Phelps Lake Project: Geology and Mineral Potential of the Keseechewun Lake–Many Islands Lake Area (parts of NTS 64M-9, -10, -15, and -16)

C.T. Harper, R.J. Wolbaum, S. Thain, M. Senkow, D. Weber, M. Gunning, and K. MacLachlan

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Abstract

The multiyear Phelps Lake Project continued in 2002 with 1:100 000 scale bedrock and surficial mapping and complimentary mineral occurrence studies in the Keseechewun Lake–Many Islands Lake area in the northeast part of the Phelps Lake map area (64M). This work identified the eastern continuation of potential Archean basement tonalitic and granitic migmatite complexes. Several smaller belts of dominantly mafic metavolcanic rocks, equivalent to the Archean Ennadai Group (ca. 2.71 to 2.6 Ga), occur in the western part of the area. Gneissic granite and tonalite, believed to be late Archean (ca. 2.6 to 2.55 Ga), intruded the migmatites and Ennadai Group rocks, but do not intrude the younger Hurwitz Group (ca. 2.45 to 1.9 Ga) supracrustal rocks. The Hurwitz Group is dominated by metasedimentary rocks and occupies two regional synclinoria in the east half of the area. The group comprises a lower pelitic sequence (correlated with the Ameto Formation), a middle carbonate sequence (correlated with the Watterson Formation), and an upper psammopelitic-pelitic sequence (correlated with the Ducker Formation). Ferruginous and copper-bearing pelites and thin zones of iron formation in the lower sequence make it more attractive for mineral exploration. Sills, dykes, sheets, and smaller plutons of generally massive, red to pink granite, leucogranite, and locally fluoritic granite and pegmatite represent a suite of late- to post-tectonic intrusions. Small-scale structures in Hurwitz Group pelites indicate that both northwest- and southeast-directed basement-cover detachment occurred during Trans-Hudson deformation as the group was squeezed between basement arches.

Mineral occurrences noted include: i) narrow zones of banded silicate-sulphide facies (quartz-garnet-amphibole-biotite-iron sulphides) and oxide facies (quartz-magnetite) iron formations in both Ennadai and Hurwitz groups; ii) disseminations of pyrite, pyrrhotite, and chalcopyrite in Ennadai Group mafic metavolcanic rocks; iii) structurally controlled pyritic quartz veins in metavolcanic rocks; iv) disseminated chalcopyrite and malachite coatings on fractures in Hurwitz Group ferruginous pelites; v) molybdenite in granite; vi) allanite±molybdenite± pyrite-bearing granitic and tonalitic migmatites; and vii) weakly pyritic quartz-tourmaline veins in granite. Rare earth elements are potential targets associated with late massive fluoritic granites, leucogranites and granite pegmatites.

Keywords*: Archean, migmatites, volcanic rocks, Paleoproterozoic, Hurwitz Group, pelites, marble, fluorite granites, deformation, metamorphism, mineralization.*

1. Introduction

Now in its third year, the Phelps Lake Project, in northeast Saskatchewan, (Figure 1) was designed to update the geological database and determine the mineral potential of this poorly understood corner of the province. This information will also be used to evaluate a proposed Representative Areas Network (RAN) site. During the summer of 2002, the multiyear program of 1:100 000 scale bedrock (Harper *et al.*, 2001, 2002a) and surficial (Campbell, 2001, this volume; Campbell and Harper, 2002) mapping of the northern half of the Phelps Lake map area, was continued, as was the evaluation of known mineral occurrences in 64M and newly discovered mineral occurrences from last year's mapping (MacDougall, 2001, this volume). Some of the latter occurrences were examined by M. Gunning during the latter part of the field season. In conjunction with the regional mapping, more detailed studies were undertaken in 2001 in part of the Archean Ennadai-Rankin greenstone belt (Coulson *et al.*, 2001) as well as a petrographic and geochemical study of mafic metavolcanic rocks at Bonokoski Lake (Rainville, 2002; Rainville *et al.*, 2002). Geochemical data derived from bedrock, till, and mineral occurrence sampling was released as Data File 21 in May 2002 (Harper *et al.*, 2002b). During 2002, M. Senkow investigated a rhodochrosite-manganite occurrence in carbonate rocks of the Hurwitz Group at Many Islands Lake for a B.Sc. thesis at the University of Regina.

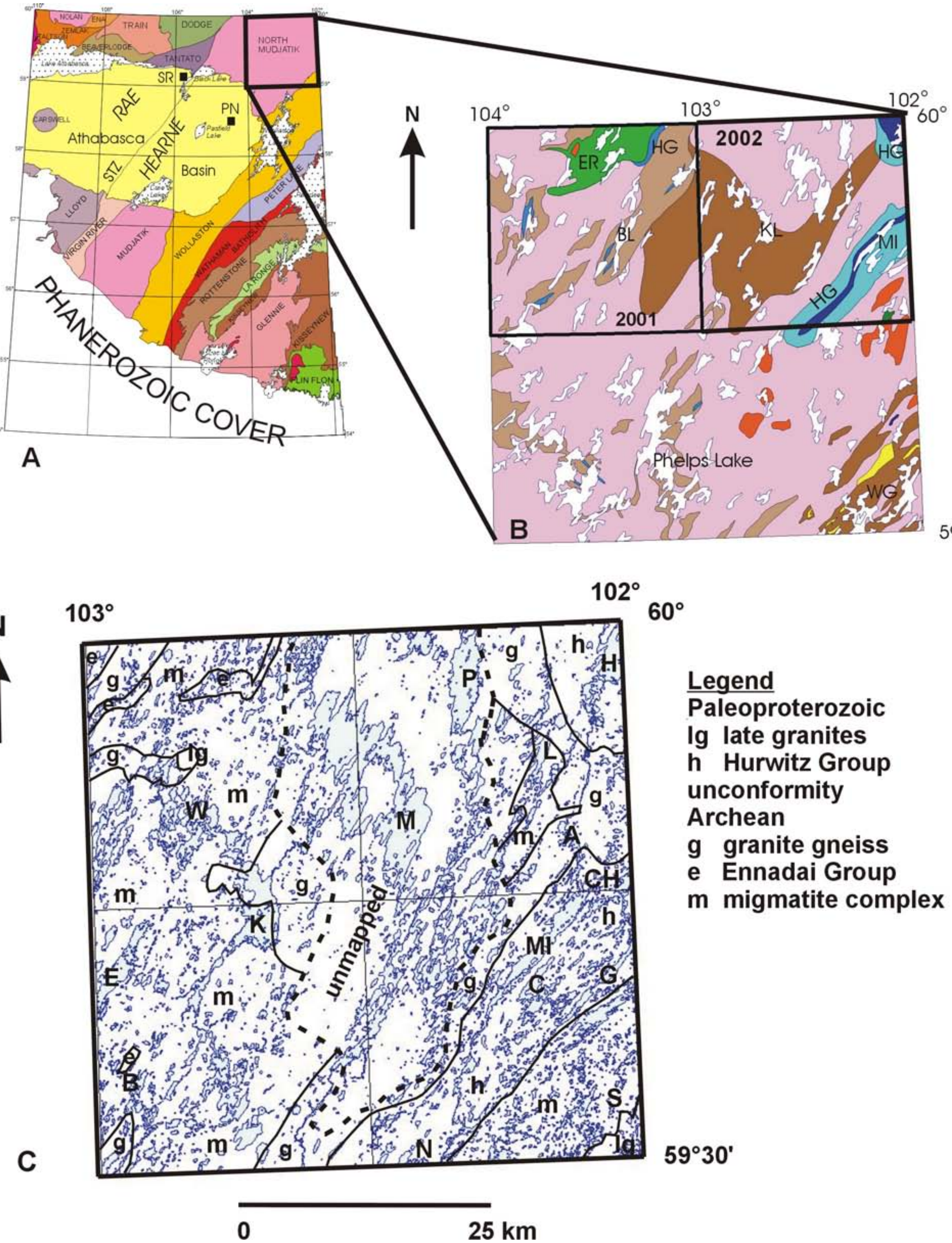

Figure 1 - Location and regional setting of the Phelps Lake Project area. A) Phelps Lake area with respect to domainal subdivision of northern Saskatchewan: STZ, Snowbird Tectonic Zone. Communities: PN, Points North Landing; SR, Stony Rapids). B) Regional geology of the Phelps Lake area showing areas mapped in 2001 and 2002: BL, Bonokoski Lake; ER, Ennadai-Rankin greenstone belt; HG, Hurwitz Group; KL, Keseechewun Lake, MI, Many Islands Lake; WG, Wollaston Group. C) General geology of the Keseechewun Lake–Many Islands Lake area. Lakes named in text: A, Archibald; B, Bakalar; C, Chobaniuk; CH, Chekask; E, Emerson; G, Grabowski; H, Hasbala; K, Keseechewun; L, Ledford; M, Misaw; MI, Many Islands; N, Nunim; P, Patterson; S, Spratt; and W, Warren.

