)	Unnamed intrusion west of Brooke	Anorthositic gabbro	Age of emplacement, titanite records metamorphic event sample 15RME-0320, on strike with Lanark-Oso pluton	Kamo and Hamilton (2017)
$1161^{+3}/_{-2}$	Silver Lake pluton	Monzonite, syenite	In Maberly shear zone	Davidson and van Breemen (2000)
1157±3	North Crosby	Monzonite, syenite	In Perth map area	Davidson and van Breemen (2000)
1156±2	Maberly stock	Gabbro to diorite	In Sharbot Lake domain just north of the Maberly shear zone	Corfu and Easton (1997)
1103.52.1 (zircon) *circa* 1100 (titanite)	Perth pluton	Monzogranite	Zircon age of emplacement, titanite cooling age, sample 16RME-0465 (Stop 4), neither Frontenac nor Kensington-Skootamatta suite	Kamo and Hamilton (2017)
1070±10 (titanite) *circa* 993 (apatite)	Paragneiss layer in marble	Paragneiss	Age of metamorphism, approximately 20–30 million years younger than other titanite ages, suggests marbles may have had different metamorphic history	Kamo and Hamilton (2017)
circa 990–1000 (apatite)	Apatite-mica pyroxenite vein	Apatite vein	Same age as all other apatite ages in region, dates younger reheating event, sample 16RME-0493 (Stop 3)	Kamo and Hamilton (2017)

Frontenac Intrusive Suite

The expression of Frontenac intrusive suite magmatism in the Perth map area may be more complex than previously recognized, all taking place in a short interval between 1178 and 1162 Ma (*see* Table 5). Regionally within Frontenac terrane, most attention has been paid to the monzonite, syenite and granitoid intrusions that are well displayed on the older generation geological maps of the area (e.g., Hewitt 1964b; Wynne-Edwards 1967). These intrusions have U/Pb zircon ages of 1178 and 1156 Ma, but with most ages clustering around 1166 Ma (Davidson and van Breemen 2000; Corfu and Easton 1997). Mapping and geochronological studies related to the Perth mapping project (*see* Table 5), however, suggest that this pulse of felsic magmatism was preceded by, and coeval with, a more mafic-dominated magmatic event, which emplaced alkaline gabbros, diorite and monzonites intrusions, both as sills and as composite bodies, that were subsequently deformed and locally migmatized during the emplacement of the felsic intrusions. Intrusions emplaced during this interval included some true anorthositic bodies (such as the Lanark–Oso intrusion to the west-southwest of the Perth map area), which subsequently served as the source of anorthositic gabbro fragments found within the Maberly shear zone, for example, as seen at Stop 16. A second reheating event at *circa* 1100 Ma is recorded in titanite grains throughout the area (*see* Table 5), coincident with emplacement of the Perth monzogranite pluton at 1103.5±2.1 Ma (Kamo and Hamilton 2017).

This more complex magmatic history does, however, fit with the Geon 11 magmatic flare-up along the full length of the Grenville Orogen, from Labrador to Texas, as described by Hynes and Rivers (2010). As summarized by Hynes and Rivers (2010), volumetrically, the magmatism was dominated by anorthosite–mangerite–charnockite–granite (AMCG) complexes that are most common in Quebec and in the Adirondack Highlands. Also present are composite monzonite–diorite–granite–syenite (MDGS) complexes, which would correspond to the main pulse of felsic magmatism seen in the Frontenac terrane. The MDGS complexes provide a compositional bridge between the typical AMCG intrusions and the granitoid complexes. Individual MDGS intrusions, which are typically no more than a few kilometres in diameter, take the form of plutons, sheets and dikes, and felsic compositions predominate. Many of the MDGS bodies exhibit some or all of the compositional range from gabbro through diorite and monzonite to granite and minor syenite. Field and chemical evidence for co-mingling and mixing of mantle- and crustal-derived magmas has been reported (Corriveau and van Breemen 2000; Grammatikopoulos, Clark and Archibald 2007). The widespread occurrence of silica-poor granitoid magmas (monzonite, syenite) and orthopyroxene-bearing granitoid magmas (charnockite, mangerite) in the AMCG and MDGS suites is suggestive of high-temperature anhydrous melting in the lower crust, whereas the less abundant leucogranite may have been a result of lower temperature, hydrous melting in the middle crust (Hynes and Rivers 2010).

Structurally, the mechanism of emplacement and deformation of this earlier magmatic pulse might be similar to the style of magmatism described for the slightly younger (*circa* 1166 Ma) Chevreuil intrusive suite in Quebec (Corriveau and van Breemen 2000). In that suite, the composite character of the subvertical sheet complexes, the short hiatus between magma pulses, the comingling of mafic and felsic magmas in plutons and dikes, and the record of repeated influxes of mafic and felsic magmas at the same emplacement sites resulted in the strong parallelism of the various intrusive sheets. Consequently, the igneous fabric is parallel with the foliation and lithological contacts of their host gneiss and is independent of their state of strain (Corriveau and van Breemen 2000).

SHARBOT LAKE DOMAIN

Rocks of Sharbot Lake domain are exposed in the northwest corner of the map area, north of the Fall River (*see* Figure 2). Thin- to medium-layered, stratigraphically continuous, calcite, dolomitic calcite and dolomite marbles predominate. There is a 1 to 2 km wide belt of tremolite-quartz-dolomite marble exposed on Ashby Road north of Fallbrook. Metamorphic grade in the domain increases southeastward toward the Maberly shear zone and, in the marbles, results in increasing grain size and a loss of layering. Rusty-weathering, fine-grained, siliciclastic metasedimentary rocks occur in an approximately 6 km long, up to 300 m wide, belt located immediately adjacent to the Maberly shear zone along the Fall River. Although sulphide rich, no significant base metal assays have been obtained from this unit.

Maberly Shear Zone

Previous work on the Maberly shear zone (Easton 1988; Davidson and Ketchum 1993) suggested the zone had a surface expression 3 to 4 km wide. Mapping during this project suggests a surface width of 5 to 8 km for the Maberly shear zone, based on the identification of high-strain zones exposed along, and south of, Highway 7 in the vicinity of Wemyss (*see* Figure 2). This greater surface extent is consistent with the observation by Magnus, Easton and Rainsford (2014) that the Maberly shear zone has an approximate width of 10 to 20 km, based on linear trends present in recently acquired airborne magnetic data for eastern Ontario (Ontario Geological Survey 2014a, 2014b) (*see* Figure 4).

In the Perth map area, the northernmost 2 to 3 km of the Maberly shear zone is dominated by Frontenac suite intrusions, now protomylonitic, of mainly felsic composition, but with some minor mafic bodies as well. These intrusions are rimmed by thin-layered, compositionally heterogeneous, highly strained gneiss of indeterminate protolith. All of the deformed Frontenac suite intrusions in the Maberly shear zone, such as the Bennett Bay pluton, are strongly magnetic and are prominent in the airborne magnetic data for the area (Ontario Geological Survey 2014a, 2014b) (*see* Figure 4).

The southernmost 3 to 5 km of the Maberly shear zone in the Perth map area shows considerable on-strike variability. In the west, highly deformed gabbroic, anorthositic and granitic rocks are abundant, and may represent the eastward, tectonized extension of the Lanark–Oso anorthosite intrusion (Wolff 1985). North of Highway 7, between Wemyss and Perth, grey, weakly migmatitic, quartzofeldspathic gneiss, cut by a variety of younger syenitoid and granitoid phases, is abundant within the Maberly shear zone, and may represent a highly deformed Elzevir suite intrusion. This unit corresponds to the "syenite-migmatite" of Wilson and Dugas (1961).

Marble slivers are common throughout the Maberly shear zone. Where well exposed, these predominantly calcite marbles are actually marble tectonic breccias, containing a variety of fragment types, including fine-grained paragneiss and calc-silicate gneiss, amphibolite and gabbroic rocks, and pyroxenite skarn pods. A spectacular, 150 m long, roadcut on the south side of Highway 7 (Stop 12, UTM 385925E 4967751N) is a microcosm of the Maberly shear zone, and consists of alternating panels, 10 to 15 m wide, of marble breccia interlayered with thin-layered, highly flattened, compositional heterogeneous silicate tectonites. What is seen at the outcrop scale in this roadcut reflects what is occurring at a much larger scale within the entire Maberly shear zone.

REGOLITH AT THE PRECAMBRIAN–PALEOZOIC UNCONFORMITY

Intense weathering of the Precambrian basement beneath the Paleozoic rocks in the map area is widespread, especially in the central part of the map area between highways 7 and 15 (*see* Figure 2). This weathering destroys both primary mineralogy and textures of the basement rocks and makes rock identification problematic. Weathering intensity can vary within individual outcrop areas, and is not restricted solely to low-lying areas. This weathering surface displays a variety of regolithic textures, including the presence of saprolite (weathered rocks that retain primary textural features), laterites (iron-enriched rocks) and possible bauxites (alumina-enriched rocks). Weathering depths of 3 to 4 m are common, with greater thicknesses likely, as most rock exposures in the map area are typically only 2 to 4 m high.

In the Precambrian marbles, silicate minerals, such as diopside and mica, are altered to greenish clay minerals. Carbonate minerals alter initially along grain boundaries, making the rock more friable. With increasing weathering, the original calcite and or dolomite grains are recrystallized to fine-grained, buff (dolomite) or chalky white (calcite) carbonate phases. When this occurs, any original structural fabric in the marbles disappears, and is replaced by a centimetre-scale subhorizontal sheeting. As a result of these mineralogical changes, especially the replacement of original calcite by fine-grained buff dolomite, it is difficult to accurately determine the extent of calcite versus dolomite marbles in much of Frontenac terrane in the map area.

In the Precambrian crystalline rocks, almost all silicate minerals, except for quartz, are reduced to clay minerals. Sulphide- and graphite-rich paragneiss are turned into reddish soils. After weathering, boudinaged quartz veins, coarse-grained quartz syenite intrusions and syenogranite pegmatite veins provide an abundance of free quartz. Thus, the abundance of quartz cobble and quartz pebble conglomerates in the Covey Hill and lowermost Nepean formations in the map area is not surprising.

A possible explanation for the extent of this regolith surface in the central part of the map area between highways 7 and 15 is the east-trending fault located between Perth and Smiths Falls (*see* Figure 2). This fault is down-dropped to the north and, during late Pleistocene glaciation, it may have formed a sufficient topographic barrier to prevent regional southward-directed ice flow (Kettles 1992) from reaching the central part of the map area. This lack of glaciation might also explain the widespread preservation of Covey Hill and Nepean formations strata in the map area.

From an exploration standpoint, this intense weathering is useful for the formation of vermiculite deposits and, perhaps, for liberating graphite from sulphide-rich crystalline rocks.

PALEOZOIC STRATA

Stratigraphic nomenclature for Paleozoic rocks in the Perth map area follows Lee (2013, p.22) and Armstrong and Dodge (2007). Five formations are present: the Cambrian (541 to 485 Ma) to Lower Ordovician (485 to 470 Ma) Covey Hill and Nepean formations, the Lower Ordovician March and Oxford formations, and the Middle Ordovician Rockcliffe Formation. In the Perth map area, the Covey Hill, Nepean or March formations may rest directly on the Precambrian basement. Most commonly, the Covey Hill or the Nepean formations are the basal Paleozoic unit. Representative analyses of the Nepean and March formation rocks are presented in Appendix 1 (*see* analyses 26 to 31).

Mapping in 2016 found that the Covey Hill and Nepean formations are more extensive east of Rideau Lake and southwest of Otter Lake than indicated by Williams and Wolf (1984). Here, the distribution of the 2 formations is closer to that depicted by Wilson and Dugas (1961) (*see* Figure 2). The reason for this discrepancy may reflect the strong degree of topographic control on the distribution of the Paleozoic rocks in this area, particularly the Covey Hill Formation. Mapping in 2016 also found many more exposures of the Covey Hill Formation south of Highway 43 and west of the Rideau fault than had been previously known.

Covey Hill Formation

The author used the following features to distinguish between the Nepean and the Covey Hill formations in the field, especially when thick conglomerate beds are absent. These diagnostic features are similar to those proposed by Sanford and Arnott (2010). As a result, some rocks assigned to the Nepean Formation by Williams and Wolf (1984), especially in the area east of Rideau Lakes, are probably part of the Covey Hill Formation.

