GS2017-1

Detailed stratigraphic and structural mapping of the Oxford Lake–Knee Lake greenstone belt at southern and central Knee Lake, Manitoba (parts of NTS 53L15, 53M2)

by S.D. Anderson

In Brief:

- Detailed mapping provides a new stratigraphic and structural framework for mineral exploration
- Imbrication of different volcanic assemblages is attributed to thrust faulting prior to regional isoclinal folding
- Diamonds and orogenic gold are hosted by fault-bounded panels within a structural collage at southern Knee Lake

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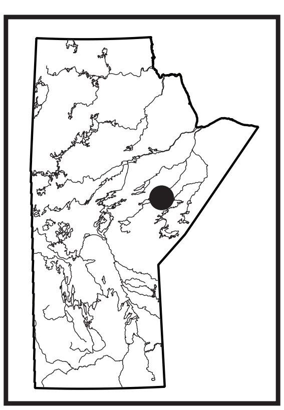

Summary

In 2017, the Manitoba Geological Survey (MGS) continued its study of the Oxford Lake–Knee Lake greenstone belt by completing new detailed bedrock mapping at southern and central Knee Lake with the objective of better understanding the stratigraphic and structural architecture of the belt, and its tectonic evolution and mineral resource potential. Building on results of MGS mapping in 2015 and 2016, salient results of the 2017 mapping are as follows: 1) definition of a structural collage at southern Knee Lake, including a fault-bounded panel that is interpreted to belong to the ca. 2.83 Ga Hayes River group (HRG), but is imbricated with panels belonging to the ca. 2.72 Ga Oxford Lake group (OLG); 2) delineation of a distinctive unit of effusive volcanic rocks, consisting of porphyritic basalt–andesite flows of shoshonitic–calcalkalic (i.e., OLG) affinity, within rocks previously assigned to the HRG at central Knee Lake, possibly indicating the location of a major thrust fault, along which these units were imbricated prior to regional shortening and isoclinal folding; 3) enhanced understanding of stratigraphic and structural complexities that control or modify several types of mineralization in the belt, including the recently discovered diamondiferous volcanic conglomerates at southern Knee Lake; and 4) identification of favourable exploration potential for orogenic gold mineralization within the structural collage at southern Knee Lake, including zones that contain quartz-feldspar porphyry (QFP) dikes, ankerite (±silica, sericite) alteration and quartz-tourmaline veins. These results represent important progress toward a comprehensive geological synthesis of the Oxford Lake–Knee Lake belt and an up-to-date assessment of its economic potential.

Introduction

In 2012, the MGS began a renewed study of the Oxford Lake–Knee Lake greenstone belt to provide a better understanding of its stratigraphy, structure, tectonic evolution and metallogeny. As the largest contiguous belt of supracrustal rocks in the northwestern Superior province, the Oxford Lake–Knee Lake belt is critical to unlocking the resource potential of the region, which is highly prospective for a variety of commodities, including gold, rare metals, nickel and diamonds, yet remains underexplored. New bedrock mapping and thematic studies, augmented by structural, lithogeochemical, Sm-Nd isotopic, U-Pb geochronological and high-resolution aeromagnetic datasets, are being used to upgrade existing maps, with the goal of a comprehensive regional synthesis and compilation for the belt.

This renewed study expands on previous investigations in the Oxford Lake–Knee Lake belt (most recently summarized in Anderson, 2017), which have indicated considerable scope for additional work to resolve outstanding questions. Shoreline mapping for the present study took place at Oxford Lake in 2012 and 2013 (Anderson et al., 2012a–c, 2013a–d) and continued at Knee Lake in 2015 and 2016 (Figure GS2017-1-1; Anderson et al., 2015a, b, 2016; Anderson, 2016a, b). Discoveries of carbonatite dikes enriched in rare metals at Oxford Lake (Anderson et al., 2012c; Reimer, 2014) and Knee Lake (Anderson, 2016a, b; Donak, 2016), and volcanic conglomerate containing diamonds at southern Knee Lake (Anderson, 2017), are direct results of this work that have stimulated renewed exploration interest in the belt. Building on these results, the goal of the 2017 fieldwork was to unravel complex stratigraphic and structural relationships identified by previous work in two key areas of the belt at southern and central Knee Lake. New shoreline mapping at a scale of 1:10 000 was augmented by data from whole-rock geochemical analyses and industry high-resolution aeromagnetic surveys to improve understanding of both areas.

Regional setting

The Oxford Lake–Knee Lake greenstone belt is situated in the western portion of the Oxford–Stull domain of the western Superior province (Stott et al., 2010). This domain consists of ca. 2.9–2.7

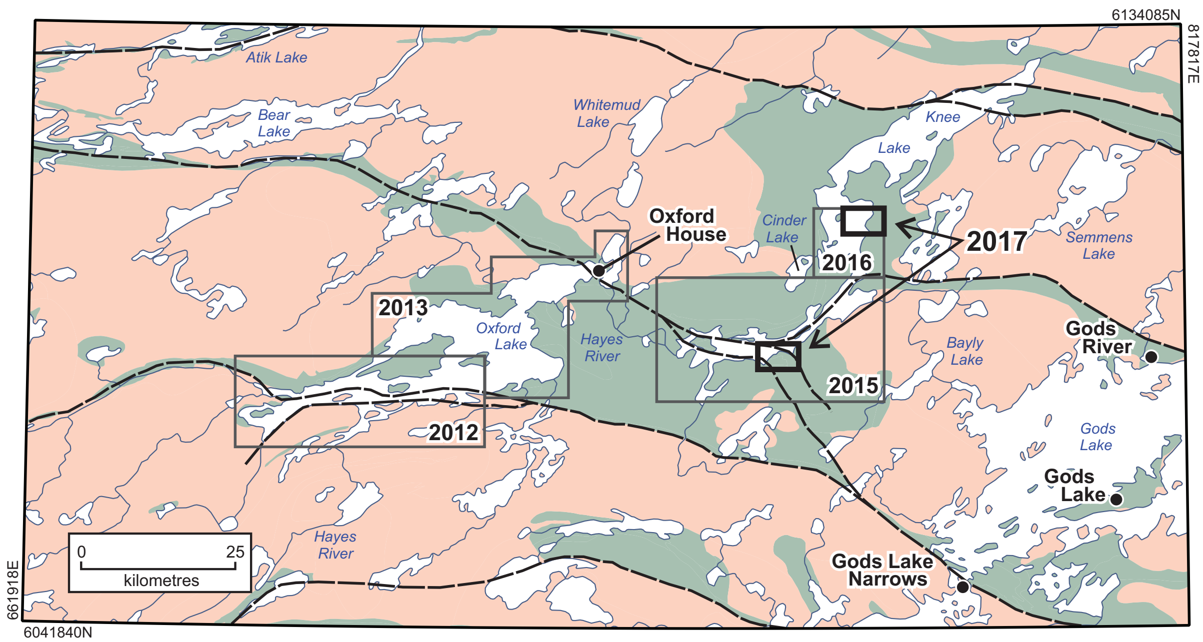

Figure GS2017-1-1: *Regional geological setting of the Oxford Lake–Knee Lake greenstone belt, showing the locations of study areas. Supracrustal rocks are indicated by green fill, whereas granitoid rocks are indicated by pink fill. Dashed black lines indicate major faults.*

Ga volcanic and plutonic rocks with mostly juvenile isotopic signatures and Nd model ages less than 3.0 Ga, thought to represent a tectonic collage of oceanic and continental-margin affinity bounded by older protocratons to the north and south (Skulski et al., 2000; Percival et al., 2006). Fault-bounded crustal blocks in the western Superior province are thought to have been juxtaposed by ca. 2.72 Ga, during a major episode of collisional orogenesis that culminated with the amalgamation of the western Superior province (Skulski et al., 2000; Lin et al., 2006; Percival et al., 2006).