In 2002 approximately 2100 km^2 was mapped in the northeast quarter of 64M, including parts of NTS map sheets 64M-9, -10, -15, and -16 and is referred to as the Keseechewun Lake–Many Islands Lake area. The centre of this area is located about 175 km northeast of Points North Landing and 190 km east-northeast of Stony Rapids and is accessible from either location by float- or ski-equipped aircraft. Fly-in fishing camps are located on Misaw and Hasbala lakes. The project was supported by a Beaver aircraft based at the Keseechewun Lake camp for eighteen days in August.

2. Previous Bedrock Mapping

The Geological Survey of Canada (GSC) completed one inch to four miles reconnaissance geological mapping of the Phelps Lake sheet in the late 1950s (Tremblay, 1960). The Saskatchewan Department of Mineral Resources carried out one inch to one mile geological mapping of the Hara Lake (part of 64M-1; Kays, 1972) and Many Islands Lake (part of NTS 64M-9; Munday, 1973) areas adjacent to Manitoba. The Saskatchewan Geological Survey (SGS) completed 1:100 000 scale reconnaissance mapping of the southeast (Lewry, 1983), southwest (Scott, 1986), and northeast (Reilly, 1989a, 1993a) quarters. Adjacent areas to the north were mapped by Taylor (1963) and Wright (1967) and to the east by Fraser (1962) for the GSC. The area to the east was also mapped by Weber *et al*. (1975) for the Manitoba Mineral Resources Division and was recently compiled at 1:250 000 scale (Manitoba Industry, Trade and Mines, 2000).

3. General Geology

The Phelps Lake area lies within the Hearne province, mainly in the northern Mudjatik Domain, but also includes part of the Wollaston Domain in the southeast corner. In the extreme northwest corner, mylonitic granites and amphibolites probably mark the southeast limit of the Striding-Athabasca mylonite zone (Hanmer and Kopf, 1993; Hanmer, 1997), which occurs on the Hearne side of the Snowbird Tectonic Zone (STZ). The STZ marks the boundary between the Rae and Hearne provinces.

The Phelps Lake area is largely underlain by presumed Archean granitoid rocks (ca. 3.3 to 2.6 Ga; see Aspler and Chiarenzelli, 1996 and references therein; Orrell *et al*., 1999), which might include an older basement component of various migmatitic orthogneisses (Harper *et al*., 2001). Archean volcanic and sedimentary rocks (ca. 2.7 to 2.6 Ga) of the Ennadai-Rankin greenstone belt (ERGB) are less abundant, occurring primarily in the northwest, but also in smaller pockets elsewhere (Figure 1). The ERGB extends over 700 km from northeast Saskatchewan to Rankin Inlet on Hudson's Bay. These rocks were intruded by ca. 2.8 to 2.6 Ga mafic to felsic plutons (Peterson and Lee, 1995; Peterson *et al*., 2000), that overlapped the volcanic activity and predated late Archean deformation and metamorphism at ca. 2.55 to 2.5 Ga (Davis *et al*., 2000b).

Paleoproterozoic Hurwitz Group metasedimentary rocks (ca. 2.4 to 1.9 Ga) occur throughout the area, being more widely distributed than previously indicated, whereas the partially time-equivalent Wollaston Group sedimentary rocks (ca. 2.1 to 1.9 Ga) are only known in the southeast. Paleoproterozoic gabbros, leucogranites, granites, and leucotonalites (ca. 1.85 to 1.75 Ga) intrude these rocks. The youngest rocks are west- and northwest-trending diabase dykes; the former possibly belonging to the ca. 2.19 Ga Tulemalu dyke swarm (Tella *et al*., 1997), and the latter, mainly defined by aeromagnetic trends, are probably related to the ca. 1.27 Ga McKenzie swarm.

The area has been affected by multiple thermotectonic events, including those related to the Trans-Hudson Orogen. The rocks generally exhibit amphibolite facies mineral assemblages, with a gradual increase from lower amphibolite facies in the northeast, to upper amphibolite, and locally granulite facies conditions, southwestwards.

As a result of the extensive glacial cover, bedrock exposure is generally poor, although pockets of better exposure occur locally, most commonly adjacent to some of the esker complexes. Topographic relief is generally 20 m or less producing a gently undulating terrain. Relief of 50 to 90 m from adjacent lakes and rivers to prominent hill tops is common, with the maximum relief being 130 m from Patterson Lake to the top of Arctic Butte. The majority of the highest hills are underlain by granitic rocks and they typically form very large crag and tail geomorphic features (Figure 2A). Enhanced bedrock exposures coincident with major esker systems (Figure 2B) are indicative of high-energy water flow rates which effectively removed much of the earlier sediment and till.

Felsenmeer, and slightly transported boulder fields (Figure 2C) are common. The angularity, large average size (typically 1 to 2 m across), predominance of a single rock type, and common association with felsenmeer, indicate that many of the boulders have not been transported very far, and thus these boulder fields can be used to map the underlying bedrock. Several rock types, notably the Archean mafic metavolcanics (garnet amphibolites) and Hurwitz Group marbles (Figure 2D), produce large glacial erratics and form easily recognized dispersion fans which can be traced back to source outcrops. Abrupt changes in the boulder composition (e.g., a change from metasedimentary rock to granite) were observed in many places and signaled the change in the underlying or nearby

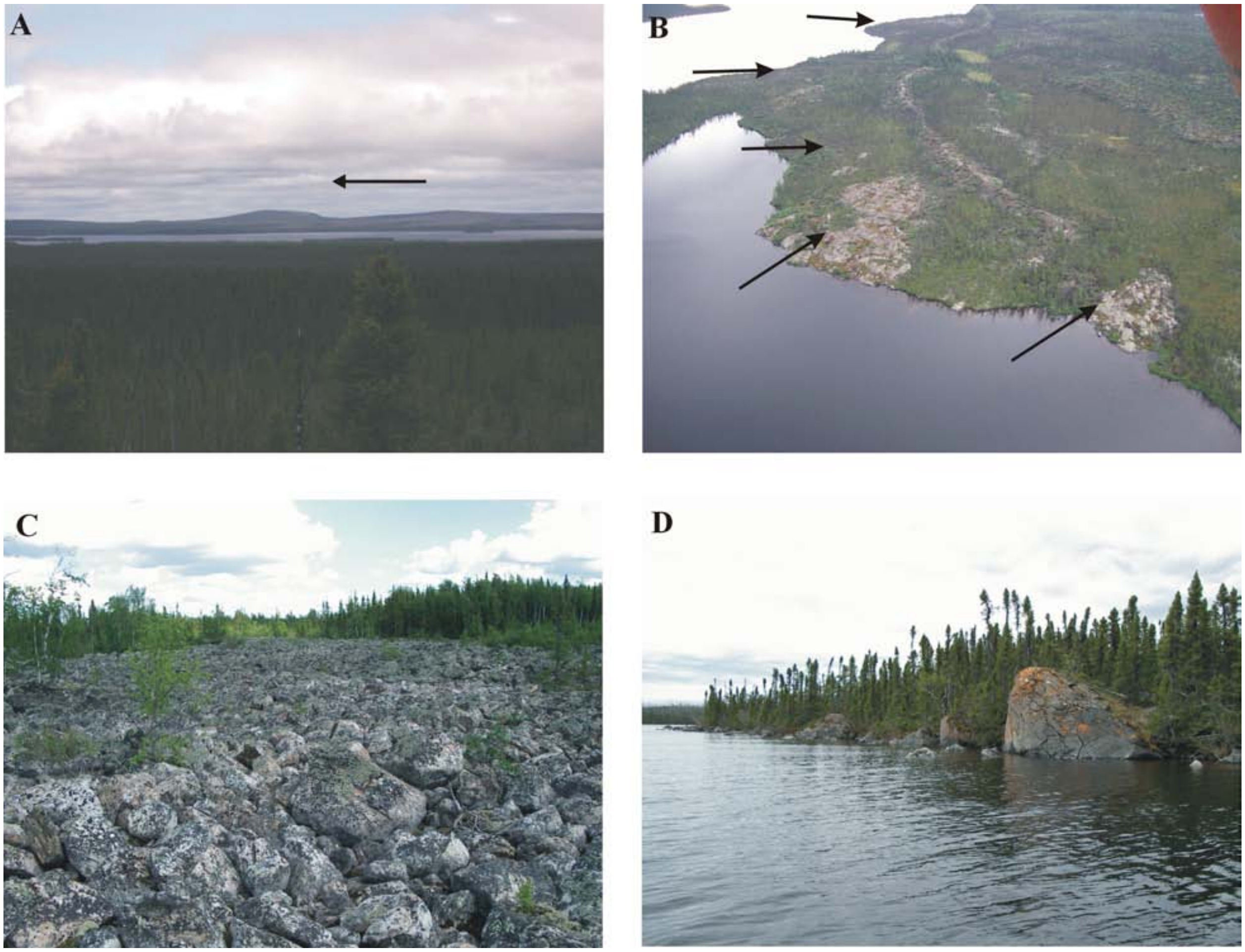

Figure 2 - Glacial features: A) looking southwest across Patterson Lake to Arctic Butte (left of arrow), a large crag and tail feature which rises 130 m above the lake; arrow indicates general direction of ice movement; B) esker system at Bakalar Lake with water swept outcrops (arrows) immediately adjacent to the esker; C) very large boulder field composed predominantly of foliated granite; and D) large Hurwitz Group marble erratics derived from local outcrop source, Many Islands Lake; largest erratic is about 5 to 6 m in height above lake level.

