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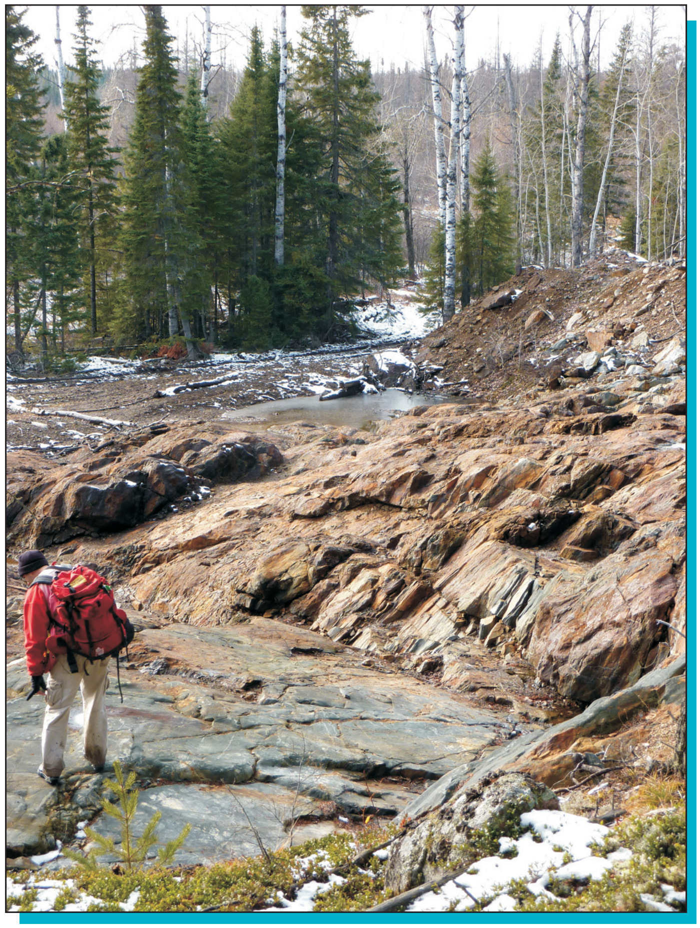

FIELD TRIP GUIDEBOOK

Field Trip Guidebook FT-C2 / Open File OF2013-7

Mafic and ultramafic intrusive rocks and associated Ni-Cu-(PGE) and Cr-(PGE) mineralization in the Bird River greenstone belt, southeast Manitoba

H.P. Gilbert, M.G. Houlé, X.M. Yang, J.S. Scoates, R.F.J. Scoates,
C.A. Mealin, V. Bécu, V.J. McNicoll and C.R. Galeschuk

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Cover illustration: Typical exposure of the ore zone at the M2 site in the Mayville intrusion.

SAFETY INFORMATION

General Information

The Geological Association of Canada (GAC) recognizes that its field trips may involve hazards to the leaders and participants. It is the policy of the GAC to provide for the safety of participants during field trips, and to take every precaution, reasonable in the circumstances, to ensure that field trips are run with due regard for the safety of leaders and participants. Field trip safety is a shared responsibility. The GAC has a responsibility to take all reasonable care to provide for the safety of the participants on its field trips. Participants have a responsibility to give careful attention to safety-related matters and to conduct themselves with due regard to the safety of themselves and others while on the field trips.

Field trip participants should be aware that any geological fieldwork, including field trips, can present significant safety hazards. Foreseeable hazards of a general nature include inclement weather, slips and falls on uneven terrain, falling or rolling rock, insect bites or stings, animal encounters and flying rock from hammering. **The provision and use of appropriate personal protective equipment (e.g., rain gear, sunscreen, insect repellent, safety glasses, work gloves and sturdy boots) is the responsibility of each participant.** Each field trip vehicle will be equipped with a moderate sized first-aid kit, and the lead vehicle will carry a larger, more comprehensive kit of the type used by the Manitoba Geological Survey for remote field parties.

Participants should be prepared for the possibility of inclement weather. In Manitoba, the weather in May is highly unpredictable. The average daily temperature in Winnipeg is 12°C, with record extremes of 37°C and -11°C. North-central Manitoba (Thompson) has an average daily temperature of 7°C, with record extremes of 33°C and -18°C (*Source:* Environment Canada). Consequently, participants should be prepared for a wide range of temperature and weather conditions, and should plan to dress in layers. A full rain suit and warm sweater are essential. Gloves and a warm hat could prove invaluable if it is cold and wet, and a sunhat and sunscreen might be just as essential in the heat and sun.

Above all, field trip participants are responsible for acting in a manner that is safe for themselves and their co-participants. This responsibility includes using personal protective equipment (PPE) when necessary or when recommended by the field trip leader, or upon personal identification of a hazard requiring PPE use. It also includes informing the field trip leaders of any matters of which they have knowledge that may affect their health and safety or that of co-participants. Field Trip participants should pay close attention to instructions from the trip leaders and GAC representatives at all field trip stops. Specific dangers and precautions will be reiterated at individual localities.

Specific Hazards

Some of the stops on this field trip may require short hikes, in some cases over rough, rocky, uneven or wet terrain. Participants should be in good physical condition and accustomed to exercise. Sturdy footwear that provides ankle support is strongly recommended. Some participants may find a hiking stick a useful aid in walking safely. Steep outcrop surfaces require special care, especially after rain. Access to bush outcrops may require traverses across muddy or boggy areas; in some cases it may be necessary to cross small streams or ditches. Field trip leaders are responsible for identifying such stops and making participants aware well in advance if waterproof footwear is required. Field trip leaders will also ensure that participants do not go into areas for which their footwear is inadequate for safety. In all cases, field trip participants must stay with the group.

Other field trip stops are located adjacent to roads, some of which may be prone to fast-moving traffic. At these stops, participants should pay careful attention to oncoming traffic, which may be distracted by the field trip group. Participants should exit vehicles on the shoulder-side of the road, stay off roads when examining or photographing outcrops, and exercise extreme caution in crossing roads.

Road cuts or rock quarries also present specific hazards, and participants MUST behave appropriately for the safety of all. Participants must be aware of the danger from falling debris and should stay well back from overhanging cliffs or steep faces. Participants must stay clear of abrupt drop-offs at all times, stay with the field trip group, and follow instructions from leaders.

Participants are asked to refrain from hammering rock. It represents a significant hazard to the individual and other participants, and is in most cases unnecessary. Many stops on this field trip include outcrop with unusual features that should be preserved for future visitors. If a genuine reason exists for collecting a sample, please inform the field trip leader, and then make sure it is done safely and with concern for others, ideally after the main group has departed the outcrop.

Subsequent sections of this guidebook contain the stop descriptions and outcrop information for the field trip. In addition to the general precautions and hazards noted above, the introductions for specific localities make note of any specific safety concerns. Field trip participants must read these cautions carefully and take appropriate precautions for their own safety and the safety of others.

Abstract

The Neoarchean Bird River Belt (BRB) in southeastern Manitoba is part of an east-trending supracrustal belt that extends for 150 km from Lac du Bonnet in the west to Separation Lake (Ontario) in the east. This greenstone belt is endowed with a unique Ta-Nb-Li-rare-element-bearing pegmatite resource (TANCO mine), as well as Ni-Cu-PGE-Cr deposits associated with mafic–ultramafic intrusions that are the objective of this field excursion. The Bird River Sill, which will be examined on the first day, is an outstanding example of a layered mafic–ultramafic intrusion and has been the subject of numerous geological investigations ever since chromite mineralization was discovered there 70 years ago. The sill consists of several discrete parts that were emplaced at the faulted contact between continental-arc and back-arc type rocks at the north margin of the main part of the BRB. Twenty kilometres to the north in a subordinate, northern arm of the BRB, the ca. 2743 Ma Mayville intrusion—to be examined on the second day of the trip—occurs in a similar crustal setting and is coeval with the ca. 2743 Ma Bird River Sill. Both intrusions have economic base-metal (and potential PGE) resources and are targets of ongoing exploration and development by Mustang Minerals Corporation and Gossan Resources Limited. The third day of this trip will include examination of surface exposures of the Bird River Sill at both the Ore Fault and Makwa properties, as well as drillcore of the Bird River Sill and the Mayville mafic–ultramafic intrusion.

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GEOLOGICAL INTRODUCTION TO THE BIRD RIVER GREENSTONE BELT
by H.P. Gilbert

The Neoarchean Bird River Belt (BRB) in southeastern Manitoba is part of an east-trending supracrustal belt that extends for 150 km from Lac du Bonnet in the west to Separation Lake (Ontario) in the east, between the English River and Winnipeg River subprovinces of the western Superior Province (Figure 1; Percival et al., 2006b; Gilbert, 2007; Gilbert et al., 2008). Regional aeromagnetic data and Nd-isotope evidence suggest that the BRB extends westward beneath the Paleozoic sedimentary cover for at least 300 km (McGregor, 1986; Stevenson et al., 2000; Percival et al., 2006a, b). Previous mapping undertaken by the Manitoba Geological Survey (MGS) interpreted the BRB to consist of several formations of volcanic and/or sedimentary rocks that were separated by unconformities and deformed by major folds, and flanked by fault-bounded basaltic rocks to the north and south (Trueman, 1980; Černý et al., 1981). More recent work (Gilbert, 2008a, Gilbert et al., 2008) has subdivided the BRB into north and south panels of continental arc-type rocks that are geochemically and stratigraphically distinct (Table 1).

Younger orogenic turbidite deposits of the Booster Lake Formation are interpreted to represent an elongate rift basin that extends through the core of the greenstone belt, whereas penecontemporaneous fluvial-alluvial rocks (Flanders Lake Formation) are confined to the eastern part of the belt (Figure 2). Flanking MORB-type rocks to the north are very similar to basalt at the south margin of the BRB (formerly Lamprey Falls Formation of Černý at al. 1981), but are thought to be stratigraphically distinct, based on modelling of the regional structure and Lithoprobe seismic data (Percival et al., 2006b). Regional faults that extend through the greenstone belt occur within or between rock formations, but the original contact relationships between these formations are uncertain. Some evidence suggests that the arc-type volcano-sedimentary sequence in the north panel is locally conformable with overlying turbidite strata of the Booster Lake Formation.

The northern arm of the belt (Cat Creek area) also contains arc-type volcanic and sedimentary rocks as well as MORB-type rocks, but correlations with the formations in the main part of the BRB are mostly conjectural. Current mapping by MGS in the northern arm (Yang et al., 2011, 2012) has indicated broad similarity between the Bird River Sill and Mayville intrusion (e.g., in compositional range and emplacement age) but the age and setting of the associated supracrustal rocks in the Cat Creek area have not yet been determined.

Previous and current work

Mineral exploration and geological investigations in the Bird River area span the past century, dating from the pioneering work of Tyrrell (1900). The discovery in 1942 of chromite mineralization at the north margin of the Bird River Sill (Bateman, 1943) led to the subsequent development of base-metal ore deposits at the Maskwa open pit and Dumbarton mine (1969-1976). The first systematic geological mapping of the BRB was undertaken over 60 years ago (Springer, 1948, 1949; Davies, 1952, 1955, 1956, 1957). Geological investigations since that time have typically been directed toward the economic mineral endowment of the BRB, which includes magmatic Ni-Cu-PGE-Cr deposits in the Bird River Sill, the world class Cs-Ta-Nb-Li-rare earth element (REE) resource at TANCO mine, and other mineral occurrences such as Au and Cu-Zn metal sulphides (Springer, 1950; Trueman and Macek, 1971; Karup-Möller and Brummer, 1971; Trueman, 1971; Trueman and Turnock, 1982; Scoates, 1983; Macek, 1985a, b; Theyer, 1991; Scoates et al., 1989; Peck et al., 2000, 2002; Anderson, 2007; Mealin, 2008; Good et al., 2009). The geology and tectonic setting of the BRB—between two continental cratonic blocks (North Caribou Terrane and Winnipeg River Subprovince; Figure 1)—have been discussed in recent publications (Beaumont-Smith et al., 2003; Percival et al., 2006a, b; Anderson, 2007, 2008; Gilbert et al., 2008; Corkery et al., 2010; Stott et al., 2010). The regional bedrock geology, including the BRB, was compiled by the MGS at a scale of 1:250 000 (Manitoba Energy and Mines, 1987), and also by subsequent collaborative mapping projects involving the MGS, Geological Survey of Canada and Ontario Geological Survey (Bailes et al., 2003; Lemkow et al., 2006).

In 2005 the MGS, in collaboration with several universities and mineral-exploration companies, initiated a four-year mapping project focusing on the main part of the BRB that extends from northeastern Lac du Bonnet in the west to Bird and Booster lakes in the east (Gilbert, 2008b; Gilbert and Kremer, 2008; Gilbert et al., 2008). The northern arm of the BRB had, until recently, received comparatively less attention. In 2011, the MGS initiated a multiyear bedrock geological mapping project focusing on the Cat Creek and Cat Lake–Euclid Lake areas in the northern arm of the BRB—a collaborative project with the Geological Survey of Canada under the Targeted Geoscience Initiative Phase IV (TGI-4) program, which is supported by mining companies including Mustang Minerals Corp.

Reconnaissance mapping was conducted in the Cat Creek–Euclid Lake area in 2011, and subsequently more detailed mapping (at 1:12 500 scale) was carried out north of Maskwa Lake and in the Cat Lake area. The resulting geological map (Yang, 2012) is the basis for Figure 22 that shows the Day 2 itinerary (see below, Day 2: Geology of the Mayville intrusion). Additional mapping is planned for the Cat Creek–Euclid Lake area in 2013.

Geochronological investigations have yielded a U-Pb zircon age of 2742.8 ±0.8 Ma for the Mayville intrusion (Houlé et al., 2013), virtually identical with the 2743.0 ±0.5 Ma age (Scoates and Scoates, 2013) of the Bird River Sill, located in the main part of the BRB. This new result strongly suggests that these two intrusions are comagmatic and part of the same Neoarchean magmatic event—the Bird River magmatic event—within the BRB (Houlé et al., 2013). Preliminary results from Bécu et al. (2013) indicate that the Coppermine Bay intrusion, located close to Coppermine Creek in the westernmost part of the main belt (Figure 2), is texturally and petrographically very similar to the Euclid Lake intrusion, located 34 km to the northeast, at the northeast margin of the BRB. The Coppermine

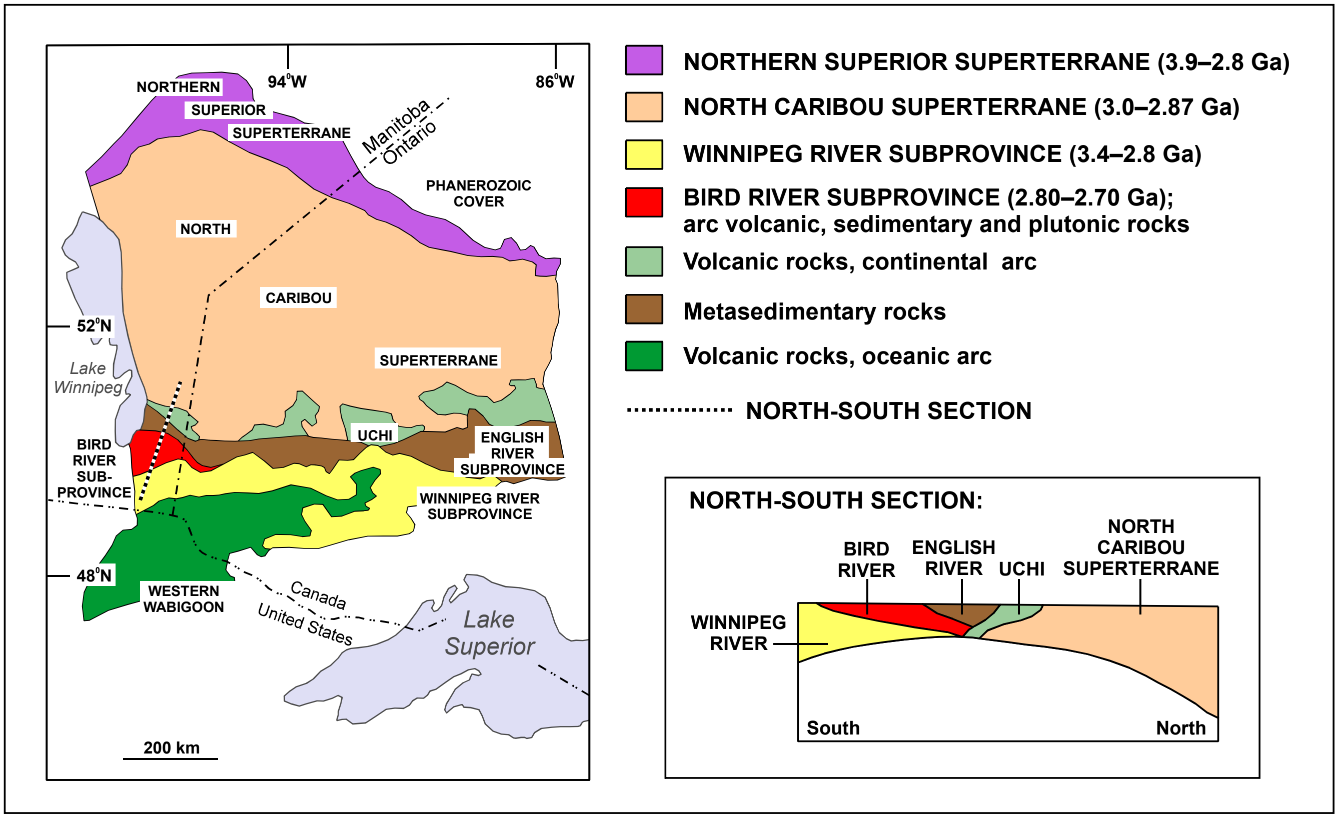


Figure 1: *Simplified geology of the western Superior Province, showing the location of the Neoarchean Bird River greenstone belt in southeastern Manitoba (after Percival et al., 2006b, Gilbert, 2007).*

Bay and Euclid Lake intrusions are also similar texturally and compositionally to the Mayville intrusion, supporting their proposed linkage with the Bird River magmatic event. Preliminary results of the on-going collaborative MGS–Geological Survey of Canada investigations support the conclusions of earlier workers that links exist between the northern and the main parts of the BRB, and specifically that the mineral endowment of the two parts of the belt might, in some cases, be intimately linked.

Regional setting and geology of the Bird River Belt

The BRB occurs in a transitional oceanic to continental-margin setting between flanking older cratonic blocks to the north and south (Figure 1 and 3). Continental-arc magmatism and orogenic sedimentation in the Bird River Subprovince (Card and Ciesielski, 1986) spanned at least 50 Ma (ca. 2.75–2.70 Ga; Gilbert et al., 2008). North panel rocks—Peterson Creek Formation (PCF, Table 1, 2) and Diverse Arc assemblage (DAA)—are compositionally akin to arc volcanic rocks at active continental margins, whereas volcanic rocks in the south panel (Bernic Lake Formation) appear to document incipient rifting of the continental-arc rocks (Gilbert et al., 2008). Mid-ocean-ridge basalt (MORB)–type rocks that extend along both the south and north margins of the main BRB are interpreted as relatively older than the arc-type rocks and probably represent ocean-floor/back-arc environments; they are flanked by older cratonic blocks to the south (Winnipeg River Subprovince, 2.8–3.4 Ga) and north (Maskwa Lake Batholith, 2.73–2.85 Ga, Figure 2, 3, 4; Gilbert et al., 2008). The northern arm of arc and MORB-type rocks that wraps around the east margin of the Maskwa Lake Batholith is provisionally interpreted to be older than the ca. 2743 Ma (Houlé et al., 2013) Mayville intrusion. The 2743.0 ±0.5 Ma Bird River Sill (Scoates and Scoates, 2013) intrudes the Northern MORB-type Formation at the north margin of the main BRB arc-type sequence, but is older than the 2.72–2.73 Ga arc-type sequence immediately to the south, which contains conglomerate with gabbroic clasts derived from the sill. The main BRB arc-type sequence thus appears to be younger than the northern arm of the greenstone belt, but further data are needed to determine this relationship.

Orogenic sedimentation (2712–2697 Ma, Gilbert, 2006) subsequent to continental-arc volcanism resulted in the deposition of turbidites (Booster Lake Formation) and penecontemporaneous fluvial-alluvial deposits (Flanders Lake Formation). The turbidites may be stratigraphically equivalent to the fluvial-alluvial rocks, but relatively more distal from the source terrane. The Booster Lake Formation occurs as a major, fault-bounded enclave and several smaller fault slivers thought to be part of a former elongate rift basin extending laterally for over 40 km through the central part of the greenstone belt, between the north and south panel arc-type rocks.

Late sanukitoid intrusive rocks (+/- associated fragmental deposits) are found in all the volcanic formations within the north panel of the BRB, as well as within the Booster Lake Formation, indicating the youngest volcanic rocks are penecontemporaneous with the Booster Lake turbidite deposits. The orogenic sedimentary rocks have been widely assumed to be equivalent to epiclastic deposits and metamorphic derivatives

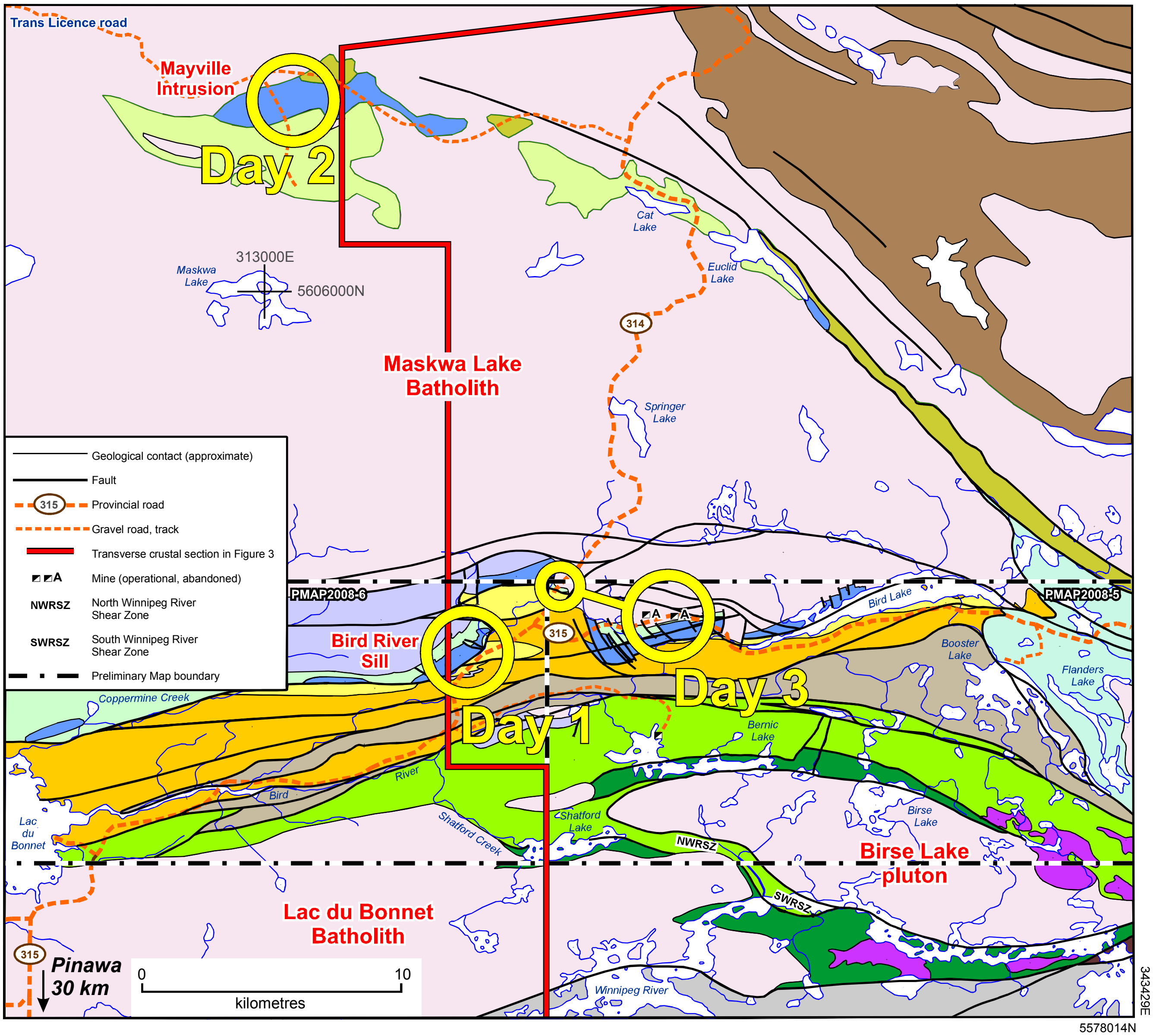
Table 1: Principal geological formations, their ages and contact relations in the Bird River Belt. The northern arm has only recently been the subject of detailed mapping, thus geological and geochronological constraints in that area are less well known compared to the main part of the Bird River Belt.

Late intrusive rocks
Granite, pegmatite, granodiorite, tonalite, quartz diorite
(TANCO pegmatite, 2640 ±7 Ma[1]
Marijane Lake pluton, 2645.6 ±1.3 Ma [2]; Lac du Bonnet Batholith, 2660 ±3[3] Ma)
Diabase, gabbro and andesitic to dacitic intrusive rocks

BIRD RIVER BELT	BIRD RIVER BELT, NORTHERN ARM
Sedimentary rocks FLANDERS LAKE FORMATION (2697 ±18 Ma[4]) Lithic arenite, polymictic conglomerate ***Fault, inferred*** BOOSTER LAKE FORMATION (2712 ±17 Ma[4]) Greywacke-siltstone turbidite, conglomerate	
Fault, inferred	
Intrusive rocks SYNVOLCANIC INTRUSIONS Gabbro, diorite, quartz-feldspar porphyry; granodiorite (Birse Lake pluton, 2723.2 ±0.7 Ma[2]; Maskwa Lake Batholith II, 2725 ±6 Ma[3]; Pointe du Bois Batholith, 2729 ±8.7 Ma[3]; TANCO gabbro, 2723.1 ±0.8 Ma[2])	
Metavolcanic and metasedimentary rocks **BIRD RIVER BELT NORTH PANEL** DIVERSE ARC ASSEMBLAGE (2706 ±23 Ma[5]) Basalt, andesite, rhyolite, heterolithic volcanic fragmental rocks; greywacke-siltstone turbidite, chert, iron-formation; polymictic conglomerate (with clasts from the Bird River Sill) PETERSON CREEK FORMATION (2731.1 ±1 Ma[2]; 2734.6 ±3.1 Ma[6]) Dacite, rhyolite; felsic tuff and heterolithic felsic volcanic breccia **BIRD RIVER BELT SOUTH PANEL** BERNIC LAKE FORMATION (2724.6 ±1.1 Ma[2]) Basalt, andesite, dacite and rhyolite; heterolithic volcanic breccia	
Unconformity/Fault	EUCLID LAKE METASEDIMENTARY ROCKS Greywacke, siltstone, polymictic conglomerate
Intrusive rocks BIRD RIVER SILL (2744.7 ±5.2 Ma[3]; 2743.0 ±0.5[7]) Dunite, peridotite, picrite, anorthosite and gabbro	**Intrusive rocks** MAYVILLE MAFIC-ULTRAMAFIC INTRUSION (2742.8 ±0.8 Ma[8]) Gabbro, leucogabbro, anorthosite, intrusion breccia and pyroxenite
Metavolcanic and metasedimentary rocks MORB-type VOLCANIC ROCKS Basalt, aphyric to plagioclase-phyric; locally megacrystic; oxide-facies iron formation ***Fault, inferred*** EAGLENEST LAKE FORMATION Greywacke-siltstone turbidite	**Metavolcanic and metasedimentary rocks** MORB-type VOLCANIC ROCKS (Mayville assemblage, Bailes et al., 2003) Basalt, aphyric to plagioclase-phyric locally megacrystic

Older intrusive rocks
Granodiorite, diorite (Maskwa Lake Batholith I, 2782 ±11 Ma[3], 2832.3 ±0.9 Ma[2], 2852.8 ±1.1 Ma[2], 2844 ±12 Ma[3])

References for geochronological data: [1] Baadsgaard and Černý, 1993; [2] Gilbert et al., 2008; [3] Wang, 1993; [4] Gilbert, 2006; [5] Gilbert, 2008a; [6] H.P. Gilbert, unpublished data, 2007; [7] Scoates and Scoates, 2013; [8] Houlé et al., 2013



Bird River Subprovince

INTRUSIVE ROCKS

- Pegmatitic granite
- Granite, granodiorite, tonalite
- Gabbro, diorite, quartz diorite
- Pyroxenite, anorthosite, gabbro

LATE SEDIMENTARY ROCKS

Flanders Lake Formation

- Arenite, polymictic conglomerate

Booster Lake Formation

- Greywacke, siltstone

VOLCANIC AND SEDIMENTARY ROCKS

BIRD RIVER BELT SOUTH PANEL

Bernic Lake Formation

- Heterolithic volcanic breccia, rhyolite, basalt, andesite

Eaglenest Lake Formation

- Greywacke, siltstone

Southern MORB-type formation

- Basalt, aphyric; gabbro

BIRD RIVER BELT NORTH PANEL

Diverse Arc assemblage

- Massive to fragmental, mafic to felsic volcanic and sedimentary rocks

Peterson Creek Formation

- Massive to fragmental felsic volcanic rocks

Northern MORB-type formation

- Basalt, aphyric; gabbro

CAT LAKE AREA

- Sedimentary and volcanic rocks, related gneiss
- Tholeiitic basalt

English River Subprovince

- Paragneiss, granitoid intrusive rocks, migmatite, pegmatite

Winnipeg River Subprovince

- Tonalite, granodiorite, granitoid gneiss

Figure 2: *Geology of the area between Winnipeg River and the area north of Cat Lake, showing the main part of the Bird River greenstone belt between Lac du Bonnet and Flanders Lake, and the northern arm extending as far as the Mayville intrusion. The line of cross-section between the Winnipeg River and English River subprovinces (Figure 3) is shown in red.*

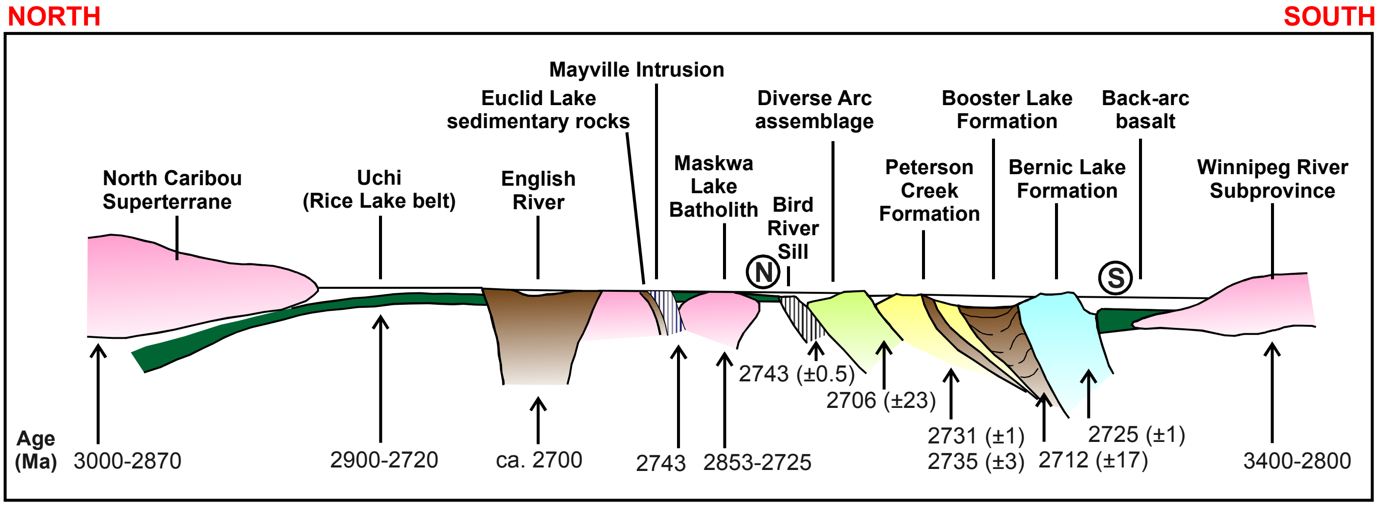


Figure 3: *Transverse crustal section from the North Caribou Superterrane in the north to the Winnipeg River Subprovince in the south, post-Booster Lake turbidite deposition (see section line in Figure 2). This transect shows the inferred spatial relationships between the main formations in the Bird River Belt and the English River and Uchi subprovinces, prior to continental collision. Note that crustal underplating to the south and deformation of supracrustal rocks assumed to have accompanied convergence of the North Caribou Superterrane and Winnipeg River Subprovince are not indicated, although convergence was probably underway during turbidite deposition (Lemkow et al., 2006). Lithoprobe studies indicate underplating of the Bird River Belt by the Winnipeg River Subprovince to the south, as well as the presence of a subduction zone to the north. Circled labels N, S denote Northern and Southern MORB-type formations, respectively.*

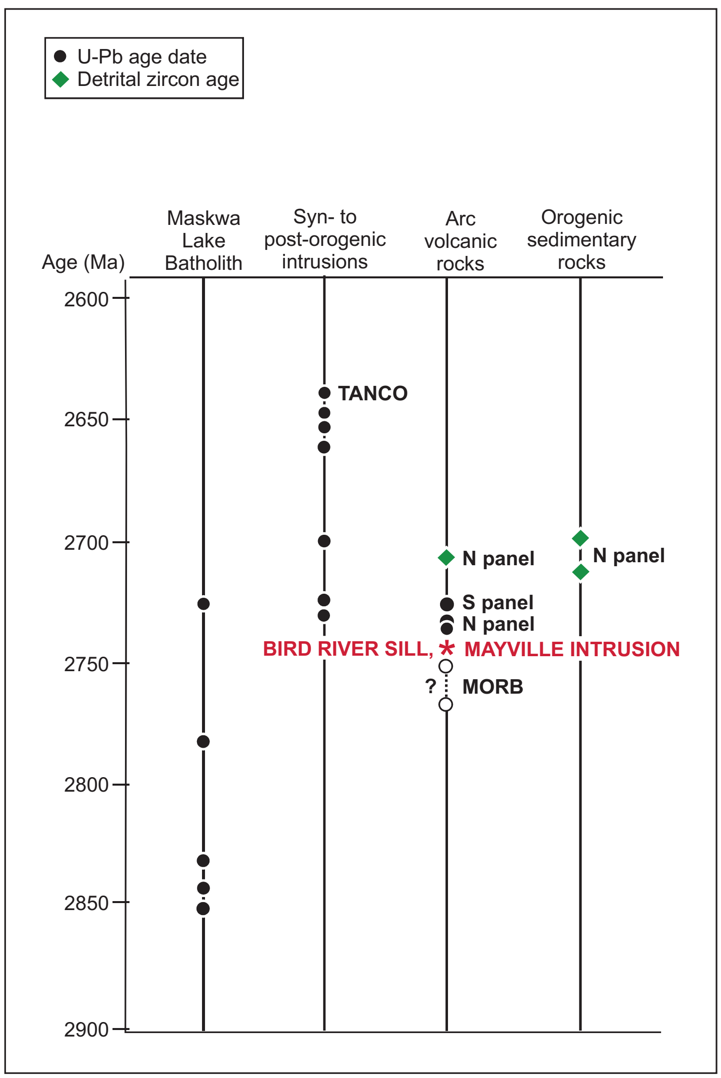


Figure 4: *Geochronological data for supracrustal and intrusive rocks in the Bird River Belt.*

Table 2: Lithostratigraphic details of the arc-volcanic type formations in the north and south panels of the main part of the Bird River Belt.