Stratigraphic context

The Oxford Lake–Knee Lake belt is the largest contiguous greenstone belt in the Oxford–Stull domain and has historically been subdivided into two principal stratigraphic units: the older Hayes River group (HRG) and younger Oxford Lake group (OLG). More recent work has demonstrated that this stratigraphic scheme is oversimplified; however, it is mostly retained here for the purpose of continuity with previous reports, although recent and ongoing investigations will necessarily lead to substantial revisions. Greenschist-facies metamorphic assemblages and ductile deformation fabrics characterize rocks through most of the study area. However, primary features are generally well preserved, allowing the rocks to be described in terms of protoliths.

The classical HRG consists of monotonous successions of tholeiitic basalt flows and subvolcanic ultramafic–mafic sills, with minor calcalkalic intermediate–felsic volcanic, volcaniclastic and turbiditic sedimentary rocks, and iron formation (Gilbert, 1985; Hubregtse, 1985; Syme et al. 1997, 1998; Anderson et al., 2013d, 2015b; Anderson, 2016b). The base of the HRG is typically defined by granitoid rocks across structural or intrusive contacts, whereas the top is defined by faults or an unconformity. The type sections at central Oxford Lake and southern Knee Lake approach 10 km in thickness and define homoclinal panels (Anderson et al., 2013d, 2015b), representing either a primary stratigraphic succession (Gilbert, 1985; Hubregtse, 1985) or a tectonic collage (Syme et al., 1999). Elsewhere (e.g., central Knee Lake), the structural geometry of the HRG is far more complex, characterized by macroscopic isoclinal folds and faults, including concordant structures along which structural panels of various ages may have been imbricated, as described herein. Results of U-Pb zircon dating of felsic volcanic rocks in the HRG at Knee Lake indicate that volcanism spanned roughly 10 m.y., between ca. 2835 and 2825 Ma (Corkery et al., 2000).

The classical OLG overlies the HRG and is generally much more heterogeneous, comprising diverse volcanic, volcaniclastic and sedimentary rocks that were deposited in subaerial to basinal marine settings. The OLG has been subdivided for mapping purposes into volcanic and sedimentary subgroups, although subsequent work has demonstrated that the stratigraphy of these rocks is considerably more complex. Coherent flows and coarse fragmental deposits consisting of basalt, andesite, dacite and rhyolite of shoshonitic–calcalkalic affinity (Hubregtse, 1978, 1985; Brooks et al., 1982; Gilbert, 1985) are interstratified with coarse volcanic sedimentary rocks interpreted as debris- and grain-flow deposits in subaqueous fans sourced from nearby subaerial or shallow-marine volcanoes (Syme et al., 1997; Anderson et al., 2013d, 2015b). At southern Knee Lake, the OLG includes ultramafic (lamprophyric), basaltic andesite (shoshonitic) and andesitic–dacitic (calcalkalic) facies associations (Figure GS2017-1-2; Anderson et al., 2015a, b). Local stratigraphic interlayering indicates that this volcanism was broadly coeval, perhaps within a volcanic field composed of multiple eruptive centres. Results of U-Pb zircon dating indicate that volcanism spanned roughly 20 m.y., between ca. 2725 and 2705 Ma (Corkery et al., 2000; Lin et al., 2006). Distal facies of the OLG comprise thick successions of submarine-fan conglomerate, sandstone, greywacke-mudstone turbidite and iron formation, with minor basalt flows; rounded cobbles of tonalite, granodiorite and gabbro in these conglomerates indicate a more diverse provenance. Type sections of the OLG at eastern Oxford Lake and southern Knee Lake have minimum stratigraphic thicknesses of 2 km; however, the OLG is everywhere characterized by structural complexities that obscure stratigraphic relationships. Hypabyssal porphyry intrusions of shoshonitic basaltic-andesite in the underlying HRG confirm it as the local basement during deposition of the OLG.

New mapping and structural analysis at southern and central Knee Lake indicate that fluvial-alluvial sandstone and conglomerate previously included in the OLG were deposited in younger basins, which are bounded at the base by angular unconformities and at the top by faults, interpreted to represent thrusts, and are thus broadly synorogenic (Anderson, 2016b). These rocks contain large-scale trough crossbeds, channel-fills and pebble–cobble lag deposits characteristic of fluvial-alluvial sequences and form homoclinal panels that range up to 800 m in thickness. Abundant clasts of vein quartz and granitoid rocks indicate that deposition was coeval with regional uplift and erosion; U-Pb dating of detrital zircons indicates maximum depositional ages of ca. 2710 Ma (Corkery et al., 2000).

Structural context

Map patterns, mesoscopic deformation structures and overprinting relationships indicate that supracrustal rocks of the Oxford Lake–Knee Lake belt have been affected by at least five generations (G_1 to G_5) of deformation structures, as summarized briefly below based on recent mapping at Knee Lake (Anderson et al., 2015b; Anderson, 2016b, 2017).

