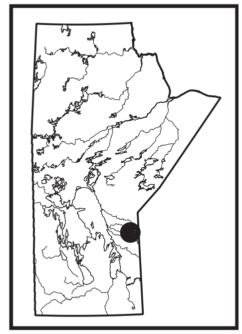

GS-2 Geological reconnaissance of the Horseshoe Lake greenstone belt, Superior Province, east-central Manitoba (part of NTS 53D4)

by P.D. Kremer, S.D. Anderson, L.A. Murphy and C.O. Böhm

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Summary

In late June 2012, two weeks of geological reconnaissance fieldwork were conducted in the Horseshoe Lake greenstone belt, to investigate the type, amount, quality and accessibility of outcrop, and to assess the feasibility of a more comprehensive mapping program in subsequent years. Supracrustal rocks in the area trend northwest and define a roughly elliptical belt that is cored by a granodiorite pluton and is everywhere bounded by granitoid intrusions. The southwestern flank of the belt is easily accessed and well exposed on the shores of Horseshoe and Night Owl lakes, and along the Berens River. Exceptionally low water levels in 2012 vastly increased shoreline exposure at Horseshoe Lake, which was consequently the main focus of reconnaissance mapping for this season. Exposures of supracrustal rocks in the northwestern portion of the lake and downstream along the Berens River indicate a structurally simple, consistently northeast-younging, homoclinal sequence. The lower section of this sequence consists of a diverse assemblage of pillowed and massive basalt flows, gabbro, greywacke-mudstone turbidites and heterolithic volcanic conglomerate. Along the southwestern margin of the belt these rocks are strongly tectonized and amphibolitized. The middle section is defined by a thick succession of crudely stratified crystal tuff, crystal-lithic lapilli tuff and tuff breccia, of dacitic to rhyolitic bulk composition, and is overlain by an upper section consisting of massive dacite flows.

Introduction

The Horseshoe Lake greenstone belt is located along the Berens River in eastern Manitoba, approximately 120 km north of Bissett. It lies in the central portion of the Berens River Subprovince of the Archean Superior Province, and is one of the few known strands of supracrustal rocks in a region dominated by ca. 2690–2750 Ma granitoid plutons (e.g., Corfu and Stone, 1998; Figure GS-2-1). As such, it has always been considered somewhat of an enigma.

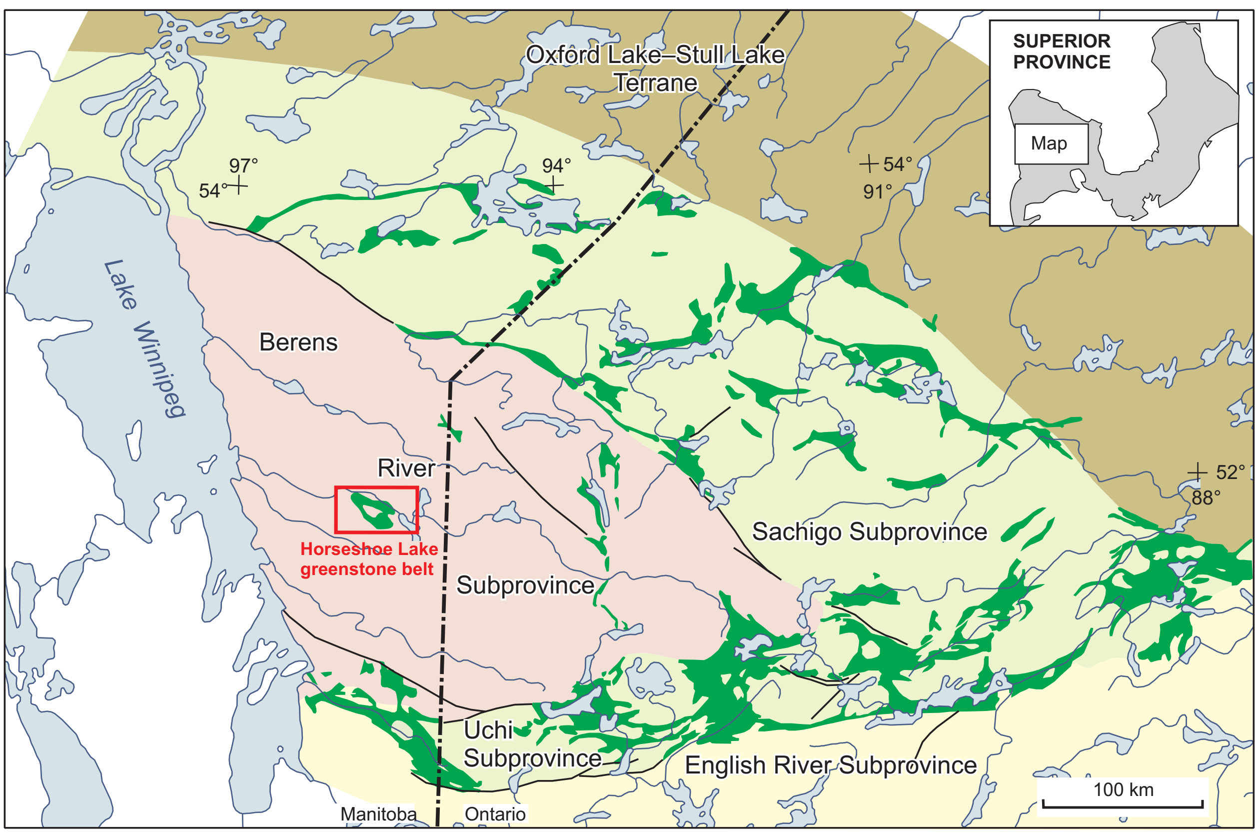

Figure GS-2-1: *Location map of the Horseshoe greenstone Lake belt, east-central Manitoba.*