Sandstones of the Covey Hill Formation are typically grey and are more friable than those of the Nepean Formation. The Covey Hill Formation is more likely to be channelized, and onlap against Precambrian topographic highs. Bioturbation is less prominent or not observed in the Covey Hill Formation. Bedding is less prominent in the Covey Hill Formation, and beds with dip angles of 10 to 25°

are common in many exposures. These higher dip angles appear to be the result of deposition in channels and/or the development of dunes, as suggested by Wolf and Dalrymple (1984), rather than being structural, as suggested by Sanford and Arnott (2010). The Covey Hill Formation conglomerates contain a wide variety of cobbles representing most Precambrian basement rock types. In contrast, thin conglomerate beds within the Nepean Formation typically contain quartz and sandstone cobbles.

Sandstones exhibiting evidence of tilting and/or folding also are assigned by Sanford and Arnott (2010) to the Covey Hill Formation. An example of the latter is an outlier of sandstone and quartz pebble conglomerate on Lanark County Road 14 (UTM 398705E 4961454N) that dips 25° east. Using the criteria of Sanford and Arnott (2010), these rocks are likely Covey Hill Formation, whereas Williams and Wolf (1984) assigned them to the Nepean Formation. Although some of the dip of the sandstone beds could be the result of the sandstone being deposited adjacent to, and draping, a Precambrian basement high, the magnitude of the dip could indicate that other processes were involved in producing the observed dip.

A previously unknown exposure of Covey Hill Formation strata, or possibly the Abbey Dawn Formation of Sanford and Arnott (2010), was identified on the north side of Highway 7 approximately 5 km west of Wemyss (optional stop located between Stops 12 and 13, UTM 385510E 4967646N). Here, a channel, at least 3 m deep and up to 20 m wide, was cut down into weathered calcite marble. The deeper (>3 m) west side of the channel is filled with red-weathering pebbly conglomerate containing subangular to subrounded rock fragments and quartz pebbles, which grade upward into thin-bedded reddish coarse sandstone. The shallower (~2 m) east side of the channel consists of red mudstone and siltstone beds (up to 1 cm thick) that immediately overlie the marble basement, and which are overlain, in turn, by thin-bedded reddish coarse sandstone.

Wolf and Dalrymple (1984) suggested that the Covey Hill Formation was deposited in an alluvial-fan system that formed on the east side of the Rideau fault (*see* Figure 2). Similarly, the abundance of Covey Hill Formation strata south of Highway 43 and west of the Rideau fault may reflect deposition in a similar environment—in this case, on the south side of the major east-trending fault that parallels the Tay River between Perth and Port Elmsley, herein termed the Port Elmsley fault (*see* Figures 2 and 4).

GEOPHYSICS

Intermediate to felsic Frontenac suite intrusions are typically magnetic (10 to 90 $\times 10^{-3}$ SI units), even those that are located within the Maberly shear zone and which are highly deformed. Ground scintillometer measurements from intermediate to felsic Frontenac suite intrusions (monzonite to syenite) give median potassium, uranium and thorium contents of 3.8 weight % K, 1.6 ppm U and 0 ppm Th, respectively, based on greater than 225 measurements. Potassium contents of the syenites and quartz syenites can be as high 8.0 weight % K, but with uranium and thorium remaining low. Low uranium and thorium contents appear to be a characteristic feature of the Frontenac suite.

Highly strained, layered, compositionally heterogeneous tectonites of the Maberly shear zone, as well as all marble units within the map area, are non-magnetic (0.1 to 0.8 $\times 10^{-3}$ SI units). All Paleozoic formations are non-magnetic (0.05 to 0.3 $\times 10^{-3}$ SI units).

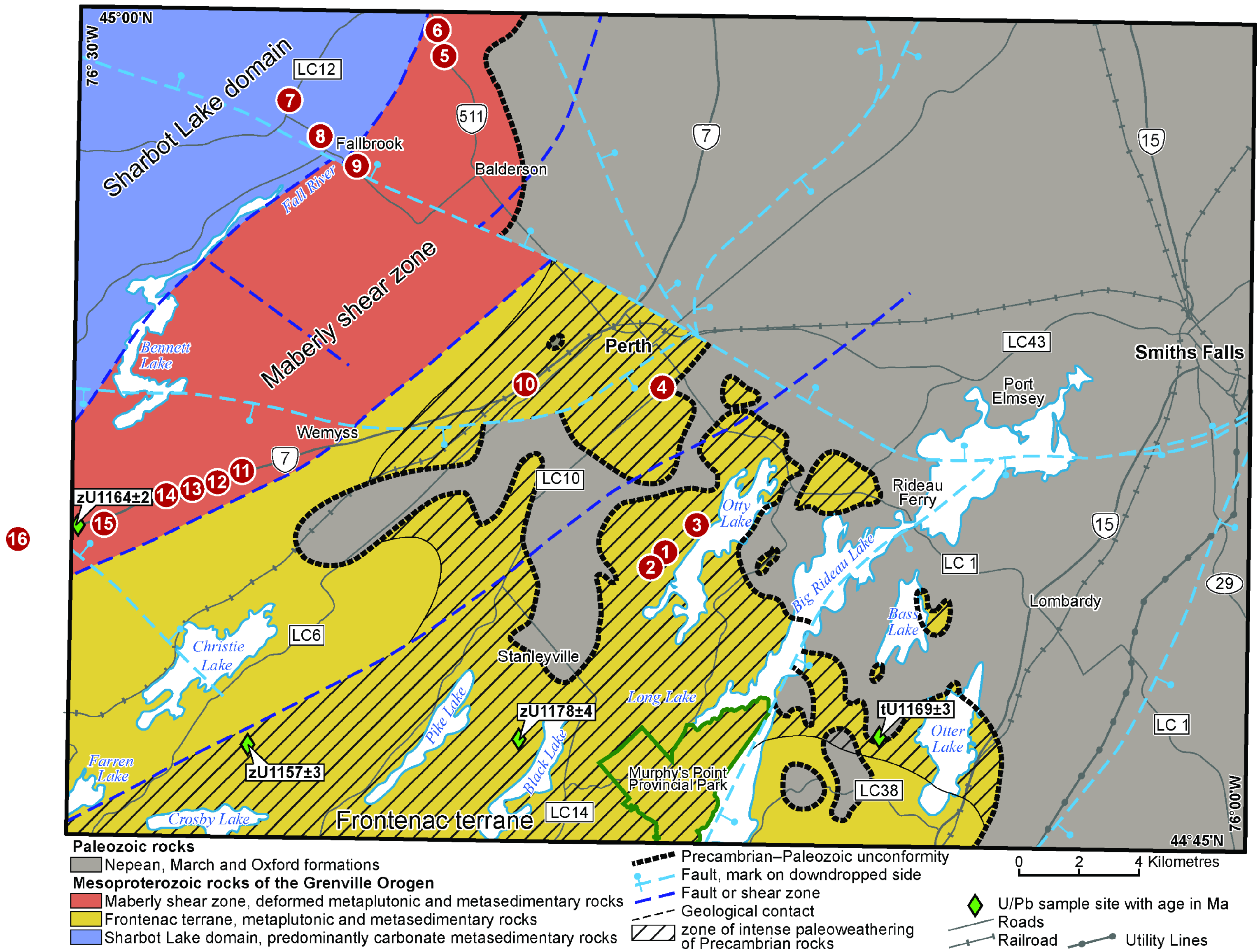

Figure 6. Location of field trip stops superimposed on a map showing the major geological features present in the Perth map area. Geology is *modified from* Hewitt (1964b), Wilson and Dugas (1961) and Williams and Wolf (1984). Geochronological data: U/Pb zircon (zU) ages, in Ma, shown on the figure are *from* Davidson and van Breemen (2000); titanite age (tU) is *from* Mezger et al. (1993). The abbreviation "LC" designates Lanark County roads. *Modified from* Easton (2015, Figure 18.1).

ROAD LOG – Frontenac Terrane and Maberly shear zone rocks in the Perth area

Note: Caution should be taken when parking vehicles on the shoulder of the highway and when examining outcrops located along Highway 7 and on other roads along the field trip route.
All UTM co-ordinates are provided in NAD83, Zone 18. Figure 6 shows the location of the field trip stops on a simplified geological map of the area.

The first 4 stops highlight rocks of Frontenac terrane. Stops 1 and 2 illustrate the relationship between paragneiss and quartzite in the central subdomain. Stop 3 is a good example of a typical-mica apatite vein common in the Perth area. Finally, Stop 4 is on a younger granitic intrusion in Frontenac terrane near the Maberly shear zone and highlights the difficulties in assigning granitoid rocks to the various plutonic suites common to the area.

Stops 5 to 16 are all within or are related to the Maberly shear zone. Stops 5 and 6 are within the shear zone itself. Stops 7 to 10 provide a north-to-south transect across the Maberly shear zone, starting in relatively well-preserved carbonate rocks of Sharbot Lake domain and crossing into the Maberly shear zone. Stops 11 to 16, all along Highway 7, provide a transect along the length of the Maberly shear zone, and illustrate the variety of rock types present within the shear zone.

Geological map references: Wilson and Dugas (1961), Easton (2018b).

0.0 km	Start at the junction of Lanark County Road 1 and County Road 10 (Scotch Line) in Perth. Head west along County Road 10.
2.4 km	Junction of Otty Lake Side Road and County Road 10. Turn left and head south along Otty Lake Side Road.
6.6 km	Otty Lake Side Road curves to the right (west) and changes into Kenyon Road, continue west (straight) on Kenyon Road.
8.7 km	Junction with Lakewood Road, continue straight (west) onto McLaren Road. Outcrop on the north side of the road (UTM 401409E 4965738N) was sampled for detrital zircon geochronology prior to extensive landscaping of the site by the current property owner. This white and blue-white glassy quartzite is on strike with the quartzite exposed at Stop 1. A chemical analysis of the geochronology sample is provided (*see* Appendix 1: analysis 13).
9.0–9.2 km	Junction, continue straight (west) for approximately 100 m and park on the shoulder of the road. Stop 1 (UTM 401005E 4965530N) and Stop 2 (UTM 400913E 4965468N) are located 100 m from one another on the right (north) side of the road.

Stop 1. Frontenac terrane quartzite

Within Frontenac terrane, quartzites are common at the boundary between the paragneiss units and marbles. At this locality, a thick, massive, glassy quartzite is observed, which is structurally underlain by the garnet gneiss at Stop 2. Locally, the quartzite is feldspathic, and was probably originally a feldspathic arenite to quartz arenite (*see* Appendix 1: analysis 13).

Figure 7 shows the geological relationships between Stops 1, 2 and 3. The garnet gneiss unit is folded into a structural basin, with marble occurring in the core of the basin and around its margins (*see* Figure 7). If it is a true basin, then this would imply that the marble in the core of the basin belongs to the upper marble unit of Wynne-Edwards (1967) (*see* Table 3). Consequently, the garnet gneiss at Stop 2 would be part of the upper gneiss unit (*see* Table 3). Unfortunately, the lack of facing direction indicators in the quartzites in the Otty Lake area means that this structural relationship cannot be verified.

Sager-Kinsman and Parrish (1993) reported ages from 2 Frontenac terrane quartzites located to the east of a major pressure–temperature boundary in Frontenac terrane. These quartzites had different, but poorly constrained, minimum ages of *circa* 1306 and *circa* 1415 Ma, with the quartzite associated with the upper gneiss unit containing the youngest detrital zircons. The quartzite unit seen at Stop 1, which corresponds to the upper quartzite unit, was sampled for detrital zircon geochronology. Preliminary results indicate the presence of older cores with an extensive age range spanning the Proterozoic (with peaks at *circa* 1400 and 1800 Ma) and a few Neoarchean grains as old as 2702 Ma (Davis and Sutcliffe 2017, p.5-17 and p.102-108). The youngest zircon analyses scatter slightly outside of error with a mean age of 1173±9 Ma (Davis and Sutcliffe 2017).