Tectonic subdivision	Formation	Rock types	Geochemistry	Contact relationships	Depositional setting
North panel. Rhyolite-dacite rock types >80%; basalt-andesite <10%	Peterson Creek Formation	Predominantly felsic volcanic rocks, subordinate andesite. In general, mainly massive flows in the east, volcanic fragmental rocks in the west. Upper part (500 m) of the formation in the western BRB consists of massive and fragmental felsic volcanic rocks intercalated with turbiditic rocks, chert and oxide-facies iron formation, interpreted as part of the Diverse Arc assemblage.	Calcalkaline	Fault contact inferred with underlying Northern MORB-type Formation. Apparently conformable, locally transitional with overlying Diverse Arc assemblage. Elsewhere, contact with overlying Booster Lake Formation faulted, but locally interpreted as conformable.	Formation consists mainly of voluminous dacite and rhyolite lava flows and pyroclastic flows, thought to be mainly subaerial. <u>Upper part of the formation in the western BRB</u>: subaerial to subaqueous setting, which ranged from a quiescent (oxide-facies IF) to higher energy environment (turbidites and mass-flow deposits; inferred talus deposits may indicate a localized subaerial setting).
	Diverse Arc assemblage	Volcanic, volcanic exhalative and epiclastic deposits. Turbidites, massive volcanic flows, pyroclastic deposits and derived debris flows (locally associated with scouring of the underlying strata). Polymictic conglomerate, interpreted as the uppermost member, contains clasts of all the main stratigraphic units within the north panel, as well as gabbroic fragments from the Bird River Sill and basaltic types probably derived from the (back-arc) Northern MORB-type Formation.	Calcalkaline	Thought to be conformable with the underlying Peterson Creek Formation. DAA possibly contemporaneous with upper part of Peterson Creek Formation in western BRB. Tectonically juxtaposed against Northern MORB-type Formation and Bird River Sill at north side of BRB.	Mostly subaqueous. Relatively tranquil conditions (e.g., thinly laminated chert and tuffaceous strata) alternated with turbidite environment and possibly subaerial, locally explosive volcanism with gravity-induced mass-flows. Conglomerate member may may mark the onset of rifting and subsequent turbidite deposition (Booster Lake Formation) - see notes below.
South panel: basalt-andesite >50%	Bernic Lake Formation	<u>Upper division</u>: Massive to fragmental rhyolite, basalt-andesite, heterolithic volcanic breccia. <u>Middle division</u>: Basalt-andesite, massive, mostly pillowed; rare spherulitic flows. Locally silificified at upper margin. Sporadic diabase and felsic intrusions. <u>Lower division</u>: Predominant dacite and rhyolite, massive and fragmental; sporadic narrow (<5 m) garnetiferous amphibolite, garnetite, oxide-facies iron formation.	Tholeiitic	Contact with overlying Booster Lake Formation and underlying Southern MORB-type rocks interpreted as faulted. <u>Upper division</u> fragmental volcanic rocks may be largely conformable with underlying <u>middle division</u> pillowed basalt flows, which locally display effects of (inferred) sea-floor alteration.	<u>Upper division</u> in part subaqueous (pillowed flows); volcanic fragmental rocks may include subaerial deposits. <u>Middle division</u> largely pillowed basalt (subaqueous) and devoid of epiclastic interlayers (beyond sources of terrigenous sediment). <u>Lower division</u> includes oxide-facies iron formation but environmental indicators are lacking in the predominant felsic volcanic rocks.
Stratigraphic model for north panel succession				Abbreviations	Notes
DAA rocks were deposited in restricted basins in the north part of the BRB; they overlie the lower and central PCF, but may be partly contemporaneous with the upper part of the PCF—apparently confined to the southwestern BRB—that is characterized by marine incursions (turbidite and minor iron formation) within the PCF felsic volcanic succession. Rifting may have resulted in 1) fault scarps, associated with talus deposits, at the south margin of the PCF—close to the (inferred) locally conformable contact between the PCF and younger BLF; and 2) conglomerate deposition in an ephemeral, littoral or fluvial environment prior to onset of turbidite deposition. Local stratigraphic analysis and the youngest detrital zircon dates from the DAA and BLF (2706 ±23, 2712 ±17 Ma respectively, Gilbert et al., 2008) are consistent with this model.				Abbreviations: BRB Bird River Belt; PCF Peterson Creek Formation; DAA Diverse Arc assemblage; BLF Booster Lake Formation; MORB mid-ocean-ridge basalt.	Late sanukitoid rocks are found 1) as intrusions in all the volcanic formations within the north panel of the BRB, 2) as DAA conglomerate clasts, and 3) as dikes in the Booster Lake Formation, indicating the youngest DAA volcanic and sedimentary rocks are penecontemporaneous with the Booster Lake turbidite deposits.

in the west- to northwest-trending English River Subprovince, which lies between the Bird River Subprovince and the Uchi Subprovince to the northeast (Figure 1, 2 and 3; Hrabi and Cruden, 2006). Subduction-related volcanic activity and orogenic sedimentation came to an end due to collision of the Uchi continental-margin succession with the Winnipeg River Subprovince, which followed 2.72–2.71 Ga convergence of the North Caribou and Winnipeg River cratonic blocks (Lemkow et al., 2006). The tectonic collision was associated with regional deformation, metamorphism and granitoid plutonism.

DAY 1: GEOLOGY AND LAYERING OF THE CHROMITIFEROUS ZONE OF THE BIRD RIVER SILL (CHROME PROPERTY), BIRD RIVER GREENSTONE BELT

by James S. Scoates and R.F. Jon Scoates

Introduction

Day one of the field trip is devoted to examining and comparing layered chromitites and peridotites from the Ultramafic Series of the Bird River Sill on the Chrome property (Figure 5). The primary goals are to demonstrate (1) the lateral continuity of individual chromitite horizons, despite persistent small-scale offsets due to faults on a scale of metres to tens of metres, and (2) the vertical change in style of mineralization and relative thickness of different chromitite groups, and (3) the remarkable internal structure of the chromitites (e.g., layered, disrupted, synmagmatic folds and faults). Until the recent discovery of chromite and Ni-Cu-(PGE) deposits in the 2.73 Ga Ring of Fire intrusions of the McFaulds Lake greenstone belt in northern Ontario (Balch et al., 2010; Mungall et al., 2010; Metsaranta and Houlé, 2011, 2012), the Bird River Sill contained Canada's known resource of layered intrusion-hosted chrome (Bannatyne and Trueman, 1982; Watson, 1985; Perron, 1995). However, unlike McFaulds Lake, where outcrop is scarce and geologic relations are based primarily on drillcore examination and correlation, the Bird River Sill, especially on the Chrome property, is exceptionally well exposed.

The field relationships that will be examined on this field excursion are largely an outgrowth of mapping of the Bird River Sill on the Chrome property in the 1980's. As part of the Ultramafic Rocks Project of the Manitoba Geological Survey (MGS), Scoates (1983) recognized and documented the internal stratigraphy of the Chromitiferous Zone. Systematic mapping of the entire intrusion by the Geological Survey of Canada

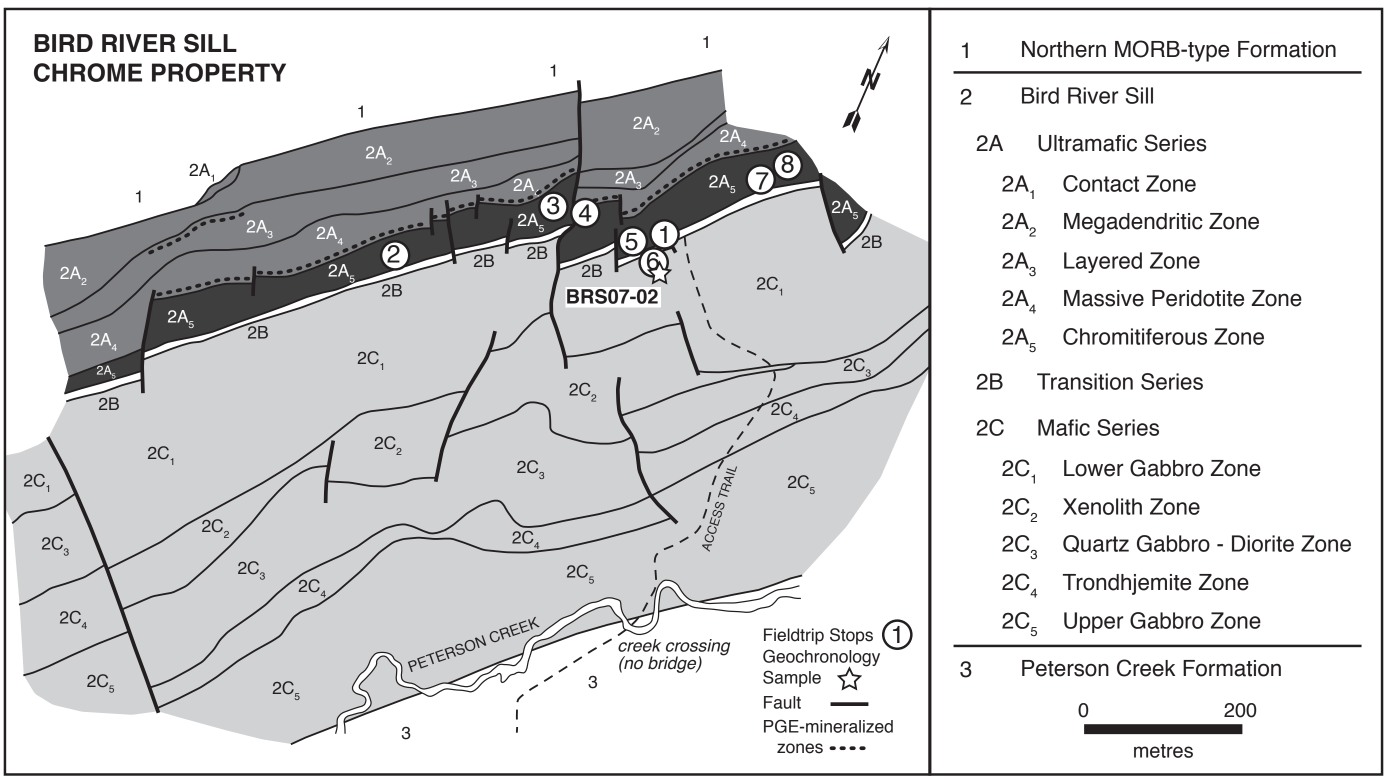


Figure 5: *Simplified geology of the Bird River Sill at the Chrome property (modified from Hulbert et al., 1988). Stop locations 1.1 to 1.8 are indicated by circled numbers in which the precursor '1'—used elsewhere to identify stops as part of 'Day 1'—has been omitted (this applies to embedded stop numbers in all subsequent figures for Day 1). The sample location with geochronological information is identified as BRS07-02 from Scoates and Scoates (2013). From base to top, the sill consists of a lower Ultramafic Series (2A), including the chromitite groups of the Chromitiferous Zone ($2A_5$), a thin Transition Series (2B), and an upper Mafic Series (2C). The basal contact with pillow basalt of the Northern MORB-type Formation is intrusive, whereas the upper contact with the Peterson Creek Formation is an unconformity. The Chrome property is accessed by crossing Peterson Creek (no bridge as of this writing) and walking along a partially overgrown access road to the first outcrops at the top of the Chromitiferous Zone (Stop 1.1).*

in the summers of 1984–1988, with a focus on the Ultramafic Series, followed. These results were compiled and summarized in Williamson (1990), a contribution to the 1984–89 Canada-Manitoba Mineral Development Agreement.

Some of the text in the background information below is based on—or modified from—previously published material. These include (1) Scoates and Scoates (2013) for the geological setting and age of rocks of the Bird River Sill, (2) the igneous stratigraphy outlined in Scoates et al. (1986) from the field guide to the Bird River Sill produced as part of a post-meeting field trip (May 21–24, 1986) following the GAC-MAC Annual Meeting in Ottawa, Ontario, itself based on the original descriptions of the Ultramafic Zone by Scoates (1983), and (3) the descriptions of Williamson (1990) accompanying the open file maps of the Chromitiferous Zone on the Chrome property that were incorporated into the section on igneous stratigraphy.

Note on use of Williamson (1990) maps in field guide

The comprehensive geological descriptions of the Bird River Sill on the Chrome property by Williamson (1990) are accompanied by 6 sheets showing the mapping results in different parts of the property and at different scales, and one poster containing stratigraphic columns of the different chromitite groups along the exposed strike length of the Chromitiferous Zone in the area. The sheets are available in print format or as downloadable pdf or jpeg files from National Resources Canada GEOSCAN that were scanned from printed copies that had been folded and aged (e.g., yellowed). They represent an extraordinary resource and we have extracted and incorporated parts of these maps from the scanned versions as figures in this field guide. As a result, black lines, text, and shading may be slightly too faint or too dark in some areas of the figures, but overall they show the key relationships required for the field trip.

Geological setting of the Bird River Sill on the Chrome property

The Bird River Sill intruded the oldest Bird River Belt unit, the Northern MORB-type Formation (formerly the Lamprey Falls Formation; Figure 5), which consists of pillowed to massive basaltic flows and intercalated gabbro, tuff and iron formation (Gilbert et al., 2008). The sill is exposed over a strike length of 20 km and the thickness of exposed magmatic stratigraphy rarely exceeds 600 m. As there is evidence that the sill has been unroofed on the Chrome property and is unconformably overlain by the Peterson Creek Formation, 600 m is considered a minimum thickness (Scoates et al., 1986; Mealin, 2006). Detailed mapping on the Chrome property (Figure 5, 6) has determined that the sill consists of a lower Ultramafic Series (~200 m thick), which in turn has been subdivided into five zones, a Transition Series (~20 m thick), and an upper Mafic Series (~500 m thick). The Mafic Series has been further subdivided into five zones, mostly plagioclase-rich with hornblende as the dominant ferromagnesian silicate, but also including a distinctive medium-grained, hornblende-bearing dioritic rock (Trondhjemite Zone). Stratiform chromitites are restricted to the Chromitiferous Zone, an interval of diffuse to dense chromitite layers (5–30 and 30–60 volume percent chromite, respectively) that occupies the upper 60 m of the Ultramafic Series (Trueman, 1971; Scoates, 1983; Williamson, 1990; Figure 6). Mealin (2006) has proposed that the segmented properties of the Bird River Sill (Page, Chrome, Wards, etc.) are separate intrusions, possibly fed from the same magma chamber, which were deformed and faulted by late east-trending fault zones, rather than being block-faulted segments of a formerly continuous sill.

Chromite deposits in the Bird River Sill were first discovered during the summer of 1942 on both the Chrome property (July 10, 1942) and Page property (July 7, 1942) (Brownell, 1942; Bateman, 1943). Trenching and bulk sampling of what is now recognized as the Upper Main Group chromitite were carried out immediately after this discovery (Figure 7). The chrome resource on the Chrome property is estimated at 7 million tonnes grading 6.9% Cr_2O_3 (Perron, 1995). Metallurgical tests done on a Chrome property bulk sample (CANMET Trench: dense member of the Lower Main chromitite to the top of the Upper Main chromitite; see below for detailed descriptions of chromitite groups) using heavy media separation produced a concentrate grading 30% Cr_2O_3 with a Cr:Fe ratio of 0.84:1.00; pre-concentration by electronic ore sorting yielded a concentrate with 30.5% Cr_2O_3 based on 64% recovery of chromite (Andrews and Jackman, 1988). For the Chrome property, Watson (1985) determined that the interval from the base of the Lower Main Group chromitites to the top of the Upper Main Group chromitites, for a strike length of 640 m, contained (measured and indicated) 20,405,385 tonnes of ore with 930,485 tonnes of Cr_2O_3 or 636,648 tonnes of chromium. Watson (1985) also performed similar resource calculations for the Page, Bird Lake and Euclid properties.

The presence of anomalous platinum group elements (PGE) contents (Pt+Pd+Au >100 ppb; Scoates et al., 1988) in the Bird River Sill was first recognized in the 1980's (Theyer, 1985; Scoates et al., 1986). The Bird River Sill contains at least four different PGE-bearing layers in the Ultramafic Series (Peck et al., 2002). However, the PGE concentration at the base of the Chromitiferous Zone (Scoates et al., 1988; Figure 6b) is the only one that appears to contain economically interesting PGE concentrations (Peck et al., 2002). Platinum group minerals associated with the chromitites are found as inclusions within both chromite and interstitial silicates and are mainly laurite, $(Ru,Os,Ir)S_2$, and rutheniridosmine, (Os,Ir,Ru alloy), except for the PGE-bearing layer at the base of the Chromitiferous Zone where both sperrylite ($PtAs_2$), and laurite, plus other less common PGM, are mainly included in silicates and sulphides (Talkington et al., 1983; Ohnenstetter et al., 1986; Cabri and LaFlamme, 1988).

The Chrome property affords the best exposure of the entire stratigraphy of the Bird River Sill at its thickest point (Figure 5) and consequently the most detailed work on the chromitite-bearing interval has been carried out there. Mapping of the Chromitiferous Zone on the Chrome property has demonstrated the remarkable stratigraphic consistency and continuity of the chromitite layers, even to mm-scale details along 800 m of strike length, despite extensive faulting (Figure 8). The magmatic stratigraphy identified on the Chrome

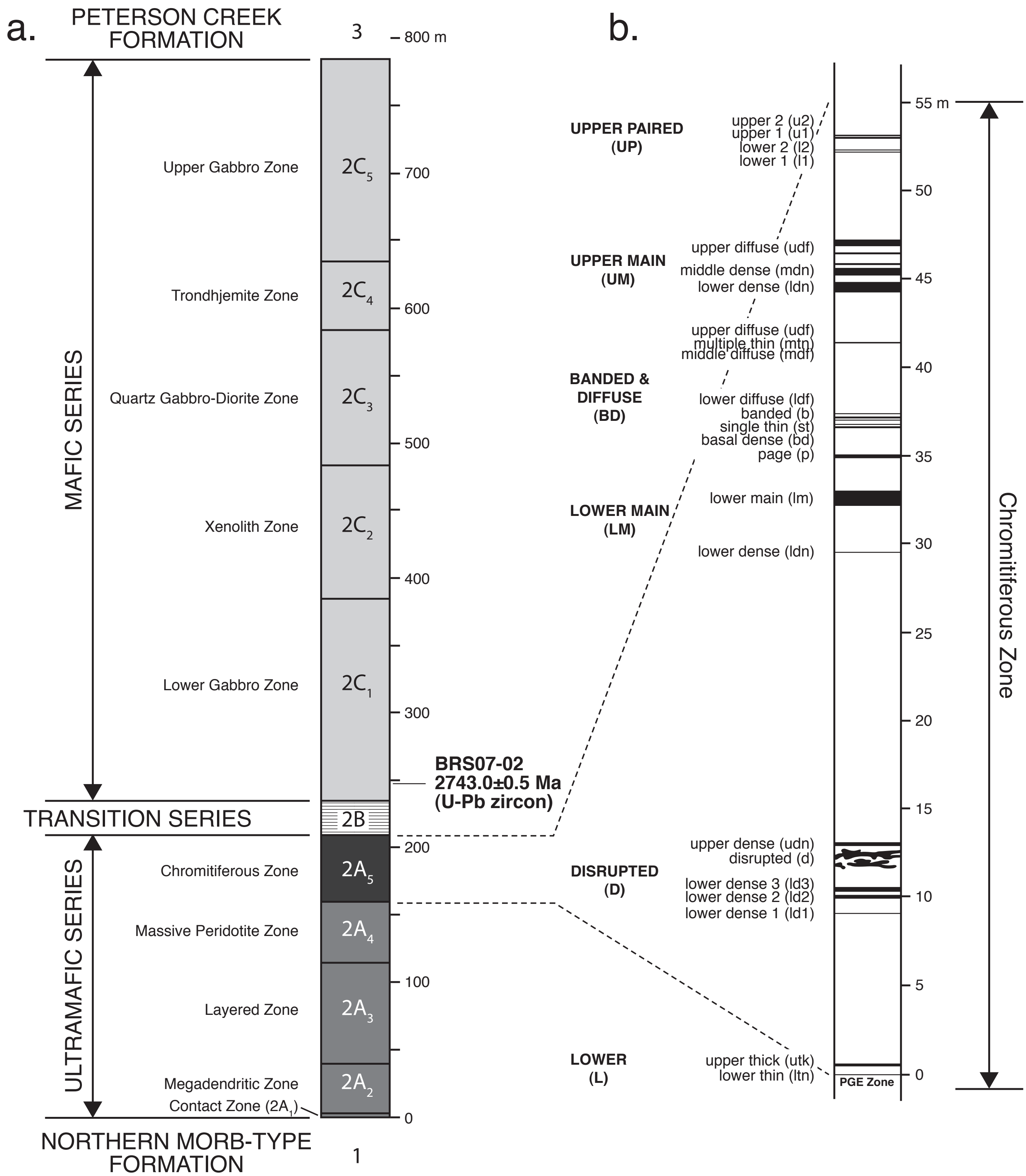


__Figure 6:__ Stratigraphy of the Bird River Sill at the Chrome property: __a)__ Stratigraphy of the Bird River Sill (modified from Williamson, 1990), showing the series/zone subdivision of the intrusion and the location of geochronological sample (BRS07-02) reported in Scoates and Scoates (2013); __b)__ Stratigraphy of the Chromitiferous Zone, showing the positions of the six main chromitiferous horizons or groups: Lower (L), Disrupted (D), Lower Main (LM), Banded & Diffuse (BD), Upper Main (UM), and Upper Paired (UP) (modified from Williamson, 1990). Individual layers or packages within the chromitiferous horizons are indicated, together with abbreviations that are also used on the detailed maps for the individual field trip stops. The field trip is designed to allow for examination of each of these horizons and their constituent layers.

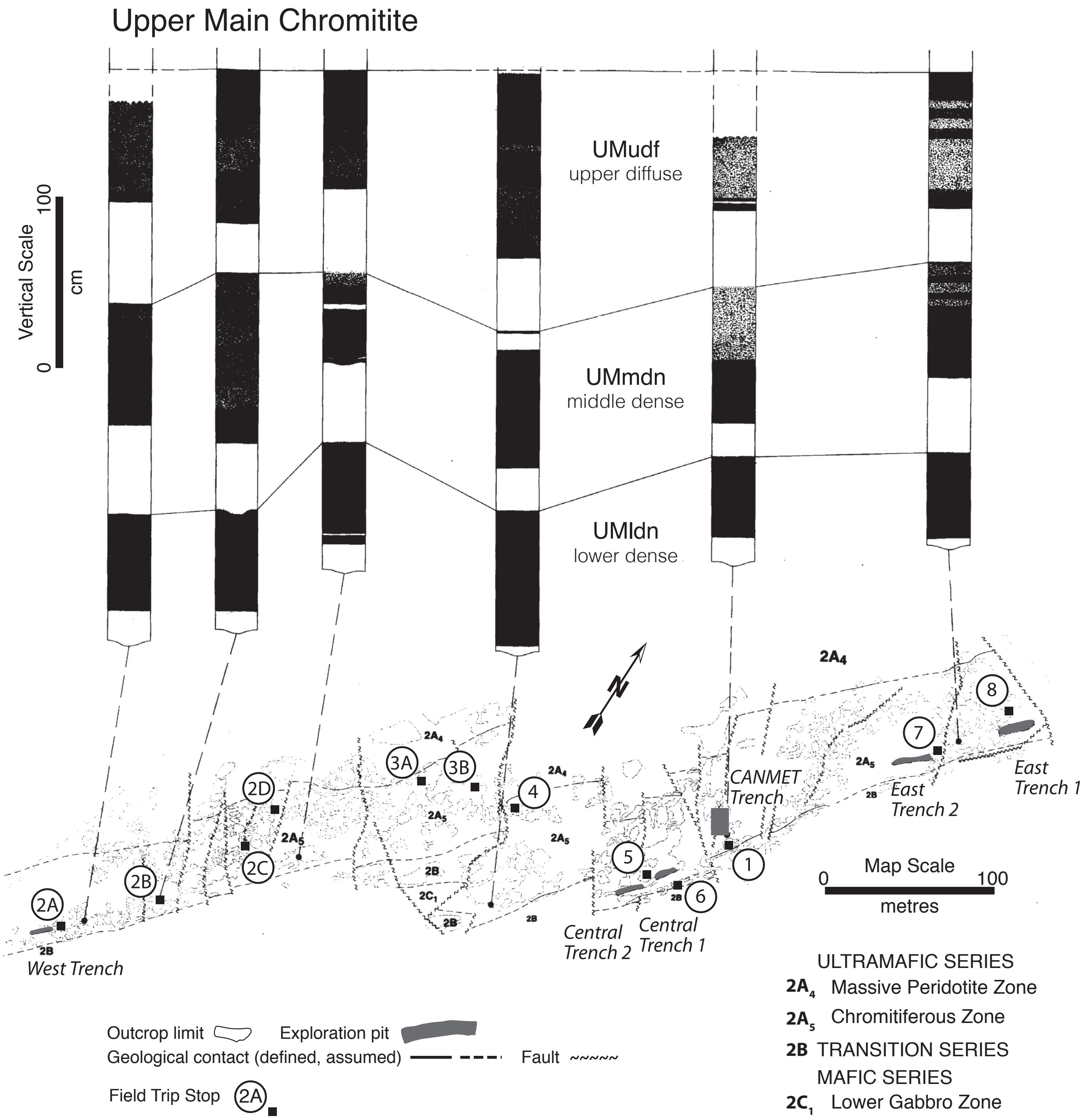


***Figure 7:** Selected stratigraphic columns through the Upper Main Group chromitites (extracted and modified from Williamson, 1990 [Williamson's Figure 25]). The datum is arbitrarily selected at the top of UMudf. Within each section, white represents peridotite, black represents dense chromitite, and stippling represents diffuse chromitite. The map below shows the locations of the sections, the exploration pits (East Trench 1, East Trench 2, CANMET Trench, Central Trench 1, Central Trench 2, West Trench), and the field trip stops. Abbreviations: UMudf = Upper Main upper diffuse, UMmdn = Upper Main middle dense, UMldn = Upper Main lower dense.*

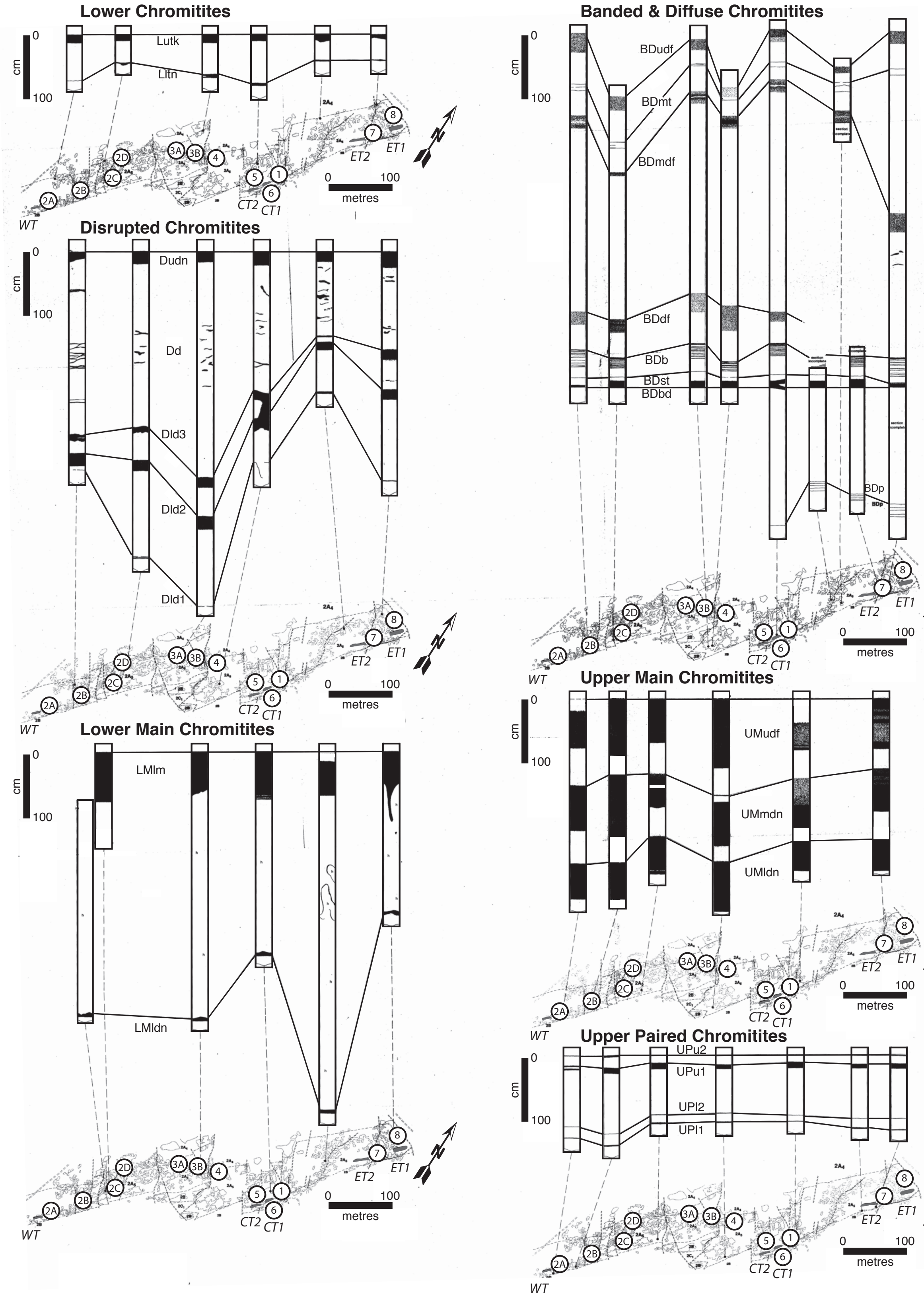


Figure 8: *Selected stratigraphic columns through all six major chromitite groups (extracted and modified from Williamson, 1990 [Williamson's Figure 8, 10, 16, 19, 25, 29]). For each chromitite group, the datum is arbitrarily selected at the top of the uppermost chromitite horizon, except for the Banded & Diffuse Group where the datum is the base of the lowermost continuous chromitite (BDbd). Within each section, white represents peridotite, black represents dense chromitite, and stippling represents diffuse chromitite. The maps below show the locations of the sections, the exploration pits (ET1 = East Trench 1, ET2 = East Trench 2, CT1 = Central Trench 1, CT2 = Central Trench 2, WT = West Trench; the CANMET Trench is covered by the circled number 1—Stop 1.1), and the field trip stops for reference. Note the difference between the horizontal and vertical scales. For abbreviations of the different chromitite horizons, see Figure 6b.*

property (Scoates, 1983; Williamson, 1990) also occurs on the Page property (2 km to the northeast; Young, 1992), and according to Juhas (1973) there is evidence from diamond drilling of a chromitite-bearing zone southwest of the Dumbarton mine (~3 km southeast of the Page property). Six main intervals of chromitite concentration have been noted in the Chromitiferous Zone on the Chrome property (Scoates, 1983; Williamson, 1990) and include, from base to top, the Lower, Disrupted, Lower Main, Banded & Diffuse, Upper Main, and Upper Paired groups (Figure 6, 8). Minor chromitite occurrences (disrupted chromitite, rounded, pebble-sized chromitite inclusions) have been noted throughout the Ultramafic Series both on the Chrome and Page properties (Scoates, 1983; Young, 1992; Theyer et al., 2001; Mealin, 2006).