bedrock. Many of the areas underlain by granitic rocks are very poorly exposed, but have the most extensively developed boulder fields. These essentially monolithologic boulder fields differ from extensive, heterolithologic boulder-rich tills, which comprise a very diverse population of well-rounded, much-traveled boulders, some having been derived from sedimentary and volcanic rocks of the Dubawnt Group and other source terrains in the Northwest Territories (NWT) and Nunavut.

4. Geology of the Keseechewun Lake–Many Islands Lake Area

Rock units are essentially the same as found in the Bonokoski Lake area to the west, thus the reader is referred to Harper *et al.* (2001) for description of the major rock types.

a) Archean Rocks

As indicated by Harper *et al.* (2001), identification of the older basement rocks is speculative because of the lack of geochronological data, however, in the current area, such rocks are believed to be represented by the granitic and tonalitic migmatites. They form a possible basement to amphibolitic and psammopelitic gneisses correlated with the Ennadai Group. Together they are intruded by a variety of variably foliated granitoid rocks of presumed Archean age as well as younger, weakly to undeformed Paleoproterozoic intrusions.

Possible Basement Rocks

Granitic and tonalitic migmatites underlie a large part of the Keseechewun Lake–Many Islands Lake area, but separation into distinct units was hindered by their close association. They comprise multiple intrusive phases (also including diorite and granodiorite), are well foliated, commonly banded, display multiple folding events (Figure 3A), and tend to have higher magnetic susceptibility signatures than most of the younger granitoids and supracrustal rocks. Magnetite grains up to several millimetres in diameter are common and typically compose 1 to 3 percent of the rock, and locally compose up to 20 percent. The migmatites are typically biotitic, but hornblende is a more common constituent around Spratt Lake, in the southeast corner, where the rocks have a more granodioritic character. The migmatites locally contain abundant lenses, pods, or xenoliths of strongly foliated and folded paragneiss and orthogneiss. Centimetre- to metre-scale banding is produced by alternating mafic (hornblende and/or biotite) and felsic (granitic to tonalitic) layers. The origin of some of the banding is equivocal; as it may derive from paragneiss, orthogneiss injections, or metamorphic segregation. Allanite is a common accessory mineral in these banded gneisses and ranges from 1 to 10 mm in diameter and composes up to two percent of the rocks locally. Radiation haloes with radial fracture patterns are developed around some allanite grains.

The migmatites are intruded by veins and sheets and locally engulfed in well-foliated tonalitic to granitic rocks which also form mappable units in places. These rocks are considered Archean, because they do not intrude rocks of the Hurwitz Group (see Harper *et al.*, 2001). The **biotite tonalite gneiss** is a distinctive light-grey to white-weathering rock, which is more homogeneous than the migmatitic tonalite, and has less complicated folding (Figure 3B). Xenoliths and lenses of well-layered amphibolite which resemble the Ennadai Group amphibolites are common, especially near the margins of some of the intrusions. This white tonalite is a common intrusive phase in outcrops of the amphibolite unit.

The granitic rocks that intrude the migmatites include typically pink-weathering, fine- to coarse-grained **biotite granite, biotite leucogranite, augen granite, and granitic pegmatite**. Hornblende is a minor constituent. In addition to the sheets and dykes that intrude the migmatite complex (Figure 3C), these rocks form large plutonic bodies in the northwest, northeast, and all along the northwest margin of the belt of Hurwitz Group metasedimentary rocks trending southwesterly through Many Islands Lake. The granites are very strongly foliated to submylonitic and develop a rather slabby, finer grained character adjacent to the metasediments suggesting that a structural contact exists. In places these slabby granites have an apparent discontinuous compositional layering marked by increased biotite, which gives the rocks a more sedimentary appearance (i.e., feldspathic psammite). Munday (1973) had also commented on these same features, and had concluded that the rocks were tectonized granites. Granitic pegmatite is an integral part of this suite as it commonly occurs in the core of many granite veins/dykes, as gradational to sharp-walled veins in the larger granite bodies, and generally has the same structural fabric. The tightly to isoclinally folded and boudinaged pink granite–granite pegmatite veins/dykes are believed to belong to this intrusive suite. Quartz and quartz-tourmaline veins cut the granites (Figure 3D).

Ennadai Group

Supracrustal rocks in the Saskatchewan part of the Ennadai-Rankin greenstone belt are referred to as the Ennadai Group (Macdonald, 1984; Reilly, 1989b, 1993b; Harper *et al.*, 2001). Harper *et al.* (2001) documented higher metamorphic grade equivalents of the Ennadai Group in a number of narrow, discontinuous belts infolded with and flanked by the migmatite complex and late Archean granitoid rocks. These belts represent deeper structural levels of a once more extensive volcanic terrane. In the Keseechewun Lake–Many Islands Lake area, amphibolitic gneisses correlated with the Ennadai Group are likewise found as narrow discontinuous belts. They are most common in the west, in particular south of Keseechewun Lake and north of Warren Lake. Only a single outcrop was found in the east, south of Ledford Lake in NTS 64M-16, but it indicates the potential of more metavolcanic rocks being present beneath the glacial overburden.

The **amphibolitic gneisses** primarily represent mafic volcanic rocks. They are nearly ubiquitously spotted; the pink to white spots developing from garnet porphyroblasts that were variably replaced by symplectic intergrowths of plagioclase±hornblende, which formed by a partial to complete decompression reaction (*cf.* Mengel and Rivers, 1991). The original porphyroblasts ranged from 1 to 2 mm to 10 mm in diameter and composed up to 25 percent of the rocks (Figure 3E). The centimetre-sized porphyroblasts form a very distinctive rock type (Figure 3F), which has a pale green-weathering matrix in contrast to the typical black-weathering amphibolite. The dark red garnets in these rocks are replaced by a mixture of biotite, chlorite±amphibole, and rarely plagioclase. They are identical to rocks found along the east edge of the Bonokoski Lake area south of Bailey Lake (see Figure 5 in Harper *et al.*, 2001).

Banded amphibolite gneiss comprising millimeter- to decimeter-scale mafic, intermediate and felsic layers (Figure 3E) is interpreted as interlayered tuffs ranging from basaltic to rhyolitic in composition. Pale- to medium-green layers, patches, and zones consisting of various amounts of diopside, epidote, calcite, quartz, and plagioclase probably represent metamorphosed calc-silicate alteration. Disseminated pyrite±pyrrhotite±chalcopyrite are