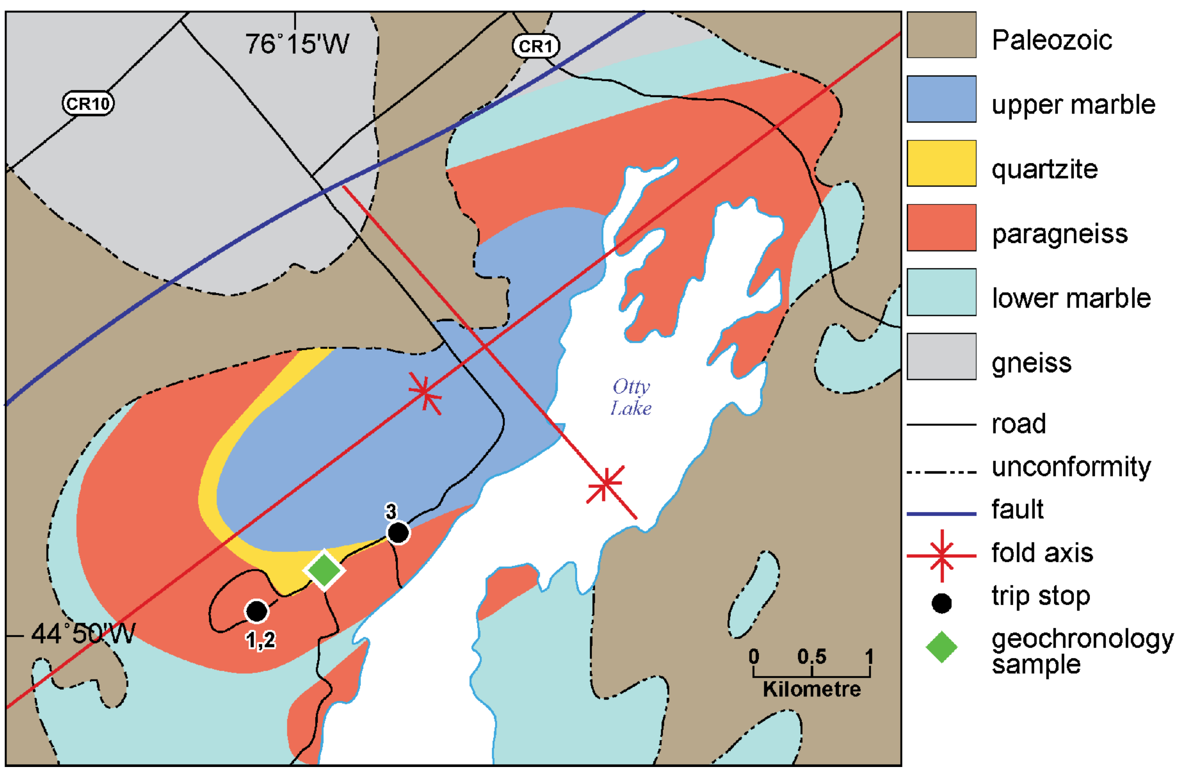

Figure 7. Geological sketch map of the area on the west side of Otty Lake showing the location of Stops 1, 2 and 3. Rock units have been assigned to the stratigraphic sequence proposed by Wynne-Edwards (1967) (*see* Table 3) based on the structural basin present in the map pattern; however, the exact stratigraphic relationship between the main rock units shown cannot be verified. Geology *modified from* Wilson and Dugas (1961) and Williams and Wolf (1984).

Along with the quartzite at Stop 1, the quartzite that was studied by Corfu and Easton(1997) on Highway 7 southwest of Carleton Place was re-sampled to investigate its detrital zircon population. It also corresponds stratigraphically to the upper quartzite unit. The newly collected sample from Highway 7 contained fresh prismatic euhedral zircon, with cores yielding Mesoproterozoic and Archean ages (*circa* 2600, 2200, 1800 and 1450 Ma), similar to the range of ages found in the sample from Stop 1 (Davis and Sutcliffe 2017, p.5-17). Overgrowths, presumably representing the time of regional metamorphism, gave an average U/Pb age of 1187±4 Ma (Davis and Sutcliffe 2017, p.5-17), somewhat older than the metamorphic age of 1169±3 Ma from the same rock obtained by U/Pb TIMS by Corfu and Easton (1997), but consistent with the timing of regional events summarized in Table 5. The youngest, most concordant, analyses on titanite from the sample, which should be the least affected by initial common lead (Pb), gave a mean age of 1146±14 Ma (Davis and Sutcliffe 2017, p.5-17), within error of the 1156±4 Ma age on titanite obtained from the same sample site by Corfu and Easton (1997).

Stop 2. Frontenac terrane aluminous garnet gneiss (corundum, kyanite, garnet rock)

This outcrop consists of a massive grey-blue, non-layered, garnet-rich feldspathic paragneiss, which, in hand specimen, may contain an aluminosilicate mineral. On the east part of the outcrop area, minor veining by quartz and tourmaline is present. The local setting of this outcrop is shown in Figure 7. A chemical analysis of this rock is provided (*see* Appendix 1: analysis 3).

As discussed in "Protolith of the Paragneisses", 3 types of feldspathic paragneisses are present in Frontenac terrane in the Perth map area: those with a calc-pelite chemistry, those with a low-Al pelite chemistry, and those with an aluminous pelite chemistry. The gneiss at this locality is a good example of the aluminous pelite type, with this sample containing 20.45 weight % Al_2O_3. Not visible in outcrop or hand specimen is the fact that this gneiss contains both corundum and kyanite (Photo 1) and kyanite, which is rimmed by andesine plagioclase and potassium feldspar (Photo 2). Two types of garnet are present in the sample: inclusion-rich garnets rimmed by inclusion-free garnet (Photo 3) and inclusion-free garnets (Photo 4). There is no substantial zoning within either type of garnets, and the 2 types are compositionally similar.

As discussed in *"*Conditions of Metamorphism*"*, the presence of co-existing corundum-kyanite grains (*see* Photo 1), as well as plagioclase-potassium feldspar coronas around kyanite (*see* Photo 2), suggests the presence of ultra-high temperatures (Mouri, Guiraud and Osanai 2004). Whether or not these feldspar rims around kyanite are true coronas (resulting from a metamorphic reaction) or are the result of partial melting of the rock with the melt armouring the aluminosilicate grains remains to be determined. Where similar features have been previously described from the Bohemian massif (Stipska et al. 2010), they were interpreted to be the product of a decompression reaction at ~8.5 kilobars, and would imply higher peak *P–T* conditions.

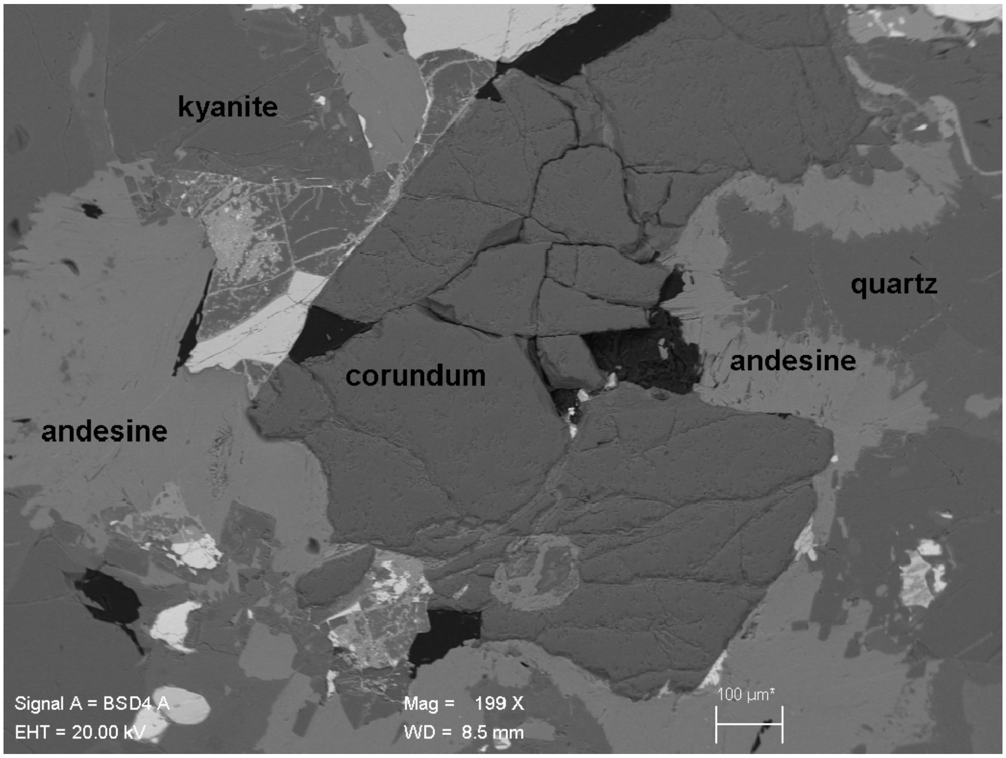

Photo 1. Backscatter scanning electron microprobe image of a large corundum grain co-existing with kyanite grain with well-developed cleavage, surrounded by andesine feldspar and quartz. Sample 16RME-0456 from Stop 2.

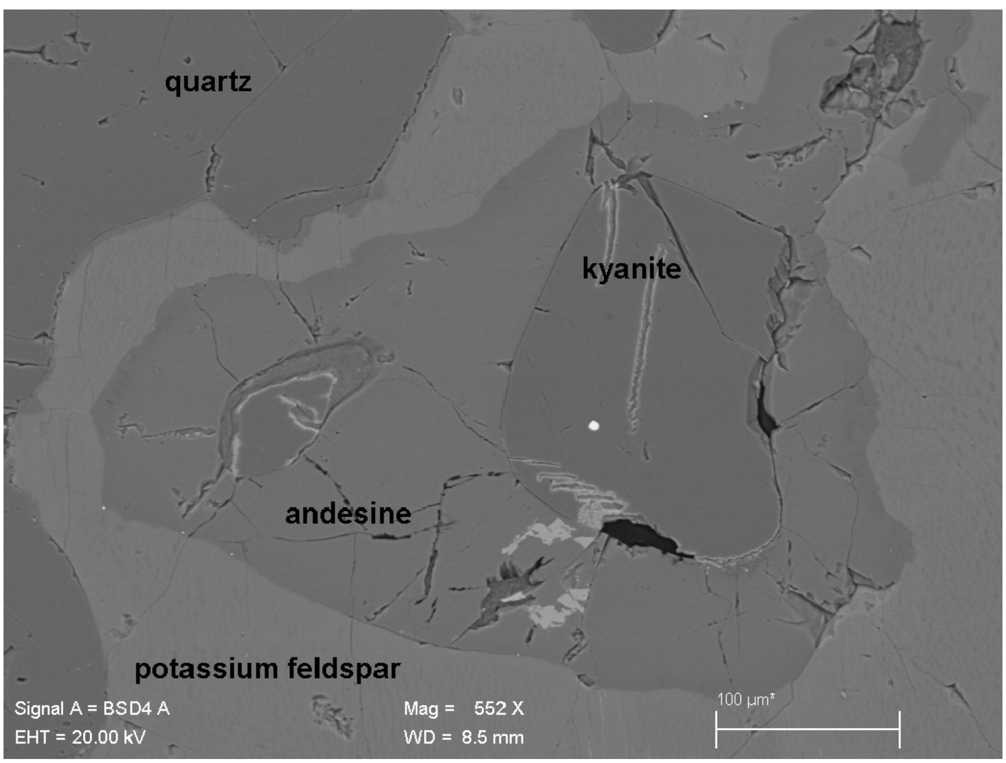

Photo 2. Backscatter scanning electron microprobe image of 2 kyanite grains surrounded by andesine feldspar and potassium feldspar. Sample 16RME-0456 from Stop 2.

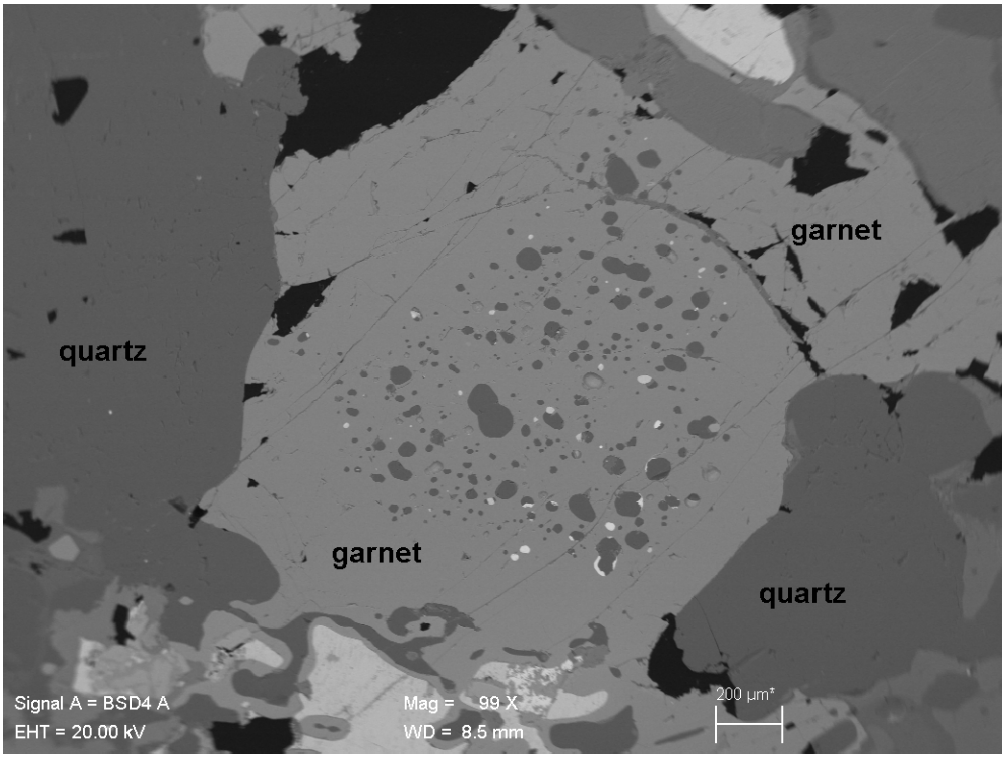

Photo 3. Backscatter scanning electron microprobe image of a garnet grain from sample 16RME-0456, Stop 2. Note inclusion-rich core and inclusion-free rim.

