Some Aspects on the Geology of the Archean Ennadai-Rankin Greenstone Belt, Northeast Saskatchewan

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Abstract

The Archean Ennadai-Rankin greenstone belt crops out in northeast Saskatchewan. It hosts mainly supracrustal rocks that extend through the Snowbird Lake area in the Northwest Territories, to Rankin Inlet on Hudson Bay in Nunavut. The belt is structurally interleaved with continental rocks of the underlying Hearne Province and the whole sequence was subsequently intruded by several granitoid suites. In northeast Saskatchewan, the Ennadai supracrustal sequence comprises dominantly mafic metavolcanic rocks (flows and tuffs), minor intermediate to felsic metavolcanic rocks, hypabyssal intrusives, and subordinate metasedimentary rocks. All rocks have been affected by regional metamorphism and tectonism.

1. Introduction

Last summer's mapping is integrated in a three-year project that commenced in 2001 with the purpose of determining the geological history, tectonic setting, and mineral potential of the Phelps Lake map area (NTS 64M), in the Archean Hearne Province. Collaborating partners are Saskatchewan Energy and Mines (SEM), the Geological Survey of Canada (GSC), and the University of Regina. The project area is located in the northeastern corner of Saskatchewan; it is bounded by the Manitoba, Nunavut, and Northwest Territory borders, occupying 59º to 60° latitude and 102º to 104° longitude (Figures 1 and 2).

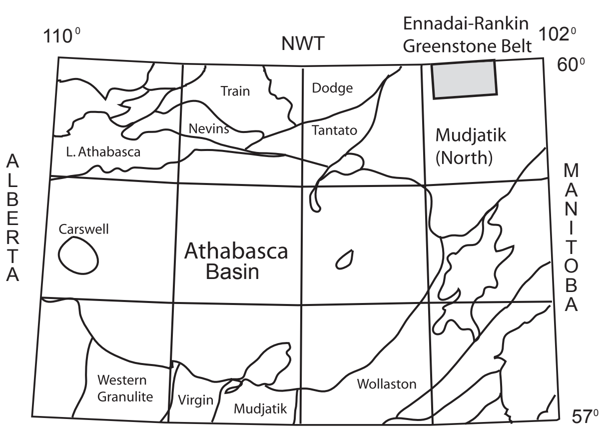

Figure 1 - Location of the Ennadai-Rankin greenstone belt in northern Saskatchewan, with respect to lithostructural domains.

In the summer of 2001, SEM began systematic 1:100 000 scale mapping in the northwestern quadrant of the Phelps Lake area, while the principal author carried out 1:20 000 scale mapping of a portion of the Ennadai-Rankin greenstone belt, along the northern edge of the project area (parts of NTS 64M-13 and -14). The GSC, with partial financial support from Saskatchewan Northern Affairs through the Provincial Centenary Fund, completed an airborne combined radiometric/magnetic/VLF-EM survey last year (Shives *et al.*, 2000), and conducted follow up studies in 2001. This report summarizes the general geology of the approximately 70 km^2 area mapped by the principal author in 2001 (Figure 2), and presents a preliminary stratigraphic record and geological history of the area. A complimentary study into the chemical evolution and tectonic reconstruction of the Ennadai-Rankin rocks is ongoing.

2. Previous Work

Previous investigations in the region date back to 1893-94, when J.B. Tyrell mapped to the west of the map area along the Wholdaia River system, and to the northeast in the Kasba Lake area (Tyrrell, 1897). A regional correlation, using available aeromagnetic maps from the GSC, was made by R.G. Agarwal (Agarwal, 1962). Tremblay (1960) mapped the Phelps Lake area (NTS 64M) at 1:253,440 scale. Mapping at 1:63,360 scale was conducted by Kays (1972) and Munday (1973), and at 1:100 000 scale by Lewry (1983) and Scott (1986) for SEM to the south and southeast of the map area. Weber *et al.* (1975) mapped the adjacent area in north-western Manitoba and Taylor (1963) mapped the Snowbird Lake area, immediately

