Bedrock Mapping at Oxford Lake, northwestern Superior province, Manitoba

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Introduction

In 2012, the Manitoba Geological Survey initiated a program of bedrock geological mapping at Oxford Lake, located 170 km southeast of Thompson. This project includes new 1:20 000 scale bedrock mapping coupled with structural analysis, lithogeochemistry, Nd-Sm isotope geochemistry, U-Pb geochronology and mineral occurrence studies, and was designed to complement and expand upon investigations done in the Knee Lake portion of the belt during the Western Superior NATMAP Project (Syme et al., 1997, 1998; Corkery et al., 2000).

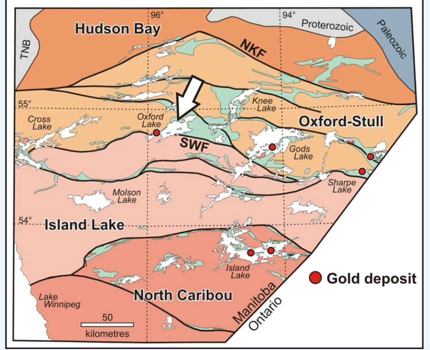
The objective is to better understand the stratigraphy, tectonic evolution and economic potential of the Oxford Lake–Knee Lake belt – the largest continuous greenstone belt in the northwest Superior craton – and to provide up-to-date geoscience data for local stakeholders and the mineral-exploration industry.

Renewed study of the Oxford Lake–Knee Lake belt began in 2012 with bedrock mapping of extensive shoreline exposures in western and central Oxford Lake (see 2012 poster). In July and August 2013, the mapping was extended into the northern and eastern portions of the lake.
During this fieldwork, a comprehensive suite of lithogeochemical samples was collected for analysis by high-precision, inductively coupled plasma–mass spectrometry (ICP-MS). Also collected were 8 samples of key supracrustal and intrusive rocks for U-Pb geochronology; these will be analyzed by laser-ablation ICP-MS (detrital zircons) or thermal ionization mass spectrometry at the University of Alberta Radiogenic Isotope Facility.

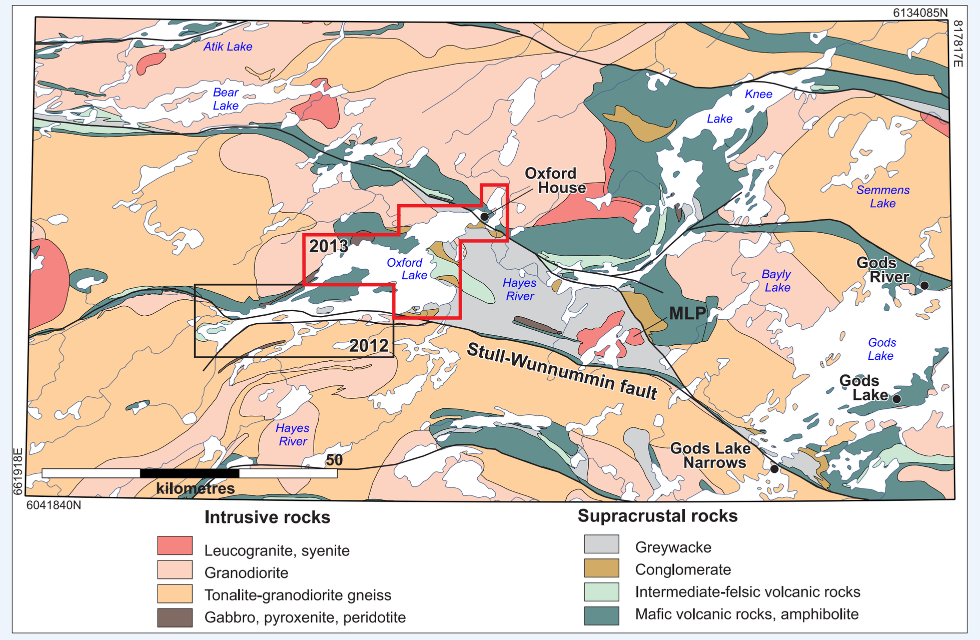
Regional setting

Oxford Lake is situated in the SW portion of the Oxford Lake–Knee Lake greenstone belt in the Oxford–Stull domain of the western Superior province (Stott et al., 2010). Following the scheme of Wright (1932), supracrustal rocks in the Manitoba segment of the Oxford–Stull domain have been divided into two units: the older, basalt-dominated Hayes River group (HRG) and the younger, more diverse Oxford Lake group (OLG; e.g., Barry, 1960; Gilbert, 1985).

The HRG consists of pillowed and massive basalt flows and gabbro, with minor intermediate to felsic volcanic rocks and fine-grained sedimentary rocks (e.g. Hubregtse, 1978, 1985). Felsic volcanic rocks in the HRG at Knee Lake vary in age from ca. 2827 to ca. 2834 Ma (Corkery et al., 2000).
Unconformably overlying rocks of the OLG are subdivided into lower volcanic and upper sedimentary subgroups, and locally include polymictic conglomerate that contains clasts derived from the HRG and tonalite–granodiorite intrusions of the Bayly Lake complex (Gilbert, 1985).