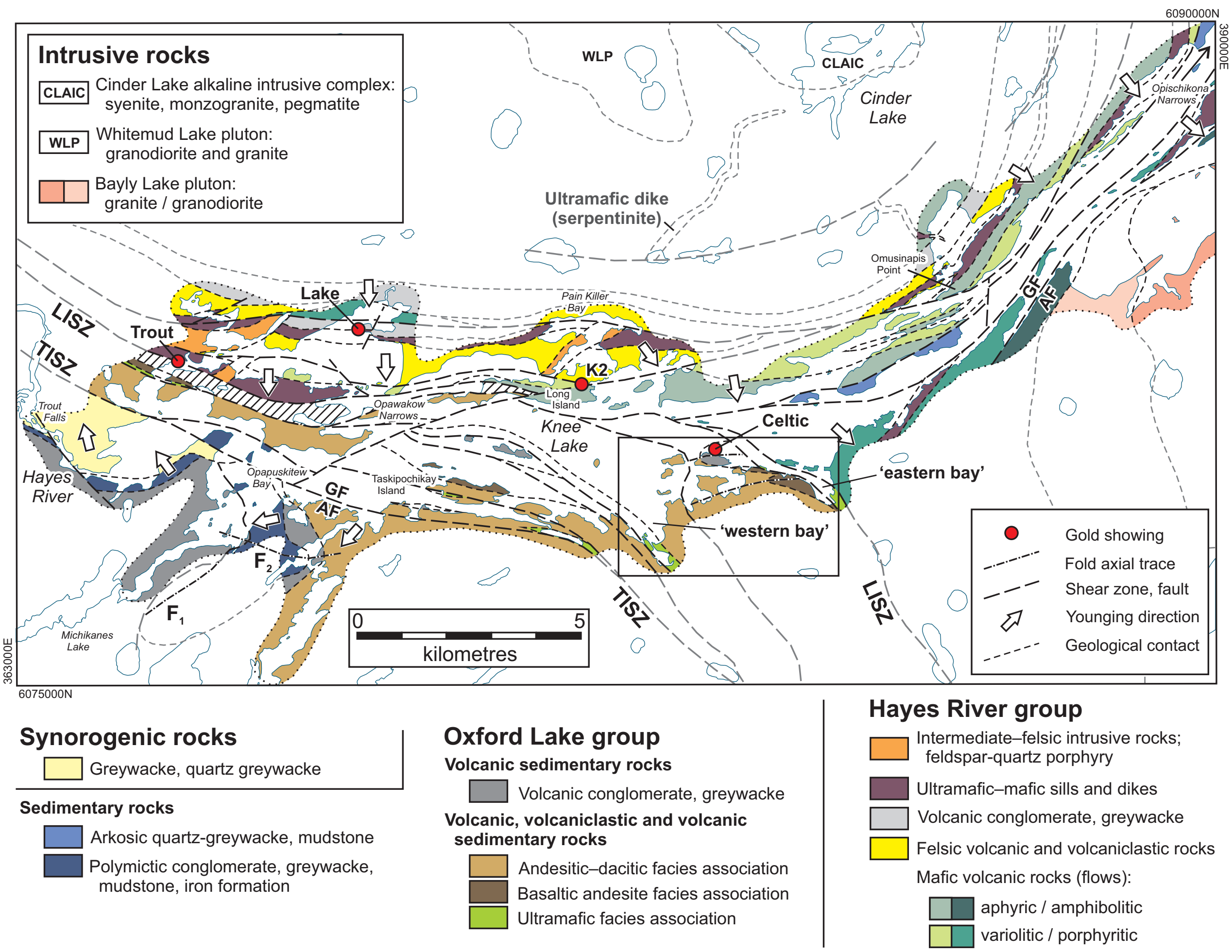

Figure GS2017-1-2: *Simplified geology of southern Knee Lake (Anderson et al., 2015a), including named gold showings and geographic features. Geology outside the 2015 mapping limit (dotted line) is simplified from Gilbert (1985) and aeromagnetic data. Hachure pattern indicates undivided tectonite of the LISZ. Abbreviations: AF and GF indicate structural boundaries between amphibolite facies and greenschist facies rocks; LISZ, Long Island shear zone; TISZ, Taskipochikay Island shear zone. Location of Figure GS2017-1-3 is outlined.*

Isoclinal F_1 folds in bedded sedimentary rocks of the OLG are the earliest ductile deformation structures observed; macroscopic F_1 folds are also inferred from bedding-cleavage relationships and aeromagnetic patterns, particularly in the area southwest of Knee Lake (Figure GS2017-1-2). The F_1 folds are overprinted by upright, open to isoclinal F_2 folds that plunge steeply and are parasitic to macroscopic F_2 folds that control map patterns within major structural panels. These folds are associated with a penetrative S_2 foliation that trends northeast to east-southeast and includes a prominent S_2 shape fabric defined by flattened primary features and a downdip stretching lineation–the main fabrics observed in most outcrops outside of later shear zones.

Macroscopic F_2 folds do not carry across the basal unconformities of the synorogenic, fluvial-alluvial sedimentary basins at Knee Lake, including the thick sequence of cross-bedded greywacke exposed at Trout Falls (Figure GS2017-1-2), which is taken to indicate that the F_2 folds are older. The faulted upper contacts of these basins, and an internal shape fabric and locally penetrative foliation, are tentatively assigned to the G_3 generation of deformation structures, and are interpreted to record structural inversion of these basins and renewed shortening during regional collisional orogenesis (Anderson, 2016b).

At southern Knee Lake, macroscopic F_2 folds are disrupted by subvertical ductile shear zones that bound major and minor structural panels, the principal examples being the Long Island shear zone (LISZ) and Taskipochikay Island shear zone (TISZ; Figure GS2017-1-2), which mostly delimit the Southern Knee Lake shear zone of Lin et al. (1998). These shear zones vary in trend from northeast to southeast; at present it is unknown whether they represent a single generation of structure, but they are assigned here to the G_4 generation on the basis of similar style and kinematics of fabrics. The shear zones contain a penetrative, commonly mylonitic, S_4 foliation. Elongate clasts define an L_4 stretching lineation that plunges shallowly and is locally subhorizontal in the cores of major G_4 shear zones. Shear-sense indicators and open to isoclinal Z-folds that overprint the S_4 foliation are interpreted to record progressive dextral shear. Systematic spatial variations in the style and orientation of deformation fabrics at southern Knee Lake indicate that deformation was strongly partitioned, possibly due to deformation-path partitioning within a kinematic regime of G_4 dextral transpression (Lin et al., 1998; Lin and Jiang, 2001) or due to overprinting by deformation structures of different generations (i.e., overprinting of G_2 fabrics by G_4 fabrics).

Later (G_5) structures include concordant to discordant, brittle-ductile or brittle faults, some of which are associated with narrow (<1 m) zones of cataclasite. A possible major structure of this type, which is defined by sharply truncated magnetic lineaments in the central portion of southern Knee Lake, trends east-northeast from Opapuskitew Bay to just south of Omusinapis Point (Figure GS2017-1-2).

Southern Knee Lake

As described in recent studies (Syme et al., 1997; Anderson et al., 2015b), each of the principal components of the Oxford Lake–Knee Lake belt is exposed in shoreline outcrop at southern Knee Lake. The HRG and OLG wrap broadly around the margins of the Bayly Lake and Whitemud Lake plutons, the latter of which includes the Cinder Lake alkaline intrusive complex (Figure GS2017-1-2). The HRG is mostly exposed along the northern and eastern shorelines of southern Knee Lake and defines homoclinal panels that are intruded inland by granitoid plutons. Internal map patterns are disrupted by shear zones and faults; those of the OLG, which is mostly exposed on the southern shoreline and adjacent islands, are further complicated by isoclinal folds. The LISZ separates the HRG on the north from the OLG on the south, whereas the TISZ coincides with an abrupt southward change from greenschist- to amphibolite-facies metamorphism in the OLG. Bedrock mapping in 2017 was focused on a complex series of structural panels bounded by the LISZ and the TISZ in the southeastern portion of southern Knee Lake, to unravel stratigraphic and structural relationships, and provide better context for occurrences of gold and diamonds in this area.

