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Geology of the Western Schreiber–Hemlo Greenstone Belt: A Geological Guidebook

2019

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Open File Report 6357

Geology of the Western Schreiber–Hemlo Greenstone Belt: A Geological Guidebook

by

S.J. Magnus

2019

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Abstract

The Schreiber–Hemlo greenstone belt is located within the Wawa–Abitibi terrane of the Superior Province. The greenstone belt includes Neoarchean supracrustal and intrusive rocks that are crosscut and unconformably overlain by Paleoproterozoic and Mesoproterozoic intrusive and supracrustal rocks of the Southern Province. Bedrock mapping in this area by the Ontario Geological Survey from 2015 to 2018 focussed on the Archean rocks of the western part of the Schreiber–Hemlo greenstone belt, with an emphasis on applying modern geochemical and geochronological techniques.

The supracrustal rocks in the western Schreiber–Hemlo greenstone belt are arranged in an upright stratigraphy, consisting of 4 distinct depositional packages with chemical and clastic metasedimentary rocks along disconformable contacts. The oldest rocks in the greenstone belt are felsic and mafic metavolcanic rocks of Package A, deposited *circa* 2720 Ma in a volcanic arc environment. These are overlain by Package B, which is composed mainly of mafic metavolcanic rocks deposited in a “back-arc” volcanic environment. In the western part of the project area, Package B is overlain by Package C, which is composed mainly of mafic metavolcanic rocks deposited in an “oceanic plateau” volcanic environment. In the eastern part of the project area, Package B is overlain by Package D (the McKellar Harbour formation), which is composed of turbiditic wacke and mudstone deposited between 2696 and 2690 Ma. The chronostratigraphic relationship between packages C and D is unknown, as contacts between these packages have not been observed.

The oldest felsic plutons that crosscut the supracrustal rocks are the Terrace Bay and Steel River plutons (*circa* 2690 Ma). Regional ductile deformation likely started at approximately this time; however, whether it began before or after emplacement of the plutons is uncertain. The Santoy Lake pluton (*circa* 2667 Ma) shows little evidence for ductile deformation along its margins, which suggests that regional ductile deformation ceased at approximately this time. Northwest ductile and brittle-ductile shear zones crosscut and displace all of the Archean rocks.

Dikes of the Paleoproterozoic Matachewan, Biscotasing and Marathon dike swarms crosscut Archean rocks in the project area, and outliers of the base of the Paleoproterozoic Gunflint Formation unconformably overlie the Archean rocks at the west end of the project area, southwest of Schreiber. The Coldwell Alkalic Intrusive Complex (*circa* 1108 Ma) intrudes the Archean rocks at the east end of the Schreiber–Hemlo greenstone belt. Alkalic diabase dikes crosscut the Archean rocks and the intrusive rocks of the Coldwell Alkalic Intrusive Complex and are believed to be related to volcanism during rifting associated with formation of the Keweenawan Midcontinent Rift.

The Archean rocks host a variety of base metal and precious metal occurrences which have been the subject of exploration and limited mining activities for over a century. The felsic metavolcanic rocks (*circa* 2720 Ma) of Package A are correlative with rocks in the nearby Winston Lake and Manitouwadge areas that host past-producing zinc-copper mines. Gold mineralization is hosted in sheared and altered metavolcanic rocks and in veined and altered granitoid rocks. Proterozoic rocks in the north shore of Lake Superior region have potential to host magmatic sulphide and oxide mineralization, including a variety of transitional metals and rare earth elements.

A day-long field excursion providing an overview of the Precambrian geology of the western Schreiber–Hemlo greenstone belt is included in this report. The majority of stops focuses on the Archean supracrustal and intrusive rocks and their structural features, with minor focus on Proterozoic rocks. This report complements geological maps, reports and data publications related to recent mapping in the Schreiber–Hemlo greenstone belt. The combination of stops included in this guidebook is designed to exhibit some of the major rock types in the belt and illustrate part of the geological evolution of this part of the Superior Province.

Geology of the Western Schreiber–Hemlo Greenstone Belt: A Geological Guidebook

S.J. Magnus[1]

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2019

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[1]**Geoscientist, Earth Resources and Geoscience Mapping Section, Ontario Geological Survey**
Seamus.magnus@ontario.ca

Introduction

PREFACE

This field trip guidebook was prepared for a 1-day, pre-meeting field trip held in conjunction with the Institute on Lake Superior Geology (ILSG) Annual Meeting hosted in Terrace Bay, Ontario, from May 7 to 10, 2019. This geological guidebook was written to showcase the preliminary results of 4 years of bedrock mapping conducted by the author for the Ontario Geological Survey from 2015 to 2018 in the Schreiber–Hemlo greenstone belt (Magnus and Walker 2015; Magnus and Arnold 2016; Arnold, Hollings and Magnus 2017; Magnus 2017a, 2017b; Magnus and Hastie 2018). The coincidence of this meeting being held in Terrace Bay (within the mapping area) as the project was wrapping up provided the perfect opportunity to showcase these preliminary results to a broad audience. The ILSG meeting has never been hosted in Terrace Bay; however, the meeting was hosted in the nearby towns of Nipigon in 2005 and Marathon in 1995. A field guide, "Geology of the Schreiber Greenstone Assemblage and its Gold and Base Metal Mineralization", was prepared for the 1995 meeting in Marathon (Smyk and Schnieders 1995); two of the five stops from that field guide are revisited in this field guide, but with updated information.

The tectonically diverse geological history of the Lake Superior region has made it a playground for geologists of every discipline. The north shore of Lake Superior has over a century of mining and exploration history, including precious metals, base metals, rare earth metals and unique industrial minerals, such as the colourful marbles at Ruby Lake. Paleoindian sites along the north shore of Lake Superior, which were likely settled during glacial retreat at about 10 000 years before present, tend to be located in close proximity to the cherty rocks of the Gunflint Formation, a source for tooling material (Norris 2012). In fact, there is evidence to show that ancient peoples south of the lake were mining, using and trading native copper as early as 4000 years before present (Pleger 2000). Furthermore, the Ojibway story of Nanabush and Waub-Ameek (the Giant Beaver) describes the glacial history of the Great Lakes (Snake et al. 1991), albeit in a mythological way. Indeed, the geology of the Lake Superior area has been of interest to humans for a long time, and the author is thankful for the opportunity to learn a little more about the geological history of the area, and even more thankful to be able to share this knowledge.

SAFETY

Some of the field trip stops are located on Trans-Canada Highway 17, which is busy year-round and especially during the summer months. This highway is the major transportation route between western and eastern Canada, and as such much of the traffic along this highway includes transport trucks and logging trucks which have great momentum, especially when fully loaded. The terrane along the north shore of Lake Superior is rugged, thus the highway in this area has many hills and blind curves and the road is mostly restricted to 2 lanes with narrow shoulders. To maximize the safety of the field trip participants and that of the drivers on the highway, and to minimize the effect that our presence has on the flow of traffic, the author has selected field trip stops that provide ample parking space away from the shoulders of the highway and have suitable sight-lines with the traffic. The area along the north shore of Lake Superior is prone to inclement weather conditions, with dense fog possible at any time of year, causing additional risk for drivers and pedestrians; please use extreme caution during foggy periods.

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.

Stop 3 involves some driving along a railway maintenance path underlain by sand, gravel and rough ground. Two-wheel drive vehicles are capable of driving on this path, but vehicles with higher clearance and all-wheel or four-wheel-drive are preferred. This stop also involves a short hike away from the parking spot, across a railroad track and up and down a steeply graded slope. Participants should be aware of the potential for railroad traffic and "slips, trips and falls" hazards. It is recommended that anyone following this field guide individually should bring first aid supplies, food and water. Cell phone service coverage at Stop 3 is not 100% for all providers, especially in areas with more rugged terrain; participants should ensure that their cell phones have adequate connection to their networks before driving down the railroad access path, and again before hiking to the outcrop.

Most of the trip routes and sites 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 to maintain good relationships with the landowners so that future access for geologists is not adversely affected.

TERMINOLOGY

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

For the sake of simplicity, the name "Wabigoon terrane" is used in figures and in the text to refer to the collective granite and greenstone domains between the Quetico and English River metasedimentary terranes. As used in this report, "Wabigoon terrane" includes several subdivisions included in Stott et al. (2010).

Rock Classification

Terminology for clastic sedimentary rocks, such as wacke and mudstone, follows Pettijohn (1975). Terminology for volcaniclastic rocks, such as tuffaceous conglomerates, follows Schmid (1981).

Geochemical Methods and Terminology

All whole rock chemical analyses that appear in this report were done at the Geoscience Laboratories, Ontario Geological Survey, Ministry of Energy, Northern Development and Mines, Sudbury. All chondrite- and primitive mantle-normalized data or diagrams referred to or shown in this report use the normalizing values of Sun and McDonough (1989).

Rock type names based on major element analyses are based on the Total Alkalis versus Silica diagram (TAS) (LeMaitre 1989), except for more ultramafic rocks such as basaltic komatiites, which have been named according to Jensen (1976).

Regional Geological Setting

The bedrock along the north shore of Lake Superior hosts rocks spanning roughly 1.9 billion years of Earth's history, from the beginning of the Mesoarchean era to the end of the Mesoproterozoic era, and include a diverse range of rocks formed in a variety of tectonic settings.

NEOARCHEAN GEOLOGICAL SETTING

The Superior Province is an Archean craton that forms part of the North American continental shield. Rocks of the Superior Province, which range in age from *circa* 3.4 Ga to 2.6 Ga, are arranged in greenstone belts and plutonic domains. The Superior Province has been subdivided into terranes in which the rocks share similar lithological, geochemical, age and isotopic characteristics and structural and metamorphic histories (Stott et al. 2010). The relationship between these terranes during the early stages of their formation is unclear; however, the histories of their evolution converge at *circa* 2700 Ma, when the terranes were amalgamated to form the Superior craton (Stott et al. 2010).

Three major terranes are present near the north shore of Lake Superior: the Wawa–Abitibi terrane to the south, the Wabigoon terrane to the north, and the Quetico terrane between them (Figure 1). The Wawa–Abitibi granite-greenstone terrane contains Neoarchean volcanic rocks erupted through juvenile oceanic crust and is interpreted to represent an oceanic arc depositional environment (Williams 1989). The Wabigoon granite-greenstone terrane contains Neoarchean volcanic rocks erupted through and deposited upon Mesoarchean crust; it is interpreted to represent a continental arc depositional environment and is considered to have been a "proto-continent" (Williams 1989). The Quetico terrane is composed mainly of turbiditic siliciclastic rocks with sparse slivers of oceanic crust and is interpreted to represent an accretionary wedge deposited offshore of the Wabigoon "proto-continent" (Williams 1989; Fralick, Purdon and Davis 2006). A preliminary compilation of geochronological data for these terranes (Figure 2) helps to visualize the timing of events.

Sedimentary rocks in the Manitouwadge greenstone belt and in the western Schreiber–Hemlo greenstone belt, both along the northern margin of the Wawa–Abitibi terrane (*see* Figure 1), contain detrital zircon populations that are correlative with those in the Quetico terrane and in the Beardmore–Geraldton greenstone belt (Zaleski, van Breemen and Peterson 1999; Fralick, Purdon and Davis 2006; Tóth 2018, Tóth et al. 2015) (*see* Figure 2). This suggests that during deposition of the sedimentary sequences, the Wabigoon, Quetico and Wawa–Abitibi terranes were a contiguous depositional environment.

In this interpreted environment, detrital material from both the ongoing Wabigoon continental arc volcanism and from erosion of Mesoarchean crust of the Wabigoon "proto-continent" was deposited into a fore-arc accretionary wedge. As the Wawa–Abitibi oceanic arc approached the proto-continent, sediments from the continent began to fill the basin between them, eventually spilling over onto the still-active Wawa–Abitibi volcanic arc (Fralick, Purdon and Davis 2006).

The end of supracrustal rock formation in the northern Lake Superior region is marked at *circa* 2690 Ma by crosscutting felsic plutons (*see* Figures 1, 2); plutonism in the region was accompanied by regional deformation and metamorphism from *circa* 2690 to *circa* 2670 Ma (*see* Figure 2). The 3 terranes were deformed synchronously during 3 main events: 1) early thrusting during collision of the terranes (D_1), 2) upright folding during continued compression (D_2), and 3) late transpressional shearing (D_3) (Williams 1989). These deformational events likely represent a succession of different styles of deformation during a single protracted event, not 3 distinct events (Williams 1989).

The proposed structural histories for the Shebandowan (Corfu and Stott 1998) and Manitouwadge greenstone belts (Zaleski, van Breemen and Peterson 1999) and the eastern part of the Schreiber–Hemlo greenstone belt (Muir 2003) are similar to Williams's (1989) broad interpretation for the region; however, the timing and development of deformation is slightly different for each greenstone belt and within each terrane. These differences are likely caused by uncertainties in the geochronological data, inconsistencies in interpretations of all of the geological and related data, and the diachronous nature of regional deformation itself (Corfu and Stott 1998).