Age of the Bird River Sill

The Bird River Sill on the Chrome property has been the focus of several U-Pb geochronological studies. Timmins (1985) and Timmins et al. (1985) reported an unpublished U-Pb TIMS zircon age for an anorthositic gabbro from the Gabbro Zone of 2745 ±6 Ma, and Wang (1993) reported an unpublished U-Pb zircon age for a gabbro, likely from the Transition Series, of 2745 ±5 Ma (both are upper intercept 207Pb/206Pb ages for discordant results from multi-grain fractions). Recently, Scoates and Scoates (2013) have provided a precise crystallization age for the Bird River Sill for a sample of coarse-grained leucogabbro from the Lower Gabbro Zone of 2743.0 ±0.5 Ma, which is a weighted mean 207Pb/206Pb age from the analysis of eight single grains of zircon (concordant U-Pb results) that were pretreated using the annealing and chemical abrasion technique. This age represents the timing of crystallization of the lowermost part of the Mafic Series and is thus a minimum age for the underlying Ultramafic Series.

Rock classification and metamorphism

The Bird River Belt underwent at least three deformation events and the metamorphic grade in the central and northern parts attained amphibolite facies (~550°C and 3–5 kb; Gilbert et al., 2008). All rocks are metamorphosed and altered to some extent, however, primary textures are preserved and thus these meta-igneous rocks are referred to using their inferred igneous mineralogy and rock classification. Dunites contain olivine (>90 modal %) + chromite (1–5 modal %) and are recognized by their pale green, smooth-weathering surface where olivine has been replaced by talc-carbonate-serpentine. Peridotite (60–90% olivine, 1–5% chromite, 10–40% interstitial pyroxene) is knobbly weathering with abundant interstitial patches or oikocrysts, now consisting of hornblende replacing original clinopyroxene. Chromitites are described as either dense or diffuse, depending on the relative amount of chromite present. Dense chromitites contain >30% chromite—typically greater than 50%—with few recognizable former olivines, in a matrix of chlorite ± tremolite ± grossular, representing original interstitial material. In contrast, diffuse chromitites contain approximately subequal amounts of chromite (~30%) and olivine (~30%), now talc-carbonate-serpentine, with ~40% interstitial material (same mineralogy as for the dense chromitites). In outcrop, a continuum between peridotite with disseminated chromite, diffuse chromitite, and dense chromitite can be observed. Finally, gabbroic rocks contain plagioclase as equant to lath-shaped crystals with incipient alteration to saussurite, pale green hornblende after original large (cm-scale) interstitial clinopyroxene, and patches of interstitial titanite after ilmenite/titanomagnetite.

Igneous stratigraphy on the Chrome property

Ultramafic Series (2A)

Contact Zone (unit $2A_1$)

The lowermost unit in the Ultramafic Series is the 2–5 m thick Contact Zone ($2A_1$, Figure 5, 6a). Where observed, the rock at the contact is intensely altered, is generally basaltic in composition, and grades upward to picrite. The chilled zone at the contact is typically 10 cm thick. Although the primary mineralogy has been replaced, primary textures are visible on the weathered outcrop surface. From this, it appears that olivine crystals were present and that the grain size of olivine increases upward through the zone from 0.5 mm at the base to 1 mm at the top. The contact with the overlying Megadendritic Peridotite Zone ($2A_2$) is gradational.

Megadendritic Peridotite Zone (unit $2A_2$)

The Megadendritic Peridotite Zone is a 30–50 m thick unit (Figure 5, 6a) that is made up largely of rough-weathering, megadendritic peridotite with domains of normal equigranular peridotite. “Megadendritic” refers to a remarkable texture that consists of radiating bundles of hornblende (after pyroxene) ranging from several to tens of centimetres in length. Megadendritic peridotite occurs in patches within smooth and knobby-weathering peridotite. The upper contact with the Layered Zone ($2A_3$) is sharp.

Layered Zone (unit $2A_3$)

The Layered Zone is 30–60 m thick (Figure 5, 6a). The lower 5–15 m, the Basal subzone of Williamson (1990), is composed of indistinctly interlayered peridotite and dunite. A 1 cm thick, wispy discontinuous chromitite layer and sporadic pods of chromite (up to 20 x 200 cm) are present. The overlying Layered subzone is 20–35 m thick, consisting of alternating decimetre-scale layers of rough-weathering, oikocryst-rich peridotite and smooth-weathering dunite. Modal and grain-size grading are observed in several peridotite layers. The uppermost Gabbro subzone is 15 m thick and is only observed in the westernmost part of the intrusion.

Massive Peridotite Zone (unit $2A_4$)

The 40–50 m thick Massive Peridotite Zone (Figure 5, 6a) is made up mainly of fine-grained olivine-chromite cumulates. It shows a similar range in the abundance of interstitial clinopyroxene (now hornblende) as the Layered Peridotite Zone ($2A_3$), but for the most part lacks readily discernable layering. Discontinuous wispy chromitite layers and pods 1–2 cm thick occur throughout the zone. Commonly, the upper 1–3 m of the zone, just beneath the Chromitiferous Zone ($2A_5$), is characterized by coarse-grained to pegmatitic peridotite with skeletal olivine and disseminated sulphides containing elevated concentrations of PGE (see Lower Group below for additional description).

Chromitiferous Zone (unit $2A_5$)

The Chromitiferous Zone is about 60 m thick and is made up of alternating layers of peridotite and chromitite (Figure 5, 6). Six groups of chromitite layers were defined by Scoates (1983; Figure 6b, 8). Each group possesses distinctive stratigraphic features and is laterally continuous (Figure 8). The characteristics of each of these groups are described below.

Lower Group (unit L)

This group typically includes two chromitite layers: a lower diffuse to dense chromitite (Ltn in Figure 6b; 1–5 cm thick) and an upper dense chromitite (Lutk; 7–15 cm thick) separated by a 30–70 cm thick peridotite layer (Figure 6b, 8). The upper chromitite layer locally bifurcates into two layers 5–15 cm apart. The chromitite layers are characterized by a gently folded character, numerous peridotite inclusions, and local disruption. Anomalous concentrations of PGE occur in the Lower Group PGE-bearing unit (PGE Zone in Figure 6b), a mineralized horizon up to 3 m thick with disseminated sulphides that is laterally continuous across the Chrome property (Scoates et al., 1988). The Lower Group is separated from the overlying Disrupted Group (D) by 5–7 m of medium- to fine-grained peridotite.

Disrupted Group (unit D)

This group includes two to four continuous dense chromitite layers and one or more disrupted chromitite layers that occur over a stratigraphic interval of 3 to 6 m (Figure 6b, 8). The lowermost chromitite layer (Dld1), which is not present everywhere, is 1–2 cm thick and is overlain by a 1–2 m thick peridotite layer. This is overlain in turn by a dense chromitite layer 25 cm thick (Dld2) that is characterized by numerous peridotite inclusions. A second inclusion-rich, dense chromitite 20–25 cm thick (Dld3) occurs in some localities, separated from the underlying chromitite by about 50 cm of peridotite. Overlying the dense chromitite is a 3–6 m thick, disrupted interval (Dd), consisting of peridotite with discontinuous, irregular-shaped segments of chromitite. The chromitite displays "drop-and-sag" and other structures suggesting that the segments represent layers that were disrupted by soft-sediment–like deformation. The peridotite within this disrupted interval consists of olivine-chromite cumulate with sporadic skeletal olivine and pegmatitic patches. The sequence is capped by a 20–25 cm thick dense chromitite member (Dudn) that commonly contains elongate silicate inclusions.

Lower Main Group (unit LM)

This group is separated from the underlying Disrupted Group by 15–20 m of medium-grained poikilitic peridotite (Figure 6b, 8). The base of the Lower Main Group is marked by a 4–15 cm thick, dense chromitite layer (LMldn). The upper and lower surfaces of the layer commonly have a scalloped structure suggestive of load casts. The lower dense member is overlain by a 2–5 m thick peridotite layer that is highly variable in character. In some places, it consists predominantly of coarse skeletal olivine (>1 cm in length), whereas in others it consists of patches of fine-grained peridotite, coarse pegmatitic pyroxene, and discontinuous or disrupted chromitite layers from a few mm to several cm thick. The overlying lower main chromitite layer (LMlm) in the group is the thickest individual chromitite layer in the Chromitiferous Zone. The lowermost 5–10 cm of this member contains layers of diffuse chromitite and the balance of the member is a dense chromite cumulate with intervals of grain-size layering. The Lower Main Group is overlain by a 3–7 m thick layer of medium-grained poikilitic peridotite.

Banded & Diffuse Group (unit BD)

This group includes as many as 20 individual chromitite layers over a stratigraphic interval of about 7 m (Figure 6b, 8). The lowermost chromitite unit is the Page member (BDp), which takes its name from a broadly similar horizon on the Page property to the east (Young, 1992). On the Chrome property, it consists of 4 or 5 thin diffuse chromitites (each ~1 mm thick)—within an interval of 10–20 cm—that are present in the eastern 450 m of strike length. Above this, the next member of the group (BDbd) is a dense chromitite layer that ranges from 5 to 15 cm in thickness. The most readily identified interval of the Banded & Diffuse Group is that containing the basal dense (bd), single thin (st, 5 mm thick), and banded (b) members (Williamson, 1990). This three-part banded interval is readily identified even where incompletely exposed. The 20–25 cm thick banded member comprises alternating layers of peridotite and chromitite that individually range from 2 mm to 2 cm thick. A 40–60 cm thick layer of medium-grained poikilitic peridotite occurs above the banded member. A 5 mm dense chromitite layer occurs about 10 cm above the base of this poikilitic layer in some outcrops. The 20–30 cm thick lower diffuse member (BDldf) contains three diffuse chromitite layers separated by medium-grained peridotite layers. The lower diffuse member is overlain by 2.5–3.0 m of medium- to coarse-grained poikilitic peridotite. An 8 cm thick layer distinguished by abundant clinopyroxene oikocrysts (now hornblende) occurs within this peridotite. The middle diffuse chromitite member (BDmdf) is 20–25 cm thick and comprises two diffuse chromitite layers separated by a 2 cm peridotite layer. The middle diffuse layer is overlain by 70 cm of medium-grained poikilitic peridotite that contains from 2 to 5 dense chromitite layers. The upper diffuse chromitite member (BDudf) is 10–25 cm thick and is characterized by numerous peridotite inclusions.

Upper Main Group (unit UM)

This group is separated from the underlying Banded & Diffuse Group by 2–3 m of medium-grained poikilitic peridotite that is characterized by 2–4 cm oikocrysts that produce a distinctive mottled appearance on the outcrop. The Upper Main Group is consistently 2.4–2.7 m thick and is made up of three chromitite members (Figure 6b, 7, 8). The lowermost member (UMldn) is a 50–60 cm thick dense chromitite. This is overlain by a 30–42 cm thick poikilitic peridotite member that contains some wispy chromitite layers in its upper part. The middle chromitite member (UMmdn) is 50–60 cm thick and grades from dense chromitite at the base to diffuse chromitite in the upper 20 cm. The middle chromitite is overlain by a 50–55 cm peridotite member that contains some diffuse chromitite layers. This upper chromitite member (UMudf) is 50–65 cm thick and has dense chromitite in the lower 5–10 cm, and diffuse chromitite above.

Upper Paired Group (unit UP)

This group occurs 4–5 m above the Upper Main Group and is separated from it by a layer of poikilitic peridotite (Figure 6b, 8). The group comprises two pairs of dense chromitite layers. The lower pair (UPl1, l2) consists of a 1–2 cm chromitite layer separated from an overlying 5–10 cm chromitite layer by 15–20 cm of peridotite. A 75–85 cm peridotite layer separates the lower pair from the upper pair (UPu1, u2), which comprises a 8–10 cm lower chromitite layer and an upper 2 cm layer, separated by 10–20 cm of medium-grained peridotite. The Upper Paired Group is overlain by 2–4 m of medium-grained poikilitic peridotite that is in sharp, faulted contact with rocks of the overlying Transition Series (2B).

Transition Series (unit 2B)

The thin Transition Series, typically 6–10 m thick, consists of a Lower Peridotite Zone, a Gabbro Zone, and an Upper Peridotite Zone ($2B_1$ to $2B_3$, respectively), with original igneous contacts between them (Figure 5, 6a). Numerous strike-parallel faults are present and stratigraphic repetitions occur (Williamson 1990).

Mafic Series (unit 2C)

The Mafic Series, 450–550 m thick, has been subdivided into five zones (in upward stratigraphic succession): Lower Gabbro, Xenolith, Quartz Gabbro/Diorite, Trondhjemite, and Upper Gabbro zones (units $2C_1$–$2C_5$, Figure 5, 6a). See Williamson (1990) for additional details on the Mafic Series.

Chromite petrography and chemistry

Brief summaries of the petrography and mineral compositions of chromite from the Chromitiferous Zone ($2A_5$) may be found in Ohnenstetter et al. (1986) and in Scoates and Scoates (2013). Chromite is typically euhedral with subrounded corners, varies in size from 0.1–0.7 mm in diameter, and reaches a maximum of about 70 modal % in the densest chromitites (Figure 9a, 9b). Silicate inclusions with circular outlines are common and found in 5–10% of the chromite crystals in a given thin section (Ohnenstetter et al., 1986; Figure 9c). These inclusions are interpreted to represent crystallized melt inclusions. All chromite grains have an outer thin rim or irregular margin of "ferritchromite" or magnetite (Figure 9c).

There is significant compositional and textural variation of chromite among the six chromitiferous groups within unit $2A_5$ (Ohnenstetter et al., 1986; Scoates et al., 1986). The chromite grains are inhomogeneous in composition (e.g., $Mg/(Mg+Fe^{2+})$ vs. $Cr/(Cr+Al)$; Figure 9d) and the compositional variation may be resolved into a primary magmatic trend and a secondary metamorphic trend (Scoates et al., 1986; Scoates et al., 1989; also noted in Ohnenstetter et al., 1986). The magmatic trend, strongly decreasing $Mg/(Mg+Fe^{2+})$ with increasing $Cr/(Cr+Al)$, is attributed to reaction of cumulus chromite either with interstitial melt or with silicate minerals during subsolidus cooling. The metamorphic trend, strongly increasing $Cr/(Cr+Al)$ with weakly decreasing $Mg/(Mg+Fe^{2+})$, reflects the development of the secondary "ferritchromite" or magnetite rims during serpentinization and regional metamorphism. The compositional range in any given sample generally spans the range defined by all the samples of the same type (i.e., chromite cumulate, chromite-olivine cumulate, or olivine-chromite cumulate) in the particular group (Figure 9d). There is little difference in compositional trend among the six groups of the Chromitiferous Zone. The exception is the trend for the Upper Paired Group (unit UP in Figure 6b), which does not extend to the relatively high $Mg/(Mg+Fe^{2+})$ ratios of the others. The observation that there is little difference in the composition of chromite cores throughout most of the Chromitiferous Zone is consistent with multiple replenishment events of new magma during formation of the main chromitite horizons.

Road log (Day 1)

0.0 km—Intersection of Tall Timber Road with Provincial Road 315 (PR 315), across from airstrip

4.9 km—Bridge over the Bird River

14.3 km—Continue on PR 315, past the turn-off (right) to Tanco mine (road to Bernic Lake)

16.8 km—Turn left at north side of PR 315 (Lat. N50°27.086, Long. W095°33.381; UTM 5591948N, 318526E in Zone 15U, NAD83; all co-ordinates quoted in this field guide are based on this datum). Proceed for 144 m along an unmarked and unmaintained access track to a parking area in woods on southwest side of the track, where it veers to the northeast (Lat. N50°27.149, Long. W095°33.451; UTM 5592068N, 318447E).

Stop descriptions

Outcrops at the time of the principal field activity (1983–1988) that ultimately resulted in the open file maps of Williamson (1990) were of very high quality (i.e., no lichen or moss) due to the effects of an intense forest fire in the mid- to late-1970's. Geologists from the MGS and the Geological Survey of Canada took advantage of this exceptional opportunity to describe, map, and sample rocks of the Bird River Sill on the Chrome property with a focus on the Ultramafic Series. The Williamson (1990) maps include four 1:200 scale detailed map sheets of the Chromitiferous Zone, a 1:500 scale detailed map of part of the lower Ultramafic Series to the west, and a 1:2000 scale geological map of the property. Mapping carried out for the 1:200 scale detailed sheets was at a 1:10 scale, thus allowing for correlation of all chromitites, even down to the millimetre scale (e.g., the single thin member of the Banded & Diffuse Group, BDst), along strike for 800 m. Figures 10, 12, 13, 14, 15, 16, 17, 19 and 20 show extracts of the Williamson (1990) 1:200 scale maps for each of the stops described below. In addition, select photographs taken in the summers of 1983, 1984, and 1986 are included (Figure 11, 18 and 21) and allow

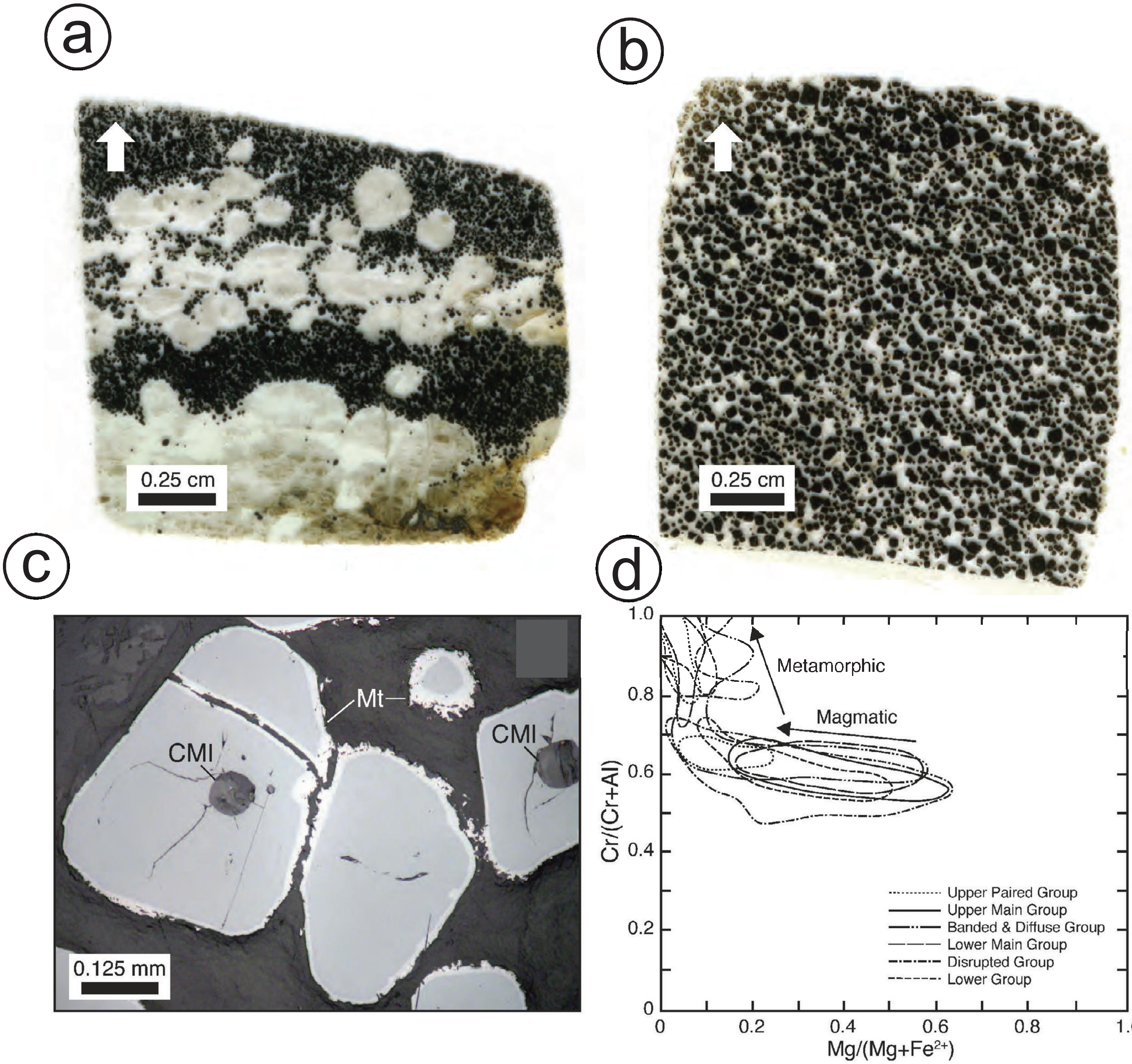


Figure 9: *Chromite textures and compositions from the Bird River Sill:* ***a)*** *Scan in transmitted light of a complete thin section across the base of the lower main member of the Lower Main Group chromitite (LMlm) showing euhedral chromite crystals (black) draped over olivine (now serpentine-talc) of the underlying peridotite, and interspersed with olivine in the lower few mm. Oriented with top pointing towards stratigraphic younging direction (see arrow); sample SEB84-15-3 (S1);* ***b)*** *Scan in transmitted light of a complete thin section in the lower part of the lower main member of the Lower Main Group chromitite (LMlm), showing a typical dense texture with euhedral chromite (black) enveloped by interstitial material (formerly pyroxene and plagioclase, now clinochlore, tremolite, and grossular). Oriented with top pointing towards stratigraphic younging direction (see arrow); sample SEB84-15-3 (S9);* ***c)*** *Photomicrograph at high magnification showing the presence of rounded crystallized melt inclusions (CMI) within euhedral chromite grains (grey) and secondary ferritchromit-magnetite (white) along the rims and fractures of chromite grains; sample BRS07-03, Upper Main Group chromitite;* ***d)*** *Plot of $Mg/(Mg+Fe^{2+})$ vs. Cr/(Cr+Al), showing the compositional variation of chromite analyzed from the six major chromitite groups on the Chrome property (adapted from Scoates et al., 1986). The fields encompass a total of about 900 microprobe analyses. Two main trends are observed: 1) a primary magmatic trend attributed to reaction of cumulus chromite either with interstitial melt or with silicate minerals during subsolidus cooling, and 2) a secondary metamorphic trend reflecting the development of "ferritchromit" to magnetite rims during regional metamorphism.*

participants to fully appreciate the outcrop exposures at the time of mapping compared to today.

There are no formally recognized names for the different trenches (exploration pits) on the Chrome property. The trenches are useful for location purposes and have been named here based on relative location (East Trench 1, East Trench 2, Central Trench 1, Central Trench 2, West Trench) or reason for sampling (CANMET Trench).

Stop 1.1: CANMET Bulk Sample Trench at end of trail from Peterson Creek

Figure 10. Location: Sheet 2 of Williamson (1990); Lat. N50°27.494, Long. W095°33.447; UTM 5592705N, 318475E. Elevation: 306 metres above sea level (masl; elevation throughout the Chrome property itinerary ranges from 305 to 321 masl).

The 20 m long, 2 m wide, and 2 m deep trench—drilled, blasted and excavated in the winter (January) of 1986 by CANMET (Andrews and Jackman, 1988)—was designed to take a bulk sample from the base of the Lower Main Group chromitites to the top of the Upper Main Group chromitites, and to test for grade over that interval. The abundant blasted blocks found around the margins of the water-filled trench are representative samples of the rock types in this interval, ranging from serpentizined peridotite to diffuse and dense chromitite. The Upper Paired Group chromitites occur in outcrops to the south of the trench (Figure 10, 11a). The thicknesses of the individual layers and the intervals between them are remarkably consistent along the strike of the Chromitiferous Zone (unit $2A_5$, Figure 6a, 8). One of the interesting features to note on these outcrops is the local bifurcation of the lowermost chromitite layer of the Upper Paired Group. To the south of this stop, across the access trail from Peterson Creek, are several outcrops of the Transition Series (2B), including rocks of the Gabbro Zone ($2B_2$) and of the Upper Peridotite Zone ($2B_3$).

Stop 1.2: Stratigraphy of the Western Chromitiferous Zone

Location: Start at West Trench on Sheet 4 of Williamson (1990); Lat/Long: N50°27.384, W095°33.769; UTM 5592517N, 318086E.

Stop 1.2 is a series of four stops (A–D) that examine the stratigraphy of the Chromitiferous Zone in the interval from the Banded & Diffuse through the Upper Main to the Upper Paired groups (Figure 6b).

Stop 1.2A: West Trench and Uppermost Chromitiferous Zone

Figure 12. (50N, 375W grid location on Sheet 4 of Williamson, 1990).

The West Trench is one of five bulk exploration pits trenched in the Upper Main Group in 1942, immediately following discovery of chromite mineralization (Bateman, 1943). In this area, the interval from the base of the Banded & Diffuse through the Upper Main to the Upper Paired groups can be observed. At this stop, the Upper Main Group is remarkably continuous, with little evidence of offset by faults. The Upper Paired Group can be followed along strike for approximately 20 m on the southern part of these outcrops.

Stop 1.2B: Uppermost Chromitiferous Zone

Figure 13. (50N, 305W grid location on Sheet 4 of Williamson, 1990).

The stop exposes a section from the base of the Banded & Diffuse through the Upper Main to the Upper Paired groups. The Upper Main Group chromitites are uncharacteristically resistant, perhaps due to the relative lack of faulting in this area. The Page member of the Banded & Diffuse Group, which is found several metres below the basal dense member, occurs in the northwest part of this outcrop, and is the westernmost extension of this chromitite horizon on the Chrome property.

Stop 1.2C: Lower Main Group Chromitites

Figure 14. (65N, 255W grid location on Sheet 4 of Williamson, 1990).

At this stop, the irregular, disrupted nature of the lower contact of the upper dense member of the Lower Main Group chromitites (LMlm) is exposed. This irregular basal contact is found in other localities on the Chrome property, most notably in the area of Stop 1.8. The Page member of the Banded & Diffuse Group occurs ~2.5 m up-section from the top of LMlm.

Stop 1.2D: Disrupted Group Chromitites

Figure 14. (75N, 230W grid location on Sheet 4 of Williamson, 1990).

This stop is the first opportunity to observe the complex nature of the Disrupted Group on the field trip, including the bounding dense chromitites and the discontinuous chromitite lenses and pods in the upper part of the group. Note the offset of the chromitites along the prominent north-trending fault through this outcrop.

Stop 1.3: Lower and Disrupted Group Chromitites

Stop 1.3 contains well-exposed areas of the lowermost stratigraphic interval of the Chromitiferous Zone ($2A_5$) on the Chrome property, spanning the uppermost Massive Peridotite Zone ($2A_4$) through the Lower Group and Disrupted Group chromitites of Zone $2A_5$ (Figure 6a, b).

Stop 1.3A: Lower Group Chromitite and PGE Zone

Figure 15. Location: Sheet 3 of Williamson (1990); Lat/Long: N50°27.473, W095°33.638; UTM 5592675N, 318247E.