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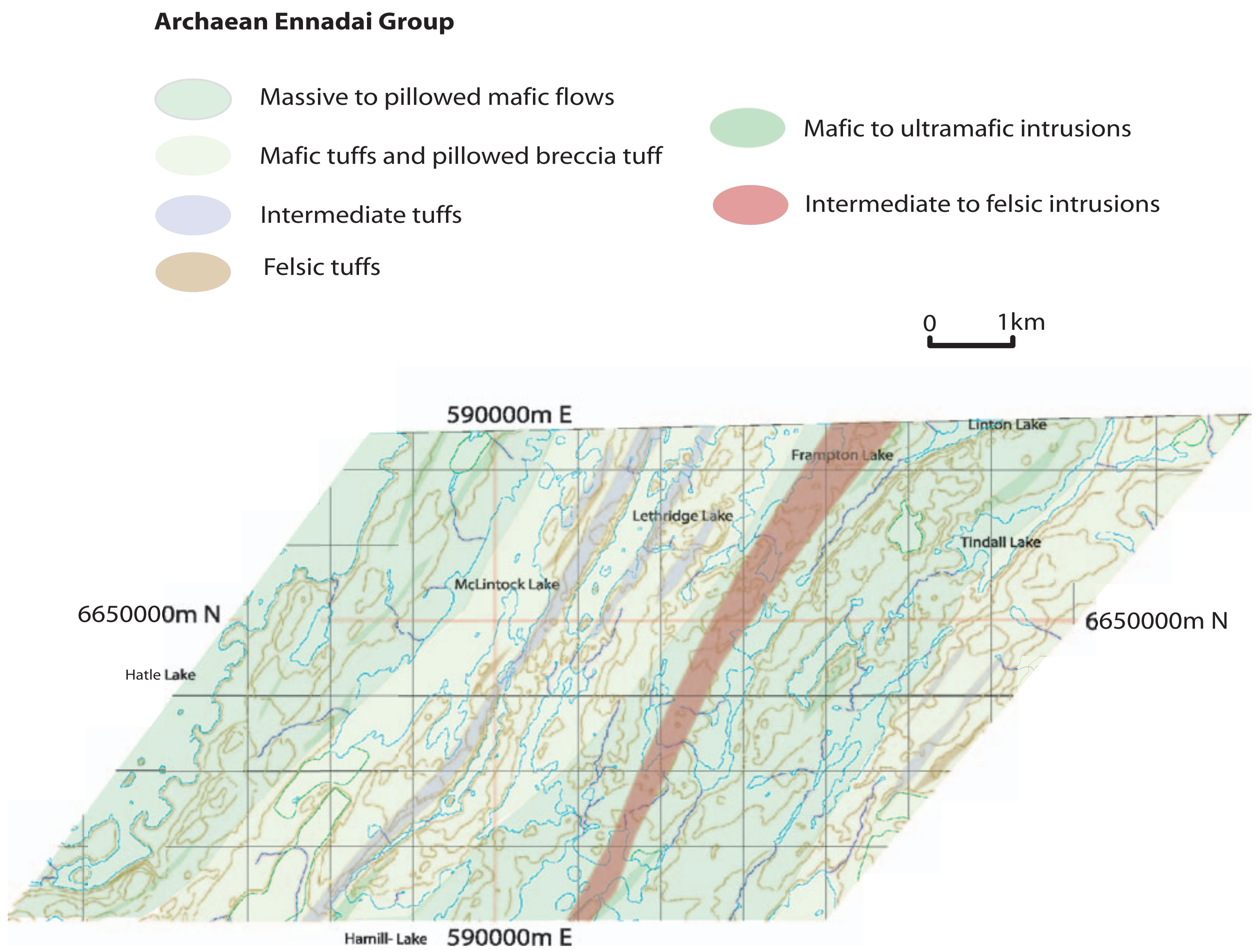

Figure 2 - Simplified geological map of the study area.

to the north in the south-eastern District of Mackenzie, Northwest Territories. The Misaw Lake area (NTS 64M-NE), due east of Hatle Lake and the Hatle Lake area (part of NTS 64M-13 and -14), was mapped by B.A. Reilly at 1:100 000 and 1:50 000 scales, respectively (Reilly, 1993a, 1993b).