Very little work has been done in this region, and the Horseshoe Lake belt remains the only greenstone belt in Manitoba that has never been systematically mapped. Early reconnaissance east of Lake Winnipeg, by the Geological Survey of Canada, demonstrated that the Horseshoe Lake belt is isolated in a sea of undivided granitoid intrusions and is the only significant accumulation of supracrustal rocks between Rice Lake in the south and Island Lake in the north (Johnson, 1936a–f; Ermanovics, 1969, 1970). Despite this isolated setting, the belt has attracted some attention from prospectors and exploration companies. In 1967, anomalous gold was discovered by Homestake Mineral Development Co. in pyritized metasedimentary rocks at Horseshoe Lake (Assessment File 92091, Manitoba Innovation, Energy and Mines, Winnipeg) and, in 1968, an airborne Questor INPUT EM survey flown by Selco Exploration Ltd. identified six anomalies (Assessment File 91728), which were later investigated by Homestake (Assessment File 92777). In 1984, the Manitoba Geological Survey conducted a three-day reconnaissance at Horseshoe Lake to identify rock types and investigate mineral occurrences (Baldwin et al., 1984). More recently, Corkery et al. (2010) conducted reconnaissance mapping of plutonic and gneissic rocks at Family and Fishing lakes, near the eastern extent of the Horseshoe Lake belt.

This report summarizes the preliminary results of a two-week reconnaissance, in June 2012, of the southwestern flank of the Horseshoe Lake belt in the area of Night Owl and Horseshoe lakes, and also includes descriptions of U-Pb geochronological results from samples collected by Corkery et al. (2010) at Family and Fishing lakes. The 2012 reconnaissance was conducted to verify the type, amount, quality and accessibility of outcrop, and to assess the feasibility of systematic, detailed (1:20 000 scale) bedrock mapping of the belt.

The southwestern flank is easily accessed via Horseshoe and Night Owl lakes and the Berens River, and outcrop is abundant, with 40–60% exposure along shorelines. Exceptionally low water levels in 2012 further increased the quantity and quality of the shoreline outcrop, particularly at Horseshoe Lake. Although access is reasonably good on this flank of the belt, inland areas are characterized by very dense immature bush and heavily lichen-covered outcrop, which together render these areas unsuitable for systematic detailed mapping purposes. This is also true for the northwestern flank, which has the additional challenge of a lack of accessible lakes or navigable rivers. For these reasons, the MGS is not presently contemplating a systematic mapping program for the Horseshoe Lake belt as a whole; however, pending the results of ongoing analytical work, it may prove worthwhile to conduct thematic studies of the well-exposed section at Horseshoe Lake (described below).

Geology and stratigraphy

During the 2012 reconnaissance program bedrock exposures on the shorelines of Family, Night Owl and Horseshoe lakes, and along the Berens River, were examined and also several traverses of inland areas were conducted. The best and most diverse exposures of supracrustal rocks were found in the northwestern portion of Horseshoe Lake and downstream along the Berens River, where they provide a nearly continuous transect over a stratigraphic thickness of approximately 6 km across the southwestern flank of the Horseshoe Lake belt. Abundant younging criteria indicate a structurally intact homoclinal succession that is consistently northeast-younging and is separated herein into lower, middle and upper sections for descriptive purposes (Figure GS-2-2).

All of the rocks in the study area have been metamorphosed and contain greenschist to (local) amphibolite-facies mineral assemblages. In the interest of brevity, however, the prefix 'meta' is not used in this report, and the rocks are described in terms of their protoliths.

Lower section

The lower section of the Horseshoe Lake homocline is the most lithologically diverse of the three sections, and consists of pillowed and massive basalt flows, greywacke-mudstone turbidite and heterolithic volcanic conglomerate, all of which are intruded by dikes and sills composed of gabbro and biotite granodiorite to quartz monzonite. Within 200 m of the southwestern margin of the belt, these rocks are tectonized and amphibolitized, and form strongly layered amphibolite gneiss that is intruded by abundant thick sheets of equigranular biotite granodiorite. Away from this marginal zone of tectonite, primary features are well preserved. The lower section is approximately 3 km thick and is defined at the base and top by basalt flows.

Basalt near the base of the section is aphyric to sparsely plagioclase-phyric, pillowed and strongly epidotized. It tends to be poorly exposed and strongly deformed, but appears to form discrete flows up to several tens of metres thick that are interstratified with planar-bedded greywacke-mudstone turbidites and heterolithic volcanic conglomerate. The turbidite intervals range up to 20 m thick and consist of monotonously interbedded greywacke and mudstone, with minor layers of siliceous mudstone, pebble conglomerate and crystal tuff. The greywacke is medium to coarse grained and forms normally graded beds up to 80 cm thick, with scoured bases and well-developed pebble lags. These beds contain up to 30% subrounded to angular quartz grains; a sample of this quartz-rich greywacke was collected for U-Pb analysis of the detrital zircon population. The greywacke is planar-bedded, but also locally contains layers with well-developed trough crossbeds. Mudstone accounts for less than 20% of the turbidite intervals and typically forms beds

