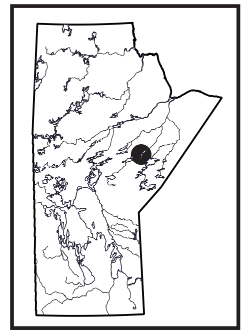
GS-1 Preliminary results of bedrock mapping at central Knee Lake, northwestern Superior province, Manitoba (parts of NTS 53L15, 53M2)

by S.D. Anderson



Anderson, S.D. 2016: Preliminary results of bedrock mapping at central Knee Lake, northwestern Superior province, Manitoba (parts of NTS 53L15, 53M2); *in* Report of Activities 2016, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 1–15.

Summary

In 2016, the Manitoba Geological Survey (MGS) continued its study of the Oxford Lake–Knee Lake belt by extending new 1:15 000 scale bedrock mapping into the central Knee Lake area with the objective of better understanding the belt's stratigraphy, tectonic evolution and mineral resource potential. Building on results of MGS mapping in 1997–1998 and unprecedented bedrock exposure due to exceptionally low water levels, salient results of the 2016 mapping are as follows: 1) definition of two sedimentary sequences in the structural basin at Opischikona Narrows, including an older marine sequence and younger shallow-marine to subaerial sequence; 2) delineation and comprehensive documentation of the contact relationships of the younger sequence, including definition of a basal angular unconformity and faulted upper contact, interpreted to represent an early thrust, with potential implications for gold prospectivity; 3) improved understanding of the structural geology and deformation history of the greenstone belt in general, including better documentation of several generations of ductile deformation structure; 4) discovery of a carbonate dike swarm in west-central Knee Lake, tentatively interpreted to represent carbonatite magmatism related to the adjacent Cinder Lake alkaline intrusive complex, with potential implications for rare-metal prospectivity; and 5) identification of numerous lamprophyre dikes throughout south-central Knee Lake, which will be assessed as potential sources of mantle-derived minerals (i.e., 'kimberlite indicator minerals'), which have previously been identified in surficial sediments at Knee Lake. 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 Manitoba Geological Survey began a renewed study of the Oxford Lake–Knee Lake belt, the largest contiguous greenstone belt in the northwestern Superior province. An improved understanding of the stratigraphy, tectonic evolution and metallogeny of this belt is critical to unlocking the resource potential of the region, which is highly prospective yet underexplored. New bedrock mapping, augmented by structural, lithogeochemical, Sm-Nd isotopic, U-Pb geochronological and high-resolution aeromagnetic datasets, is being used to upgrade existing maps, with the goal of a comprehensive regional synthesis and seamless geological compilation for the entire Oxford Lake–Knee Lake belt.

Early work in the belt included route surveys of the Hayes River and reconnaissance mapping by the Geological Survey of Canada, most notably by Wright (1926, 1932). Subsequent work by the MGS involved systematic mapping (Barry, 1959, 1960, 1964; Gilbert, 1985; Hubregtse, 1985)—the latter two studies as part of the 'Greenstone Project' (1970–1973)—with the objective of improving the geological context for mineral exploration. Follow-up studies described alkaline rocks at Oxford Lake (Hubregtse, 1978; Brooks et al., 1982) and pegmatite in the Knee Lake area (Lenton, 1985). Mineral occurrences in the area were described by Wright (1926, 1932), Barry (1959, 1960), Southard (1977), and Richardson and Ostry (1996).

In 1997–1998, shoreline outcrops on Knee Lake were remapped at 1:20 000 scale by the MGS under the auspices of the Western Superior NATMAP Project. New stratigraphic, geochemical, structural and geochronological data collected during this project provided important new insights into the complexities of the belt (Syme et al., 1997, 1998; Lin et al., 1998; Corkery et al., 2000; Lin and Jiang, 2001). Regional MGS multimedia geochemical and mineralogical surveys (Fedikow et al., 2000, 2001, 2002a, b) identified anomalous abundances of kimberlite indicator minerals in surficial sediments (glacial till and beach sand), prompting a brief surge in diamond exploration (1999–2004). More recent studies have addressed the Cinder Lake alkaline intrusive complex (Chakhmouradian et al., 2008; Kressall et al., 2010; Kressall, 2012) and regional surficial geology (Trommelen, 2014a, b, c, d).

Shoreline mapping for the present study took place at Oxford Lake in 2012 and 2013 (Anderson et al., 2012a, b, c; 2013a, b, c, d), and continued at the southern basin of Knee Lake in 2015 (Anderson et al., 2015a, b; Figure GS-1-1). The goal of the 2016 fieldwork at central Knee Lake was to: 1) examine key localities identified by previous mapping; 2) remap areas of incomplete data coverage; and 3) unravel the complex stratigraphic and structural relationships in the area of Opischikona Narrows (between southern and central Knee Lake). Results of the new shoreline mapping were augmented by data from inland mapping (Gilbert, 1985) and industry high-resolution

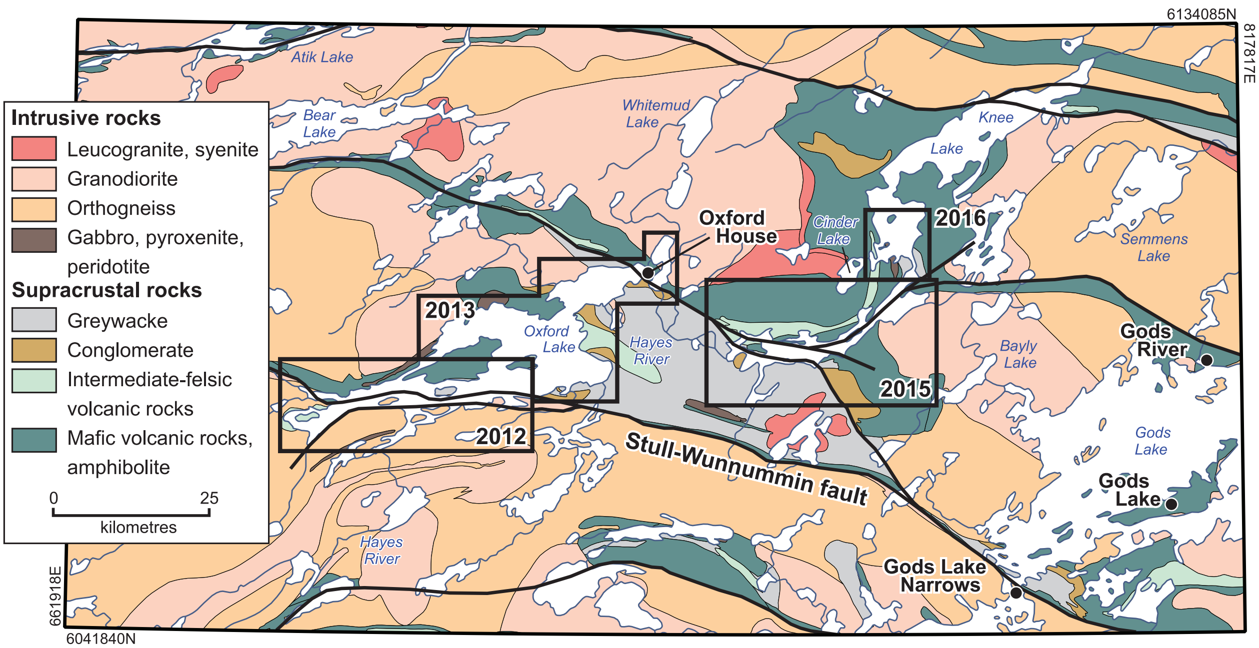


Figure GS-1-1: *Regional geological setting of the Oxford Lake–Knee Lake belt, showing the locations of the 2012, 2013, 2015 and 2016 study areas. Thicker black lines on the map indicate major faults.*

aeromagnetic surveys to generate a new 1:15 000 scale map of south-central Knee Lake (PMAP2016-1, Anderson et al., 2016), covering an area of 100 km^2.

Regional setting and stratigraphic context

Knee Lake is situated in the eastern portion of the Oxford Lake–Knee Lake greenstone belt (Figure GS-1-1) in the Oxford–Stull domain of the western Superior province (Stott et al., 2010). As described by previous workers, supracrustal rocks in this belt are overprinted by at least two generations of tight to isoclinal folds, intruded by granitoid plutons, and segmented by shear zones and faults; consequently, stratigraphic and structural relationships of adjacent and often dissimilar map units have proven difficult to establish. Major discordant structures are part of a regional array that merges into the Stull-Wunnummin fault, which is thought to represent a fundamental tectonic boundary and metallotect in the Superior province, separating an older protocontinental terrane to the south from a juvenile oceanic terrane to the north (e.g., Skulski et al., 2000; Stott et al., 2010).

In the original stratigraphic scheme of Wright (1932), supracrustal rocks in the Oxford Lake–Knee Lake belt were divided into two stratigraphic units: the older, volcanic Hayes River group (HRG) and the younger, sedimentary Oxford group (OG). Based on subsequent detailed mapping, Barry (1959) subdivided the HRG into a lower unit of mostly mafic flows and an upper unit of mostly intermediate–felsic volcanic rocks, and inferred an unconformable contact relationship between the HRG and OG based on map patterns. Of relevance to the present study, clastic sedimentary rocks and iron formation exposed north and south of Opischikona Narrows at Knee Lake were included in the upper HRG by Barry (1959), although he noted that their stratigraphic position remained ambiguous, despite excellent exposure due to an “exceptionally low” water level at Knee Lake during the 1958 field season.

