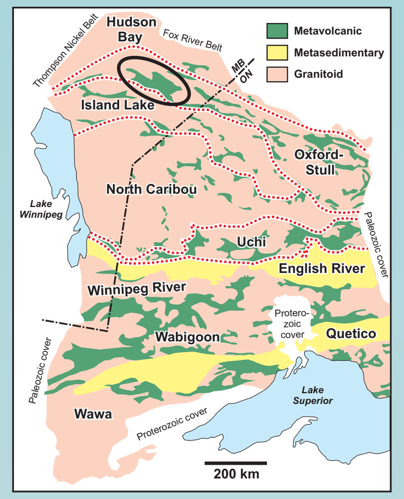
Toward a revised tectonostratigraphic framework for the Oxford Lake–Knee Lake greenstone belt...

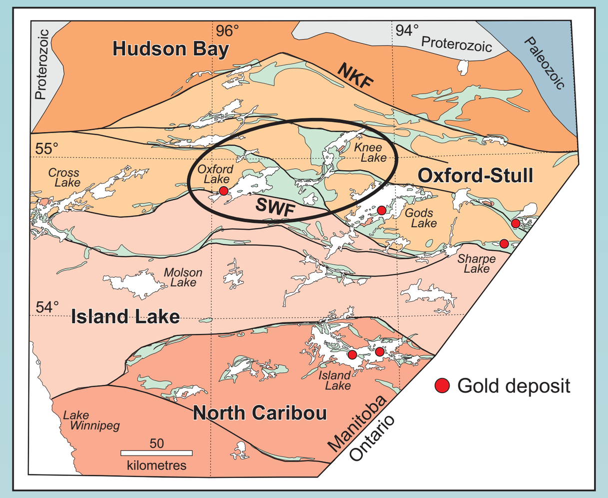
Introduction

In 2012, the Manitoba Geological Survey began a renewed study of the Oxford Lake–Knee Lake belt, the largest contiguous greenstone belt in the northwestern Superior province. New bedrock mapping, augmented by structural, lithogeochemical, Sm-Nd isotopic, U-Pb geochronological and high-resolution aeromagnetic datasets, is being utilized to upgrade existing maps, with the goal of a comprehensive regional synthesis and seamless geoscience compilation for the entire belt.

Shoreline mapping took place at Oxford Lake in 2012 and 2013 (Anderson et al., 2012, 2013), and continued at the south basin of Knee Lake in 2015. The goal of the 2015 fieldwork was to examine key localities identified during the Western Superior NATMAP Project (1997–1998; Syme et al., 1997, 1998) and to remap areas of incomplete data coverage. Results of this work, augmented by data from inland mapping (Gilbert, 1985) and high-resolution aeromagnetic surveys, were used to generate a new 1:20 000 scale map (PMAP2015-1; Anderson et al., 2015) for southern Knee Lake.

This poster summarizes key results from work completed at Oxford Lake (2012–2013) and Knee Lake (2015). Work to date provides an improved stratigraphic and structural context for known mineral occurrences, and for areas with high potential for volcanogenic Cu-Zn-Pb-Ag-Au, magmatic Ni-Cu-PGE, alkaline-intrusion–related rare metals, and orogenic Au deposits.





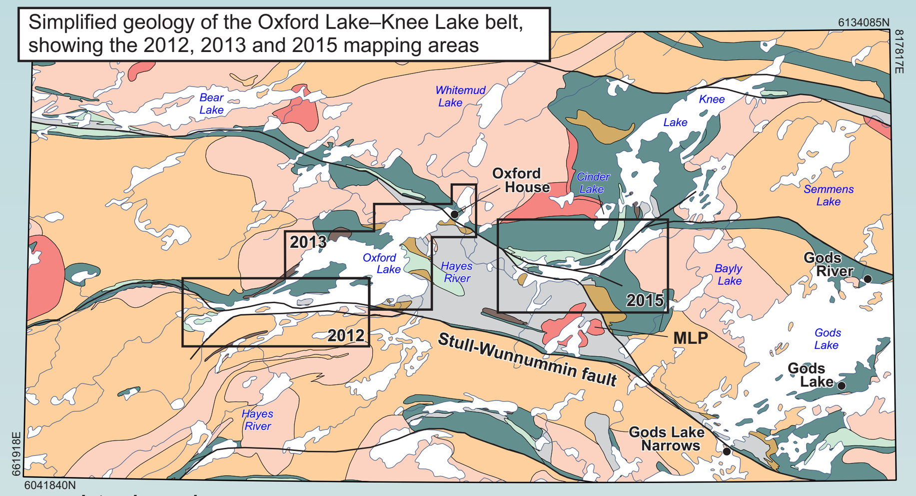
Regional setting

The regionally extensive Oxford Lake–Knee Lake greenstone belt is situated in the Oxford–Stull domain (OSD) of the western Superior province (above, left).