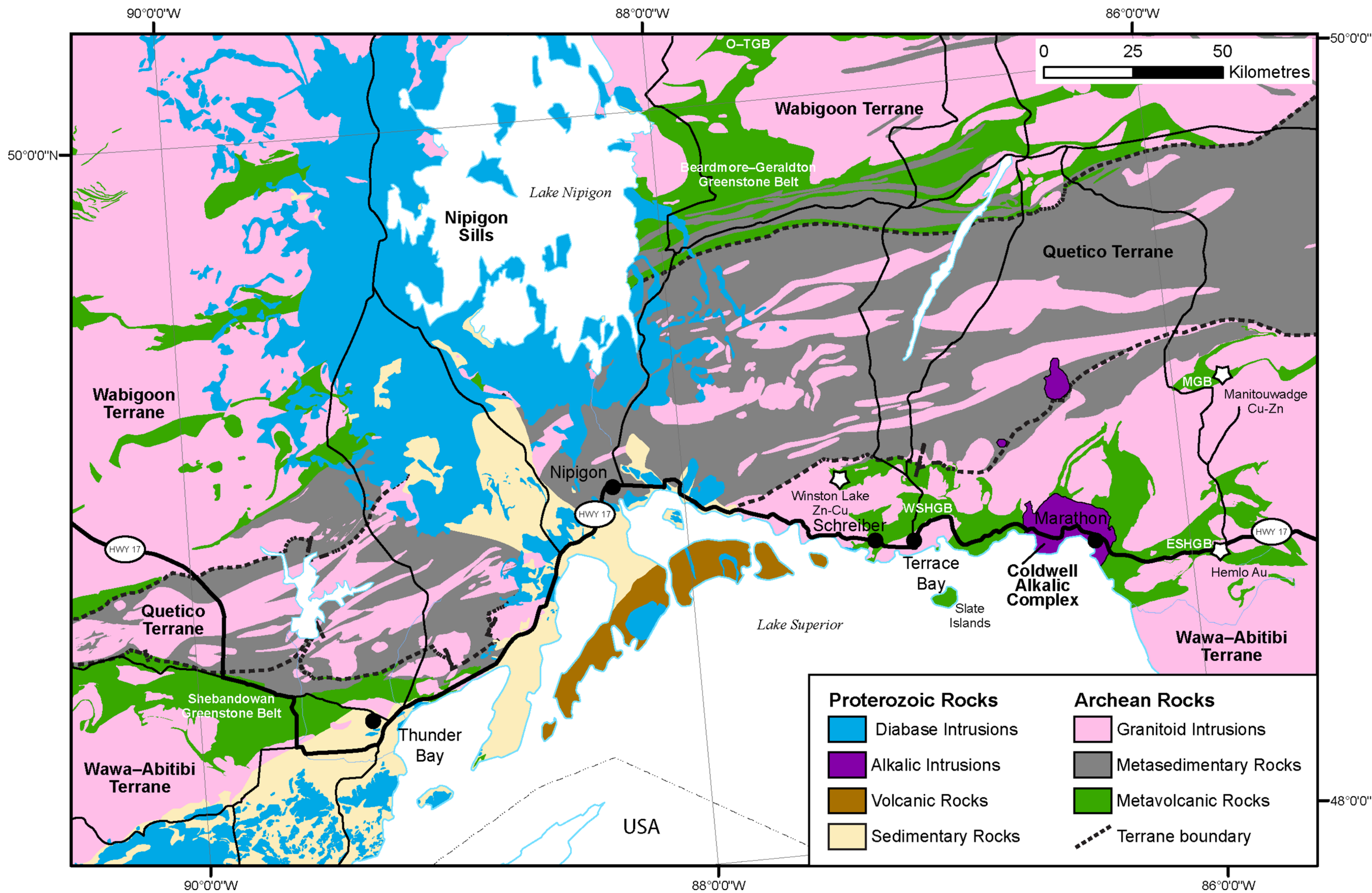

Figure 1. Regional map of the north shore of Lake Superior, displaying Archean and Proterozoic geology. White stars indicate local past-producing and currently producing mines. Abbreviations: O-TGB = Onaman–Tashota greenstone belt, MGB = Manitouwadge greenstone belt, ESHGB = eastern Schreiber–Hemlo greenstone belt, WSHGB = western Schreiber–Hemlo greenstone belt, HWY 17 = Trans-Canada Highway 17. Geology *from* Ontario Geological Survey (2011); Terrane and domain boundaries from Stott et al. (2010).

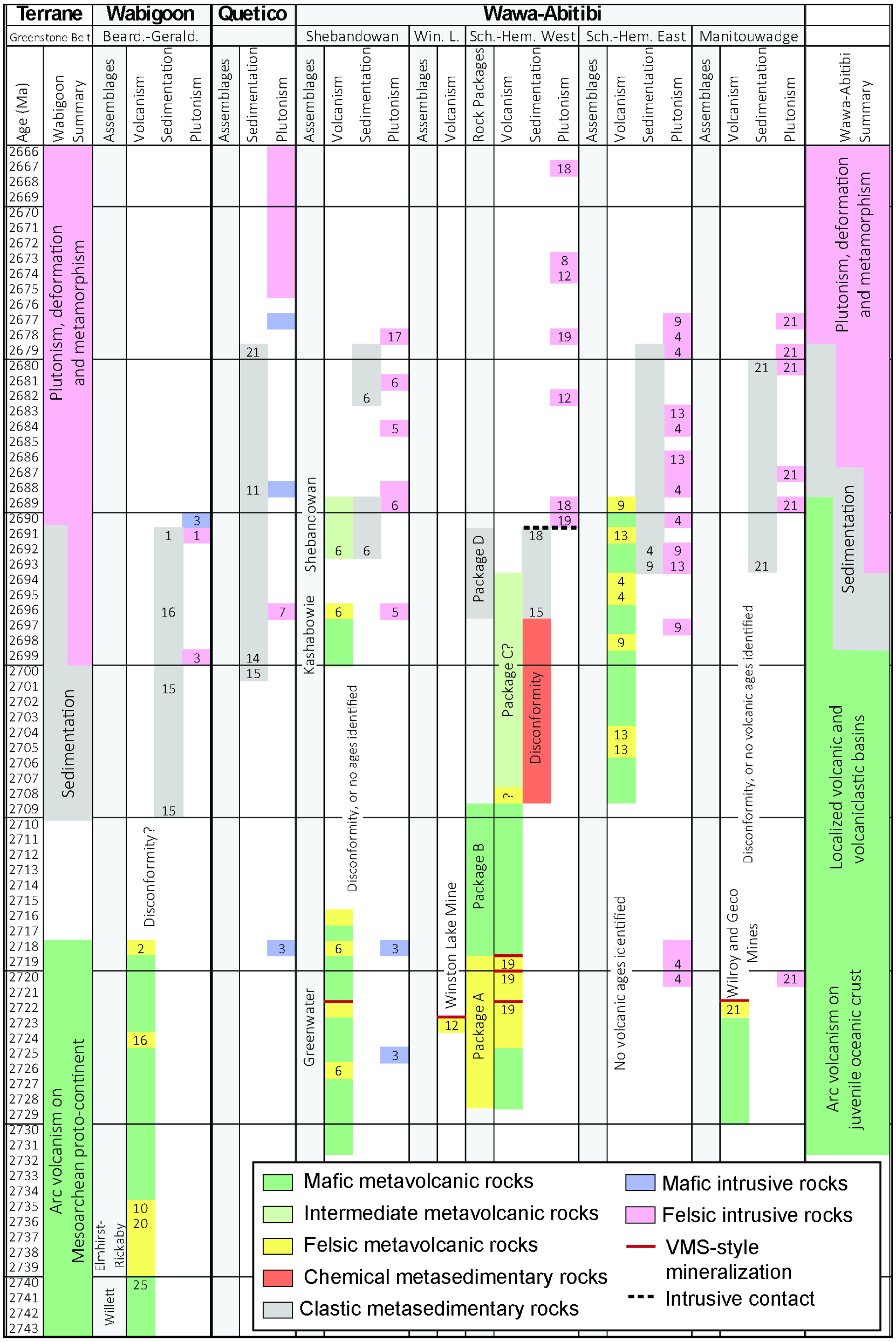

Figure 2. A preliminary compilation of geochronological data for the Wabigoon, Quetico and Wawa–Abitibi terranes. Error bars have not been illustrated, for the sake of visual simplicity. Abbreviations: Beard.–Gerald. = Beardmore–Geraldton, Win. L. = Winston Lake, Sch.–Hem. = Schreiber–Hemlo. Numbers correspond to sources for geochronology data: 1 = Anglin et al. (1988), 2 = Blackburn et al. (1985), 3 = Corfu (2000), 4 = Corfu and Muir (1989), 5 = Corfu and Stott (1986), 6 = Corfu and Stott (1998), 7 = Davis (1996), 8 = Davis and Sutcliffe (2017), 9 = Davis, Beakhouse and Jackson (1998), 10 = Davis et al. 1985, 11 = Davis, Pezzutto and Ojakangas (1990), 12 = Davis, Schandl and Wasteneys (1994), 13 = Fage (2011), 14 = Fralick and Davis (1999), 15 = Fralick, Purdon and Davis (2006), 16 = Hart, teMeer and Jolette (2002), 17 = Kamo (2015), 18 = Kamo (2016), 19 = Kamo and Hamilton (2017), 20 = Tóth and Lafrance (2018) and references therein, and 21 = Zaleski, van Breemen and Peterson (1999).

PALEOPROTEROZOIC GEOLOGICAL SETTING

Several Paleoproterozoic mafic dike swarms are present in the area north of Lake Superior, including dikes from the Matachewan (2480–2445 Ma, Heaman 1997; Bleeker et al. 2012), Biscotasing (2175–2166 Ma, Buchan, Mortensen and Card 1993; Davis and Stott 2003; Halls and Davis 2004; Hamilton and Stott 2008) and Marathon (2122–2100 Ma, Halls et al. 2008) dike swarms (Figure 3).

Sedimentary rocks of the Animikie Group unconformably overly the Superior craton and the Paleoproterozoic dike swarms (*see* Figure 1). The base of the Animikie Group is defined by a thin, locally developed Kakabeka Conglomerate, which hosts carbonaceous microfossils (*Gunflintia* and *Huronosporia*) preserved in cherty stromatolites, interpreted to have formed in nearshore and shallow water environments (e.g., Wacey et al. 2013). These rocks are overlain by iron formation, carbonate rocks and siliciclastic rocks of the Gunflint Formation, which is interpreted to have been deposited during multiple marine transgressions in an extensional basin between the Penokean volcanic arc and the Superior craton prior to their collision at *circa* 1.86 Ga (Fralick, Davis and Kissin 2002) or, alternatively, in a foreland basin north of the Penokean fold-thrust belt (Ojakangas, Morey and Southwick 2001). The Gunflint Formation is overlain by fine-grained argillites and slates of the Rove Formation, which contain a mixture of Archean zircons and zircons with ages *circa* 1.83–1.77 Ga (Heaman and Easton 2006) and are interpreted to have been deposited in a deep marine setting between the assembled Laurentian craton and the Yavapai volcanic arc (*circa* 1.8–1.7 Ga) (Whitmeyer and Karlstrom 2007). The boundary between the Gunflint Formation and the Rove Formation, and their lithostratigraphic equivalents in the USA, is marked by an unusual rock unit thought to represent distal ejecta from the Sudbury impact event, *circa* 1.85 Ga (Addison et al. 2005; Cannon et al. 2010).

MESOPROTEROZOIC GEOLOGICAL SETTING

The Sibley Group (*circa* 1.4 Ga), a sequence of sediments deposited in alluvial–fluvial, lacustrine and eolian settings, unconformably overlies the Paleoproterozoic Animikie Group (Rogala, Fralick and Metsaranta 2005).

The Keweenawan Midcontinent Rift event (*circa* 1.1 Ga) caused widespread magmatic activity in the Lake Superior area. Pre-rift intrusive rocks are preserved north of Lake Superior, including the Prairie Lake carbonatite-ijolite complex (*circa* 1157–1164 Ma) (Rukhlov and Bell 2010; Wu et al. 2017). Early-rift rocks north of Lake Superior include mafic to ultramafic intrusions (1120–1110 Ma) such as the Thunder Bay North intrusive complex, Kitto and Seagull intrusions and the Logan diabase sills (Bleeker et al. 2018, and references therein). Most of the preserved rift-related rocks were emplaced between 1109 and 1093 Ma and include both intrusive and supracrustal rocks, including the Osler Volcanic Group, the Nipigon and Inspiration diabase sills and the Coldwell Alkalic Intrusive Complex (*circa* 1108 Ma) (Bleeker et al. 2018; Liikane et al. 2018, and references therein). Younger dike rocks include the Pigeon River and Cloud river dike swarms (*circa* 1099–1095 Ma) (Liikane et al. 2018). The supracrustal rocks include several packages of mafic and felsic volcanic rocks and sedimentary rocks, which are overlain by late-rift volcanic and sedimentary rocks as young as *circa* 1083 Ma (Miller and Nicholson 2013, and references therein). These supracrustal rocks crop out primarily south of Lake Superior in Minnesota, Wisconsin and Michigan, and occur sporadically along the northern and eastern shores of Lake Superior. In the Terrace Bay area, mafic volcanic rocks of the Osler Group (<1108 Ma) unconformably overlie the Sibley Group (*circa* 1400 Ma) (Davis and Sutcliffe 1985; Heaman and Easton 2006), and 2 groups of volcanic rocks of unknown age, the Coubran Lake and Wolfcamp Lake volcanic rocks, are present within the Coldwell Alkalic Intrusive Complex (*circa* 1108 Ma: Heaman and Machado 1987, 1992) (*see* Figure 3) (Cundari 2012; Davis 2016; Davis, Hollings and Cundari 2017).

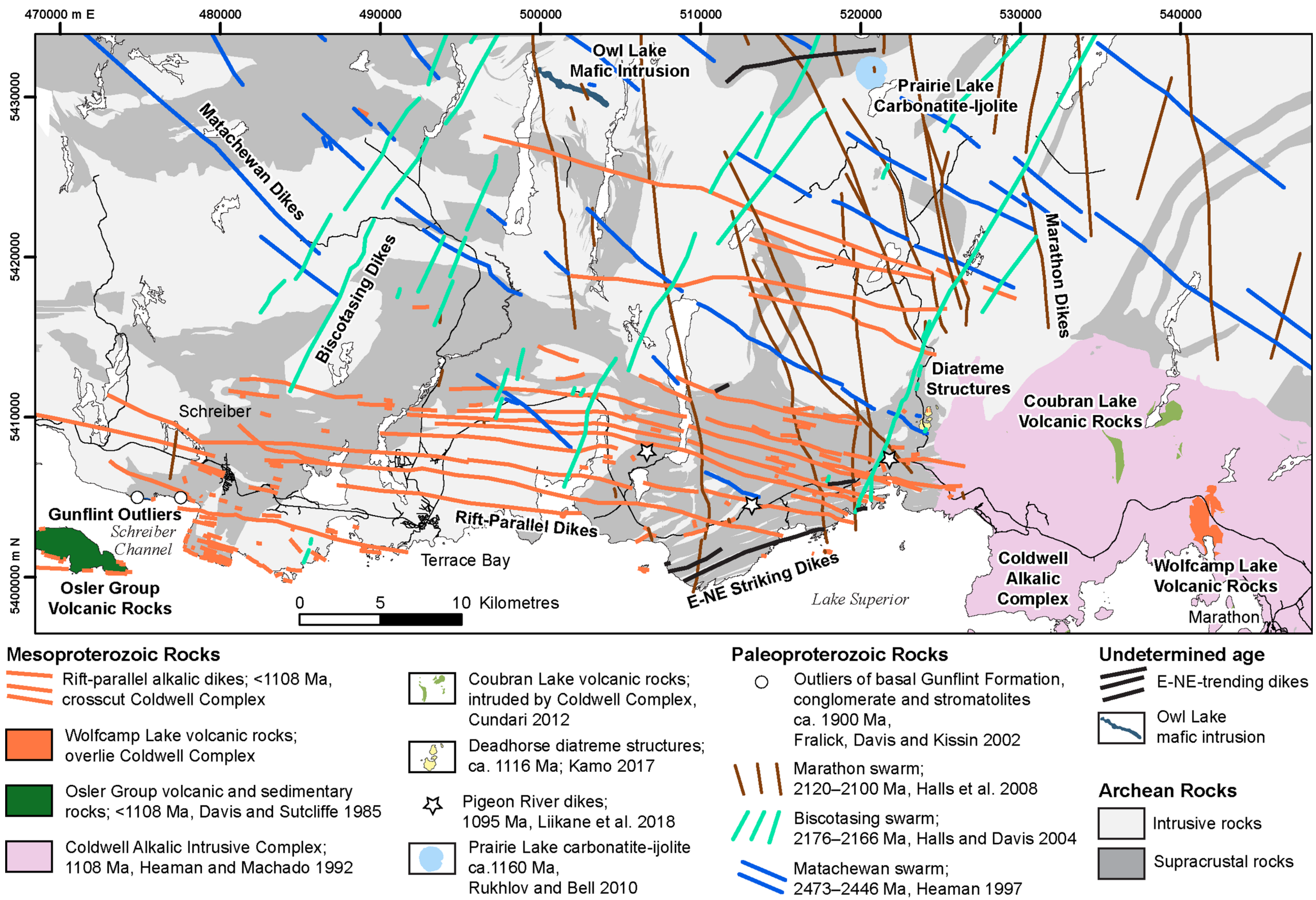

Figure 3. Simplified geological map of the Schreiber–Marathon area highlighting the Proterozoic formations in the area. All UTM co-ordinates provided using NAD83 in Zone 16.