Gilbert (1985) and Hubregtse (1985) further revised the stratigraphy, defining the HRG to consist of pillowed and massive basalt flows and related gabbro, with minor intermediate–felsic volcanic rocks, and fine-grained sedimentary rocks, constituting five mafic–felsic volcanic cycles (Hubregtse, 1978). At Knee Lake, the entire HRG section was estimated to be 9.7 km thick. Neither the base nor top was identified: the base is everywhere defined by granitoid plutons of the Bayly Lake complex (BLC), whereas the top is defined by faults or an unconformity at the base of the ‘Oxford Lake group’ (OLG). Included in the redefined OLG was a lower unit of mostly fragmental volcanic rocks (mainly constituting the ‘upper HRG’ of Barry, 1959), conformably overlain by sedimentary rocks containing clasts derived from the HRG and BLC. The volcanic unit consisted of porphyritic volcanic rocks of calcalkalic to shoshonitic (high-K) affinity, ranging in composition from basalt to rhyolite, intercalated with locally derived epiclastic rocks (Hubregtse, 1978, 1985; Brooks et al., 1982; Gilbert, 1985). Greywacke-mudstone turbidite, iron formation, crossbedded sandstone and polymictic conglomerate, deposited in marine and subaerial settings, were included in the sedimentary unit. In keeping with Barry (1959), the sedimentary rocks exposed north and south of Opischikona Narrows were included in the HRG, although Gilbert (1985) noted that contact relationships were not observed.

The stratigraphic scheme of Gilbert (1985) was largely adopted by Syme et al. (1997), with the exception that the Opischikona Narrows sedimentary rocks were depicted as having unknown stratigraphic affinity, due to the fact that the stratigraphic and structural relationships with the underlying HRG remained equivocal. Like Barry (1959) and Gilbert (1985), these authors described a complex synclinal basin, the contacts of which were unexposed; Syme et al. (1997) inferred that contacts on both limbs of the structure were intruded by gabbro. These authors further concluded that the sedimentary unit of the OLG is not a simple continuous sequence, but noted that the complexities could not be resolved given the available data. Based on the results of additional mapping at central Knee Lake the following summer, Syme et al. (1998) provisionally correlated the Opischikona Narrows sedimentary rocks with the OLG and, on the basis of map patterns, interpreted them to overlie previously deformed HRG units across an angular unconformity. These authors described two northwest-trending synclines cored by sedimentary rocks and bounded by the folded unconformity.

Subsequent U-Pb zircon dating of felsic volcanic rocks at Knee Lake (Corkery et al., 2000; Lin et al., 2006) demonstrated that volcanism in the HRG (ca. 2835–2825 Ma) predates that in the OLG (ca. 2720 Ma) by over 100 million years, and indicates that both are overlain across a significant unconformity by younger (<2707 Ma) sedimentary rocks. As suggested by Syme et al. (1997), these data indicate that the OLG is not a simple continuous sequence.

New detailed mapping of the structural basin at Opischikona Narrows (reported herein) supports this inference and indicates two distinct stratigraphic units: an older marine sequence consisting of greywacke-mudstone turbidites, iron formation, mafic volcanic rocks and gabbro, and a younger shallow-marine to subaerial sequence of turbiditic and trough-crossbedded sandstone and pebble–boulder conglomerate. Apparently unprecedented low water levels in 2016 provided an exceptional opportunity to document stratigraphic and structural relationships that were previously ambiguous due to poor exposure, and also facilitated discovery of carbonate and lamprophyre dikes, with potential economic implications.

Local geology

Supracrustal and intrusive units in south-central Knee Lake are described below in general order of decreasing known or apparent age. Unit codes in the text correspond to those on PMAP2016-1 (Anderson et al., 2016). As most of the key map units were described in some detail by Syme et al. (1997, 1998) and Anderson et al. (2015b), this report is focused mainly on describing PMAP2016-1 and new results from fieldwork in 2016. Greenschist-facies metamorphic assemblages characterize rocks throughout the study area. In the interest of brevity, the prefix 'meta' is not used in this report and the rocks are described in terms of protoliths.

Hayes River group

The HRG in south-central Knee Lake consists mainly of mafic volcanic rocks, with lesser ultramafic–mafic sills, felsic volcaniclastic and volcanic sedimentary rocks, and is disposed in three north- or northwest-trending structural panels (Figure GS-1-2). The HRG in the 'southwest' panel forms an east-younging homocline more than 4 km in thickness that is intruded at its base, beyond the limits of the map area, by the Whitemud Lake pluton and Cinder Lake alkaline intrusive complex, and is overlain to the east by sedimentary rocks of the Opischikona Narrows basin. The HRG in the 'central' panel is tightly folded and largely bounded by faults, but is also locally overlain to the northeast by a thin homocline of sedimentary rocks. In the 'northeast' panel, the HRG defines a tight to isoclinal, northwest-facing, anticline-syncline fold pair and is intruded to the east by the Seller Lake pluton. Stratigraphic relationships between the HRG sections of each panel are ambiguous.

Mafic volcanic rocks (unit 1)

Pillowed and massive flows of basalt, basaltic andesite and lesser andesite dominate the HRG in the Oxford Lake–Knee Lake belt (Figure GS-1-2). As described by previous workers, stratigraphic units have been identified in seemingly monotonous sections of subaqueous basaltic flows on the basis of field characteristics such as weathering colour, phenocryst or variole content, pillow morphology and flow organization (Gilbert, 1985; Hubregtse, 1985; Syme et al., 1997, 1998; Anderson et al. 2013d, 2015b). Based on the dominant textural types of flow, three basaltic map units have been identified in the HRG at south-central Knee Lake.

Plagioclase-phyric flows (subunit 1a) are composed of basalt, basaltic andesite and andesite, and consist mostly of pillowed flows, with minor massive flows and local intercalations of coarse flow breccia. Pillows are typically large (up to 4 m in length), with thick selvages. Plagioclase phenocrysts up to 6 mm are concentrated in pillow cores and the proportion of phenocrysts (up to 40%) decreases outward toward the selvage. These flows occur near the base of the stratigraphic section in the southwest and northeast panels, and are associated with felsic volcanic sedimentary rocks in both locations, suggesting a possible correlation.

Variolitic flows (subunit 1b) are also composed of basalt-andesite, but consist almost entirely of pillowed flows, with very minor massive flows and almost no flow breccia. The pillows tend to be very large and bulbous,

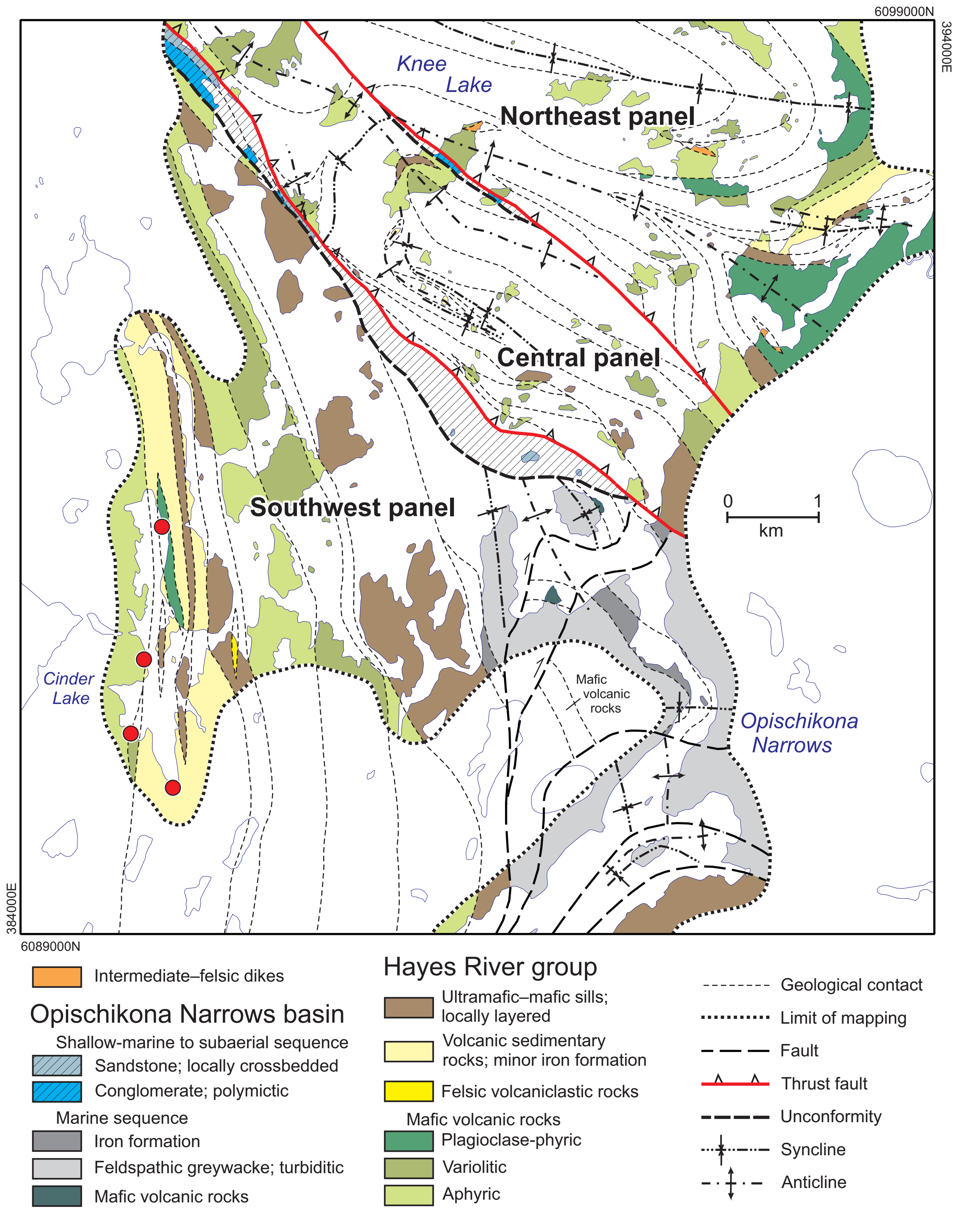


***Figure GS-1-2:** Simplified geology of the south-central Knee Lake area (after PMAP2016-1; Anderson et al., 2016). Geology outside the mapping limit is based on Gilbert (1985) and high-resolution aeromagnetic data. Hachured pattern indicates the extent of the shallow-marine to subaerial sequence of the Opischikona Narrows basin. Red circles in the bay east of Cinder Lake indicate locations of carbonate dikes described in the text. Map units 8, 11, 13, 14 and 15 are too small to depict at the scale of this figure.*

with thick selvages, and are characterized by centimetre-scale varioles that coalesce to dense masses in pillow cores. These flows define important marker units in each of the structural panels. Associated aphyric flows (subunit 1c) are composed of basalt and basaltic andesite, and consist mostly of pillowed flows, with subordinate composite and massive flows, and minor flow breccia. The pillows tend to be smaller (<1 m) and are bun shaped to irregular, with thin dark green selvages and interpillow hyaloclastite. Aphyric flows dominate in each structural panel and are locally intercalated with variolitic flows. Identical major- and trace-element signatures (primitive arc-tholeiite; E.C. Syme et al., unpublished data, 1998) suggest a common magma source. The variolitic flows, which are thought to represent severely under-cooled basaltic melts (Sandstå et al., 2011), suggest that differences in flow texture and morphology may be related to transient changes in eruption temperature.