In Manitoba, the OSD consists of isotopically juvenile volcanic and sedimentary rocks, interpreted to represent an oceanic terrane that was accreted to the north margin of the continental North Caribou terrane during amalgamation of the western Superior province (Skulski et al., 2000).

The crustal-scale Stull–Wunnummin fault (SWF; above, right) defines the south boundary of the OSD and is thought to represent a fundamental tectonic boundary in the western Superior province (Stott et al., 2010).

Simplified geology of the Oxford Lake–Knee Lake belt, showing the 2012, 2013 and 2015 mapping areas



Intrusive rocks
- Leucogranite, syenite
- Granodiorite
- Tonalite-granodiorite gneiss
- Gabbro, pyroxenite, peridotite

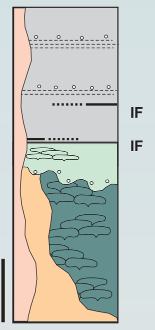
Supracrustal rocks
- Greywacke
- Conglomerate
- Intermediate-felsic volcanic rocks
- Mafic volcanic rocks, amphibolite

0 50 kilometres

Regional stratigraphy

The previous lithostratigraphic framework (shown at right) for supracrustal rocks in the OSD included the older basalt-dominated Hayes River group (HRG) and the younger, lithologically diverse, Oxford Lake group (OLG).

Voluminous tonalite-granodiorite plutons of the Bayly Lake complex (BLC) intrude the HRG.



Intrusive rocks
- Granodiorite, granite

Oxford Lake Group
- Sedimentary subgroup: greywacke, conglomerate, quartz wacke, iron formation
- Volcanic subgroup: mafic to felsic volcanic rocks (high-K), derived sedimentary rocks

—angular unconformity—

Bayly Lake complex
- Tonalite, granodiorite

Hayes River Group
- Mafic volcanic flows, gabbro, felsic volcanic rocks, fine grained sedimentary rocks, iron formation

Unconformably overlying rocks of the OLG were subdivided into a lower volcanic subgroup, containing calcalkalic to shoshonitic (high-K) volcanic rocks (Hubregtse, 1978, 1985; Brooks et al., 1982; Gilbert, 1985), and an upper sedimentary subgroup.

Recent studies have indicated that this framework requires revision. U-Pb ages for felsic volcanism in the 'HRG' span close to 200 m.y., whereas those for the volcanic subgroup of the OLG span roughly 30 m.y., and indicate that it was at least locally coeval with the sedimentary subgroup (Corkery et al., 2000; Lin et al., 2006).

Results from Oxford Lake mapping

Oxford Lake (2012–2013): Revised tectonostratigraphic framework

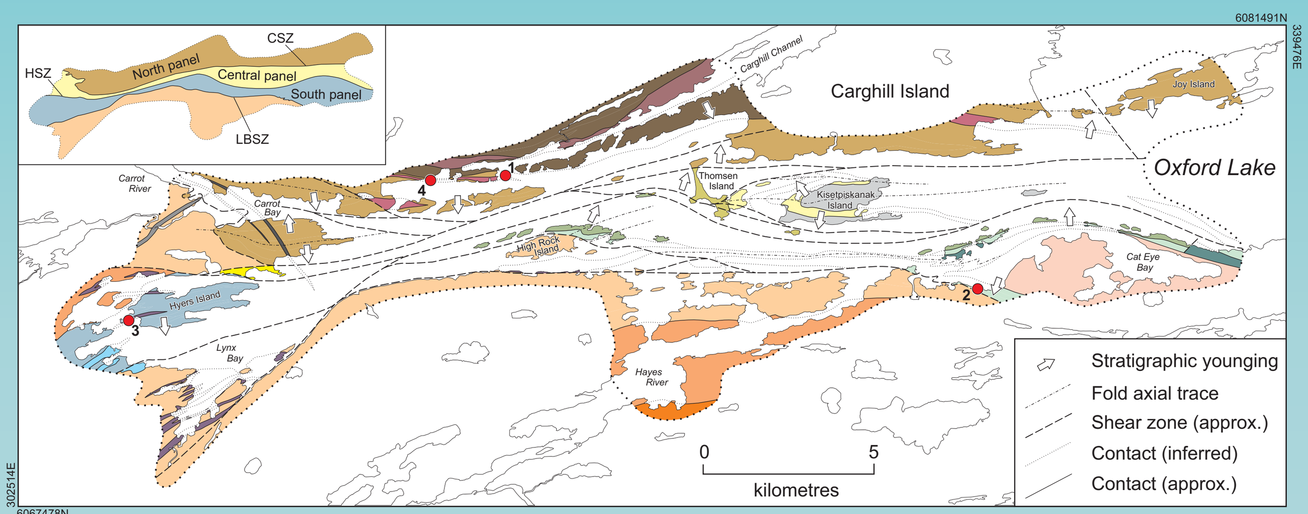
Remapping of Oxford Lake (2012–2013) indicated the presence of four tectonostratigraphic assemblages (below), characterized by different associations of rock types, and inferred to reflect distinct depositional settings and possibly ages. To avoid implied correlations with adjacent belts, these assemblages were assigned provisional names from geographic features at their type localities.