Archean Geology of the Western Schreiber–Hemlo Greenstone Belt

The western Schreiber–Hemlo greenstone belt is a roughly 50 km long belt of supracrustal and intrusive rocks bounded on its north and west sides by Archean granitoid plutonic rocks. It extends southward under Lake Superior and is separated from the eastern Schreiber–Hemlo greenstone belt by the Mesoproterozoic Coldwell Alkalic Intrusive Complex (*see* Figure 1). The greenstone belt is apparently connected to a greenstone belt in the Winston Lake–Big Duck Lake area to the north by a north-trending sliver of greenstone, but the relationship between the belt and the Archean volcanic rocks on the Slate Islands, 10 km to the south, is unknown (*see* Figure 1).

STRATIGRAPHY OF THE SCHREIBER–HEMLO GREENSTONE BELT

Based on stratigraphic way-up indicators, such as flow contacts, pillow cusps and graded bedding, the supracrustal rocks of the western Schreiber–Hemlo greenstone belt are arranged in upright, generally open folds that are locally intensified to tight and isoclinal folds proximal to pluton boundaries and in shear zones (Figure 4 and *see* Figure 5). The supracrustal rocks have been subdivided into several stratigraphic packages based on common volcanic and sedimentary facies as well as geochemical characteristics and geochronological constraints (*see* Figure 4, inset). At the time of the ILSG field trip, geochemical and geochronological data for the rocks north and west of the Terrace Bay pluton is pending, thus the stratigraphic arrangement presented herein is tentative.

East of the Terrace Bay pluton, 3 packages of supracrustal rocks are present: Package A, dominated by felsic metavolcaniclastic rocks; Package B, dominated by mafic metavolcanic rocks, and Package D, a sequence of turbiditic wackes equivalent to the McKellar Harbour formation of Fralick, Purdon and Davis (2006); Package C is not present (Magnus and Walker 2015; Magnus and Arnold 2016; Magnus 2017a, 2017b). North and west of the Terrace Bay pluton, Packages A and B are present; however, Package B is disconformably overlain by Package C, another sequence of distinct mafic metavolcanic rocks, and package D is not present (Magnus and Hastie 2018). The highly strained and structurally complex area between the Terrace Bay and Santoy Lake plutons appears to mark the boundary between these 2 stratigraphic sections.

Package A

Package A is composed mainly of felsic volcaniclastic rocks, including tuffs, crystal tuffs, tuffaceous conglomerates and minor coherent flows. The crystal tuffs contain plagioclase phenocrysts and, in many cases, contain blue quartz phenocrysts. The tuffaceous conglomerates are generally clast-supported and contain pebble- to cobble-sized clasts of coherent felsic rocks with similar plagioclase and blue quartz phenocrysts in a felsic tuffaceous matrix (Magnus 2017b). This package contains minor mafic to intermediate massive to pillowed flows, including some massive flows with a high concentration of quartz and/or calcite-filled amygdules. Chert and sulphide-bearing chemical metasedimentary rocks are present in this package, most commonly near and along the contact between this package and Package B.

An incredibly well-preserved package of felsic, intermediate and mafic metavolcanic rocks southwest of the town of Schreiber is stratigraphically correlative with Package A (i.e., below Package B, from younging directions); however, the volcanic facies are different than those present in the majority of Package A as described in the previous paragraph (Magnus and Hastie 2018). The most notable difference

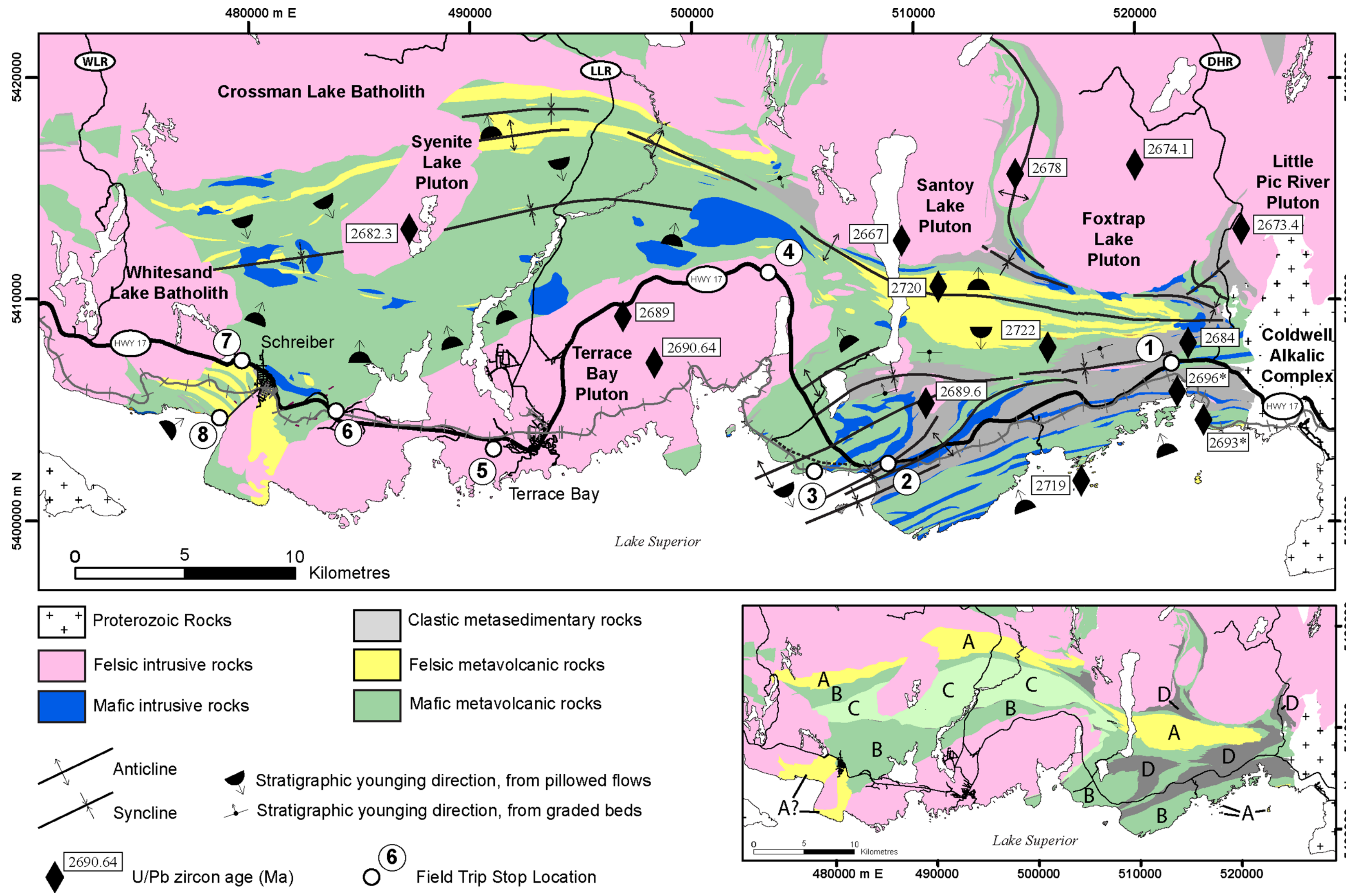

Figure 4. Simplified geological map of the western Schreiber–Hemlo greenstone belt, highlighting the major Archean rock types, some of the stratigraphic younging indicators observed during this study, all of the U-Pb zircon geochronological data in the area, and the inferred fold axial traces. An inset figure outlines the inferred depositional packages A, B, C and D. Abbreviations: DHR = Dead Horse Road, HWY 17 = Trans-Canada Highway 17, LLR = Long Lake Road. Asterisks (*) = ages from Fralick, Purdon and Davis (2006). All UTM co-ordinates provided using NAD83 in Zone 16.

is the absence of the blue quartz phenocrysts present throughout the remainder of Package A. There are also fewer tuffs and crystal tuffs; the felsic rocks present are predominantly massive plagioclase porphyritic flows and breccias with angular clasts of similar plagioclase porphyritic material. Several intermediate, plagioclase and amphibole porphyritic massive to brecciated flows are also present, as well as massive to pillowed mafic flows up to 200 m thick. Interflow formations in this sequence include chert and magnetite-bearing chemical metasedimentary rocks and tuffaceous wackes and conglomerates.

Package A contains the oldest known rocks in the western Schreiber–Hemlo greenstone belt; three samples from the top of the package have ages of *circa* 2720 Ma, which is correlative with similar felsic volcanism in the Winston Lake area, in the Manitouwadge greenstone belt and within the Greenwater assemblage in the Shebandowan greenstone belt (Davis, Schandl and Wasteneys 1994; Davis and Sutcliffe 2017). Volcanic rocks of this age have not yet been identified in the eastern Schreiber–Hemlo greenstone belt; however, there are numerous felsic volcanic formations on that portion of the Schreiber–Hemlo belt that do not have any age information. Older phases of both the Pukaskwa and Black–Pic batholiths from the eastern Schreiber–Hemlo belt, however, have yielded similar ages of *circa* 2720 Ma (Corfu and Muir 1989; Beakhouse and Davis 2005).

The mafic to intermediate rocks in this package contain trace element concentrations consistent with both arc volcanic and oceanic plateau volcanic settings.

A–B Disconformity

In the Schreiber area, a substantial sequence of interbedded graphitic argillite, chert, sulphide-facies iron formation and felsic tuffaceous breccias represents a disconformity between packages A and B. The Elwood and Morley base metal sulphide occurrences occur along this horizon (*see* Figure 8)

Above this disconformity, there are several massive to pillowed flows which are overlain by a chemical metasedimentary sequence that includes graphitic argillite, sulphide-facies iron formation and marble. So far 2 exposures of this horizon have been observed. In one, the marble is composed mainly of calcite with minor silicate and sulphide components; the other is a breccia, with mafic volcanic, argillite and sulphide clasts supported by a matrix of calcite. The significance of these marbles is unknown and requires further study. Is the carbonate derived from a primary sedimentary source? Could the breccia have been formed in a karst-like environment? Or was the carbonate introduced during later hydrothermal alteration?

Elsewhere in the belt, similar chert and sulphide-facies iron formation are concentrated along the A–B disconformity, including one occurrence of marble south of the Foxtrap Lake pluton. However, the occurrence of these rocks is more sporadic, which may be a consequence of their location in areas that are more highly strained, metamorphosed and potentially boudinaged, making them more difficult to trace than the well-preserved occurrences in the Schreiber area.

A unique feature of the A–B disconformity, which crops out along Highway 17 in Schreiber, is a sequence of interbedded turbiditic wacke and siltstone with basaltic andesitic composition that was deposited either synchronously or directly on top of the chemical metasedimentary rocks. The mafic composition of these rocks indicates they were derived primarily from a mafic volcanic source. No zircons have been found in these rocks, which precludes detrital geochronology, but a whole rock Sm-Nd isotopic study may help identify possible sources for this mafic sediment.

Package B

Package B is dominated by massive to pillowed mafic flows with 2 distinct geochemical populations based on trace elements that are consistent with both oceanic plateau volcanism and back-arc basin volcanism. Flows with trace elements consistent with an oceanic plateau volcanic setting are typical green to grey-green massive to pillowed flows, with lath-shaped plagioclase microphenocrysts visible in thin section and small vesicles concentrated around the edges of the pillows. Some massive flows with this chemistry also contain abundant calcite-filled amygdules. Flows with trace elements consistent with a back-arc volcanic setting have distinct variolitic textures as well as irregular-shaped cavities that likely served as conduits for volatile fluids and gases rather than typical vesicles, which are not present in these rocks (Magnus 2017b).

One occurrence of a coherent felsic flow, with a perlitic texture and possible flow banding, has been observed near the top of this package near the Steel River (Magnus 2017b).

B–C Disconformity

North and west of the Terrace Bay pluton, the top of Package B is marked by a horizon of felsic volcaniclastic rocks including tuffs, tuffaceous wackes and tuffaceous conglomerates, locally interbedded with chert and sulphide-facies iron formation. This horizon is located between the Terrace Bay pluton and the Lunch Lake pluton (an area known locally as the Empress Structure) and wraps around the southeastern edge of the Terrace Bay pluton (*see* Figure 4, inset).

Package C

Package C is dominated by massive to pillowed mafic to intermediate flows with trace element concentrations that are predominantly consistent with oceanic plateau volcanism, including a more thorium-enriched variety of that chemical signature, and some calc-alkalic arc volcanism. The rocks in this package commonly contain medium-grained, equant plagioclase phenocrysts, which are uncommon in the other metavolcanic packages. This package lacks the variolitic back-arc volcanic rocks that are a distinctive feature of Package B. Apart from the felsic volcaniclastic rocks that mark the lower contact between this package and Package B, several other isolated lenses of felsic volcaniclastic material have been observed in this package.

A sequence of tuffaceous metasedimentary rocks along the western edge of the Santoy Lake pluton may represent the top of Package C. This sequence includes tuffaceous wackes with abundant plagioclase phenocrysts that locally display graded bedding interbedded with tuffaceous conglomerates. The tuffaceous conglomerates are clast supported and polymictic, with a variety of felsic and mafic metavolcanic rocks, including clasts of mafic rocks with equant plagioclase phenocrysts like those in the mafic rocks of Package C (Magnus 2017b).

B–D Disconformity

East of the Terrace Bay pluton, packages B and D are in disconformable contact. This disconformity is marked by a sequence of chert, graphitic argillite and sulphide-facies iron formation that is continuous along the entire contact.