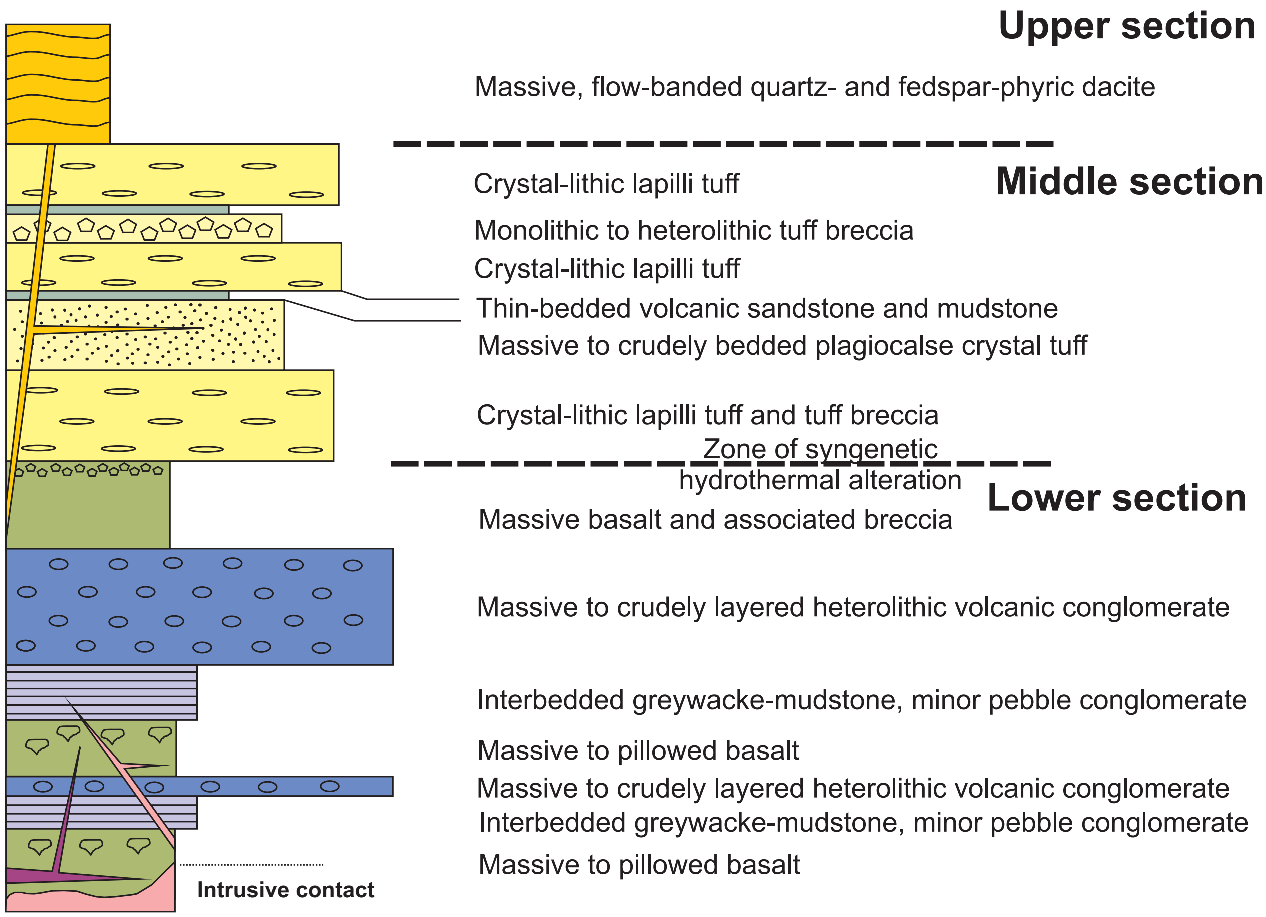

Figure GS-2-2: *Simplified stratigraphic column for the southwestern flank of the Horseshoe Lake belt, east-central Manitoba.*

less than 10 cm thick. Intervals of monotonous thin-bedded greywacke and mudstone locally contain well-developed load structures (Figure GS-2-3a). Coupled with the associated pillowed basalt flows, these features indicate deposition below wave base in a marine setting.

The associated volcanic conglomerate layers range up to 10 m in thickness and are heterolithic, matrix or clast supported, poorly sorted and massive to crudely stratified. They consist of angular to subrounded clasts that range up to 1 m across and consist mostly of variably plagioclase-phyric andesite or dacite, with minor clasts of crystal tuff and basalt. Some of these layers contain abundant polygonal-jointed clasts of plagioclase-phyric dacite or andesite. The matrix is distinctly fine grained and muddy, and lacks coarse detrital quartz. These features are indicative of subaqueously deposited debris flows derived from a nearby felsic volcanic centre.

The lower section is capped by a distinctive basalt flow that was traced discontinuously along strike for 1.1 km and is 'open' in both directions. The basalt is dark brown to green, fine grained, aphyric to plagioclase-phyric, and contains sparse quartz amygdules up to 5 mm across. It appears to form a single massive flow that ranges from 40 to 80 m in thickness and is marked at the base and top by thin (<5 m) layers of clast-supported monolithic flow breccia (Figure GS-2-3b). Near the top, and locally near the base, the flow contains irregular, isolated to fracture-controlled, quartz-filled vugs and patchy to fracture-controlled zones of intense chlorite–garnet±magnetite alteration. Large (up to 1 cm) idioblastic porphyroblasts of garnet locally form bulbous coalesced masses and stringer-style veins. The flow is capped in one location by a 1.5 m thick interval of thin-bedded mafic tuff, which likely represents reworked hyaloclastite. Near the southeastern defined extent, the flow is successively overlain by a 10 m thick layer of volcanic conglomerate and a thick (>5 m) layer of planar-bedded volcanic sandstone that contains normally graded beds and load structures. The conglomerate layer contains weak to moderate, fracture-controlled magnetite alteration that extends upward to the base of the sandstone layer, where it is sharply truncated (Figure GS-2-3c). This relationship clearly indicates the syngenetic nature of the alteration, which was perhaps related to hydrothermal circulation induced by heat from the massive basalt flow.