Major geological domains, greenstone belts and shear zones in the Manitoba segment of the northwestern Superior province. Abbreviations: NKF, North Knife fault; SWF, Stull-Wunnummin fault; TNB, Thompson nickel belt.



Regional geological setting of the Oxford-Knee Lake greenstone belt showing 2012 and 2013 study areas. Abbreviations: MLP, Magill Lake pluton.

More details on the regional setting of Oxford Lake area can be reviewed on 2012's poster.

Field work in 2013 was focused on the northern and eastern portions of Oxford Lake, including the eastern extensions of the Carghill and Thomsen assemblages. The Carghill assemblage widens considerably and is exceptionally well exposed in the 2013 study area. It includes perhaps the thickest, most complete and best exposed section of 'HRG' stratigraphy in the western portion of the Oxford–Stull domain.
The general characteristics and stratigraphy of these units are described briefly below:

Lower section, Carghill assemblage

The lower section is provisionally subdivided into 3 stratigraphic units, mostly on the basis of the field characteristics of associated subaqueous lava flows; flows in each unit were also sampled for lithogeochemistry to determine if they are chemically distinct.

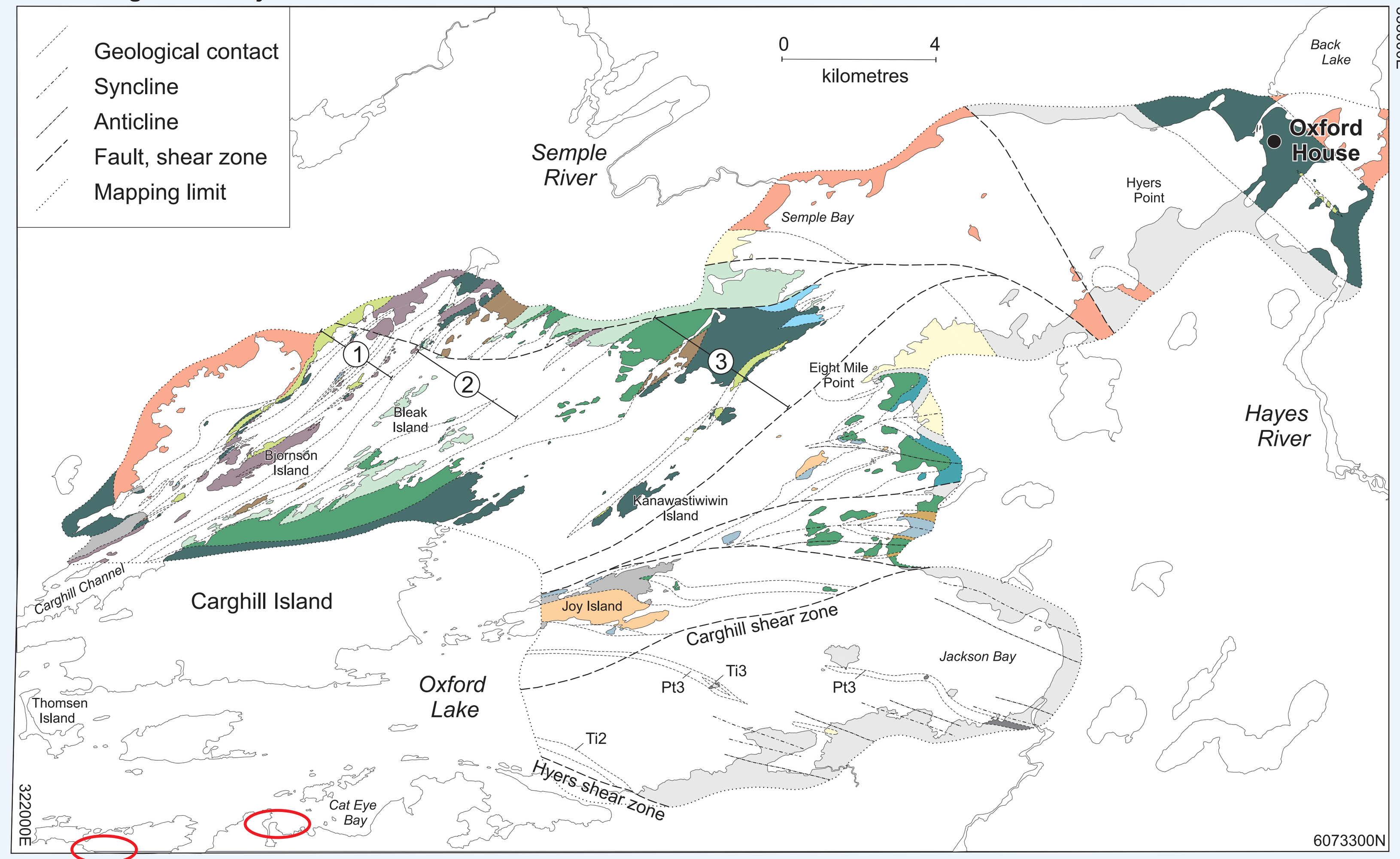
1) Bjornson Island unit (plagioclase-phyric flows)
The Bjornson Island unit consists of pillowed and massive aphyric to plagioclase-phyric basalt flows, associated mafic volcaniclastic rocks, and subordinate feldspathic greywacke, heterolithic volcanic conglomerate, felsic volcaniclastic rocks and iron formation. It is the base of the Carghill assemblage and is the most diverse of the three units of the lower section. It is cut out by the Semple River pluton, but is at least 2 km in thickness.