Three main structural panels were also defined (below, inset): a 'south panel' containing the Cat Eye Bay and Hyers assemblages; a 'north panel' containing the Carghill assemblage; and a 'central panel' containing the Thomsen assemblage.

Crosscutting relationships of intrusions suggested at least three broad ages of volcanism at Oxford Lake—an inference that has since been supported by U-Pb age dating, which demonstrates three major intervals of volcanism at ca. 2900 Ma, 2830 Ma and 2720 Ma (see below).

'Intratectonic' intrusions in the south panel, including the Cat Eye Bay and Hyers plutons, post-date penetrative deformation in the Cat Eye Bay and Hyers assemblages, indicating at least two phases of regional deformation: one predating ca. 2705 Ma plutons, and another post-dating <2695 Ma fluvial-alluvial sedimentary rocks of the Thomsen assemblage.

As outlined below, new results from U-Pb geochronology indicate a 100 m.y. age difference between rocks in the lower and upper sections of the Carghill assemblage, necessitating further revision of the 2012–2013 framework.



Bayly Lake intrusive complex
- Biotite tonalite
- Biotite-hornblende tonalite
- Orthogneiss

Hyers assemblage
- Subvolcanic porphyry intrusions
- Intermediate to felsic volcaniclastic and epiclastic rocks; derived tectonite

Cat Eye Bay assemblage
- Upper section: pillowed basalt
- Middle section: volcaniclastic rocks, pillowed basalt, komatiite, quartzite, iron formation
- Lower section: pillowed basalt

Carghill Channel layered intrusion
- Gabbro, peridotite

Carghill assemblage
- Gabbro
- Upper section: polymictic volcanic conglomerate, greywacke, mudstone, mafic to intermediate flows, volcaniclastic rocks, iron formation
- Lower section: pillowed basalt, mafic volcaniclastic rocks, iron formation

Intra-tectonic intrusions
- Biotite tonalite (Cat Eye Bay pluton)

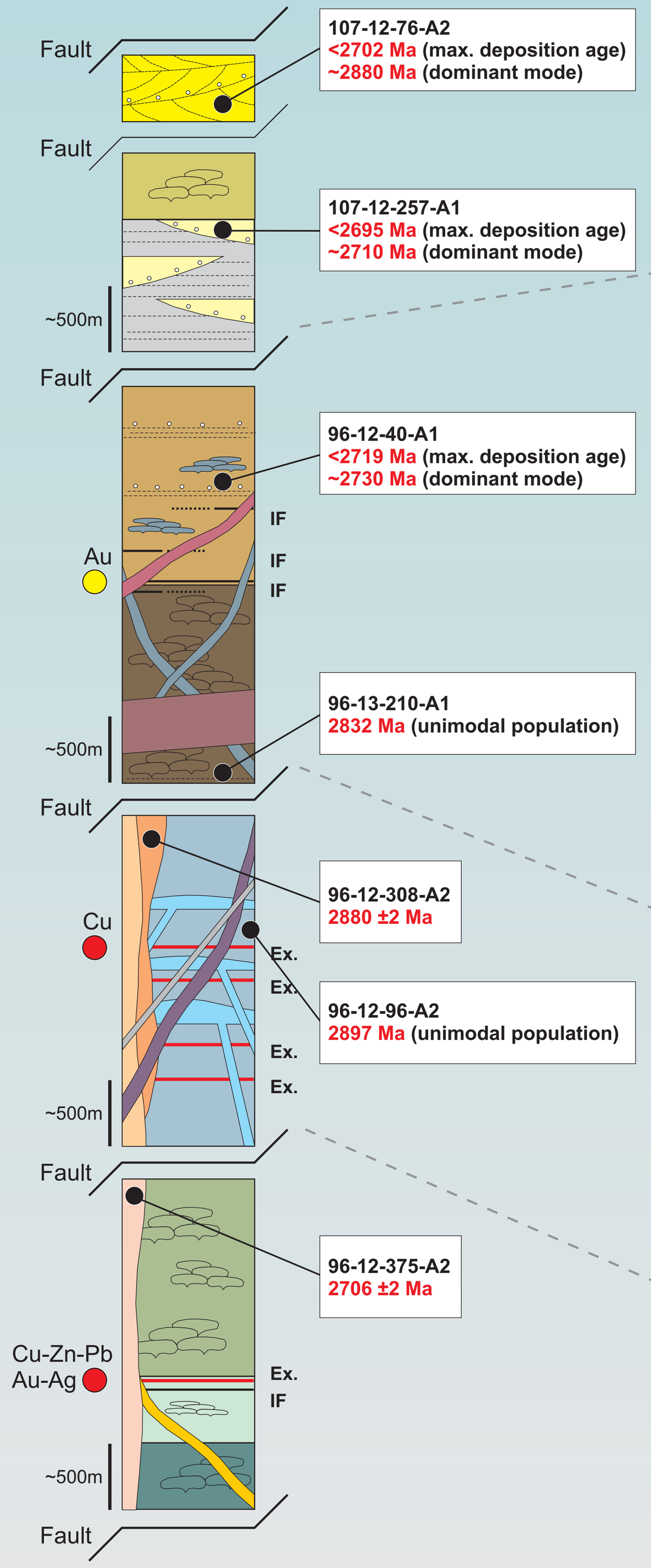
Lynx Bay intrusive suite
- Gabbro, pyroxenite, peridotite