3. Geological Setting

a) Regional

The principal author's map area is underlain mainly by supracrustal rocks that extend from Saskatchewan, through the Snowbird Lake area (Taylor, 1963) in the Northwest Territories, to Rankin Inlet on Hudson Bay in Nunavut. These rocks form part of the Archean Ennadai-Rankin greenstone belt (Wright, 1967). The term Ennadai Group informally proposed by Macdonald (1984) is used in this report for Archean metavolcanic and metasedimentary rocks of the Ennadai-Rankin greenstone belt in northeast Saskatchewan (*cf.* Reilly, 1993b). In the study area, the Ennadai Group comprises metavolcanic and metasedimentary rocks which structurally overlie Paleoproterozoic carbonates and calc-silicates correlated with the Watterson Formation of the Hurwitz Group (Reilly, 1993b; Aspler *et al.*, 1989). During the 2001 field season, it has been further demonstrated that these calcareous units have been overthrust by the Ennadai rocks (see Harper *et al.*, this volume).

The Ennadai Group is also structurally interleaved with continental rocks of the underlying Hearne province and the whole sequence was subsequently intruded by several granitoid suites (Hoffman, 1990).

Reilly (1993b) presented a summary of the geochronological work from the Ennadai-Rankin greenstone belt. A U-Pb zircon age of 2682 ±5.9 Ma obtained from a rhyolite unit of the Ennadai Group near Hamill Lake (Chiarenzelli and Macdonald, 1986) is broadly consistent with U-Pb zircon ages (2697.5 ±1.4, 2692 ±1, and 2681 ±3 Ma) recorded for Ennadai Group rhyolites from the Northwest Territories (Mortensen and Thorpe, 1987; Patterson and Heaman, 1991). These ages were interpreted as crystallization ages. The Hurwitz Group is constrained at between 2.45 and 2.1 Ga (Patterson and Heaman, 1991; Reilly 1993b).

The crystallization age of a granodiorite which intrudes the Ennadai Group metavolcanic rocks east of the southern end of Lichfield Lake area, 14 km southwest of the dated rhyolite, has been estimated at 2708 +3/-2 Ma (Delaney *et al.*, 1990; U-Pb zircon). This proves problematical in that this granitoid appears to be older than the rocks it intrudes. Reilly (1993b) suggested that the metavolcanic units in the vicinity of the intrusion could be older than those mentioned above.

U-Pb titanite ages on the same granitic unit suggest a minimum age for the time of the latest metamorphic overprint is 1771 ±14 Ma (L. Heaman, in Reilly, 1993b). This estimate confirms that Hudsonian metamorphism overprinted the Archean rocks. As all of the rocks have been metamorphosed, the prefix ‘meta’ will be dropped.

Volcanic rocks, the main component of the Ennadai Group are cut by sheet-like, intermediate to felsic intrusions. Combined with poor exposure and outcrop quality, particularly in the eastern third of the study area, and a veneer of glacial deposits, stratigraphic correlation was difficult. Geological boundaries, where not identified in the field, were inferred with the aid of aerial photographs and airborne multisensor survey data (Carson *et al.*, 2001).

4. Unit Descriptions

a) Ennadai Group

Mafic Volcanic Rocks

Dark greenish grey, mafic volcanic rocks (Figures 3 to 9) comprise both flows and pyroclastic rocks, with flows being more abundant. The flow rocks range from massive to pillowed (Figure 3), and include localized hyaloclastite pillow breccia (Figure 4), as well as vesicular, amygdaloidal, and plagioclase porphyritic units. The pyroclastic rocks are dominated by tuffs and crystal tuffs (Figure 5). Grain size is generally fine, although some coarse crystal-rich horizons are fine to medium grained.

The rocks are composed dominantly of blue-green pleochroic hornblende, and actinolite (Figures 10 and 11), along with lesser plagioclase. Other minerals include minor chlorite, biotite, opaques (including pyrite and pyrrhotite), apatite, titanite, and rarely garnet. Plagioclase is variously sericitized. Quartz, carbonate (Figure 12) and epidote veins, pods and patches are found locally, particularly in flow rocks to the west of Frampton Lake.

Intermediate to Felsic Volcanic Rocks

Rare fine- to medium-grained intermediate to felsic volcanic rocks are generally pyroclastic, comprising interlayered tuffs, crystal tuffs, and lapilli tuff breccias. The felsic volcanics tend to be more massive and are

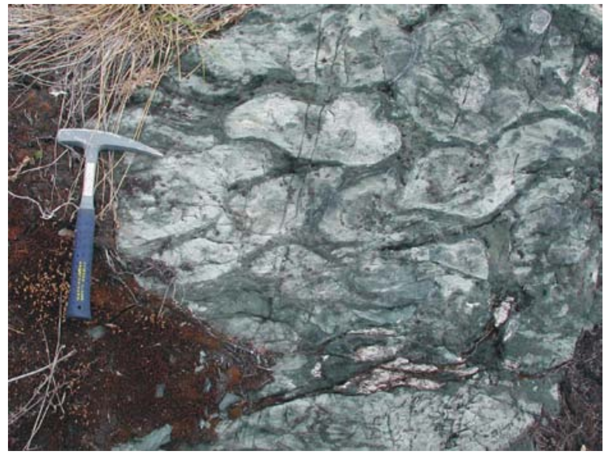

Figure 3 - Well-developed pillows in mafic volcanic unit east of Hatle Lake.