Package D – McKellar Harbour Formation

Package D, also known as the McKellar Harbour formation (Fralick, Purdon and Davis 2006), represents the youngest known supracrustal rocks in the western Schreiber–Hemlo greenstone belt. This package is composed of a sequence of interbedded turbiditic wacke, sandstone and mudstone with normal graded bedding and sharp bedding contacts.

The youngest detrital zircon at the base of the package is 2696±3 Ma, which marks the maximum age of deposition for the package, and the youngest detrital zircon from the top of the package is 2693±4 Ma, which suggests that the basin had a source for young zircons during deposition (Fralick, Purdon and Davis 2006). The sedimentary rocks are crosscut by the Steel River pluton (2689.6±2 Ma: Kamo and Hamilton 2017), which places a minimum age of deposition for the package, suggesting deposition occurred between 2690 and 2696 Ma. There is volcanism recorded during the 2696–2689 Ma interval in both the eastern Schreiber–Hemlo greenstone belt (Corfu and Muir 1989; Davis and Lin 2003) and in the nearby Shebandowan greenstone belt which could have provided young detrital material during deposition of the package.

Older detrital zircons are present in this package, including several Mesoarchean zircons at *circa* 2900 Ma (Fralick, Purdon and Davis 2006) and a single concordant Paleoarchean grain at 3423±10 Ma (Davis and Sutcliffe 2017). This implicates a continental component for the source of the sediments, which is interpreted to have been the Wabigoon proto-continent (Fralick, Purdon and Davis 2006) and/or the Minnesota River Valley terrane.

Mafic to Intermediate Intrusive Rocks

A series of sill-like gabbroic rocks that intrude Package B are parallel to stratigraphy and have chemistry similar to the nearby variolitic mafic metavolcanic rocks. These have been interpreted as synvolcanic intrusions and may in some cases represent medium- to coarse-grained massive flows. In several of these bodies, rocks with basaltic chemistry display spinifex-like textures composed of abundant elongate amphibole crystals; invariably these rocks are associated with massive rocks of basaltic komatiitic chemistry, which may represent cumulate phases within an ultramafic flow or sill.

Mafic intrusive rocks that occur locally along the contact between packages B and D east of the Terrace Bay pluton, as well as near the contact between packages B and C northwest of the Terrace Bay pluton, typically have elongate, "plumose" amphibole crystals with interstitial plagioclase feldspar. These intrusions have chemistry similar to arc basalts, which helps distinguish them from the rocks with the spinifex-like texture described above.

The Lunch Lake and Longworth Lake plutons are both composed mainly of diorite and have generally equigranular hypidiomorphic textures. The Lunch Lake pluton also includes porphyritic diorite with distinct blue quartz phenocrysts, which have not been observed in any other mafic or intermediate intrusive rocks in the belt, but which are common in the felsic volcanic and volcaniclastic rocks.

Felsic Intrusive Rocks

Felsic intrusive rocks that surround and crosscut the western Schreiber–Hemlo greenstone belt were emplaced over a period of at least 20 million years (*see* Figures 1, 2).

The Terrace Bay, Steel River and Syenite Lake plutons have ages between 2690–2680 Ma (Kamo 2016; Kamo and Hamilton 2017, 2018). These plutons are generally oblate and irregular in shape and have well-developed foliations along their contacts that penetrate up to 500 m into the surrounding rocks. The Terrace Bay and Steel River plutons are both composed mainly of grey, equigranular quartz and/or alkali feldspar porphyritic granodiorite with minor dioritic components; the Syenite Lake pluton is composed mainly of pink alkali feldspar porphyritic quartz monzonite and quartz monzodiorite.

The Foxtrap Lake and Little Pic River plutons, as well as the small pluton between them, have ages between 2680–2670 Ma (Kamo and Hamilton 2017, 2018). These plutons are round in plan view and have well-developed foliations along their margins, which continue up to 1 km into the surrounding rocks. These plutons are composed mainly of grey, equigranular alkali-feldspar porphyritic granodiorite.

The Santoy Lake pluton, with a zircon age of 2667±4 Ma (Kamo 2016), is round to irregular in shape and has a weakly developed foliation along its contacts. This pluton is composed of pink quartz monzonite to monzonite, with local alkali feldspar porphyritic varieties, and contains a distinctly low abundance of mafic minerals.

The Crossman Lake batholith (age unknown) is elongate and has a very well-developed foliation along its southern contact that penetrates up to 3 km into the supracrustal rocks to the south. The intrusion is composed of equigranular white to grey trondhjemite, tonalite and granodiorite.

A small pluton (age unknown) south of the town of Schreiber is irregular in shape and does not have foliations developed along its contacts. This intrusion is mostly composed of grey to pink quartz porphyritic granite with more intermediate varieties towards its southern contact.

Quartz and/or feldspar porphyritic felsic dikes (age unknown) are abundant around Schreiber and northwest of the Terrace Bay pluton but are uncommon elsewhere in the greenstone belt.

The “Whitesand Lake batholith” (age unknown) is heterogeneous and appears to include more than one distinct intrusion; further mapping is required to better delineate the granitoid rocks of this batholith.

ARCHEAN STRUCTURAL GEOLOGY

The degree of metamorphism and the nature of structural fabrics varies throughout the western Schreiber–Hemlo greenstone belt. Distinct domains containing common metamorphic mineral assemblages and structural fabrics are illustrated in Figure 5. Few crosscutting relationships have been observed between these different fabrics, thus, the structural features displayed on the map have been separated into 2 structural events: the early penetrative ductile fabrics, and the later more discrete brittle-ductile fabrics (*see* Figure 5). Observations of stratigraphic younging indicators, bedding-cleavage relationships and fold closures, as well as stratigraphic correlation using geochronology, have provided evidence for the upright folded Archean stratigraphy in the Schreiber–Hemlo greenstone belt (*see* Figures 4).

The intensity of deformation and metamorphism tends to increase towards the granitoid plutons (*see* Figure 5). The supracrustal rocks in a 1 to 1.5 km wide zone along the northern margin of the greenstone belt have amphibolite facies mineral assemblages and display strong penetrative foliations which define tight to isoclinal fold axial planes that are parallel to the margin. South of this zone, the rocks are generally less deformed, have greenschist to amphibolite facies mineral assemblages and have east- to northeast-trending foliations and fold axial traces. These fold axial traces indicate that the rocks were deformed under northwest-directed compression during regional ductile deformation (*see* Figure 4). Discrete, outcrop-scale shear zones within the “Open Folding” domains (*see* Figure 5) are also east to northeast striking and have kinematic indicators that indicate reverse, south-side up vertical displacement with a dextral horizontal component, which is consistent with northwest-directed compression.

A thin zone of high strain up to 200 m wide is present along the margins of the Terrace Bay pluton (*circa* 2690 Ma: Kamo and Hamilton 2018). Kinematic indicators along the strained margins of the pluton indicate reverse, south-side up vertical displacement with a dextral horizontal component. In plan

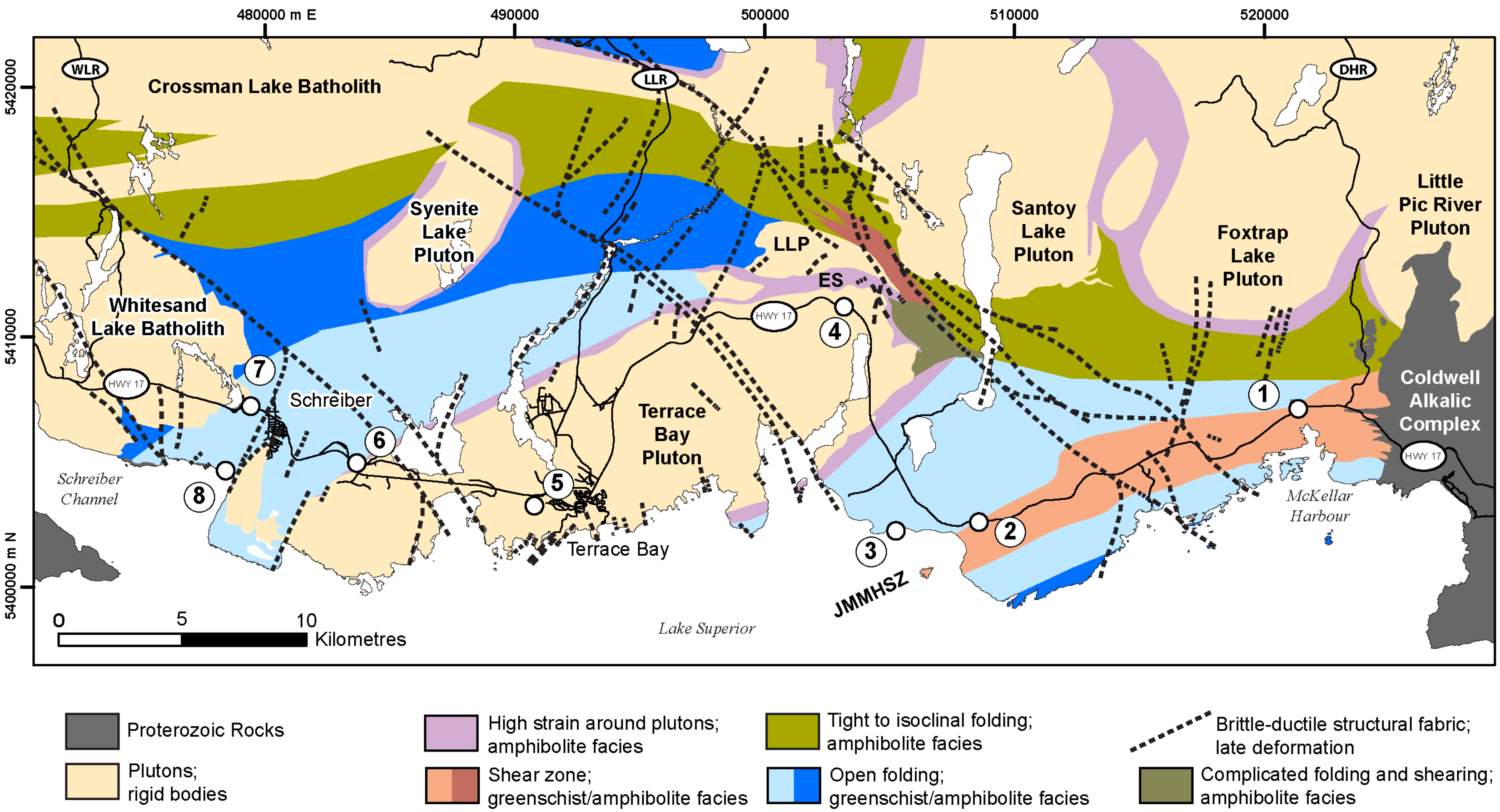

Figure 5. Map of the western Schreiber–Hemlo greenstone belt outlining domains with distinct structural and metamorphic characteristics. The locations of the 8 field trip stops are also shown. Abbreviations: ES = Empress Structure, JMMHSZ = Jackfish–Middleton–McKellar Harbour Shear Zone, LLP = Lunch Lake pluton, HWY 17 = Trans-Canada Highway 17. All UTM co-ordinates provided using NAD83 in Zone 16.

view, this pluton and the Syenite Lake pluton (2682.3±1.1 Ma: Kamo and Hamilton 2018), which are both hosted within the greenstone belt, strike northeast and resemble large-scale dextral sigma clasts. This suggests that the bulk of horizontal displacement in the greenstone belt during regional ductile deformation was dextral. The Terrace Bay pluton is the oldest known pluton in this part of the Schreiber–Hemlo greenstone belt; there has been no evidence to determine whether regional ductile deformation had commenced prior to emplacement of this pluton.

The Foxtrap Lake pluton (2674.1±1.3 Ma: Kamo and Hamilton 2018) truncates several east-trending fold axial traces, which are overprinted by fold axial traces that are parallel to the pluton margins. This indicates that regional ductile deformation had commenced prior to 2674 Ma and continued after emplacement of the pluton.

The Santoy Lake pluton (2667±4 Ma: Kamo 2016) truncates several east-trending fold axial traces and has very thin zones of strain along its margins. This suggests that the pluton was emplaced during the later stages of regional ductile deformation.

There are 2 highly strained zones to note in the greenstone belt (*see* Figure 5). 1) The Jackfish–Middleton–McKellar Harbour Shear Zone is a 1 to 2 km wide zone of greenschist-facies rocks that are isoclinally folded and heavily sheared along lithological contacts. 2) The Empress Structure, located in a narrow band between the Terrace Bay and Lunch Lake plutons, hosts amphibolite facies rocks that are isoclinally folded and sheared with a moderate penetrative foliation throughout the zone. Throughout the greenstone belt, other thinner, unnamed ductile shear zones occur that are generally parallel with the regional ductile fabric.

Conjugate northwest-striking and north- to northeast-striking brittle-ductile shear zones and faults crosscut the greenstone belt and offset lithological contacts and the ductile fabrics.

Proterozoic Geology

GUNFLINT FORMATION

Several occurrences of polymictic, clast-supported conglomerate with pebble- to cobble-sized clasts and interspersed lenses of stromatolitic chert unconformably overly the Archean basement along the shore of Lake Superior southwest of Schreiber. This conglomerate represents the base of the Gunflint Formation and hosts the famous microfossils *Gunflintia* and *Huronosporia* (e.g., Wacey et al. 2013).

DIABASE DIKES

A multitude of diabase dikes are present throughout the Schreiber–Terrace Bay area. Where possible, these dikes have been assigned to dike swarms that have been previously recognized in the area based on their orientation and chemistry.

Dikes from 3 Paleoproterozoic dike swarms have been recognized, including the Matachewan swarm (*circa* 2460 Ma), the Biscotasing swarm (*circa* 2170 Ma) and the Marathon swarm (*circa* 2120 Ma) (Bleeker et al. 2012; Halls and Davis 2004; Halls et al. 2008, respectively).

Three northeast-striking dikes with chemistry similar to dikes of the Pigeon River swarm (*circa* 1096 Ma) (Liikane et al. 2018) have been observed. Previously the Pigeon River swarm has only been recognized in the Thunder Bay area; however, the dikes in the Schreiber–Hemlo greenstone belt are approximately along strike from those dikes (180 km away). These dikes do not present a distinctive geophysical signature in the aeromagnetic data set, thus tracing their extent is difficult.

A series of east- to northeast-striking subalkalic dikes is present east of Terrace Bay which has not yet been correlated with other regional events. The author believes these to be related to the Keweenawan Midcontinent Rift (*circa* 1.1 Ga).

The most abundant dikes in the area are a series of west- to northwest-striking alkalic, olivine tholeiitic diabase dikes that are similar in chemistry to, and appear to point directly to, the Wolfcamp Lake volcanic rocks that unconformably overly the Coldwell Alkalic Intrusive Complex. If this interpretation is correct, then it is likely that the alkalic dikes are related to an episode of Keweenawan volcanism younger than 1108 Ma (the age of the Coldwell Complex which they crosscut).