Post-tectonic dikes
- Diabase (Mackenzie swarm)
- Diabase (Molson swarm)

Thomsen assemblage
- Quartz arenite, quartz-pebble conglomerate
- Greywacke, mudstone, conglomerate
- Polymictic conglomerate
- Basalt and basaltic andesite flows

Mineral occurrence
1. Blue Jay zone (Au)
2. Cat Eye Bay (Cu, Zn, Pb, Au, Ag)
3. Hyers Island (Cu)
4. Rusty zone (Au)

Composite tectonostratigraphic column: western Oxford Lake



Thomsen assemblage: includes polymictic conglomerate (<2695 Ma; right), greywacke-mudstone turbidite, basalt–basaltic andesite flows, and quartz arenite and quartz-pebble conglomerate (<2702 Ma). Rounded granitoid clasts in the conglomerate indicate significant subaerial transport; fluvial quartz arenite and pebble conglomerate also contain clasts of vein quartz.


Polymictic conglomerate with abundant granitoid cobbles

Carghill assemblage: as noted above, new U-Pb age dating indicates that the 'Carghill assemblage' comprises two assemblages, separated in age by more than 100 m.y.

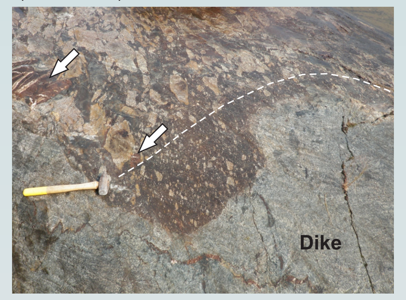
The upper section, corresponding to the classical 'Oxford Lake group', includes volcanic and volcaniclastic rocks of calcalkalic to shoshonitic affinity. Basaltic to rhyolitic flows are intercalated with primary volcaniclastic rocks and volcanic sedimentary rocks (<2719 Ma), deposited in shallow-subaqueous settings.


Autoclastic flow breccia composed of plagioclase-phyric andesite (shoshonite)

The lower section, corresponding to the classical 'Hayes River group', consists mostly of basalt flows of arc-tholeiitic affinity, with minor felsic volcaniclastic rocks (ca. 2832 Ma) and iron formation, consistent with a more distal-marine depositional setting.


Pillowed flow composed of aphyric basalt (arc tholeiite)

Hyers assemblage: consists mainly of intermediate to felsic volcaniclastic rocks (ca. 2897 Ma) and porphyry intrusions (right), with minor epiclastic rocks. Stratiform ankerite alteration is capped by lenses of near-solid to solid sulphide (pyrite ±chalcopyrite), including the Hyers Island VMS deposit, which contains a small resource grading 2.5% copper (A.F. 72236). The Hyers assemblage is intruded by ca. 2880 Ma tonalite-granodiorite of the BLC.



Stratified tuff breccia cut by felsic porphyry dike (arrows indicate ankerite clasts)

Cat Eye Bay assemblage: consists of basalt and komatiite flows, felsic volcaniclastic rocks and iron formation (right), suggesting an analogy to Archean rift sequences documented elsewhere in the Superior province. The absolute age of this assemblage remains unknown: it is intruded by the 2706 Ma Cat Eye Bay pluton.


Sulphide-facies iron formation at the top of the middle section, Cat Eye Bay assemblage

Results from Knee Lake mapping

Knee Lake (1997–1998; 2015): Stratigraphic framework

For mapping purposes in 2015 and in keeping with previous nomenclature, supracrustal rocks at southern Knee Lake were subdivided into the HRG and OLG

Hayes River Group

The HRG is exposed along the northern and eastern shorelines of southern Knee Lake, and defines a series of monoclinal panels that wrap broadly around large elliptical plutons of the BLC. The panels are often bounded by semiconcordant faults, such that their stratigraphic relationships are ambiguous.