Figure 4 - Pillows and pillow breccia in mafic volcanics west of Tindall Lake.

Figure 5 - Interbedded (and deformed) mafic to intermediate bedded tuffaceous units, western shore of McLintock Lake.

Figure 6 - Coarse porphyroblastic ultramafic-mafic intrusion cutting bedded tuffs, western shore of McLintock Lake.

Figure 7 - Mafic dyke (possible feeder) cutting pillowed mafic volcanics east of Hatle Lake.

Figure 8 - Small intrafolial (F_3) folds in mafic tuffs, western shore of McLintock Lake (view looking north at near horizontal exposure).

Figure 9 - Possible pillow closure (?deformed) in more massive mafic flow, east of Hatle Lake.

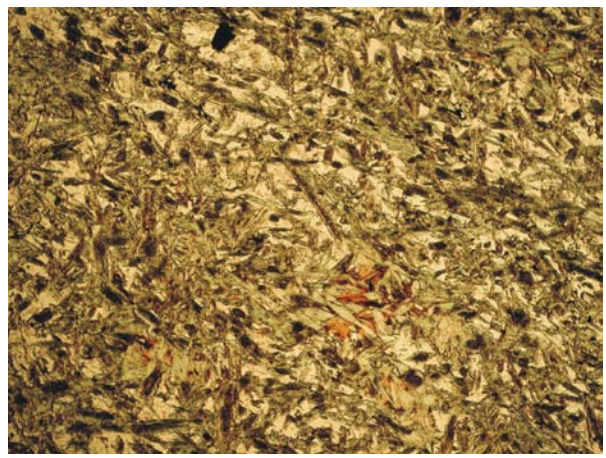

Figure 10 - Photomicrograph of mafic flow. Note strongly coloured hornblende (plane polarized light: width of field of view 6 mm).

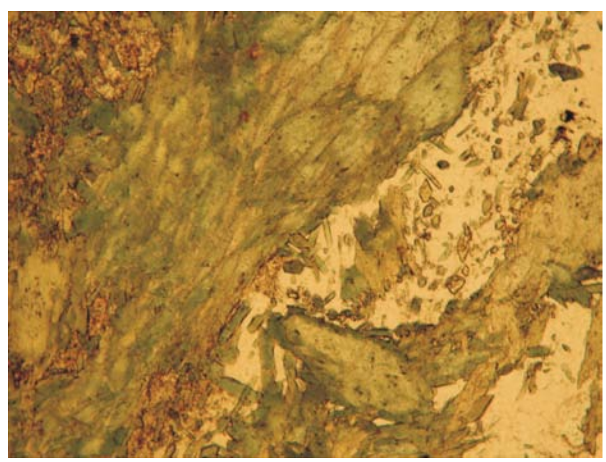

Figure 11 - Photomicrograph of mafic unit. Note feathery actinolite (plane polarized light: width of field of view 6 mm).

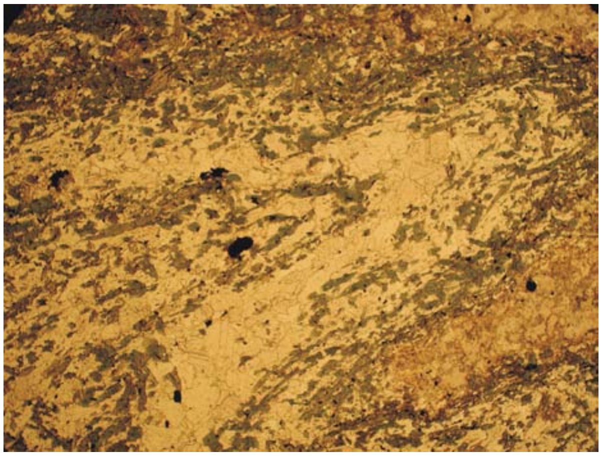

Figure 12 - Photomicrograph of strongly folded carbonate vein in tuffaceous unit (plane polarized light: width of field of view 6 mm).

probably flows. They are interlayered with mafic volcanic rocks on a centimetre to decimetre scale, forming units from a few metres to tens of metres thick. These rocks are pale grey to buff, and dominated by quartz and variously sericitized plagioclase, along with minor blue-green pleochroic hornblende, actinolite, chlorite, biotite, and opaques.

