Geology and economic potential of the Oxford Lake–Knee Lake greenstone belt, Manitoba



Introduction

In 2012, the Manitoba Geological Survey began a renewed study of the stratigraphy, tectonic evolution and metallogeny of the Oxford Lake–Knee Lake greenstone belt.

The Oxford Lake–Knee Lake belt is part of the largest contiguous greenstone belt in the northwestern Superior province and is considered to be highly prospective, yet remains under-explored.

New bedrock mapping, augmented by structural, lithogeochemical, Sm-Nd isotopic, U-Pb geochronological and high-resolution aeromagnetic data, is being used to upgrade existing maps, with the goal of a comprehensive regional synthesis and up-to-date assessment of its mineral potential.

Scott D. Anderson Manitoba Geological Survey

Synorogenic clastic basins: Implications for gold potential

New bedrock mapping by the MGS in 2016, aided by unprecedented low water levels at Knee Lake and resulting extensive bedrock exposure, provides a much improved geological context for exploration.

In south-central Knee Lake, three major structural panels have been defined (southwest, central and northeast), separated by early faults. The Opischikona Narrows basin, the stratigraphic and structural context of which were previously unknown, was found to include two distinct sedimentary sequences.

Turbidites, iron formation and mafic volcanic rocks of the older marine sequence define a complex isoclinal syncline in the southwest panel. Trough crossbedded sandstones and polymictic conglomerates of the younger shallow-marine to subaerial sequence define two homoclines at the northeast margins of the southwest and central panels.

Contact relationships of the younger sequence were well exposed in 2016: the basal contact is a pronounced angular unconformity, whereas the upper contact is tectonic, interpreted to represent an early thrust fault.

In this regard, the younger sequence is broadly synorogenic, in that regional deformation both pre-dates and post-dates deposition. It is similar in most respects to 'Timiskaming-type' rocks elsewhere in the Superior province, with implications for identifying structural settings favourable for orogenic gold mineralization.

Revised bedrock geology and structure of central Knee Lake from 2016 mapping



Ultramafic–mafic sills; locally layered)pischikona Narrows basi ——— Fault rocks; minor iron formatior _____ Thrust fault Conglomerate: polymictic Felsic volcaniclast ---- Unconformity Marine sequenc afic volcanic rock Iron formation Plagioclase-phyric Feldspathic greywacke; turbiditic Variolitic ··- Anticline

Anderson et al. 2016: MGS PMAP2016-1



A simplified, schematic cross section through central Knee Lake (above) shows the interpreted structural geometry, with thin homoclines of shallow-marine to subaerial sedimentary rocks along the northeast margins of both the southwest and central structural panels.

The homoclines consistently young to the northeast and are bounded by an angular unconformity at the base, and at the top by an interpreted thrust fault.

The entire section is interpreted to represent a southwestverging thrust stack, with the southwest panel at the base and the northeast panel at the top.

Characteristic rock types of the shallow-marine to subaerial sequence



Medium-grained sandstone showing well-developed trough crossbedding



erosional scours

Characteristic rock types and structure of the marine sequence





Tightly folded chert-magnetite iron formation

Detailed outcrop map of the younger sequence in the central panel The thin homocline of sedimentary rocks at the northeast margin of the central panel was well exposed in 2016 along the shoreline of a large island in central Knee Lake.

The unconformity is marked by a coarse polymictic conglomerate that contains clasts of iron formation and overlies oxidized and fractured basalt flows of the Hayes River group.

The interpreted thrust fault at the top of the homocline consists of 1-2 m of chloritic mylonite, which separates bedded greywacke and conglomerate from pillowed variolitic basalt flows. Younging criteria indicate a face-to-face contact relationship.







Comparison to other synorogenic clastic basins: the Abitibi belt The stratigraphic and structural geometry of synorogenic clastic basins at Knee Lake are comparable to those of the Abitibi belt in Ontario.

In the model of Bleeker (2015; diagrams below), these basins are thought to delineate the critical, early, crustal-scale faults that controlled the location of major orogenic gold districts.





Shoreline mapping took place at Oxford Lake in 2012 and 2013, and continued at Knee Lake in 2015 and 2016. The goal of the 2015–2016 fieldwork was to examine key localities identified during the Western Superior NATMAP Project (1997–1998) and to remap areas of incomplete data coverage.

This poster summarizes new results from work completed at Knee Lake, with emphasis on exploration implications.





greywacke and conglomerate (foreground) and pillowed basalt (background). Hammer rests on the contact, which is marked by chloritic mylonite.



Sharp contact between reworked basalt (bottom) ar polymictic conglomerate (top). Note large clast of chert-magnetite iron formation in the conglomerate (left of hammer).



Implications for exploration targeting at Knee Lake

Detailed mapping and high-resolution aeromagnetic data indicate the distribution and geometry of synorogenic basins at Knee Lake. At the west end of southern Knee Lake, turbidites and iron formation contain refolded isoclinal folds and are overlain, across an angular unconformity, by a thick homocline of fluvial sandstone.