Mineral Potential

The Western Schreiber–Hemlo greenstone belt has a long history of mineral exploration and has potential for a variety of styles of base and precious metal mineralization.

Base metal sulphide and precious metal occurrences are associated with supracrustal rocks throughout the greenstone belt. Sulphide mineralized rocks occur near and along the upper contact of the metavolcanic rocks (*circa* 2720 Ma) of Package A. The host rocks are sulphide-facies iron formation and chert, interbedded with felsic volcaniclastic rocks and garnetiferous mafic metavolcanic rocks. These rocks are lithologically similar and chronologically correlative with metavolcanic rocks, having an age of *circa* 2720 Ma, in the Winston Lake and Manitouwadge areas, which both host past-producing zinc-copper-silver base metal mines (*see* Figure 1) (Davis, Schandl and Wasteneys 1994; Zaleski, van Breemen and Peterson 1999).

Gold and base metal sulphide occurrences are associated with highly strained supracrustal rocks, including the Jackfish–Middleton–McKellar Harbour Shear Zone, the Empress Structure, strained rocks surrounding plutons and other discrete shear zones throughout the greenstone belt. Mineralization in these shear zones typically occurs in quartz and carbonate veins in the shear zones and in silicate and carbonate-altered haloes adjacent to the veins. The Hemlo gold mine, located in the eastern part of the Schreiber–Hemlo greenstone belt, is hosted in highly strained and altered supracrustal rocks (*see* Figure 1) (e.g., Muir 2003).

Gold occurrences, with minor silver, molybdenum and copper mineralization, are associated with the Terrace Bay pluton and other granitoid rocks in the map area. Mineralization occurs in sulphide-bearing quartz veins and in altered granitoid rock adjacent to the veins. The veins are typically straight, with sharp contacts, and occur in parallel sets and in "stockwork" arrangements (Arnold, Hollings and Magnus 2017; Marmont 1984).

Zinc, silver and lead mineralization (with minor copper and gold) is associated with north- to northeast-striking faults near Schreiber. Mineralization occurs as massive sulphide in irregularly shaped veins, and in sulphide-bearing quartz veins. Where these structures crosscut felsic metavolcanic rocks, the rocks are typically altered from grey to beige, and feldspar phenocrysts are altered to a distinct bright green colour (Magnus and Hastie 2018).

Proterozoic rocks near the north shore of Lake Superior host a variety of commodities, including nickel, copper and platinum group elements associated with mafic to ultramafic intrusions; other transitional metals, such as niobium, tantalum and titanium and rare earth elements, associated with carbonatitic (e.g., the Prairie Lake carbonatite-ijolite complex) and alkalic rocks (e.g., the Coldwell Alkalic Intrusive Complex); and diamond, associated with lamprophyric and kimberlitic dikes.

Road Log

Note: Caution should be taken when parking vehicles on the shoulder of the highway and when examining outcrops located along Highway 17. All UTM co-ordinates are provided in NAD83, Zone 16. Figures 4 and 5 show the location of the field trip stops.

The primary focus of this trip is on the Archean rocks of the Schreiber–Hemlo greenstone belt; however, because of the abundance of Proterozoic diabase dikes in the area, some of the stops will also feature Proterozoic rocks. Note the mileages in the road log are not cumulative, rather each number is the distance from one stop to another.

Distance: 41.7 km	Starting in Terrace Bay, drive east along Highway 17 for roughly 42 km (25 minutes). About 1.5 km (1 minute) before the parking spot, you will pass under 2 power transmission lines and Ripple Lake will be on the southeast side of the road; begin to slow down at this point to make sure vehicles behind you have time to react, as you will be pulling off the road shortly. As you approach the parking spot, you will drive downhill across the McKellar Creek bridge. The parking spot is on the right (south) side of the road, at the east end of this bridge, just past the guardrail. If you pass the stop, turn at the junction between Highway 17 and Deadhorse Road, find a suitable location to turn around and retrace your route back to the stop.
Distance: 40.3 km	If starting in Marathon, drive west along Highway 17 for 40.3 km (29 minutes). After crossing the Little Pic River Bridge, then passing Deadhorse Road, Stop 1 will be on the south (left) side of the highway. Beware of oncoming traffic prior to turning into the parking area; east-bound vehicles will be driving speedily downhill at this location. Stop 1 location: UTM 521355 mE, 5407099 mN

STOP 1. SHEARED ROCKS, DIABASE AND LAMPROPHYRE

There are outcrops on the north and south sides of the highway at this location. The highway marks a contact between metasedimentary rocks to the north and mafic metavolcanic and intrusive rocks to the south.

The metasedimentary rocks north of the highway are wacke and siltstone with local sulphide mineralization. Box folds are observed throughout these rocks, which indicate that the rocks have been subjected to bedding-parallel shearing. Several biotite porphyritic ultramafic lamprophyre dikes, up to 8 cm wide, crosscut the metasedimentary rocks, which exhibit iron carbonate alteration haloes adjacent to the dikes.

A single, 240 m long, near vertically faced outcrop is present south of the highway. In this large outcrop, the mafic rocks display varied degrees of strain. In more highly strained areas, fractures and quartz veins tend to be parallel to the strong foliation, and where the outcrop surface is parallel to the foliation plane, geometric shapes appear in the outcrop. In less-strained areas, fractures are more irregular, and parallel sets of quartz veins dip shallowly to the south, nearly perpendicular to the foliation in the outcrop. These areas are most easily observed by viewing the entire outcrop from the north side of the highway.

All primary textures have been obliterated in the highly strained areas, where a strong steeply dipping foliation hosts folded and boudinaged quartz veins and box folds and local sulphide mineralization. Quartz vein boudins with both sigma and delta asymmetries indicate the latest displacement was vertical: reverse motion with the northern side moving up towards the south. Two lineations are present in the outcrop: one shallowly plunging lineation, which is interpreted to be a crenulation lineation, and a steeply plunging lineation, which is interpreted to be a stretching lineation, both formed during the reverse shearing event. The trend and plunge of these lineations vary throughout the outcrop as the foliations that host them waver.

The 2 areas of more competent rock are composed of massive, medium-grained, equigranular aphyric mafic rock, which may represent either massive metavolcanic flows or intrusive rocks. In the western zone, a dike of granodioritic rock crosscuts the mafic rock.

Near the west end of the outcrop, 2 adjacent alkalic diabase dikes crosscut the Archean rocks, striking west and dipping to the north. Together, these dikes are about 10 m wide. These dikes are generally equigranular, with fine-grained chilled margins and fractures orthogonal to the contacts. A 5 cm wide feldspar porphyritic diabase dike is present at the very west end of the outcrop. Several north-striking biotite porphyritic ultramafic lamprophyre dikes are present near the middle and at the east end of the outcrop, similar to those on the north side of the highway. The mineralogy and texture of these dikes, including their associated iron carbonate alteration, are typical of lamprophyre dikes in this area.

Return to vehicles and turn left to drive west on Highway 17.

12.9 km — Drive west on Highway 17 for 12.9 km (8 minutes). Two minutes before Stop 2, you will pass Black Fox Lake on the right (north) side. The parking location for Stop 2 will be on the left (south) side of the highway in a turn-around location, on the east side of the Steel River Bridge (Figure 6). If you miss the stop, there is a suitable turn-around location on the west side of the bridge.

Stop 2 location: UTM 508700 mE, 5402577 mN

STOP 2. TURBIDITIC WACKE

There are outcrops on both the north and south sides of the highway at this location. The outcrop on the north side of the highway is shorter in length, and has cleaner outcrop surfaces, so it will be the focus of this stop. Stop 2 is the same locality as Stop 1 in Smyk and Schnieders (1995).

This outcrop is composed of southward-younging, normally graded wacke interbedded with mudstone (Photo 1). On the south side of the road, and in outcrops along Santoy Bay and on Lawson Island, the younging direction of graded beds switches from south to north repetitively within tens of metres. These tight younging reversals are the main evidence for isoclinal folding in the area (*see* Figure 6).

A pervasive schistosity throughout the outcrop, axial planar to local isoclinal folding, is at a low angle to bedding. Along this schistosity, the bedding planes display a strange pattern in which the more fissile mudstone layers form tabular projections into the sandstone, whereas the sandstone layers form more lobate projections into the mudstone. This may be interpreted as a primary loading structure that has been sheared during folding.

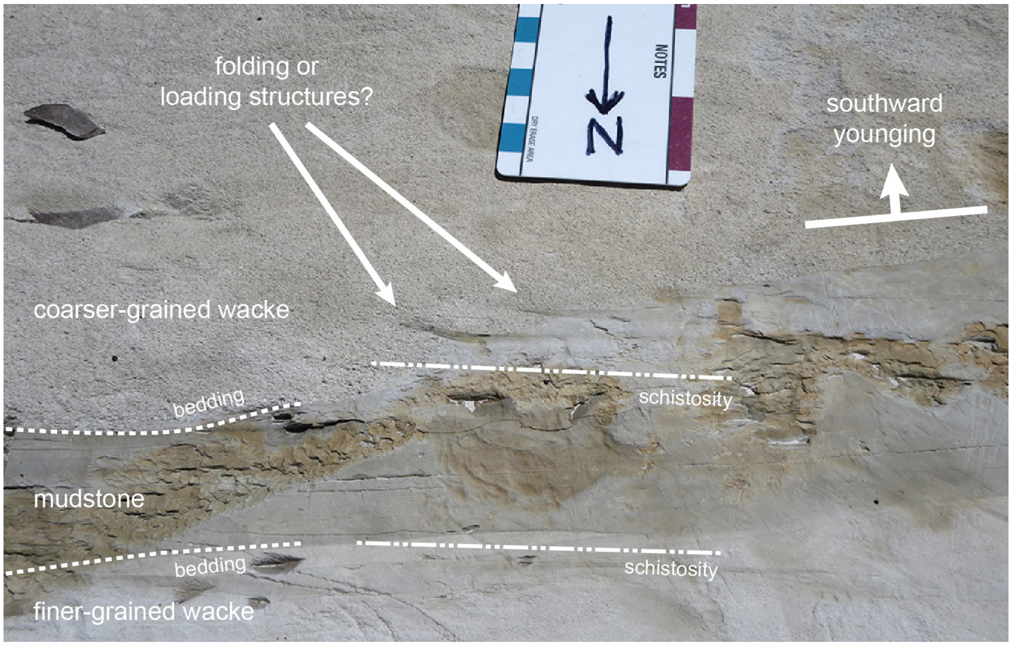

Photo 1. This photograph displays normally graded wacke interbedded with mudstone. Arrows point to enigmatic features which may be related to primary loading structures, folding or both. The outcrop surface is horizontal, and a scale card is pointing north.

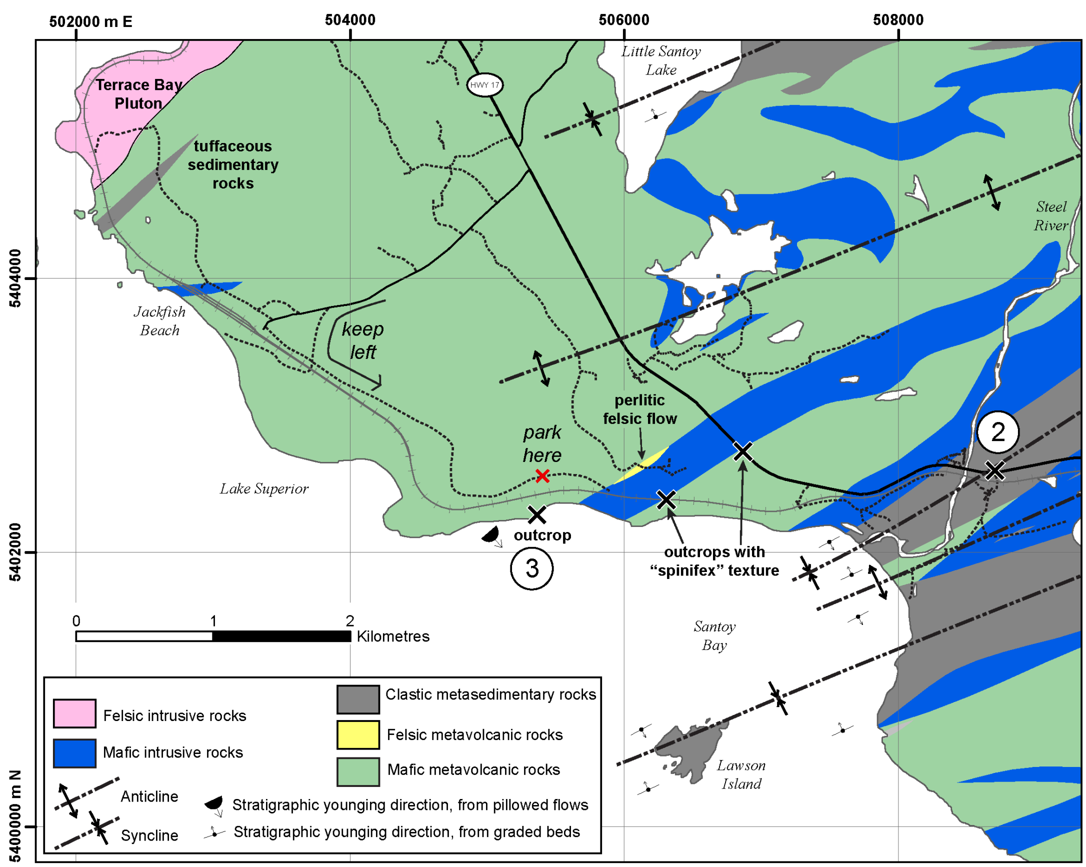

Figure 6. Simplified geological map of the Santoy Bay area, which includes Stops 2 and 3. Several rocks of interest near Stop 3 are also indicated but will not be visited during this field trip. All UTM co-ordinates provided using NAD83 in Zone 16.

Return to the vehicles and turn left to drive west on Highway 17.

4.6 km	Drive west on Highway 17 for 4.6 km (3 minutes). You will be driving uphill on a moderate to steep grade, and any westbound transport trucks on this stretch of road will be driving below the speed limit with their 4-way flashers on. Do not pass these trucks; stay well behind them to ensure they do not decide to pull over and stop. After cresting the hill, the next turn will be about 1 minute away. Look for a "road intersection" sign and prepare to turn left (south).
2.2 km	Drive down this gravel road south towards Lake Superior, always keeping to the left at any junction. Eventually you will turn east and pass a gravel pit and a railway crossing. Slow down considerably and continue onward.
~2.0 km	The road turns from gravelly to sandy and narrows to a single lane. Continue driving eastward with caution. There are several branches of this trail that quickly lead to dead ends; if you reach a dead end, turn around and try another path. If at any time you feel unsafe or are unsure whether your vehicle is capable of driving in this terrain, turn back and skip ahead to Stop 4. The parking spot for Stop 3 is located at UTM 505400 mE, 5402555 mN, in a location where the path widens and there is a clearing through the trees on the south side of the path.
250-300 metres	Unpack your hiking gear, including food, water and first aid equipment. Walk south along a footpath towards the railway; there is good line-of-sight along the rails at this location to see any oncoming trains. For the 2019 ILSG trip, there will be a flagged trail through the bush towards the lakeshore outcrop (Stop 3). For future users of this guidebook, you will have to navigate directly southward to the lake.