Clastic Sediments

Clastic sedimentary rocks have been reported from the Ennadai Group (e.g. Reilly, 1993b), particularly south and west of the mapped area (see Harper *et al.*, this volume). Only thin horizons (2 to 5 cm) however, were found interlayered within the more mafic volcanics. Numerous boulders comprising medium- to coarse-grained psammitic schist (quartz-feldspar-biotite) occur over a large area between Frampton Lake and Lethridge Lake (Figure 2). This suggests unexposed sediments exist in the sequence.

Chemical Sediments

Chemical sediments, mainly iron formation, occur interlayered with the mafic and intermediate to felsic volcanic rocks. The iron formation is dominantly silicate facies and occurs as 10 to 20 cm thick bands. Weathered surfaces are rusty brown to reddish orange and fresh surfaces are dark greenish grey.

Ultramafic to Mafic Intrusive Rocks

Medium- to coarse-grained ultramafic to gabbroic bodies intruded the entire sequence. They are typically massive and homogeneous, 1 m to more than 100 m thick, and are equigranular to locally, strongly foliated. Some varieties are strongly porphyroblastic with amphibole grains up to 2 cm in diameter (Figure 6). The more ultramafic units probably originated as pyroxenites. Field relations suggest that the ultramafic-mafic intrusives, which form sill and dyke complexes, were a feeder system to the volcanics (Figure 7).

Granitoids and Other Felsic-Intermediate Intrusions

Granitoids comprising granite, granodiorite, quartz diorite, migmatite, pegmatite, and subordinate aplite crop out in the eastern half of the map area. They are salmon to pale grey, typically weakly to strongly foliated, and range from medium-coarse to coarse-very coarse grained and porphyroblastic. They occur as a series of sheet-like bodies from centimetres (dykes and veins) to tens of metres in thickness, within a 1 to 2 km wide zone between Frampton Lake and Lethridge Lake (Figure 2). These rocks typically exhibit diffuse contacts with each other, although locally there are multiple cross-cutting phases.

5. Geological Evolution

a) Volcanism

Well-developed pillows and hyaloclastite textures in the volcanic rocks suggest that these units were erupted, at least in part, in a marine or lacustrine environment. More massive flows and pyroclastics could have been erupted sub-aerially; proximity to the pillows, however, at least in the case of the more mafic lithologies, is evidence/argument against this. Field relationships (see Figures 6 and 7) show that the ultramafic-mafic sills and dykes probably acted as feeders to these units. The Intermediate and felsic volcanic rocks indicate evolution of the magmatic system, with rocks likely emplaced as explosive pyroclastic deposits and minor flows.

Based on comparisons with other parts of the Ennadai-Rankin greenstone belt it is possible that the entire volcanic package represents a sequence of several mafic-felsic magmatic cycles (*cf.* Davis *et al.*, 1998). However, repetition of lithologies could also be the result of folding and/or faulting.

b) Structure

The early structural history of the Ennadai Group predates depositions of the Hurwitz Group; however, other than an intense $S_{1/2}$ composite fabric, early structures (related, for example, to the amalgamation process of the Ennadai and Hearne), have not been identified. Generally the rocks strike northeast and dip northwesterly and structurally overlie the younger Hurwitz Group rocks. Three generations of structures (F_3 to F_5) are recognized that affected both Ennadai Group and Hurwitz Group rocks.

The earliest post-Hurwitz structures are probably thrust faults placing Ennadai Group rocks over top of the Hurwitz Group rocks. Near the base of the overlying northwesterly dipping Ennadai rocks, there is a marked strain increase compared to the regional strain. This increase is expressed by a very intense foliation, layer boudinage, and small intrafolial F_3 folds (Figure 8) which in places are northwesterly overturning, indicating, after refolding, a broadly down dip west-northwest tectonic transport. Some fold-axis rotation towards the direction of tectonic transport occurred during shearing. Similar features were noted elsewhere, suggesting a series of stacked parallel thrusts. The apparent northwest transport would appear to be contradictory to the mostly ubiquitous northwesterly dip of the Ennadai Group volcanics and sediments both within and outside of the map area. This warrants further investigation.