It is pervasively intruded by basalt dikes and thick gabbro sills, which are rare in the overlying Bleak Island unit and are tentatively correlated with the Carghill Channel layered intrusion. Minor felsic porphyry dikes in this unit are presumed to be related to the Semple River pluton. This unit also tends to be more strongly deformed than overlying units, perhaps due to its location on the margin of the belt.


Characteristic flow type: plagioclase-phyric pillowed basalt, showing seriate-porphyritic texture


Thin-bedded oxide-facies iron formation and feldspathic greywacke (left) underlain by strongly deformed pillowed flow of plagioclase-phyric basalt (right).

Simplified geology of northern and eastern Oxford Lake, showing the main components of the various supracrustal assemblages and major structural features



Post-tectonic dikes
Pt3 Gabbro

Semple River pluton
Sr1 Granodiorite, granite

Thomsen assemblage
Ti3 Greywacke, mudstone, conglomerate
Ti2 Polymictic conglomerate

Carghill Channel layered intrusion
Cc2 Gabbro, pyroxenite, peridotite

Carghill assemblage
Ci9 Hypabyssal felsic intrusions
Ci8 Gabbro
Ci6,7 Greywacke, mudstone, iron formation
Ci5 Volcanic conglomerate
Ci4 Intermediate to felsic volcaniclastic rocks
Ci3 Mafic volcaniclastic rocks

Ci2 Basaltic andesite and andesite flows
a,b,c Sparsely porphyritic (plagioclase-pyroxene) to aphyric
d Variolitic
f Plagioclase-phyric (shoshonite)
Ci1 Basalt and basaltic andesite flows
a Aphryic
b Plagioclase-phyric

B.Sc. thesis location

2) Bleak Island unit (variolitic flows)
The Bleak Island unit is approximately 3 km in thickness and is remarkably homogeneous: it consists almost exclusively of pillowed basalt (and/or basaltic andesite) flows, with only minor massive flows and very rare flow-breccia; epiclastic rocks are absent.
The characteristic basalt weathers pale grey-green to buff and is aphyric, non-amygdaloidal and strongly variolitic. The varioles are typically light grey, round and less than 1 cm in diameter, with an internal structure that varies from concentric to radial. They are locally arranged in concentric bands along the inner side of pillow margins, and increase in size and abundance toward the pillow cores, where they commonly coalesce into dense masses.

Near its base, the Bleak Island unit contains a thick (ca. 500 m) sill that shows an upward variation from fairly homogeneous equigranular mesogabbro in the lower portion to heterogeneous, faintly-layered leucogabbro in the upper portion. Some layers in the upper portion contain well-developed quench-crystallization textures (bow-tie, plumose and radiating spinifex) and abundant (up to 10%) quartz or carbonate amygdules, suggesting the sill represents very high-level intrusion or crypto-flow; neither the base nor top is exposed.


Detail of pillowed variolitic basalt, showing a decrease in size and abundance of varioles toward a thick pillow selvage.


Large bulbous pillow of variolitic basalt, showing well-developed drain-out structures (above hammer).


Faintly layered leucogabbro near the top of the thick, sill-like intrusion at the base of the Bleak Island unit (dashed lines indicate trend of layers; ruler for scale is 15 cm in length).


Detail of a leucogabbro layer showing quartz-carbonate amygdules (arrows) and plumose spinifex texture.

3) Kanawastiwiwin Island unit (aphyric flows)
The Kanawastiwiwin Island unit is approximately 4 km in thickness and defines the top of the lower section of the Carghill assemblage. It consists of massive, pillowed and brecciated basalt flows that are interstratified on meso- to macroscopic scales and thus display well-developed flow organization.
The basalt is amygdaloidal, non-variolitic and typically aphyric; flows shows systematic textural variation toward the top of the unit, perhaps related to a change in composition. Near the base, the basalt is light-green, sparsely amygdaloidal and massive to pillowed, with only minor flow breccia; pillows are relatively large (0.5–1.5 m) and bulbous. Near the top, the basalt weathers dark green-grey and contains abundant round amygdules or radial pipe-amygdules, concentrated along the inner margins of pillow selvages (<40%; <1.5 cm).
The upper parts of flows exhibit a much higher proportion (up to 50% in places) of pillow-fragment breccia.