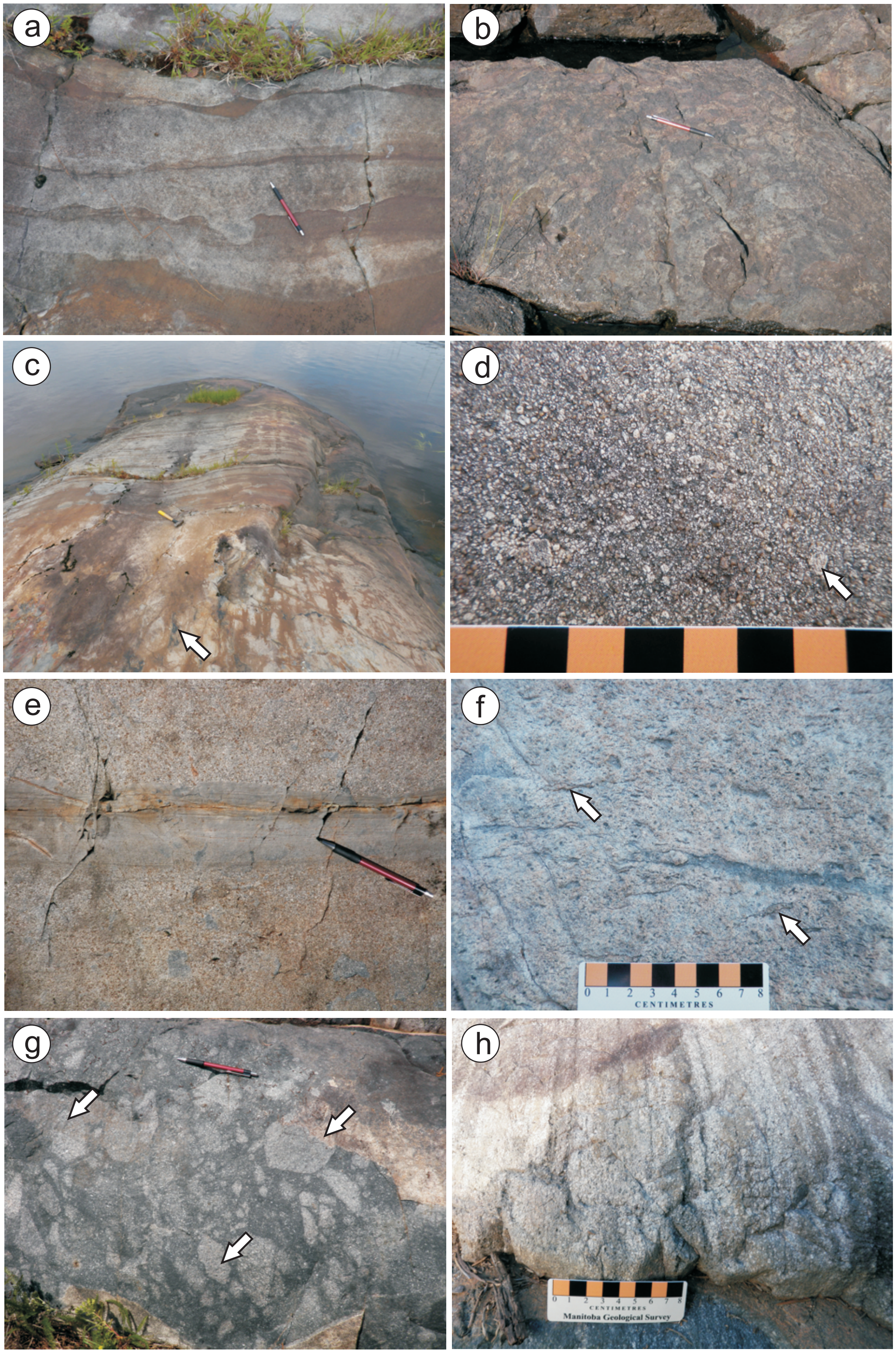

Figure GS-2-3: *Outcrop photographs of representative rock types in the homoclinal succession of supracrustal rocks at Horseshoe Lake, east-central Manitoba (younging direction is toward the top of each photograph):* ***a)*** *bedded greywacke and mudstone, showing normally graded beds and load structures;* ***b)*** *monolithic basalt flow breccia;* ***c)*** *volcanic conglomerate (bottom) with fracture-controlled magnetite alteration (arrow) overlain by bedded volcanic sandstone (top);* ***d)*** *dacitic crystal tuff with example of broken plagioclase crystal (arrow);* ***e)*** *thin layer of volcanic sandstone separating thick massive layers of crystal tuff (top and bottom); note scoured basal contact of the upper layer;* ***f)*** *examples of well-preserved fiamme (arrows), interpreted to represent collapsed pumice, in crystal-lithic lapilli tuff;* ***g)*** *dacitic tuff breccia with abundant polygonal- and hexagonal-jointed clasts (arrows);* ***h)*** *flow-banded porphyritic dacite.*

Middle section

The middle section is approximately 2 km thick and consists of stratified crystal tuff and crystal-lithic lapilli tuff of dacitic to rhyolitic composition, with minor tuff breccia. These rocks are well exposed in the central and northwestern portions of Horseshoe Lake. A recent forest fire produced excellent exposure toward the top of the volcaniclastic succession in the northernmost part of Horseshoe Lake. The middle section is interpreted to extend to the southeast along strike to Night Owl Lake, where it is well exposed in shoreline outcrop.