The thrust sheets have been overprinted at all scales by northeasterly trending, relatively open F_4 folds with shallow plunging axes. As a consequence, parts of the F_3 thrust sheets will dip southeasterly. One of us (JK) had the impression that the large F_4 folds are verging to the west-northwest.

The thrust sequence and the F_4 folds are refolded again by centimetre- to metre-scale asymmetric F_5 crenulation folds. They have parallel profiles (i.e. hinges are not thickened) and have shallowly northerly to northeasterly plunging axes and steep northerly to northeasterly trending axial planes. The large-scale folds resemble a regional-scale Z-asymmetrical fold in the Uranium City area, Rae Province (Kraus and Ashton, 2000), and are also similar to transpression-related F_3 folds in the Thompson Nickel Belt (Kraus *et al.*, 1998). Although speculative without geochronological data, the F_5 folds may record the same dextral Hudsonian shearing as reported for the Rae Province (Kraus and Ashton, 2000), and the Wollaston Domain (e.g. Portella and Annesley, 2000).

c) Metamorphism

The grade and possible cyclicity of metamorphism is difficult to estimate due to the lack of indicator minerals. The best indicator is ubiquitous of strongly pleochroic, blue-green hornblende in all mafic units (Figure 10). Actinolite (Figure 11), chlorite, and, more rarely, garnet and biotite are also present and, collectively, these assemblages are consistent with low pressure, medium temperature metamorphism. In the Hurwitz Group rocks, mineral assemblages indicate a similar grade, possibly suggesting coeval metamorphism of the two groups (Reilly, 1993b).

d) Alteration and Mineralization

The Ennadai-Rankin greenstone belt has significant exploration potential for gold and base-metal deposits (Goff and Kerswill, 1999). Directly to the west of the study area (about 6 km) is the Nirdac Creek gold occurrence (1.5 m section assaying 0.401 oz gold per ton; Reilly, 1993b). It is hosted by thinly layered, silicate facies iron formation, and is associated with gossanous zones. Several favourable environments for mineralization were recognized during the current mapping (iron formation, gossanous outcrops, and boulders) and are the focus of a companion study by MacDougall (this volume).

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7. References

Agarwal, R.G. (1962): Regional Correlation of Geological and Geophysical Data in the Lake Athabasca Area, Northern Saskatchewan. Sask. Dep. Miner. Resour., Rep. 75, 4p.

Aspler, L.B., Bursey, T.L., and Miller, A.R. (1989): Sedimentology, structure, and economic geology of Poorfish-Windy thrust-fold belt, Ennadai Lake area (65/C), District of Keewatin, and the shelf to foreland transition in the Foreland of Trans-Hudson Orogen; *in* Current Research, Part C, Geol. Surv. Can., Pap. 89-1C, p143-156.

Carson, J.M., Holman, P.B., Shives, R.K.K., Ford, K.L., Harper, C.T., and Slimmon, W. (2001): Phelps Lake area geophysical maps; Geol. Surv. Can., Open File 3951, Sask. Energy Mines, Open File 2001-2, series of 160 geophysical maps at 1:50 000 scale.

Chiarenzelli, J.R. and Macdonald, R. (1986): A U-Pb zircon date for the Ennadai Group; *in* Summary of Investigations 1986, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 86-4, p112-113.

Davis, W.J., Hanmer, S., Peterson, T.D., Rainbird, R., Ryan, J., and Sandeman, H.A.I. (1998): Preliminary U-Pb geochronology of volcanic rocks in the Kaminak belt, Western Churchill Province, Kivalliq Region, Northwest Territories; Program and Abstracts of Talks and Posters, NWT Geoscience Forum Yellowknife; Northwest Territories Geology Division, Indian Affairs and Northern Development, Yellowknife, p30-31.

Delaney, G.D., Heaman, L.M., Kamo, S., Parrish, R.R., Slimmon, W.L., and Reilly, B.A. (1990): U-Pb sphene/zircon geochronological investigations; *in* Summary of Investigations 1990, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 90-4, p54-57.