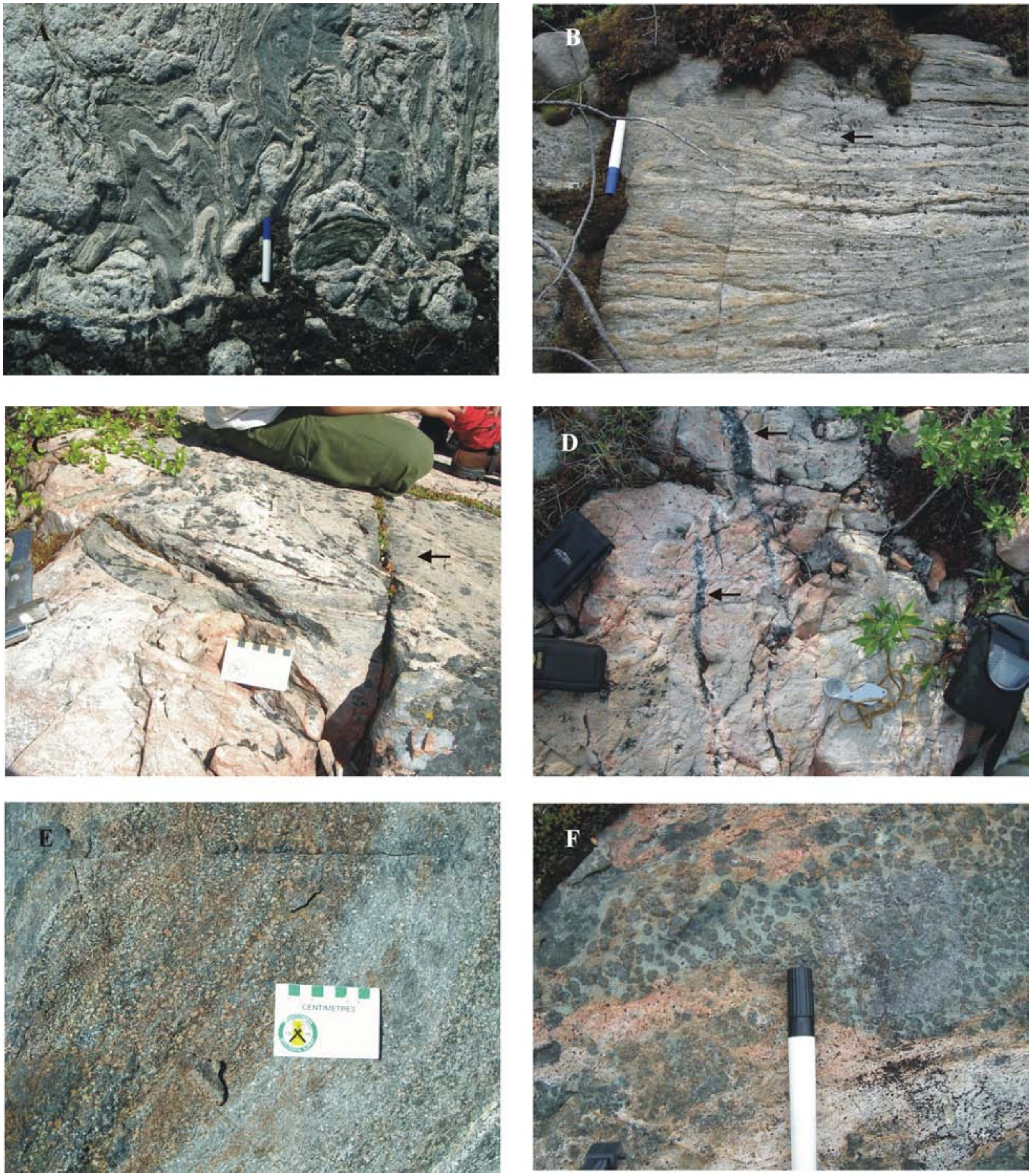

Figure 3 - Archean rocks: A) tonalite migmatite complex showing multiple orthogneiss phases, a mafic pod to the right of the felt marker (about 14 cm long), and complex folding; B) white weathering, homogeneous tonalite gneiss with leucotonalite leucosome veins and more simple Z fold (arrow) (looking east at subvertical rock face); C) pink well-foliated leucogranite with large folded tonalite migmatite xenolith; D) *en echelon* ***quartz-tourmaline veins (arrows) cutting pink biotite granite (Palm pilot case is 13 cm long); E) garnet-spotted mafic and intermediate metavolcanic rocks of Ennadai Group; many of the garnets have rims of plagioclase+hornblende; and F) garnet porphyroblasts, up to one centimetre in diameter, partially replaced by biotite and chlorite in mafic metavolcanic rock also cut by pink granitic veins (felt marker about 14 cm long).***

commonly associated with these zones and elsewhere in the amphibolites, and produce patchy to more pervasive iron staining. Quartz veining is common in these rocks.

Locally the amphibolites are interlayered with iron formation and psammopelitic gneiss. In outcrop the **iron formation** consists of 1 to 2 m thick zones of strongly oxidized pyrite- and pyrrhotite-bearing silicate facies rocks with alternating quartz-rich and silicate mineral-rich layers. Biotite, amphibole, diopside, and garnet are the common silicate minerals. Chalcopyrite and magnetite are rare accessory minerals. **Psammopelitic gneiss** typical of those included in the Ennadai Group (Harper *et al*., 2001) was found in the area north of Warren Lake, and west of Bakalar Lake. The northern occurrence is mainly represented by abundant boulders and at least one area of felsenmeer. These weakly graphitic rocks are weakly rusty weathering, and contain boudinaged and folded quartz veins. West of Bakalar Lake a leucosomal-rich psammopelite represents an eastward continuation of similar rocks west and south of Emerson Lake.

Minor Intrusions

Mafic dykes and/or sills occur sporadically in the migmatite complex and a single ultramafic intrusion was found in the mafic volcanic rocks. The **mafic intrusions** are typically hornblende-plagioclase rocks of gabbroic composition. They are black on fresh and weathered surfaces, medium grained, equigranular, well foliated, and less than 50 cm thick. They are commonly strongly boudinaged and dismembered to the point of being unrecognizable as dykes. They are considered to be Archean because of their state of deformation and they are not found in the Hurwitz Group. A **serpentinized metaperidotite** intrusion occurs in the outcrop of mafic metavolcanic rocks south-southeast of Ledford Lake. It is brown weathering, black on fresh surfaces, and strongly magnetic. Magnetite replaces the host rock along irregular fractures/veins in the rock. It is interpreted as a syn-volcanic intrusion, and, therefore, Archean in age.

b) Paleoproterozoic Rocks

Paleoproterozoic rocks in the Keseechewun Lake–Many Islands Lake area include the metasedimentary rocks of the Hurwitz Group and a suite of younger granitoids related to the Trans-Hudson Orogen. Weakly defined northwest-trending magnetic linear features may represent the 1.27 Ga (LeCheminant and Heaman, 1989) Mackenzie dyke swarm.

Hurwitz Group

The Hurwitz Group occurs in two main synclinoria; one surrounds Hasbala Lake in the northeast corner and the other extends southwestward for 45 km from the Manitoba border to Nunim Lake at the south edge of the map area. These were defined by previous mapping (Tremblay, 1960; Munday, 1973; Reilly, 1989a, 1993a), and were not extended any further during the current mapping. A single outcrop of Hurwitz type calc-silicate rocks was found north of Warren Lake in the northwest. Local concentrations of Hurwitz Group boulders may point to subcrop beneath the glacial overburden.

The Hurwitz Group comprises (from apparent oldest to youngest): 1) non-magnetic pelites and magnetic ferruginous pelites with intercalated calcareous pelite, psammopelite, minor iron formation, cherty quartzite, calcareous chert breccia, and felsic volcanic rocks; 2) marble and calc-silicate rocks; and 3) psammopelite-pelite with intercalated psammite, calcareous psammopelite, and calc-silicate. Although typically rounded boulders of quartz arenite, quartz pebble conglomerate, and polymictic conglomerates, which are characteristic of the lower sequence of the Hurwitz Group (Aspler *et al.*, 1992), occur in the till, none of these rock types were observed in outcrop. Metamorphic grade is generally lower amphibolite facies, in contrast to the Bonokoski Lake area where granulite facies conditions were reached in the southwest. Most of the areas underlain by the Hurwitz Group correspond to sharply defined aeromagnetic lows (Carson *et al*., 2001a, 2001b) with the exception of the ferruginous pelites and intercalated iron formation producing linear magnetic highs.