Results from the 2017 field season

Detailed bedrock mapping at 1:10 000 scale in 2017 indicates that the area bounded by the LISZ and TISZ in the southeastern portion of southern Knee Lake includes nine lithostructural panels, defined on the basis of lithology, structural style and/or metamorphic grade (Figure GS2017-1-3). Gilbert (1985) and Syme et al. (1997) identified three major panels in this area that correspond, from northeast to southwest, respectively, to the HRG and the volcanic and sedimentary subgroups of the OLG. Well-preserved sedimentary structures such as cross-bedding, scours and load casts provide unambiguous younging directions that, in several locations, indicate 'back-to-back' relationships between adjacent panels (e.g., panels 1, 2, 3), which is interpreted to indicate that they are fault-bounded. Direct evidence of faulted contacts, in the form of mapped tectonite and mylonite, is observed on both margins of panels 5 and 8, as well as the southern margin of panel 1 (corresponding to the LISZ). Panel 5 is intruded by abundant dikes of QFP and basalt that are not observed in adjacent panels, suggesting that the contacts are not simply fault-modified (as is demonstrably the case for the contact between panels 7 and 8; Anderson, 2017), but entirely structural (see below). Panels 2–7 are characterized by greenschist-facies metamorphic assemblages, whereas panels 1 and 9 contain amphibolite-facies assemblages and are intruded beyond the limits of Figure GS2017-1-3 by granitoid rocks and local pegmatite, consistent with the presence of major, possibly crustal-scale structures in these locations (i.e., the LISZ and TISZ). Brief descriptions of the lithological characteristics of each panel are provided in Figure GS2017-1-3; more detailed descriptions for all but panel 5 can be found in Syme et al. (1997) and Anderson et al. (2015b), and are not repeated here. Panels 2 and 7 contain primitive alkaline rocks of the

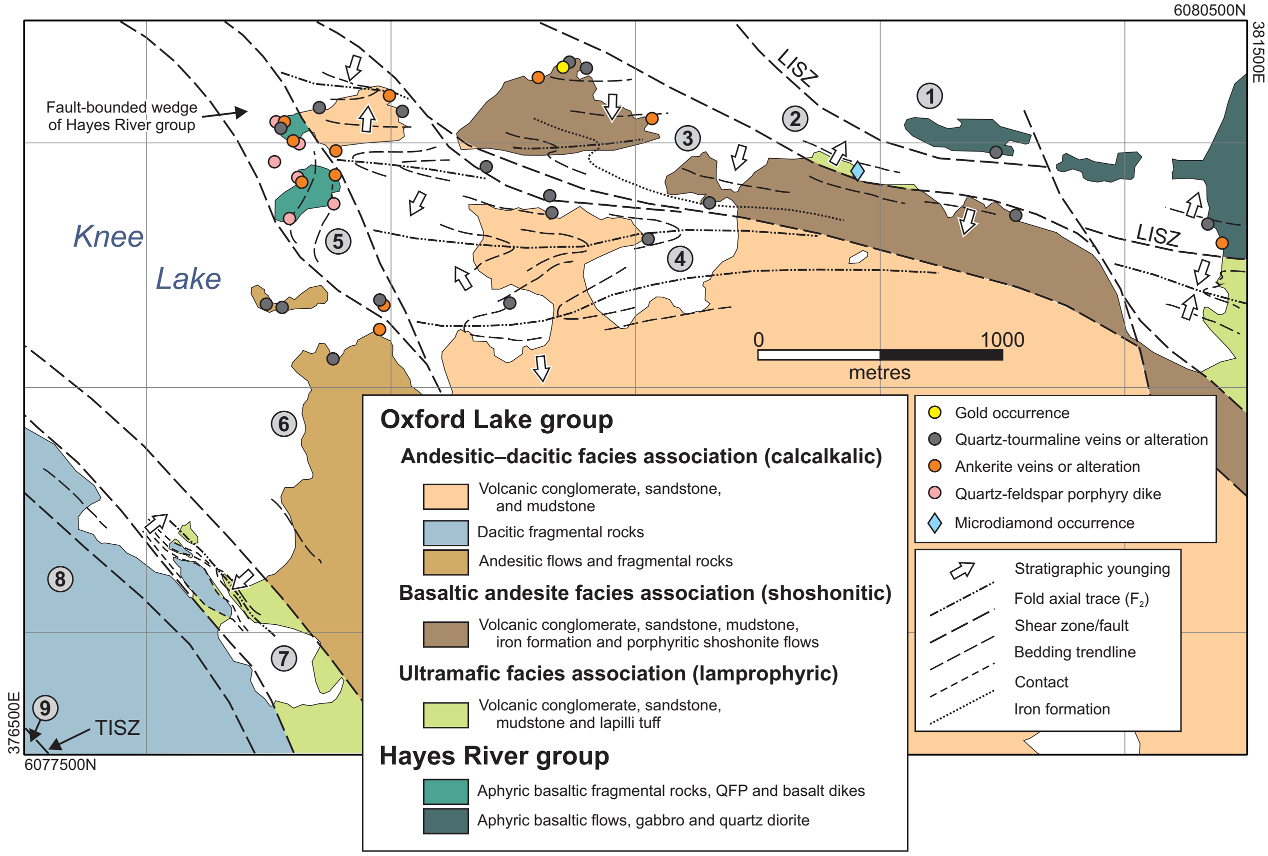

Figure GS2017-1-3: *Simplified geology of the southeastern portion of southern Knee Lake. Numbers (1–9) indicate the major lithostructural panels described in the text. Abbreviations: LISZ, Long Island shear zone; QFP, quartz-feldspar porphyry; TISZ, Taskipochikay Island shear zone. Note microdiamond and gold occurrences in panels 2 and 3, respectively.*

ultramafic facies association, which are locally diamondiferous (Anderson, 2017).

Panel 5 is particularly interesting in that it shares a number of characteristics with mafic volcanic rocks of the HRG exposed along the northern shoreline of southern Knee Lake and is distinct from all surrounding components of the OLG at southern Knee Lake. In particular, this panel consists of breccia, tuff breccia and lapilli tuff of basaltic composition, with minor interlayers of bedded tuff and rare, massive to vaguely pillowed, basalt flows. The coarse fragmental rocks are monolithic, crudely stratified and contain matrix-supported, unsorted clasts that are typically angular, and commonly distinctly cuspate, suggestive of coarse hyaloclastite (Figure GS2017-1-4a). The clasts consist of dark green, aphyric to sparsely plagioclase-phyric basalt in a matrix of similar composition; whole-rock geochemical analyses are pending. Dikes of pale pink-green QFP are ubiquitous and range up to more than 10 m in thickness; they contain conspicuous feldspar (20–25%) and lesser quartz (2–3%) phenocrysts (<5 mm) in an aphanitic, siliceous groundmass. The felsic dikes are cut by dikes of dark green, fine-grained, aphyric basalt (Figure GS2017-1-4b) that range up to 50 cm in thickness and are sparsely amygdaloidal, with thick (~5 cm) chilled margins. As noted above, neither the QFP nor the basalt dikes are observed outside of panel 5. Most of the outcrops within this panel are characterized by a penetrative L>S fabric that includes a down-dip stretching lineation (L_2); this fabric appears to be overprinted by penetrative mylonitic fabrics along both margins of the panel, possibly corresponding to G_4 shear zones.

Based on these features, panel 5 is interpreted to represent a structural slice of the HRG that has been imbricated with the OLG, either during early thrust faulting (G_1 or G_2; see below) or later transcurrent shearing (G_4). Such features support the contention of Syme et al. (1999) that much of the belt constitutes an imbricate tectonic collage, rather than a relatively intact, though deformed, stratigraphic succession. As discussed below, panel 5 also represents an excellent target for gold exploration.

Central Knee Lake

Stratigraphic and structural aspects of the central Knee Lake area have been addressed by Syme et al. (1998) and Anderson (2016b). As described by Anderson (2016b), unusually low water levels in 2016 facilitated a much improved understanding of the geology in south-central Knee Lake, including the delineation of three northwest-trending structural panels, interpreted to be separated by thrust faults (Figure GS2017-1-5).