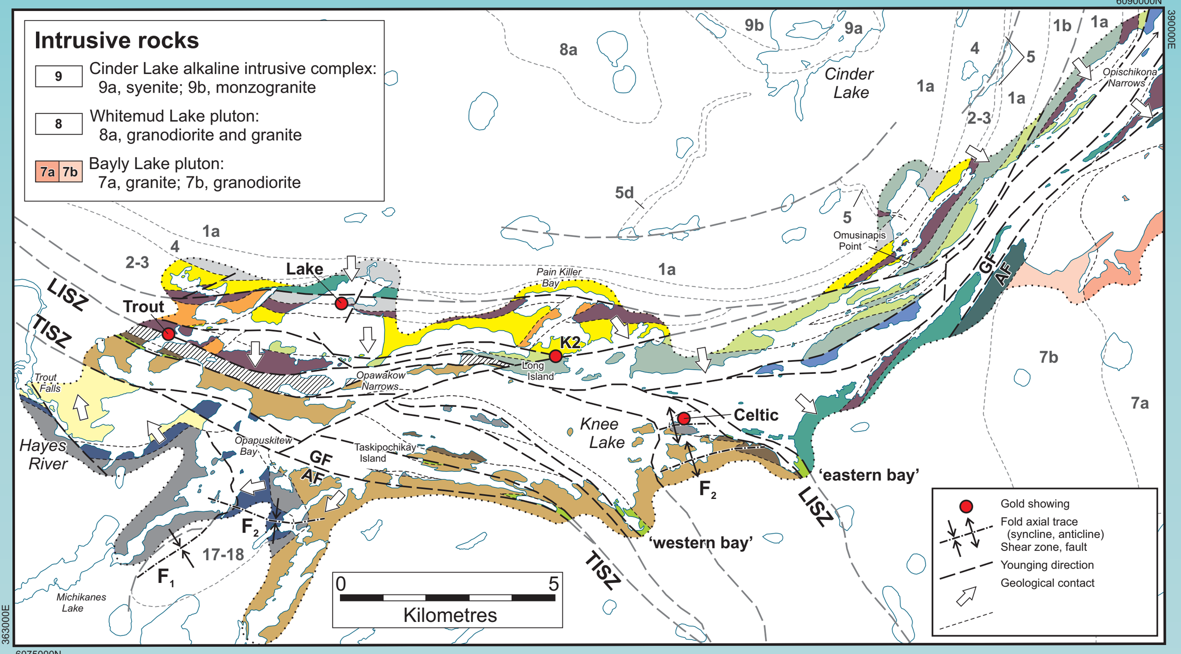
Younging directions are mostly toward the south or southeast, away from the Whitemud Lake pluton (unit 8) and toward the Bayly Lake pluton (unit 7). To the southwest, the HRG is truncated by the Long Island shear zone (LISZ).

Oxford Lake group

The OLG underlies the southwest portion of southern Knee Lake and defines a series of monoclinal to tightly folded, fault-bounded structural panels, the internal stratigraphy of which remains uncertain. Following previous workers (Gilbert, 1985; Syme et al., 1997), the OLG was subdivided into volcanic and sedimentary 'subgroups'.

The volcanic subgroup includes three, newly defined, 'volcanic facies associations' (see below): ultramafic (unit 11), basaltic andesite (unit 12) and andesitic–dacitic (unit 13).

The sedimentary subgroup is divided on the basis of grain size, composition and bedforms into four units (17–20). In the western part of the map area, these rocks are only found south of the Taskipochikay Island shear zone (TISZ).



Oxford Lake group

Sedimentary subgroup
- 20 Greywacke, quartz greywacke
- 19 Arkosic quartz-greywacke, mudstone
- Polymictic conglomerate, greywacke, mudstone, iron formation

Volcanic subgroup

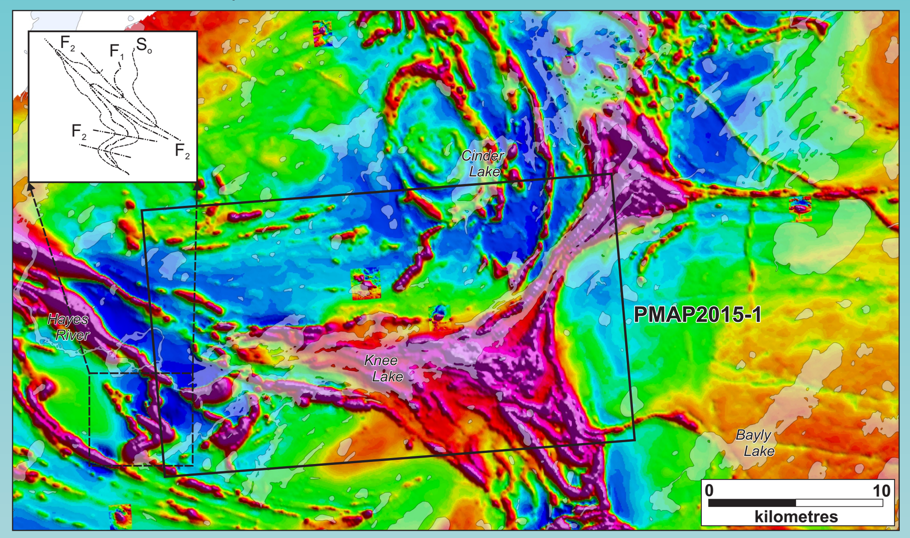
Volcanic sedimentary rocks
- 14-15 Volcanic conglomerate, greywacke