At this stop, the base of the Chromitiferous Zone is exposed and is marked by the Lower Group chromitites comprising two dense chromitite layers, each 2–7 cm thick (Figure 11b, 15). The lower thin member is disrupted in places and locally bifurcates into two or more layers separated by peridotite. Also present is the Lower Group PGE-bearing unit, a horizon of anomalous PGE mineralization that has been traced for 800 m along strike on the Chrome property (Scoates et al., 1988; Figure 5). The PGE-mineralized unit includes the Lower Group chromitites and extends downward (from several tens of

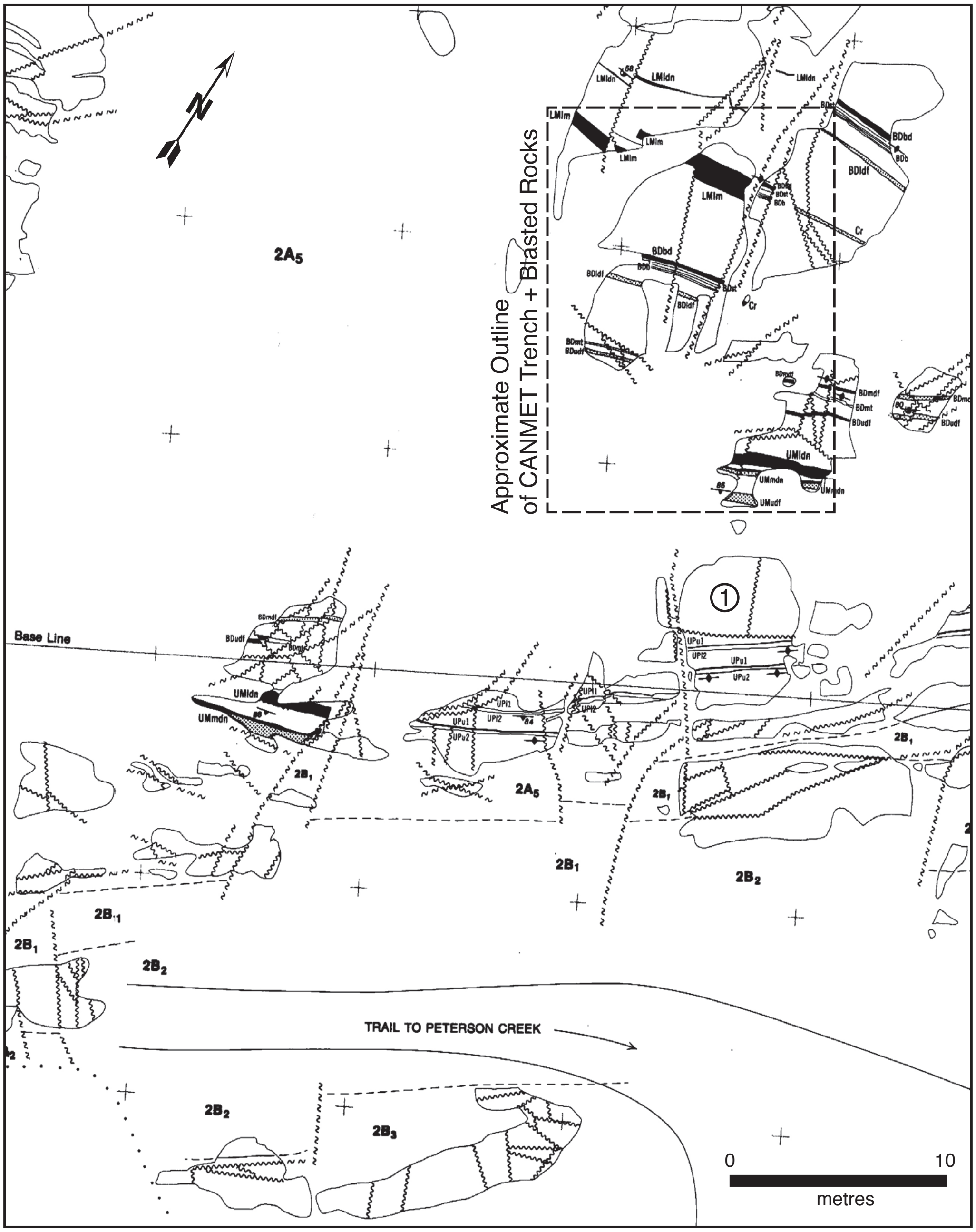


***Figure 10:** Detailed geology for Stop 1.1 of a section through the Chromitiferous Zone ($2A_5$) of the Bird River Sill at the Chrome property (see Figure 6a for a complete stratigraphic section). Map is extracted from Sheet 2 (western part) of Williamson (1990) and shows a section mapped at a scale of 1:200 from the Lower Main Group chromitites (top of figure) through the Upper Paired Group to the overlying Transition Series (bottom of figure). The stop locality is at the end of the access road that leads north from Peterson Creek. A bulk sample from the base of the Lower Main Group to the top of the Upper Main Group chromitites was taken at the CANMET Trench (approximate outline shown with dashed line). Rock blasted from the trench covers much of the outcrop in the northern part of this map area. Layering is mostly subvertical (the stratigraphic up direction in the intrusion is to the southeast). The solid line labeled "Base Line" refers to the mapping grid of Williamson (1990).*

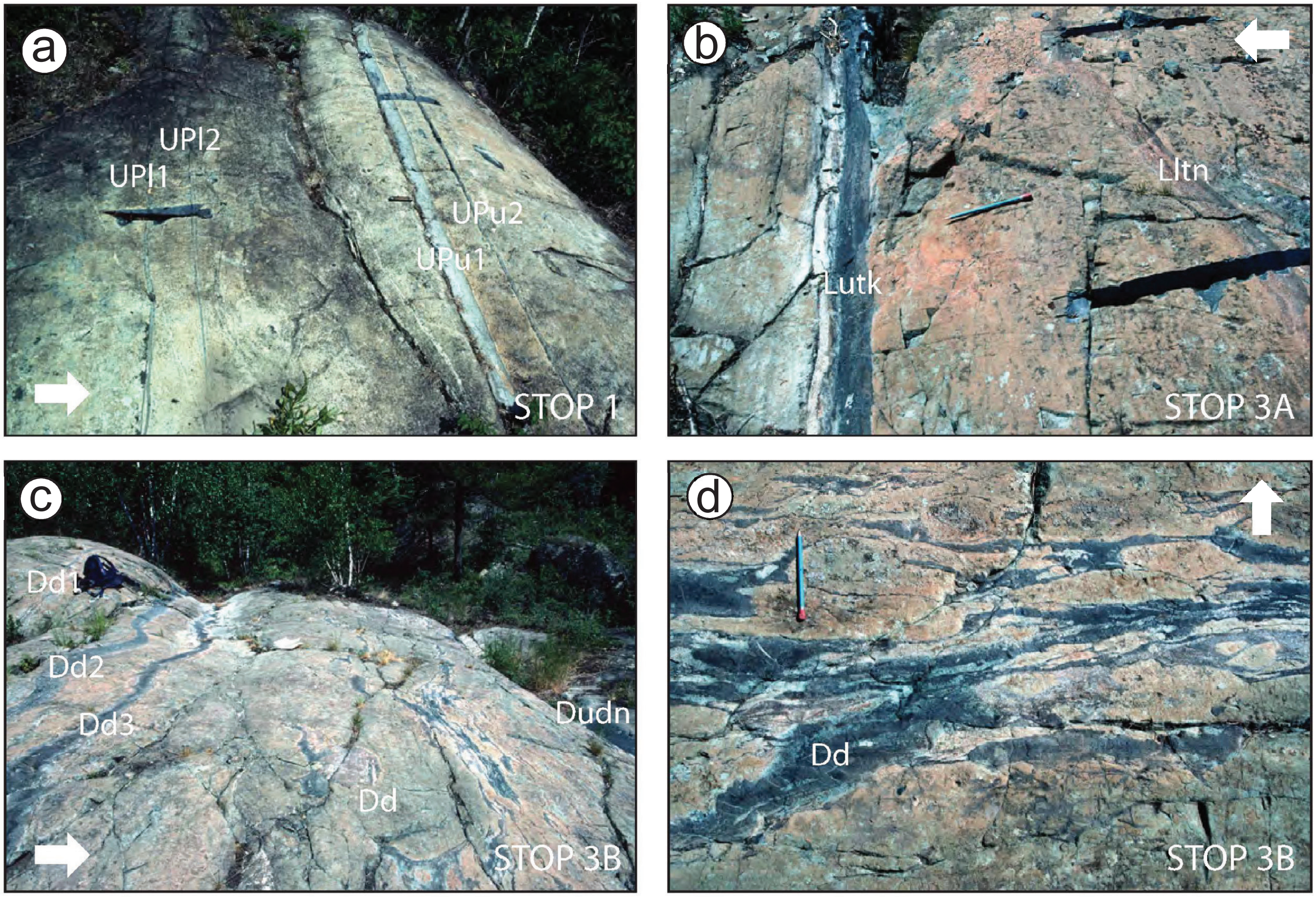


***Figure 11:** Photographs showing field relations of chromitites in the Chromitiferous Zone from Stops 1.1, 1.3A, and 1.3B. White arrow points to stratigraphic tops in all images: **a)** Stop 1.1: Upper Paired Group consisting of a lower pair of chromitite layers (UPl1 and UPl2) and upper pair of chromitites (UPu1, UPu2). The relative thickness of this group of chromitites and the separation between individual chromitite layers is remarkably consistent across the entire Chrome property. The pocket knife is 10 cm long and the photograph was taken in summer, 1984; **b)** Stop 1.3A: Lower Group consisting of a lower thin diffuse chromitite layer (Lltn) and an upper dense chromitite layer (Lutk). The lower chromitite layer is discontinuous along strike at this locality, within a zone of coarse-grained peridotite with skeletal olivine. The pencil is 16 cm long and the photograph was taken in summer, 1986; **c)** Stop 1.3B: Disrupted Group consisting of three lower dense chromitite layers (Dd1, Dd2, Dd3), a highly convoluted disrupted horizon (Dd), and an upper dense chromitite (Dudn). The open notebook is 24 cm across and the photograph was taken in summer, 1986; **d)** Stop 1.3B: disrupted member of the Disrupted Group (Dd) from the right-central portion of image **c**, showing discontinuous chromitite layers that are interpreted to have been disturbed by processes analogous to "soft-sediment–like" deformation. The disrupted chromitite segments form "drop-and-sag" structures developed as a result of gravitational instability. The pencil is 16 cm long and the photograph was taken in summer, 1986.*

centimetres to 3 m) into peridotite of the underlying Massive Peridotite Zone ($2A_4$, Figure 6a). The mineralized unit is recognized by the presence of disseminated sulphide, particularly evident on the faces of sporadic saw-cuts in outcrops through this interval. PGE concentrations range up to 700 ppb Pd and up to 1800 ppb Pt; a variety of platinum group minerals have been identified (in decreasing order of abundance): sperrylite ($PtAs_2$), kotulskite (PdTe), merenskyite ($PdTe_2$), laurite (RuS_2), hollingworthite (RhAsS), irarsite (IrAsS), and keithconnite ($Pd_{3-x}Te$) (Scoates et al., 1988). Disseminated sulphide is also observed sporadically between the Lower and Disrupted Group chromitites on the southern part on this outcrop.

Stop 1.3B: Disrupted Group Chromitite

Figure 15. Location: Sheet 3 of Williamson (1990); Lat/Long: N50°27.478, W095°33.620; UTM 5592683N, 318268E.

This is the best exposure of the Disrupted Group on the Chrome property; at this locality it is exposed over a stratigraphic interval of about 6 m. The lower dense chromitite members exhibit gentle folds (Figure 11c). The disrupted member is made up of equigranular peridotite with patches of coarse-grained pegmatitic peridotite, and contains segments of disrupted chromitite layers (Figure 11c). Some of these segments exhibit "drop-and-sag" structures, interpreted to represent soft-sediment–like deformation (Figure 11d). Each of the constituent members of the Disrupted Group, including the dense chromitites and the central disrupted part, are recognized across both the Chrome and Page properties (Young, 1992). In contrast to the Lower, Upper Main, and Upper Paired Group chromitites, which are remarkably consistent in stratigraphic thickness across the Chrome property, the thickness of the Disrupted Group varies considerably (Figure 8). Disseminated

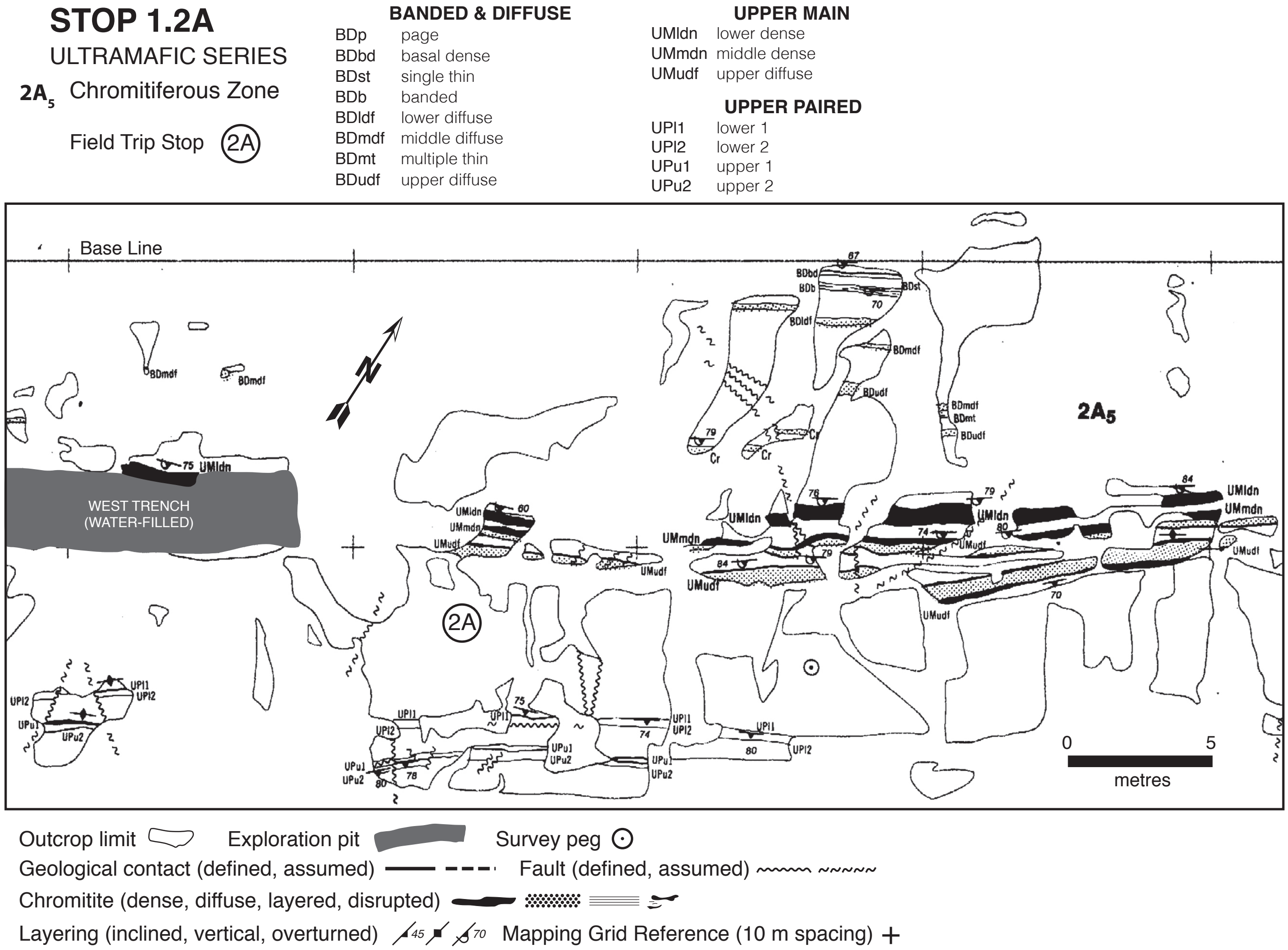


***Figure 12:** Detailed geology for Stop 1.2A of a section through the Chromitiferous Zone of the Bird River Sill at the Chrome property. Map is extracted from Sheet 4 (western part) of Williamson (1990) and shows a section mapped at a scale of 1:200 from the Banded & Diffuse Group (top of figure) through the Upper Main Group to the Upper Paired Group chromitites (bottom of figure). The exploration pit (West Trench) sampled the Upper Main Group including the lower dense, middle dense, and upper diffuse layers. Layering is subvertical to overturned (the stratigraphic up direction in the intrusion is to the southeast). The solid line labeled "Base Line" refers to the mapping grid of Williamson (1990).*

sulphides are noted below the second dense layer (Dld2) on this outcrop.

Stop 1.4: Lower Main Chromitite in Fault

Figure 16. Location: Sheet 3 of Williamson (1990); Lat/Long: N50°27.487, W095°33.579; UTM 5592698N, 318318E.

A prominent north-trending fault cuts the Chromitiferous Zone at this location. To the west, the Lower Main Group and Banded & Diffuse Group chromitites are recognizable in their normal stratigraphic position and orientation. In the central part of the mapped area, numerous intervals of sheared peridotite—ranging from a few to several tens of centimetres in thickness—can be observed and correlate with a major fault that offsets the upper and lower contacts of the Chromitiferous Zone with ~40–50 m of right-lateral displacement (Figure 5). Within the sheared peridotites, there are several misoriented blocks of dense chromitite that represent fault-bounded blocks of the Lower Main Group lower main member (LMlm). Immediately east of the fault, Lower Group chromitites are encountered and can be traced east across the outcrop and down a narrow gulley (now tree-filled).

Stop 1.5: Disrupted Group

Figure 17. Location: West part of Sheet 2 (15W, 0N) of Williamson (1990); Lat/Long: N50°27.477, W095°33.460; UTM 5592677N, 318415E.

At this locality, a section containing all chromitite groups within the Chromitiferous Zone can be observed (including the Upper Paired Group chromitites of Stop 1.6). The focus of the stop is on the Banded & Diffuse Group (BD, Figure 6b), which is exposed in the outcrops just to the north of the two exploration pits (Central Trenches 1 and 2) within the Upper Main Group chromitites. Please note that the trenches are usually water-filled, rendering observation of the Upper Main

STOP 1.2B

ULTRAMAFIC SERIES

$2A_5$ Chromitiferous Zone

Field Trip Stop (2B)

BANDED & DIFFUSE

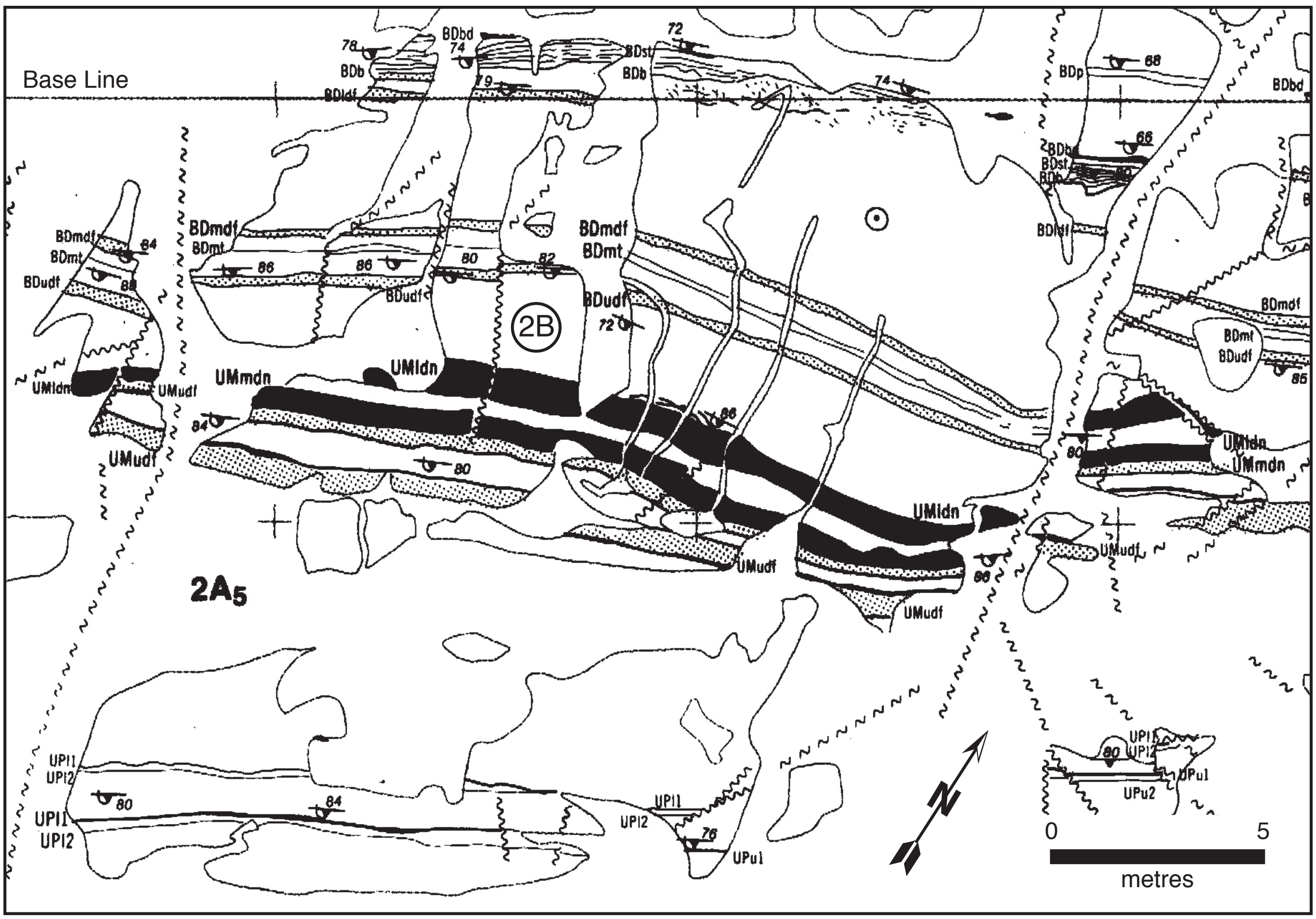
BDp page
BDbd basal dense
BDst single thin
BDb banded
BDldf lower diffuse
BDmdf middle diffuse
BDmt multiple thin
BDudf upper diffuse

UPPER MAIN

UMldn lower dense
UMmdn middle dense
UMudf upper diffuse

UPPER PAIRED

UPl1 lower 1
UPl2 lower 2
UPu1 upper 1
UPu2 upper 2



Outcrop limit Survey peg

Geological contact (defined, assumed) Fault (defined, assumed)

Chromitite (dense, diffuse, layered, disrupted)

Layering (inclined, vertical, overturned) 45 70 Mapping Grid Reference (10 m spacing) +

***Figure 13:** Detailed geology for Stop 1.2B of a section through the Chromitiferous Zone of the Bird River Sill at the Chrome property. Map is extracted from Sheet 4 (central part) of Williamson (1990) and shows a section mapped at a scale of 1:200 from the Banded & Diffuse Group (top of figure), including the lowermost Page member, through the Upper Main Group to the Upper Paired Group chromitites (bottom of figure). Layering is mostly overturned (the stratigraphic up direction in the intrusion is to the southeast). The solid line labeled "Base Line" refers to the mapping grid of Williamson (1990).*

STOPS 1.2C + 1.2D

ULTRAMAFIC SERIES

$2A_4$ Massive Peridotite Zone

$2A_5$ Chromitiferous Zone

DISRUPTED

Dld1 lower dense 1
Dld2 lower dense 2
Dld3 lower dense 3
Dd disrupted
Dudn upper dense

LOWER MAIN

LMldn lower dense
LMlm lower main

BANDED & DIFFUSE

BDp page

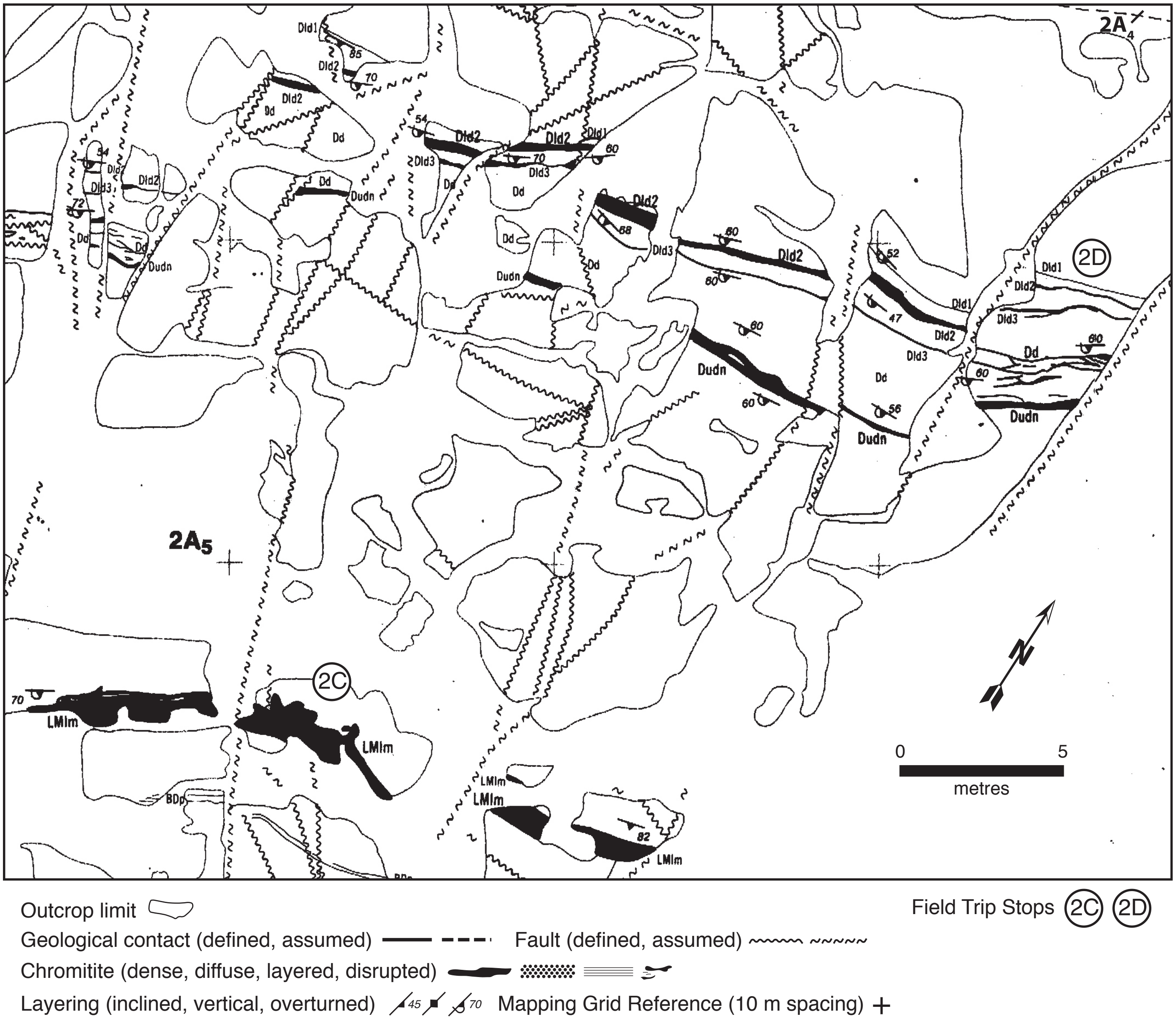


Figure 14: *Detailed geology for Stops 1.2C and 1.2D of a section through the Chromitiferous Zone of the Bird River Sill at the Chrome property. Map is extracted from Sheet 4 (east part) of Williamson (1990) and shows a section mapped at a scale of 1:200 from the Disrupted Group (top of figure) to the Lower Main Group (bottom of figure) and the thin Page member of the Banded & Diffuse Group. Layering is mostly overturned (the stratigraphic up direction in the intrusion is to the southeast).*

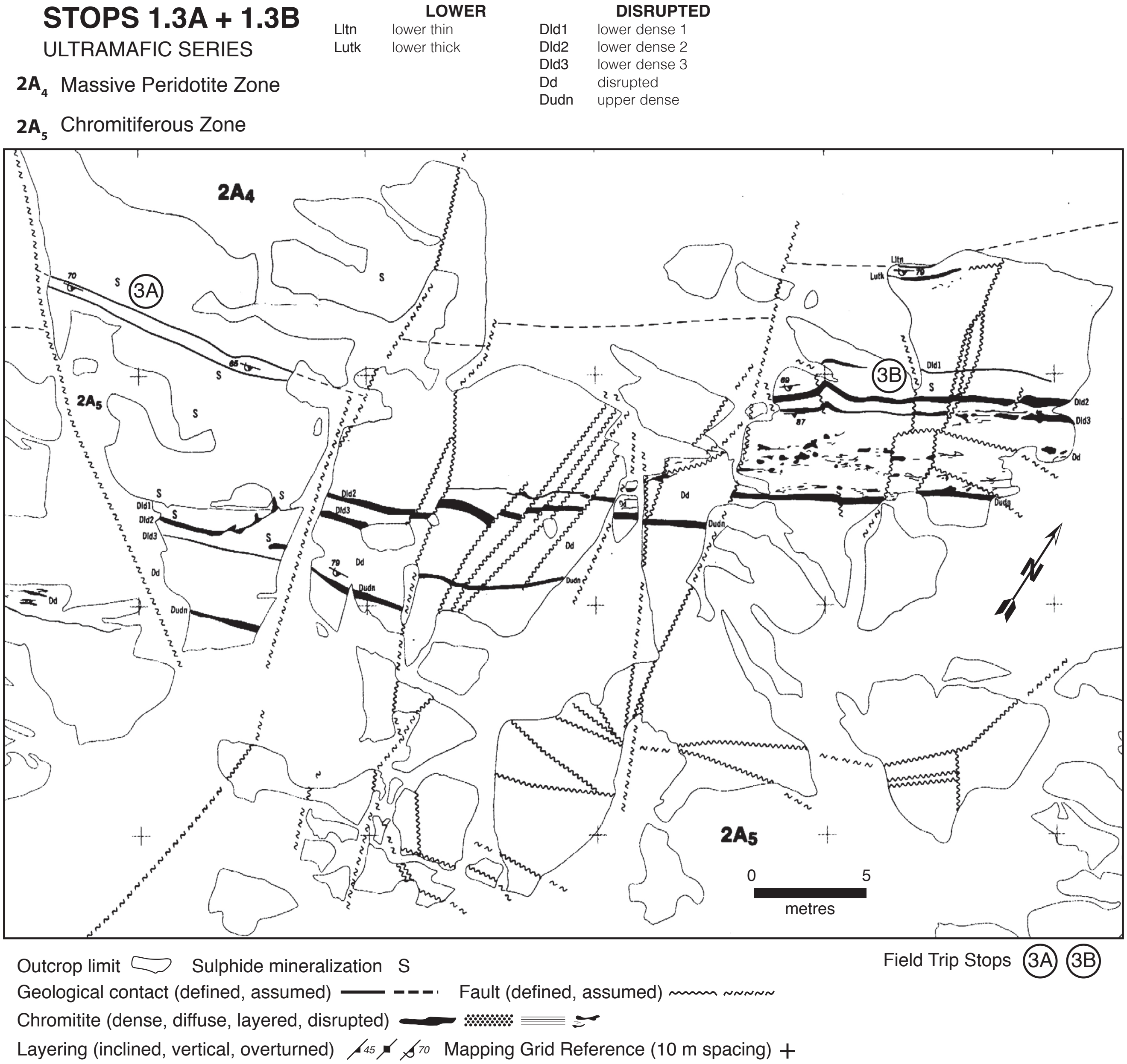


***Figure 15:** Detailed geology for Stops 1.3A and 1.3B of a section through the Chromitiferous Zone of the Bird River Sill at the Chrome property. Map is extracted from Sheet 3 of Williamson (1990) and shows a section mapped at a scale of 1:200 from the Lower Group (top of figure) through the Disrupted Group chromitites (central part of figure) and overlying peridotites. Layering is mostly overturned (the stratigraphic up direction in the intrusion is to the southeast). The PGE-mineralized horizon is found stratigraphically below the Lower Group chromitites at Stop 1.3A; oxidized sulphides can be observed on the outcrop and in the saw-cut just beneath the Lower lower thin member (Lltn).*

chromitites impossible or at least hazardous. The lower part of the Banded & Diffuse Group is readily identifiable and consists of the basal dense (BDbd), single thin (BDst), and banded (BDb) members. Trough structures and scours can be noted in the banded member (Figure 18a). The Banded & Diffuse Group is overlain by about 20 m of fine- to medium-grained poikilitic olivine-chromite cumulate (Figure 18b). Also present on this outcrop is the Lower Main Group that occurs stratigraphically below the Banded & Diffuse Group chromitites. The Lower Main Group consists of a thin lower chromitite layer (LMldn), a coarse-grained to pegmatitic peridotite member (2.5 m thick), and a 70 cm-thick upper bounding chromitite (LMlm).

Stop 1.6: Upper Paired Group, Transition Series, and Lower Gabbro

This stop provides a transect from the Upper Paired Group chromitites at the top of the Chromitiferous Zone through the thin Transition Series into the lowermost part of Mafic Series (Figure 6a).

Stop 1.6A: Upper Paired Group Chromitites and Transition Series

Figure 17. Location: Sheet 2 of Williamson (1990); Lat/Long: N50°27.492, W095°33.460; UTM 5592701N, 318459E.