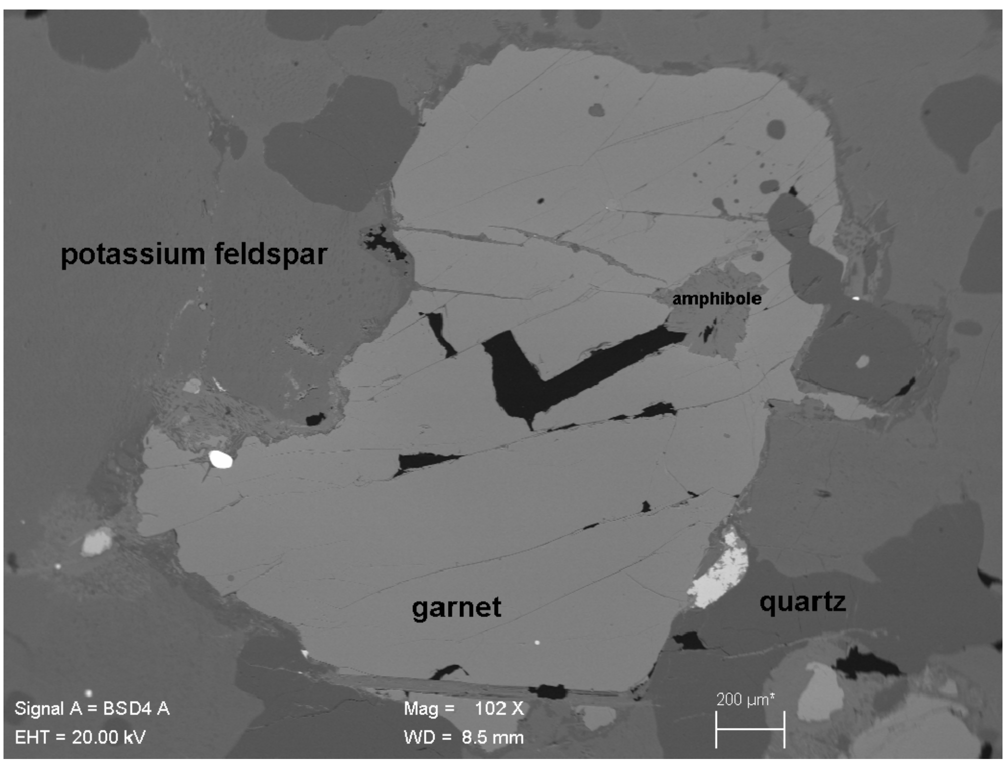

Photo 4. Backscatter scanning electron microprobe image of a garnet grain from sample 16RME-0456, Stop 2. Note absence of an inclusion-rich core.

Return to vehicles and continue west on McLaren Road which loops back onto itself.

9.4 km	Outcrop on the north side of the road just before the curve is an aluminous garnet gneiss similar to that seen at Stop 2 (UTM 400662E 4965266N).
10.7 km	Junction with McLaren Road. Turn left and head east toward Kenyon Road.
11.0 km	Junction with Lakewood Road, continue straight on Kenyon Road.
11.7 km	Pull over and park on the shoulder just past the junction with Beaver Dam Lane. Examine large roadcut on the south side of the road (UTM 402030E 4966039N).

Stop 3. Mica-apatite vein cutting aluminous garnet gneiss, Frontenac terrane

Some of the earliest exploited and, at the time, nationally important, mineral deposits in Ontario were located in Frontenac terrane near Perth. These deposits were sources of non-metallic minerals, such as apatite (source of phosphorus and acid production) and mica (e.g., Currie 1951; Hoadley 1960; Spence 1920). Most of these deposits were small in size and were associated with a complex series of host rocks including "calcite vein dikes", coarse-grained pink calcite rocks, diopsidites, apatite veinlets and mica pyroxenites (Easton 2016b). They occur as veins or pods of limited length and extent, as seen at this stop. Mineralogy can vary considerably from place to place, with some being calcite dominated, others being mica pyroxenite dominated, and in showing varying degrees of country rock alteration, ranging from minimal to extensive (Easton 2016b). The variation in mineralogy is reflected by the fact that, at the turn of the 19th century, some deposits were mined for apatite (e.g., Spence 1920; Currie 1951), whereas others were mined for mica (e.g., Currie 1951; Hoadley 1960). Currie (1951) was one of the few authors to recognize the genetic similarity between the mica and the apatite deposits and to consider them as one deposit type. These deposits are now of interest for rare earth minerals, particularly rare earth carbonate minerals hosted in the associated pink calcite rocks (Easton 2016a, 2016b).

This outcrop shows a typical example of one of these mica-apatite veins. The near-vertical vein exposed at this stop transects an aluminous garnet paragneiss (Photo 5) similar to the rock seen at Stop 2. The outer margins of the vein consist of mica pyroxenite, with the pyroxene being diopside (Photo 6). The core of the dike consists of bluish grains of apatite (Photo 7). In the bush behind the east end of the outcrop is an old mining pit located on the extension of the vein. This pit was not indicated on the map of Currie (1951), and cannot be related to any mica-apatite pits currently listed in the Mineral Deposit Inventory (Ontario Geological Survey 2016).

A sample of this vein (Photo 8) was collected for geochronology. The apatite from this vein has yielded an age of *circa* 990–1000 Ma (Kamo and Hamilton 2017). The interpretation of this result is problematic, as other apatite grains from the Perth map area have also yielded similar ages between 990 and 1000 Ma (*see* Table 5) (Kamo and Hamilton 2017). As such, it may reflect a younger reheating event and not the timing of vein emplacement. The 990–1000 Ma age is younger than the inferred ages of late metasomatic veins in the Bancroft area (e.g., Easton 2016b), and could suggest that the veins are unrelated to Frontenac intrusive magmatism, as speculated in Easton (2016b). Nonetheless, the association of these veins with major structural boundaries, such as the Maberly shear zone and the Central Metasedimentary Belt boundary tectonic zone, suggests some degree of structural control on their emplacement, even if it occurred during the final waning stages of the Ottawan Orogeny.

Return to vehicles. Continue east on Kenyon Road.

Photo 5. Garnet-bearing aluminous gneiss at Stop 3, host to mica-apatite vein. Gneiss is similar to that observed at Stop 2. Scale card is 10 cm long.

Photo 6. Mica-pyroxenite rock forming outer shell of mica-apatite vein at Stop 3. Scale card is 10 cm long.

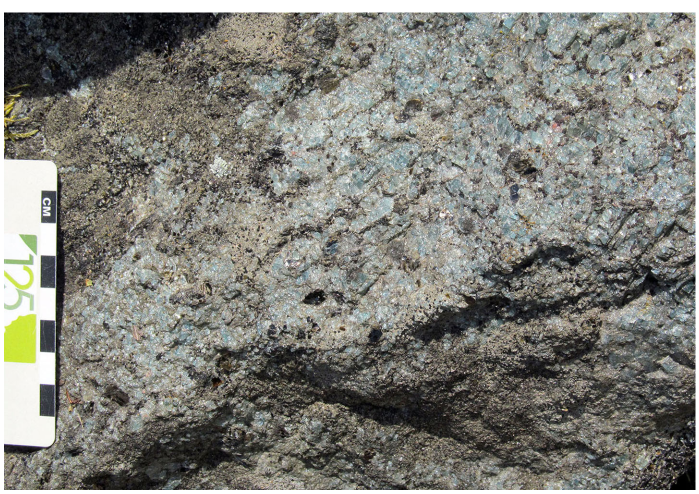

Photo 7. Apatite vein (apatite is bluish) that forms inner shell of mica-apatite vein present at Stop 3. Scale card is 10 cm long.

13.1 km	Kenyon Road curves into Otty Lake Side Road, continue northwest (straight) on Otty Lake Side Road.
17.5 km	Junction of Otty Lake Side Road and County Road 10 (Scotch Line), turn right onto County Road 10 toward Perth.
18.7 km	Pull over and park on the shoulder of the road. Examine outcrop on the north side of the road in front of storage unit facility (UTM 401273E 4971068N).

Photo 8. Geochronology sample site at Stop 4. A pink, medium-grained monzogranite of unit 11 on Map 1089A. Location: UTM 401273E 4971068N. Scale card is 10 cm long.

Stop 4. Frontenac terrane monzogranite

This pink, medium-grained monzogranite is one of the youngest intrusions in the Perth map area, as noted by Wilson and Dugas (1961). This granite is exposed throughout downtown Perth (Figure 8), and has features of both the Frontenac suite at *circa* 1170 Ma or the Kensington–Skootamatta suite at *circa* 1070 Ma. Rocks of the Frontenac and Kensington–Skootamatta suites are commonly difficult to distinguish from one another geochemically; however, granites are somewhat more common in the latter suite. A chemical analysis of this rock is provided (*see* Appendix 1: analysis 17).

This site was sampled for geochronology and yielded a thermal ionization mass spectrometry U/Pb age on zircon of 1103.5±2.1 Ma (Figure 9), with a similar age on titanite of 1090±16 Ma (Kamo and Hamilton 2017). This age is so far unique in Frontenac terrane. It is 55 million years younger than any known Frontenac suite intrusion, and 10 to 15 million years older than the oldest known Kensington–Skootamatta suite intrusion. As such, it may represent a magmatic event transitional between the 2 suites.

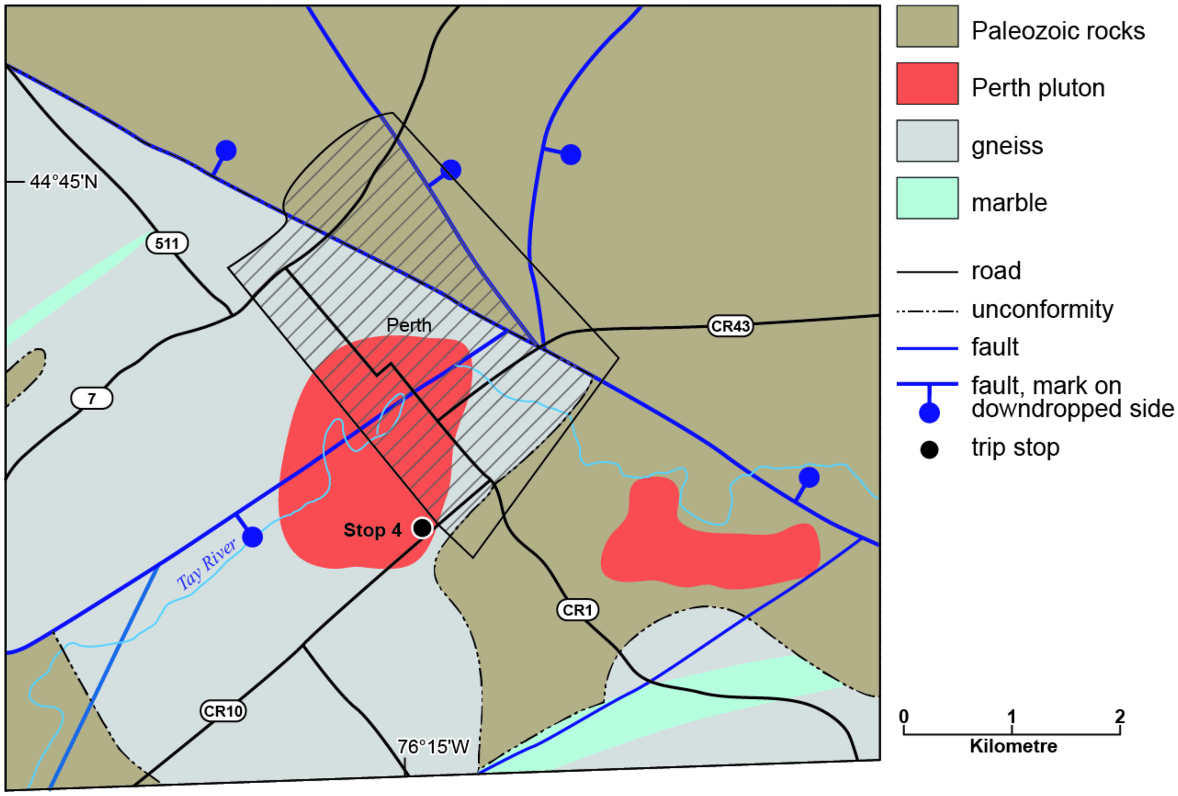

Figure 8. Geological sketch map of the area around the town of Perth showing the location of the granite pluton examined at Stop 4. Geology *modified from* Wilson and Dugas (1961) and Williams and Wolf (1984).