By analogy with the Abitibi belt, chemical and/or structural traps in the footwalls of unconformities represent key exploration targets for orogenic gold deposits.



Carbonatite magmatism:

Implications for rare metal potential

Shoreline mapping by the MGS in 2016 resulted in the discovery of a swarm of carbonate dikes in the westernmost bay of south-central Knee Lake, immediately east of Cinder Lake.

These dikes weather earthy brown and are typically fine-grained and equigranular. They consist mostly of carbonate (>80% calcite-dolomite), with lesser silicate, oxide and sulphide mineral phases; most are strongly magnetic, indicating the presence of fine disseminated magnetite.

The dikes have sharp, planar contacts and vary from massive to flow layered. They dip steeply north or south and discordantly cut ductile deformation fabrics in the hostrock. Dark green metasomatic haloes adjacent to the dikes range up to 40 cm in thickness.

Field photographs of carbonate dikes at central Knee Lake



Carbonate dikes at the southern-most exposure showing steep orientation



Detail of carbonate dike showing thick, dark green metasomatic halo in host gabbro

Carbonate dikes in relation to the Cinder Lake alkaline intrusive complex



Whole-rock geochemistry of the Knee Lake carbonate dikes

Whole-rock geochemical data indicate the carbonate dikes at Knee Lake (red) are comparable to documented carbonatite dikes elsewhere in Manitoba (e.g., Oxford Lake, green; Paint Lake, purple), but show significantly greater enrichments in light rare earth elements.

These new data indicate that the Cinder Lake complex may have significant exploration potential for carbonatite-hosted rare metals.

Lefebvre, N., Kopylova, M. and Kivi, K. 2005: Precambrian Research, v. 138, p. 57–87.



(hammer handle points north)



Detail of carbonate dike showing carbonate-dominant mineralogy and laminated internal structure



Carbonate dikes were identified in four locations over a north-south distance of 3 km, and generally become thicker and more abundant toward the south.

On the basis of mineralogical and geochemical evidence, Chakhmouradian et al. (2008) concluded that the adjacent Cinder Lake alkaline intrusive complex is likely associated with unexposed carbonatite—an assertion supported by the discovery of the carbonate dikes immediately to the east at Knee Lake.

Regional aeromagnetic data indicate the complex is elliptical, concentrically zoned and roughly 10 km in maximum diameter.

The main carbonate dikes at each locality are roughly orthogonal to the margins of the complex, suggestive of a radial dike swarm.



Anderson, S.D., Syme, E.C., Corkery, M.T., Bailes, A.H. and Lin, S. 2015: Report of Activities 2015, Manitoba Geological Survey, p. 9–23 Anderson, S.D., Syme, E.C. and Corkery, M.T. 2016: Manitoba Geological Survey, Preliminary Map PMAP2016-1, 1:15 000 scale. Bleeker, W. 2015: Geological Survey of Canada, Open File 7852, p. 25–47.

Stott, G.M., Corkery, M.T., Percival, J.A., Simard, M. and Goutier, J. 2010: Summary of Field Work and Other Activities 2010, Ontario Geological Survey, Open File Report 6260, p. 20-1–20-10.

Bruce, L.F., Kopylova, M.G., Longo, M. and Ryder, J. 2010: GeoCanada 2010 conference, Calgary, Alberta, May 10–14, 2010 (extended abstract). Chakhmouradian, A.R., Böhm, C.O., Kressall, R.D. and Lenton, P.G. 2008: Report of Activities 2008, 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: Report of Activities 2000, Manitoba Geological Survey, p. 129–136.

Fedikow, M.A.F., Nielsen, E., Conley, G.G. and Lenton, P.G. 2002: Manitoba Geological Survey, Open File Report OF2002-1. Gernon, T.M., Brown, R.J., Tait, M.A. and Hincks, T.K. 2012: Nature Communications, v. 3, art. 832, 7 p. Kjarsgaard, B.A. 2007: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, p. 245-272.

Lin, S., Davis, D.W., Rotenberg, E., Corkery, M.T. and Bailes, A.H. 2006: Canadian Journal of Earth Sciences, v. 43, p. 749–765. Percival, J.A., Sanborn-Barrie, M., Skulski, T., Stott, G.M., Helmstaedt, H. and White, D.J. 2006: Canadian Journal of Earth Sciences, v. 43, p. 1085–1117. Skulski, T., Corkery, M.T., Stone, D., Whalen, J.B. and Stern, R.A. 2000: Report of Activities 2000, Manitoba Geological Survey, p. 117–128.

Regional setting

The Oxford Lake–Knee Lake greenstone belt is situated in the Oxford–Stull domain of the western Superior province (Stott et al., 2010). The Oxford–Stull domain is thought to represent a collage of oceanic and continental-margin terranes that were accreted to the margin of the North Caribou superterrane during the ca. 2.72 Ga Northern Superior orogeny (e.g., Skulski et al., 2000; Percival et al., 2006; Stott et al., 2010).

Uranium-lead geochronological data from Oxford Lake and Knee Lake indicate that major volcanism occurred in three pulses: 2.9–2.87 Ga, 2.83–2.81 Ga and 2.73–2.69 Ga (Corkery et al., 2000; Lin et al., 2006).