Crystal tuff is the dominant rock type and typically weathers buff to light grey. It contains abundant crystals (<5 mm) of slightly blue-grey quartz and white plagioclase in a very fine grained quartzofeldspathic matrix. Characteristically, it also contains equant grains or clusters of magnetite up to 5 mm across, which account for less than 3% of the rock. The quartz grains are typically equant and subhedral to anhedral, whereas the plagioclase grains are tabular, euhedral to subhedral, and are commonly broken and zoned (Figure GS-2-3d). Angular to wispy, grey-brown weathering, aphanitic lithic lapilli (<2 cm) occur locally in the crystal tuff. Most outcrops are very homogeneous and massive, although some display a very faint stratification defined by variations in the size and proportion of the crystal component.

The crystal tuff is interstratified at various scales with crystal-lithic lapilli tuff that is texturally very similar, but contains a distinct population (10–15%) of light grey or brown, aphyric to sparsely quartz- or plagioclase-phyric lithic lapilli. Both rock types form massive nongraded layers that range up to several tens of metres in thickness in continuous exposures, and possibly represent primary pyroclastic-flow deposits. Where exposed, the upper and lower contacts are marked by thin (<50 cm) intervals of thin-bedded, normally graded volcanic sandstone and mudstone (Figure GS-2-3e). The basal flow contacts are deeply scoured and normally graded. In one location, beds of crystal-lithic lapilli tuff contain up to 10% fiamme (collapsed pumice; Figure GS-2-3f) that become coarser and more abundant upsection, and are thus suggestive of reversely graded pumice-flow deposits.

Subordinate layers of monolithic (dacite) and heterolithic tuff breccia are matrix to clast supported, poorly sorted and massive to crudely stratified. They contain very angular to subrounded clasts that range up to 25 cm across and consist of plagioclase (±quartz±hornblende) dacite, with or without subordinate clasts of andesite, rhyolite or basalt. They typically include abundant and locally very coarse examples of polygonal-jointed clasts (Figure GS-2-3g). Where stratified, individual beds are locally capped by thin (<30 cm) layers of thin-bedded, fine-grained volcanic sandstone and mudstone. In one location, polygonal clasts of aphyric andesite protrude upward into the base of an overlying mudstone layer, as is commonly observed in debris-flow deposits.

Upper section

The upper section is exposed only in the northernmost portion of Horseshoe Lake, where it is at least 800 m thick and consists of massive or flow-banded quartz- and feldspar-phyric dacite flows (Figure GS-2-3h). The dacite weathers buff to light grey and contains 20–30% feldspar phenocrysts (<7 mm) and 1–2% pale blue quartz phenocrysts (<3 mm) in an aphanitic, siliceous matrix. Flow banding is well developed in some exposures and is locally highly contorted. Flow breccia, with subangular to polygonal clasts of flow-banded dacite, occurs in one location approximately 200 m north of Horseshoe Lake. A sample of massive flow-banded dacite was collected for U-Pb geochronological analysis.

Dacitic to andesitic dikes and sills are common throughout the stratigraphy and are interpreted to represent synvolcanic feeders to the overlying flows. Dacite dikes weather light grey and contain 15–20% euhedral plagioclase phenocrysts up to 1 cm, and 1–5% subhedral, blue quartz phenocrysts (2–5 mm) in an aphanitic groundmass. Dikes of flow-banded, aphyric to sparsely porphyritic dacite crosscut volcaniclastic rocks of the middle section in several locations. Coarser grained dikes of quartz and feldspar porphyry locally contain up to 70% euhedral blocky plagioclase crystals up to 1.5 cm in size. Andesite dikes weather medium to dark grey and contain up to 25% euhedral to subhedral hornblende phenocrysts and 5–15% euhedral plagioclase phenocrysts. Dike thickness varies from less than 1 m to more than 10 m; contacts are sharp, planar to wavy and chilled.

Lithogeochemistry

Felsic volcanic, volcaniclastic and subvolcanic intrusive rocks, typically composed of calcalkalic dacite and rhyolite, dominate the middle and upper sections of the thick succession on the southwestern flank of the Horseshoe Lake belt. On a primitive-mantle–normalized extended element plot, these rocks display steep negative slopes with strong enrichment of large-ion lithophile and light rare earth elements, and pronounced negative Nb and Ti anomalies (Figure GS-2-4a). The basalt flows in the lower section have similar trace and rare earth element profiles but are more enriched in rare earth elements (REE) relative to the felsic rocks (Figure GS-2-4b). These geochemical features indicate a potential analogy to bimodal calcalkalic volcanic rocks in modern suprasubduction settings.

The supracrustal rocks are intruded to the south by biotite granodiorite to quartz monzonite, which contain abundant xenoliths and enclaves of supracrustal rocks. The biotite granodiorite and quartz monzonite are characterized by strongly fractionated REE patterns with