Toward the northeast along strike, the Kanawastiwiwin Island unit is intruded by two large bodies of feldspar-phyric dacite that are unique to this unit. This rock weathers buff to light grey and is dark grey on fresh surfaces, with a fine-grained, seriate-porphyritic texture defined by blocky phenocrysts of plagioclase (5–10%; 0.5–5 mm) in an aphanitic, siliceous groundmass. Some outcrops contain a false-fragmental texture produced by fracture-controlled sericite alteration, although most are homogeneous and strongly foliated. The external contact is exposed in one location and is sharp, somewhat irregular and clearly discordant to the adjacent pillowed flow.

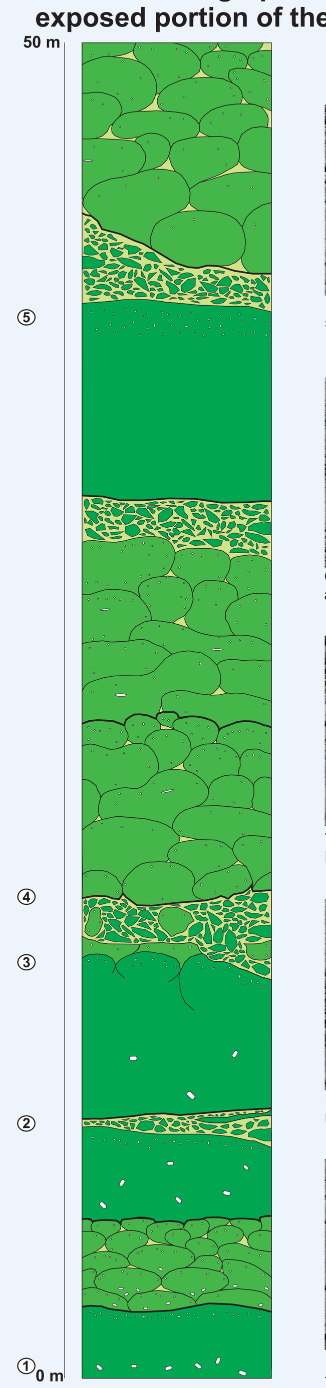

Bulbous to bun-shaped pillows of light green-grey, sparsely amygdaloidal basalt near the base of the Kanawastiwiwin Island unit.

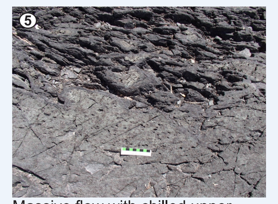

Bun-shaped to amoeboid pillows of dark green, highly amygdaloidal basalt near the top of the Kanawastiwiwin Island unit.


Pillow-fragment breccia near the top of the Kanawastiwiwin Island unit; outside the frame of this photo, the breccia grades downward (to the upper left) into pillowed basalt and is sharply overlain (to the lower right) by massive basalt.


False-fragmental texture defined by sericitized fractures in porphyritic dacite (Kanawastiwiwin Island unit).

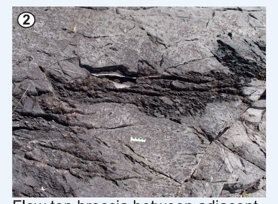
Detailed stratigraphic section of a well-exposed portion of the Kanawastiwiwin Island Unit

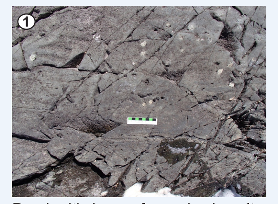



Massive flow with chilled upper selvage capped by flow top breccia


Contact between flow top breccia and overlying pillowed flow


Transition from massive to pillowed basalt flow


Flow top breccia between adjacent massive flows


Porphyritic base of massive basalt flow

Upper section, Carghill assemblage

The upper section of the Carghill assemblage is at least 2 km thick and shows a systematic progression from a dominantly epiclastic lithofacies in the west to a dominantly volcanic and volcaniclastic lithofacies in the east. The epiclastic rocks were examined at the western end of Joy Island, where they consist mostly of thick-bedded feldspathic greywacke and heterolithic volcanic conglomerate, with minor coherent flows of pyroxene (±plagioclase)–phyric andesite and associated volcaniclastic rocks.
This lithofacies continues along strike to the W for over 30 km and is fairly uniform. Analytical results from 2012 samples indicate that the coherent flows are high-K calcalkalic–shoshonitic andesite and dacite, and have a maximum age of ca. 2715 Ma (Anderson et al., 2013, unpublished data). Although structural data indicate the presence of macroscopic tight to isoclinal, E-trending folds, most of the epiclastic lithofacies tops toward the S and is overturned. In western Oxford Lake, the basal contact is concordant with lava flows in the lower section of the Carghill assemblage, which is also overturned to the S, consistent with a depositional contact relationship. However, the absence of macroscopic folds in the underlying rocks suggests décollement along the contact.