The lower **pelitic sequence** weathers brown, to light grey to tan which belie the ubiquitous black of fresh surfaces. Some exceptionally black varieties may be derivatives of carbonaceous mudstones. The ferruginous pelites have patchy to pervasive rusty weathering. Magnetite-rich layers are blue black. Where the pelites are interlayered with calcareous pelites or calc-silicate rocks they are banded black and green. Interlayers of psammopelite and psammite produce lighter colour banding. The pelites, psammopelites, and psammites are all very fine grained, finely laminated to thinly bedded, and also well foliated and become phyllitic with increasing deformation. Pelites between Chobaniuk and Grabowski lakes contain elongate, inclusion-rich cordierite porphyroblasts up to 2 cm in length and 1 cm wide, which are best seen on weathered foliation surfaces. Millimetre-sized garnet porphyroblasts are a rare constituent. Highly disrupted and folded quartz veins are common in this lower pelitic sequence (Figure 4A). Besides bedding, primary sedimentary structures preserved locally include cross laminae and graded bedding. A distinctive, black and white mottled, pelitic breccia crops out on the east side of Archibald Lakes in the hinge of a

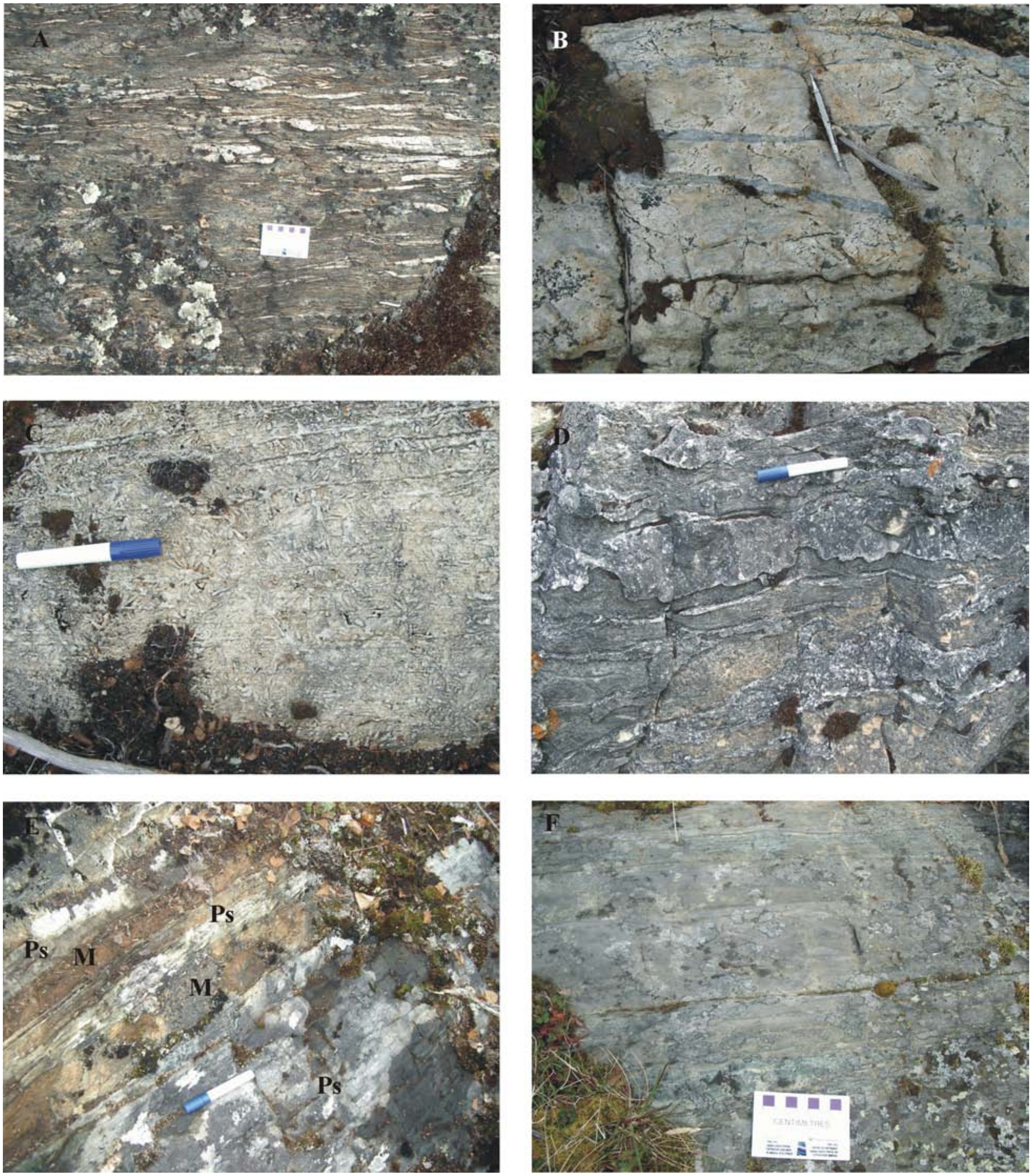

Figure 4 – Hurwitz Group rocks: A) ferruginous pelite unit with abundant folded and boudinaged quartz veins; B) vaguely layered cherty quartzite with several quartz veins (pencil magnet is 14 cm long); C) dolomitic marble with wollastonite rosettes overprinted by phlogopitic-rich foliation surfaces (marker is 14 cm long); D) interlayered pale brown-weathering, recessive marble and pale green resistant calc-silicate rocks; note development of boudin necks in calc-silicate layer; E) interlayering of marble (M) and psammopelite (Ps) (upper left half of photo) at transition from Watterson Formation to Ducker Formation; and F) finely laminated and graded bedding in upper psammopelitic unit on island in north central Many Islands Lake; note lack of quartz veining.

large, open, north-trending, south-plunging synform. The quartz- and calcite-veined pelite is intensely brecciated and folded and has a later calcareous cement. The brecciation decreases away from the hinge zone. Overlying cherty quartzite layers have a well-developed cleavage.

The **ferruginous pelites** typically contain up to 10 percent very fine-grained disseminated magnetite and locally contain pyrite or pyrrhotite instead of magnetite. In a few places banded cherty magnetite iron formation or pyritic silicate facies iron formation is developed over a metre or two. Centimetre-scale hornblende-rich layers in these rocks commonly have trace disseminations of chalcopyrite and malachite coatings on weathered and fracture surfaces.

Cherty quartzite and calcareous chert breccia occur near the southwest end of Archibald Lakes, within a sequence of non-magnetic pelites. The white- to pale-pink weathering, very fine-grained quartzite has vague layering (Figure 4B), and in places resembles rhyolite. It is interlayered with a calcite-cemented chert breccia, as well as pelites and psammopelites in a zone about 30 m wide. The chert breccia has a white to light grey, rough-weathered surface from the resistant cherty material and recessive carbonate matrix. Fragments or clasts of the chert are angular to subrounded and range from 1 to 10 cm in length. In addition, cherty quartzite also outcrops on the east side of Archibald Lakes where the pelitic breccia occurs. In this same outcrop, a light grey-weathering, fine-grained, **feldspar phyric felsic (rhyolite) volcanic** lies structurally above the cherty quartzite, but contacts are not exposed. The felsic volcanic is massive and thus could be either a flow or high-level intrusive sill. This rock was sampled for possible future geochronological studies.

Marble and calc-silicate rocks occur along Many Islands Lake, in several zones southeast of Many Islands Lake, and west of Hasbala Lake. They are commonly interlayered to some extent, which produces a ribbed weathered surface, with the silicate-rich layers being more resistant. The marbles weather pale brown to tan to white and light grey, but are almost exclusively white on fresh surfaces. They are generally medium to coarse grained, layered, and well foliated. They are both calcite and dolomite bearing and contain a variety of silicate minerals including: quartz, diopside, phlogopite, wollastonite, tremolite, and possibly idocrase and scapolite (Figure 4C). At the southwest end of Many Islands Lake, pink rhodochrosite and black metallic manganite occur in several large erratics and in a nearby outcrop believed to be their source. The colour of these rocks reflects the constituent silicate minerals, for instance pale brown for phlogopitic varieties, or pale green for diopsidic ones. Wollastonite and tremolite typically form elongate lath-like crystals, in sheaf or rosette clusters that show random orientation relative to layering and foliation (Figure 4C). They range from a few millimetres to several centimetres in length. In places, a phlogopitic fabric truncates earlier formed silicate crystals. Quartz veining is also common in the marbles, and as in the pelites, boudinage and folding of the veins is characteristic.

Calc-silicate rocks associated with the marbles are generally white to pale green, coarse grained, and composed predominantly of diopside, quartz, and minor plagioclase and calcite. Where calc-silicate rocks predominate, they tend to be greener and alternate with millimetre- to centimetre-scale brown to light to dark grey pelitic (?) interlayers. Interlayered carbonate layers are typically tan to light brown weathering (Figure 4D). The fine layering preserved in some outcrops may be an indication of algal laminations or less likely stromatolite development, which are well preserved in some areas in Nunavut (Aspler *et al*., 2001). The transition to the overlying psammopelitic unit is marked by a 1 to 2 m wide zone of interlayering of the two units (Figure 4E).

The "upper" **psammopelitic-pelitic-psammitic** sequence occurs in the core of several synformal folds between Many Islands Lake and Grabowski Lakes as well as at the north end of Hasbala Lake. These rocks tend to show the best preservation of primary sedimentary structures (e.g., cross laminae, graded bedding, channel scours), and have significantly less quartz veining than the lower pelitic sequence (Figure 4F). They are light grey to brown grey weathering, but typically are black on fresh surfaces. Calc-silicate layers are pale yellow green to green on weathered and fresh surfaces and comprise various amounts of epidote, diopside, actinolite, quartz, calcite, and plagioclase. Black 'slaty' pelite (mudstone) occurs on the peninsula in the northwest part of Hasbala Lake.