Safety Note: the hill between the railway and Lake Superior is steeply sloping and built out of cobbles. This is a health and safety risk to those with reduced mobility. If at any time you feel unsafe to continue, turn back and skip ahead to Stop 4.

Stop 3 location: UTM 505366 mE, 5402266 mN

STOP 3. VARIOLITIC MAFIC FLOWS

This lakeshore outcrop, which has been kept lichen free by winter ice in Lake Superior, is the best exposure of variolitic mafic flows in the western Schreiber–Hemlo greenstone belt (*see* Figure 6). Exposure here is good enough to trace flow contacts and to observe various macrotextures present in at least 4 consecutive flows (Figure 7).

Pillows are generally 30 cm across, with single rinds up to 3 cm thick, and selvages filled with glassy material and hydrothermal minerals like quartz, calcite and epidote. These pillows lack vesicles or amygdules, but some pillows situated at or near the top of flow sequences contain elongate, discontinuous, quartz- and carbonate-filled cavities, which the author interprets to represent large, formerly gas-filled cavities.

The most conspicuous feature of these pillows is the variolitic texture (*see* Figure 7). Inward from the chilled margins, the pillows are dark green and very fine grained, with only a few small varioles (up to 2 mm). Varioles become larger (up to 8 mm) and more abundant toward the core of the pillow, where they appear to have amalgamated to produce a more massive, leucocratic pillow core (*see* Figure 7). The interiors of the varioles are concentrically zoned with bands of calc-silicate minerals. The distribution of varioles in the pillows is not always perfectly concentric; their distribution seems to be more erratic at the tops of the pillows. Very few pillows display multiple concentric variolitic and nonvariolitic bands. In pillows that contain both gas cavities and varioles, the gas cavities are always located in the dark green, nonvariolitic upper portions of the pillows.

The massive flows, which may be traced in this outcrop for up to 50 m in length, have widths that vary in proportion to their lengths (i.e., thinner flows are less laterally extensive). The internal structure of the flows is similar to that observed in the pillows, with nonvariolitic, dark green material inside the rinds that grades into massive variolitic cores. The transition from rind to variolitic core at the base of the flows occurs over approximately 5 cm, whereas, at the top of the flows, the varioles have coalesced into lobes and pods that appear pillow like, without the necessary rinds (i.e., pseudopillows). Randomly oriented, elongate crystals of amphibole are present in the massive, medium-grained core of the thickest flow in this outcrop.

These flows and all other variolitic mafic flows in the greenstone belt have trace element contents consistent with mafic rocks erupted in "back-arc basin" volcanic environments. This is the defining characteristic of Depositional Package B, which is dominated by rocks of this chemistry intercalated with mafic rocks of "oceanic plateau" volcanic affinity.

Nearby outcrops of a perlitic felsic flow (accessible along a footpath) and outcrops of spinifex-textured mafic to ultramafic rocks (accessible along Highway 17 or along the railway) are indicated in Figure 6. These rocks will not be visited during this field trip; however, the occurrence of spinifex-textured rock on Highway 17 is Stop 2A in the field guide of Smyk and Schnieders (1995). Please use caution, especially along the highway and the railway, if you decide to visit these rocks.

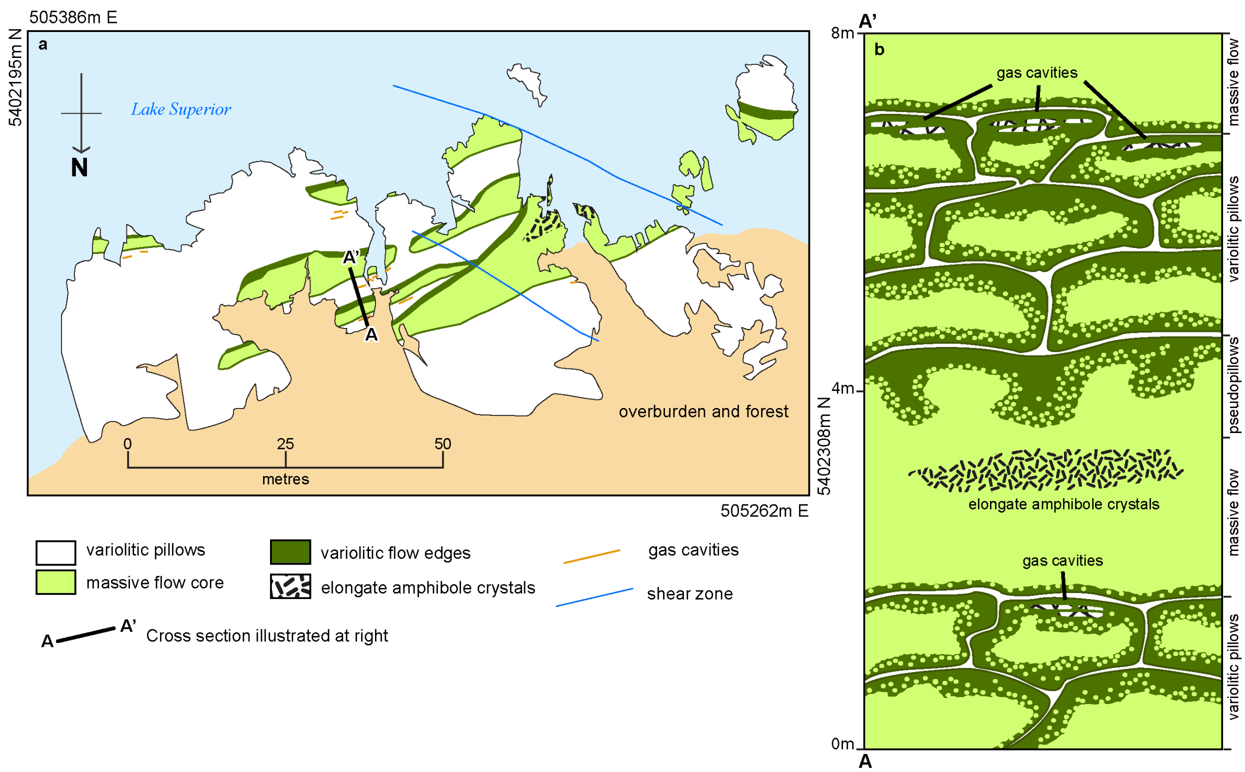

Figure 7. **A)** Simplified bedrock geology map of the shoreline outcrop at Stop 3, and **B)** illustration of the macrotextures observed in outcrop along A–A′. All UTM co-ordinates provided using NAD83 in Zone 16.

Return to vehicles by the same path you took to the outcrop. Turn the vehicles around and drive west along the path.

~2.0 km	Drive back along the sandy path the way you entered, until you reach the gravel pit.
2.2 km	Keep to the right and drive north until the gravel road intersects with Highway 17.
7.3 km	Turn left and drive west on Highway 17 for 7.3 km (4 minutes). Along the way, you will get an excellent view over Jackfish Lake and the terraced hills to the north. Those hills are the location of the historical Empress gold mine, which produced 112 oz Au at 0.10 oz/ton from 1896–1897. After passing the lake and beginning to drive up hill, prepare to slow down for Stop 4.

The parking spot for Spot 4 is a turn-around spot on the left (south side) of the highway, on the west end of a large granite and diabase outcrop.

Stop 4 location: UTM 503233 mE, 5411222 mN

STOP 4. GRANITE, SHEARED MAFIC ROCKS AND DIABASE DIKES

There are outcrops on the north and south sides of the highway at this location. On the south side of the highway, grey to pink granodiorite of the Terrace Bay pluton is crosscut by a 50 m wide plagioclase porphyritic diabase dike. This dike trends generally northward and is aligned with a north-northeast–trending geophysical anomaly consistent with dikes of the Biscotasing dike swarm. There are smaller plagioclase porphyritic dikes with chilled margins that crosscut the large dike.

On the north side of the road, there are 2 outcrops composed of a series of southward-dipping panels of granite, mica schist, mafic intrusive rocks and massive felsic rocks.

The bottom of the western outcrop is massive grey to pink granodiorite of the Terrace Bay pluton, the top of the outcrop is a dike or sill of weakly foliated, massive, fine-grained aphyric felsic rock, and a panel of mica schist lies between them. The mica schist is composed of biotite and chlorite with abundant quartz and calcite veins. The dominant foliation in the mica schist dips more steeply to the south than the contacts between the schist and the felsic rocks between which it is sandwiched. This looks like a C-S structural fabric; the contacts between units represent the “C” plane, and the strong foliation in the schistose rock represents the “S” plane. Quartz veins in the schist are boudinaged; asymmetric boudins (mostly sigma clasts) and the orientation of the C-S fabric both indicate south-side up reverse displacement northward. Box folds in this schist postdate the sigmoidal quartz boudins. A biotite porphyritic ultramafic lamprophyre dike crosscuts the rocks at the west end of the outcrop.

The eastern outcrop is a massive sheared mafic rock composed mainly of amphibole and biotite with minor quartz, feldspar and carbonate minerals, cut by a small granitoid dike at the west end of the outcrop. Southward-dipping shear zones crosscut this rock with C-S fabrics similar to those observed in the western outcrop, indicating the same south-side up reverse displacement. The trace element composition of this mafic rock is similar to that of the granitoid rocks in the Terrace Bay pluton, with higher concentrations of transitional elements such as iron, magnesium, chromium, vanadium, nickel and copper. This rock is interpreted to represent mafic country rock that was altered during emplacement of the Terrace Bay pluton.

Similar schistose rocks with similar kinematic indicators are present along Highway 17 to the east and are associated with the nearby Mogotherium and Elgin Silver Mine gold and base metal occurrences (Schnieders et al. 1996).

Return to the vehicles and turn left to drive west on Highway 17.

17.4 km — Drive west on Highway 17 for 17.4 km (12 minutes). You will pass through the town of Terrace Bay. On the west side of town, just west of the Aguasabon River, turn left at the intersection between the highway and Aguasabon Gorge Road.

Note the outcrops of grey granodiorite, locally altered to pink granodiorite, along the highway towards Terrace Bay. Most of the rocks in the Terrace Bay pluton look like this.

750 metres — Drive to the end of the road. There will be a large parking area with outhouses and picnic tables. There is a boardwalk with railings at the south end of this parking lot that leads towards a vista with a view of the Aguasabon Falls and Lake Superior.

Safety Note: Although there are small foot-paths off of the main boardwalk, do not hop over the railing to walk on these paths. Falling into the gorge would lead to death.

Stop 5 location: UTM 490833 mE, 5403233 mN

STOP 5. AGUASABON FALLS GORGE; STRUCTURES AND ALTERATION

This vista overlooks granitoid rocks of the Terrace Bay pluton (Photo 2). Granodiorite in the pluton is normally grey; locally, the granodiorite is altered pink, caused by hydrothermal alteration around regional-scale shear zones and faults. North-, northwest- and northeast-striking faults, which correlate with similar shear zones that crosscut the supracrustal rocks of the greenstone belt, control the vertical cliff faces in the Aguasabon River Gorge.

Return to vehicles, drive back along Aguasabon Gorge Road and turn left to drive west on Highway 17.

8.1 km — Drive west on Highway 17 for 8.1 km (5 minutes). Along the way you will get an excellent view of Lake Superior (Terrace Bay). One minute before the next turn, you will pass an intersection between the highway and Worthington Bay Road. You will then cross a train bridge; turn right onto Hays Lake Road 200 m north of the bridge (*see* Figure 8).

Note the large outcrop of sulphide-bearing chert and graphitic argillite at the beginning of Hays Lake Road.

800 metres — Drive for 800 m along Hays Lake Road; there will be a clearing in the trees on the north side of the road. Pull your vehicle safely to the shoulder of the road and park.

Stop 6 location: UTM 483711 mE, 5404933 mN

Photo 2. View of the Aguasabon Falls Gorge, with Lake Superior and the Slate Islands in the background. Photo taken from a vista at the end of Aguasabon Gorge Road.

STOP 6. HARKNESS HAYS AND GOLD RANGE

North of the road, there is a northeast-trending ridge of outcrops that have been the subject of gold exploration for more than a century, with the earliest staking recorded in 1917. Over the following several decades, numerous adits and shafts were used to sample the bedrock in this ridge, which hosts the Harkness–Hays property to the west and the Gold Range property to the east. The Harkness–Hays property produced 200 oz Au at 2.58 oz/t during intermittent mining activities between 1920 and 1936; the Gold Range property produced 36.35 oz Au at 0.91 oz/t during intermittent mining activities from 1921 to 1941 (Schnieders et al. 1996). The focus for this stop will be on the Harkness–Hays property, which is the most easily accessible (and has the better historical gold grade).

These outcrops are composed mainly of massive to pillowed mafic metavolcanic rocks, crosscut by quartz feldspar porphyritic felsic dikes and biotite porphyritic lamprophyre dikes. These rocks are located in a moderately strained zone along the northwest edge of the Terrace Bay pluton and contain amphibolite facies mineral assemblages (*see* Figures 5 and 8). Quartz veins in the northeast-striking foliation, parallel to the contact with the pluton, host gold-bearing sulphides and occurrences of native gold.

Native gold at this site is found most commonly in white, vuggy quartz veins. Much of the bedrock has been blasted, and quartz vein-bearing rocks are dispersed throughout the resultant pile of rocks. It is recommended that visitors search through this pile of rock, rather than scale the pile to access the steep, cliffy outcrops.

A more detailed description of these outcrops is provided in Smyk and Schnieders (1995, Stop 4).

Return to vehicles, turn the vehicles around and drive back towards Highway 17.

5.3 km — Turn right and drive westward on Highway 17 for 5.3 km (4 minutes). Along the way you will pass through the town of Schreiber. After passing the Villa Blanca Inn, on the west side of town, you will begin driving uphill. The parking spot for Stop 7 will be on the right (north) side of the road at the top of this hill; prepare to stop.

Note as you drive through Schreiber, on the right (northeast) side of the road are several outcrops of turbiditic mafic-derived metasedimentary rocks.