Primary features are exceptionally well-preserved in the area between Eight Mile Point and Jackson Bay, allowing for detailed interpretation of eruptive processes and settings, despite the effects of isoclinal folding indicated by structural data.

Field data from this study, coupled with results from previous geochemical and petrographic studies (e.g. Hubregtse, 1985; Brooks et al., 1982), indicate that the volcanic rocks range in composition from basalt to rhyolite, and show a systematic progression from shoshonitic or high-K calcalkalic affinity in mafic end-members (ca. 51–56 wt. % SiO_2) to low-K calcalkalic affinity in felsic end-members (ca. 73–74 wt. % SiO_2).
The volcanic rocks are typically plagioclase-phyric; mafic end-members also contain pseudomorphs (chlorite-biotite) after primary pyroxene or amphibole, whereas felsic end-members locally contain quartz phenocrysts.
Coherent, brecciated and pillowed flows of the volcanic lithofacies are intercalated with thick volcaniclastic deposits that include spectacular examples of primary autoclastic (±hyaloclastic) and pyroclastic material. The eruptive setting was clearly subaqueous and interlayers of cross-bedded volcanic sandstone and heterolithic volcanic conglomerate indicate a setting that was likely transitional from subaerial to shallow-marine; the conglomerate locally contains well-rounded boulders up to 2.5 m in diameter, indicating at least some detritus underwent subaerial transport. This lithofacies includes distinctive flows of coherent, brecciated and locally pillowed basaltic- andesite that are densely packed with coarse tabular phenocrysts of plagioclase (40–60%; 0.5–1.5 cm). In most locations, these flows contain a diffuse to well developed flow foliation defined by aligned phenocrysts and round to amoeboid quartz amygdules. Clasts of this textural type are readily identifiable in associated coarse autoclastic or epiclastic deposits (the internal flow-foliation commonly parallels the clast margins, indicating fragmentation by spalling from the margins of highly viscous flow-lobes; as noted by Hubregtse (1985), these clast types are also common in polymictic conglomerate of the Thomsen assemblage N of Eight Mile Point, indicating its younger relative age.

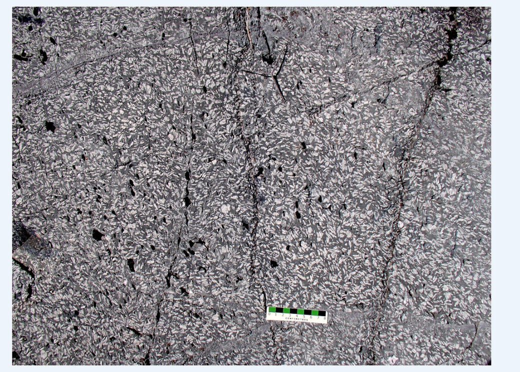

Plagioclase-phyric basaltic andesite of shoshonitic affinity in the upper Carghill assemblage: autoclastic breccia overlying a coherent flow, showing flow-foliation (dashed line) of plagioclase phenocrysts that roughly parallels the margin of an irregular lobe or lobe of basaltic andesite.


Eastern portion of the upper Carghill assemblage: autoclastic breccia composed of angular blocks of plagioclase-phyric andesite; note the broken selvage on the largest block (under pen).

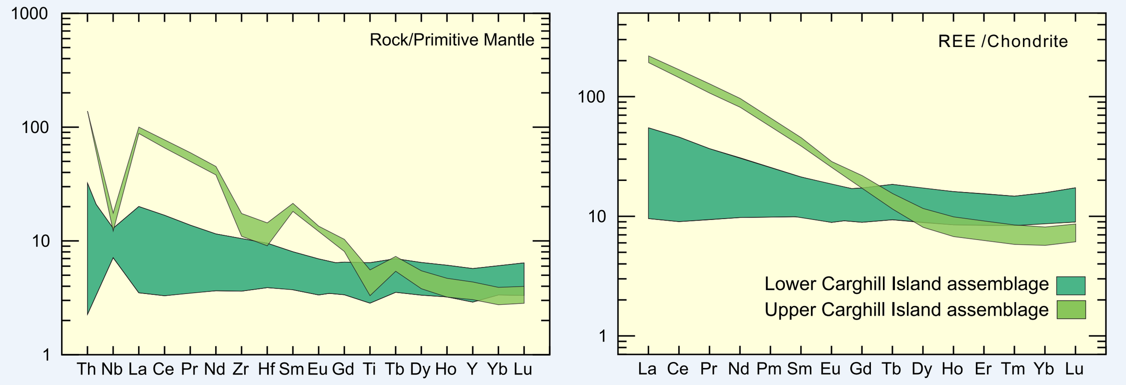

Eastern portion of the upper Carghill assemblage: intact andesitic scoria block in monolithic, crudely stratified, poorly-sorted tuff breccia, possibly representing a proximal scoria-fall deposit.