Munday (1973) used the term Many Islands Belt when describing these metasedimentary rocks, and concluded that they were equivalent to the Hurwitz Group as defined by Bell (1970) at nearby Kasba Lake, just across the border in the NWT and continuous with rocks at Hasbala Lake in Saskatchewan. Munday (1973) also speculated whether these rocks were equivalent with the Hidden Bay assemblage (Wallis, 1971) in the upper part of the Wollaston Group. Later, the term Many Islands group (Lewry, 1983) was used informally to refer to the same metasediments and became entrenched in the literature. Lewry stated there was no obvious correlation between the Hidden Bay assemblage and the Many Islands group. Reilly (1989a, 1993a) chose to refer to the rocks as Hurwitz Group and correlated the pelitic sequence with the Ameto Formation and the marble and calc-silicate rocks with the Watterson Formation as defined in Nunavut (Aspler *et al*., 1992). The Hurwitz Group designation is used in this study, and a younger psammopelitic-pelitic unit above the Watterson Formation carbonate rocks, is equated with the Ducker Formation (Aspler *et al*., 1992).

The Ameto Formation marks the end of deposition of the lower Hurwitz Group and is constrained by an age of 2.11 Ga (Heaman and LeCheminant, 1993) obtained from gabbro sills, which intrude the Ameto Formation. The Watterson Formation is the lowermost formation of the upper Hurwitz Group (Aspler *et al*., 1992). Recent detrital zircon geochronological studies of the Hurwitz Group (Davis *et al*., 2000a) have shown that the Watterson, Ducker, and Tavani formations were deposited ca 1.9 Ga almost 200 million years after deposition of the lower Hurwitz Group. In general, the transition from lower to upper Hurwitz Group is reported to be disconformable, as would appear to be the case in the Keseechewun Lake–Many Islands Lake area.

Paleoproterozoic Intrusive Rocks

Two periods of granitoid plutonism have been recognized in the Hearne province in Nunavut; the Hudson granitoids (ca. 1.85 to 1.81 Ga) and the Nueltin suite (ca. 1.76 to 1.75 Ga) (Peterson *et al*., 2000). Minor intrusions including mafic to felsic dykes and sills cover a similar time span (*ibid.*), and the still younger Mackenzie diabase dykes were emplaced ca. 1.27 Ga (LeCheminant and Heaman, 1989). Although no rocks were observed that showed intrusive relationships with Hurwitz Group rocks in the Keseechewun Lake–Many Islands Lake area, intrusive rocks assumed to be Paleoproterozoic comprise generally massive, pink- to red-weathering leucogranite and granite pegmatite; coarse-grained to porphyritic, typically fluorite-bearing, biotite granite and monzogranite; and an unusually strongly foliated hornblende-biotite granodiorite. Two massive felsites, interpreted as high-level intrusions, were noted during the current mapping. Reilly (1993a) mapped a massive diabase dyke apparently intruding Hurwitz Group rocks west of Hasbala Lake. This could be a Mackenzie dyke, but it was not relocated.

The **leucogranite and granite pegmatites** typically occur as veins, dykes, sills and small irregular intrusions within the basement complex, only a few of which are large enough to indicate on the map. Tiny biotite flakes compose less than one percent of the rock. A weak foliation is developed locally, suggesting that these intrusions might be part of the Hudson suite. The pegmatites typically show some zonation, with quartz and feldspar grains growing perpendicular to the dyke/vein walls and passing inwards to a coarser interlocking mosaic of quartz and K-feldspar. One of the **felsite** intrusions occurs as dykes up to 40 cm wide within a small stock of fine-grained, massive, dark pink leucogranite 3 km east of north Patterson Lake (Figure 5A). The aphanitic felsite is buff weathering, light grey on fresh surfaces, and has conchoidal fracture. The other felsite is in the strongly foliated, pink biotite granite–leucogranite of the basement complex along the northwest flank of the Hurwitz Group about 4 km west of central Many Islands Lake. The red-weathering, aphanitic felsite forms an irregular-shaped body at least 30 m long, and displays gently arcing, subvertical, columnar-style joints (Figure 5B), that exhibit chisel marks on the joint surfaces (Figure 5C).

Fluorite-bearing granites and monzogranites crop out in the southeast around Spratt Lake and between Spratt and Nunim lakes. Two other fluoritic granite plutons are located just across the border in Manitoba (Weber *et al*., 1975); the one at Chekask Lake apparently intrudes the Hurwitz Group. Four similar intrusions located in adjacent Nunavut all yielded U-Pb zircon ages of ca. 1.76 to 1.75 Ga (Peterson and van Breeman, 1999), typical of the Nueltin Suite. Therefore, the fluoritic intrusions around Spratt Lake are believed to be part of the Nueltin Suite. At Spratt Lake these rocks are pink to light grey, medium to coarse grained to porphyritic, massive (Figure 5D), and have several prominent joint sets, the most notable ones being subhorizontal (Figure 5E) and vertical. Biotite is in clusters up to 1 cm in diameter, and composes from 10 to 20 percent of the rock. Quartz is generally grey to dark grey and ranges from 20 to 25 percent. Phenocrysts of both potassium feldspar and plagioclase 1 to 2 cm long compose 10 to 30 percent of the rock. Fluorite generally occurs as millimetre-sized, interstitial grains having pink to purplish colouration. It is slightly coarser in the porphyritic variety and locally composes up to 3 percent of the rock. Pegmatite dykes or sills intrude these rocks.

Strongly foliated **hornblende-biotite granodiorite** occurs north of Warren Lake. It is pink to grey on fresh and weathered surfaces and contains abundant ragged mafic streaks which probably represent incompletely melted amphibolite xenoliths. This rock also contains well-foliated amphibolite xenoliths which are composed of high-grade metamorphic assemblage and calc-silicate type alteration (Figure 5F) characteristic of the Ennadai Group mafic volcanic rocks. The age of this granitoid is uncertain, but it must post-date formation of the foliation and metamorphism in the amphibolite. The strong deformation in the granodiorite suggests that it is pre-Trans-Hudson; therefore, it could range from pre-Hurwitz (ca 2.45 Ga) to the Hudson granitoid period (ca 1.85 to 1.81 Ga).

5. Structure

The Phelps Lake region had a complex structural history, which as proposed by Harper *et al*. (2001), likely involved both Archean and Paleoproterozoic events. A tentative geological history is summarized in Table 1. Several key outcrops examined this year have helped solidify the history, but also indicate potential for revision and the need for geochronological data to constrain the timing of some events. To distinguish these different events, proposed Archean events will be prefixed by ‘A’ (e.g., AS0, AS1), and Paleoproterozoic events by ‘P’ (e.g., PS0, PS1).

Figure 5 – Late intrusive rocks: A) part of felsite (Fel) dyke intruding late, massive pink granite (under pencil), contact is parallel to and about 2 cm below pencil (about 17 cm long); B) cliff exposure of red-weathering felsite showing curved columnar-like joints, arrow points to approximate location of Figure 5C; C) faint arcuate lines (arrow) on joint surface resemble chisel marks found on columnar jointed lavas; D) massive, coarse-grained fluoritic granite outcrop on east shore of Spratt Lake; E) sub-horizontal joints in fluoritic granite are well defined on cliff face at top of hill south of Spratt Lake; and F) exceptionally xenolithic, and well-foliated hornblende-biotite granodiorite with a large rotated block of well-foliated, upper amphibolite facies mafic volcanic; note the smaller fragments (arrow) that have broken away from main xenolith and the high-degree of assimilation of mafic xenoliths into the granodiorite (marker is about 14 cm long).

Table 1 - Tentative geological history of the Phelps Lake region.