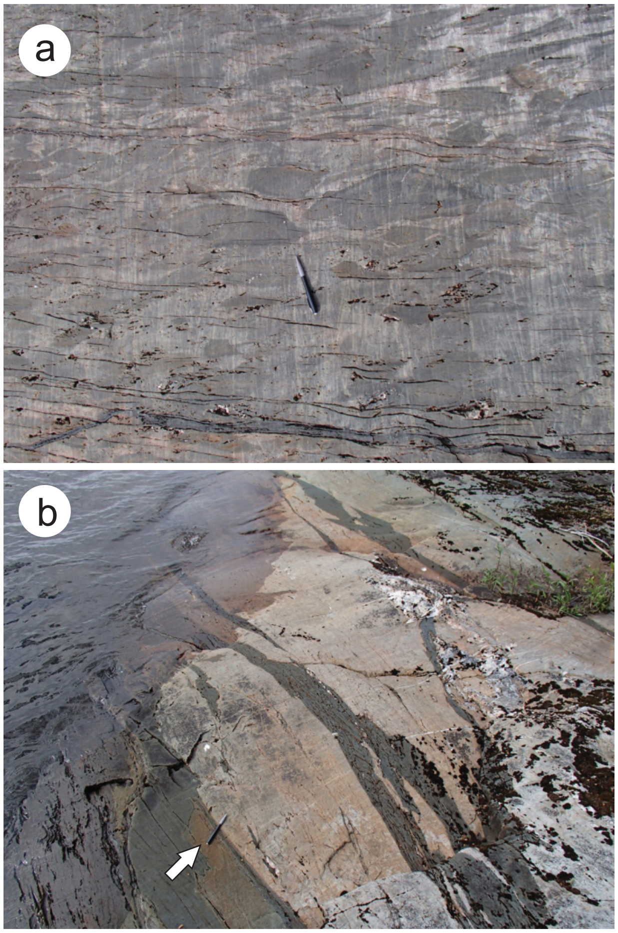

Figure GS2017-1-4: *Outcrop photographs of characteristic rock types in panel 5 of the structural collage at southern Knee Lake:* ***a)*** *tuff breccia, showing angular cuspate clasts of aphyric basalt;* ***b)*** *thick quartz-feldspar porphyry dike (pale pink) intruded by irregular dikes of aphyric basalt; arrow indicates pencil for scale.*

The ‘southwest’ panel includes an east-younging homocline of the HRG that is intruded at its base, beyond the limits of the map area, by the Whitemud Lake pluton and Cinder Lake alkaline intrusive complex. The HRG is overlain to the east by tightly folded marine sedimentary and volcanic rocks thought to belong to the OLG (an interpretation supported by U-Pb ages of detrital zircons, which indicate an abundance of Neoarchean detritus in the greywacke turbidites; S.D. Anderson, unpublished data, 2017). Both are overlain by a homocline of fluvial-alluvial conglomerate and sandstone across a prominent angular unconformity; gabbro intrusions and early isoclinal folds in the marine sequence do not continue upward into the fluvial-alluvial sequence, demonstrating both the presence and angular nature of the unconformity in this location. In the ‘central’ panel, tightly folded rocks of the HRG are overlain to the northeast by another homocline of fluvial-alluvial sedimentary rocks, comparable to that in the southwest panel, but considerably thinner and possibly less continuous.

Reconnaissance mapping in 2016 indicated that the northeast panel is similarly complex, but consists entirely of HRG rocks, interpreted to define a tight to isoclinal, northwest-facing, anticline–syncline fold pair (Anderson, 2016b). One outcrop located in the central portion of the panel was found to consist of a series of subvolcanic sills or massive flows characterized by carbonate amygdules, vague fragmental textures, thick chilled margins and abundant plagioclase as coarse tabular phenocrysts (~30%; 2–10 mm) in a dark grey biotitic groundmass–similar in most respects to shoshonite flows within the OLG. Results of a subsequent whole-rock geochemical analysis of a representative sill/flow indicate that it is andesitic, with strongly enriched K_2O (4.3 wt. %), light rare-earth and large-ion lithophile elements (chondrite-normalized La/Yb = 19.4; 1107 ppm Ba; 106 ppm Rb; 428 ppm Sr), and relatively depleted Nb (3.8 ppm). The chemistry of this rock is thus comparable to modern and ancient shoshonite, including that in the OLG (e.g., Brooks et al., 1982; Anderson, 2016a), suggesting that the northeast panel may contain previously unrecognized rocks belonging to the OLG. Hence, follow-up mapping in central Knee Lake during the 2017 field season was focused on the northeast panel, with an eye to establishing the distribution of shoshonitic rocks, documenting their field characteristics and resolving contact relationships.

Results from the 2017 field season

Figure GS2017-1-6 presents a revised interpretation of the bedrock geology in the northeast structural panel at central Knee Lake based on mapping during the 2017 field season as well as a compilation of previous work by Syme et al. (1998) and high-resolution aeromagnetic data. Map patterns and younging criteria are interpreted to indicate the presence of a macroscopic isoclinal F_2 syncline that has been disrupted by late (G_4 and G_5) faults, the most obvious of which is the highly-discordant structure that passes through the cluster of islands in the central portion of the mapped area. The geometry of the macroscopic syncline is best defined by a distinctive package of porphyritic volcanic rocks characterized by coarse, crowded phenocrysts of plagioclase. This package clearly includes lava flows (as opposed to subvolcanic intrusions cutting the HRG; see below) that have been identified on the basis of field characteristics in eight locations on both limbs of the macroscopic fold closure. Whole-rock geochemical data indicate that these flows include both alkaline (shoshonitic) and subalkaline (high-K calcalkalic) compositions, similar to the chemical diversity exhibited by the OLG at the type localities at southern Knee Lake and eastern Oxford Lake (Brooks et al., 1982; Anderson, 2016a).

The HRG in the northeast panel is typical of exposures elsewhere–it consists mostly of aphyric tholeiitic basalt and basaltic andesite flows, which are generally pillowed, but also include minor massive flows and flow breccia. Lenticular map units can be defined at various scales on the basis of variole content. Pillow cusps and shelves provide unambiguous younging directions in most locations. Minor intervals of interbedded felsic volcanic sandstone and mudstone with turbidite bedforms are