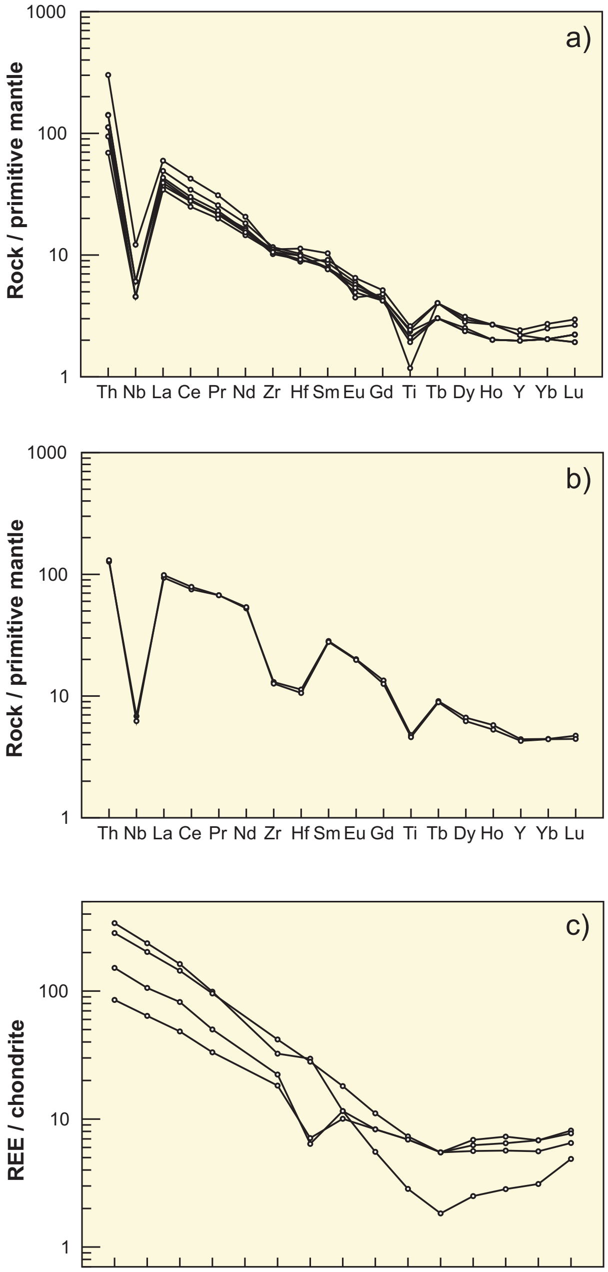

***Figure GS-2-4:** Geochemical plots of volcanic and plutonic rocks in the Horseshoe Lake area, east-central Manitoba: **a)** felsic volcanic, subvolcanic and volcaniclastic rocks; **b)** basalt; **c)** intrusive rocks. Normalizing values are from McDonough and Sun (1995) for both chondrite and primitive mantle.*

variable Eu anomalies and variable enrichment in REEs (Figure GS-2-4c). These geochemical data are similar to those for a peraluminous granite suite described by Corfu and Stone (1998).

Geochronology

In 2010, a reconnaissance mapping program was conducted in the Family and Fishing lakes area, immediately east of the Horseshoe Lake belt (Corkery et al., 2010). To help constrain the magmatic history of the area, four samples of volcanic and plutonic rocks were collected for U-Pb zircon isotopic analysis. Corfu and Stone (1998) subdivided plutonic rocks in the Berens River Subprovince into six distinctive suites based on variations in composition, U-Pb age and geochemical signature, and demonstrated that magmatism was essentially continuous between 2750 and 2690 Ma. This work provides a framework to which geochronological data from the Family and Fishing lakes area can be compared.

Dacite

A sample of feldspar-phyric dacite was collected from western Family Lake, at the eastern termination of the southern flank of the Horseshoe Lake belt, to constrain the age of volcanism. The sample yielded equant, pink prismatic zircons and a small, tan prismatic zircon. The Th/U ratios average 0.5 (Table GS-2-1), which is a typical value for magmatic zircons. The U-Pb concordia age results vary slightly depending on the zircon fractions used in the calculation; however, both solutions suggest an age of about 2735 Ma for the dacite sample (Figure GS-2-5a).

Quartz monzonite

Megacrystic quartz monzonite from southern Family Lake intrudes the Horseshoe Lake belt to the south. Quartz monzonite contains numerous inclusions of felsic to intermediate supracrustal rocks, and dikes of quartz monzonite are abundant within the volcanic and sedimentary rocks along the southwestern flank of the greenstone belt. The U-Pb data indicate a zircon crystallization age of 2713.3 ±1.0 Ma that is interpreted as the emplacement age of the quartz monzonite intrusion (Figure GS-2-5b). This is consistent with observed field relationships between quartz monzonite and ca. 2735 Ma dacite of the Horseshoe Lake belt.

Hornblende tonalite

Hornblende tonalite occurs along the western shore of Fishing Lake. Field relationships suggest that it grades into weakly megacrystic tonalite to granodiorite, and is locally associated with tonalite to granodiorite gneiss (Corkery et al., 2010). Contact relationships between hornblende tonalite and the supracrustal rocks were not observed. The sample yielded small pink prismatic zircons (Table GS-2-1). The U-Pb isotopic data of four morphologically and geochemically similar zircon fractions scatter slightly and can be interpreted in two ways (Figure GS-2-5c). Using zircon fractions 3 and 4 results in a concordia upper intercept age of 2710.2 ±1.5 Ma, similar to the interpreted emplacement age for quartz monzonite, whereas using zircon fractions 2 and 4 results in a crystallization age of 2734.0 ±2.5 Ma, synchronous with volcanism within the greenstone belt. Corfu and Stone (1998)

Table GS-2-1: Isotopic U-Pb zircon data from isotope dilution–thermal ionization mass spectrometry for samples from the Family and Fishing lakes area, east-central Manitoba.