STOP 1.4

ULTRAMAFIC SERIES

$2A_4$ Massive Peridotite Zone

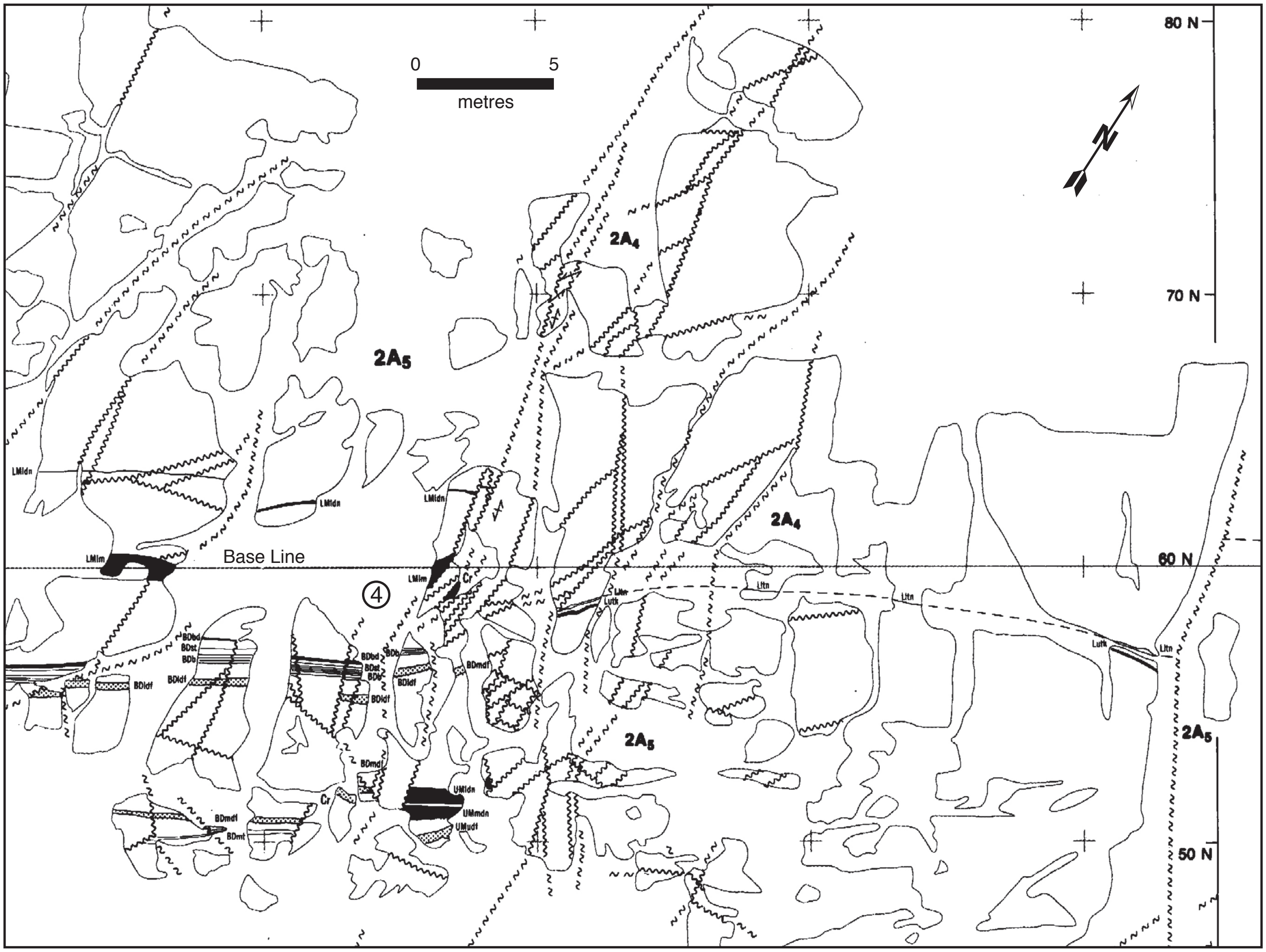
$2A_5$ Chromitiferous Zone

LOWER	
Lltn	lower thin
Lutk	lower thick

LOWER MAIN	
LMldn	lower dense
LMlm	lower main

BANDED & DIFFUSE	
BDp	page
BDbd	basal dense
BDst	single thin
BDb	banded
BDldf	lower diffuse
BDmdf	middle diffuse
BDmt	multiple thin
BDudf	upper diffuse

UPPER MAIN	
UMldn	lower dense
UMmdn	middle dense
UMudf	upper diffuse



Outcrop limit

Geological contact (defined, assumed)

Fault (defined, assumed)

Chromitite (dense, diffuse, layered, disrupted)

Layering (inclined, vertical, overturned) 45 70

Mapping Grid Reference (10 m spacing)

Field Trip Stop 4

***Figure 16:** Detailed geology for Stop 1.4 of a section through the Chromitiferous Zone of the Bird River Sill at the Chrome property. Map is extracted from Sheet 3 of Williamson (1990) and shows a faulted section mapped at a scale of 1:200 that includes the top of the Massive Peridotite Zone (top of figure), the Lower Group (east-central part of map), and the Lower Main, Banded & Diffuse, and Upper Main Group chromitites (bottom of figure). Although there are no structural measurements on this part of the map sheet, layering is predominantly subvertical (the stratigraphic up direction in the intrusion is to the southeast). The major north-trending fault zones that cut this series of outcrops correlate with the large fault shown on Figure 5 (dextral motion, ~40 m of off-set). Note the mis-oriented chromitite horizons within the fault zones. The solid line labeled "Base Line" refers to the mapping grid of Williamson (1990).*

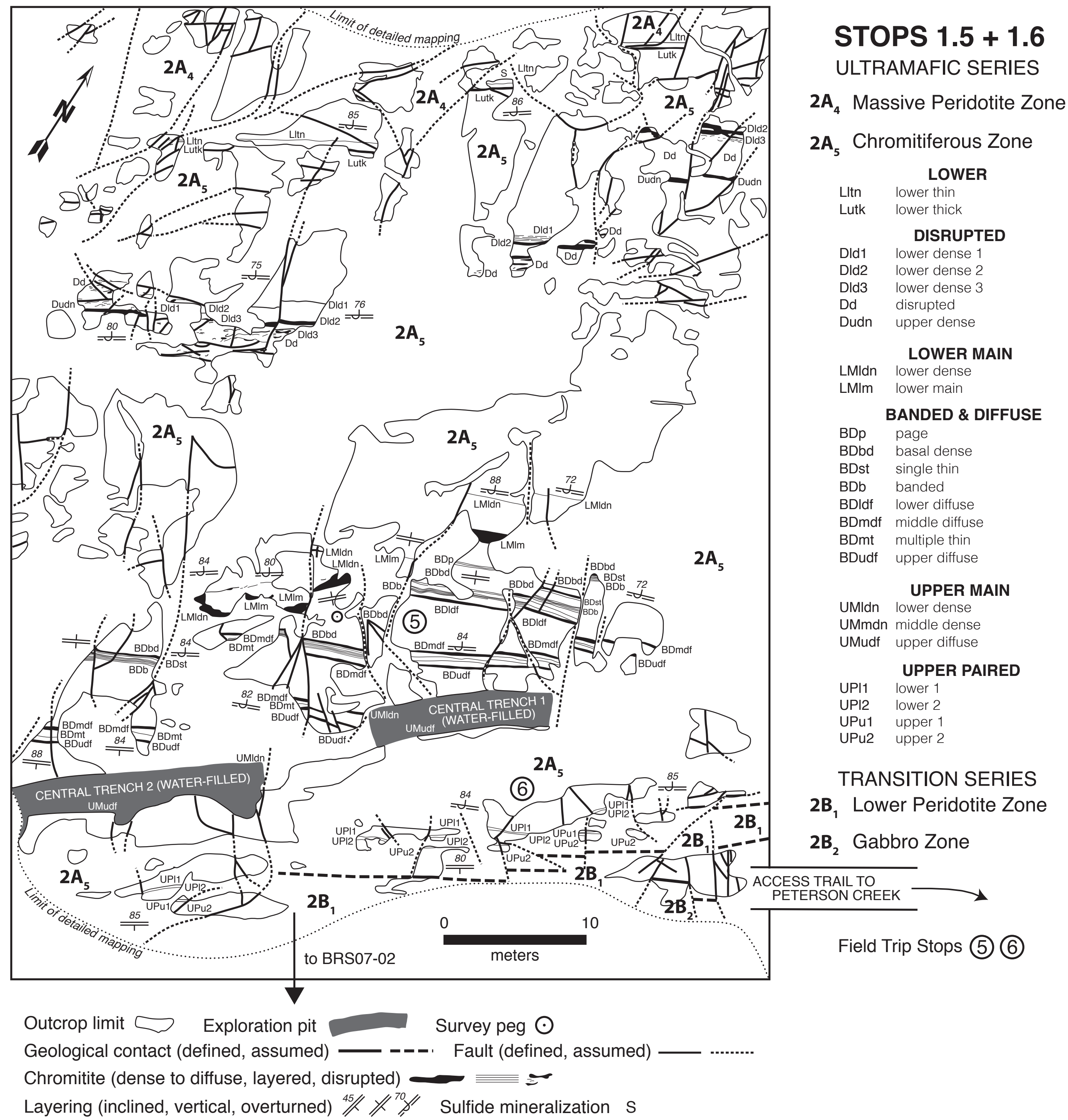


***Figure 17:** Detailed geology for Stop 1.5 and part of Stop 1.6 of a section through the Chromitiferous Zone of the Bird River Sill at the Chrome property. Map is redrawn from Sheet 2 (western part) of Williamson (1990) and shows a complete section of th e Chromitiferous Zone mapped at a scale of 1:200 from the underlying Massive Peridotite Zone (top of figure) to the overlying Transition Series (bottom of figure). The exploration pits (Central Trench 1, Central Trench 2) sampled the Upper Main Group chromitite including the lower dense, middle dense, and upper diffuse layers. Throughout most of the map area, layering is overturned (the stratigraphic up direction in the intrusion is to the southeast). Stop 1.5 extends from the outcrops adjacent to the exploration pits, north to the Lower Group chromitites. Stop 1.6 begins at the Upper Paired Group chromitites to the south of the water-filled trenches, and continues off the map area, southwards through a grove of trees to a large outcrop of the Lower Gabbro Zone in the Mafic Series.*

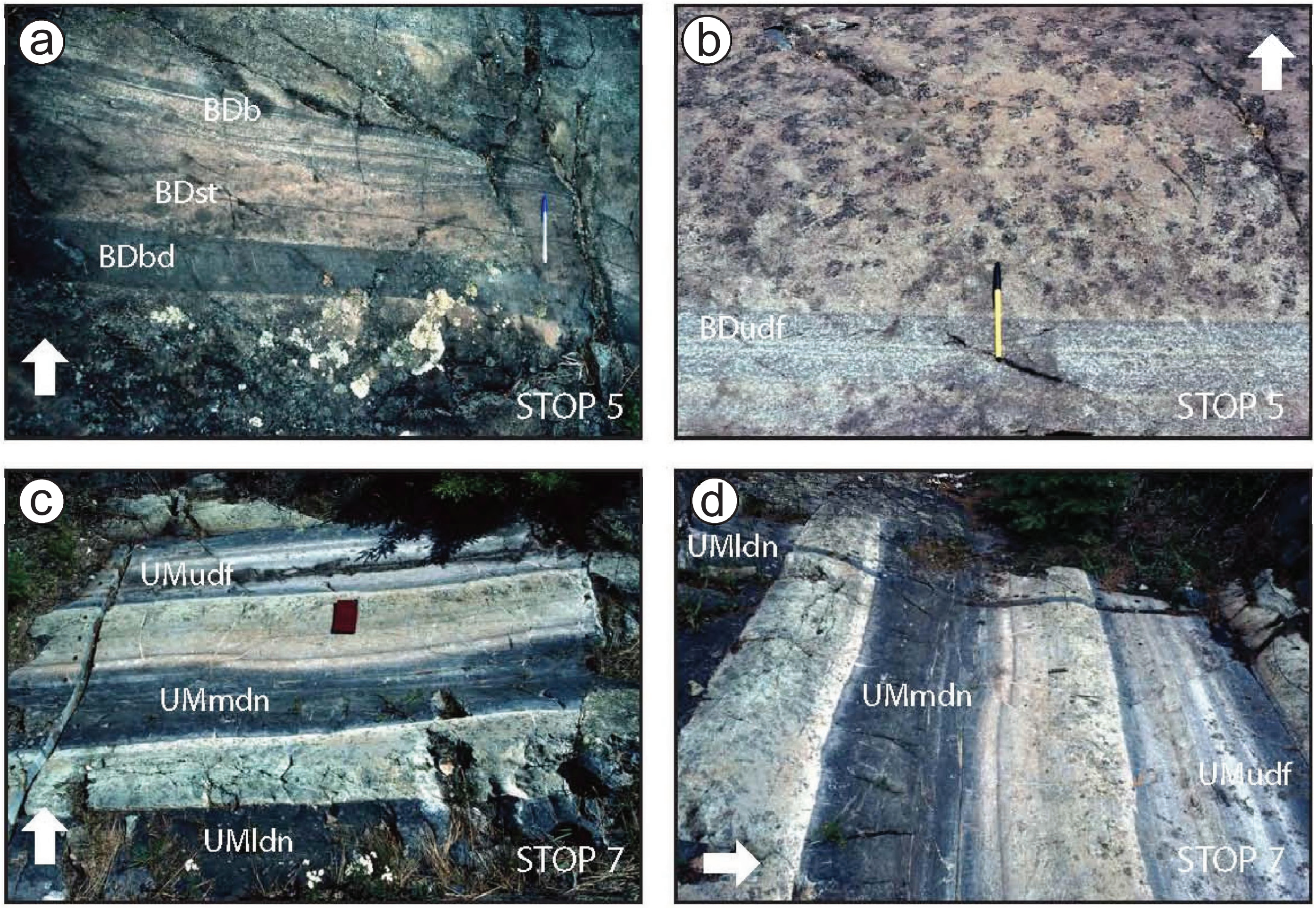


Figure 18:** Photographs showing field relations of chromitites in the Chromitiferous Zone from Stops 1.5 and 1.7. White arrow points to stratigraphic tops in all images:* ***a) *Stop 1.5: lower part of the Banded & Diffuse Group showing the basal dense (BDbd), single thin (BDst), and banded (BDb) members. This is the most readily identifiable sequence of chromitites across the Chrome property. Note the planar nature of the single thin member and the series of truncations in the banded member that are interpreted as magmatic scour features. The pen is 14 cm long and the photograph was taken in summer, 1986;* ***b)*** *Stop 1.5: upper contact of the Banded & Diffuse Group, showing the upper diffuse member (BDudf) and the overlying poikilitic peridotite (oikocrysts are hornblende after original pyroxene). The pen is 14 cm long and the photograph was taken in summer, 1983;* ***c)*** *Stop 1.7: Upper Main group consisting of a lower dense chromitite (UMldn), a poikilitic olivine cumulate, a middle dense chromitite (UMmdn), an olivine cumulate (notebook location), and an upper diffuse chromitite (UMudf). Note minor fault in centre-left of photograph. The notebook is 21 cm long and the photograph was taken in summer, 1986;* ***d)*** *Stop 1.7: Upper Main Group, close-up view along the chromitite and peridotite layers shown in image* ***c****, illustrating sharp planar contacts between major layers, cm-scale layering within chromitites and peridotites, and the typical recessive nature of dense chromitite horizons on the Chrome property. The pocket knife is 10 cm long and the photograph was taken in summer, 1983.*

Outcrops containing the Upper Paired Group chromitites occur ~5–10 m to the south of the Central Trenches. Similar features to those observed at Stop 1.1 can be seen in these small outcrops, especially in those to the south of the eastern end of Central Trench 1. Before heading farther south to the Lower Gabbro Zone of the Mafic Series through a treed area with no outcrops, a small outcrop shows the lowermost two units—Lower Peridotite and Gabbro zones—of the Transition Series, and their contact.

Stop 1.6B: Lower Gabbro, Mafic Series

Figure 17. Location: Sheet 6 of Williamson (1990); Lat/Long: N50°27.456, W095°33.442; UTM 5592637N, 318478E.

The Mafic Series is dominated by plagioclase-bearing rocks. The lowermost unit, the Lower Gabbro Zone, is 90–200 m thick and varies considerably in composition (hornblende-rich melagabbro to anorthosite) and grain-size/texture (medium- to coarse-grained and locally pegmatitic). The stop is at the sample locality (BRS07-02) of Scoates and Scoates (2013) from which a U-Pb zircon age of 2743.0 ±0.5 Ma was determined (Figure 5).

Stop 1.7: Upper Main Group at east end of East Trench 2

Figure 19. Location: Sheet 1 of Williamson (1990); Lat/Long: N50°27.545, W095°33.379; UTM 5592799N, 318558E.

STOP 1.7

ULTRAMAFIC SERIES

2A$_5$ Chromitiferous Zone

LOWER MAIN

LMldn lower dense
LMlm lower main

BANDED & DIFFUSE

BDp page
BDbd basal dense
BDst single thin
BDb banded
BDldf lower diffuse
BDmdf middle diffuse
BDmt multiple thin
BDudf upper diffuse

UPPER MAIN

UMldn lower dense
UMmdn middle dense
UMudf upper diffuse

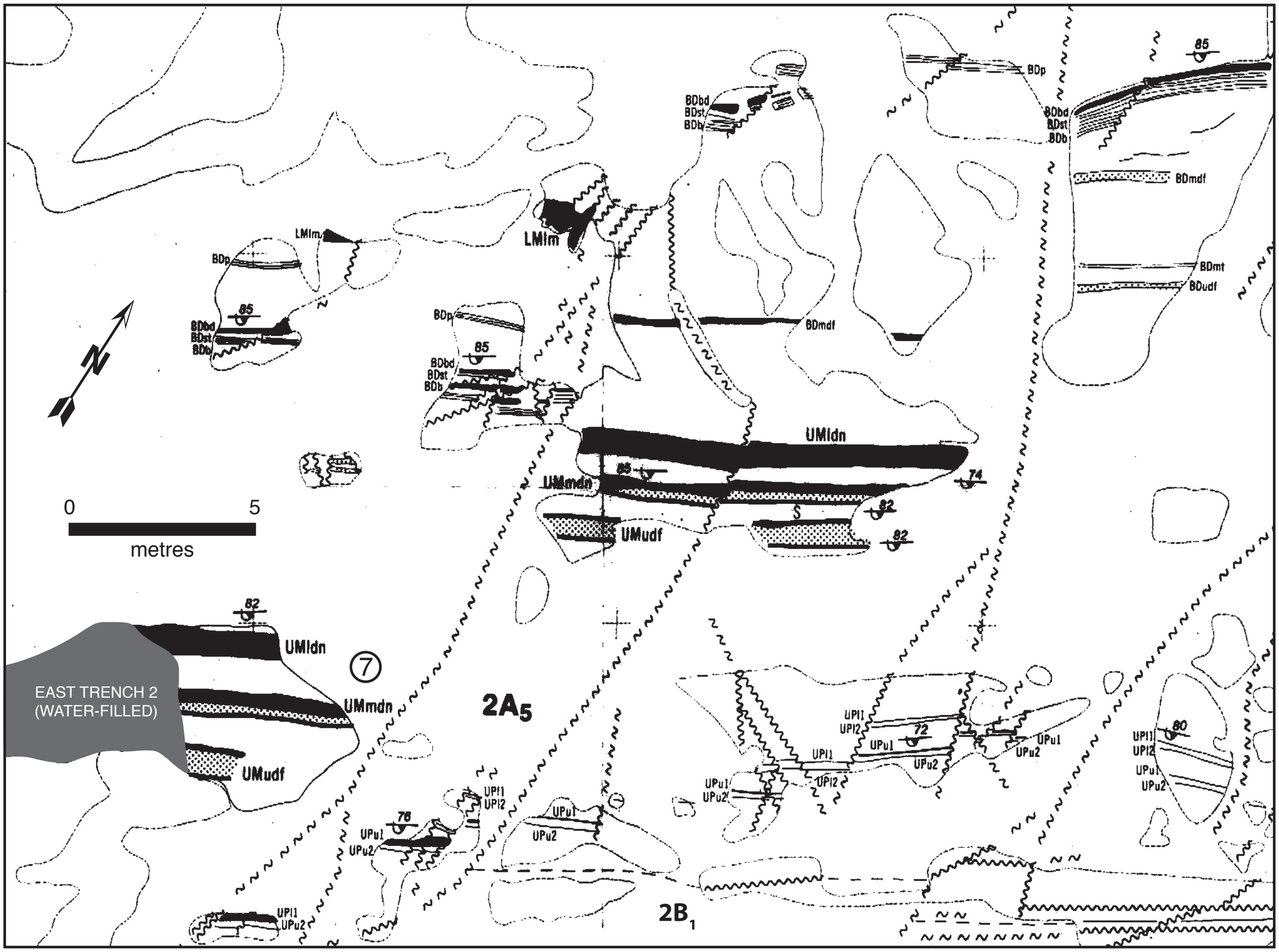
UPPER PAIRED

UPl1 lower 1
UPl2 lower 2
UPu1 upper 1
UPu2 upper 2

TRANSITION SERIES

2B$_1$ Lower Peridotite Zone

Field Trip Stop ⑦



Outcrop limit   Exploration pit
Geological contact (defined, assumed)   Fault (defined, assumed)
Chromitite (dense, diffuse, layered, disrupted)
Layering (inclined, vertical, overturned) 45 70   Mapping Grid Reference (10 m spacing) +

Figure 19: *Detailed geology for Stop 1.7 of a section through the Chromitiferous Zone of the Bird River Sill at the Chrome property. Map is extracted from Sheet 1 (central part) of Williamson (1990) and shows a section mapped at a scale of 1:200 that includes the Lower Main Group (in faults), the Banded & Diffuse Group (top of page), the Upper Main Group, the Upper Paired Group, and the lowermost unit of the Transition Series (2B$_1$, bottom of figure). The first outcrop of Stop 1.7 is located on the west side of East Trench 2. Layering is overturned (the stratigraphic up direction in the intrusion is to the southeast). The most exceptional occurrence of the Upper Main Group chromitite on the Chrome property is located in the central part of this map area, within a glacially grooved and polished zone that is now mostly covered in lichen. The new narrow zone of blasted rock (not shown on the map) appears to follow the prominent northwest-trending fault from the base of the Banded & Diffuse Group to the base of the Upper Main Group chromitites.*

The Upper Main Group is exposed in outcrop at the eastern end of East Trench 2. To the east—and offset along a north-trending fault by 9 m (left-lateral displacement)—is the best exposure of the Upper Main Group on the Chrome property (Figure 18c, 18d). The lower dense chromitite member is overlain in turn by poikilitic peridotite, the middle dense chromitite, a peridotite member and the upper diffuse chromitite; the latter member has dense chromitite at its basal and upper margins. To the north (~5 m), another example of Lower Main Group chromitite caught up within a north-trending fault can be observed (Figure 19).

Stop 1.8: Disruption of Lower Main and Banded & Diffuse Group Chromitites

Figure 20. Location: Sheet 1 of Williamson (1990); Lat/Long: N50°27.567, W095°33.354; UTM 5592838N, 318589E.

The entire Chromitiferous Zone is exposed in this outcrop area and offers an exceptional overview of all the major features of the chromitites. Please be aware of the hazard at the precipitous eastern end of the outcrop, which is due to a major northwest-striking fault marking the eastern limit of the sill on the Chrome property.

Stop 1.8A: Disruption of the Banded & Diffuse Group Chromitites

Figure 20. (45N, 200E grid location of Williamson, 1990).

An excellent example of disruption of the continuity of the lower chromitite members of the Banded & Diffuse Group can be observed at this locality. Both brittle and ductile deformation is evident in the basal dense member, the single thin occurs as a sequence of dismembered segments, and the overlying banded member is offset and locally disrupted (Figure 21a, b, c). These features are interpreted as "liquid escape" or "flow-through" structures, produced by rising interstitial melt that became ponded beneath impermeable chromitite layers and subsequently ascended along synmagmatic faults. Note also the very irregular nature of the uppermost layer in the banded member.

Stop 1.8B: Disruption of the Lower Main Group Chromitites

Figure 20. (50N, 195E grid location of Williamson, 1990).

A large-scale example of disruption of the Lower Main Group can be examined here. The lower contact of the lower main member is extremely irregular, with dense chromitite protruding downward into the peridotite (i.e., "drop-and-sag" structures; Figure 21d), which is itself a chaotic mixture of coarse-grained to pegmatitic peridotite, medium- to fine-grained peridotite, and irregular patches of dense chromitite. The upper and lower contacts of the lower dense member are remarkably planar, but locally show lobate shapes (Figure 21e). The stratigraphic thickness of the Lower Main Group chromitite at this locality is less than elsewhere on the Chrome property (Figure 8). Note also the abundant faults and associated offsets mapped in this outcrop area (Figure 20).

Stop 1.8C: Disrupted Group and Lower Group Chromitites

Figure 20. (70N, 195E grid location of Williamson, 1990).

Approximately 20 m to the northwest of Stop 1.8B is a good exposure of the Disrupted Group chromitites and ~14 m farther west (80N, 175E grid location of Williamson, 1990), the Lower Group chromitites are exposed and disseminated sulphides can be observed in saw-cuts.

Stop 1.8D: Upper Paired Group and Transition Series

Figure 20. (25N, 185 E grid location of Williamson, 1990).

On the southern edge of this outcrop area, to the south of East Trench 1, the Upper Paired Group and the faulted contact of the Ultramafic Series and Transition Series can be observed.

From here, walk west back to Stop 1.1 (CANMET Trench) at the end of the access trail from Peterson Creek (follow the Upper Paired Group chromitites in outcrop), then take the access trail south to the creek, cross, and return to the vehicles (Figure 5).

Acknowledgments

We thank and acknowledge the many geologists who contributed, over the years, to the observations and ideas that are presented in this field guidebook, including current or former employees of 1) the MGS: Tim Corkery, Paul Gilbert, Josef Macek and Dave Peck, and 2) the Geological Survey of Canada: Murray Duke, Roger Eckstrand, Dave Garson, Kim Nguyen and Brian Williamson. Students made many important contributions to mapping in the 1980's and include Karen Hudson, Greg Leibrecht, Steve Parker, John Russell, Pam Schwann, Dave Trueman and Perry Yamada. We gratefully acknowledge the assistance of the MGS and especially Neill Brandson, for providing field equipment during fieldwork to prepare this guide. Funding for fieldwork was from an NSERC Discovery Grant to J.S. Scoates.

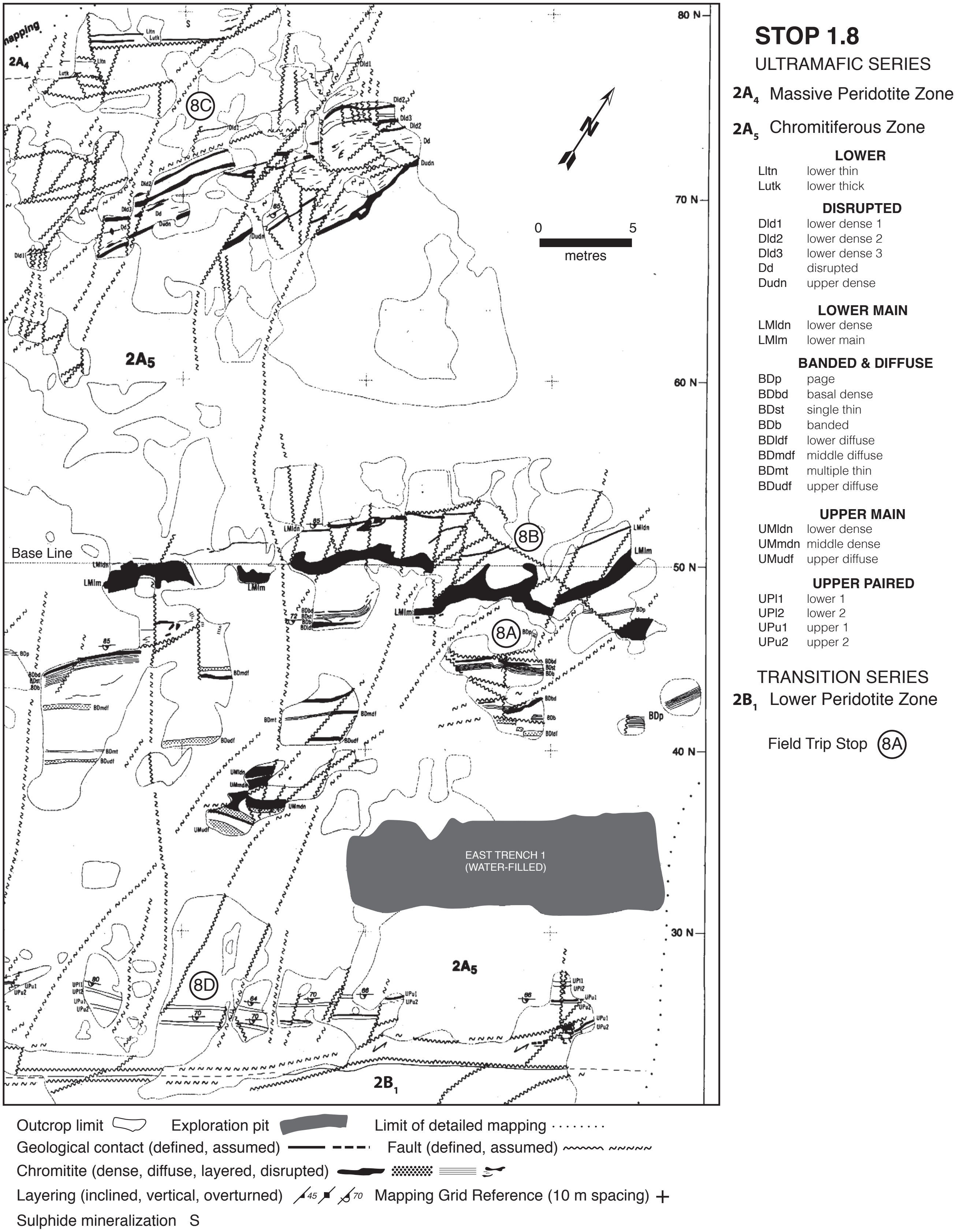


Figure 20: *Detailed geology for Stop 1.8 of a section through the Chromitiferous Zone of the Bird River Sill at the Chrome property. Map is extracted from Sheet 1 (east part) of Williamson (1990) and shows a complete section of the Chromitiferous Zone mapped at a scale of 1:200 from the Lower Group (L, top of figure) to the Upper Paired Group (UP, bottom of figure) and into the overlying Transition Series (2B). The first outcrop (Stop 1.8A) is located to the north of East Trench 1. Layering is overturned (the stratigraphic up direction in the intrusion is to the southeast). Many remarkable features can still be observed in these outcrops (see description of Stop 1.8 for details). The solid line labeled "Base Line" refers to the mapping grid of Williamson (1990).*

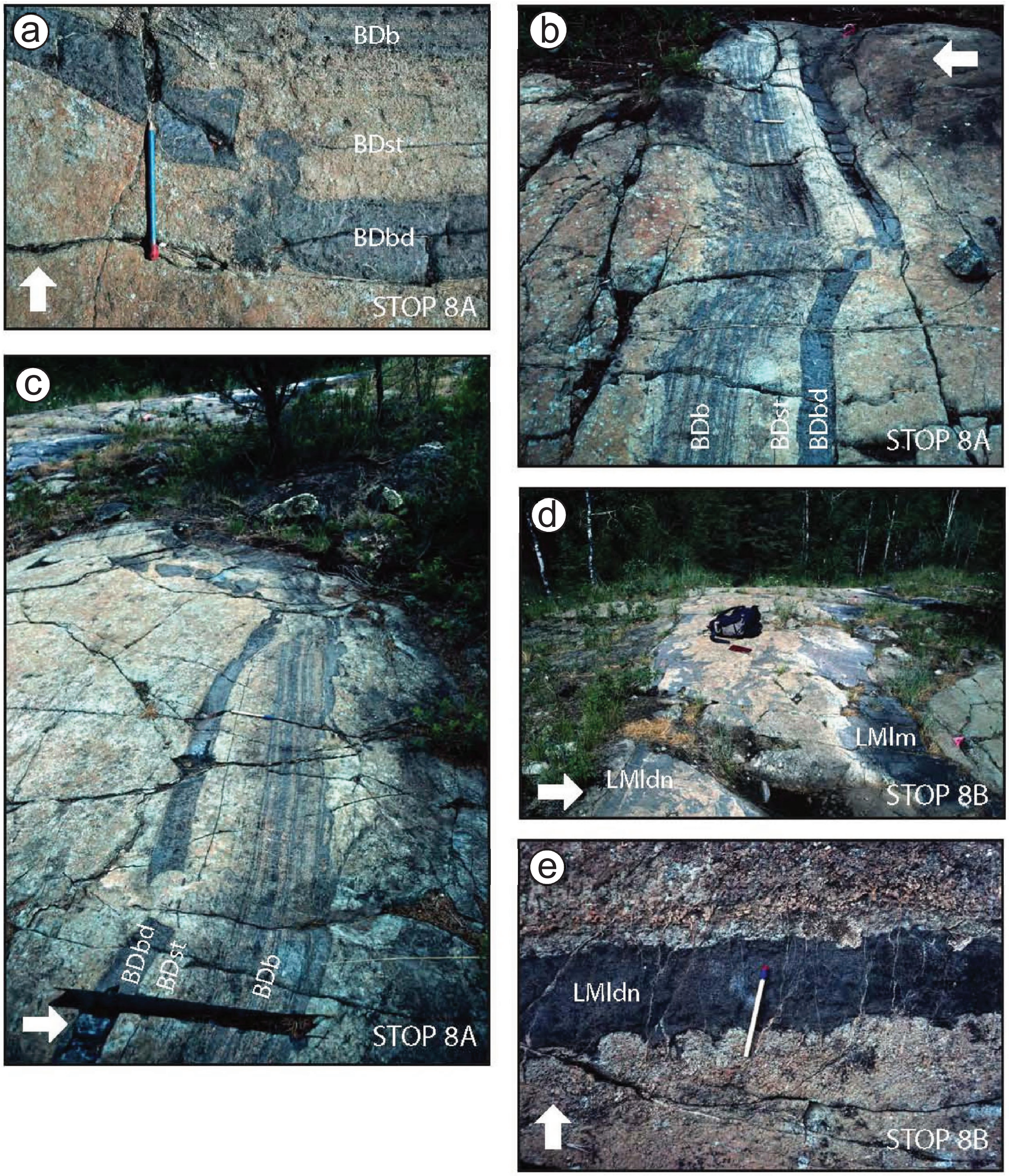


Figure 21: *Photographs showing field relations of chromitites in the Chromitiferous Zone from Stops 1.8A and 1.8B. White arrow points to stratigraphic tops in all images:* ***a)*** *Stop 1.8A: disrupted basal dense member of the Banded & Diffuse Group (BDbd). The basal dense member exhibits stepped offsets characteristic of brittle behavior. The structure is interpreted as a "liquid escape" structure produced by rising interstitial melt that was ponded beneath impermeable chromitite layers, and released along a synmagmatic fault that ruptured the basal dense member. Note the segmentation of the single thin (BDst) above the basal dense. The pencil is 16 cm long and the photograph taken in summer, 1986;* ***b)*** *Stop 1.8A: view to the west along the lower part of the Banded & Diffuse Group, showing the area covered by the photograph in image* ***a****. Note the presence of several offsets along the banded member (BDb), including the region of offset and disruption above the faulted basal dense member. The upper contact of the banded member is highly irregular. The pen is 14 cm long and the photograph was taken in summer, 1986;* ***c)*** *Stop 1.8A: lower part of the Banded & Diffuse Group looking east, ~10 m to the west of the photograph in image* ***b****, showing segmentation of the basal dense (BDbd) and single thin (BDst) members below a continuous banded member (BDb) in the foreground, as well as segmentation and down-warping (synmagmatic fault?) of the entire lower part of the Banded & Diffuse Group in the background. The pen is 14 cm long and the photograph was taken in summer, 1986;* ***d)*** *Stop 1.8B: Lower Main Group, stratigraphically below the Banded & Diffuse Group shown in images* ***a****,* ***b*** *and* ***c****, showing the sharp basal contact of the lower dense member (LMld), the disrupted character of the overlying peridotite with abundant discontinuous lenses of chromitite, and the Lower Main lower main member (LMlm) with well-developed "drop-and-sag" features along the base of the chromitite. The notebook is 21 cm long and the photograph was taken in summer, 1986;* ***e)*** *Stop 1.8B: close-up view of the lower dense member of the Lower Main Group (LMldn) showing lobate peridotite and chromitite along the base of the layer, a structure that is interpreted to represent load casts developed between layers of different density and viscosity. The matchstick is 4 cm long and the photograph was taken in summer, 1983.*

DAY 2: GEOLOGY OF THE MAYVILLE INTRUSION IN THE NORTHERN ARM OF THE BIRD RIVER GREENSTONE BELT

by X.M. Yang, M.G. Houlé, V.J. McNicoll, V. Bécu, C.R. Galeschuk and H.P. Gilbert

Introduction

The Mayville mafic–ultramafic intrusion, located in the northern arm of the Bird River greenstone belt, hosts significant Cu-Ni resources and platinum group element (PGE)–Cr occurrences. It is an east-trending, mafic–ultramafic intrusion, approximately 10.5 km in length and up to 1.5 km in width, and is emplaced into mid-ocean-ridge basalt (MORB) that is extensive in the area immediately south and west of the Mayville intrusion; the contact with granitoid rocks to the east is interpreted as faulted (Figure 22). To the north, the Mayville intrusion is provisionally interpreted to be in intrusive contact with a sequence of intercalated metasedimentary and volcaniclastic rocks, but structurally juxtaposed against granitoid rocks. The Mayville intrusion consists essentially of a lower heterolithic breccia zone and an upper anorthosite to leucogabbro zone (Peck et al., 1999, 2002). The compositional range of the Mayville intrusion is broadly similar to many other Archean anorthositic complexes elsewhere in the Superior Province (Ashwal, 1993).