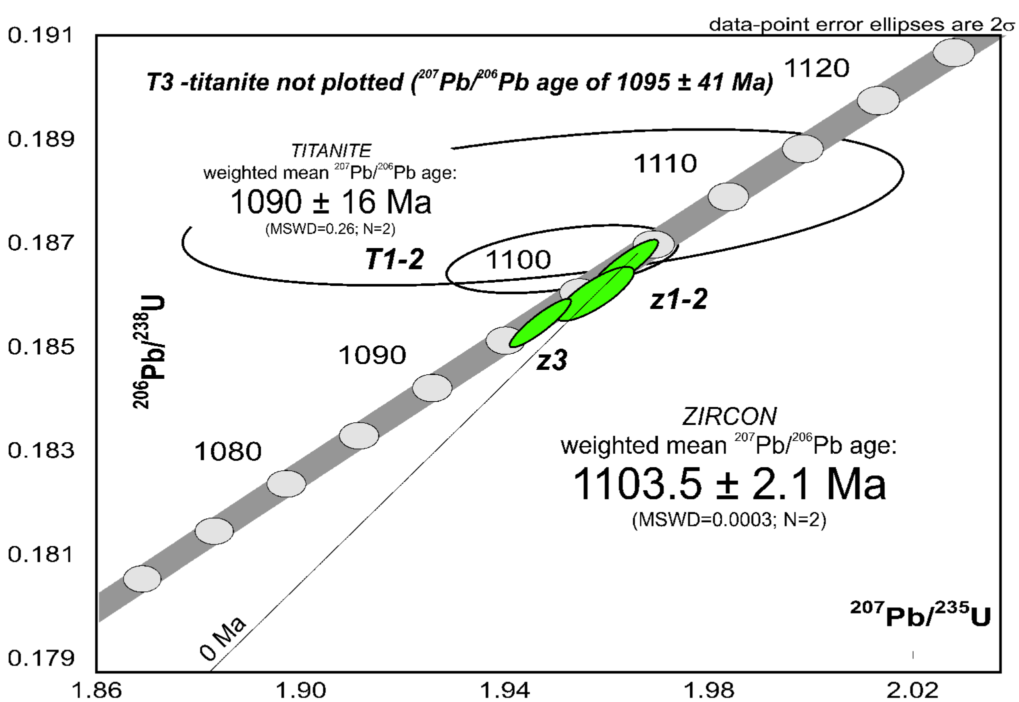

Figure 9. Concordia diagram for sample 16RME-0465 (Stop 4), monzogranite of the Perth pluton. Figure *from* Kamo and Hamilton (2017).

Return to vehicles. Continue east on Scotch Line.

19.7 km	End this segment at the junction of Lanark County Road 1 and County Road 10 in Perth. Make your way through town to the junction of highways 7 and 511 on the west side of Perth.
0.0 km	Highway 7 and 511. Reset odometer to zero (“0”) and head northwest on Highway 511.
7.0 km	Junction in Balderson, continue north on Highway 511.
11.6 km	Pull over and park on the shoulder of the road just before (south) the bridge over the Fall River. Examine large outcrop on the east side of the road (UTM 394014E 4982685).

Stop 5. Frontenac terrane quartzite in the Maberly shear zone

The outcrop at this stop is a massive, white-pink, medium-grained feldspathic litharenite, now quartzite, located in the Maberly shear zone. A chemical analysis of this rock is provided (*see* Appendix 1: analysis 11). Corfu and Easton (1997) obtained a U/Pb zircon age of metamorphism of 1169±3Ma from a quartzite in a similar stratigraphic position as this stop, along strike approximately 17 km to the east-northeast. Corfu and Easton also obtained a U/Pb titanite age of 1156±4 Ma from the same sample.

The stop is about 800 m south of the north side of the Maberly shear zone and is the farthest west that quartzite has been found in the Maberly shear zone (*see* Figure 3). To the west, rocks in the Maberly shear zone, adjacent to Sharbot Lake domain, consist of Frontenac suite intrusions and gabbroic anorthosite intrusions. In contrast, from here eastward, quartzite and migmatitic paragneiss units become common within the Maberly shear zone. This would appear to suggest that the Maberly shear zone transects an earlier lithostructural fabric [“fabric” in a general sense] present within rocks of Frontenac terrane (*see* Figure 3).

Return to vehicles. Continue northwest on Highway 511.

12.1 km	Pull over and park on the shoulder of the road. Carefully cross the road and examine outcrop on the west side of the road (UTM 393882E 4983116N).

Stop 6. Frontenac suite syenite in the Maberly shear zone

This stop is located in the Maberly shear zone near its northern boundary. It is a pink-grey, medium-grained, near mylonitic, augen gneiss of quartz syenite composition. Its deformation state is typical of felsic Frontenac intrusive suite rocks found in the Maberly shear zone. A similar rock is present in the southernmost outcrop at Stop 9, and at the optional stop located between stops 9 and 10.

Return to vehicles. Continue northwest on Highway 511.

13.5 km	Approximate location of the Maberly shear zone–Sharbot Lake domain boundary, south of Lanark County Road 9.
14.9 km	First junction (stop sign) in Lanark. Turn left into Lanark.
15.0 km	Second junction (stop sign) in Lanark. Continue straight (west) onto County Road 12.
18.9 km	Roadcut on the north side of the road exposes clean, thin-layered, dolomite marble (*see* Appendix 1: analysis 25).
19.5 km	Roadcut on the north side of the road exposes clean, thin-layered, calcite marble (*see* Appendix 1: analysis 26).

22.1 km Pull over onto the shoulder of the road just west of the junction with Iron Mine Road, across from the Mississippi River. Examine large outcrop on the north side of the road (UTM 389050E 4980800N).

Stop 7. Sharbot Lake domain marble

This large outcrop shows typical marbles of the Sharbot Lake domain. This stop is located approximately 2 km north of the northernmost part of the Maberly shear zone (Figure 10). Layering (transposed bedding?) in the marble is dipping moderately to the south-southeast. The marble itself is white-blue, medium- to coarse-grained, thin-layered (i.e., weak) calcite to dolomitic calcite marble with chondrodite and tremolite.

Return to vehicles. Continue west on County Road 12.

22.7 km Junction, County Road 12 and County Road 7. Turn left onto County Road 7 and head south.

22.9 km Immediately after the turn, pull over and park in the churchyard on the east side of the road. Walk along the shoulder to examine the low outcrop on the east side of the road.

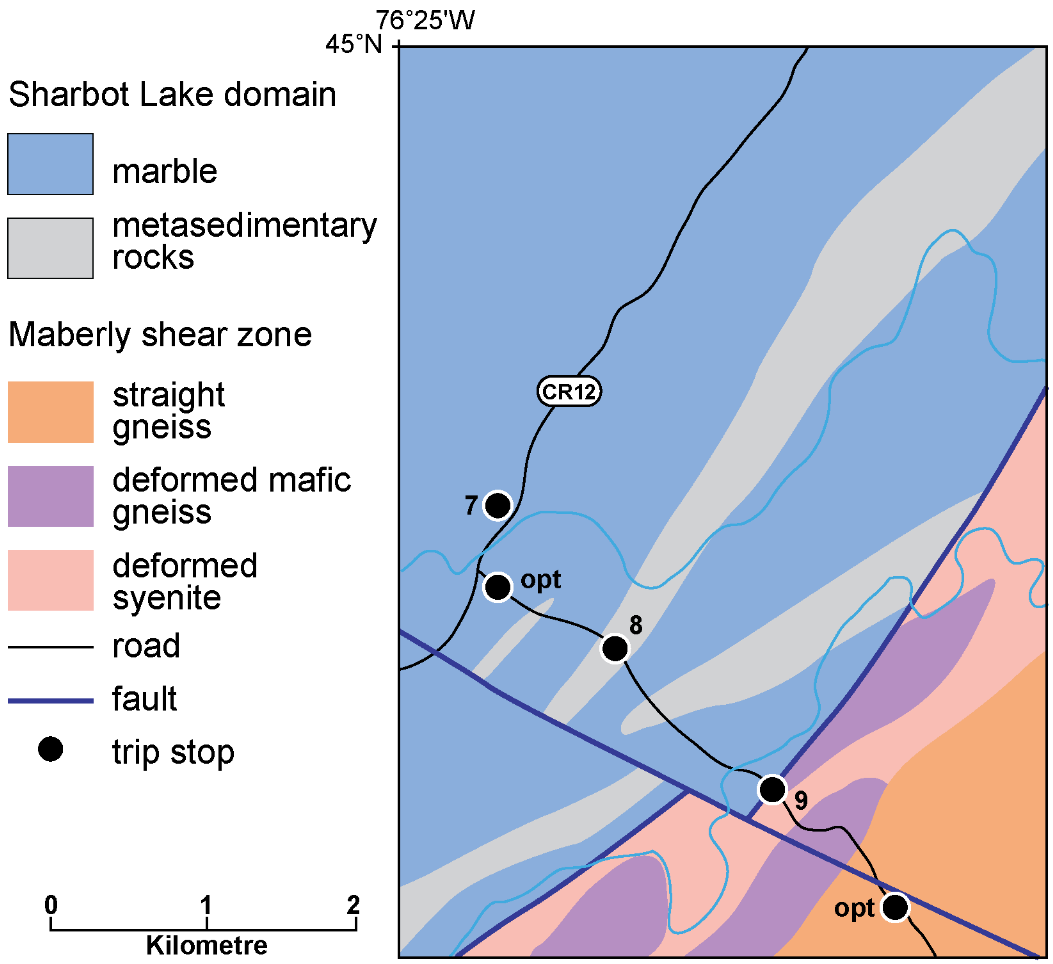

Figure 10. Geological sketch map of the area around the community of Fallbrook showing the location of Stops 8, 9 and 10 in relationship to the northern limit of the Maberly shear zone. Geology *modified from* Wilson and Dugas (1961) and Williams and Wolf (1984).

Optional stop – Sharbot Lake domain marble

Another example of Sharbot Lake domain marbles, with this stop located approximately 1.7 km north of the Maberly shear zone (*see* Figure 10). Grain size has increased from the rocks observed at Stop 7, and the layering in the marbles is less well defined. The marbles are coarse- to very coarse-grained dolomitic calcite marble and calcite marble, all relatively clean with less than 5% silicate minerals.

Return to vehicles. Continue south on County Road 7.

23.7 km Pull over and park on the shoulder by the large outcrop. Outcrops on either side of the road can be examined (UTM 389640E 4979870N, centre of east outcrop).

Stop 8. Sharbot Lake domain paragneiss, marble, folding, felsic veins

Three main rock types are present at this stop, which is located within Sharbot Lake domain (*see* Figure 10). The main rock is a rusty-weathering, thin-layered rusty paragneiss, psammitic and calc silicate gneiss. In the east-central side of the 2 roadcuts is a weakly layered, coarse-grained calcite marble, which is in the core of synform that is one of the many folds present in this outcrop (Photo 9). In the central part of the eastern roadcut, just south of the marble, is one of several, discordant, leucocratic tonalite veins that cut the rusty paragneiss. at the south end of outcrop. The age and affinity of these veins is currently unknown, and there is no pluton in the surrounding vicinity to which they could be related. The veins are non-radiogenic, with average gamma-ray scintillometer readings of 200 counts per second.