Sample number Description of zircon fractions		Weight (mg)	U (ppm)	Pb (ppm)	Th/U	^{204}Pb (pg)	Isotopic ratios ^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	Age (Ma) ^{207}Pb/^{206}Pb	± 1 σ abs.	% disc.
104-10-010-1A (dacite, Family Lake)												
1	4 best pink prisms	10.3	145	84	0.56	6	0.49552	12.8169	0.18759	2721.2	0.5	5.7
2	6 second best pink prisms	21.0	146	86	0.60	67	0.48644	12.6945	0.18927	2735.8	1.3	8.0
3	1 tiny tan prism	8.8	145	84	0.54	8	0.49668	12.9378	0.18892	2732.8	0.4	5.9
4	2 equant pink prisms	19.8	143	86	0.55	5	0.51564	13.4449	0.18911	2734.4	0.3	2.4
104-10-02-1A (quartz monzonite, Family Lake)												
1	4 tiny tan prisms	8.3	208	119	0.67	9	0.47921	12.2236	0.18500	2698.2	0.6	7.8
2	3 medium tan to brown prisms	17.8	221	131	0.76	11	0.49011	12.6225	0.18679	2714.1	0.3	6.4
3	1 large tan prism	12.1	220	151	0.89	95	0.52979	13.6360	0.18667	2713.1	0.9	-1.2
4	1 broken large tan prism	8.3	180	110	0.85	11	0.49221	12.6845	0.18691	2715.1	0.6	6.0
104-10-19-1A (hornblende tonalite, Fishing Lake)												
1	7 small best pink prisms	10.1	225	128	0.48	11	0.49740	12.8472	0.18733	2718.8	0.5	5.2
2	7 second best pink prisms	11.6	216	127	0.56	6	0.50603	13.1359	0.18827	2727.1	0.5	3.9
3	3 pink prisms	8.4	353	205	0.42	9	0.51616	13.2761	0.18654	2711.9	0.4	1.3
4	2 pink prisms	8.1	161	92	0.61	4	0.48663	12.5819	0.18752	2720.5	0.4	7.3
104-10-001-1A (granodiorite, Family Lake)												
1	2 pink 3:1 euhedral prisms	3.7	307	168	0.50	8	0.47325	12.0707	0.18499	2698.1	0.8	8.9
2	2 brown long prisms	3.3	603	300	0.59	17	0.41953	10.6606	0.18430	2691.9	0.6	19.1
3	4 brown prisms	1.7	1215	635	0.43	10	0.46029	11.7780	0.18558	2703.4	0.3	11.7
4	13 tiny tan to brown prisms	4.2	784	400	0.59	38	0.42854	10.9540	0.18539	2701.7	0.5	17.7

Abbreviations: abs., absolute error; disc., discordance relative to concordia

suggest that hornblende tonalite elsewhere in the Berens River area forms part of an older suite emplaced between 2740 and 2720 Ma, which is compatible with the results of this study.

Granodiorite

Granodiorite occurs in the southern half of the Family and Fishing lakes area. Its texture varies from homogeneous equigranular through seriate to porphyritic (Corkery et al., 2010). A sample of this granodiorite yielded zircons that range from small, elongate, brown prisms to euhedral, pink prisms. Based on U-Pb analysis of four zircon fractions, the interpreted crystallization age of granodiorite is 2705 ±36 Ma (Figure GS-2-5d). The larger age uncertainty associated with the sample makes it difficult to resolve the relationship of this granodiorite to supracrustal and other plutonic rocks in the area.

Economic considerations

By analogy to other Archean greenstone belts with abundant felsic volcanic rocks in the Superior Province, the Horseshoe Lake belt is considered to have at least notional potential for volcanogenic massive sulphide and orogenic gold mineralization. However, based on the results of previous exploration and reconnaissance mapping conducted as part of this project, this potential is considered to be low. Felsic volcanic rocks in the Horseshoe Lake area are locally altered (epidotized or silicified), and contain zones of pyrite enrichment up to 10%, but there are no reported occurrences of base-metal mineralization. As described above, the massive basalt flow that defines the top of the lower section of the homocline at Horseshoe Lake is associated with fracture-controlled chlorite-garnet and magnetite alteration (Figure GS-2-6a, b), which suggests at least local operation of a hydrothermal circulation system. Contact relationships with overlying sedimentary rocks also indicate a broadly synvolcanic timing for this alteration. However, two samples of the most strongly altered basalt collected in 2012 failed to produce any anomalous results. Historical samples collected from strongly recrystallized rocks along the southwestern margin of the belt have locally yielded anomalous gold values (Assessment File 92777), but follow-up diamond drilling failed to produce any results of economic interest (Assessment File 92091). Given the apparent absence of through-going structures in this area, the potential for orogenic gold mineralization is considered to be low.