1.27 Ga	Mackenzie diabase dykes	
	Late north-trending brittle faults of the Tabbernor the Fault system Late northwest-trending brittle faults Northeast-trending brittle faults	
1.77 to 1.75 Ga	Felsite Leucogranite, fluoritic granite-monzogranite, granite pegmatite Leucotonalite	
1.85 to 1.8 Ga	Trans-Hudson Orogen; Granite, granodiorite leucotonalite	(D5 deformation) (D4 deformation, M4 metamorphism ?) (D3 deformation, M3 metamorphism)
2.0 to 1.9 Ga	? Taltson - Thelon Orogen ? Wollaston Group deposition Upper Hurwitz Group deposition	(?D3 deformation, M3 metamorphism)
~~	Disconformity ~~~~~~	
2.45 to 2.1 Ga	Lower Hurwitz Group deposition	
~~	Unconformity ~~~~~~	
2.55 to 2.5 Ga	(D2 deformation and M2 metamorphism)	
2.65 to 2.6 Ga	Granite, leucogranite, tonalite	
2.71 to 2.65 Ga	Ennadai Group volcanism, sedimentation Early gabbroic to granodiorite intrusions	
~~	Unconformity ~~~~~~	
3.3 to 2.8 Ga	(D1 deformation, M1 metamorphism) Granitic and tonalitic basement, amphibolite	

The granitic and tonalitic migmatite complexes have composite fabrics derived from several superimposed deformational events. One outcrop in particular, 1 km south of Keseechewun Lake, illustrates this relationship. The well-foliated tonalite migmatite is intruded by several pegmatite veins (Figure 6A). The oldest pegmatite vein (P1) cuts the foliation, which is probably a composite fabric (e.g., AS1/AS2) derived from isoclinal folding of an earlier fabric and emplacement of leucotonalite leucosome veins. The P1 pegmatite was then tightly folded and an axial planar fabric developed, possibly during northwest-southeast compression (present coordinates), with the older foliation being transposed into the new axial planar fabric (?AS3).

A younger pegmatite vein (P2) intrudes this composite fabric and early pegmatite (but may be a later stage of the same event as P1) and is also folded by northwest-southeast compression (Figure 6A), but into more open folds, with an axial plane essentially the same as the earlier one. A weaker fabric (?PS1) is developed in the hinge zones of these folds, thus the resulting foliation in the tonalite is a composite of at least three or four events. This younger pegmatite also shows dextral offset along parts of the limbs of the folds indicating a shear component. Adjacent to these two pegmatites, another pegmatite is emplaced nearly parallel to the composite fabric. The pegmatite is boudinaged and the boudins back rotated (Figure 6B) documenting dextral shear parallel to the foliation. Unfortunately, the timing of the folding events is uncertain as they could be both Archean, or Archean and Paleoproterozoic, or even both Paleoproterozoic.

On this same outcrop, a section of banded migmatite displays dome-and-basin–style interference folds (Figure 6C) and also shows effects of the sinistral shearing. The interference folds are developed on west-northwest– and north-trending axial planes, neither of which develops a new fabric. These fold axes are characteristic of fold trends developed during the Trans-Hudson deformation. The small-scale folds are probably also a reflection of the regional-scale structures.

Deformation in the Ennadai Group metavolcanic and metasedimentary rocks is considered to have occurred near the end of the Archean (ca. 2.6 to 2.5 Ga) overlapping the period of voluminous granite and tonalite emplacement (see Harper *et al*., 2001). The fabric developed at that time is believed to be AS2. There is evidence elsewhere in the Ennadai-Rankin greenstone belt (Nunavut) for two late Archean deformation events (Park and Ralser, 1992); however, this is difficult to recognize in the Phelps Lake region.

Bedding (PS0), layer-parallel foliation (PS1), and early quartz veins in Hurwitz Group rocks are tightly to isoclinally folded about northeast-trending axial planes (Figure 6D). Continued northwest-southeast compression related to the Trans-Hudson Orogen apparently caused basement-cover shearing along the base of the Hurwitz Group. This period of deformation formed crenulation folds and locally a crenulation cleavage. Along the southeast margin of the Many Islands belt, the crenulation folds have northwesterly dipping axial planes and sub-horizontal axes (Figure 6E). The southeasterly verging crenulation folds and large drag fold along the margin, indicate southerly directed fold-related detachment. This contrasts with other areas in the belt where crenulation folds are also developed, and the axial planes dip southeasterly suggesting a northwest sense of movement. The same is true for the Hasbala Lake synclinoria. Along the western margin, crenulation folds and large drag folds indicate northwest directed detachment, whereas along the southern margin a single outcrop shows the Hurwitz Group is

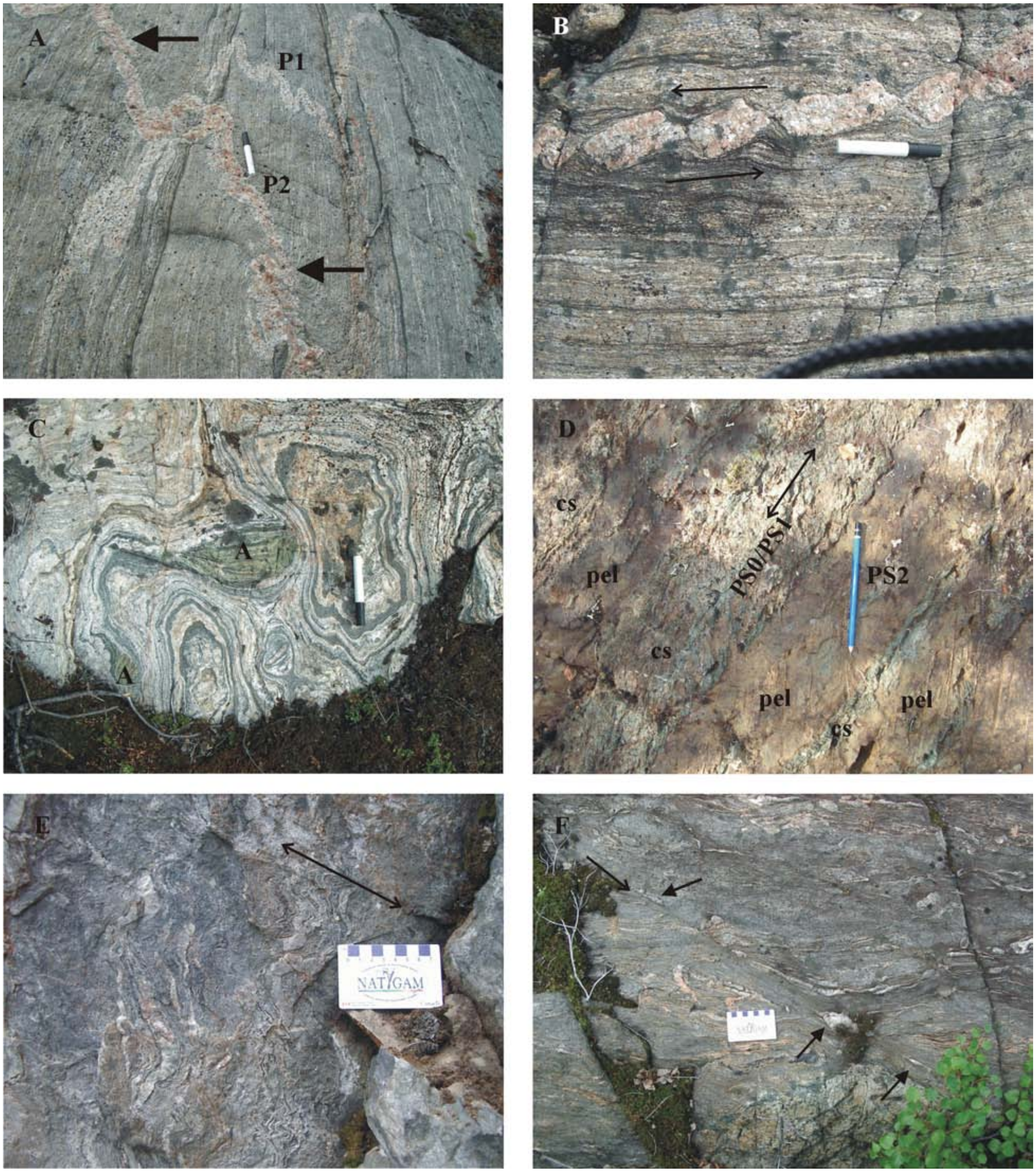

Figure 6 – Structural features: A) composite fabric developed in leucosome-veined tonalite migmatite intruded by a tightly folded early granite pegmatite (P1) and refolded after a younger granite pegmatite (P2) was intruded; arrows point to dextrally sheared limbs of P2; B) boudinaged and back-rotated granite pegmatite indicates dextral shear sense parallel to foliation; C) dome-and-basin–style interference folds developed in banded migmatite, note highly dismembered amphibolite layer (A); D) structural relationships demonstrated in interlayered Hurwitz Group pelite (pel) and calc-silicate rocks (cs) in hinge zone area of northeast-trending (indicated by pencil and PS2 fabric) regional synformal fold; E) looking southwest at vertical face of crenulated ferruginous pelitic schists; double arrowed line indicates northwest-dipping axial plane of crenulation folds, which refold isoclinally folded quartz veins; and F) east-trending tension shear (open arrow) with discontinuous quartz veins (solid arrows) disrupting crenulated ferruginous pelitic schist.

transported southerly over the basement granites. Reilly (1993a) had only observed structures which he interpreted to indicate northwest thrusting. The opposing directions of movement documented here might have formed from the outward flow of Hurwitz Group rocks as they were progressively squeezed between rigid basement arches. The two Hurwitz synclinoria are separated by a basement arch composed mainly of the presumed late Archean granite-leucogranite unit.