Volcanic, volcaniclastic and volcanic sedimentary rocks
- 13 Andesitic–dacitic facies association
- 12 Basaltic andesite facies association
- 11 Ultramafic facies association

Hayes River group
- 6 Intermediate–felsic intrusive rocks; feldspar-quartz porphyry
- Ultramafic–mafic sills
- 4 Volcanic conglomerate, greywacke
- 2-3 Felsic volcanic and volcaniclastic rocks

Mafic volcanic rocks (flows):
- 1a 1c 1a, aphyric; 1c, amphibolitic
- 1b 1d 1b, variolitic; 1d, porphyritic

Magnetic total field image derived from high-resolution aeromagnetic data (De Beers Canada; A.F. 94884), showing the outline of PMAP2015-1. An example of F_1-F_2 fold interference, defined by iron formation southwest of Knee Lake, is indicated by the dashed rectangle (inset shows the corresponding structural interpretation). The prominent circular anomaly at Cinder Lake is interpreted to represent the Cinder Lake alkaline intrusive complex.



Alkaline intrusive rocks

The Cinder Lake alkaline intrusive complex (unit 9) consists of syenite, syenitic pegmatite and monzogranite; U-Pb ages (ca. 2720–2705 Ma; Chakhmouradian et al., 2008; Kressall et al., 2010; Kressall, 2012) indicate emplacement coeval with high-K volcanism in the OLG. Aeromagnetic data (above) indicate that the complex is concentrically zoned and ~10 km in diameter.


Biotite-phyric lamprophyre(?)

Lamprophyre(?) dikes (unit 10) cut the HRG and Bayly Lake pluton, and include porphyritic varieties that contain biotite phenocrysts up to 2.5 cm (right, top photo). The dikes have sharp planar contacts (right, bottom photo) and appear to postdate at least some of the deformation recorded by their host rocks.


Lamprophyre(?) dike in the Bayly Lake pluton

Whole-rock geochemical results are pending; however, the apparently K-rich composition of these dikes suggests a possible association with high-K volcanism in the OLG.

Oxford Lake group: volcanic facies associations

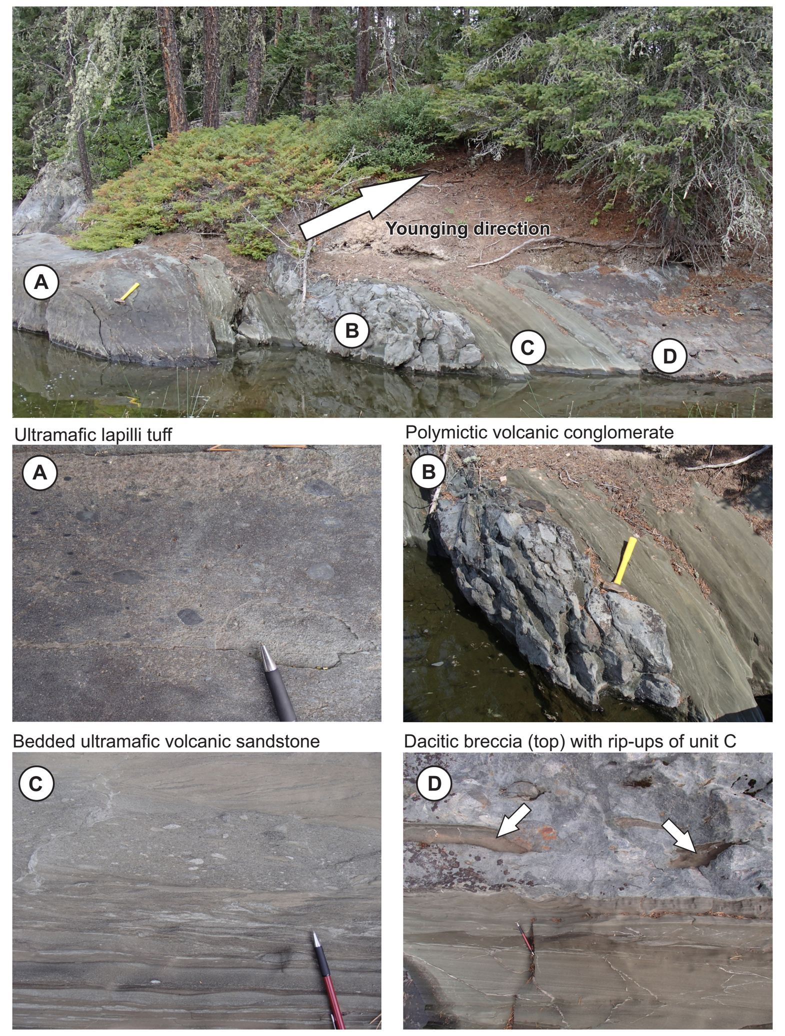
Based on mapping in 2015, three volcanic facies associations were recognized in the OLG at Knee Lake.