Photo 9. Macroscopic folds in paragneiss at Stop 8. Photo was taken by the author in 1988 when the outcrop was less rusty than it is today. Hammer handle is 30 cm long.

Slivers of rusty-paragneiss interlayered with marble are common in the southern part of the Sharbot Lake domain. Unlike paragneiss samples from Frontenac terrane, the rusty gneisses within Sharbot Lake domain have heavy rare earth patterns similar to the post-Archean Australian Shale composite of Taylor and McLennan (1985), but with some light rare earth depletion. The latter could reflect a detrital component related to mafic volcanic rocks present in Sharbot Lake domain. Frontenac terrane paragneiss samples do not show this light rare earth depletion.

Return to vehicles. Continue south on County Road 7.

24.9 km	Bridge over the Fall River.
25.1 km	Pull over and park on the shoulder by the large outcrop. Outcrops on either side of the road can be examined. Marble outcrop centred at UTM 390650E 4978985N, gneiss outcrop centred at UTM 390705E 4978945N and deformed syenite outcrop at UTM 390742E 4978875N.

Stop 9. Marble, Maberly shear zone tectonites and deformed syenite

This stop consists of 3 near-continuous outcrop areas, which, from north to south, are

1. outcrops on both sides of the road, approximately 100 m long, of marble;
2. outcrop on the east side of the road, approximately 45 m long and up to 2.5 m high, of layered mafic gneiss cut by a variety of younger, but highly strained, felsic veins (Photos 10 and 11); and
3. an outcrop on the west side of the road, up to 1 m high of deformed syenite.

The marble consists of massive, coarse-grained dolomitic calcite marble, that is relatively clean (<5% silicate minerals). It is typically white, but it is locally weathered to buff fine-grained dolomite. This dolomitization was probably related to diagenesis during the Paleozoic Eon. Whether or not these marbles belong to the Sharbot Lake domain or Frontenac terrane cannot be determined for certain. To the north, and along strike, marbles are the dominant rock type, suggesting that these marbles may be part of Sharbot Lake domain.

The central part of the outcrop represents the northernmost extent of highly strained rocks typical of the Maberly shear zone (*see* Figure 10), and was one of the outcrops used by Easton (1988) in tracing the shear zone from Maberly through Fallbrook to Carleton Place. In fact, the outcrop exposed at the optional stop on Highway 7 at Maberly (later in the trip) is almost identical to the outcrop seen here. The mafic component of the outcrop (*see* Photo 10) consists of highly flattened amphibolite and mafic and intermediate gneiss of unknown protolith, along with rafts of deformed gabbro (*see* Photo 11). These gabbroic rocks could be mafic plutonic rocks of the Frontenac intrusive suite, or could be derived from another source. A variety of felsic veins of different generations cut the mafic gneisses. Some veins are concordant, whereas others are slightly discordant to the fabric (*see* Photo 10). Composition of the veins is typically syenite or quartz syenite, and the veins likely represent felsic intrusive rocks of the Frontenac suite. All are extremely deformed, with well-developed elongated quartz aggregates. There is no unequivocal indication of shear sense in the gneiss present at this outcrop.

The southernmost outcrop on the west side of the road is similar to Stop 6, consisting of pink-grey, medium-grained, near-mylonitic, augen gneiss of quartz syenite composition. Its deformation state is typical of felsic Frontenac intrusive suite rocks found in the Maberly shear zone, and is consistent with the deformation observed in the central part of the outcrop area.

Return to vehicles. Continue south on County Road 7.

Photo 10. View looking east of the central part of the outcrop at Stop 9 showing layered and veined gneiss in the immediate hanging wall of the Maberly shear zone. Photo was taken by the author in 1988 when the outcrop was less weathered than it is today. No scale.

Photo 11. Close-up view of part of the outcrop shown in Photo 10 at Stop 9, showing blocks of coarse-grained mafic orthogneiss surrounded by fine-grained mafic gneiss, with both cut by younger, but deformed syenite veins. Photo was taken by the author in 1988 when the outcrop was less weathered than it is today. Hammer handle is 30 cm long.

25.8 km	Pull over and park on the shoulder by outcrop on the west side of the road (UTM 391268E 4978480N). Outcrop is approximately ~15 m long, up to 1.5 m high, and is vegetated and lichen covered.

Optional stop – Frontenac suite syenite in the Maberly shear zone

This stop in the Maberly shear zone is similar to Stop 6 and the southernmost outcrop at Stop 9. It is a pink, protomylonitic to mylonitic quartz monzonite gneiss of the Frontenac intrusive suite (*see* Figure 9). A chemical analysis of this rock is provided (*see* Appendix 1: analysis 18). Return to vehicles. Continue south on County Road 7.

28.5 km	Junction, County Road 7 and Keays Road. Turn right onto Keays Road and head west toward Harper Road.
29.8 km	Junction, turn left and head south on Harper Road.
34.75 km	Migmatite outcrop on the west side of Harper Road is a weakly migmatitic, purple-grey-green medium- to coarse-grained quartzofeldspathic gneiss. It has some chemical similarities to monzonites of the Frontenac intrusive suite, but is more deformed and metamorphosed than the Frontenac intrusive suite rocks observed at Stops 6 and 9. A chemical analysis of this rock is provided (*see* Appendix 1: analysis 19). This unit was sampled for geochronology, and yielded a U/Pb thermal ionization mass spectrometry age on zircon of 1178±3 Ma (Kamo and Hamilton 2017) (*see* Table 5). This age is consistent with this rock being an early emplaced member of the Frontenac intrusive suite, and is approximately 10 million-years older than the age of regional metamorphism determined by Corfu and Easton (1997). UTM 395478E 4972117N.
35.2 km	Pull over and park on the shoulder by the large outcrop. Outcrops on either side of the road can be examined, although the mafic dike described below is only observed at the north end of the outcrop on the east side of the road. UTM of outcrop on east side is 395765E 4971765N.

Stop 10. Migmatite and mafic dike

These outcrops are located in the southern part of the Maberly shear zone. The main rock types in these outcrops consist of fine-grained greyish diorite to tonalite gneiss with closely spaced thin monzogranite leucosome (or diatexite), all flattened, and all cut by later discordant monzogranite veinlets and monzonite. These rocks are part of a migmatite-syenite unit identified by Wilson and Dugas (1961, their unit 6d), which is largely restricted to the Maberly shear zone on the west of Highway 511. This is one of the better exposures of this unit. Outcrops in this area are either poorly exposed and/or intensely paleoweathered, making identification of the protolith of these rocks problematic. Without considerably more work, the origin of these gneisses is unclear, especially given their location within the Maberly shear zone. Could they be basement rocks to Frontenac terrane into which younger Frontenac suite intrusive rocks were emplaced? Alternatively, are they part of a rock package present in the western part of the Maberly shear zone, which includes the Lanark–Oso gabbroic anorthosite, but which is not present toward the east (*see* Figure 3)?

The 80 cm wide discordant, but recrystallized, magnetic, fine-grained mafic dike that cuts these gneisses is of far greater interest. It is one of several mafic dikes and associated plutons identified throughout the Perth map area, both in the Maberly shear zone and the Frontenac terrane, that have a distinctive chemical signature, as shown in Appendix 1 (*see* analyses 20 to 24). Analysis 20 is from the dike at this stop, but analyses 21 to 24 all have similar chemistry, which is characterized by high TiO_2,

P_2O_5 and alkali (Ba, K, Rb, Sr) contents. The bulk composition of these rocks is basaltic trachyandesite to trachyandesite using the International Union of Geological Sciences (IUGS) total alkali–silica classification for volcanic rocks (LeMaitre et al. 2002). Scanning electron microscopy (SEM) indicates that the magnetite in all of these rocks formed early in the crystallization sequence, and is surrounded by later formed titanite and/or apatite. Amphibole and biotite in these rocks are also rich in chlorine. A U/Pb thermal ionization mass spectrometry age on zircon of 1164±2 Ma was obtained from one of the larger gabbroic bodies of this suite (Kamo and Hamilton 2017; *see also* Appendix 1: analysis 23). If this dike is similar in age, it suggests that deformation in the Maberly shear zone was largely complete at that time, consistent with the ages from the Bennett Bay and the Silver Lake plutons (*see* Table 5).

Return to vehicles. Continue south on Harper Road toward Highway 7.

36.1 km	Junction of Harper Road and Highway 7, turn right and continue west along Highway 7. Reset odometer to zero ("0").
1.4 km	On the south side of Highway 7 is the Omya Canada Inc. plant. The quality dry ground calcium carbonate products produced at this plant are used by the paint, plastics and building products industries. The slurry grades are used by paper and packaging manufacturers in Canada and the United States. The source for these products is the Tatlock marble quarry, located near Highway 511 approximately 40 km north of Perth.
2.0 km	Picnic area on north side of Highway 7.
7.9 km	Pull over and park on the shoulder by the large outcrop. Examine outcrop on the north side of the road (UTM 394589E 4970425N).

Optional stop – Maberly shear zone

Large, north-trending granitoid pegmatitic veins are common in the Maberly shear zone in the Perth map area. This outcrop is typical of many of these veins, which here consists of pink, medium- to coarse-grained protomylonitic quartz monzonite to quartz syenite.

Although many syenitic to granitic pegmatite veins were exploited or considered for feldspar extraction in the Perth map area, the largest past-producing feldspar mines, such as the Bathurst Mine (Goad 1990, p.167), are restricted to the Maberly shear zone. The key features of these exploited pegmatite veins are a north to northwest orientation, a tapered form characterized by wide centres (up to 35 m), but narrow ends (<10 m), and limited strike length (<300 m) (Goad 1990). All of the largest veins were emplaced into deformed Frontenac suite syenite intrusions in the Maberly shear zone. The age of these pegmatite veins is not known, but they must be younger than the Bennett Bay pluton (1164±2 Ma: Davidson and van Breemen 2000). The shape of the veins and their concentration in a major deformation zone and in a rheologically strong rock unit (Frontenac intrusive suite plutons) suggest that their emplacement was structurally controlled. This could have occurred either late in the formation of the Maberly shear zone (*circa* 1155 Ma) or perhaps during reactivation of the Maberly shear zone during the main phase of the Ottawan Orogeny (*circa* 1080 to 1050 Ma). Although veins are located in Frontenac terrane, historical data suggest that veins in that area were less productive than those in the Maberly shear zone (~2750 t versus >150 000 t feldspar extracted from the Maberly shear zone: Hewitt 1952, 1964a).

Return to vehicles. Continue west on Highway 7.

9.5 km	Junction with Old Brooke Road, continue west on Highway 7.
10.0 km	Pull over and park on the shoulder by the large outcrop, just east of junction with Doran Road. Examine outcrops on the north side of Highway 7 (UTM 386850E 4968132N).

Photo 12. Highly strained, intermediate composition gneiss at Stop 11 in the Maberly shear zone.

Stop 11. Maberly shear zone, gneiss and calc-silicate gneiss

This relatively fresh roadcut exposes thin- to medium-layered, fine- to medium-grained mafic, intermediate and felsic straight gneiss of the Maberly shear zone. At the west end of the outcrop on the north side of the highway, the felsic layers are thicker, and are interlayered with a calc-silicate gneiss with green diopside pods. This outcrop is 5 km south of the northern boundary of the Maberly shear zone, and demonstrates that highly strained gneisses (Photo 12) are present well south of the boundary.

Return to vehicles. Continue west on Highway 7.

10.8–11.0 km Pull over and park on the shoulder opposite the large outcrop area on the south side of Highway 7. Cross the road with caution to examine outcrops on the south side of Highway 7 (UTM 385925E 4967751N).

Stop 12. Maberly shear zone in microcosm

This 250 m long discontinuous outcrop on the south side of Highway 7 typifies the larger scale map pattern of the Maberly shear zone. It includes interleaved panels of gneiss and marble tectonic breccia. Thin- to medium-layered mafic, intermediate, and felsic straight gneiss and calc-silicate gneiss occur at both the west and east ends of the outcrop (Photos 13, 14 and 17). At the west end, pink calcite marble (Photo 15) and sulphide-bearing mica-pyroxenite skarn (Photo 16) rocks are well exposed.

Return to vehicles. Continue west on Highway 7.

11.5 km Pull over and park on the shoulder opposite a large outcrop area on the north side of Highway 7. Examine outcrop on the north side of Highway 7 (UTM 385503E 4967645N).