Felsic volcaniclastic rocks (unit 2)

Felsic volcaniclastic rocks are exposed in a single outcrop in the southwest panel, where they appear to occur as a large raft in an ultramafic–mafic sill. The outcrop consists of monolithic felsic breccia thickly interbedded with variably reworked felsic tuff breccia, lapilli tuff and tuff (subunit 2a). The breccia consists of very coarse, angular clasts of quartz- and feldspar-phyric rhyolite in a felsic matrix, suggesting a proximal depositional setting with respect to a felsic volcanic centre. The stratigraphic position of this unit roughly corresponds to the felsic volcanic rocks exposed in Pain Killer Bay in southern Knee Lake, suggesting a probable correlation.

Volcanic and chemical sedimentary rocks (unit 3)

Volcanic sedimentary rocks of the HRG are only extensive in the southwest panel, where they define a map unit that ranges from 600 m to 1.2 km in thickness (Figure GS-1-2). This unit is exposed in southwest-central Knee Lake and is inferred to be under-represented in outcrop due to preferential erosion; commonly, these rocks are only exposed low on the flanks of outcrop ridges underlain by gabbro. This unit is stratigraphically equivalent to similar rocks exposed 5 km along strike in southern Knee Lake (Gilbert, 1985; Syme et al., 1997, 1998). Similar rocks define a thin map unit in the eastern portion of the northeast panel. Chemical- and volcanic-sedimentary rocks occur locally in the central panel but are only exposed on isolated small islands, with the result that their stratigraphic context is ambiguous.

The volcanic sedimentary rocks in the southwest and northeast panels consist mainly of sandstone and mudstone (subunit 3a), interlayered with pebble conglomerate (subunit 3b). The sandstone is typically light grey to white, feldspathic and pebbly, and includes minor quartz grains or granules. Beds vary from thin to very thick (2–3 m), with turbidite bedforms that include scours, normal grading, rip-up clasts and load structures. Clast populations in the conglomerate are typically heterolithic but are dominated by aphyric or porphyritic (feldspar ±quartz) intermediate–felsic volcanic material, with subordinate clasts of mudstone, chert, basalt and gabbro. Well-rounded clasts indicate significant transport in a subaerial or shallow marine setting, whereas well-developed turbidite bedforms indicate deposition in a basinal marine setting. As described by Syme et al. (1997), the section in the southwest panel appears to represent a more distal facies of a clastic apron that extends north from southern Knee Lake and records erosion of an intermediate–felsic volcanic edifice.

Included in unit 3 are isolated outcrops of chemical and volcanic sedimentary rocks in the central panel. Banded chert and magnetite iron formation (subunit 3c) underlies a single island, roughly 80 by 120 m, in west-central Knee Lake and is complexly folded (Figure GS-1-3a). A very prominent circular aeromagnetic anomaly centred just south of the island indicates that this unit lacks strike continuity; coupled with the structural complexity, this is inferred to be due to interference folding and intense structural transposition in the central panel. Mafic volcanic sedimentary rocks of subunit 3d are similarly exposed on two isolated islands approximately 700 m southeast of the island described above and are also complexly folded. They consist of interlayered, dark grey-green pebbly sandstone, heterolithic pebble conglomerate and minor mudstone. Beds are generally thick to very thick and massive to normally graded. Intervals of planar-bedded sandstone and mudstone up to 5 m thick contain turbidite bedforms. Conglomerate beds, ranging up to 5 m in thickness, are matrix-supported, unsorted and massive to crudely stratified, with diffuse contacts. Clasts are angular to subrounded (<15 cm) and consist mostly of aphyric basalt, with minor gabbro and felsic (chert or aphyric rhyolite) pebbles (Figure GS-1-3b). On the western island, the volcanic sedimentary rocks are intercalated with pillowed and massive flows of aphyric basalt. The marked contrast to the felsic-derived volcanic sedimentary rocks in the southwest panel indicates a significantly different, more proximal provenance for these rocks.

Ultramafic–mafic sills (unit 4)

Ultramafic–mafic sills intrude the HRG in each of the structural panels, but are thickest and most extensive within the southwest panel, where they range up to 1.3 km in thickness and are traced continuously along strike to southern Knee Lake (Figure GS-1-2). These intrusions are typically fine to medium grained and equigranular, and are subdivided into four subunits: quartz diorite (subunit 4a); mesogabbro, leucogabbro, quartz gabbro (subunit 4b); pyroxenite and melagabbro (subunit 4c); and peridotite (subunit 4d). Some sills contain sparse phenocrysts or glomerocrysts of pyroxene or plagioclase.

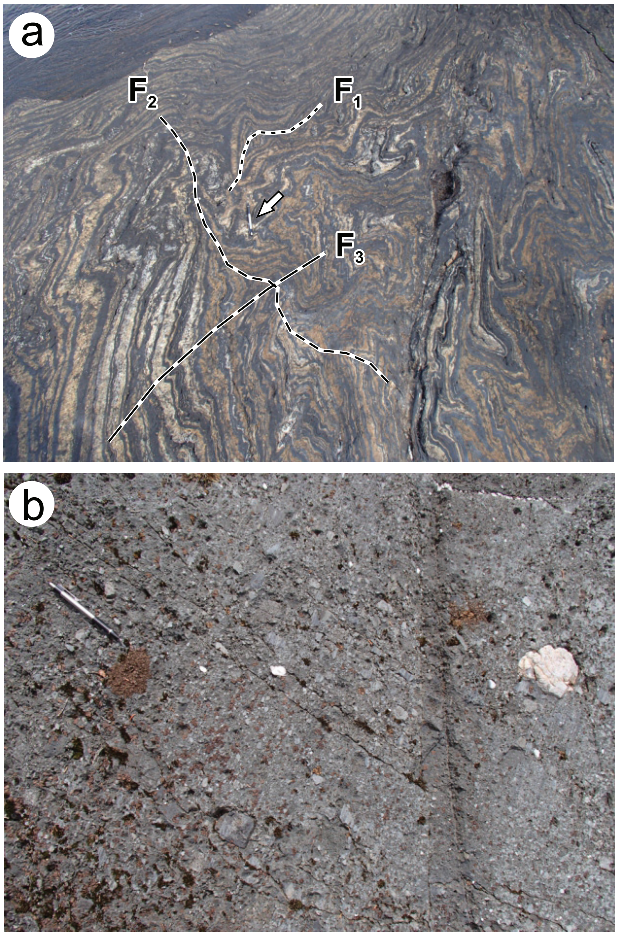


Figure GS-1-3: *Outcrop photographs of sedimentary rocks in the Hayes River group (central panel):* ***a)*** *banded chert-magnetite iron formation showing complex fold interference (F_1-F_2-F_3; arrow indicates pencil for scale);* ***b)*** *mafic volcanic conglomerate containing minor pebbles of chert or aphyric rhyolite (white).*

The arrangement of subunits in individual sills typically shows a progression to more felsic compositions in the local direction of stratigraphic younging, indicating in-situ differentiation within a volcanic sequence that was horizontal at the time of emplacement. The thickest sills in the southwest panel include discontinuous basal layers of peridotite or pyroxenite that transition upward into mesogabbro, leucogabbro, and quartz gabbro or quartz diorite. These sills are presumed to be broadly synvolcanic—this hypothesis will be tested using lithogeochemistry and U-Pb geochronology.

Opischikona Narrows basin

New detailed mapping in 2016, aided by excellent bedrock exposure due to low water levels, indicates that the Opischikona Narrows basin (ONB) includes two sedimentary sequences: an older marine sequence that overlies the HRG either conformably or disconformably and defines a structurally complex isoclinal syncline; and a younger shallow-marine to subaerial sequence that defines a northeast-younging homocline and overlies both the HRG and older sequence across an angular unconformity. The unconformity was well-exposed in 2016 and cuts downsection toward the northwest, through the folded older sequence, such that the younger sequence directly overlies the HRG in the northwestern portion of the map area (Figure GS-1-2). Gabbro intrusions and early isoclinal folds in the older sequence do not continue upward into the younger sequence, demonstrating both the presence and angular nature of the unconformity. Both sequences are truncated to the northeast by a fault that is interpreted to represent an early thrust, along which the central panel was thrust over the southwest panel. A thin homocline of the younger sequence and its basal unconformity are also exposed along the northeastern margin of the central panel, indicating the presence of another early thrust, along which the central panel was, in turn, overthrust by the northeast panel, thus defining a southwest-verging thrust stack (Figures GS-1-2, -4). U-Pb ages of detrital zircons in the younger sequence indicate the maximum age of deposition and thrust faulting (ca. 2710 Ma; E.C. Syme et al., unpublished data, 2008). U-Pb ages are not available for the older sequence, although a sample of greywacke was collected in 2016 for this purpose.

Marine (older) sequence

The older sequence of the ONB is best exposed immediately north and south of the narrows. The contacts are nowhere exposed: the western contact with the HRG is inferred to represent either a conformity or disconformity, whereas the eastern contact is inferred to be an early thrust fault, which defines the boundary between the southwest and central panels. Toward the south, the sequence is truncated by a major shear zone that trends along the northeastern arm of southern Knee Lake and curves inland toward the east, just south of the narrows. To the north the older sequence is unconformably overlain and cut-out (i.e., eroded through) by the younger sequence.