Note that all rocks have been subjected to regional metamorphism and have been altered to some extent; however primary textures are generally preserved and the inferred original igneous mineralogy and rock classification are used in the following description; the prefix 'meta-' for these rock types is omitted in this guidebook for simplicity. Day 2 of this excursion will focus on selected outcrops across the Mayville intrusion, in order to examine the anorthositic, mafic and mixed 'breccia' phases (stops 2.1–2.3), chromitite layering (Stop 2.3), Ni-Cu-PGE-Cr mineralization at the main ore zone (Stop 2.4, M2 deposit) and the basal contact of the intrusion with MORB-type basalt of the footwall (Stop 2.5).

Geology of the Mayville intrusion

Geological setting

Regional geological mapping between Maskwa Lake and Cat Lake as well as in the Bird River area to the south (Springer, 1948, 1949, 1950) suggested that the dominant structure in the region is anticlinal. The configuration of the mafic–ultramafic Bird River Sill, Mayville intrusion and similar, probably related rocks at Euclid Lake (Figure 2) was thought to reflect the closure of an east-plunging anticlinal fold; this interpretation was supported by Trueman and Macek (1971), Trueman (1980), and Černý et al. (1981). Macek (1985a, b) suggested the Mayville intrusion and Bird River Sill may originally have been parts of the same intrusion, and now occupy the opposing limbs of a major anticlinal fold ('Bird River Sill structure'). The results of current mapping (Yang, 2012; Yang et al., 2012) are, so far, consistent with this structural model. The Cat Creek area, located in the northern arm of the BRGB, contains four main components: 1) supracrustal rocks that include mafic to felsic volcanic and related intrusive rocks, as well as epiclastic and minor volcaniclastic rocks, 2) the Mayville mafic–ultramafic layered intrusion, 3) a tonalite-trondhjemite-granodiorite (TTG) suite, and 4) late peraluminous granitoid rocks and related pegmatite (Figure 22).

Igneous stratigraphy of the Mayville intrusion

The Mayville intrusion—consisting of anorthosite, anorthositic gabbro, leucogabbro, subordinate melagabbro and pyroxenite—has been subdivided into a lower heterolithic breccia (HBX) zone and an upper anorthosite to leucogabbro zone (ALZ; Figure 23; Peck et al., 1999, 2002; Theyer, 2003; Yang et al., 2011, 2012). Within these two zones, the stratigraphic sequence of the five main gabbroic units is as follows: 1) basal melagabbro and pyroxenite, 2) HBX, 3) gabbroic anorthosite and anorthosite, 4) leucogabbro, and 5) strongly magnetic gabbro that caps the sequence (Figure 22). The legend in Figure 22—the source of map-unit descriptions for all references to units in the text below—consists of 12 map units. Only the intrusive rock units that form the Mayville intrusion (4–10) are described in this guidebook; although map units 9 (diabase/gabbro) and 10 (quartz diorite to tonalite) are classified as part of the Mayville intrusion, their age and affinity are uncertain.

Basal mafic–ultramafic rocks (unit 4)

Basal mafic–ultramafic rocks occur within the western part of the Mayville intrusion, but are absent—possibly due to faulting—farther east, where the intrusion is in contact with granodiorite to tonalite. The basal mafic–ultramafic unit consists of fine- to medium-grained melagabbro and medium- to coarse-grained, locally strongly foliated and magnetite-bearing chlorite-amphibole schist and hornblendite (after pyroxenite). This basal unit is estimated to be up to 100 m thick, but the true extent is uncertain because the southern part is largely unexposed. Disrupted chromitite layers are locally present in the upper part of the basal unit, and disseminated chromite is evident in some places. Diamond drilling intersected a chromitite zone up to 5.9 m in width (PGE zone; drillhole MAY-11-07 of Mustang Minerals Corp.). Hiebert (2003) observed chromitite banding and disseminated chromite within pyroxenite in this zone.

Magnetite stringers and layers are common in the basal unit and exhibit a strong magnetic response. Disseminated and semi-massive to massive sulphide minerals—consisting mainly of pyrrhotite, chalcopyrite and pentlandite—are also common, especially at the base of the M2 deposit, the M2W zone, the 'Copper Contact zone', and the 'Hititrite' occurrence (Yang et al., 2012).

Heterolithic breccia (unit 5)

Heterolithic breccia (HBX; Peck et al., 2002 and Mackie, 2003) is an intrusion breccia composed of diverse rock types, including medium- to coarse-grained, megacrystic melagabbro, gabbro, pyroxenite, pegmatitic/megacrystic leucogabbro, and anorthosite. The various phases occur as irregular pods, diffuse

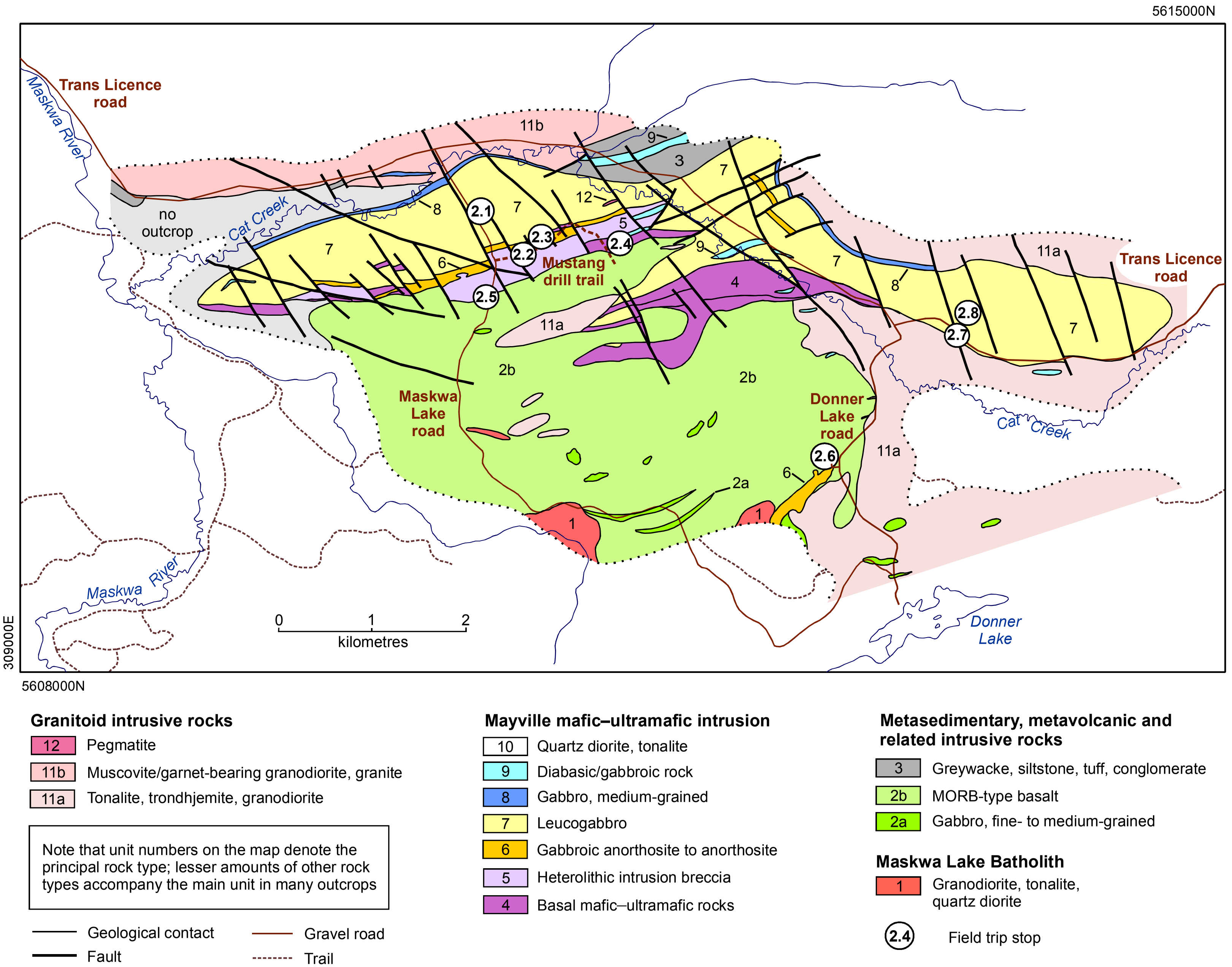


Figure 22: *Simplified geological map of the Neoarchean Mayville intrusion in the northern arm of the Bird River greenstone belt, southeastern Manitoba (modified after Yang, 2012). Quartz diorite to tonalite (unit 10) intrusions are not shown on the map. Field trip stops 2.1 to 2.8 are marked by circled numbers.*

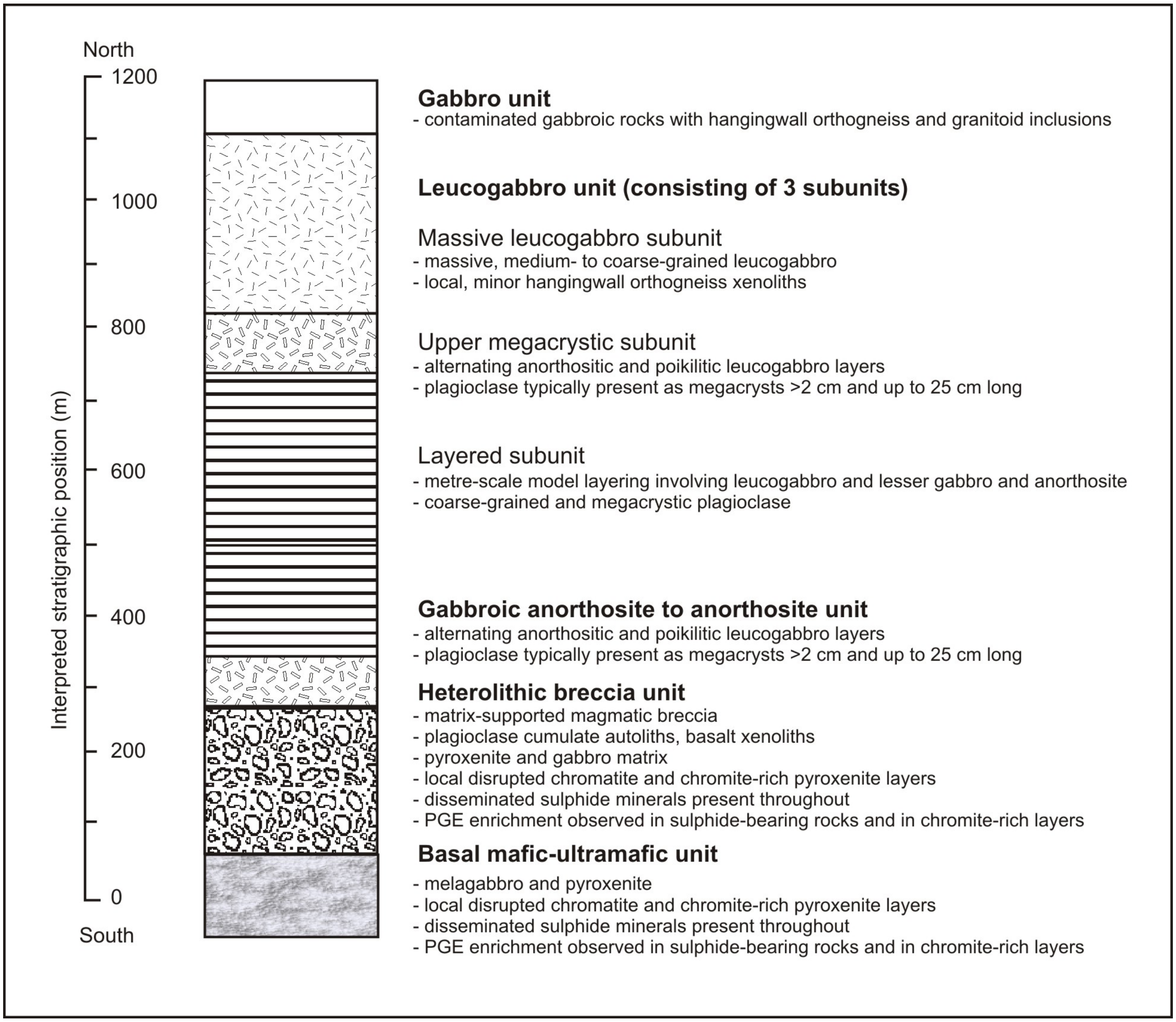


Figure 23: *Stratigraphic section through the Mayville mafic–ultramafic intrusion (modified after Peck et al., 2002). Note that neither the top nor the base of the sequence is exposed. Abbreviation: PGE, platinum group element.*

patches, veins and layers ranging up to 100 m in thickness. Basalt xenoliths from the country rocks occur in the lower part of the HBX, whereas leucogabbro to anorthosite fragments are widespread higher up in the unit, where the rock consists almost entirely of magmatic phases derived from the Mayville intrusion. The HBX is thought to have been emplaced later than leucogabbro and anorthosite of the ALZ (units 6, 7) to the north, because the HBX contains leucogabbro and anorthosite fragments that appear to have been derived from the ALZ. The HBX is locally intruded by fine- to medium-grained quartz diorite to tonalite dikes (unit 10) that locally contain rare sulphide disseminations. Sulphide minerals (mainly pyrrhotite with minor chalcopyrite ± pyrite) occur sporadically in the HBX as disseminations, net-textured veins and/or locally massive sulphide layers. Massive chromitite and disrupted chromitite-pyroxenite layers are locally present in the middle to upper parts of the HBX (Peck et al., 2002; Hiebert, 2003).

The eastern part of the Mayville intrusion (northeast of the Donner Lake Road in Figure 22) lacks both HBX and the uppermost gabbro of map unit 8 (see below).

Gabbroic anorthosite to anorthosite (unit 6)

Unit 6 is a relatively thin (less than 50 m) but persistent member of the Mayville intrusion; it consists of very coarse grained to megacrystic, locally glomeroporphyritic gabbroic anorthosite to anorthosite. Gabbroic anorthosite contains >80% calcic plagioclase as equant, euhedral to subhedral crystals and crystal aggregates (up to 10 cm), and minor interstitial amphibole (after pyroxene). Anorthosite contains >90% plagioclase (Ashwal, 1993). ‘Golf-ball’ leucogabbro/anorthosite that occurs in the southeast part of the intrusion is characterized by subhedral to euhedral plagioclase megacrysts/glomerocrysts typically 3–5 cm in diameter.

Leucogabbro (unit 7)

Leucogabbro is the most abundant rock type within the Mayville intrusion. It is locally characterized by igneous layering, defined by variations in grain size and/or mineralogical composition. Elsewhere, pegmatitic zones up to 2 m across have gradational contacts with the surrounding coarse-grained rock; the pegmatite consists of euhedral plagioclase laths and elongate hornblende crystals. Near the top of unit 7, the leucogabbro contains partly assimilated xenoliths of metasedimentary and fine-grained volcanic rocks that are provisionally interpreted as derived from map units 3 and 2b respectively.

Leucogabbro is typically coarse to very coarse grained, locally megacrystic and contains 65–80% calcic plagioclase, 15–25% hornblende (after pyroxene?) and accessory Fe-Ti oxide(s), zircon and apatite. Plagioclase crystals are equant, subhedral to euhedral, and lack zoning. Hornblende is typically anhedral and interstitial, and locally displays simple twinning. It is uncertain whether some of the hornblende is primary or, alternatively, all is of metamorphic origin. Sulphide minerals (disseminated pyrite ± chalcopyrite) occur locally in sheared zones. At the top of unit 7, the rock is texturally gradational with finer grained gabbro of unit 8.

Gabbro (unit 8)

Gabbro of unit 8 extends along much of the northern margin of the Mayville intrusion, except for the eastern part (Figure 22). The rock is massive, equigranular, medium- to coarse-grained and locally strongly magnetic. It consists of 50–60% plagioclase, 30–40% hornblende and accessory magnetite and ilmenite. Plagioclase laths (0.3–0.5 cm long) and subhedral to anhedral hornblende (after pyroxene, 0.2–0.5 cm) are locally intergrown in ophitic texture. Secondary sericite, chlorite, epidote and biotite are common, especially in fault zones, whereas sulphide minerals are rare.

Diabase/gabbro (unit 9)

Fine- to medium-grained diabase and gabbro occur as dikes and sills within the Mayville intrusion as well as metasedimentary rocks (unit 3) located north of the Mayville intrusion (Figure 22). These intrusions are undeformed and contain sporadic leucogabbro and anorthosite xenoliths. Diabase and gabbro are typically aphyric (locally plagioclase-phyric) and dark green on fresh surface; some dikes display chilled margins. The rocks consist of amphibole and plagioclase (± rare pyrrhotite), and are typically non-magnetic. Diabase (unit 9) is texturally very similar to basalt (unit 2b) but is distinguished by its intrusive setting.

Quartz diorite to tonalite (unit 10)

Sporadic quartz diorite–tonalite dikes (unit 10) are provisionally interpreted as part of the Mayville intrusion. The dikes are undeformed and locally display chilled margins. At the Hititrite occurrence at the base of the Mayville intrusion (Yang et al., 2012), a southeast-trending, 1.5 m wide dike of unit 10 cuts basal melagabbro (unit 4). The quartz diorite–tonalite is fine to very fine grained and consists of plagioclase (50–60%) quartz (10–20%), biotite (15%) and accessory K-feldspar (<10%), hornblende (5%) and minor disseminated magnetite and pyrite. In contrast to the quartz diorite–tonalite dike, the gabbroic hostrock is locally mineralized with up to 7% disseminated pyrrhotite and chalcopyrite.

Discussion

The geochemistry and origin of the Mayville intrusion were discussed in Yang et al. (2011, 2012); it was suggested that the Mayville intrusion was formed from multiple injections of tholeiitic magma derived from partial melting of the upper mantle. Successive magmas are interpreted to have undergone assimilation and fractional crystallization during transport and subsequent emplacement in an extensional tectonic setting. Geological mapping and the available geochemical data indicate that the Mayville intrusion is a composite, relatively evolved mafic–ultramafic intrusion, comparable to Archean megacrystic anorthosite complexes elsewhere (Ashwal, 1993).

The tectonic setting of the Mayville intrusion has been investigated (Yang et al., 2011, 2012) by way of various discriminant plots, such as Th/Ta vs Yb (Gorton and Schandl, 2000), Zr vs TiO_2 (Syme, 1998), Th/Nb vs Y (Syme et al., 1999), and Th/Yb vs Zr/Y (Ross and Bédard, 2009). The geochemical data and geological mapping indicate that MORB-type basalts and synvolcanic intrusive rocks (units 2b and 2a in Figure 22), as well as the Mayville intrusion itself (units 4 to 10), were emplaced in a back-arc environment, close to a continental margin characterized by a relatively thin crust (<25 km). This magmatic event may have marked the onset of arc-rifting in an extensional crustal setting.

Sulphide saturation, segregation and subsequent accumulation are thought to be the cause of Ni-Cu-PGE mineralization of the mafic–ultramafic rocks, which occurred at the contact in the basal part of the Mayville intrusion, as well as in transitional zones between different phases in the lower part of the intrusion. Although differentiation and crustal contamination may have resulted in sulphide enrichment in the residual magma, an additional external sulphur source is thought to have played a role in order to achieve sulphide saturation and subsequent mineralization of the mafic–ultramafic rocks; the identity of such a sulphur source remains, so far, problematic. Redox conditions during the evolution of the magma may have varied from reduced to relatively oxidized; this may have facilitated crystallization and accumulation of chromite, which is locally concentrated in chromitiferous layers and more diffuse zones within the intrusion.

Day 2 itinerary

The Day 2 itinerary includes four stops within the main part of the Mayville intrusion that display the anorthositic, mafic and mixed ‘breccia’ intrusive phases (stops 2.1–2.3), chromitite layering (Stop 2.3), and Ni-Cu-PGE-Cr mineralization at the main ore zone (Stop 2.4, M2 deposit). The basal contact of the intrusion with footwall basalt (not exposed) is located at Stop 2.5. In case of adverse conditions restricting access to some of stops 2.1 to 2.5, alternative outcrops that may be examined in the eastern part of the intrusion include Stop 2.6 (megacrystic anorthosite) and stops 2.7 and 2.8 (leucogabbro).

Road log (Day 2)

0.0 km—Bridge on the provincial road (PR 315) over the Bird River, at the end of the paved section (UTM 5588007N, *309299E in Zone 15U, NAD83; all co-ordinates quoted in this field guide are based on this datum). Proceed east on PR 315.*

15.3 km—Junction of PR 315 and PR 314. Continue north on PR 314.

39.4 km—Intersection (5610866N, 326141E) with the Trans-license road (logging road) to west. Turn left onto Trans-license road and proceed west for 14.1 km.

53.5 km—Intersection (5613686N, 313439E) with the Maskwa Lake road (logging road). Turn left along *the Maskwa Lake road and proceed south (across Cat Creek) for 800 m.*

54.3 km—Stop 2.1 (5612969N, 313948E).

Stop Descriptions

Stop 2.1: Leucogabbro to anorthosite (units 6 and 7)

At this location (5612969N, 313948E), the major leucogabbro to anorthosite rock units of the Mayville intrusion are well exposed. Leucogabbro is the most abundant rock type in the intrusion; it is locally gradational to anorthosite, which consists of >90% equant plagioclase crystals and subordinate interstitial hornblende. Localized igneous layering (at decimetre to metre scale) is defined by variations in grain size and/or mineralogical composition. Pegmatitic leucogabbro zones up to 2 m across are gradational with the surrounding leucogabbro.

Leucogabbro is coarse to very coarse grained or megacrystic, and contains 65–85% calcic plagioclase, 15–25% hornblende (after clinopyroxene?) and accessory Fe-Ti oxide(s), zircon and apatite. Poikilitic to varitextured varieties are not uncommon. Rare disseminated sulphide minerals are locally evident, and scattered pyrite and chalcopyrite disseminations and/or veinlets are characteristic of shear zones.

From Stop 2.1, return to the Maskwa Lake road and proceed south for 500 m, parking the vehicles at the top of the hill (5612503N, 314127E). Walk south 50 m to the intersection with a wide trail ('Mustang drill trail' in Figure 22); take the left fork and walk east on this muddy trail for 400 m to a clean outcrop on the south side of the trail (Stop 2.2, 5612469N, 314479E).

Stop 2.2: Basal mafic–ultramafic rocks (unit 4) and heterolithic breccia (HBX, unit 5)

At this locality (5612469N, 314479E), basal mafic–ultramafic rocks are interspersed with HBX; the results of detailed, 1:100 scale mapping that was conducted by Exploratus Ltd. in 2001 and Mackie (2003) are reproduced in Figure 24. A leucogabbro block in the HBX—sample 111-11-16-1—yielded a U-Pb zircon age of 2742.8 ±0.8 Ma, interpreted as the age of crystallization (Houlé et al., 2013).

The basal mafic–ultramafic rock unit consists of 1) fine- to medium-grained melagabbro, and 2) medium- to coarse-grained, locally strongly foliated and magnetite-bearing hornblendite (after pyroxenite) and associated chlorite-amphibole schist. HBX is an intrusion breccia composed of diverse rock types, including medium- to coarse-grained, locally megacrystic melagabbro, gabbro and pyroxenite, as well as various pegmatitic or megacrystic leucogabbro and anorthosite phases that occur as irregular pods, patches, veins and layers. Irregular-shaped fragments of leucogabbro to anorthosite are locally evident higher up in the breccia zone. Sporadic, partly assimilated ultramafic enclaves in the HBX are assumed to be derived from unit 4. One such xenolith—containing several saw-cuts—is conspicuous in the south-central part of the exposure; it consists of approximately 30% disseminated chromite, 60% chlorite and 10% tremolitic amphibole.

The age relationship between HBX (unit 5)—located at the south margin of the Mayville intrusion—and units 6 and 7 farther to the north (Figure 22) is not clearly determined. However, HBX appears locally to have been emplaced later than units 6 and 7, because it contains leucogabbro and anorthosite xenoliths probably derived from units 6 and 7.The HBX is intruded by a fine- to medium-grained, undeformed quartz diorite dike (unit 10) characterized by chilled margins and disseminated sulphide minerals.

From Stop 2.2, proceed east on the trail for 200 m; at this location (5612568N, 314670E) turn left and proceed northwest through a clearing with sporadic outcrops for 75 m to reach a large cleared area of extensive rock exposure (Stop 2.3, 5612599N, 314610E).

Stop 2.3: Basal mafic–ultramafic rocks (unit 4) and anorthosite (unit 6)

Basal mafic–ultramafic rocks and very coarse grained to megacrystic anorthosite and leucogabbro are interspersed at this locality (5612599N, 314610E). A disrupted, massive chromitite layer (approximately 40 cm thick) occurs locally within deformed pyroxenite (altered to an amphibole-chlorite rock). Sporadic magnetite veinlets and disseminations result in a strong magnetic response in the pyroxenite.

Gabbroic anorthosite to anorthosite at this location is a relatively thin (<50 m) but persistent member of the Mayville intrusion. The rock is very coarse grained to megacrystic, locally glomeroporphyritic. Calcic plagioclase occurs as equant, euhedral to subhedral crystals and crystal aggregates up to 10 cm in size, accounting for >80% of the rock; minor amphibole (after pyroxene) is interstitial. Sporadic pegmatitic zones in leucogabbro are gradational with the surrounding medium- to coarse-grained rock. Several pyroxenite and melagabbro dikes (up to 0.5 m wide) intrude the anorthositic rocks, which are undeformed except for localized shearing.

Return south for 75 m, back to the Mustang drill trail; turn left and proceed in a general easterly direction for 1.0 km to the intersection with a bush trail on the left at 5612609N, 315307E; take this trail and proceed east for 100 m to a large clearing with an extensive, iron-stained rock exposure (Stop 2.4—the M2 deposit—5612598N, 315438E).

Stop 2.4: M2 deposit, basal mafic-ultramfic rocks (unit 4) and heterolithic breccia (unit 5)

The extensive cleared area at Stop 2.4 was stripped of overburden and hosed clean in order to expose Cu-Ni-(PGE) sulphide mineralization at the location of the M2 deposit (5612598N, 315438E). The mineralization is hosted by basal mafic–ultramafic rocks and HBX (units 4 and 5 respectively),

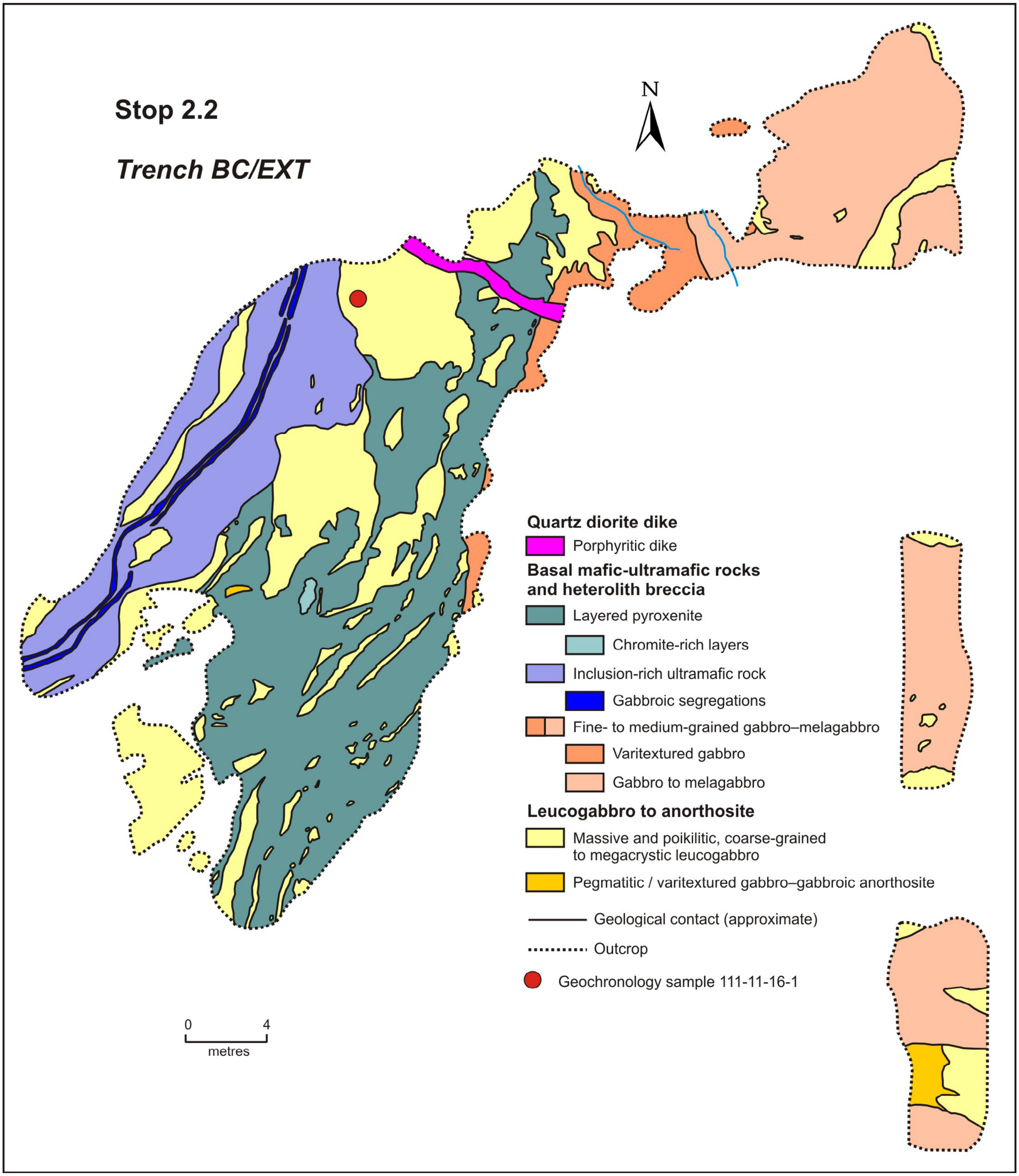


Figure 24: *Geological map of Stop 2.2, showing basal mafic–ultramafic rocks (unit 4) and heterolithic breccia (HBX, unit 5), in which disseminated sulphide minerals and chromite are present (modified after Mackie, 2003). The location of geochronology sample 111-11-16-1 (Houlé et al., 2013) is indicated at upper left.*

which are underlain by MORB-type basalt to the south. The M2 orebody is intruded by late fine-grained diabase/gabbro (unit 9); an example of this diabasic gabbro (containing leucogabbro xenoliths) is seen in the northeastern, upper part of this extensive rock exposure.