A subsequent east-west compressional event is responsible for open north-trending, shallowly, south-plunging folds best developed north of the north end of Many Islands Lake. Elsewhere this event is indicated by subvertical, delicate north-trending quartz stringers best developed in the marbles and calc-silicate rocks. Also related to this event are narrow, east-trending, partially quartz vein-filled, discontinuous, tension gash/shear zones in the pelitic units (Figure 6F).

Late brittle faults have northeast, northwest, and north trends. Northeast-trending faults are very difficult to identify because of pervasive southwest-trending glacial fabric. Northwest- and north-trending linear topographic features and rare cliff faces are good evidence for those fault systems. North-trending faults of the Tabbernor fault system are marked locally by cliffs and low magnetic linear features which truncate the normal magnetic signature. Northwest-trending faults may have provided a locus for emplacement of the ca. 1.27 Ga Mackenzie dykes.

6. Metamorphism

Metamorphic grade varies from lower to middle amphibolite facies in the Hurwitz Group to middle to upper amphibolite facies in the various basement components. The tonalitic and granitic migmatite complexes record an early period of Archean high-grade metamorphism attaining melting conditions, which produced the abundant leucosomal veins in these rocks. The Ennadai Group supracrustal rocks and contemporaneous granitoids also show evidence of having attained melting conditions. Growth of garnet porphyroblasts in the mafic metavolcanic rocks post-dates development of the foliation in these rocks, but it is not clear whether this is a late Archean or Paleoproterozoic event. The subsequent conversion of the garnets to plagioclase and hornblende symplectites results from a decompression reaction (*cf.* Mengel and Rivers, 1991) during progressive uplift presumably following the Trans-Hudson Orogen.

Metamorphic grade in Hurwitz Group rocks is defined by blue-green hornblende, rare garnet, and cordierite in the pelitic rocks and by diopside, wollastonite, and phlogopite in the marbles and calc-silicate rocks. The formation of cordierite signaled a change from lower amphibolite to middle amphibolite facies (Winkler, 1976) as does the formation of wollastonite in the carbonate rocks. There is no evidence of melting in Hurwitz Group rocks. A lower amphibolite facies overprint of the basement rocks is indicated by the presence of blue-green hornblende in most rock types. Late stage sphene is also common in the mafic rocks. The late granitoids don’t show evidence of undergoing any metamorphism, but do show effects of deuteric alteration.

7. Mineral Occurrences and Potential

Very few mineral occurrences are documented, but very limited mineral exploration has been carried out. Known occurrences comprise base metals in Hurwitz carbonates and Archean supracrustal gneisses, radioactive pegmatites and allanite-molybdenite in granitic migmatite, rhodochrosite in Hurwitz carbonate, and fluoritic granites (Munday, 1973; Reilly, 1993a; Saskatchewan Industry and Resources (SIR) Mineral Assessment Files; MacDougall, this volume). The most notable of these is the Ledford Lake base metal occurrence where 16 diamond drill holes were completed by Saskoba Mines Inc. on a northerly trending EM conductor east of Ledford Lake (SIR Mineral Assessment File 64M16-NE-0003). Diamond drill hole SK14, examined by M. Gunning, consisted mainly of white, medium-grained, biotite-plagioclase tonalite gneiss to the end of the hole at 124 m. A number of intervals, ≤1 m in width, of dark grey, medium-grained amphibolite containing 5 to 15 percent retrograded, chalky white garnet porphyroblasts occur between 53 and 69 m in the hole. The garnets are replaced by feldspar-dominated polycrystalline aggregates. Four intervals, from 0.6 to 5.5 m in width, of rusty weathered, crudely layered quartz-amphibole-garnet rock, which contain seams and disseminations of fine-grained pyrrhotite and rare chalcopyrite, occur at depths of 55 m and between 72 and 99 m. These intervals might represent silicate-sulphide facies iron formation.

A rhodochrosite occurrence hosted by Hurwitz Group carbonates at the southwest end of Many Islands Lake was mentioned in a 1969 Gulf Minerals Canada Ltd. mineral assessment report (SIR Mineral Assessment File 64M7-0006). A detailed examination of the occurrence was undertaken by M. Senkow. The occurrence consists of a number of glacial erratics up to 10 m x 5 m x 5 m and a nearby outcrop believed to be the source of the erratics. Millimetre- to centimetre-size grains of pink to red rhodochrosite occur along bedding/foliation surfaces and are also associated with boudinaged and folded quartz veins in dolomitic marble. A black metallic mineral, believed to be manganite, is closely associated with the rhodochrosite. In places there is up to 10 percent rhodochrosite. A yellowish green mineral accompanying these two minerals is tentatively identified as willemite, a zinc silicate. One analyzed sample contains 117 ppm zinc (see also MacDougall, this volume).

The following types of mineral occurrences were noted during mapping in 2002: 1) narrow zones of banded silicate-sulphide facies (quartz-garnet-amphibole-biotite-iron sulphides) and oxide facies (quartz-magnetite) iron formations in both Ennadai and Hurwitz groups; 2) disseminations of pyrite, pyrrhotite, and chalcopyrite in Ennadai Group mafic metavolcanic rocks; 3) structurally controlled pyritic quartz veins in metavolcanic rocks; 4) disseminated chalcopyrite and malachite coatings on fractures in Hurwitz Group ferruginous pelites; 5) molybdenite in granite; 6) allanite±molybdenite±pyrite-bearing granitic and tonalitic migmatites; and 7) weakly pyritic quartz-tourmaline veins in granite. Miller and Reading (1993) discuss the potential for significant gold mineralization in banded iron formation in the Hurwitz Group in Nunavut, and although quartz veining is well-developed in the Hurwitz pelites at Many Islands Lake, they do not appear to have potential for hosting gold mineralization.

The fluoritic granites also represent a potential site for intrusion-hosted gold mineralization and as well they are a potential source for REE and do contain anomalous concentrations of the light REE (Peterson and van Breeman, 1999; MacDougall, this volume).

Allanite typically contains enriched concentrations of rare earth elements (REE), thus they represent potential REE occurrences. Molybdenite is commonly associated with radioactive occurrences in granitic rock, therefore, it might be a guide to radioactive occurrences and, therefore, also REE.

8. Summary

The geologic history of the Phelps Lake region is very complex, involving multiple episodes of magmatism, supracrustal deposition, mineralizing events, deformation, and metamorphism, possibly spanning two billion years of earth history from ca. 3.3 to 1.27 Ga. Presumed Archean tonalitic and granitic migmatites and granite intrusions occupy large parts of the area; however, discontinuous remnants of presumed Archean Ennadai-Rankin greenstone belt are more abundant and extensive than previously known. They mainly comprise garnetiferous amphibolitic gneisses interpreted as mafic volcanic rocks. Rocks of intermediate to felsic composition are a minor component.

Beyond the two major synclinoria hosting Hurwitz Group rocks, at least one outlier was mapped in the northwest of the area, but abundant boulders in some places suggest there may be other areas where Hurwitz Group rocks may also be found. The group comprises a lower pelitic sequence (correlated with the Ameto Formation), a middle carbonate sequence (correlated with the Watterson Formation), and an upper psammopelitic-pelitic-psammitic sequence (correlated with the Ducker Formation). Ferruginous and copper-bearing pelites and thin zones of iron formation in the lower sequence make it more attractive for mineral exploration. Hurwitz carbonate rocks host the only known rhodochrosite occurrence in northern Saskatchewan.

Sills, dykes, sheets, and smaller plutons of generally massive, red to pink granite, leucogranite, felsite and locally fluoritic granite and pegmatite represent a suite of late- to post-tectonic intrusions. Although geochronological constraints are lacking, field evidence and regional correlations suggest that Archean and Paleoproterozoic tectonothermal events are responsible for the structural complexity. Small-scale structures in Hurwitz Group pelites suggests that both northwest- and southeast-directed basement-cover detachment occurred during Trans-Hudson deformation as the group was squeezed between basement arches flanking the two synclinoria.

The volcanic belts are unexplored and contain rocks capable of hosting gold and base metal mineralization. Allanite±molybdenite±pyrite-bearing granitic and tonalitic migmatites and the fluoritic granites represent unexplored sources for REE mineralization. Furthermore, large parts of the area have been burned in the past decade, making it ideal for boulder prospecting.

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