Mafic volcanic rocks (unit 5)

Mafic volcanic rocks in the older sequence are exposed along the northeastern shoreline of the large island at the outlet of Opischikona Narrows, as well as on several small islands and reefs along strike to the southeast (Figure GS-1-2). These rocks are also exposed on a short peninsula of the mainland south of this island and similar rocks were mapped by Gilbert (1985) in the inland area south of this peninsula (not examined by the present author). These three areas of exposure are interpreted to represent a single unit that was segmented and offset by a series of right-lateral faults, which were later folded (as is observed in the adjacent greywacke). The mafic volcanic unit consists of massive basalt (subunit 5a) and

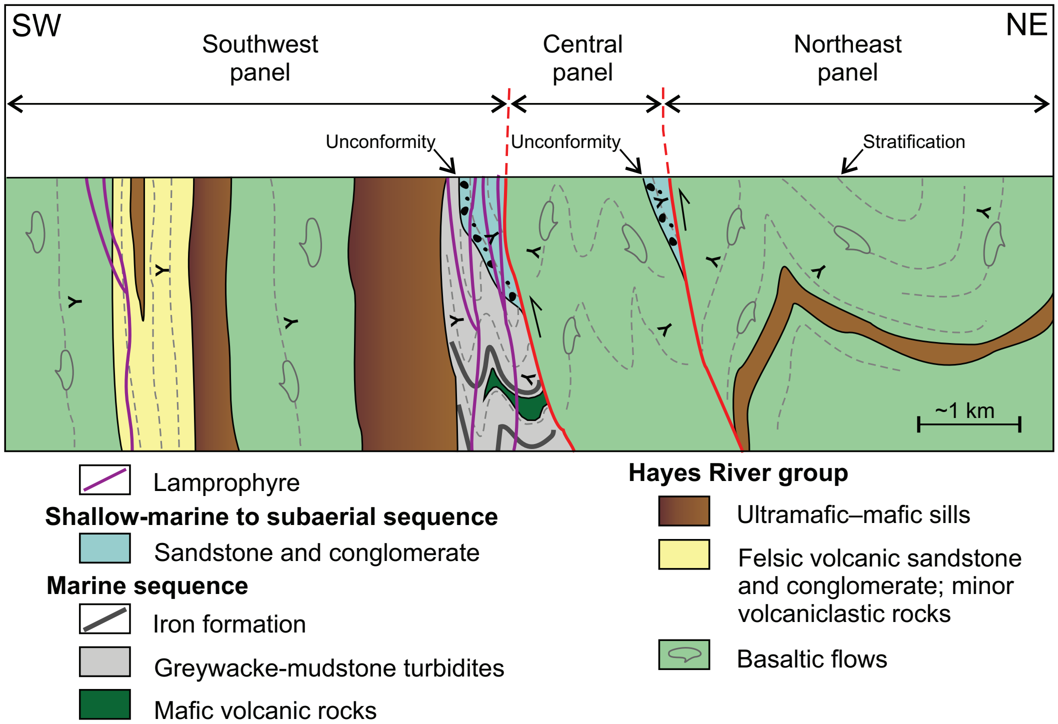


Figure GS-1-4: *Schematic composite cross-section showing the simplified stratigraphy and structural geometry through the central basin of Knee Lake. Thrust faults bounding the major structural panels are shown in red; stratigraphic younging directions indicated by the inverted 'Y' symbol.*

associated breccia (subunit 5b). The basalt weathers dark green and is fine-grained, aphyric and sparsely vesicular. Massive portions range up to 15 m in thickness and have sharp, somewhat irregular contacts with thick (5–10 cm) chilled margins (Figure GS-1-5a). They are characterized by irregular networks of recessive fractures filled with Fe-carbonate and chlorite; the fracturing is considered to be mostly primary, as the fractures do not extend into hypabyssal mafic dikes that intrude the basalt or into the adjacent greywacke. Massive portions transition upward into clast-supported breccia layers that range up to 20 m in thickness and are normally graded, particularly near the top. Clasts are angular, shard-like, less than 15 cm in size and consist exclusively of basalt. Locally, breccia occurs as thin discontinuous layers in massive basalt and, conversely, massive basalt forms thin lenticular bodies in breccia. The absence of pillows is unusual given the demonstrably marine depositional setting, but may relate to atypical lava composition, temperature or eruption rate. Alternatively, this unit may represent a composite cryptodome that was emplaced at shallow depth and was intensely fractured due to quenching.

Feldspathic greywacke (unit 6)

Greywacke is the dominant rock type in the older sequence and is rhythmically interbedded with mudstone, with rare lenses of polymictic conglomerate (subunit 6a). Well-preserved bedforms and ubiquitous younging criteria provide key insights into the complex structure of the ONB. The greywacke is feldspathic, with up to 10% quartz locally, and is generally fine to medium grained. It forms planar, normally-graded beds that are typically less than 30 cm thick but locally range up to 2 m in thickness. Thicker beds are scoured and pebbly at the base, and contain abundant mudstone rip-ups. Some intervals contain thin (<5 cm) beds of chert (Figure GS-1-5b). Mudstone generally accounts for 10–30% of the section and is locally black, siliceous and laminated. Load structures and soft-sediment folds are common. Pebble-conglomerate beds range up to 2 m in thickness and are matrix supported, massive to crudely graded and poorly sorted. They consist of angular to well-rounded clasts of mudstone, chert, gabbro, felsic porphyry and quartz; the clasts in some beds consist almost entirely of slab-like pebbles and cobbles of chert (subunit 6b). These features indicate deposition mainly by low-density turbidity currents in a basinal marine setting.

Iron formation (unit 7)

Oxide-facies iron formation is a characteristic feature of the older sequence and is not observed in the younger sequence, except as clasts in conglomerate; its distribution is clearly delineated by high-resolution aeromagnetic data. Two subunits are distinguished: banded chert and

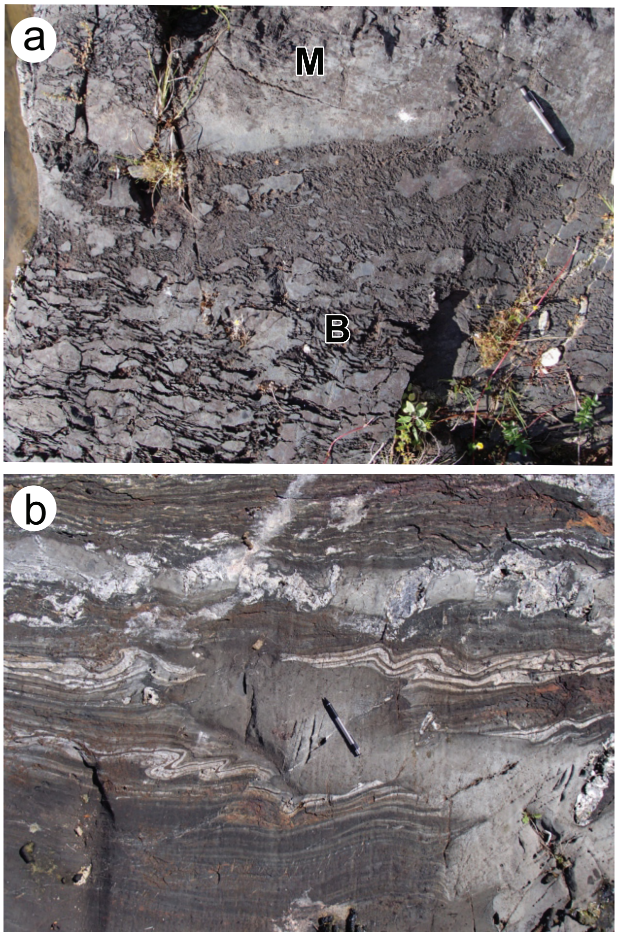


*Figure GS-1-5: Outcrop photographs of rock types associated with the older marine sequence of the Opischikona Narrows basin: **a)** breccia (B) overlain by massive basalt (M) with an irregular, chilled contact; **b)** thin-bedded greywacke, mudstone and chert, intruded by hypabyssal mafic dike.*

magnetite (subunit 7a); and bedded mudstone, magnetite and greywacke (subunit 7b). Both are characterized by thin, planar beds and multiphase folds. Subunit 7b locally contains up to 10% disseminated pyrrhotite. Iron formation occurs near the base of the sequence along the southwestern margin of the basin, suggesting that it, along with the associated basalt flows, records the earlier increments of basin infilling, possibly in a rift setting. However, due to the structural complexity of this sequence, the internal stratigraphy remains poorly understood.

Gabbro, diorite (unit 8)

The older sequence of the ONB is intruded by abundant dikes and sills of mafic to intermediate composition. These intrusions are typically fine grained and are subdivided into three textural types, based on phenocryst populations: equigranular (subunit 8a); plagioclase-phyric (subunit 8b); and pyroxene-phyric (subunit 8c). They typically have well-developed chilled margins and range up to more than 15 m in thickness, although most are less than 1 m thick (e.g., Figure GS-1-5b). Some dikes are compound or heterogeneous, the latter containing zones of intrusion breccia composed of melanocratic phases in a more leucocratic matrix. At least some of these intrusions are likely synvolcanic with respect to the basalt flows. Included in this unit is a multiphase, plagioclase-phyric intrusion of probable shoshonitic (high-K) affinity in the northeast panel, which may be a subvolcanic equivalent to similar rocks in the overlying Oxford Lake group (Anderson, GS-2, this volume).

Shallow-marine to subaerial (younger) sequence

The younger sequence of the ONB consists of sandstone and conglomerate, and is best exposed on small islands in south-central Knee Lake, where it reaches a maximum thickness of approximately 500 m (Figure GS-1-2). It defines an upright homocline that is traced along strike for 6.5 km and dips steeply to the northeast. This homocline extends inland to the northwest, beyond the present mapping limits, and is truncated to the southeast by the fault that defines its upper contact. A thin (<100 m) homocline of the younger sequence is also traced along strike for 1.2 km at the northeastern margin of the central panel and is likewise fault bounded along its upper contact. The basal unconformity was well exposed in several locations in 2016 and the best sites (one each from the central and southwest panels) were mapped in detail. At all locations, the immediately underlying rocks of the HRG are fractured, carbonatized and rusty weathering, and contain localized breccia, 'corestones' (Figure GS-1-6a; e.g., Babechuk and Kamber, 2010) and Fe-carbonate veins; the latter are truncated at the unconformity (Figure GS-1-7). At the most spectacular site (Figure GS-1-7), quartz diorite is overlain by polymictic conglomerate that contains rounded boulders of quartz diorite in a chert-pebble matrix and grades upward into massive chert-pebble conglomerate (Figure GS-1-6b). The overall features of this sequence are comparable to late synorogenic clastic basins in many other Archean greenstone belts.