Well developed crossbeds in medium-grained pebbly volcanic sandstone; the thin-bedded volcanic sandstone, pebble conglomerate and mudstone section is bounded above and below by coherent to brecciated flows of densely porphyritic basaltic-andesite; arrow indicates the sharp, chilled basal contact of the overlying flow.


Eastern portion of the upper Carghill assemblage: very large rounded boulder of plagioclase-phyric andesite in heterolithic volcanic conglomerate (note hammer for scale), indicating significant subaerial transport of detritus and a proximal, high-energy depositional setting.


Plagioclase-phyric basaltic andesite of shoshonitic affinity in the upper Carghill assemblage: coherent flow, showing densely-packed plagioclase phenocrysts.

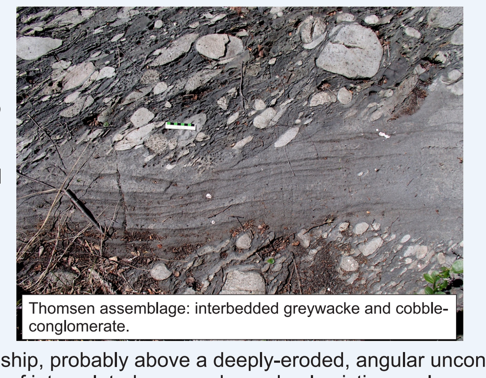
Whole rock geochemistry of the Carghill Island assemblage

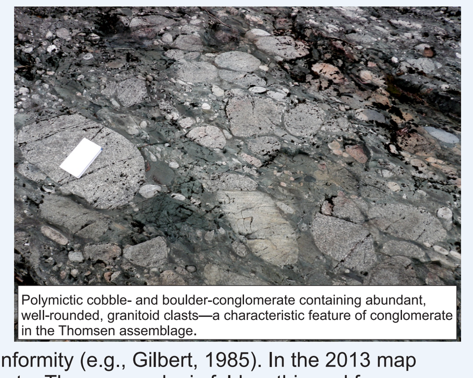


Normalized trace-element compositions of samples from the Lower and the Upper Carghill Island assemblage (primitive mantle of McDonough & Sun 1995). Preliminary results show a clear difference between the Lower and the Upper Carghill Island assemblage. Final whole rock geochemistry will allow refining the difference between the different units wihtin the Lower section of the Carghill assemblage.

Thomsen assemblage

The Thomsen assemblage is mainly exposed along the shoreline of Jackson Bay and NE of Eight Mile Point. This distribution appears to define two major panels that may represent two separate, possibly fault-founded, basins or perhaps a single basin disposed on opposite limbs of a macroscopic fold. The northern panel is intruded and disrupted by biotite granodiorite of the Semple River pluton, whereas the southern panel is intruded by rare gabbro and possible lamprophyre dikes. Contact relationships with older rocks are nowhere exposed at Oxford Lake, but the high abundance of apparently local detritus in both panels strongly suggests a depositional relationship, probably above a deeply-eroded, angular unconformity (e.g., Gilbert, 1985). In the 2013 map area, the Thomsen assemblage consists mostly of intercalated greywacke and polymictic conglomerate. The greywacke is feldspathic and forms planar, normally-graded beds that range up to several metres in thickness. Thicker beds are deeply scoured and pebbly at the base, contain abundant mudstone rip-ups, and are capped by thin mudstone beds, or distinct layers of thin-bedded greywacke-mudstone turbidites up to 50 cm thick. The greywacke locally defines thick, monotonous intervals that contain only minor diffuse layers of pebble- to cobble-conglomerate.
Polymictic conglomerate is most extensive along the shoreline NE of Eight Mile Point, but also occurs at Semple Bay and Hyers Point in the N basin of Oxford Lake, and more sporadically along the N and S shorelines of Jackson Bay. The conglomerate is poorly sorted, massive to crudely stratified and matrix- to clast-supported. It contains angular to very well-rounded clasts, and is clearly distinguished from superficially similar rocks in the upper section of the Carghill assemblage by the high proportion of well-rounded clasts of medium to coarse-grained tonalite, granodiorite and granite.

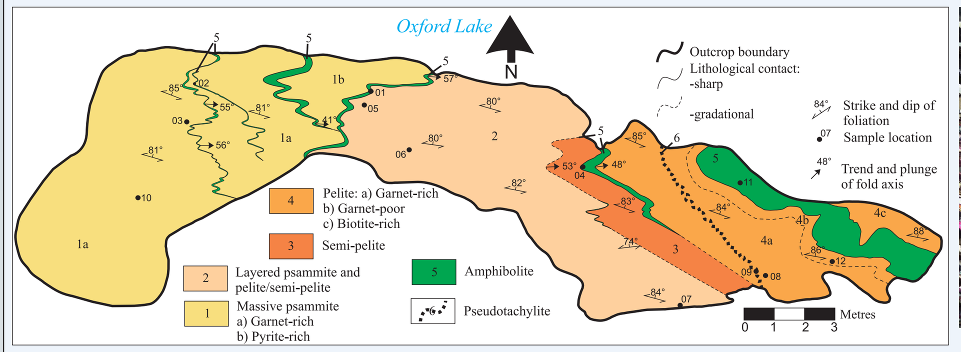

Thomsen assemblage: interbedded greywacke and cobble-conglomerate.