Photo 13. Southeast-dipping, flattened, mafic, intermediate and calc-silicate gneisses within the Maberly shear zone at the west end of Stop 12.

Photo 14. Close-up view of gneisses shown in Photo 13 showing flattened, mafic, intermediate and calc-silicate gneisses within the Maberly shear zone at the west end of Stop 12. Scale card is 10 cm long.

Photo 15. Close-up of metasomatic, pink calcite rock at the west end of Stop 12. Scale card is 10 cm long.

Photo 16. Close-up of mica pyroxenite rock associated with pink calcite rock shown in Photo 15, at the west end of Stop 12.

Photo 17. Close-up of flattened calc-silicate gneisses within the Maberly shear zone at the east end of Stop 12. Scale card is 10 cm long.

Optional stop – Weathered marble tectonic breccia and channel fill of Paleozoic sedimentary rocks

This outcrop consists mainly of paleoweathered marble tectonic breccia. Where less weathered, the marble breccia consists of coarse-grained, white, calcite marble with 10 to 20% silicate minerals, with 10 to 15%, 2 to 10 cm size paragneiss fragments. Weak subhorizontal sheeting and recrystallization to fine-grained calcite is visible in the outcrop where weathering was more intense. Toward the east end of the outcrop is a channel cut into the marble breccia that is filled with reddish, Paleozoic siliciclastic rock. The channel is at least 3 m deep and up to 20 m wide and was cut down into weathered calcite marble. The deeper (>3 m) west side of the channel is filled with red-weathering pebbly conglomerate containing subangular to subrounded rock fragments and quartz pebbles, which grade upward into thin-bedded reddish coarse sandstone. The shallower (~2 m) east side of the channel consists of red mudstone and siltstone beds (up to 1 cm thick) that immediately overlie the marble basement and which are overlain, in turn, by thin-bedded reddish coarse sandstone. These mudstones to sandstones are likely part of the Covey Hill Formation, or alternatively, the Abbey Dawn Formation.

Return to vehicles. Continue west on Highway 7.

12.5 km Pull over and park on the shoulder opposite a large outcrop area on the south side of Highway 7. Cross the road with caution to examine outcrops on the south side of Highway 7 (UTM 385925E 4967751N).

Stop 13. Maberly shear zone, pink calcite rock

The east end of the outcrop consists of a band, approximately 40 m wide, of pink coarse-grained marble breccia (Photo 18) with abundant diopside, diopside-replaced fragments, and mafic fragments (i.e., diorite, gabbro). This type of rock is typical of metasomatic rocks that are associated with syenite intrusions in both Frontenac and Bancroft terranes, some of which contain rare earth carbonate minerals. A chemical analysis of this rock is provided (*see* Appendix 1: analysis 16). The pink calcite marble at this locality is not enriched in rare earth elements.

Rocks at the west end of the outcrop consist of fine- to medium-grained grey gneiss (diorite, gabbro) with white granodiorite veinlets, which produce almost a net vein or intrusion breccia look, with pyroxene syenite veinlets also present. This rock could be a precursor to some of the flattened intermediate and calc-silicate tectonites seen at Stops 11 and 12.

Return to vehicles. Continue west on Highway 7.

13.9-14.0 km Pull over and park on the shoulder opposite a large outcrop area on the north side of Highway 7. Examine outcrop on the north side of Highway 7 (UTM 383904E 4967405N).

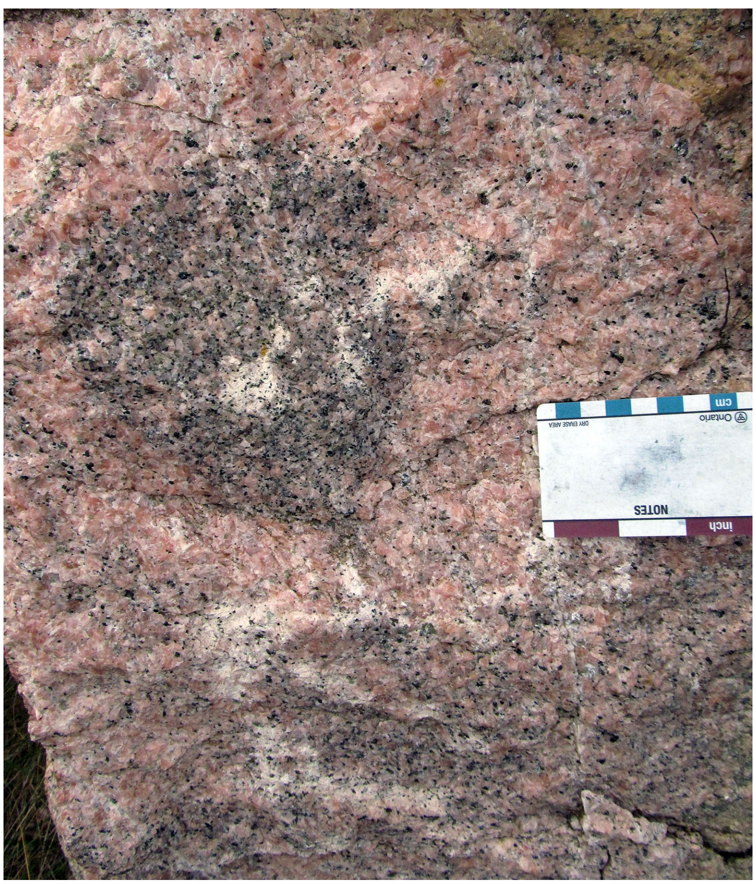

Photo 18. Close-up of pink calcite rock in the Maberly shear zone at Stop 13. Scale card is 10 cm long.

Stop 14. Maberly shear zone, marble tectonic breccia

This outcrop in the Maberly shear zone is approximately 2.8 km south of the northern boundary of the shear zone and approximately 300 m south of the southern margin of the Bennett Bay pluton. It consists mainly of coarse-grained calcite marble breccia with 10 to 20% silicate minerals and 2 to 6 cm fragments of paragneiss and/or calc-silicate rock, rusty gneiss, or white plagioclase-rich pegmatite. Some fragments may be as large as 30 cm. At the east end of the outcrop is a zone of coarse-grained pale green to nearly white diopside. This rock is better exposed in the outcrop on the south side of the highway.

Return to vehicles. Continue west on Highway 7.

15.1 km	This 50 m long, up to 2.5 m high, in part foliation plane, freshly blasted outcrop is located on north side of Highway 7, at the McGowan Road turnoff. Pull over and park on the shoulder and examine the outcrop on the north side of Highway 7 (UTM 382000E 4966743N).

Stop 15. Maberly shear zone, mafic gneiss

This stop is approximately 200 m from the southern margin of the Bennett Bay pluton, and approximately 2.3 km south of the northern boundary of the Maberly shear zone. The east end of the outcrop is protomylonitic to mylonitic gabbroic anorthosite, possibly related to the Lanark–Oso intrusion that crops out to the south-southwest. The west end is protomylonitic to mylonitic monzonite, possible a phase of Bennett Bay pluton, which is a Frontenac suite intrusion. Return to vehicles. Continue west on Highway 7.

15.4–15.9 km	Southward-dipping outcrops on the north side of the road are highly strained gneiss of the Maberly shear zone on the south flank of the Bennett Bay pluton (1164±2 Ma: Davidson and van Breemen 2000).
16.2 km	Junction with Old Brooke Road on south side of highway, continue west on Highway 7. An outdoor art exhibit located along Old Brooke Road makes for an interesting diversion from looking at rocks (*see* http://fieldworkproject.com/).
18.3 km	Junction of County Road 36 and Highway 7. Continue west on Highway 7.
18.8 km	Pull over and park on the shoulder by the large outcrop on the north side of Highway 7 (UTM 378270E 4965755N).

Optional stop – Maberly shear zone on Highway 7 at Maberly

This large outcrop is similar to that observed at Stop 9 just south of Fallbrook. The mafic component of the outcrop consists of highly flattened amphibolite and mafic and intermediate gneiss of unknown protolith, along with small rafts of deformed gabbro. These gabbroic rocks could be mafic plutonic rocks of the Frontenac intrusive suite, or could be derived from another source. A variety of felsic veins of different generations cut the mafic gneisses. Some veins are concordant, whereas others a slightly discordant to the fabric. All are extremely deformed, with well-developed elongated quartz aggregates common in the quartz syenite veins. Lineation is not well developed, and there is no unequivocal indication of shear sense. Return to vehicles. Continue west on Highway 36 to Main Street.

19.1 km	Turn right onto Main Street and head into Maberly.
19.4 km	Junction in Maberly, turn right and head east along County Road 36.
19.9 km	Pull over and park on the shoulder by the municipal garage and playground. Walk back 300 m to the west to examine low outcrops exposed along the curve in the road (UTM 378515E 4965965N).

Photo 19. Augen in deformed felsic layer in straight gneiss in the Maberly shear zone at Stop 16 in Maberly. Photograph was taken in 1994 by the author. This outcrop is no longer this well exposed. Knife is 9 cm long.

Photo 20. Raft of gabbro within deformed gneisses of the Maberly shear zone at Stop 16 in Maberly. Photograph was taken in 1994 by the author. This outcrop is no longer this well exposed.

Stop 16. Maberly shear zone in Maberly

This outcrop was previously described as Stop 3-2 in Easton and Davidson (1994). The low outcrops on the south side of the road and an outcrop in a yard just west of the old church expose highly strained gneisses of the Maberly shear zone. These rocks show well-developed augen structure in some places (Photo 19), and characteristics of straight gneiss in others. At the east end of the roadcut, several tectonic enclaves of anorthositic gabbro are preserved, similar to the example shown in Photo 20. These tectonites were evidently derived from mafic igneous rocks cut by granite, syenite and pegmatite dikes. Lineation is not well developed, and there is no unequivocal indication of shear sense. Return to vehicles. Continue east on County Road 36.

20.2 km Junction of County Road 36 and Highway 7.

End of road log.

Appendix 1.

Geochemical Data

Appendix 1. Geochemical data for selected Grenville Supergroup (analyses 1 to 9) and Frontenac suite (analyses 10 to 14) rocks from the Frontenac terrane, Perth area. All analyses were performed at the OGS Geoscience Laboratories, Sudbury. Complete data are available in Easton (2018a). The UTM co-ordinates are provided using NAD83 in Zone 18.

Analysis Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Sample Number	**15RME-0420**	**16RME-0214**	**16RME-0456**	**16RME-0558**	**15RME-0403**	**16RME-0225**	**16RME-0230**	**16RME-0222**
Stop Number	n/a	n/a	2	n/a	n/a	n/a	n/a	n/a
Easting (m)	398200	401021	400913	402258	398129	398348	398424	402376
Northing (m)	4958467	4961018	4965468	4959940	4956525	4958972	4959286	4961160
Subdomain	central	central	central	central	central	central	central	central
Rock Name	garnet-oligoclase paragneiss	garnet-kyanite paragneiss	garnet-paragneiss	garnet-paragneiss	feldspathic paragneiss	feldspathic paragneiss	feldspathic paragneiss	garnet-feldspar paragneiss
Easton (1997) Rock Name	aluminous pelite	aluminous pelite	aluminous pelite	aluminous pelite	low-Al pelite	low-Al pelite	low-Al pelite	calc-pelite
Magnetic Susceptibility*	2.266 ± 5.947	1.548 ± 1.861	3.117 ± 4.822	0.401 ± 0.419	0.391 ± 0.169	1.277 ± 0.857	19.290 ± 21.843	1.064 ± 0.473
SiO_2 (wt %)	57.17	57.09	57.66	62.71	51.41	61.57	61.21	73.40
TiO_2	1.49	1.57	1.56	1.55	2.03	1.16	0.90	0.98
Al_2O_3	20.76	21.07	20.46	17.09	17.11	13.17	15.02	9.90
$Fe_2O_3^{total}$	9.41	8.15	9.29	6.98	8.45	5.52	3.59	6.80
MnO	0.075	0.053	0.075	0.049	0.114	0.074	0.046	0.086
MgO	3.69	3.80	2.76	3.31	4.00	3.71	1.68	1.82
CaO	1.05	1.02	0.77	1.21	3.39	3.01	4.21	2.56
Na_2O	3.69	0.87	1.25	1.48	5.30	3.16	2.82	0.62
K_2O	3.55	5 .78	5.04	4.91	3.99	6.17	5.84	2.88
P_2O_5	0.064	0.065	0.11	0.04	1.81	0.117	0.085	0.079
CO_2	<0.023	<0.023	<0.023	0.117	0.17	0.85	2.52	0.77
S	0.21	0.06	0.20	0.12	0.06	0.42	0.32	0.23
LOI	0.35	1.10	0.31	0.67	0.75	1.54	2.78	1.42
Total	101.32	100.63	99.37	100.10	100.02	99.31	98.51	100.60
Mg Number	43.72	48.02	37.05	48.44	48.40	57.11	48.11	34.65
CIA	81.87	75.61	74.35	69.23	71.07	61.25	59.11	67.94
Ba (ppm)	178	551	852	776	641	902	2935	469
Rb	44	129	125	101	89	107	120	51
Sr	12	51	39	194	963	296	272	184
Pb	2	4	5	5	12	16	21	5
Th	17.1	2.55	15	9	7.0	5.13	8	2.31
U	1.6	0.47	<1.6	<1.6	2.4	0.66	<1.6	0.28
Zn	14	14	72	50	108	162	39	52
Zr	205	184	226	319	607	284	233	307
Y	52	29	54	38	40	31	44	25
Total REE	377.3	74.9	>205	>105	493.1	155.2	248.72	121.0

Notes: **Magnetic susceptibility values are ×10^{-3} SI units: the first row is the average value of 10 readings at the sample site, the second row indicates range in values.*
Major element oxides are in weight %; trace element data are in parts per million;
Mg number = atomic Mg/Mg + Fe, where Fe = total Fe expressed as ferrous iron. Mg number and CIA are dimensionless.
Abbreviations: *CIA = chemical index of alteration; LOI = loss-on-ignition; n/a = not applicable; REE = rare earth elements.*

Appendix 1, *continued*.