Conglomerate (unit 9)

Polymictic conglomerate of unit 9 is subdivided into two subunits based on clast populations: pebble to boulder conglomerate containing diverse types of clasts (subunit 9a); and pebble to cobble conglomerate containing mostly chert clasts (subunit 9b). Subunit 9a is abundant in the northwestern portion of the southwest panel and is the dominant rock type of the younger sequence in the central panel. This conglomerate is typically clast supported and poorly sorted. It forms massive to normally graded beds that range up to 10 m in thickness. Clasts are subangular to well rounded (locally spherical) and consist of various textural types of mafic, intermediate and felsic volcanic rock, mudstone, felsic porphyry and chert. The pebbly

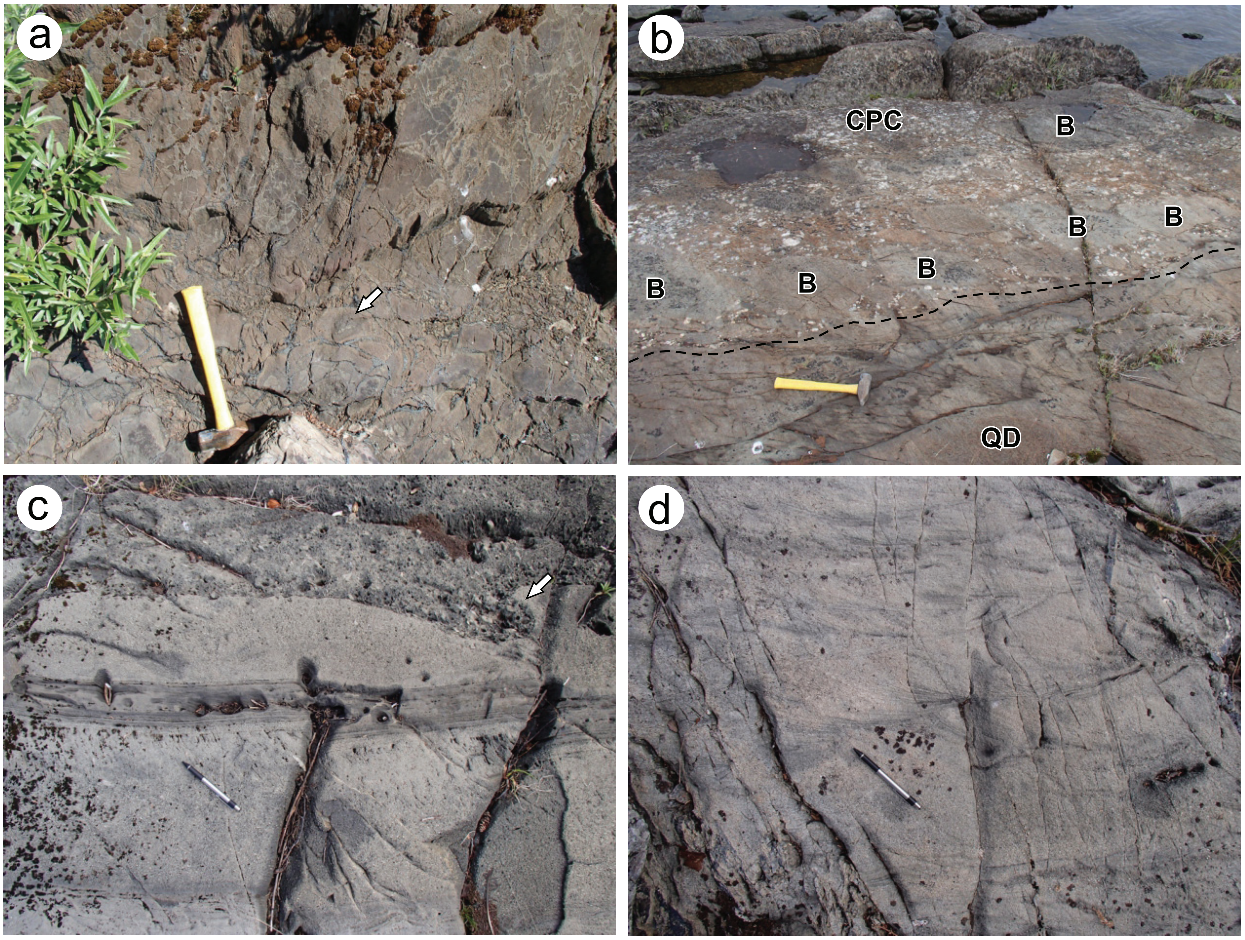


Figure GS-1-6: *Outcrop photographs of rock types associated with the younger shallow-marine to subaerial sequence of the Opischikona Narrows basin:* ***a)*** *massive basalt flow of the Hayes River group immediately beneath the unconformity in the central panel, showing fractures, carbonatization, breccia and minor corestones (arrow);* ***b)*** *basal unconformity in the southwest panel, showing quartz diorite (QD) overlain by polymictic conglomerate that contains boulders (B) of quartz diorite in a chert-pebble matrix and chert-pebble conglomerate (CPC);* ***c)*** *thick-bedded turbiditic sandstone and mudstone in the southwest panel, showing deep scour filled with pebble conglomerate (arrow);* ***d)*** *trough-crossbedded sandstone in the southwest panel (same outcrop as in Figure GS-1-6c).*

sandstone matrix locally contains wisps of fuchsite. Rounded clasts of banded chert-magnetite iron formation are locally abundant and form discrete lag deposits in otherwise massive beds, particularly in the central panel. The conglomerate also contains minor lenticular interbeds of sandstone or sulphidic mudstone. Conglomerate of subunit 9b contains mostly chert clasts and is only abundant near the base of the sequence in the southwest panel. It forms either massive clast-supported beds up to several metres thick that contain mostly well-rounded clasts (e.g., Figure GS-1-6b) or more diffuse, graded and lenticular beds that are matrix supported, and contain abundant slabs of chert. These rocks are interpreted to record uplift and largely subaerial erosion of the older marine sequence and the underlying HRG.

Sandstone (unit 10)

Sandstone of unit 10 is abundant and well-exposed in the southeastern portion of the southwest panel (Figure GS-1-2). It consists of trough-crossbedded (subunit 10a) and planar-bedded (subunit 10b) sandstone, with minor mudstone and pebble conglomerate. These subunits are commonly interlayered on a scale of 5 to 10 m. The sandstone is generally medium grained, feldspathic and pebbly, with variable quartz content (<15%). Intervals of planar-bedded sandstone exhibit well-developed turbidite bedforms, including scours, normal grading, rip-up clasts, soft sedimentary folds, load structures and ripples. Deep scours and channels in these sections are locally filled with crossbedded sandstone or polymictic pebble conglomerate (Figure GS-1-6c). Sections of trough-crossbedded sandstone (Figure GS-1-6d) are commonly associated with diffuse beds of chert-pebble conglomerate; foresets indicate that the transport direction was highly variable. Collectively, these features indicate deposition within the channelized portion of a shallow-marine to subaerial fan.

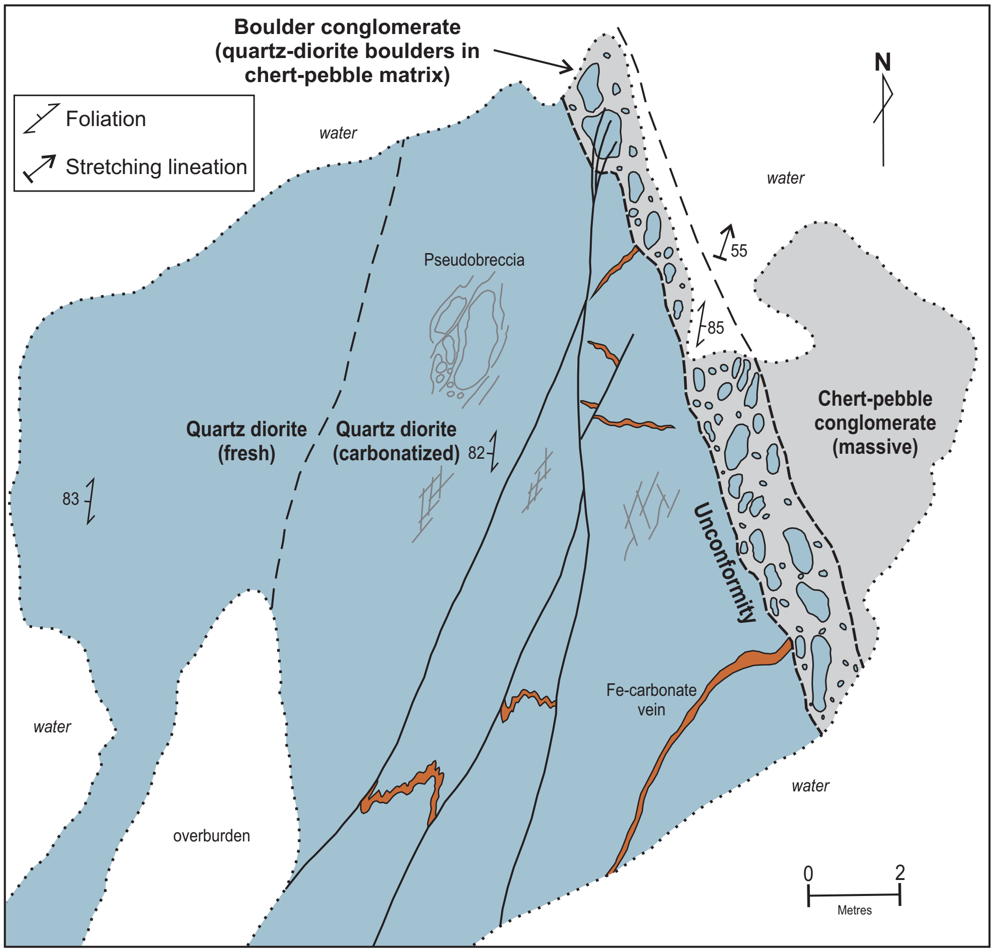


Figure GS-1-7: Outcrop map of the basal unconformity of the younger shallow-marine to subaerial sequence of the Opischikona Narrows basin (southwest panel), showing quartz diorite overlain by quartz-diorite–boulder conglomerate and chert-pebble conglomerate; the upper 5–10 m of the quartz diorite is moderately to strongly carbonatized in this location and contains veins of Fe-carbonate that are truncated by the unconformity.