Goff, S.P. and Kerswill, J.A. (1999): Preliminary investigation of significant mineral occurrences in the central Rankin-Ennadai supracrustal belt, Kaminak Lake area, Northwest Territories (Nunavut): *in* Current Research 1999-C, Geol. Surv. Can., p147-156.

Hoffman, P.F. (1990): Subdivision of the Churchill Province and extent of the Trans-Hudson Orogen; *in* Lewry, J.F. and Stauffer, M.R. (eds.), The Early Proterozoic Trans-Hudson Orogen of North America, Geol. Assoc. Can., Spec. Pap. 37, p15-39.

Kays, M.A. (1972): The Geology of the Hara Lake Area, Saskatchewan; Sask. Dep. Miner. Resour., Rep. 146, 37p.

Kraus, J. and Ashton, K.E. (2000): New insights into the structural geology and tectonic setting of the Uranium City area, northwestern Saskatchewan; *in* Summary of Investigations 2000, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2000-4.2, p16-25.

Kraus, J., Peck D.C., and Bleeker, W. (1998): Structural investigation of the Thompson Mine South Pit, Thompson Nickel Belt, Manitoba; Manitoba Energy Mines, Minerals Division, Rep. Activities, p60-65.

Lewry, J.F. (1983): Geology of an Area Around Kohn Lake, Sask. Energy Mines, Rep. 222, 20p.

Macdonald, R. (1984): Notes on the Ennadai Group; *in* Summary of Investigations 1984, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 84-4, p76-77.

Mortensen, J.K. and Thorpe, R.I. (1987): U-Pb zircon ages of felsic volcanic rocks in the Kaminak Lake area, District of Keewatin; *in* Radiogenic Age and Isotopic Studies, Report 1, Geol. Surv. Can., Pap. 87-2, p123-128.

Munday, R.J.C. (1973): The Geology of the Dutton Lake Area (East Half), Saskatchewan; Sask. Dep. Miner. Resour., Rep. 155, 22p.

Patterson, J.G. and Heaman, L.M. (1991): New geochronologic limits on the depositional age of the Hurwitz Group, Trans-Hudson hinterland, Canada; Geol., v19, p1137-1140.

Portella, P. and Annesley, I.R. (2000): Paleoproterozoic thermotectonic evolution of the eastern sub-Athabasca basement, northern Saskatchewan: Integrated geophysical and geological data; *in* Summary of Investigations 2000, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2000-4.2, p191-200.

Reilly, B.A. (1993a): Reconnaissance bedrock geological mapping, Misaw Lake area (NTS 64M-NE); Sask. Energy Mines, Open File Rep. 93-1, 21p.

__________ (1993b): Bedrock geological mapping, Hatle Lake area (part of NTS 64M-13 and -14). Sask. Energy Mines, Open File Rep. 93-2, 21p.

Scott, B.P. (1986): Geology of the Phelps Lake (south-west) area, Saskatchewan. Sask. Energy Mines, Open File Rep. 86-2, 12p.

Shives, R.B.K., Carson, J.M., Holman, P.B., Ford, K.L., Grant, J.A., Ashton, K.E., Harper, C.T., and Delaney, G.D. (2000): Airborne multisensor (gamma ray spectrometric/magnetic/VLF-EM) surveys in northern Saskatchewan: A status report; *in* Summary of Investigations 2000, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2000-4.2, p26-28.

Taylor, F.C. (1963): Snowbird Lake Map-area, District of Mackenzie; Geol. Surv. Can., Mem. 333, 23p.

Tremblay, L.P. (1960): Phelps Lake Map-area, Saskatchewan; Geol. Surv. Can., Map. 5-1960.

Tyrrell, J.B. (1897): Report on the Doobaunt, Kazan, and Ferguson rivers and the north-west coast of Hudson Bay; Geol. Surv. Can., Annu. Rep., v9, Pt. F, 218p.

Weber, W., Schledewitz, D.C.P., Lamb, C.F., and Thomas, K.A. (1975): Geology of the Kasmere Lake–Whiskey Jack Lake (north half) area (Kasmere Project), Manitoba; Manit. Mineral. Resour. Div., Geol. Serv. Branch, Publ. 74-2, 163p.

Wright, G.M. (1967): Geology of the Southeastern Barren Grounds, Parts of the Districts of Mackenzie and Keewatin; Geol. Surv. Can., Mem. 350, 91p.