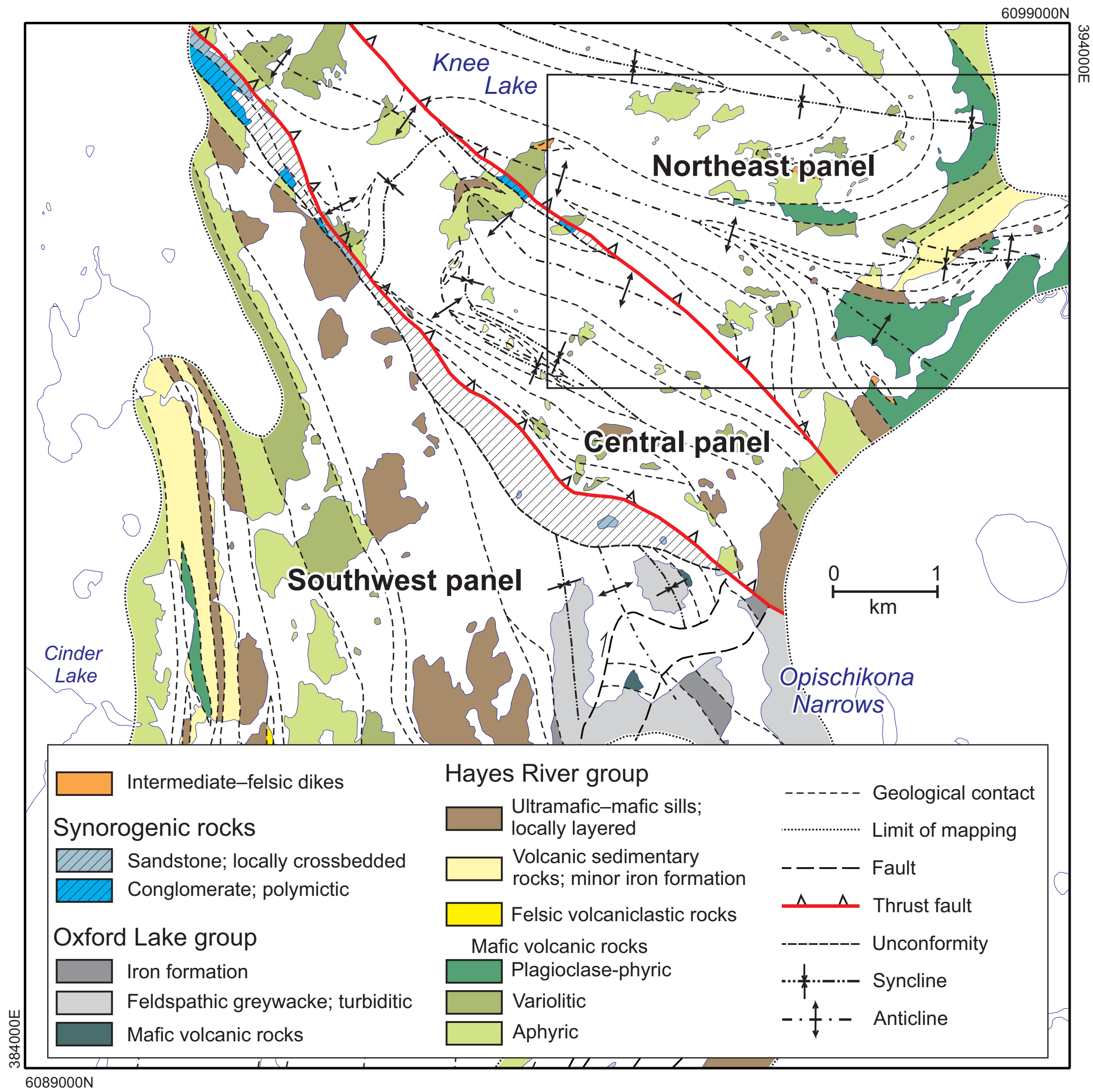

***Figure GS2017-1-5:** Simplified geology of the south-central Knee Lake area (Anderson et al., 2016). Hachured pattern indicates the extent of the fluvial-alluvial sedimentary rocks that unconformably overlie the Hayes River group and Oxford Lake group. Location of Figure GS2017-1-6, which provides a revised interpretation of the geology and structure of the northeast panel based on new results from the 2017 field season, is outlined.*

interstratified with the basalts and locally provide useful marker horizons. Thick gabbro sills within the HRG are mesocratic and fine to medium grained, and contain prominent magmatic layering or evidence of in situ differentiation in some locations. All of these rocks are intruded by dikes and sills of QFP.

The shoshonitic–calcalkalic porphyry flows in the northeast panel consist of basalt, basaltic andesite and minor andesite characterized by coarse, crowded phenocrysts of plagioclase (25–50%; 2–10 mm) in a fine-grained groundmass of actinolite, chlorite and biotite. Although typically pillowed, some outcrops are massive, whereas others contain thin layers of pillow-fragment or amoeboid-pillow breccia (Figure GS2017-1-7a). The pillows tend to be very large and bulbous, with thick dark grey selvages and minor (<10%) interpillow hyaloclastite. Plagioclase phenocrysts are coarser and more abundant in pillow cores, and locally show a concentric flow alignment parallel to the pillow selvage (Figure GS2017-1-7b). Most of these flows also contain irregular carbonate (±quartz) amygdules that range up to several centimetres across. The flows are interstratified with crudely bedded sections of coarse, plagioclase-crystal–rich volcanic sandstone (Figure GS2017-1-7c), likely representing reworked hyaloclastite, and poorly exposed intervals of interbedded volcanic conglomerate and sandstone, with minor layers of banded oxide- and sulphide-facies iron formation. The best exposures of these rocks occur on the large island in central Knee Lake, where they define a section approximately 500 m in thickness, and also in the large bay in the eastern portion of the map area, where pillowed flows are particularly well exposed. Sills of fine- to medium-grained gabbro intrude these rocks, but the QFP dikes observed in the HRG are apparently lacking. At southern Knee Lake, dikes and sills of felsic porphyry are also