Late intrusions

Diabase dikes (unit 11)

Thin (<1 m) diabase dikes and sills cut the shallow-marine to subaerial sedimentary rocks at three locations in the northwestern extent of the ONB. These intrusions weather greenish grey, and are fine grained and aphyric. They typically have thick (up to 5 cm) vesicular chilled margins consistent with high-level emplacement. Contacts are sharp and locally irregular.

Intermediate–felsic dikes (unit 12)

High-level porphyritic intrusive rocks of intermediate–felsic composition are sporadically exposed throughout south-central Knee Lake. These intrusive rocks are characterized by a pale pink to buff, aphanitic to very fine-grained groundmass, and are divided into two subunits on the basis of phenocryst content: feldspar porphyry (subunit 12a); and quartz-feldspar porphyry (subunit 12b). Quartz and feldspar phenocrysts are typically less than 5 mm in size and account for less than 20% of these rocks. The dikes have sharp, planar contacts with thick chilled margins; the largest intrusions of this type form dikes or sills up to 100 m thick near the southwestern margin of the northeast structural panel (Figure GS-1-2).

Lamprophyre dikes (unit 13)

Lamprophyre dikes cut the HRG and ONB, and also locally intrude major plutons that bound the Oxford Lake–Knee Lake belt (Anderson et al., 2015b). These dikes weather a distinctive dark green or emerald green, and include equigranular (subunit 13a) and porphyritic (subunit 13b) subtypes. The latter contains 10–20% dark brown or black phlogopite/biotite phenocrysts up to 2.5 cm in size in a fine-grained groundmass, whereas the former contains fine-grained phlogopite/biotite in the groundmass. The dikes range up to 3 m in thickness and are characterized by sharp planar contacts and thick (3–5 cm) chilled margins (Figure GS-1-8a); some dikes

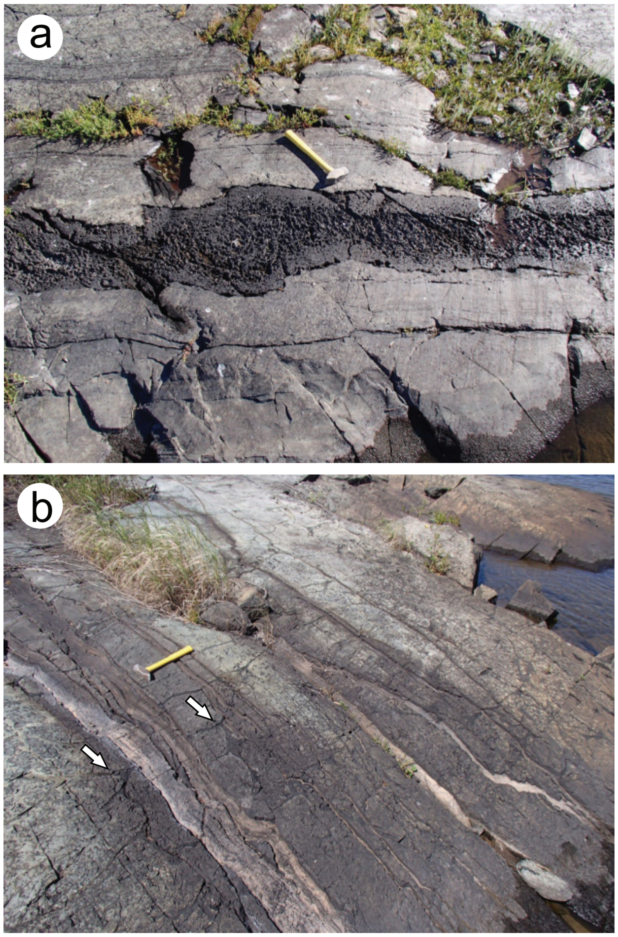


Figure GS-1-8: *Outcrop photographs of late intrusive rocks in the study area:* ***a)*** *lamprophyre dike cutting turbiditic sandstone of the younger sedimentary sequence in the southwest panel; note thick chilled margins and coarsely porphyritic core, with recessively weathered phlogopite/biotite phenocrysts;* ***b)*** *discrete swarm of thin carbonate dikes, tentatively interpreted as carbonatite, cutting Hayes River group pillowed basalt in the southwest panel (arrows indicate pillow selvages); note dark green metasomatic halo surrounding the dikes.*

contain apparently exotic granitoid xenoliths. These rocks, and their potential reworked extrusive equivalents, are described in a companion report (Anderson, GS-2, this volume).

Carbonate dikes (unit 14)

One of the salient outcomes of the 2016 mapping was the discovery of a swarm of carbonate dikes in the westernmost bay of south-central Knee Lake, immediately east of Cinder Lake (Figure GS-1-2). These dikes are tentatively interpreted to represent carbonatite, perhaps related to the adjacent Cinder Lake alkaline intrusive complex. The earthy brown-weathering dikes are typically fine-grained and equigranular. They consist mainly of carbonate (>80% calcite-dolomite), with lesser silicate, oxide and sulphide mineral phases; most are magnetic, indicating the presence of fine disseminated magnetite. The dikes have sharp, planar contacts and vary from massive (subunit 14a) to flow layered (subunit 14b). The hostrocks (gabbro, basalt and volcanic sedimentary rocks) adjacent to the dikes contain dark green metasomatic haloes that range up to 40 cm in thickness (Figure GS-1-8b). The dikes trend generally east, dip steeply north or south and range up to 1 m in thickness; they discordantly cut ductile deformation fabrics in the hostrock. Some dikes appear to be controlled by northwest-trending sinistral and northeast-trending dextral faults, perhaps representing a conjugate set, and locally appear to have filled dilation jogs along these structures. The dikes were identified in four locations over a north–south distance of approximately 3 km, and generally appear to become thicker and more abundant toward the south. On the basis of mineralogical and geochemical evidence, Chakhmouradian et al. (2008) concluded it was highly probable that the Cinder Lake alkaline intrusive complex is associated with unexposed carbonatite—an assertion supported by the discovery of the carbonate dikes immediately to the east at Knee Lake. Whole-rock geochemical data indicate these rocks are strongly enriched in Ba, Sr and light rare-earth elements, which supports the inference that they crystallized from primary carbonatitic magmas, rather than representing remobilized sedimentary carbonate or hydrothermal veins.

Tectonite

Tectonite (unit 15)

In marked contrast to the southern basin, tectonite tends to be much thinner and less extensive in the central basin of Knee Lake, where zones of phyllonite and mylonite rarely exceed 5 m in thickness. The most continuous zones mark the faulted contacts of the three major structural panels. Kinematic indicators are not well developed on horizontal outcrop surfaces, suggesting the major or latest increment of movement was primarily dip-slip. In most locations, these zones contain weak to moderate chlorite-sericite±ankerite alteration and minor, highly attenuated quartz-carbonate-chlorite veins.

Structural geology

Map patterns, mesoscopic deformation structures and overprinting relationships indicate a very complex history of deformation in the Opischikona Narrows area. Analysis of structural data collected in 2016 is ongoing; in the interest of brevity and for the purpose of understanding map patterns and structural relationships of the various map units, only a brief summary of preliminary findings is provided here.

The main ductile deformation fabric observed in most outcrops is defined by flattened and stretched primary features (e.g., pebbles, pillows, amygdules) and an associated penetrative foliation. This fabric generally trends northwest, dips subvertically and contains a downdip stretching lineation that varies from oblate to strongly prolate. In the older sedimentary sequence, this fabric is axial-planar to macroscopic, tight to isoclinal, upright folds that trend northwest and plunge steeply to the southeast (Figure GS-1-9a). This fabric transects earlier tight to isoclinal folds indicated by younging reversals in the greywacke turbidites and, for this reason, is assigned to the second generation (G_2) of deformation structure, with the early folds representing G_1 structures. Toward the north, the macroscopic F_2 folds do not carry across into the younger shallow-marine to subaerial sequence (i.e., macroscopic younging reversals are not observed in the younger sequence; Figure GS-1-2, -4), which is taken to indicate that the F_2 folds are older. Thus, the basal contact of the younger sedimentary sequence is interpreted to be an angular unconformity and this sequence can be thought of as broadly synorogenic.