Stop 7 location: UTM 479511 mE, 5407266 mN

STOP 7. ELWOOD OCCURRENCE

There are outcrops on the north and south sides of the highway at this location (Figure 8). On both sides of the highway, the outcrops are an upright, north-dipping sequence of interbedded chert and graphitic argillite with minor beds of felsic tuffaceous conglomerate. Sulphide mineralization is disseminated throughout the outcrop and occurs in calcite-sulphide veins and as conformable lenses of massive sulphide. The sulphide minerals are dominantly pyrrhotite and pyrite with minor chalcopyrite.

On the north side of the highway, a massive mafic flow marks the top of this sequence and forms an erosion-resistant cap on the outcrop. At the base of this flow, the rock contains abundant siliceous xenoliths of chert ripped up from the underlying cherty units, as well as abundant quartz and calcite amygdules, likely caused by the release of volatile fluids from the underlying sediments as the mafic flow was deposited. One 15 cm wide dike of similar composition crosscuts the underlying rocks and is interpreted to be a feeder dike to the flow.

The sequence of sedimentary rocks is roughly 80 m thick and represents a significant disconformity between the arc volcanic rocks of Package A and the back-arc basin volcanic rocks of Package B (*see* Figure 4). These rocks have a strong electromagnetic signature which is traceable along strike; eastward, the anomaly coincides with the mafic metasedimentary rocks along the highway in Schreiber and with chemical metasedimentary rocks at the Morley occurrences southeast of town (*see* Figure 8). Several other chemical sedimentary rocks occur east of town, including 2 occurrences of marble interbedded with argillite and sulphide-facies iron formation and the outcrop of sulphide-bearing chert and argillite observed earlier at the intersection of Highway 17 and Hays Lake Road (*see* Figure 8). Whether these nearby rocks represent separate sequences or are part of the same depositional sequence but separated by cryptic folding requires further, more detailed mapping.

The strata in this area are arranged in open, upright folds, which is apparent in this outcrop. However, the more fissile argillite-rich zones have developed C-S fabrics, kink folds and kinematic indicators like sigma and delta clasts that all indicate a significant amount of dextral shearing has affected these rocks. Because the only place locally that this deformation has been observed is in these argillitic rocks, the timing and cause of this shearing is unknown.

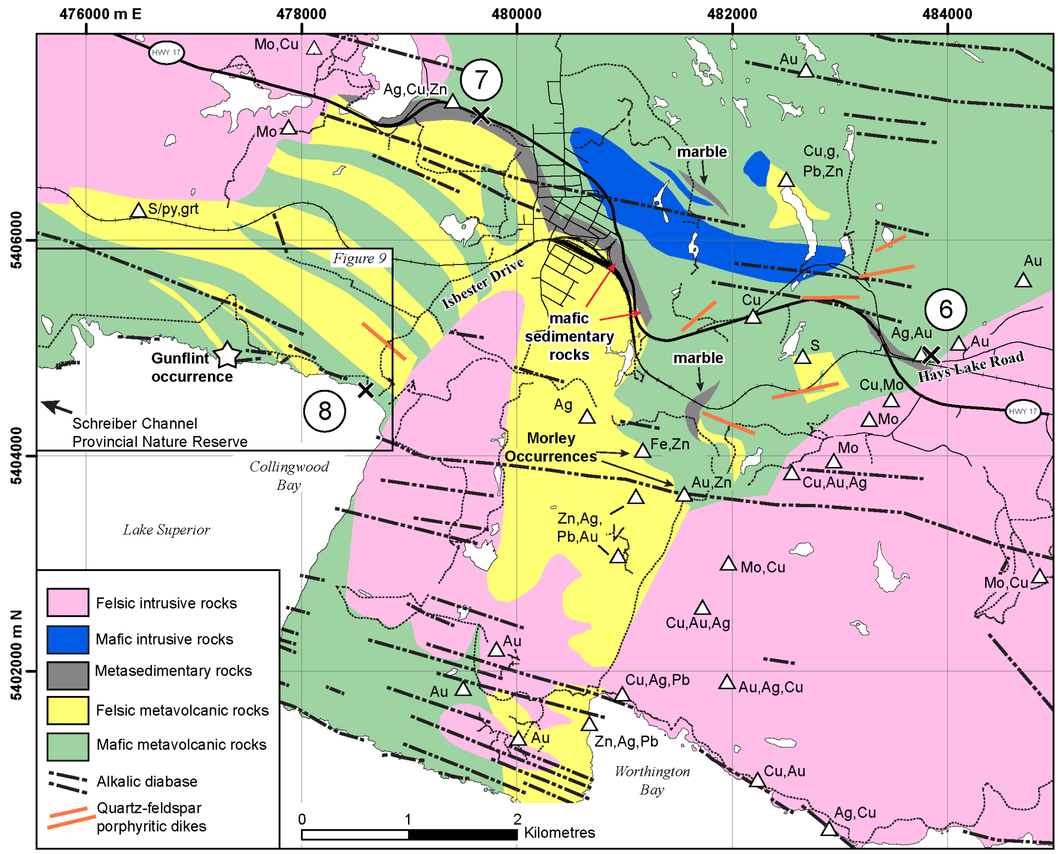

Figure 8. Simplified geological map of the Schreiber area, which includes field trip Stops 6, 7 and 8. The mafic metasedimentary rocks and the Morley occurrences, which are correlative with the rocks at Stop 7, are indicated, as well as nearby occurrences of marble associated with other chemical metasedimentary rocks. A box outlines the area covered in Figure 9. Abbreviations: Ag = silver, Au = gold, Cu = copper, Fe = iron, g = graphite, grt = garnet, Mo = molybdenum, Pb = lead, py = pyrite, S = sulphur, Zn = zinc. All UTM co-ordinates provided using NAD83 in Zone 16.

Return to vehicles and turn left to drive east on Highway 17.

1.2 km	Drive 1.2 km into the town of Schreiber and take the third right onto Winnipeg Street. This is the street immediately east of the Golden Rail chip truck.
600 m	Drive to the end of Winnipeg Street, where you will see a railroad museum, and turn right onto Scotia Street.
70 m	Drive 1 block west on Scotia Street, then turn left on Subway Street.
210 m	Driving south on Subway Street, you will pass beneath the railway. Take the first right onto Isbester Drive.
2.3 km	Drive south to the end of Isbester Drive. There is a parking lot at the end of the road, and an outhouse and a gazebo down near the beach.

Walk down the footpath to the beach, then turn right (west) and walk towards the first outcrop. This is Stop 8.

Stop 8 location: UTM 478600 mE, 5404600 mN

STOP 8. SCHREIBER BEACH OUTCROPS

The outcrops at Schreiber Beach (Photo 3) are the best exposure of a conformable sequence of Archean metavolcanic and metasedimentary rocks in the Schreiber–Hemlo greenstone belt and perhaps throughout Ontario (Figure 9). From the easternmost outcrop to the Schreiber Channel Provincial Nature Reserve, where exposures of Proterozoic rocks interrupt the Archean exposure, there are 3 km (as the crow flies) of near-continuous rocky shoreline, with less than 5% of the shoreline covered by cobble beaches. Winter ice scraping against the rocky shoreline keeps the rocks, up to several metres inland, lichen-free, displaying beautiful mineral, volcanic and sedimentary textures. The rocks are not pervasively deformed, only crosscut by discrete fractures with minimal displacement and up to metre-wide shear zones. There are only a few altered areas in which the primary textures of the rocks are preserved. The upright stratigraphy strikes northwest and dips shallowly to the northeast, such that the straight, west-trending shoreline provides for us a perfect cross-section; walking west along the shoreline guides us down through stratigraphy.

The author only had the opportunity to map the shoreline between Schreiber Beach and Twin Harbours, and so that stretch will be the focus of this description.

From compiled data, the Archean rock between Twin Harbours and the granite-greenstone contact to the west is composed mainly of mafic metavolcanic rock. The world-famous Schreiber Channel Stromatolite outcrop and associated Gunflint conglomeratic rocks occur along this stretch of shoreline, and a Keweenawan diabase sill occupies the Archean–Proterozoic unconformity.

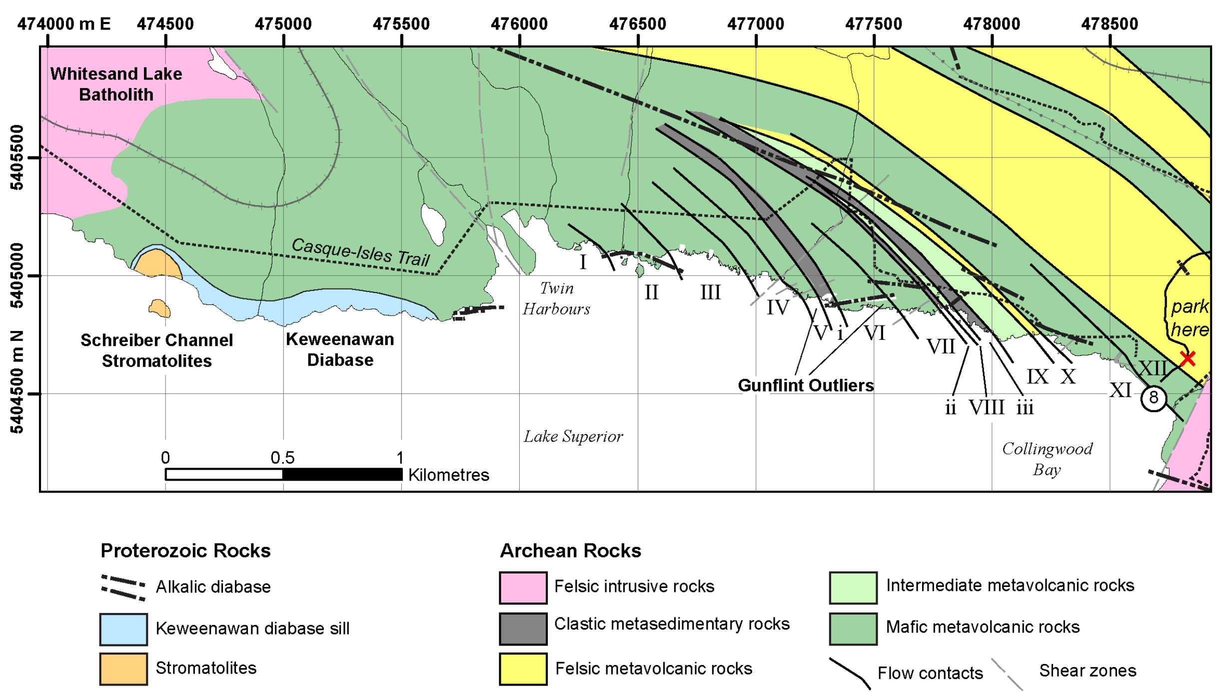

Figure 9. Simplified geological map of the shoreline west of Schreiber Beach (Stop 8) on Lake Superior. Metavolcanic flows and metasedimentary sequences are labelled I to XII and i to iii, respectively. Proterozoic rocks of interest are labelled. Note that the Casque-Isles Trail is well constrained for 2 km west of the Schreiber Beach, but the author was not able to get better a resolution trace of the trail further west. All UTM co-ordinates provided using NAD83 in Zone 16.

Photo 3. View of Schreiber Beach and the rocky shoreline westward, taken from a vista along the Casque-Isles Trail.

Eastward from Twin Harbours, higher in the stratigraphy, are 5 consecutive mafic metavolcanic flows up to 200 m in apparent thickness (roughly 175 m in true thickness, with an estimated 30º dip) (*see* Figure 9). These flows are massive at the base, with medium- to coarse-grained equigranular textures that could easily be mistaken for mafic intrusive rocks. Thin beds of sulphide-bearing chert are present along the flow contacts. Flow II is crosscut by an alkalic diabase dike, flow III is crosscut by 2 north-trending, carbonate-altered mafic dikes up to 25 m wide, and flow V is crosscut by a series of north-trending dikes that display unique Liesegang textures.

A 50 m thick sequence (i) of tuffaceous conglomerates with pebble- to cobble-sized mafic and felsic volcanic clasts lies atop flow V (*see* Figure 9). Minor graded beds of sandy to gravelly material are present within these conglomerates. These rocks are crosscut by alkalic diabase dikes, and unconformably overlain by an outlier of the Gunflint Formation basal conglomerate, including cherty stromatolite domes similar to those observed at the Schreiber Channel Provincial Nature Reserve. The conglomerate is massive, polymictic and clast supported, with dominantly pebble- to cobble-sized clasts. The conglomerates are interpreted to have been deposited in a shallow water environment akin to the cobble beaches present along the shores of Lake Superior today.

Eastward from metasedimentary sequence i are 2 consecutive massive to pillowed mafic flows similar to flows I to V. Another outlier of the Gunflint basal conglomerates and stromatolites, crosscut by an alkalic diabase dike, unconformably overlies pillows near the top of flow VI (*see* Figure 9).

A thin sequence of tuffaceous wacke (ii) marks the top of flow VII. This is overlain by an intermediate volcanic flow (VIII) with plagioclase and amphibole phenocrysts. This flow is generally massive, with an agglomerate of similar composition at its top. This agglomerate grades into the polymictic tuffaceous conglomerate (iii) similar to the conglomerates in sequence i.

Another massive intermediate flow (IX, roughly 100 m thick) with plagioclase and amphibole phenocrysts overlies the conglomerates of sequence iii, with agglomerate at its top similar to that of flow VIII. This agglomerate is overlain by a 3 m sequence of normally graded tuffaceous wacke, which is then overlain by a massive to brecciated felsic flow with feldspar phenocrysts (Flow X).

Two consecutive massive to pillowed mafic flows (XI and XII) overlie Flow X, with a 1 m wide sequence of banded chert and magnetite between them. Outcrop exposure ends just above the base of Flow XII, which is then covered by the sands of Schreiber Beach. This easternmost outcrop will be the subject of our last stop on the field trip (*see* Figure 9).

To access the shoreline to the west, one could either walk along the rocky shoreline, which is quite rugged and slippery when wet, or follow the Casque-Isles Trail, which intermittently jogs down towards the shoreline (*see* Figure 9). There is a stream with steep-sided banks roughly halfway between Schreiber Beach and Twin Harbours, at the contact between flows IV and V. At the mouth of this stream, there are cobbles and boulders along the shoreline that may be crossed if there are no waves on Lake Superior and the outflow from the stream is minimal. A small wooden footbridge, wide enough for one person, crosses this stream about 500 m to the north along the Casque-Isles Trail. Neither of these choices are particularly safe, so exercise extreme caution whichever path you choose to follow. Note that aside from the Schreiber Channel stromatolites, most of the rocks observed between here and Twin Harbours are massive to pillowed mafic flows (*see* Figure 9). To reach the Schreiber Channel stromatolites, it is recommended to start at the west end of the trail in Rossport or to approach the location by boat.

End of road log.

Acknowledgments

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Appendix 1.