Very fine grained, northwest-facing MORB-type basalt (unit 2b) south of the cleared area represents the footwall of the M2 deposit. Massive, fine-grained amphibolite at the south margin of the cleared area may be part of unit 2b, but no pillows are preserved at this locality. Diamond-drill core indicates that the contact between the footwall MORB-type basalt and melagabbro (unit 4) immediately to the north is faulted. The melagabbro is medium- to coarse-grained and contains 65–80% amphibole (after clinopyroxene) and up to 15% plagioclase. Pyrrhotite (± minor chalcopyrite and pyrite) occurs as disseminations, net-textured veins and locally in massive sulphide layers. The rocks are characterized throughout by rusty-weathered surfaces due to widespread oxidation of sulphide minerals.

Heterolithic intrusion breccia overlying the mineralized melagabbro consists of subrounded to irregular leucograbbro and anorthosite fragments/diffuse zones within a matrix of medium-grained melagabbro and pyroxenite. Sulphide minerals in the breccia (pyrrhotite, chalcopyrite, pyrite and pentlandite) occur as disseminations, blebs and/or veinlets.

The M2 deposit consists of several lensoid ore bodies that strike east-northeast (067°) and dip steeply to the south, according to the 3D-modelling scheme of Ross and Evans (2006). The orebodies range in thickness from 2 m to 100 m or more; sulphide mineralization is continuous along strike for at least 800 m and extends down dip for up to 350 m below the surface.

Three styles of magmatic sulphide mineralization have been identified within the Mayville intrusion: 1) contact-style magmatic Ni-Cu-PGE at the base of intrusion; 2) reef-style, stratiform magmatic Ni-Cu-PGE-Cr mineralization; 3) mineralization at contacts or diffuse transitional zones between different intrusive phases, e.g., between melagabbro and pyroxenite within HBX. The Ni, Cu, and PGE contents of the mineralized rocks correlate positively with their sulphur contents (Figure 25; Peck et al., 1999; Yang et al., 2011, 2012). The Cu content of the M2 orebodies is typically higher than Ni; Pd/Pt ratios are consistently greater than 3.0 (Ross and Evans, 2006; Peck et al., 2002).

From Stop 2.4, return west 100 m back to the Mustang drill trail; turn right (northwest) and retrace the route for 1.6 km, back to the intersection with the Maskwa Lake road, very close to the vehicle parking spot; then turn left and proceed south for 450 m to arrive at Stop 2.5 (5612056N, 314091E).

Stop 2.5: Pillowed to massive basalt (unit 2b)

Pillowed to massive (MORB)-type basalt that faces northeast represents the footwall of the Mayville intrusion at this locality (5612056N, 314091E). The pillows are strongly deformed and characterized by 1-2 cm thick spherulitic selvages. The aphyric flows here are typical for unit 2b, but subordinate plagioclase-phyric or megacrystic basalt occurs elsewhere. Synvolcanic gabbro intrusions (unit 2a) are common in the volcanic sequence, especially northwest of Donner Lake (Figure 22). The amphibole-plagioclase-epidote±chlorite mineral assemblage is consistent with the lower amphibolite facies grade of metamorphism inferred for these rocks. Map unit 2 ('Mayville assemblage' of Bailes et al., 2003) is geochemically and petrologically equivalent to the Northern MORB-type Formation of Gilbert et al. (2008).

From Stop 2.5, return north-northeast along the Maskwa Lake road for 500 m to reach the hilltop parking area. Drive a further 800 m north to the junction with the Trans-license road (5613686N, 313439E) and turn right. Proceed east for approximately 5.6 km to the junction with the Donner Lake road (5611937N, 318329E). Fork right onto the Donner Lake road and proceed south for 2.0 km, stopping to park at the intersection with a bush trail on the west side of the road (5610122N, 317817E). Walk west for 300 m to a high, steep-sided outcrop on the south side of the trail (Stop 2.6, 5610187N, 317590E).

Stop 2.6: Megacrystic anorthosite (unit 6)

Megacrystic gabbroic anorthosite to anorthosite that forms a 10–20 m wide sill within MORB-type basalt at this location (5610187N, 317590E) is interpreted as part of the Mayville intrusion. Euhedral, equant plagioclase crystals and crystal aggregates up to 6 cm across constitute approximately 90% of the sill. The megacrysts are typically associated with interstitial amphibole (after clinopyroxene), but are locally set in a groundmass of medium- to coarse-grained, plagioclase-phyric melagabbro. Igneous layering, defined by grain-size variation and/or modal variation, suggests the sill is north facing, consistent with the surrounding north-facing pillowed flows (Macek, 1985a; Peck et al., 2002; Yang et al., 2012). The anorthosite is generally massive and undeformed, but minor sheared zones are locally evident.

From Stop 2.6, return east for 300 m to the parking spot and thence proceed 2.0 km north on the Donner Lake road to the junction with the Trans-license road. Turn right and proceed east approximately 750 m to a small outcrop on the north side of the road, just east of a creek (Stop 2.7, 5611603N, 319143E).

Stop 2.7: Leucogabbro to gabbroic anorthosite (unit 7)

Very coarse grained to megacrysitic leucogabbro to gabbroic anorthosite is well preserved at this locality (5611603N, 319143E). A narrow gabbro dike intrudes the anorthosite, which is also locally cut by a conspicuous shear zone.

From Stop 2.7, drive farther east for approximately 250 m and park at the side of the road. Walk north approximately 320 m to Stop 2.8 (5611829N, 319160E).

Stop 2.8: Leucogabbro to gabbroic anorthosite (unit 7)

Very coarse grained to megacrystic leucogabbro to gabbroic anorthosite is well exposed along a small ridge at Stop 2.8 (5611829N, 319160E). Localized igneous layering is defined by grain-size and/or mineralogical variation.

Acknowledgments

We are grateful to C. Böhm for invaluable guidance and support, especially at the beginning of the mapping project, as well as L. Lafreniere (University of Manitoba), M. Hamilton (Brandon University), and C. Boudreau (Université Laval), who provided assistance in the field. We are also indebted to Mustang Minerals Corp. for providing access to their property, drillcore and geological database; J. Fulton-Regula and A. Dietz are thanked for their generous assistance. P.D. Kremer and M.T. Corkery offered comments and fruitful discussion regarding the geology of the Bird River greenstone belt. B. Lenton is thanked for drafting the figures.

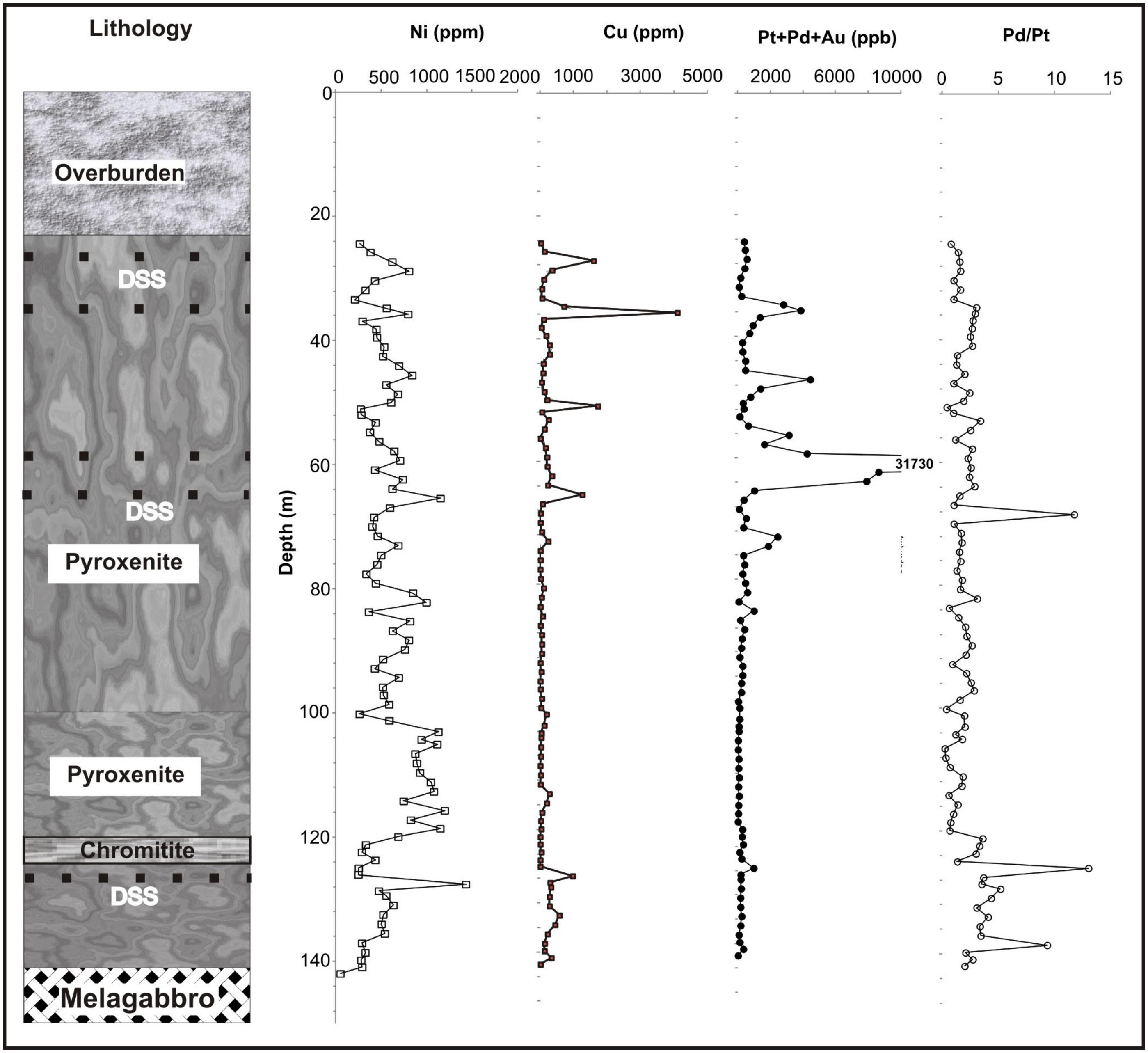


Figure 25: Variation in the concentrations of base metals (Ni and Cu, in ppm) and precious metals (combined Pt+Pd+Au, in ppb), and Pd/Pt ratios in drillcore. Analytical data are from diamond-drill hole MAY-11-07 (depth of drillcore in metres) in Mustang Minerals Corp. (2011). DSS denotes disseminated sulphide minerals consisting of chalcopyrite, pyrrhotite, pentlandite and minor pyrite (indicated by sporadic black squares).

DAY 3: Ni-Cu-(PGE) SULPHIDE MINERALIZATION IN THE BIRD RIVER GREENSTONE BELT

by C.A. Mealin, M.G. Houlé, V. Bécu, and C.R. Galeschuck

Introduction

Day 3 of the field trip is devoted to examining and comparing the Ni-Cu-(PGE) sulphide mineralization associated with 1) the Bird River Sill and 2) the Mayville intrusion, located in the main part and northern arm of the Bird River greenstone belt, respectively. The primary goals are to examine the following:

- mafic and felsic volcanic country rocks of one of the Ore Fault mafic–ultramafic intrusions and amphibolite derived from an intrusive phase, as well as remobilized Ni-Cu mineralization within the Peterson Creek Shear Zone (Duguet et al., 2007) on two stripped outcrops
- peridotitic rocks hosting the main part of the Ni-Cu-(PGE) mineralization—as well as Ni-Cu-(PGE) sulphide veins within the footwall volcanic rocks—in the vicinity of the Maskwa deposit open pit
- surface exposures showing the Ni-Cu-(PGE) mineralization associated with the Dumbarton mineralized horizon
- representative mineralized intervals—in drillcores—of the basal Ni-Cu-(PGE) mineralization at the Maskwa deposit, of the stratabound Ni-Cu mineralization of the Dumbarton horizon, and of the Cu-Ni-(PGE) contact-style and PGE reef-style mineralization in the Mayville intrusion

Ore Fault deposits

As the name implies, previous geological interpretations of the Ore Fault property and associated mafic–ultramafic intrusions invoked a northwest-trending fault that separated the Maskwa and Page intrusions of the Bird River Sill. In this model, the Ore Fault intrusions were interpreted as small, fault-bounded slices of the Bird River Sill (Anderson, 1997). Recent studies by Duguet et al. (2006, 2007) and Mealin (2008) discount the existence of major, north-northwest-trending faults and shear zones subdividing the Bird River Sill (Trueman, 1971), and interpret Maskwa and Page intrusions, as well as other parts of the sill, as separate intrusive bodies. The following section is based on the most recent work on the Ore Fault property by Good et al. (2009).

Geology of the Ore Fault property

The Ore Fault deposit is associated with two mafic–ultramafic intrusive bodies that are emplaced in a sequence of felsic-intermediate tuff and mafic volcanic flows near the margin of the Maskwa Lake Batholith (Figure 26, 27), 2 km north of the junction between PR 314 and 315 in Figure 2. The Ore Fault mafic–ultramafic intrusions are partly to completely altered to serpentinite and related serpentine-talc-carbonate-bearing rocks that grade into amphibolite near the margins of the intrusions. The amphibolite is interpreted to represent an altered mafic phase of the Ore Fault intrusions. The serpentinite and, to a lesser extent, the amphibolite locally contain centimetre-sized magnetic ferrochromite clasts. Compared to other Bird River Sill bodies, the Ore Fault intrusions are much narrower and have a different orientation; they are 40–80 m thick and trend north-northwest, with moderate dip to the west.

The mafic flows and felsic-intermediate fragmental volcanic rocks that are exposed within the vicinity of the Ore Fault property are assumed to overlie the Maskwa Lake Batholith. The mafic flows consist of fine- to medium-grained, massive and pillowed basalt. This unit has undergone variable chlorite-epidote-carbonate alteration, but pillow selvages are well preserved and indicate a south to southwest younging direction. The felsic-intermediate volcaniclastic rocks are locally interlayered with the mafic volcanic flows (Figure 27). The fragmental unit is comprised of crystal-lapilli-tuff, which contains abundant round blue quartz ‘eyes’ and subrounded to angular, elongate, white lithic fragments in a fine-grained, gray to black matrix. Both volcanic rock types are cross-cut by quartz-feldspar porphyry dikes. These dikes have a very fine grained, siliceous groundmass that contains subrounded blue quartz and subhedral to euhedral, white plagioclase phenocrysts.

The regional foliation trends east-southeast to east-northeast and is defined by biotite and/or chlorite in both the mafic and felsic-intermediate volcanic rock types. All rock units within the Ore Fault property have been deformed by faults and/or shear zones. Faults strike north to northwest, dip steeply southward and are cross-cut by northeast- to east-trending, 1–8 m wide shear zones (Murphy and Theyer, 2005). The east-trending shear zone is interpreted as part of an array of anastomizing shear zones—the regional Peterson Creek Shear Zone, characterized by ‘north-side-up’ displacement and left-lateral movement (Duguet et al., 2007).

Mineralization of the Ore Fault property

Ni-Cu mineralization was first reported at the Ore Fault property in the 1950’s. Previous investigations on sulphide mineralization include those Nickel (1971), Raicevic and Bruce (1971), Ritchie (1973), Juhas (1973), Anderson (1997), Petak (2005), and Murphy and Theyer (2005). In general, there are three types of mineralization present at the Ore Fault property: 1) magmatic Ni-Cu sulphides associated with the Ore Fault mafic–ultramafic intrusive bodies; 2) shear-hosted Ni-Cu sulphides associated with the northeast-trending Peterson Creek Shear Zone; and 3) Zn-Cu-Ag vein or stockwork mineralization contained within quartz veins and intense garnet-chlorite alteration domains associated with north-trending faults.

The magmatic Ni-Cu sulphide mineralization consists of disseminated, net-textured, and massive sulphides hosted by serpentinite and amphibolite in the stratigraphically lower Ore Fault mafic–ultramafic intrusive body (Figure 27). Massive sulphide layers consist predominantly of pyrrhotite with minor pentlandite, and rare violarite and smythite (Nickel, 1971; Richie, 1973). Net-textured to disseminated sulphides in the immediate vicinity of the massive sulphide mineralization are typically chalcopyrite rich. The stratigraphically upper,

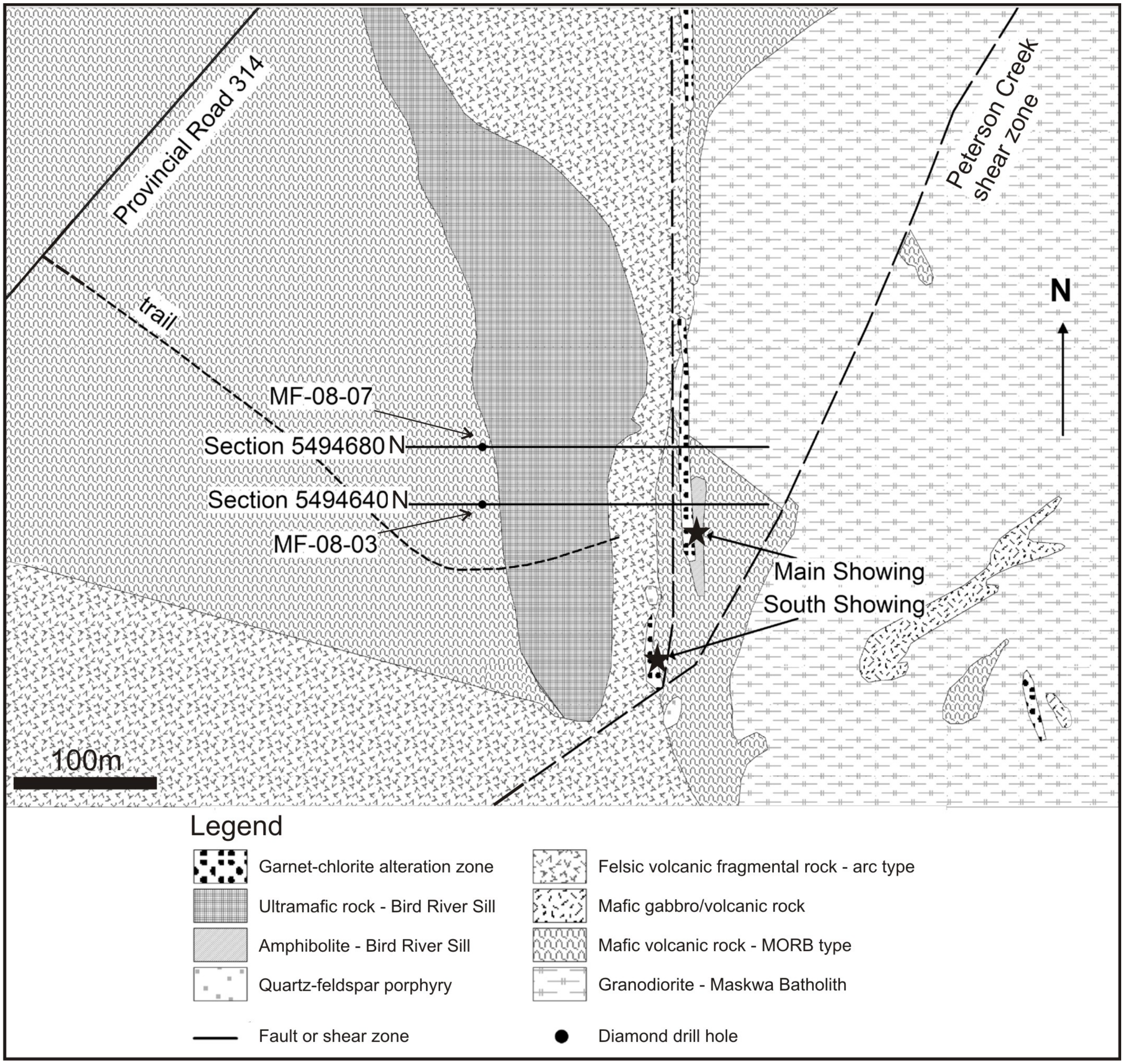


Figure 26: *Geological map of the Ore Fault property, showing locations of diamond-drill holes and section lines depicted in Figure 27. From Good et al. (2009).*

ultramafic intrusion contains disseminated pyrrhotite and chalcopyrite.

Within the main and southern showings (Figure 26), shear zones contain massive to disseminated sulphide mineralization which consists mainly of a concentration of fine-grained pyrrhotite and lesser chalcopyrite (Murphy and Theyer, 2005). Sulphides are interpreted to have been mobilized from the local mafic and ultramafic rocks (Murphy and Theyer, 2005).

The third style of mineralization at the Ore Fault property (but not discussed in detail here) consists of a later hydrothermal Zn-Cu-Ag mineralization within a garnet-chlorite alteration zone associated with north-trending faults, and cut by quartz veins. The mineralization consists of sphalerite, chalcopyrite, pyrrhotite and minor galena.

Maskwa-Dumbarton Deposits

Geology of the Maskwa-Dumbarton area, Makwa property

The main stratigraphic feature of the Makwa property is the Maskwa intrusion, a part of the Bird River Sill that extends east along strike for approximately 5 km (Figure 28). It consists of a lower ultramafic series composed of peridotite, pyroxenite with localized chromitite horizons, and an upper mafic series composed of leucogabbro, anorthositic gabbro, anorthosite and sporadic glomeroporphyritic gabbro. The mafic–ultramafic intrusion is underlain by pillowed to massive volcanic rocks of the Northern MORB-type Formation (formerly Lamprey Falls Formation of Černý et al., 1981) and unconformably overlain

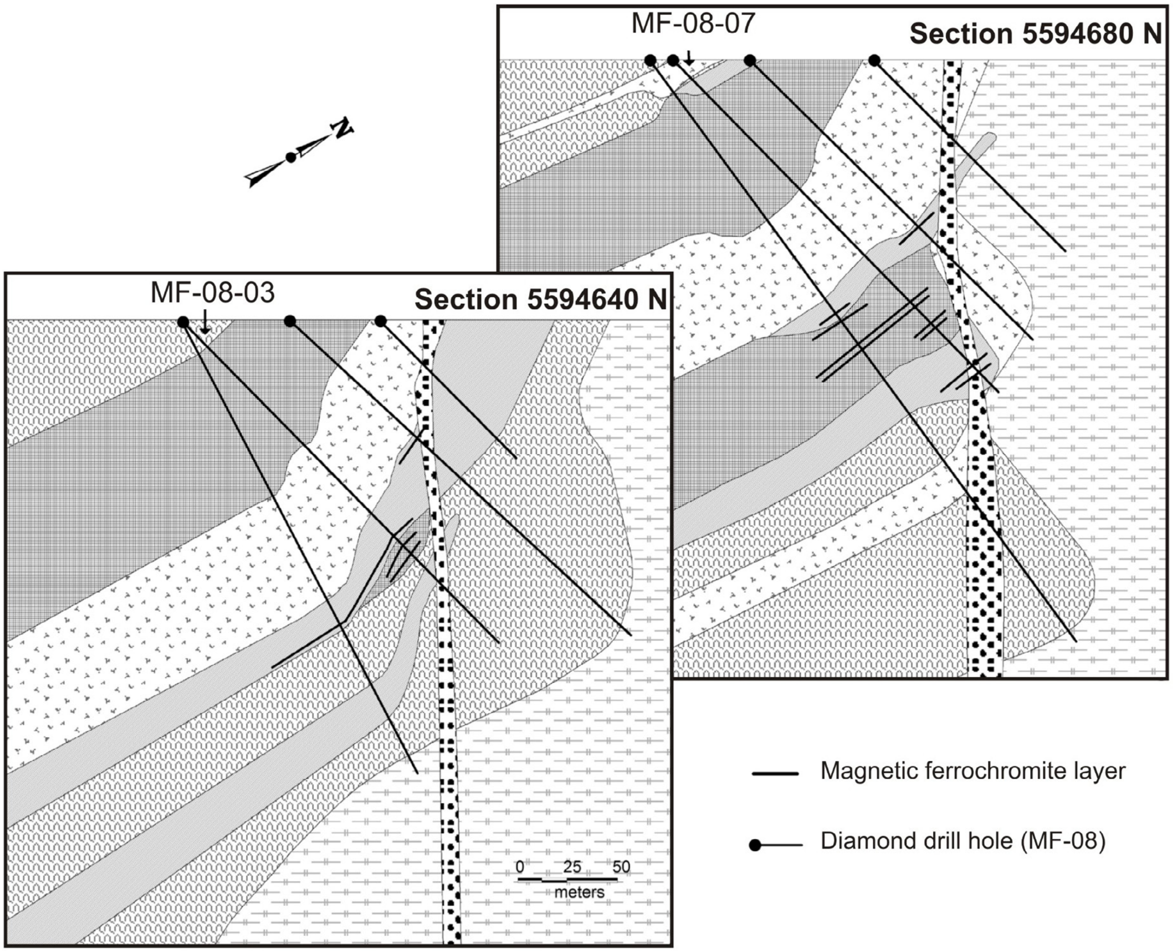


Figure 27: *Cross-sections of the Ore Fault deposit showing the geology and diamond-drill hole locations. Legend as in Figure 26. Section lines are indicated in Figure 26. From Good et al. (2009).*

by felsic volcanic rocks of the Peterson Creek Formation (Gilbert et al., 2008).

The Maskwa intrusion is a subvertical, south-facing sill that intrudes granitoid rocks of the Maskwa Lake Batholith to the north; peridotitic dikes also intrude the batholith and are interpreted as feeder dikes for the Maskwa intrusion immediately to the south (Shegelski, 2008). A sulphide-facies iron formation that occurs within the volcanic succession at the north margin of the mafic–ultramafic Maskwa intrusion has been delineated by geophysics, in conjunction with diamond drilling. This formation extends intermittently for 8 km across the Makwa property; similar rocks south of the junction between PR 315 and 314 are interpreted as part of the same stratigraphic unit, approximately 7.5 km west of the iron formation locality north of the Maskwa intrusion (Harper, 2004). The iron formation is interpreted by Juhas (1973) to be vertically zoned, with magnetite-rich layers predominant near the base (north side) and sulphide-rich zones more abundant to the south, nearer the hanging wall of the Maskwa orebody.

Four styles of orthomagmatic mineralization have been recognized within the Maskwa mafic–ultramafic intrusion by Ferreira et al. (1999); minor mineral showings described by Juhas (1973) are not necessarily related to the Bird River Sill and are not included in this discussion. The four main mineralization styles are represented by 1) the Maskwa Ni-Cu-PGE deposit, 2) the Dumbarton Ni-Cu deposit, 3) the F-Zone Cu-Ni deposit, and 4) chromite mineralization within the ultramafic part of the intrusion. The Maskwa Ni-Cu-PGE and the Dumbarton Ni-Cu deposits are described in more detail below. The F-Zone deposit occurs along strike to the east of the Dumbarton deposit, and is located at the same stratigraphic horizon as that deposit. The grade and tonnage of the F-Zone deposit is unknown, because previously-quoted production figures were invariably combined with those of the Dumbarton deposit. The chromite mineralization is located near the contact between the ultramafic and mafic series of the intrusion. Ferreira et al. (1999) reported that the chromite occurs as stratigraphic layers up to approximately 10 feet thick, grading up to ~25% Cr_2O_3 over widths of several feet. The Fe:Cr ratio appears to be low (approximately 1:1); the combined Pd+Pt content is up to 1.5 g/t. In 2008, a drilling program by Mustang Minerals Corp. (unpublished data) reported Cr/Fe ratios greater than 3 (locally with Cr >40 wt.%).

Mineralization of the Maskwa-Dumbarton deposits

Ni-Cu-(PGE) Mineralization at the Maskwa mine

The Maskwa deposit, discovered in May 1974, produced 8,491,000 pounds of Ni and 1,464,000 pounds of Cu (Harper,

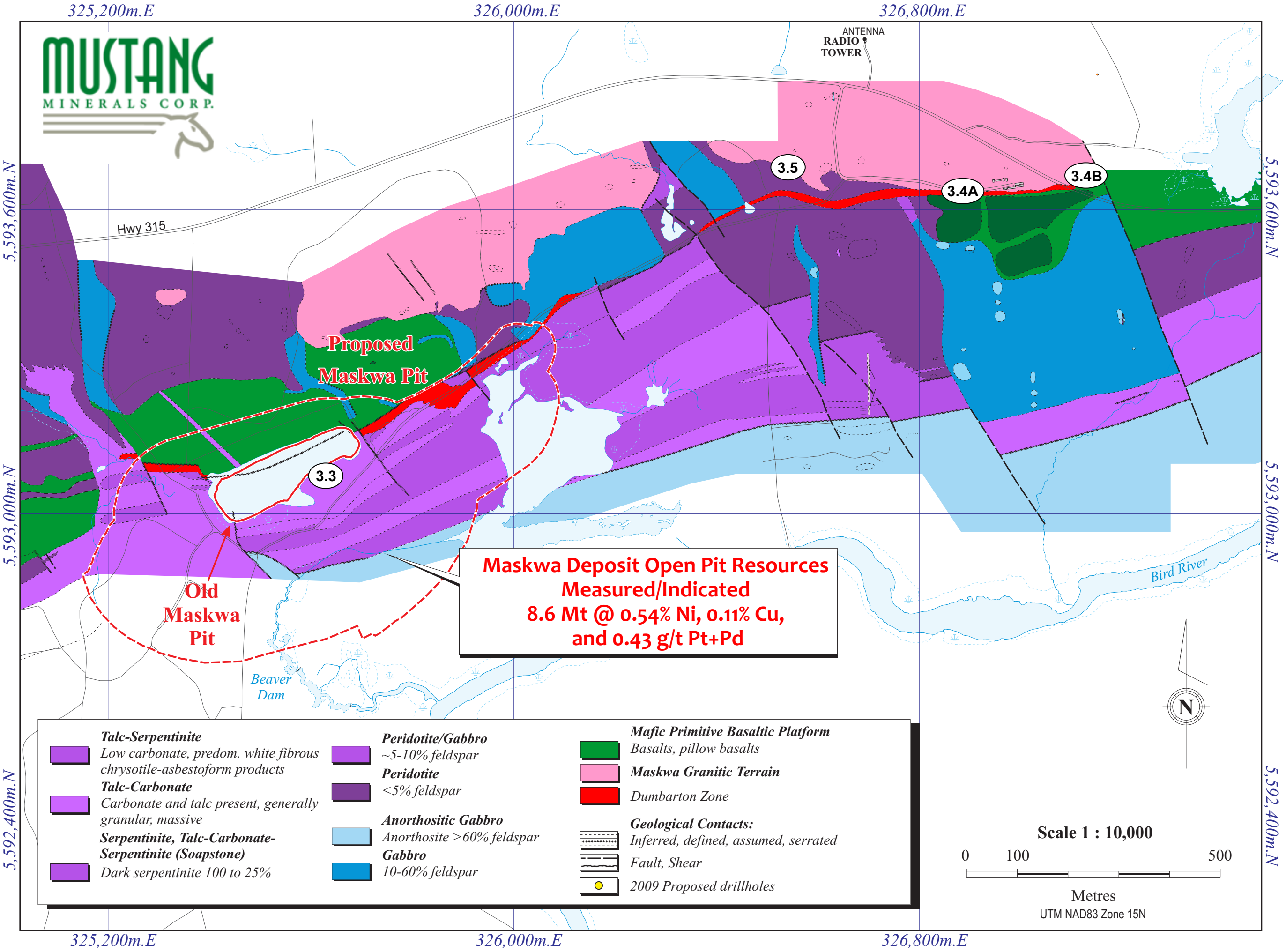


Figure 28: *Simplified geological map of the Mustang Minerals Corp. Makwa property (Mustang Minerals Corp., unpublished data), showing stop locations 3.3 to 3.5.*

2004). Approximately 0.37 Mt of ore averaging 1.16% Ni and 0.23% Cu were mined from the Maskwa deposit open pit from 1974 to June 1976 (Coats et al., 1979). Recently, Mustang Minerals Corp. completed an updated mineral estimate that raised the geological resource—in the probable category—to 9.86 Mt with 0.54% Ni, 0.11% Cu and 0.43g/t PGE (Mustang Minerals Corp., 2013).