The younger sequence also contains a planar-linear (S-L) shape fabric and locally penetrative foliation. These fabrics also trend northwest but, in contrast to the S-L fabric in the older sequence, are only associated with minor open S-folds that plunge steeply to the northwest. These structures are interpreted to result from renewed shortening subsequent to F_2 folding of the older sequence and are therefore considered to be G_3 structures (the S_3-L_3 fabric is spectacularly developed in lamprophyre dikes cutting the younger sequence; Figure GS-1-9b). In this model, the G_2 fabric in the older sequence thus represents a composite

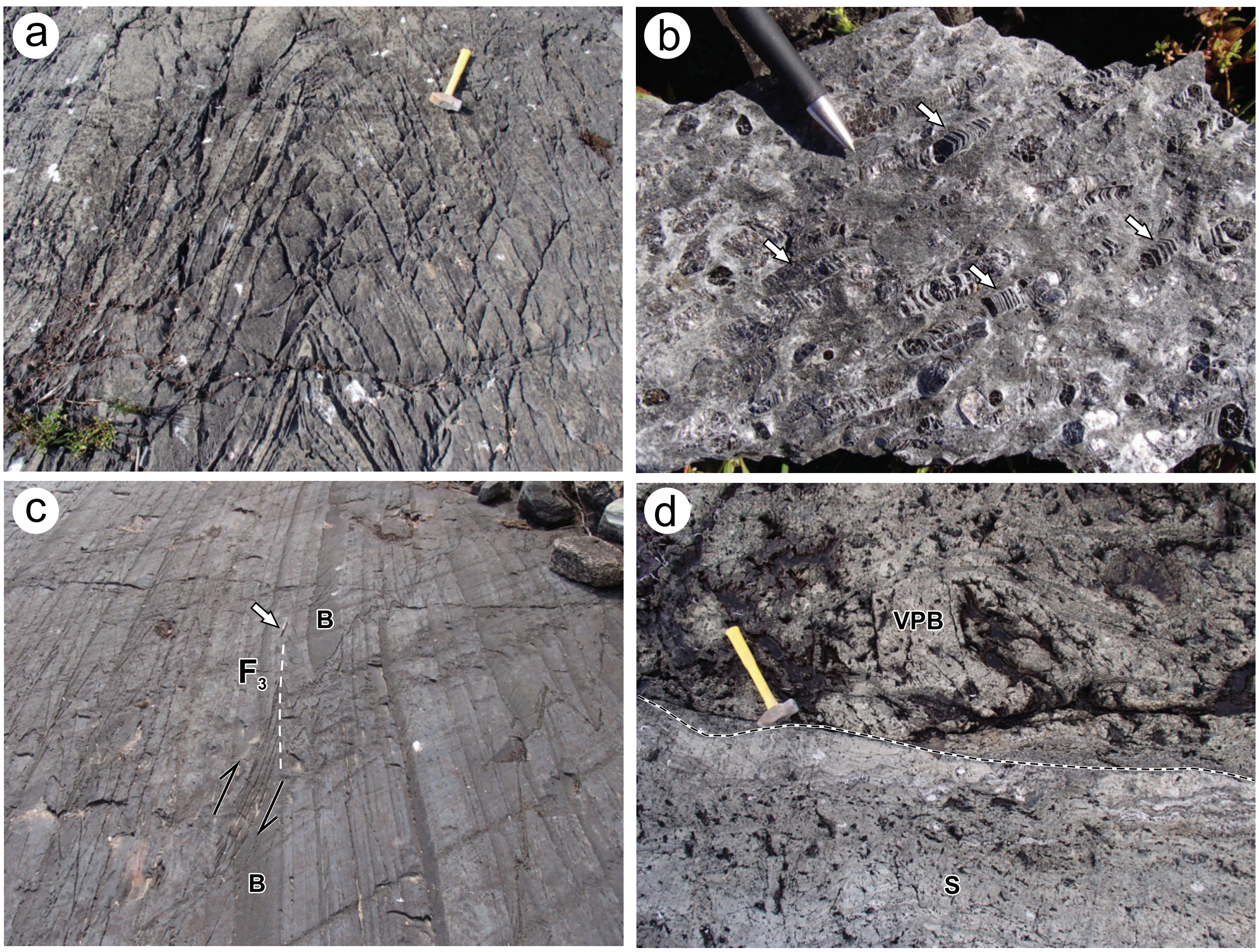


***Figure GS-1-9:** Outcrop photographs of deformation structures in the Opischikona Narrows basin (southwest panel): **a)** tight, upright, steeply-plunging F_2 fold in greywacke turbidites of the older sequence; **b)** stretching lineation defined by phlogopite/biotite phenocrysts (arrows) in lamprophyre, which were pulled apart along cleavage planes (same dike as in Figure GS-1-8a); **c)** example of discrete right-lateral shear zones on the limb of a macroscopic F_2 isocline in the older sequence (arrow indicates pencil for scale); the shears crosscut beds (B) and the bedding-parallel G_2 fabric, and are overprinted by tight F_3 folds (dashed line); this is interpreted to represent a small-scale example of the folded right-lateral structures that offset mafic volcanic rocks of unit 5 (Figure GS-1-2); **d)** sandstone (S) of the younger sequence juxtaposed with Hayes River group variolitic pillowed basalt (VPB) across an inferred thrust fault (dashed line); crossbedding and pillow cusps indicate a 'face-to-face' contact relationship in this location; the fabric associated with the thrust overprints the regional G_3 shape fabric, and is itself overprinted by later crenulations.*

G_2-G_3 fabric that records renewed tightening of the macroscopic F_2 folds during later shortening. Evidence of the composite nature of this fabric is found in the turbidites west of the narrows, where discrete right-lateral shear zones crosscut bedding and the bedding-parallel G_2 fabric on the limb of a macroscopic F_2 isoclinal fold, and are overprinted by tight F_3 folds that trend northwest, subparallel to the G_2 fabric (Figure GS-1-9c). Both the shear zones and later folds are attributed to continued G_3 shortening.

The G_3 shape fabric (S_3-L_3) is transposed into the penetrative ductile foliation associated with the faulted contacts of the major structural panels (Figure GS-1-9d); hence, these faults and associated fabrics either formed during a later increment of G_3 shortening or represent younger, G_4 generation structures. All of these fabrics are in turn overprinted by a northeast-trending crenulation or fracture cleavage, which is generally the youngest fabric observed in the Opischikona Narrows area, thus corresponding to G_4 or G_5 structure. Later brittle-ductile or brittle structures include concordant to highly discordant faults, some of which are associated with narrow (<1 m) zones of cataclasite or pseudotachylite.

Major ductile shear zones of the type described at southern Knee Lake (e.g., Lin et al., 1998; Lin and Jiang, 2001; Anderson et al., 2015b) are not observed in south-central Knee Lake, suggesting this area was sheltered from that style of regional deformation, perhaps due to its location in a north-trending neck of supracrustal rocks bounded by plutons.

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-PGE, intrusion-related rare metals, orogenic Au, and diamonds. Results from this study provide an improved understanding of the stratigraphic and structural framework, which can be used to formulate exploration strategies.

Felsic volcanic rocks of the HRG have been explored in the past for volcanogenic massive sulphide (VMS) deposits and contain strong evidence of VMS potential, including: calcalkalic, arc-type geochemistry; vent-proximal volcanic facies associations such as rhyolite flows and coarse volcaniclastic rocks; drill intercepts 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-style alteration (e.g., Assessment Files 72612, 94730). Layered ultramafic–mafic intrusions in the HRG have also been tested by diamond drilling, presumably as targets for magmatic Ni deposits, but assay results for Ni were not reported (e.g., Assessment Files 91190, 91191, 91192); these remain interesting exploration targets, particularly where they show evidence of in-situ magmatic differentiation or discordant footwall feeder dikes (e.g., Anderson et al., 2015b).

The Cinder Lake alkaline intrusive complex, which intrudes the HRG just west of the map area, exhibits several indications of rare-metal potential, including: numerous species of rare-earth element (REE)–bearing minerals (Kressall et al., 2010); potentially complex internal zoning (as indicated by aeromagnetic data); and a possible association with carbonatite (Chakhmouradian et al., 2008; this study), which is the major host of REE deposits worldwide. Despite these attributes, this complex has not been systematically explored for rare-metal mineralization.

The geology and structure of the Oxford Lake–Knee Lake belt in general, and south-central Knee Lake in particular, indicate significant similarities to major gold districts elsewhere in the Superior province, including Timmins and Kirkland Lake in Ontario, and Rice Lake in Manitoba. Commonalities include: early faults and folds, synorogenic clastic basins, alkaline intrusions and volcanic rocks, thick-skinned thrusts, and late strike-slip faults. Of particular note is the structural geometry of the younger sedimentary sequence, which includes two homoclinal basins bounded by a footwall unconformity and hangingwall thrust fault (Figure GS-1-4). This geometry is similar, albeit on a smaller scale, to that described by Bleeker (2015) for the Kirkland Lake and Timmins districts in the Abitibi belt, where such basins are thought to offer a first-order guide to the most favourable portions of the gold metallotect. In the present case, and by analogy with these districts, chemically favourable rocks (mafic flows and iron formation) in the immediate footwall of the thrust that bounds the older marine sequence are logical exploration targets.

Acknowledgments

The author thanks D. Downie (University of Manitoba) for cheerful and capable assistance in the field; E. Anderson and N. Brandson (MGS) for efficient expediting services; P. Lenton, L. Chackowsky, M. Pacey and B. Lenton (MGS) for digital cartographic, GIS and drafting expertise; H. Crane for ongoing liaison with the Bunibonibee Cree Nation; Wings Over Kississing and Government Air Services for air support; and M. Rinne and C. Böhm for reviewing drafts of this report. Special thanks go to C. Castillo of the North Star Resort (Knee Lake), and to guests J. Lauria and V. Mancuso, for a cheerful and much appreciated tow back to camp after the MGS field party's outboard motor was thoroughly disabled by a reef.

References

Anderson, S.D., Kremer, P.D. and Martins, T. 2012a: Geology and structure of southwest Oxford Lake (east part), Manitoba (parts of NTS 53L12, 13); Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Preliminary Map PMAP2012-2, 1:20 000 scale.

Anderson, S.D., Kremer, P.D. and Martins, T. 2012b: Geology and structure of southwest Oxford Lake (west part), Manitoba (parts of NTS 53L12, 13, 63I9, 16); Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Preliminary Map PMAP2012-1, 1:20 000 scale.

Anderson, S.D., Kremer, P.D. and Martins, T. 2012c: Preliminary results of bedrock mapping at Oxford Lake, northwestern Superior Province, Manitoba (parts of NTS 53L12, 13, 63I9, 16); *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 6–22.

Anderson, S.D., Kremer, P.D. and Martins, T. 2013a: Geology and structure of northeastern Oxford Lake, Manitoba (parts of NTS 53L13, 14): sheet 1; Manitoba Mineral Resources, Manitoba Geological Survey, Preliminary Map PMAP2013-1, 1:20 000 scale.

Anderson, S.D., Kremer, P.D. and Martins, T. 2013b: Geology and structure of northeastern Oxford Lake, Manitoba (parts of NTS 53L13, 14): sheet 2; Manitoba Mineral Resources, Manitoba Geological Survey, Preliminary Map PMAP2013-2, 1:20 000 scale.

Anderson, S.D., Kremer, P.D. and Martins, T. 2013c: Geology and structure of northeastern Oxford Lake, Manitoba (parts of NTS 53L13, 14): sheet 3; Manitoba Mineral Resources, Manitoba Geological Survey, Preliminary Map PMAP2013-3, 1:20 000 scale.