Geochemical Data

Appendix 1. Geochemical data for typical samples of the major rock types in the western Schreiber–Hemlo greenstone belt. All analyses were performed at the OGS Geoscience Laboratories, Sudbury. Complete data are available in Magnus (2017b) (Tuuri and Walsh townships), Magnus (2019) (Syine Township) and in upcoming Miscellaneous Release—Data reports for Priske and Strey townships.

Sample Number	**17SJM013C**	**17SJM013C**	**17SJM013C**	**15SJM068A**	**15SJM068A**	**16SJM157 A**	**17SJM082C**	**15SJM204B**
Related Stop	Stop 2	Stop 2	Stop 2	S&S Stop 2A	S&S Stop 2A	near Stop 2	none	S&S Stop 2B
Rock Name	mafic volcanic rock	mafic volcanic rock	mafic volcanic rock	mafic volcanic rock	mafic volcanic rock	melanogab bro	mafic volcanic rock	mafic volcanic rock
Formation	Package B	Package B	Package B	Package B	Package B	Package B	Package C	Package B
Volcanic Setting	back arc volcanic	back arc volcanic	back arc volcanic	back arc volcanic	back arc volcanic	back arc volcanic	plateau volcanic	plateau volcanic
Easting (m)	505364	505364	505364	506861	506861	506123	501620	506190
Northing (m)	5402267	5402267	5402267	5402734	5402734	5402406	5412183	5403315
Notes	base of flow	middle of flow	top of flow	"spinifex" texture	base of flow	n/a	thorium-enriched	trachytic texture
TAS rock name	basalt	basalt	basaltic andesite	basalt	basalt	picro-basalt	basalt	basalt
Tectonic Setting	back arc basin	back arc basin	back arc basin	back arc basin	back arc basin	back arc basin	continental arc	continental arc
SiO_2 (wt %)	48.67	50.07	52.7	49.56	46.17	36.97	47.89	45.45
TiO_2	0.9	1.02	1.05	0.66	0.34	0.22	2.18	1.93
Al_2O_3	12.32	14.05	14.21	12.08	6.2	4.43	15.36	14.76
Cr_2O_3	0.078	0.044	0.054	0.08	0.31	0.58	0.008	0.02
$Fe_2O_3^{total}$	12.99	12.44	11.28	12.07	11.66	10.62	14.57	13.13
MnO	0.194	0.199	0.213	0.173	0.137	0.175	0.242	0.339
MgO	11.08	8.11	6.01	11.06	24.23	26.37	2.54	3.08
CaO	10.036	8.439	9.481	9.384	5.055	6.66	12.959	8.382
Na_2O	0.93	1.02	2.37	1.93	0.02	<0.02	0.42	2.9
K_2O	0.23	2.59	0.27	0.08	0.01	0.03	1.19	0.73
P_2O_5	0.099	0.109	0.118	0.047	0.027	0.018	0.356	0.372
LOI	3.41	2.99	2.98	2.99	6.02	14.12	1.73	9.1
Total	100.95	101.11	100.75	100.12	100.18	100.19	99.47	100.2
Mg Number	0.82	0.78	0.74	0.83	0.92	0.93	0.49	0.56
Th (ppm)	0.382	0.424	0.436	0.212	0.097	0.062	1.151	0.765
Nb	3.098	3.47	3.706	1.29	0.597	0.478	8.719	9.274
Ta	0.205	0.23	0.236	0.071	0.033	0.024	0.562	0.528
Ti	5267	5972	6139	4028	1952	1326	12625	11341
Zr	73	80	85	42	22	14	172	142
La/Lu_{CI}	1.08	1.07	1.07	1.05	1.08	0.98	2.53	3.65
Total REE	44.06	49.17	52.90	25.42	10.89	8.57	112.25	108.66

Notes: *"Formation" refers to the depositional package, pluton or dike swarm that the sample is related to;*
"Volcanic Setting" refers to the volcanic environment inferred using different geochemical and geological parameters;
"Tectonic Setting" refers to the inferred tectonic setting of mafic rocks, based on Cabanis and Lecolle (1989);
"TAS Rock Name" refers to the rock name based on the Total Alkalis versus Silica diagram from Le Maitre (1989);
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; this value is dimensionless
La/Lu_{CI} includes elements normalized using values from Sun and McDonough (1995); this value is dimensionless
Abbreviations: LOI = loss-on-ignition; n/a = not applicable; REE = rare earth elements; S&S = Smyk and Schnieders (1995); TAS = Total Alkalis versus Silica.

Appendix 1, *continued*

Sample Number	17SJM016B	17SJM016A	16SJM213A	16WM043A	17SJM129C	17SJM168B	16WM027A
Related Stop	Stop 8	Stop 8	none	none	none	none	like Stop 2
Rock Name	mafic volcanic rock	mafic volcanic rock	lapilli tuff	crystal tuff	tuffaceous conglomerate	tuff	wacke
Formation	Package A	Package A	Package A	Package A	B-C Disconformity	B-C Disconformity	Package D
Volcanic Setting	arc volcanic	arc volcanic	arc volcanic	arc volcanic	arc volcanic	arc volcanic	n/a
Easting (m)	478600	478600	512241	514731	498541	499867	513955
Northing (m)	5404609	5404609	5409187	5408709	5402882	5412118	5411351
Notes	pillow core, Flow XI	base of flow, Flow XII		quartz and feldspar phenocrysts	clasts up to 5cm	with interbedded chert	n/a
TAS Rock Name	basaltic andesite	andesite	dacite	rhyolite	dacite	dacite	dacite
Tectonic Setting	transitional arc	calc-alkaline	calc-alkaline	calc-alkaline	calc-alkaline	calc-alkaline	calc-alkaline
SiO_2 (wt %)	54.7	58.89	70.26	76.1	69.22	64.6	63.96
TiO_2	1.32	0.74	0.47	0.1	0.56	0.49	0.57
Al_2O_3	15.92	15.16	14.66	12.05	13.14	12.35	15.92
Cr_2O_3	0.027	0.022	<0.002	0.01	0.009	0.024	0.03
$Fe_2O_3^{total}$	11.85	6.44	3.75	1.35	3.61	5.66	5.99
MnO	0.11	0.084	0.052	0.047	0.034	0.17	0.094
MgO	3.31	4.53	1	0.11	4.04	3.55	3.14
CaO	2.651	5.437	3.518	0.502	2.99	6.886	3.511
Na_2O	2.38	3.63	4.27	0.45	2.82	2.19	4.03
K_2O	1.84	0.51	1.35	8.99	0.61	1.09	1.79
P_2O_5	0.12	0.174	0.113	0.017	0.145	0.108	0.179
LOI	5.62	5.33	1.28	0.85	2.23	2.35	1.04
Total	99.86	100.98	100.76	100.64	99.42	99.5	100.28
Mg Number	0.60	0.79	0.59	0.31	0.86	0.77	0.74
Th (ppm)	0.559	2.941	3.728	5.249	1.816	1.764	9.035
Nb	3.969	6.999	6.471	9.436	4.74	3.572	7.056
Ta	0.251	0.468	0.603	0.918	0.335	0.275	0.471
Ti	6481	5823	2781	563	3209	2842	3462
Zr	86	175	187	167	133	86	158
La/Lu_{CI}	3.29	13.81	6.25	5.12	6.33	9.55	19.71
Total REE	61.83	163.67	101.45	124.07	80.13	58.96	181.12

Notes: *"Formation" refers to the depositional package, pluton or dike swarm that the sample is related to;*
"Volcanic Setting" refers to the volcanic environment inferred using different geochemical and geological parameters;
"Tectonic Setting" refers to the inferred tectonic setting of mafic rocks, based on Cabanis and Lecolle (1989);
"TAS Rock Name" refers to the rock name based on the Total Alkalis versus Silica diagram from Le Maitre (1989);
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; this value is dimensionless
La/Lu_{CI} includes elements normalized using values from Sun and McDonough (1995); this value is dimensionless
Abbreviations: LOI = loss-on-ignition; n/a = not applicable; REE = rare earth elements; S&S = Smyk and Schnieders (1995);
TAS = Total Alkalis versus Silica.

Appendix 1, *continued*

Sample Number	17SJM147A	17SJM038A	15JW094A	17KA040A	15JW006A	16SJM171A	17SJM200A	17SJM033B
Related Stop	Stops 4 and 5	none	none	none	none	none	none	none
Rock Name	granodiorite	granodiorite	granite	monzogranite	quartz monzodiorite	tonalite	quartz syenite	porphyritic dike
Formation	Terrace Bay pluton	Crossman Lake batholith	Foxtrap Lake pluton	Santoy Lake pluton	Little Pic River pluton	Steel River pluton	Syenite Lake pluton	porphyritic dikes
Easting (m)	506412	488795	522826	507404	524180	511259	487180	482667
Northing (m)	5410351	5423075	5412786	5412210	5413445	5405636	5415617	5405457
TAS rocktype	dacite	dacite	rhyolite	rhyolite	trachy-andesite	dacite	trachy-dacite	dacite
SiO_2 (wt %)	64.15	69.74	71.6	70.18	61.77	64.34	67.92	67.67
TiO_2	0.44	0.36	0.18	0.28	0.58	0.53	0.25	0.25
Al_2O_3	15.19	15.19	16.04	14.99	17.36	14.05	15.82	14.87
Cr_2O_3	0.017	0.006	<0.002	0.004	<0.002	0.02	0.006	0.022
$Fe_2O_3^{total}$	4.04	3.56	1.37	2	5.1	6.1	2.21	2.73
MnO	0.078	0.062	0.024	0.025	0.086	0.082	0.04	0.042
MgO	3.03	0.98	0.5	0.55	2.17	2.91	1.03	2.49
CaO	3.89	3.282	1.122	1.129	4.113	2.713	2.067	2.937
Na_2O	4.57	4.09	6.31	5.23	4.67	2.84	4.95	5.58
K_2O	2.45	1.52	2.95	4.66	2.86	2.42	4.17	0.89
P_2O_5	0.256	0.13	0.085	0.127	0.292	0.138	0.136	0.099
LOI	1.46	1.19	0.81	0.81	0.72	3.81		3.39
Total	99.7	100.14	101.14	100.08	99.84	100.04	99.3	101.02
Mg Number	0.80	0.60	0.67	0.60	0.70	0.72	0.72	0.83
Th (ppm)	9.668	3.212	5.215	32.841	6.723	7.388	13.741	1.795
Nb	5.497	7.076	3.251	11.59	6.843	5.554	7.084	2.326
Ta	0.378	0.726	0.194	0.683	0.385	0.42	0.612	0.193
Ti	2551	2046	1106	1661	3396	3278	1477	1438
Zr	190	160	94	287	191	144	174	87
La/Lu_{CI}	24.83	5.45	19.80	52.14	23.09	17.57	31.85	17.62
Total REE	244.97	77.55	84.17	270.77	230.87	137.44	185.46	66.37

Notes: *"Formation" refers to the depositional package, pluton or dike swarm that the sample is related to;*
"TAS Rock Name" refers to the rock name based on the Total Alkalis versus Silica diagram from Le Maitre (1989);
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; this value is dimensionless
La/Lu_{CI} includes elements normalized using values from Sun and McDonough (1995); this value is dimensionless
Abbreviations: LOI = loss-on-ignition; n/a = not applicable; REE = rare earth elements; S&S = Smyk and Schnieders (1995);
TAS = Total Alkalis versus Silica.

Appendix 1, *continued*

Sample Number	16SJM178D	15SJM019B	15JW072E	16SJM119C	15SJM068B	17SJM006B	16SJM139A
Related Stop	Stop 1	none	Stops 1 and 4	Stop 4	S&S Stop 2A	none	none
Rock Name	alkalic diabase	alkalic diabase	lamprophyre	subalkalic diabase	subalkalic diabase	subalkalic diabase	subalkalic diabase
Formation	rift-parallel alkalic dikes	rift-parallel alkalic dikes	lamprophyre dikes	Biscotasing	Marathon	Matachewan	Pigeon River
Easting (m)	515772	523556	512213	517970	506861	498906	506570
Northing (m)	5408307	5407664	5405453	5406078	5402734	5412471	5407803
Notes	n/a	trachytic texture	n/a	n/a	n/a	n/a	n/a
TAS rocktype	basalt	trachy-dacite	foidite	basalt	basalt	basalt	basalt
Tectonic Setting	continental arc	continental arc	intercontinental rift	continental arc	calc-alkaline	calc-alkaline	continental arc
SiO_2 (wt %)	46.11	60.78	29.55	49.74	47.65	50.08	48.02
TiO_2	1.19	0.49	4.35	1.22	0.74	1.45	1.93
Al_2O_3	14.54	15.66	3.97	14.77	13.35	13.68	16.04
Cr_2O_3	0.02	<0.002	0.1	0.02	0.11	0.02	0.02
$Fe_2O_3^{total}$	12.77	8.63	15.76	14.04	10.82	14.92	13.86
MnO	0.217	0.234	0.269	0.206	0.171	0.19	0.193
MgO	5.51	0.34	15.94	6.4	10.47	6.9	6.04
CaO	10.656	1.814	13.069	10.428	11.079	8.774	9.742
Na_2O	3.22	6.41	0.1	2.27	1.71	2.81	2.75
K_2O	1.53	4.82	2.35	0.4	0.31	0.39	0.48
P_2O_5	1.099	0.077	0.876	0.118	0.117	0.098	0.214
LOI	2.89	0.82	12.61	0.7	3.33	1.5	0.54
Total	99.92	100.08	99.04	100.32	99.87	100.83	99.86
Mg Number	0.70	0.18	0.85	0.71	0.84	0.72	0.70
Th (ppm)	9.282	56.416	8.508	1.138	0.496	3.17	1.669
Nb	63.339	>277	124.706	4.426	2.866	6.18	11.382
Ta	2.739	14.976	7.901	0.28	0.129	0.435	0.774
Ti	7279	2967	>25000	6976	4623	3630	11126
Zr	180	1041	375	80	62	148	160
La/Lu_{CI}	26.63	19.55	53.01	2.16	4.20	11.19	3.50
Total REE	468.09	923.53	418.37	56.87	62.82	144.04	103.50

Notes: *"Formation" refers to the depositional package, pluton or dike swarm that the sample is related to;*
"Tectonic Setting" refers to the inferred tectonic setting of mafic rocks, based on Cabanis and Lecolle (1989);
"TAS Rock Name" refers to the rock name based on the Total Alkalis versus Silica diagram from Le Maitre (1989);
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; this value is dimensionless
La/Lu_{CI} includes elements normalized using values from Sun and McDonough (1995); this value is dimensionless
Abbreviations: LOI = loss-on-ignition; n/a = not applicable; REE = rare earth elements; S&S = Smyk and Schnieders (1995); TAS = Total Alkalis versus Silica.

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Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton(short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 9**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy) / ton (short)	1 ounce (troy) / ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights / ton (short)	1 pennyweight / ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

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

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

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