The Maskwa deposit is a basal Ni-Cu-PGE sulphide mineralization type, located at or near the base of the Ultramafic Series of the Maskwa intrusion within the Bird River Sill (Harper, 2004; Figure 29). The sulphide horizon strikes east-northeast (060º–070º), parallel to the Bird River Sill at this locality, and dips subvertically (60º–90º). The deposit appears to have a moderate plunge to the southwest, is approximately 500 m long by 10 m wide, and extends at least 500 m below surface. The ore zone is characterized by lenses containing 10–15% disseminated sulphide minerals; other facies types include massive, semi-massive and net-textured sulphides (Figure 30b, c, d). All types appear to consist largely of pyrrhotite, pentlandite, chalcopyrite, pyrite and minor merenskyite (Stansell, 2006). The ultramafic hostrock at the Makwa property consists of grey-weathering peridotite, altered to a talc-carbonate-serpentine-chlorite assemblage. The content of dark green to black serpentine is variable (Coats et al., 1979); typically, irregular patches of serpentine are surrounded by a talc-carbonate matrix. Sporadic, elongate bladed serpentine crystals are interpreted by Coats et al. (1979) to be due to serpentinization of metamorphic olivine. Numerous north-northwest–trending faults displace the Bird River Sill in the immediate vicinity of the Maskwa open pit, but the amount of displacement is uncertain. Harper (2004) interpreted north-striking faults that intersect the Maskwa ore zone as reverse, and thus may have induced structural thickening of the deposit in that area.

The sulphide mineralization at the Maskwa deposit has been interpreted as due initially to segregation of immiscible sulphides, with extensive (post-magmatic) modification suggested by textural features resulting from subsequent remobilization and recrystallization (Coats et al., 1979; Stansell, 2006).

Ni-Cu Mineralization at the Dumbarton mine

The Dumbarton deposit and the F-Zone were mined from 1969 to 1973 from the Dumbarton portal. A total of 1,540,000 tonnes averaging 0.81% Ni and 0.30% Cu was extracted from underground workings, to produce 24,948,000 pounds of nickel (Coats et al., 1979). The Dumbarton deposit was mined to a

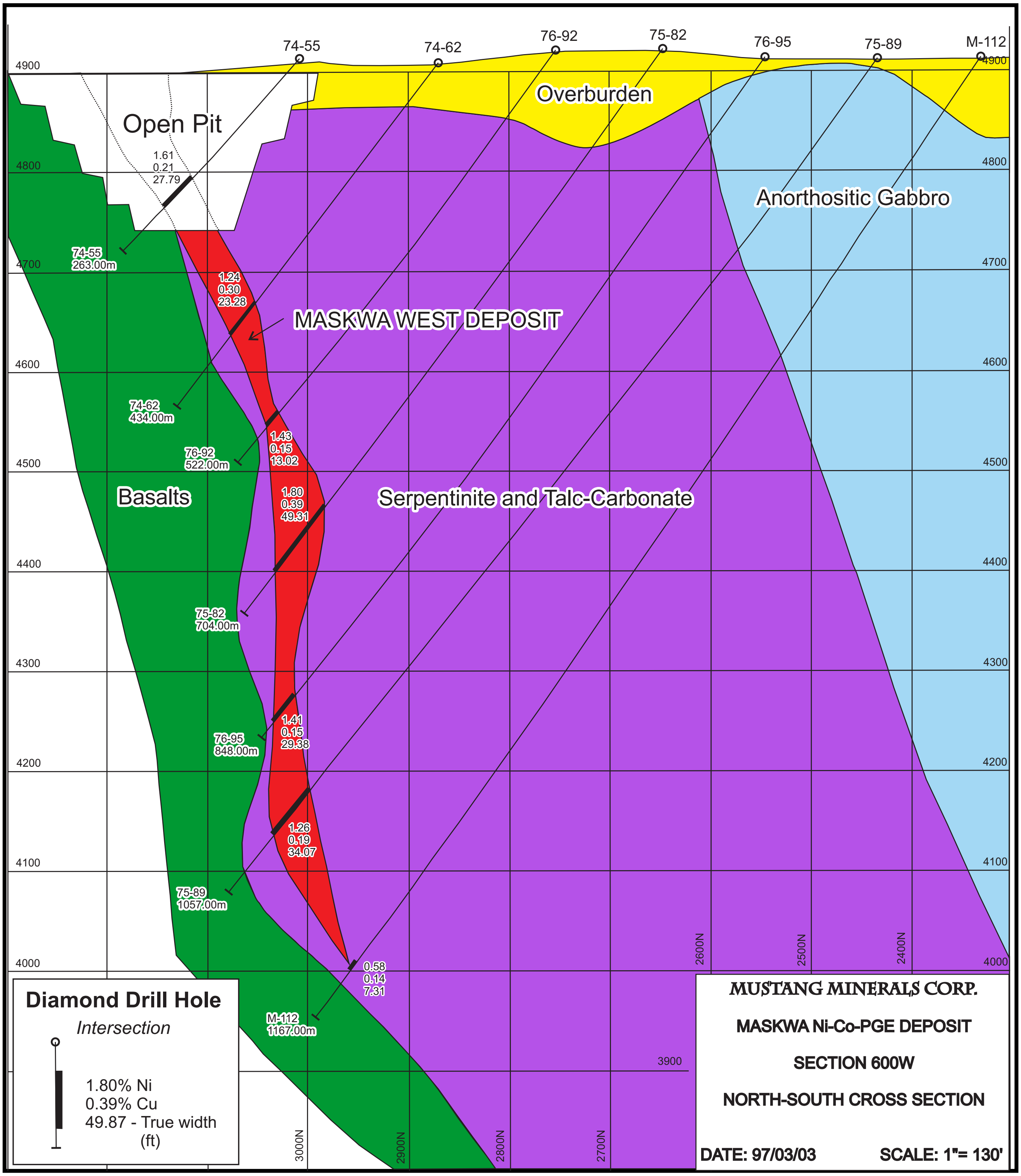


Figure 29: *Geological cross-section 600W of the Maskwa Ni-Cu-PGE deposit (modified after Ferreira et al., 1999; section is north (left) to south (right).*

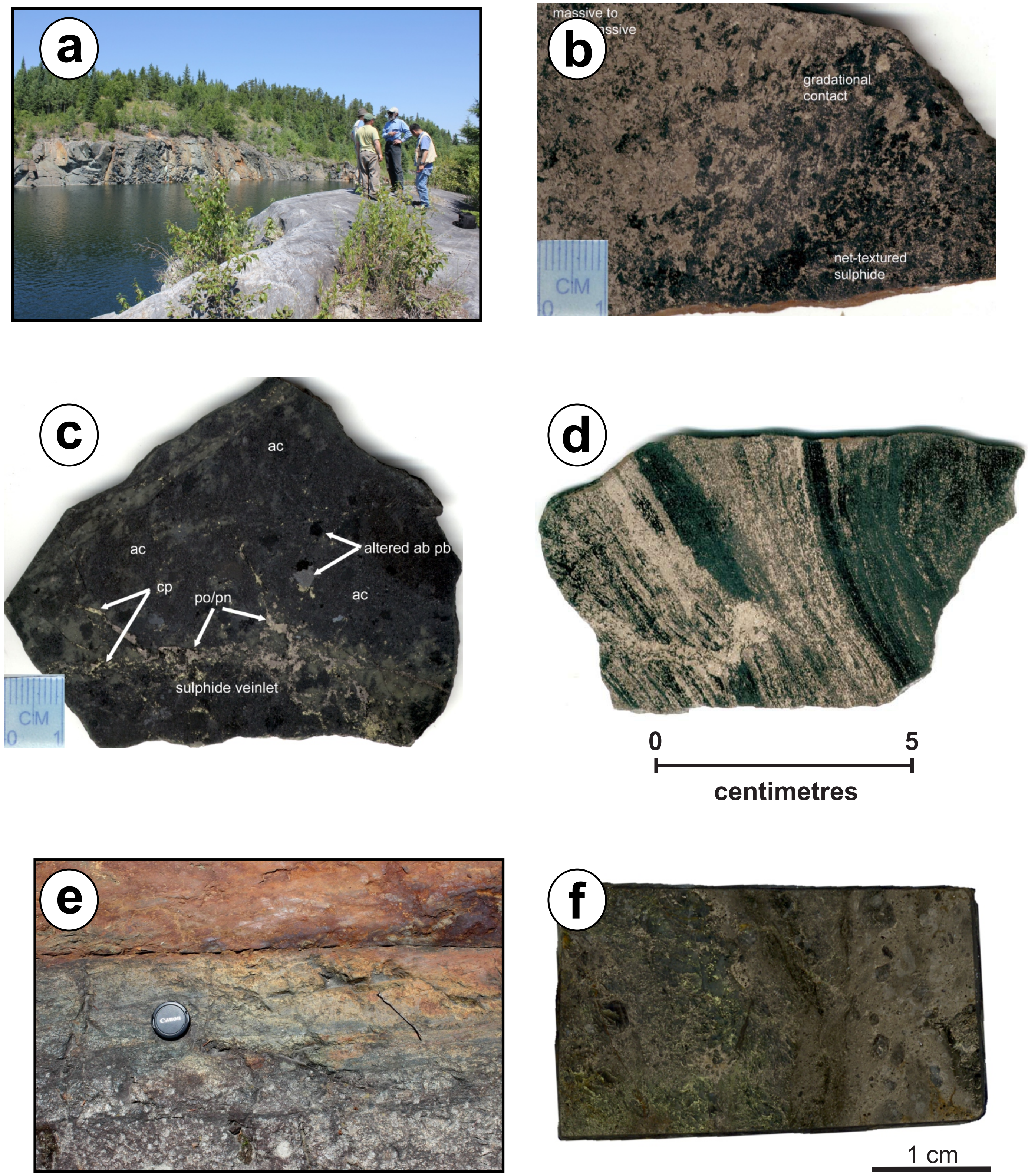


***Figure 30:** Field photographs and polished slab images of selected samples highlighting contact features and ore textures at Maskwa open pit and the former Dumbarton mine: **a)** Maskwa open pit, looking north; **b)** Maskwa waste pile: sample showing the transition between net-textured sulphide minerals and massive to semi-massive sulphide minerals (from Stansell, 2006); **c)** Maskwa waste pile: massive to disseminated pyrrhotite with minor pentlandite, cross-cut by remobilized sulphides (from Stansell, 2006); **d)** Maskwa waste pile: macroscopic image of amphibolite showing narrow chalcopyrite-pyrrhotite-pentlandite-pyrite veinlets crosscutting hostrock (altered komatiitic basalt). Large blocky grains are possibly relict pyroxenes (now actinolite), possibly replacing former amphibole porphyroblasts (pb) or pyroxenes (from Stansell, 2006); **e)** Contact between the Dumbarton horizon and the structural hanging wall at Stop 3.4B; **f)** Dumbarton deposit: macroscopic image of massive to semi-massive pyrrhotite, pentlandite and chalcopyrite interspersed with amorphous mafic minerals and magnetite. This sample yielded 2.03% Ni and 0.67% Cu.*

vertical depth of 183 m over a strike length of approximately 750 m, whereas the F-Zone was mined to a vertical depth of 150 m over a strike length of approximately 150 m. At the Dumbarton mine and vicinity, sulphides occur within volcanic rocks, near or at the contact with granitoid rocks; the volcanic rocks appear to be located at the same stratigraphic horizon as a sulphide-facies iron formation. This iron formation is described as intermittent over an 8 km strike length, averaging 1–2 m in thickness, and containing pyrrhotite-rich sulphide and chert layers, locally associated with graphitic shales (Ferreira et al. 1999; Harper, 2004). Gabbroic plugs and ultramafic rocks disrupt the sedimentary rocks at this horizon.

According to Juhas (1973), an ideal north–south profile across the mineralized zone should encounter—successively—the following rock types: quartz diorite, mafic volcanic rocks intercalated with gabbro and/or calcareous sedimentary rocks, the mineralized zone, basalt, and the mafic–ultramafic Maskwa intrusion (Bird River Sill). In several places—but not everywhere—the rocks associated with the mineralized zone are separated from granitic rocks by cordierite schist and grunerite-rich quartzite (interpreted as metamorphic equivalents of silicate-facies iron formation), massive andesite, and massive gabbro or calc-silicate rock (Figure 31). The Dumbarton mineralized zone can be subdivided into 1) a lower member, characterized by massive magnetite layers and irregular sulphide pods, veinlets and disseminations, and 2) an upper member with massive sulphide layers, but lacking magnetite (Juhas, 1973). Drillhole data indicate the lower member is very irregular and lenticular in shape, whereas the upper member is a more consistent layer with an average width of 40 cm (Juhas, 1973).

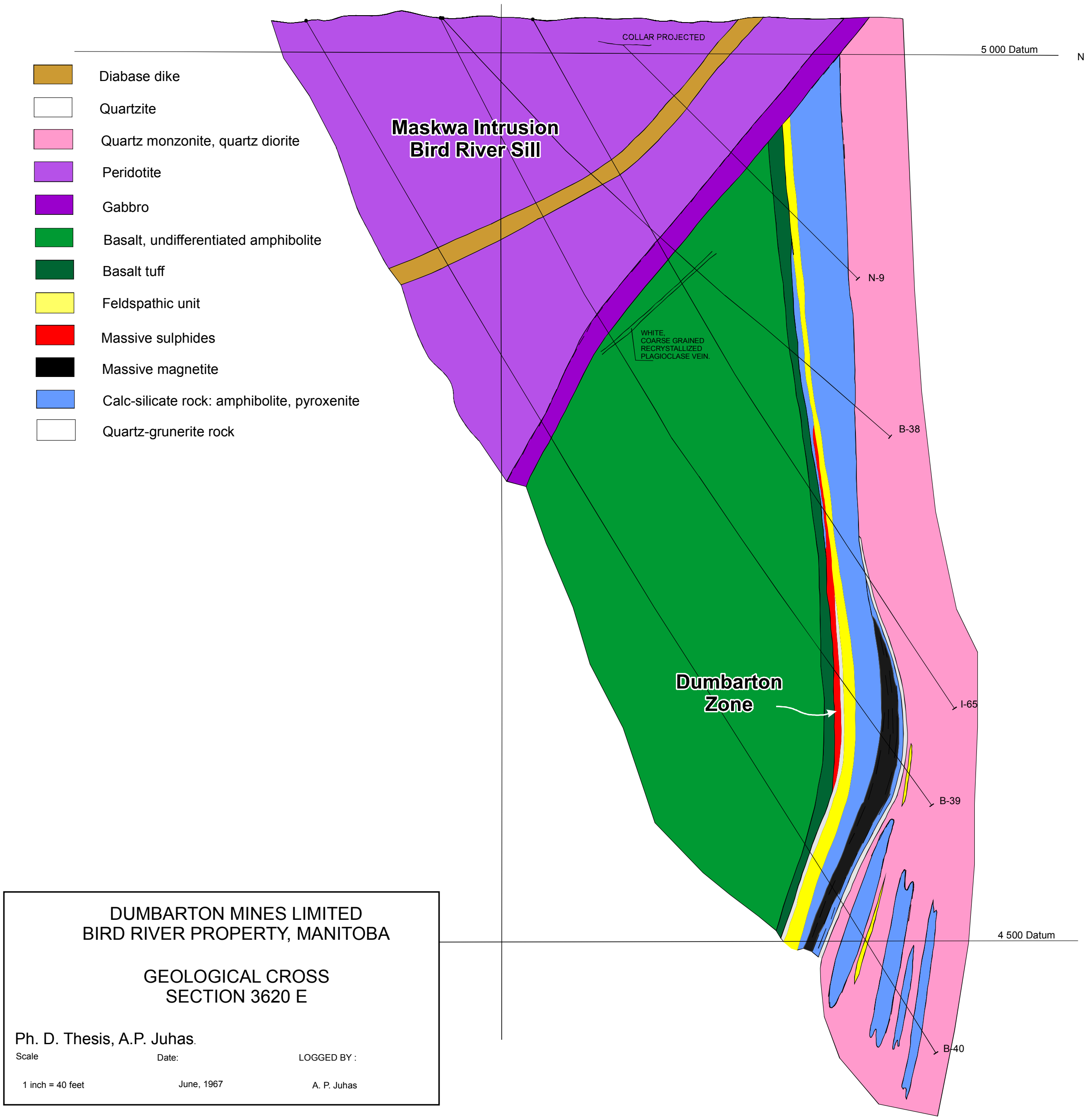


Figure 31: *Geological cross-section 3620E of the Dumbarton Ni-Cu deposit (modified after Juhas, 1973). Section is north (right) to south (left).*

Pyrrhotite, the dominant primary sulphide mineral, is associated with minor to trace amounts of interstitial pentlandite and/or chalcopyrite, and rare grains of sphalerite, primary pyrite, cubanite, and galena. Rare cobaltite is the only arsenide mineral observed.

Over the years, various interpretations have been proposed to explain the origin of the Ni and Cu mineralization found at Dumbarton mine. Juhas (1973) noted that the iron formation on the Makwa property is nickel bearing when located between granitoid intrusions and the ultramafic portion of the Bird River Sill. He concluded that nickel ions, released during dehydration and metamorphism of the ultramafic rocks of the Bird River Sill, were superimposed upon the existing sulphide-facies of iron formation. However, Ferreira et al. (1999) observed that the most extensive and highest-grades of Ni and Cu mineralization at Dumbarton appear to occur adjacent (on both sides) to a 60 m long gabbroic plug within the iron formation, and that this gabbro apparently influenced the localization and enrichment of Ni and Cu at this horizon. Karup-Möller and Brummer (1971) have reported clear evidence of shearing, brecciation and disruption of the ore zone at Dumbarton. Shegelski (2008) followed the surface manifestations of this mineralized horizon and noted a lack of tangible evidence on surface for the presence of an iron formation (Figure 30f); he interpreted this horizon as an initial magmatic nickel-rich sulphide deposit which was subsequently enriched in copper during remobilization by granitoid rocks. Analogies were drawn between the Dumbarton mine and mineralization in ultramafic skarn deposits elsewhere, which could explain the introduction of additional copper into the Dumbarton system. Furthermore, Shelgelski (2008) suggested that late ductile shearing disrupted and smeared out the Dumbarton ore into its present easterly trend, along the contact with the hanging-wall basaltic member to the south.

Day 3 itinerary

Surface exposures of the Ore Fault intrusion and its hostrocks will be examined first, after which the group will proceed to the Maskwa open pit, where altered ultramafic rocks in the mineralized zone and the contact with footwall basalt are exposed. If time allows, the Dumbarton Nickel zone will be included in the itinerary, otherwise the final part of the trip will take place at the Mustang Minerals core storage facility, where drillcore from the Mayville and Maskwa intrusions will be examined.

Road log (Day 3)

0.0 km—Bridge on the provincial road (PR 315) over the Bird River, at the end of the paved section (UTM 5588007N, 309299E in Zone 15U, NAD83; all co-ordinates quoted in this field guide are based on this datum). Proceed east on PR 315.

15.3 km—Junction of PR 314 and PR 315. Continue north on PR 314 for 2 km.

17.3 km—Junction with an unpaved track heading southeast from the road (5594814N, 322072E). Walk 500 m along this track to a clearing with extensive (water-hosed) outcrop—Stop 3.1 (5594612N, 322529E).

Stop Descriptions

Safety

The two Ore Fault localities are steep-sided rock exposures that require care, especially in wet weather. Please be cautious and mindful not to dislodge rocks that might fall on others below.

Stop 3.1: Ore Fault property, Main Showing

This outcrop is one of the few surface exposures of an Ore Fault mafic–ultramafic intrusive body. Amphibolite at this locality (5594612N, 322529E) was initially mapped as massive basalt but has since been reinterpreted as an altered mafic phase of the Ore Fault intrusion. The amphibolite locally contains abundant ferromagnetic chrome clasts (Figure 32a). Pyrrhotite and chalcopyrite are disseminated throughout the outcrop and also concentrated within two northeast-trending shear zones (Murphy and Theyer, 2005).

From Stop 3.1, continue south for 100 m along the track that led from Hwy 314 to Stop 3.2 (5594520N, 322500E).

Stop 3.2: Ore Fault property, Southern Showing

This stop (5594520N; 322500E) contains mafic volcanic flows, felsic-intermediate tuff and quartz-feldspar porphyry that represent the hostrocks of the Ore Fault mafic–ultramafic intrusive bodies. These rocks are moderately to extensively chloritized and deformed by several well defined north- to northwest-trending faults. The faults are cross-cut by an 8 m wide, northeast-trending shear zone that contains massive pyrrhotite-chalcopyrite mineralization (Murphy and Theyer, 2005; Figure 32b). Mafic volcanic flows dominate the outcrop and consist of sparsely mineralized pillowed basalt and locally rusty-weathering, massive basalt near the southern edge of the exposure (Figure 32c, d). Feldspathic tuff at the western side of the outcrop contains angular to rounded, 2 mm blue quartz crystals, 1 mm plagioclase crystals, and 1–5 mm garnets in a fine-grained matrix (Murphy and Theyer, 2005). The tuff locally contains altered, chlorite-garnet-bearing lapilli (Figure 32e). Quartz-feldspar porphyry at the eastern edge of the outcrop contains subrounded blue quartz eyes and is characterized by a very fine grained, siliceous groundmass, and conchoidal fracture (Figure 32f). The three rock types depicted in Figure 32c–f all locally occur as large (>1 m wide) boudins within the northeast-trending shear zone. Quartz veins within the shear zone contain steep, south-plunging folds that display a left-lateral sense of movement.

From Stop 3.2, walk 500 m back along the same track to return to the vehicles. Proceed southwest along PR 314 for 2 km to the junction with PR 315, turn left (east) and proceed for 5.8 km to a track at right—directly opposite a tall microwave tower (5593851N, 326648E)—leading to the Mustang Minerals Corp. core shed (5593674N, 326537E). Drive through the gate to the Mustang Minerals Corp. property, bear west 100 m and park at the core shed (Stop 3.5).

Directions to reach Stop 3.3 are as follows ~

From the Mustang Minerals Corp. core shed (5593674N, 326537E), drive southwest on the gravel road for 1.2 km until

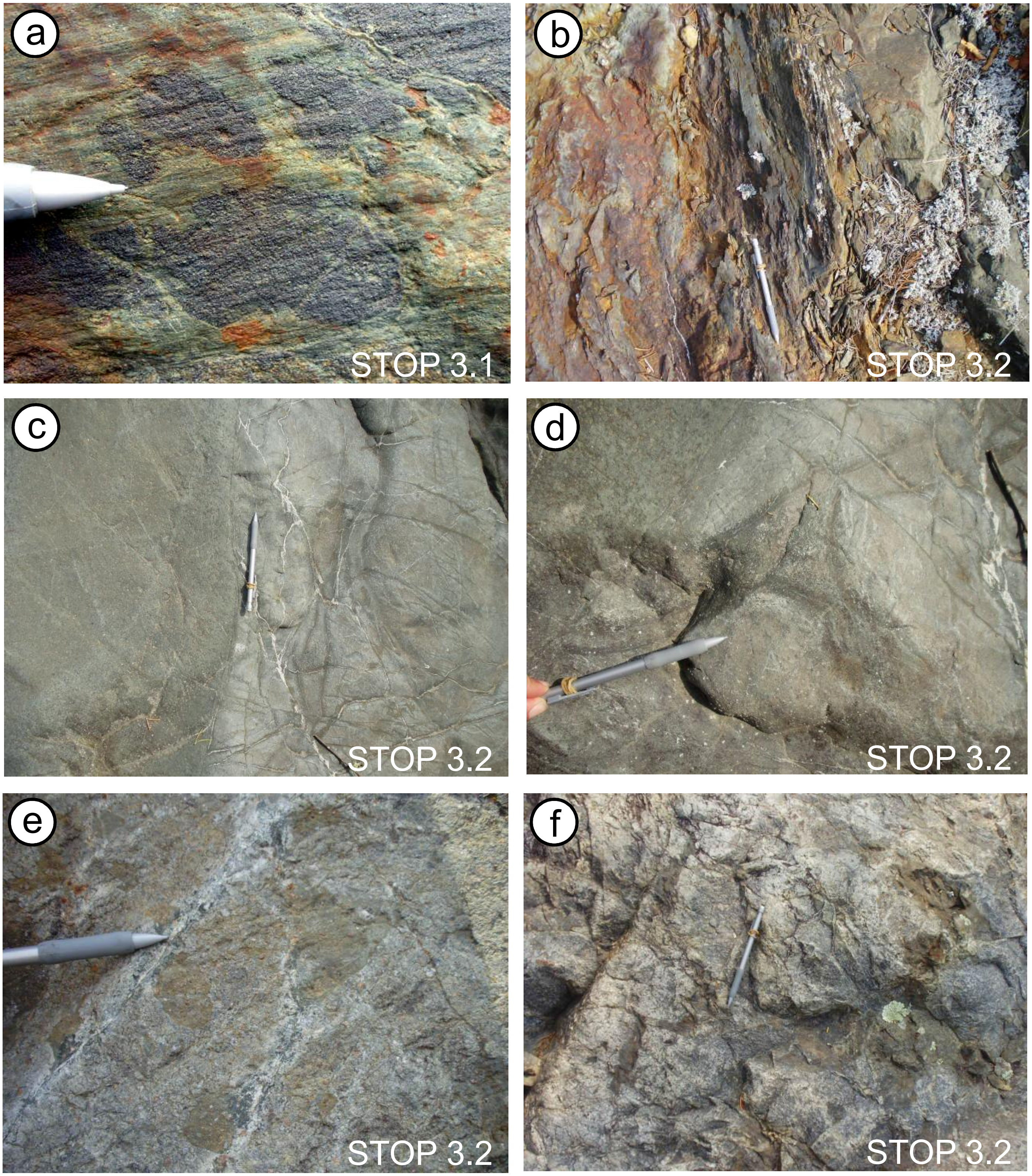


***Figure 32:** Field photographs of rock types at the Ore Fault property, 1) at the main showing (Stop 3.1)—**a)** magnetic ferrochromite clast in amphibolite, and 2) at the southern showing (Stop 3.2)—**b)** mineralized shear zone, **c)** and **d)** sharp contact between massive and pillowed basalt, **e)** chlorite-garnet altered clasts within lapilli tuff, and **f)** quartz-feldspar porphyry.*

reaching a large clearing at the Maskwa open pit (5593073N, 325529E). Walk roughly 50 m north through sporadic waste boulders to reach outcrops at the south margin of the water-filled pit.

Safety

Please exercise caution at the unprotected edge of the open pit.

Stop 3.3: Maskwa Open Pit

The Maskwa open pit is approximately 300 m long by 100 m wide by 50 m deep (Figure 30a). At this location at the south rim of the pit (5593073N, 325529E), the host rocks of the Maskwa Ni-Cu-PGE deposit are exposed; the outcrop consists of highly altered, grey-weathering peridotite, composed largely of talc and carbonate, with minor dark serpentinite stringers and wispy trails.

Looking across the pit to the north, the cliff at the north rim—representing the footwall of the Maskwa intrusion—consists of massive to pillowed mafic volcanic rocks typical of the Northern MORB-type Formation (Gilbert et al., 2008). At the east end of this cliff, the contact between MORB-type basalt and basal rocks of the Maskwa intrusion is exposed; the basal rocks consist of strongly schistose peridotite with—close to the base—several mineralized horizons with typical rusty staining. The peridotite foliation is sub-vertical and strikes west-southwest (250º), roughly parallel with the elongation of the pit. Most of the mineralization in the ultramafic rock unit occurs above the basal contact; sporadic semi-massive to massive Ni-Cu sulphide veins, characterized by vertical, streaky malachite staining, strike roughly north (350º). These veins grade up to 2.2% Ni and 1.0% Cu (Mustang Minerals Corp., unpublished data).

The configuration of the Maskwa intrusion as well as an equivocal gabbroic unit are well displayed from the vantage point of the east end of the pit. A roughly northwest-striking unit of subophitic gabbro–melagabbro apparently intrudes the MORB-type basalt along a northwest-trending fault. The relationship between the gabbroic rocks on the one hand, and the contiguous basalt and Bird River Sill intrusive rocks on the other, is uncertain. The gabbro is either synvolcanic—one of many such intrusions associated and intercalated with the MORB-type basalt elsewhere—or part of the feeder system for this particular part of the Bird River Sill.

The Maskwa waste pile, located just south of the open pit, contains sporadic, sulphide-rich samples from mineralized parts of the Maskwa mine. Rock samples collected from this waste pile yielded up to 6.5% Ni, 0.2% Cu, and 9.5 g/t Pd+Pt.

Leaving the Maskwa pit, return along the same gravel road toward the parking area at the Mustang core shed. Follow the gravel road, passing south of the core shed, and continue east for 250 m to Stop 3.4A, located south of the road (5593636N, 326834E).

Stop 3.4A: Dumbarton Nickel zone

This elongate outcrop, located on the south side of the gravel road (5593636N, 326834E), is thought to represent the main surface exposure of the Dumbarton nickel horizon on the Makwa property. Looking east along the gravel road, the distribution of old installations from the past Dumbarton mining operation suggests an overall east trend for the Dumbarton and F-zone orebodies. This mine horizon has been traced for more than 200 m east of the Dumbarton mine portal, and is still open in both directions. The mine horizon is coincident with a 2–11 m wide ductile shear zone; it contains a variety of rock types, but appears to be dominated by sheared mafic volcanic rocks and subordinate coarse-grained amphibolite. A chert-like layer at this locality may be either an altered, silicified volcanic rock or a chert unit within a thicker chemical sedimentary member, equivalent to those reported in several sections within drillcore in the same vicinity (Juhas, 1973). The footwall contact of the Maskwa intrusion is not recognized and possibly absent at this locality, but the stratigraphic hanging wall is exposed, and represented here by pillowed to massive basalt of the Northern MORB-type Formation. The mineralization at this locality, from selected grab samples, grades up to 3.6% Ni and 1.6% Cu (Mustang Minerals Corp., unpublished data).

From the Stop 3.4A, walk east on the gravel road for approximately 180 m to reach PR 315; continue eastwards for 100 m to Stop 3.4B (5593636N, 326834E).

Stop 3.4B: Dumbarton Nickel zone (optional)

The flat outcrop at Stop 3.4B (5593636N, 326834E) exposes the extension of the Dumbarton nickel horizon between the (past-producing) Dumbarton mine and the F-Zone deposit. In contrast to the previous stop, this outcrop exposes the complete sequence from the structural footwall, through the mineralized horizon to the stratigraphic hanging wall (Figure 30e). The structural footwall is composed of felsic intrusive rocks that may be part of the intrusive granitoid suite of the Maskwa Lake Batholith, where it is sheared at the margin. The stratigraphic hanging wall consists of massive to locally pillowed basalt of the Northern MORB-type Formation. The nature of the mineralized zone needs to be clarified, but it appears to consist of basaltic rocks with disseminated to semi-massive Ni-Cu sulphide mineralization. Selected grab samples at this locality grade up to 2.0% Ni and 0.58% Cu.

From Stop 3.4B, return west along PR 315 and the gravel road to the vehicles at Stop 3.4A, and proceed farther west to the Mustang Minerals Corp. core shed, Stop 3.5 (5593674N, 326537E)

Stop 3.5: Mustang Minerals Corp. core shed. Drillcore observation: orthomagmatic mineralization associated with mafic–ultramafic intrusions within the Bird River greenstone belt

At this final stop, participants will visit the core storage facility of Mustang Minerals Corp. (5593674N, 326537E). Approximately 2 hours will be spent looking at different styles of mineralization within the Bird River Sill and the Mayville intrusion, such as 1) Ni-Cu-(PGE) mineralization from Maskwa mine in the Bird River Sill and 2) Ni-Cu-(PGE) and PGE mineralization in the Mayville intrusion. Mustang Minerals Corp. staff have kindly agreed to lay out and discuss typical mineralized drillcore sections from these deposits.

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