Each facies association is dominated by coarse epiclastic rocks interpreted to represent debris-flow deposits in channelized subaqueous fans (Syme et al., 1997), which likely formed in close proximity to their subaerial or shallow-marine volcanic sources.

Local stratigraphic interlayering (see photo panel to right) indicates that ultramafic–dacitic volcanism was broadly coeval, perhaps within a volcanic field composed of multiple eruptive centres.

Ultramafic facies association | **Basaltic andesite facies association** | **Andesitic–dacitic facies association**

Exceptional preservation of primary textures and structures in many locations permits documentation of deposition processes and contact relationships. In the example below, various lithofacies of the ultramafic (A, C) and andesitic–dacitic (B, D) facies associations are interstratified, indicating coeval, compositionally diverse volcanism.



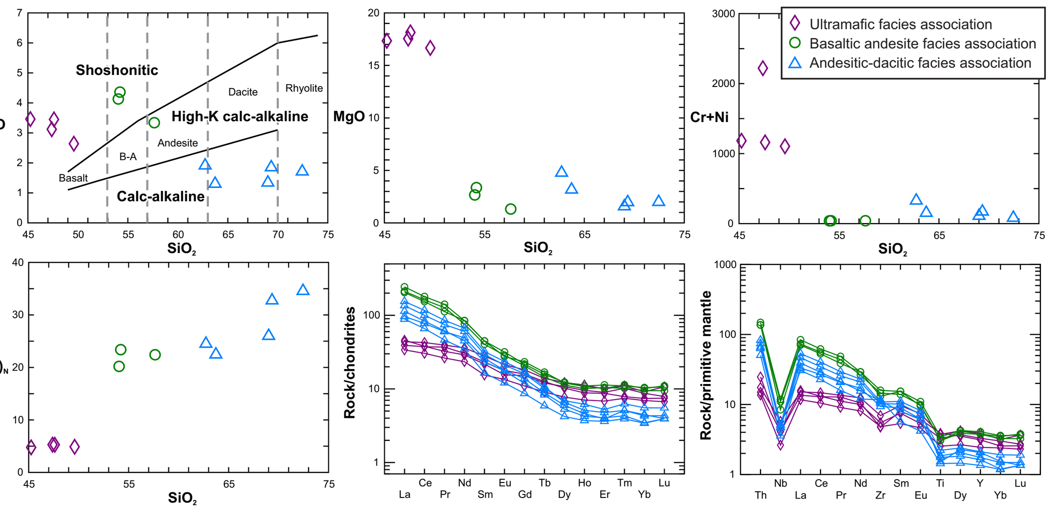
Geochemistry

The ultramafic facies association is strongly enriched in MgO, Cr and Ni, with high K_2O values indicative of alkaline affinity. Bulk chemical compositions are comparable to Archean ultramafic lamprophyres elsewhere in the Superior province (e.g., Lefebvre et al., 2005), suggesting these rocks may derive from lamprophyric volcanism. Ultramafic–mafic plutonic clasts in sedimentary facies of this association may represent coeval basement, entrained in mantle-derived magmas.

The basaltic andesite facies association is strongly enriched in K_2O and is comparable in terms of chemistry and texture to shoshonitic volcanic rocks documented at Oxford Lake (e.g., Hubregtse, 1978; Brooks et al., 1982).

The andesitic–dacitic facies association has bulk chemical characteristics typical of calcalkalic (arc) volcanic rocks.

Each chemical type is characterized by smoothly sloped chondrite-normalized REE profiles and significant negative HFSE anomalies (Nb, Zr, Ti) on primitive-mantle normalized profiles, consistent with modern arc volcanic rocks.