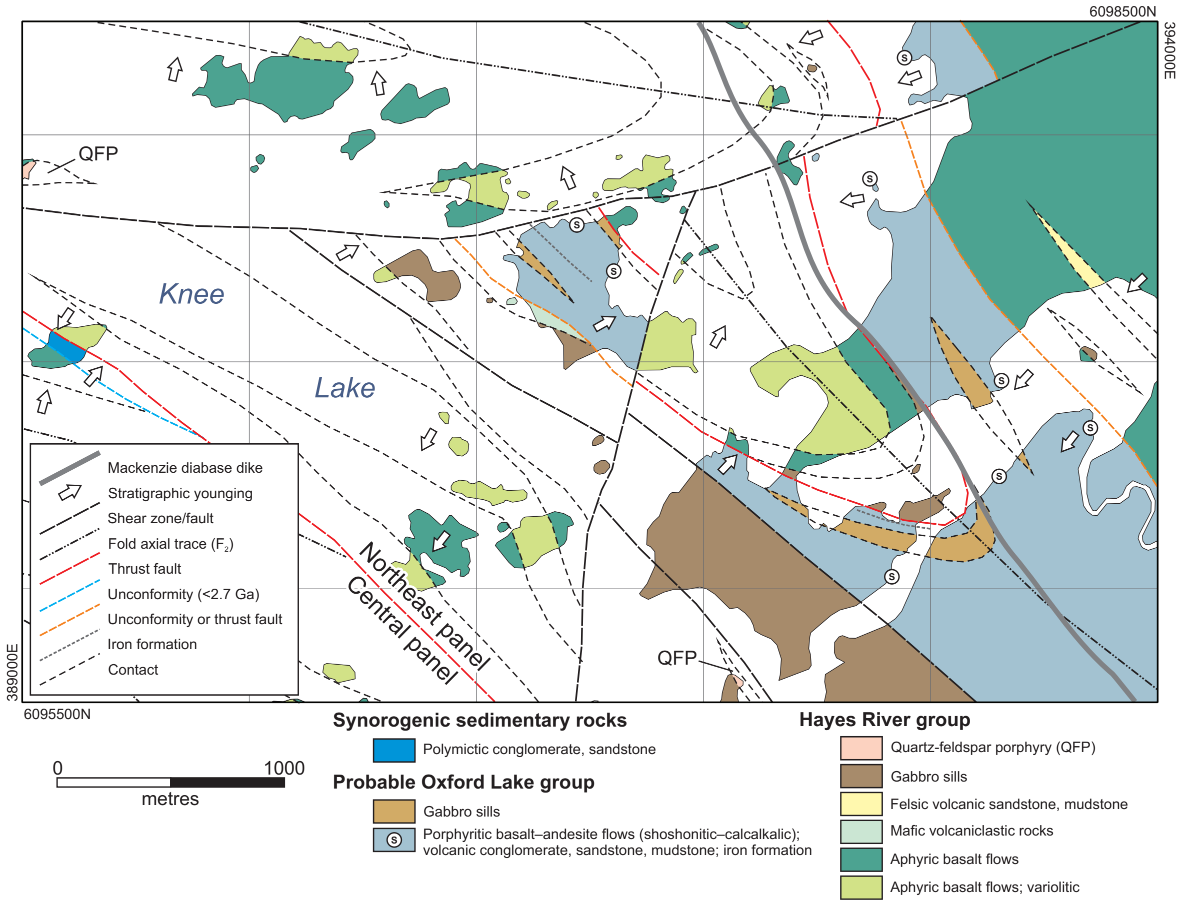

Figure GS2017-1-6: *Revised geology of the eastern portion of central Knee Lake, corresponding to the northeast structural panel of Anderson (2016b), showing the locations of porphyritic flows of shoshonitic–calcalkalic affinity (S). The Mackenzie dike is inferred from high-resolution aeromagnetic data.*

absent from the OLG, but are abundant and extensive in the HRG. This is taken to indicate that they predate the OLG, or perhaps represent subvolcanic feeders to OLG volcanic rocks.

Shoshonitic volcanism of equivalent age to the HRG has not been documented elsewhere in the northwestern Superior province, nor are there any documented occurrences of shoshonite flows within the HRG (Gilbert, 1985; Hubregtse, 1978, 1985). Moreover, the major and trace-element characteristics of the shoshonitic–calcalkalic flows in the northeast panel at central Knee Lake are closely comparable to representative examples of shoshonite flows and subvolcanic sills from the type localities at Oxford Lake and southern Knee Lake (Figure GS2017-1-8). For these reasons, the map unit containing shoshonitic flows at central Knee Lake is interpreted to represent a structural slice of the OLG (basaltic-andesite facies association of Anderson et al., 2015b) that was tectonically interleaved with the HRG, comparable but opposite to the relationship previously described at southern Knee Lake (i.e., slice of HRG within OLG; Figure GS2017-1-3). The lower contact may represent an unconformity or possibly an early (pre-F_2) thrust (Figure GS2017-1-6), but is nowhere exposed. The upper contact is almost certainly structural; it is exposed on the large island in Knee Lake, where a 1–2 m thick chloritic mylonite separates pillowed basalt flows in the hangingwall, interpreted to belong to the HRG, from a gabbro sill that intrudes shoshonitic volcanic rocks in the footwall. This contact is provisionally interpreted as an early thrust fault that formed prior to regional shortening and macroscopic folding (F_2), and is thus assigned to the G_1 generation of deformation structures. The recognition of such features is critical to resolving the stratigraphic and structural architecture of the Oxford Lake–Knee Lake belt, and provides key constraints to achieving a more thorough understanding of its tectonic and metallogenic evolution.

Economic considerations

Based on what is presently known about its geology, coupled with results of previous exploration, the Knee Lake area has potential for a number of mineral-deposit types, including volcanogenic Cu-Zn-Pb-Au-Ag, magmatic Ni-Cu-platinum group elements, intrusion-related rare metals, orogenic Au, and diamonds. Results from this study provide an improved understanding of stratigraphy and structure, which will help to inform exploration strategies. In particular, this report sheds considerable new light on the structural complexities that may be encountered in attempting to trace mineralization controlled or modified by structure; the newly discovered diamondiferous

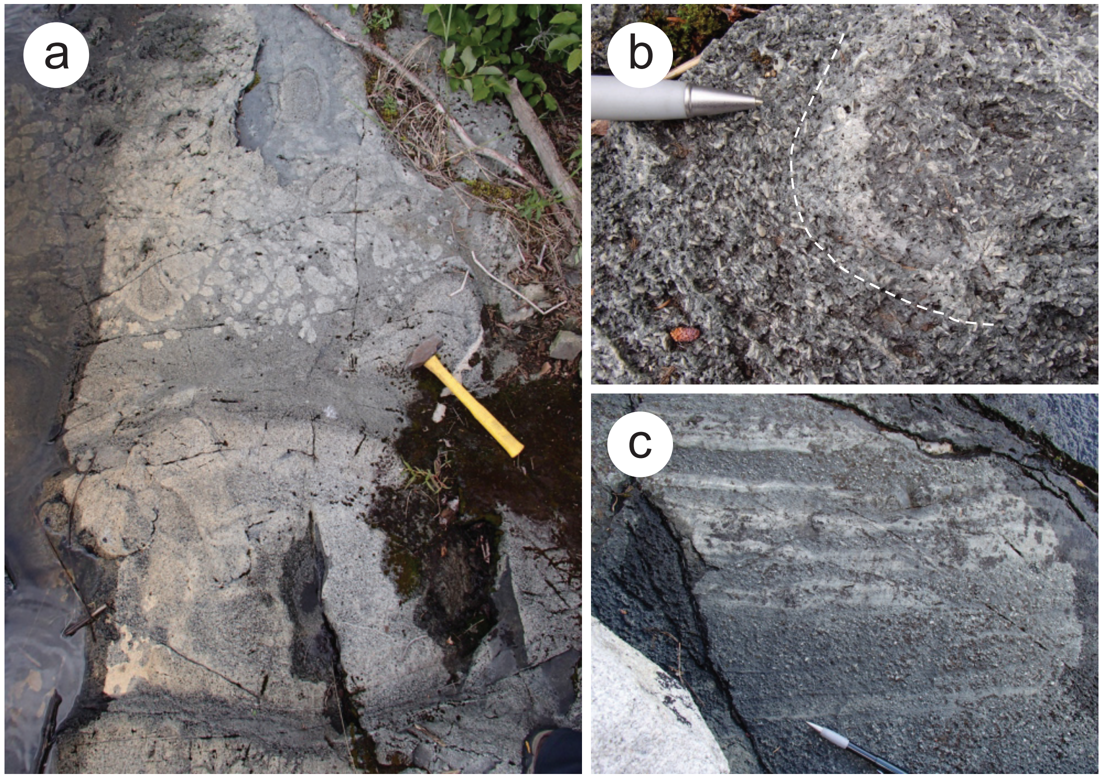

Figure GS2017-1-7: *Outcrop photographs of shoshonitic–calcalkalic volcanic rocks in the northeast structural panel of central Knee Lake:* ***a)*** *contact between pillowed flow of high-K calcalkalic basalt (bottom) and overlying breccia composed of amoeboid pillows and pillow fragments (top);* ***b)*** *detail of pillow core showing concentric flow alignment (indicated by dashed line) of plagioclase phenocrysts;* ***c)*** *bedded volcanic sandstone containing coarse plagioclase crystals, interpreted to represent reworked hyaloclastite.*