Older assemblages (>2.8 Ga) consist mostly of submarine bimodal (basalt and rhyolite) volcanic rocks, traditionally referred to as the 'Hayes River group'.

Lamprophyre (shoshonitic) volcanism: Implications for diamond potential

The Oxford Lake–Knee Lake belt contains a wide diversity of alkaline rocks, including lava flows, cryptodomes, primary volcaniclastic rocks, reworked volcanic sedimentary rocks, and subvolcanic intrusions ranging in size from dikes to plutons.

At southern Knee Lake, these rocks include a distinctive association of hypabyssal dikes, primary volcaniclastic (pyroclastic) and reworked volcanic sedimentary rocks that have ultramafic-mafic bulk compositions and strongly alkaline (shoshonitic) affinities.

Anderson et al. (2015) referred to these rocks as the 'ultramafic facies association'.

Although these rocks are spatially associated with major faults, they show remarkable preservation of primary features. Type examples of the key facies are shown below.

Hypabyssal intrusive facies







Monolithic, graded lapilli tuff of ultramafic, alkaline composition





Volcanic sandstone and conglomerate showing diffuse graded beds and crossbedding



Volcanic conglomerate with abundant cored clasts interpreted to represent pelletal lapilli





lamprophyre dike





Volcanic conglomerate showing polymictic clast population dominated by ultramafic and mafic clasts

The polymictic volcanic conglomerate locally contains a high proportion of cm-sized composite clasts consisting of a lithic (generally mafic plutonic) core surrounded by a fine-grained rim of lithic material.

pipes, including kimberlites.

0 0

Pelletal lapilli are thought to form when volatilerich alkaline melts are injected into unconsolidated crater-fill and undergo intensive

This results in coating of lithic clasts by a process referred to as 'fluidized spray granulation' (Gernon et al., 2012).

Younger assemblages (<2.73 Ga) are more diverse in terms of bulk compositions (basalt to rhyolite) and chemical affinity (tholeiitic to calcalkaline to alkaline), and are associated with marine turbidite and subaerial sandstone and conglomerate, traditionally referred to as the 'Oxford Lake group'.

These supracrustal rocks are overprinted by tight to isoclinal folds, intruded by granitoid plutons and segmented by faults; consequently, stratigraphic and structural relationships of adjacent and often dissimila map units have proven difficult to establish.

Resolving these relationships is one of the major goals of the ongoing MGS mapping program at Oxford Lake and Knee Lake.



Coarse, deformed phenocrysts of phlogopite/biotite in

Detail of angular, ragged pyroclast, with phenocrysts of phlogopite/biotite and quartz amygdules

These cored clasts are comparable to 'pelletal lapilli', which are common features of diatreme

Whole-rock geochemistry



Whole-rock geochemical data for lamprophyre dikes (red), pyroclastic rocks (purple) reworked volcanic sedimentary rocks (green) and clasts in volcanic conglomerate (blue) show primitive bulk compositions (low SiO₂; high MgO, Ni and Cr), with strongly enriched large ion lithophile elements (K, Ba, Sr, Rb), depleted high field strengt elements (Nb, Zr, Ti), and variable enrichment of the light rare earth elements.

These features are typical of alkaline magmatic rocks in suprasubduction zone settings.

A depositional model: lamprophyric diatreme volcanism



The diagram at left shows the classic South African model of a diatreme (kimberlite) pipe with nomenclature used to describe such rocks, including previous terminology (from Kjarsgaard,

The volcanic facies of shoshonitic lamprophyre at Knee Lake are comparable to the hypabyssal, pyroclastic and resedimented volcaniclastic facies of a diatreme pipe system.

The variable trace element geochemistry of these rocks points towards a complex system, perhaps comprised of more than one volcanic centre.

It should be noted that no examples of massive volcaniclastic rocks of the type associated with the 'diatreme facies' have yet been recognized at Knee Lake.

Operation Superior: diamond prospectivity of the Knee Lake area

Regional multimedia geochemical and mineralogical surveys carried out by the MGS under the auspices of Operation Superior (1997–2001) identified anomalous concentrations of mantle-derived minerals (i.e., kimberlite indicator minerals) in surficial sediments at Knee Lake (Fedikow et al., 2002).

Despite a brief surge in diamond exploration (1999–2004), a bedrock source of these minerals, some of which are indicative of diamondiferous hostrocks, has not been identified.

Although kimberlite is the main worldwide host of conventional diamond deposits, significant deposits also occur in other types of mantle-derived intrusions, including lamprophyre. One such example occurs near Wawa, ON, where diamondiferous rocks include calcalkaline lamprophyre dikes as well as polymictic volcaniclastic breccia and conglomerate (e.g., Lefebvre et al., 2005; Bruce et al., 2010).

The lamprophyric volcanic rocks at Knee Lake are potential analogues of these rocks, but have yet to be assessed as possible sources of mantle indicator minerals, including diamonds.



Fedikow et al., 2002; MGS Open File OF2002