Polymictic cobble- and boulder-conglomerate containing abundant, well-rounded, granitoid clasts—a characteristic feature of conglomerate in the Thomsen assemblage.

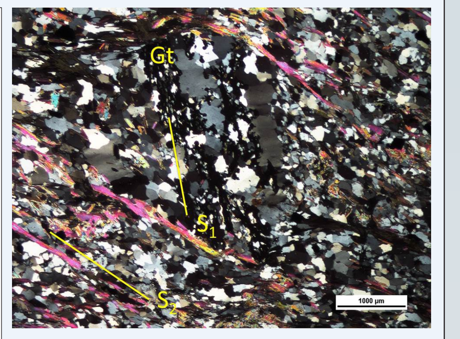
Ongoing B.Sc. theses at University of Manitoba:

1) Metamorphic petrology and structural geology of the Lynx Bay shear zone, south margin of the Oxford Lake-Knee Lake greenstone belt, northwest Superior province

Student: Megan Scott
Advisor: Alfredo Camacho



Outcrop of the Lynx Bay shear zone, located along the south shore of Oxford Lake, Manitoba.



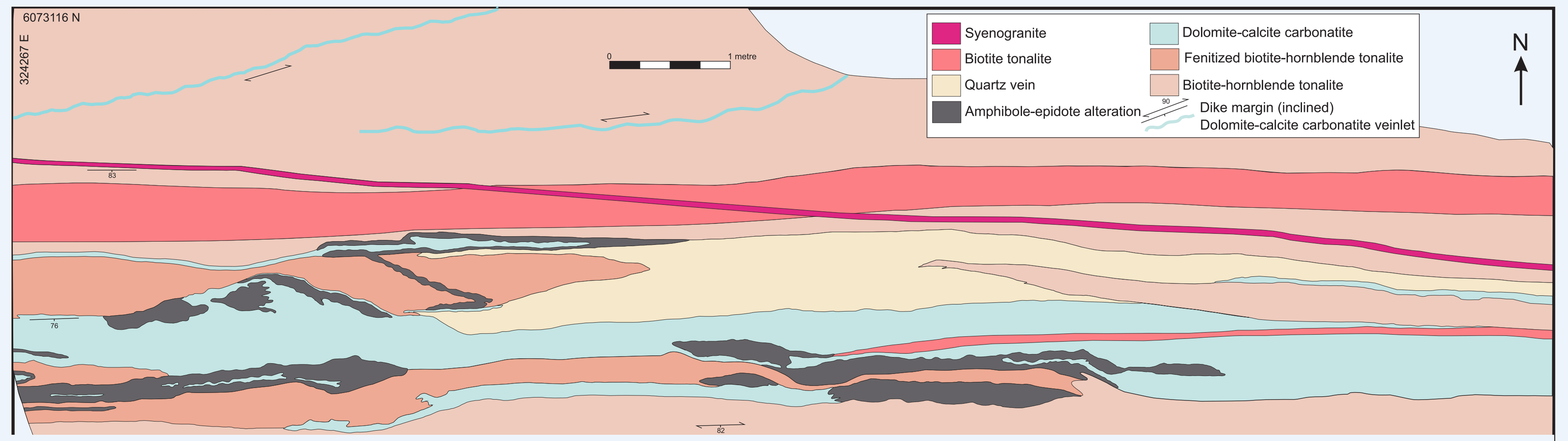
Post-S_1, pre-S_2 growth of a garnet (Gt) porphyroblast in a garnet-rich psammite.

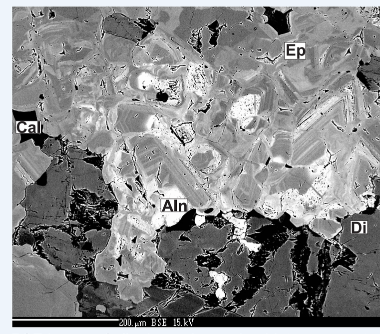
During a three day period from July 28 to 30, 2013, two outcrops of the north-west trending Lynx Bay shear zone, located in Cat Eye Bay, Oxford Lake, Manitoba, were mapped at a scale of 1:50 and 1:100. The Lynx Bay shear zone is part of a network of shear zones that connect with the Stull-Wunnummin fault of the Manitoba segment of the northwestern Superior province and is part of the boundary between the Oxford-Stull domain and Island Lake domain. The two outcrops mapped contain abundant shear-sense indicators such as asymmetric Z-folds, boudins, S-C fabrics, and sheath folds all displaying dextral shear-sense of movement. The objectives of this project include, determining the relative timing of the deformational events and their relationship to the regional geology, and relating textures to these events. Preliminary work suggests at least two deformation events, where S_2 is a pervasive axial planar foliation, and a greenschist facies overprint on amphibolite facies. Another outcrop to the southeast of the two outcrops mapped was also sampled. It contains kyanite, which may allow for pressure and temperature conditions to be determined. With the use of petrography, detailed mapping, stereonets and whole rock lithogeochemistry, the evolution of the Lynx Bay shear zone will be further described in terms of metamorphic petrology and structural geology.