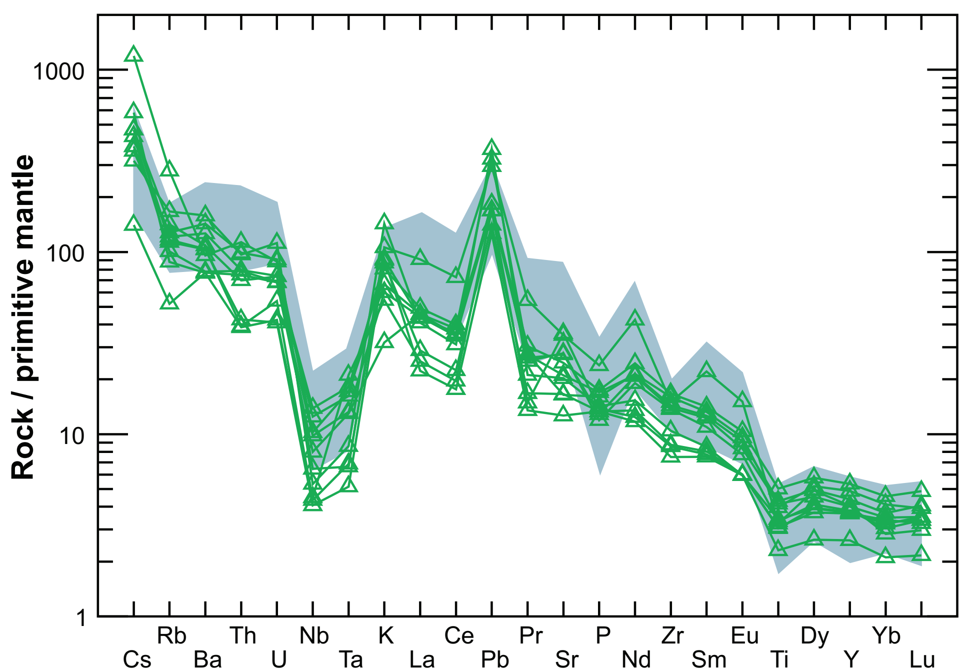

Figure GS2017-1-8: *Primitive-mantle–normalized extended-element plot illustrating geochemical similarities between shoshonitic–calcalkalic flows from central Knee Lake (green triangles; n = 10) and shoshonitic rocks from the type localities at Oxford Lake and southern Knee Lake (shaded field; n = 11). Normalizing values from Sun and McDonough (1989).*

conglomerates at southern Knee Lake (Anderson, 2017) are a notable example, as their present distribution is controlled by complex structural modifications within the imbricate structural collage described in this report.

The Oxford Lake–Knee Lake belt in general, and Knee Lake in particular, shares significant similarities with major Archean gold districts elsewhere in the Superior province, including Timmins and Kirkland Lake in Ontario, and Rice Lake in Manitoba. Commonalities include: chemically-favourable tholeiitic basalt, iron formation and gabbro; early faults and folds; synorogenic clastic basins; alkaline intrusions and volcanic rocks, including lamprophyre dikes; thick-skinned thrusts; and late strike-slip faults. Of particular note is the structural geometry of the synorogenic clastic basins, which are bounded by a footwall unconformity and hangingwall thrust fault, and are thus comparable in many respects to 'Timiskaming-type' sedimentary basins in the Kirkland Lake and Timmins districts in the Abitibi belt. Such basins are thought to offer a first-order guide to the most favourable portions of these gold metallotects, with major deposits often located in the immediate footwall, beneath the basal unconformity. This spatial coincidence is thought to reflect the fundamental role of crustal-scale faults in controlling the development of synorogenic clastic basins, channeling the large-scale hydrothermal systems required to produce orogenic gold deposits, and ultimately facilitating their preservation (Bleeker, 2015).

In the present case, and by analogy with these districts, chemically favourable rocks (mafic flows and iron formation) in the immediate footwall of these basins are logical exploration targets (Anderson, 2016b). Also of interest from the 2017 field season is the fault-bounded panel of basaltic rocks (panel 5; Figure GS2017-1-3) in the structural collage at southern Knee Lake, which is heavily intruded by felsic porphyry dikes and is thus interpreted as a structural slice of the HRG interleaved with panels belonging to the OLG. Panel 5 contains semipervasive ankerite (±silica, sericite) alteration and abundant quartz-tourmaline veins controlled by the competency contrast between porphyry dikes and their basaltic hostrocks (Figure GS2017-1-9a); both of these features are favourable indicators of orogenic gold potential. Similar alteration and veins (with haloes of acicular arsenopyrite) are associated with the 'Celtic' gold occurrence at the northern tip of the large island within panel 3 (Figure GS2017-1-3); grab samples collected by MGS in 2016 returned 2.3 and 2.6 ppm gold. Fault-fill and extensional quartz-tourmaline veins are widespread in other panels within the structural collage, but are particularly abundant along the faulted contact between panels 3 and 4 (Figure GS2017-1-3), where they commonly range up to 50 cm in thickness (Figure GS2017-1-9b). Although none of these veins are known to be auriferous, there was no evidence in the field to suggest that they have been systematically sampled.

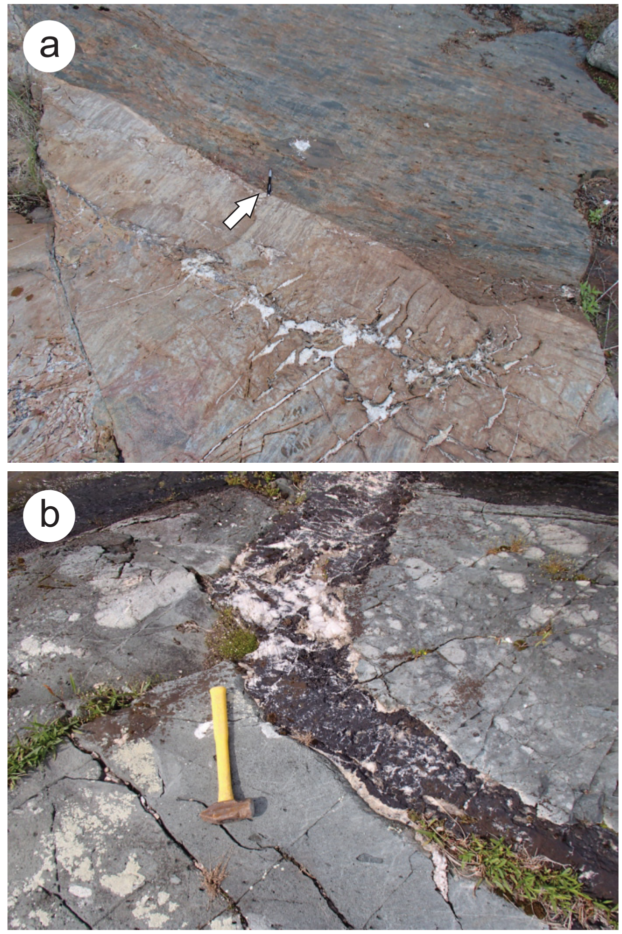

Figure GS2017-1-9: *Outcrop photographs of veins and alteration in the 2017 mapping area at southern Knee Lake:* ***a)*** *quartz-tourmaline veins and ankerite alteration in a quartz-feldspar porphyry dike (bottom) cutting basaltic lapilli tuff (top) in panel 5 (arrow indicates pencil for scale);* ***b)*** *tourmaline-quartz-carbonate±pyrite vein cutting volcanic conglomerate at the southern margin of panel 3.*

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