Anderson, S.D., Kremer, P.D. and Martins, T. 2013d: Preliminary results of bedrock mapping at Oxford Lake, northwestern Superior province, Manitoba (parts of NTS 53L13, 14); *in* Report of Activities 2013, Manitoba Mineral Resources, Manitoba Geological Survey, p. 7–22.

Anderson, S.D., Syme, E.C., Corkery, M.T., Bailes, A.H. and Lin, S. 2015a: Bedrock geology of the southern Knee Lake area, Manitoba (parts of NTS 53L14, 15); Manitoba Mineral Resources, Manitoba Geological Survey, Preliminary Map PMAP2015-1, 1:20 000 scale.

Anderson, S.D., Syme, E.C., Corkery, M.T., Bailes, A.H. and Lin, S. 2015b: Preliminary results of bedrock mapping at southern Knee Lake, northwestern Superior province, Manitoba (parts of NTS 53L14, 15); *in* Report of Activities 2015, Manitoba Mineral Resources, Manitoba Geological Survey, p. 9–23.

Anderson, S.D., Syme, E.C. and Corkery, M.T. 2016: Bedrock geology of south-central Knee Lake, Manitoba (parts of NTS 53L15, 53M2); Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, Preliminary Map PMAP2016-1, 1:15 000 scale.

Babechuk, M.G. and Kamber, B.S. 2010: Detailed (1:10 scale) mapping of regolith structure in dolerite below the Missi unconformity, Flin Flon area, Saskatchewan (part of NTS 63K12); *in* Report of Activities 2010, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 94–104.

Barry, G.S. 1959: Geology of the Oxford House–Knee Lake area, Oxford Lake and Gods Lake Mining Divisions, 53L/14 and 53L/15; Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 58-3, 39 p.

Barry, G.S. 1960: Geology of the western Oxford Lake–Carghill Island area, Oxford Lake Mining Division, 53L/13; Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 59-2, 37 p.

Barry, G.S. 1964: Geology of the Parker Lake area, 53M/2, Gods Lake Mining Division, Manitoba; Manitoba Department of Mines and Natural Resources, Mines Branch, Publication 62-1, 26 p.

Bleeker, W. 2015: Synorogenic gold mineralization in granite-greenstone terranes: the deep connection between extension, major faults, synorogenic clastic basins, magmatism, thrust inversion, and long-term preservation; *in* Targeted Geoscience Initiative 4: Contributions to the Understanding of Precambrian Lode Gold Deposits and Implications for Exploration, B. Dubé and P. Mercier-Langevin (ed.), Geological Survey of Canada, Open File 7852, p. 25–47.

Brooks, C., Ludden, J., Pigeon, Y. and Hubregtse, J.J.M.W. 1982: Volcanism of shoshonite to high-K andesite affinity in an Archean arc environment, Oxford Lake, Manitoba; Canadian Journal of Earth Sciences, v. 19, p. 55–67.

Chakhmouradian, A.R., Böhm, C.O., Kressall, R.D. and Lenton, P.G. 2008: Evaluation of the age, extent and composition of the Cinder Lake alkaline intrusive complex, Knee Lake area, Manitoba (part of NTS 53L15); *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 109–120.

Corkery, M.T., Cameron, H.D.M., Lin, S., Skulski, T., Whalen, J.B. and Stern, R.A. 2000: Geological investigations in the Knee Lake belt (parts of NTS 53L); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 129–136.

Fedikow, M.A.F., Nielsen, E., Conley, G.G. and Lenton, P.G. 2000: Operation Superior: multimedia geochemical and mineralogical survey results from the southern portion of the Knee Lake greenstone belt, northern Superior Province, Manitoba (NTS 53L); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Open File Report OF2000-2.

Fedikow, M.A.F., Nielsen, E., Conley, G.G. and Lenton, P.G. 2001: Operation Superior: kimberlite indicator mineral survey results (2000) for the northern half of the Knee Lake greenstone belt, northern Superior Province, Manitoba (NTS 53M/1, 2, 3, 7 and 53L/15); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Open File Report OF2001-5.

Fedikow, M.A.F., Nielsen, E., Conley, G.G. and Lenton, P.G. 2002a: Operation Superior: multimedia geochemical survey results from the northern portion of the Knee Lake greenstone belt, northern Superior Province, Manitoba (NTS 53L); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Open File Report OF2001-1.

Fedikow, M.A.F., Nielsen, E., Conley, G.G. and Lenton, P.G. 2002b: Operation Superior: compilation of kimberlite indicator mineral survey results (1996–2001); Manitoba Industry, Trade and Mines, Manitoba Geological Survey, Open File Report OF2002-1.

Gilbert, H.P. 1985: Geology of the Knee Lake–Gods Lake area; Manitoba Energy and Mines, Geological Services, Geological Report GR83-1B, 76 p.

Hubregtse, J.J.M.W. 1978: Chemistry of cyclic subalkaline and younger shoshonitic volcanism in the Knee Lake–Oxford Lake greenstone belt, northeastern Manitoba; Manitoba Department of Mines, Resources and Environmental Management, Mineral Resources Division, Geological Paper 78/2, 18 p.

Hubregtse, J.J.M.W. 1985: Geology of the Oxford Lake–Carrot River area; Manitoba Energy and Mines, Geological Services, Geological Report GR83-1A, 73 p.

Kressall, R.D. 2012: The petrology, mineralogy and geochemistry of the Cinder Lake alkaline intrusive complex, eastern Manitoba; M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, 396 p.

Kressall, R.D., Chakhmouradian, A.R. and Böhm, C.O. 2010: Petrological and geochemical investigation of the Cinder Lake alkaline intrusive complex, Knee Lake area, east-central Manitoba (part of NTS 53L15); *in* Report of Activities 2010, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 146–158.

Lenton, P.G. 1985: Granite-pegmatite investigations: Knee Lake-Magill Lake area; *in* Report of Field Activities 1985, Manitoba Energy and Mines, Geological Services, p. 203–208.

Lin, S. and Jiang, D. 2001: Using along-strike variation in strain and kinematics to define the movement direction of curved transpressional shear zones: an example from northwestern Superior Province, Manitoba; Geology, v. 29, p. 767–770.

Lin, S., Jiang, D., Syme, E.C., Corkery, M.T. and Bailes, A.H. 1998: Structural study in the southern Knee Lake area, northwestern Superior Province, Manitoba (part of NTS 53L/15); *in* Report of Activities 1998, Manitoba Energy and Mines, Geological Services, p. 96–102.

Lin, S., Davis, D.W., Rotenberg, E., Corkery, M.T. and Bailes, A.H. 2006: Geological evolution of the northwestern Superior Province: clues from geology, kinematics, and geochronology in the Gods Lake Narrows area, Oxford–Stull terrane, Manitoba; Canadian Journal of Earth Sciences, v. 43, p. 749–765.

Richardson, D.J. and Ostry, G. 1996: Gold deposits of Manitoba; Manitoba Energy and Mines, Economic Geology Report ER86-1 (2nd Edition), 114 p.

Sandstå, N.R., Robins, B., Furnes, H. and de Wit, M. 2011: The origin of large varioles in flow-banded pillow lava from the Hooggenoeg Complex, Barberton Greenstone Belt, South Africa; Contributions to Mineralogy and Petrology, v. 162, p. 365–377.

Skulski, T., Corkery, M.T., Stone, D., Whalen, J.B. and Stern, R.A. 2000: Geological and geochronological investigations in the Stull Lake–Edmund Lake greenstone belt and granitoid rocks of the northwestern Superior Province; *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 117–128.

Southard, G.G. 1977: Exploration history, compilation and review, including exploration data from cancelled assessment files, for the Gods, Knee and Oxford lakes areas, Manitoba; Manitoba Department of Mines, Resources and Environmental Management, Mineral Resources Division, Open File Report 77/5, 93 p.

Stott, G.M., Corkery, M.T., Percival, J.A., Simard, M. and Goutier, J. 2010: A revised terrane subdivision of the Superior Province; *in* Summary of Field Work and Other Activities 2010, Ontario Geological Survey, Open File Report 6260, p. 20-1–20-10.

Syme, E.C., Corkery, M.T., Bailes, A.H., Lin, S., Cameron, H.D.M. and Prouse, D. 1997: Geological investigations in the Knee Lake area, northwestern Superior Province (parts of NTS 53L/15 and 53L/14); *in* Report of Activities 1997, Manitoba Energy and Mines, Geological Services, p. 37–46.

Syme, E.C., Corkery, M.T., Lin, S., Skulski, T. and Jiang, D. 1998: Geological investigations in the Knee Lake area, northern Superior Province (parts of NTS 53L/15 and 53M/2); *in* Report of Activities 1998, Manitoba Energy and Mines, Geological Services, p. 88–95.

Trommelen, M.S. 2014a: Surficial geology of the Knee Lake map area, Manitoba (NTS 53L15); Manitoba Mineral Resources, Manitoba Geological Survey, Geoscientific Map MAP2013-9, scale 1:50 000.

Trommelen, M.S. 2014b: Surficial geology of the Makakaysip Lake area, Manitoba (NTS 53M1); Manitoba Mineral Resources, Manitoba Geological Survey, Geoscientific Map MAP2013-6, scale 1:50 000.

Trommelen, M.S. 2014c: Surficial geology of the Mines Point map area, Manitoba (NTS 53M2); Manitoba Mineral Resources, Manitoba Geological Survey, Geoscientific Map MAP2013-7, scale 1:50 000.

Trommelen, M.S. 2014d: Surficial geology of the Oxford House map area, Manitoba (NTS 53L14); Manitoba Mineral Resources, Manitoba Geological Survey, Geoscientific Map MAP2013-8, scale 1:50 000.

Wright, J.F. 1926: Oxford and Knee Lakes area, northern Manitoba; *in* Canada Department of Mines, Geological Survey, Summary Report, 1925, Part B, p. 16B–26B.

Wright, J.F. 1932: Oxford House area, Manitoba; *in* Canada Department of Mines, Geological Survey, Summary Report, 1931, Part C, p. 1C–25C.