2) Petrography, Mineralogy and Geochemistry of the Oxford Lake Carbonate Dike in the Oxford Lake-Knee Lake greenstone belt, northwestern Superior province, Manitoba

Student: Erin R. Reimer
Advisor: Anton Chakhmouradian

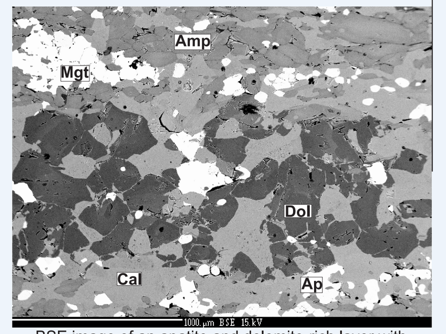
The Oxford Lake carbonate dike was discovered by the Manitoba Geological Survey in 2012 as part of a bedrock geological mapping program at Oxford Lake, located approximately 170 km southeast of Thompson, Manitoba. The dike is located on a small island near the southwestern shore of Oxford Lake within the western portion of the Oxford Lake-Knee Lake greenstone belt, part of the northwestern Superior province. The 1.5 m thick, recessively weathered carbonate dike is exposed for approximately 13 m along strike on a small shoreline outcrop. Detailed mapping of the carbonate dike outcrop was done at a scale of 1:25, and a set of 10 representative samples was collected during the July 2013 field season.





BSE image of allanite and zoned epidote aggregate at the contact between the carbonatite and the biotite tonalite. (Abbreviations: allanite-Aln; epidote-Ep; calcite-Cal; diopside-Di.)

The main objective of this thesis is to characterize the dike in terms of its mineralogy, petrology, and geochemistry. A further objective is to constrain the relationships between the carbonate body and associated silicate rocks to determine its history of emplacement and subsequent alteration and metamorphism. These data will help develop a petrogenetic model for carbonatite magmatism in the area, and to the current understanding of carbonatite petrogenesis as a whole. Preliminary work suggests the dike is a possible dolomite-calcite carbonatite, comprising predominantly calcite, dolomite, apatite, amphibole and phlogopite. Importantly, the carbonatite contains accessory rare-earth and radioactive minerals including: allanite [$CaREEAl_2Fe(SiO_4)_3OH$], monazite ($REEPO_4$), bastnasite ($REECO_3F$), thorite ($ThSiO_4$) and uraninite (UO_2). Further detailed examination by electron microprobe analysis, Raman spectroscopy, and optical cathodoluminescence will identify compositional variations in carbonate and other rock-forming minerals. Whole rock geochemical and stable isotope analyses will be used to determine the nature of the source magma and its crystallization history.



BSE image of an apatite and dolomite-rich layer with interstitial calcite. Amphiboles are aligned parallel to layering. (Abbreviations: apatite-Ap; amphibole-Amp; calcite-Cal; dolomite-Dol; magnetite-Mgt.)

Economic considerations: Previous mineral exploration at Oxford Lake has resulted in the discovery of several base- and precious-metal occurrences in the western portion of the lake, thus demonstrating significant exploration potential. Exhalative base-metal sulphide occurrences are restricted to the south panel and include the Hyers Island Cu deposit and the Cat Eye Bay Cu-Zn-Pb-Au-Ag occurrence in the Hyers and Cat Eye Bay assemblage, respectively. Results from the 2012 mapping program provide a much improved understanding of the stratigraphic and structural context of these occurrences. Iron-formation–hosted, orogenic Au mineralization occurs in the north panel, at the interface between the lower and upper sections of the Carghill assemblage (i.e., the Rusty zone) in the western portion of Oxford Lake.
Preliminary results from detailed structural analysis of folds and shear zones in 2012 provide important new constraints on the possible structural settings and controls of gold mineralization. In addition, results from the 2013 field season indicate that, rather than extending W through Carghill Island (i.e., along the contact between the upper and lower sections of the Carghill assemblage), the favourable stratigraphy (including iron formations) may trend NE along Carghill Channel, where its presence is obscured by the Carghill Channel layered intrusion, and may correlate with the Bjornson Island unit near the base of the assemblage. If correct, this correlation would provide a much improved understanding of the stratigraphic setting of the Rusty zone—the most significant Au deposit discovered to date at Oxford Lake—and may indicate significant economic potential in a seemingly overlooked portion of the belt.
Fieldwork in 2013 also included a detailed examination of the carbonatite occurrence reported in 2012, (see detail map to the right); an attempt to identify additional occurrences was unsuccessful.

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