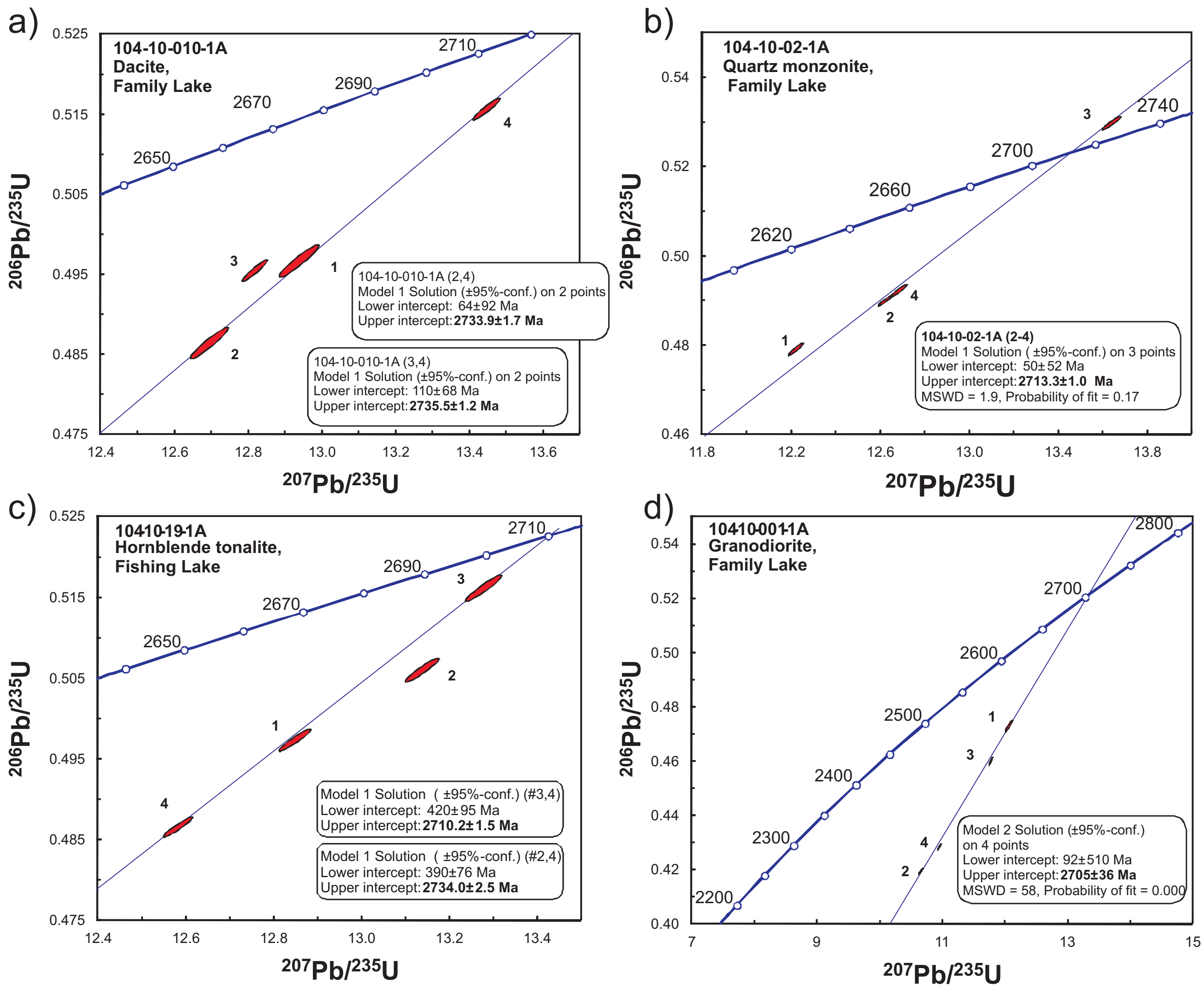

Figure GS-2-5: *U-Pb zircons geochronological results of rocks from the Family and Fishing lakes area, east-central Manitoba:* ***a)*** *dacite, Family Lake;* ***b)*** *quartz monzonite, Family Lake;* ***c)*** *Hornblende tonalite, Fishing Lake;* ***d)*** *Granodiorite, Family Lake. Error ellipses on Concordia diagrams are plotted at the 2σ uncertainty level.*

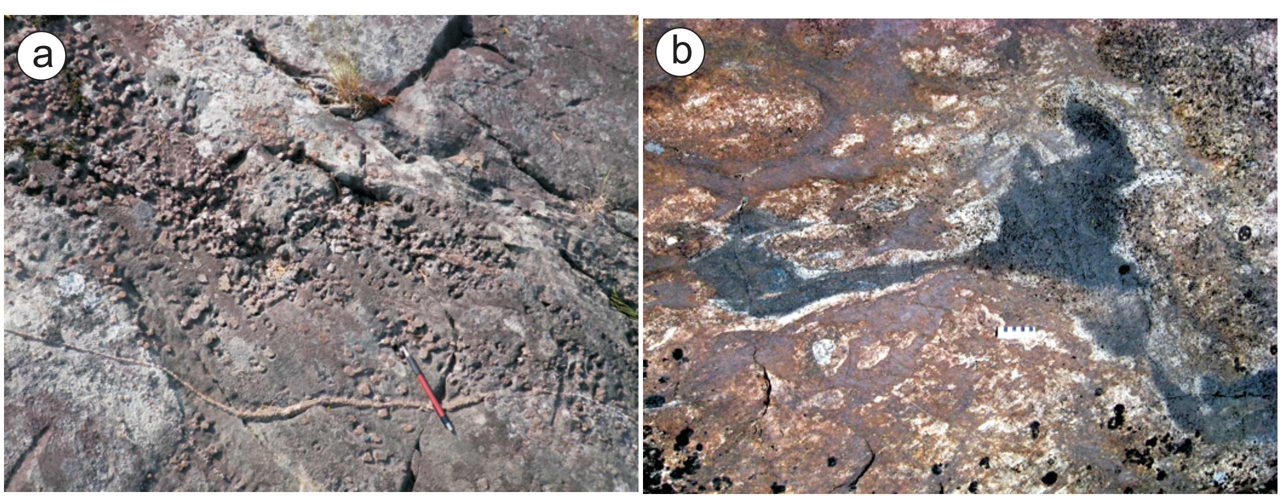

Figure GS-2-6: *Outcrop photographs of alteration associated with the basalt flow at the top of the lower section of the Horseshoe Lake homocline, southwestern shoreline of Horseshoe Lake, east-central Manitoba:* ***a)*** *large garnet porphyroblasts in irregular zone of intense chlorite-garnet alteration in flow breccia;* ***b)*** *irregular magnetite replacement in volcanic conglomerate in the footwall of the flow.*

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