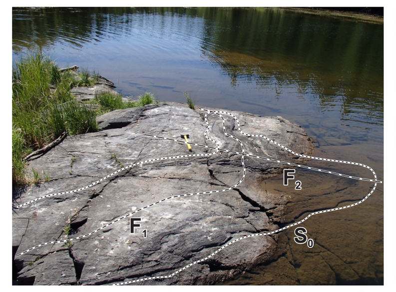
Structural geology

Map patterns, mesoscopic deformation structures and overprinting relationships indicate that supracrustal rocks at Knee Lake have been affected by at least three generations of ductile deformation followed by brittle-ductile and brittle faulting.

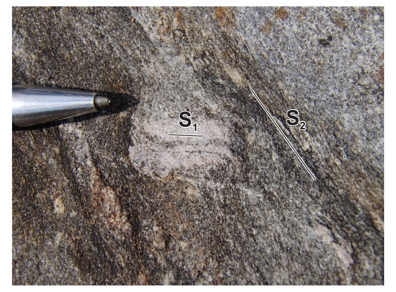
The earliest ductile structures are isoclinal F_1 folds and an axial-plane S_1 foliation. Macroscopic F_1 folds are also inferred from bedding-cleavage relationships and from aeromagnetic patterns (map and inset to left).

Mesoscopic F_1 folds are overprinted by open to isoclinal F_2 folds and a subvertical S_2 foliation, which is the main fabric observed in most outcrops outside of late shear zones.

South of the TISZ, sigmoidal inclusion trails in porphyroblasts on F_2 fold limbs indicate that F_2-S_2 structures likely formed during peak metamorphism.



Isoclinal F_1 fold, defined by iron formation (S_0), overprinted by open to tight F_2 folds

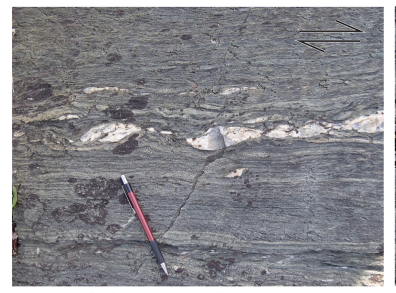


Inclusion trails in cordierite, representing S_1 fabric overgrown during development of S_2

Macroscopic F_2 folds are cut by subvertical ductile shear zones that bound major and minor structural panels. The shear zones vary in trend from northeast to southeast and contain a penetrative mylonitic S_3 foliation.

The L_3 stretching lineation shows systematic patterns of orientation (Lin et al., 1998): it plunges steeply on the margins of shear zones and progressively becomes more shallowly plunging toward the centres.

Dextral shear-sense indicators are well developed on horizontal surfaces. As described by Lin and Jiang (2001), the overall strain geometry is indicative of deformation-path partitioning within a kinematic regime of dextral transpression.


Mylonitic S_3 foliation and F_3 Z-folds in the Long Island shear zone (dextral shear)


L_3 stretching lineation defined by deformed clasts in conglomerate

Late structures include brittle-ductile or brittle faults, some of which are associated with narrow (<1 m) zones of cataclasite or pseudotachylite.

A possible major structure of this type is defined by truncated magnetic lineaments in the central portion of southern Knee Lake and trends east-northeast from Opapuskitew Bay to just south of Omusinapis Point.

Economic considerations

The Knee Lake area has good potential for a number of important deposit types. Results from this study improve the stratigraphic and structural framework of the area and can therefore help formulate exploration strategies. Specific target areas with favourable potential include the following:

Felsic volcanic rocks (HRG) south of Cinder Lake: exhibit several indicators of VMS potential, including calcalkalic (arc type) rhyolite flows and proximal volcaniclastic rocks; lenses of solid sulphide (massive pyrite-pyrrhotite over core lengths of 20–33 m); weakly anomalous Zn (0.86%) and Cu (0.31%); layers of siliceous exhalite; and stringer chlorite-garnet alteration (A.F. 72612, 94730).

Layered ultramafic–mafic intrusions at Knee Lake: several bodies of serpentinized peridotite have been tested by drilling, presumably as targets for magmatic Ni deposits (A.F. 91190, 91191, 91192; assay results not reported), and these remain interesting exploration targets, particularly the inferred footwall feeder dikes, which have not been systematically evaluated.

The Cinder Lake alkaline intrusive complex: exhibits several favourable attributes (Kressel et al., 2010), including: numerous species of REE-bearing minerals in syenite; potentially complex internal zoning (as indicated by aeromagnetic data); and a potential association with carbonatite (a major host of REE deposits worldwide).

Long Island shear zone: this major structure is spatially associated with several Au occurrences (A.F. 93139, 93183, 94459, 94891). Significant results from previous drilling include 1.45 g/t Au over 13.7 m at the Celtic showing, with individual assays up to 5.1 g/t Au and 18 000 ppm As (A.F. 93184). On a regional scale, shear zones at or near the contact between the HRG and OLG host significant deposits at Oxford Lake (Rusty Zone) and Twin Lakes (Monument Bay) suggesting that this contact represents a key regional metallotect for orogenic Au deposits.

References

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