Analysis Number	9	10	11	12	13	14	15	16
Sample Number	**15RME-0411**	**16RME-0265**	**15RME-0092**	**15RME-0396**	**16RME-0491**	**16RME-0153**	**16RME-0108**	**15RME-0331**
Stop Number	n/a	n/a	5	n/a	1	n/a	n/a	13
Easting (m)	399457	386076	394014	403232	401409	409945	407128	384472
Northing (m)	4857879	4960525	4982686	4962305	4965738	4956910	4961396	4967396
Subdomain	central	central	MSZ	central	central	eastern	eastern	MSZ
Rock Name	paragneiss	calc-silicate gneiss	quartzite	quartzite	quartzite	dolomite marble	pink marble	pink marble
Easton (1997) Rock Name	calc-pelite	calc-pelite	n/a	n/a	n/a	n/a	n/a	n/a
Magnetic Susceptibility*	2.455 ± 3.942	0.710 ± 0.891	n/a	0.060 ± 0.051	1.139 ± 1.046	0.035 ± 0.025	0.025 ± 0.022	n/a
SiO_2 (wt %)	65.67	52.72	76.70	92.92	95.50	0.50	0.04	4.84
TiO_2	0.63	0.68	0.21	0.17	0.30	<0.01	<0.01	0.07
Al_2O_3	11.99	11.30	12.31	2.24	1.87	0.59	0.09	1.05
$Fe_2O_3^{total}$	3.08	5.96	1.64	0.71	1.52	0.38	0.25	0.79
MnO	0.027	0.10	0.009	0.007	0.009	0.04	0.034	0.021
MgO	4.88	6.83	0.1	0.41	0.17	20.14	1.00	3.75
CaO	4.64	13.71	0.82	0.87	0.16	30.20	54.12	49.92
Na_2O	7.43	2.73	3.04	0.34	0.15	<0.02	<0.02	0.09
K_2O	5.23	3.35	4.30	0.58	0.36	<0.01	<0.01	0.20
P_2O_5	0.075	0.143	0.01	0.01	0.01	<0.002	0.017	0.018
CO_2	2.29	0.87	<0.023	0.54	0.09	45.32	39.82	40.86
S	0.81	1.75	0.22	0.23	0.03	<0.003	0.03	0.003
LOI	<0.03	1.59	99.52	0.68	0.32	46.97	43.85	39.94
Total	100.62	99.25	10/78	98.76	100.40	98.78	99.39	100.70
Mg Number	75.84	69.43	60.15	53.36	18.14	99.06	88.00	90.39
CIA	61.26	<42.00	76.70	55.54	73.71	n/a	n/a	n/a
Ba (ppm)	998	1366	737	139	54	<8	65	342
Rb	83	68	88	11	7	<1	3	12
Sr	69	324	74	27	35	35	1678	639
Pb	<2	2	8	<1.7	<1.7	<1.7	14	7
Th	4.5	6.88	5.7	2	<1.5	0.04	0.57	0.32
U	1.1	2.49	0.78	<1.6	<1.6	0.04	0.14	0.03
Zn	4	63	12	2	9	5	3	15
Zr	128	127	231	154	134	<2	<1.8	10
Y	18	27	54	12	2	4	41	5
Total REE	154.8	137.3	176.43	<22	<22	9.1	747.7	22.23

Notes: **Magnetic susceptibility values are $\times 10^{-3}$ SI units: the first row is the average value of 10 readings at the sample site, the second row indicates range in values.*
Major element oxides are in weight %, trace element data are in parts per million;
Mg number = atomic Mg/Mg + Fe, where Fe = total Fe expressed as ferrous iron. Mg number and CIA are dimensionless.
Abbreviations: *CIA = chemical index of alteration; LOI = loss-on-ignition; MSZ = Maberly shear zone, n/a = not applicable; REE = rare earth elements.*

Appendix 1, *continued*.

Analysis Number	17	18	19	20	21	22	23	24
Sample Number	**16RME-0465**	**15RME-0219**	**15RME-0247**	**15RME-0090**	**16RME-0253**	**15RME-0409**	**16RME-0280**	**16RME-0237**
Stop Number	4	optional	optional	10	n/a	n/a	n/a	n/a
Easting (m)	401273	391255	395456	395767	394069	398227	386710	395813
Northing (m)	4971068	4978475	4972142	4971764	4956345	4957790	4951058	4963938
Subdomain	MSZ	MZS	MSZ	MSZ	western	central	western	western
Rock Name	monzogranite	syenite	migmatite	mafic dike basaltic trachyandesite	mafic dike basaltic trachyandesite	mafic dike basaltic trachyandesite	gabbro basaltic trachyandesite	diorite trachyandesite
Magnetic Susceptibility*	1.504 ± 1.517	26.332 ± 13.483	6.337 ± 6.386	41.510 ± 12.589	0.582 ± 0.11	5.575 ± 7.876	147.70 ± 28.76	0.376 ± 0.073
SiO_2 (wt %)	74.32	60.19	62.01	48.61	47.42	49.79	40.89	48.33
TiO_2	0.06	0.90	0.95	2.15	2.28	2.36	4.30	1.79
Al_2O_3	14.61	18.50	15.60	14.99	16.21	15.76	10.42	15.94
$Fe_2O_3^{total}$	0.69	3.55	6.80	12.51	10.09	9.27	18.33	9.95
MnO	0.006	0.024	0.038	0.165	0.112	0.116	0.227	0.144
MgO	0.12	1.24	2.76	5.38	5.82	5.31	5.97	4.72
CaO	1.12	2.07	1.76	8.18	8.88	7.76	9.91	7.05
Na_2O	4.58	4.78	2.75	3.50	3.95	4.31	2.64	2.87
K_2O	4.00	6.58	6.49	2.33	0.92	2.81	2.31	5.59
P_2O_5	0.01	0.282	0.13	1.00	0.60	1.03	2.94	1.76
CO_2	0.20	0.51	0.59	0.51	2.41	1.24	0.60	0.63
S	<0.003	0.04	0.62	0.25	0.19	0.63	0.39	0.18
LOI	0.64	1.26	1.54	0.24	2.75	2.07	1.27	1.21
Total	100.21	99.54	100.93	99.85	99.08	100.71	99.50	99.61
Mg Number	25.63	40.90	44.57	46.01	53.33	53.16	39.22	57.03
CIA	60.09	58.89	59.98	59.98	68.69	62.81	47.28	48.45
Ba (ppm)	428	1568	722	1089	337	1004	1503	2390
Rb	84	91	197	36	11	40	38	109
Sr	194	508	169	899	666	110	781	2606
Pb	10	16	8	7	9	13	7	29
Th	4	0.72	4.39	1.02	1.40	1.35	2.89	9.20
U	<1.6	0.77	0.58	0.34	0.63	0.39	0.88	0.55
V	5	34	96	217	212	212	251	162
Zn	8	35	49	154	94	115	283	183
Zr	70	553	221	215	230	171	184	228
Y	7	34	18	52	53	35	93	42
Total REE	<22	156.77	124.98	271.0	201.0	176.1	563.0	575.5

Notes: **Magnetic susceptibility values are $\times 10^{-3}$ SI units: the first row is the average value of 10 readings at the sample site, the second row indicates range in values.*
Major element oxides are in weight %, trace element data are in parts per million;
Mg number = atomic Mg/Mg + Fe, where Fe = total Fe expressed as ferrous iron. Mg number and CIA are dimensionless.
Abbreviations: *CIA = chemical index of alteration; LOI = loss-on-ignition; MSZ = Maberly shear zone, n/a = not applicable; REE = rare earth elements.*

Appendix 1, *continued*.

Analysis Number	25	26	27	28	29	30	31
Sample Number	**15RME-0099**	**15RME-0104**	**15RME-0080**	**15RME-0023**	**15RME-0006**	**15RME-0049**	**15RME-0035**
Stop number	optional	optional	n/a	n/a	n/a	n/a	n/a
Easting (m)	390814	390376	405734	412923	404334	417594	407436
Northing (m)	4983444	4983029	4968001	4978261	4982078	4981421	4974798
Rock Name	Dolomite marble	Calcite marble	Sandstone	Sandstone	Sandy dolostone	Sandy dolostone	Clayey dolostone
Formation	Grenville Supergroup	Grenville Supergroup	Nepean	March	March	March	March
Magnetic Susceptibility*	0.005 ± 0.003	0.005 ± 0.003	0.009 ± 0.003	0.031 ± 0.015	0.083 ± 0.016	0.059 ± 0.014	0.061 ± 0.037
SiO_2 (wt %)	0.18	0.40	98.22	98.11	34.12	59.65	16.75
TiO_2	0.01	0.01	0.04	0.05	0.02	0.04	0.17
Al_2O_3	0.16	0.12	1.48	1.21	0.98	0.91	3.93
$Fe_2O_3^{total}$	0.20	0.12	0.17	0.07	1.21	0.29	1.02
MnO	0.02	0.003	0.005	0.004	0.172	0.124	0.132
MgO	21.02	4.64	0.07	0.05	10.57	2.01	15.39
CaO	30.39	51.10	0.09	0.04	22.64	18.72	23.61
Na_2O	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.05
K_2O	0.03	0.05	0.10	0.04	0.11	0.39	2.48
P_2O_5	0.01	0.01	0.05	0.01	0.01	0.01	.06
CO_2	46.07	42.57	<0.023	<0.023	28.85	16.83	34.47
LOI	47.42	44.40	0.27	0.18	30.05	17.27	36.11
Total	99.44	100.86	100.44	99.76	99.90	99.43	99.71
Mg Number	99.52	98.71	44.93	58.60	94.54	93.21	96.76
CIA	n/a	n/a	88.68	93.65	n/a	n/a	n/a
CaO/MgO	1.45	11.01	1.27	0.84	2.14	9.31	1.53
Ba (ppm)	<8	<8	<8	12	127	40	176
Rb	1	2	1	2	3	6	33
Sr	39	313	31	128	62	68	99
Pb	<1.7	<1.7	<1.7	<1.7	<1.7	2	8
Zn	2	2	<1	2	2	1	18
Y	3	3	1	2	6	7	7
Zr	2	3	32	55	32	40	81
Total REE	5.1	5.8	19.8	8.8	28.3	47.3	40.1

Notes: **Magnetic susceptibility values are $\times10^{-3}$ SI units: the first row is the average value of 10 readings at the sample site, the second row indicates range in values.*
Major element oxides are in weight %, trace element data are in parts per million;
Mg number = atomic Mg/Mg + Fe, where Fe = total Fe expressed as ferrous iron. Mg number and CIA are dimensionless.
Abbreviations: *CIA = chemical index of alteration; LOI = loss-on-ignition; MSZ = Maberly shear zone, n/a = not applicable; REE = rare earth elements.*

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Metric Conversion Table

SI Unit	Multiplied by	Gives	Imperial Unit	Multiplied by	Gives
Conversion from SI to Imperial			**Conversion from Imperial to SI**		
		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.*

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