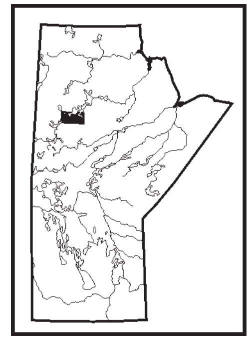
GS-7 Eden deformation corridor and polymetallic mineral belt, Trans-Hudson Orogen, Leaf Rapids area, Manitoba (NTS 64B and 64C)

by A.H. Mumin[1] and L. Corriveau[2]



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Summary

A previously unrecognized belt of intense deformation, referred to as the 'Eden deformation corridor' (EDC), is situated parallel to and southeast of the Johnson Shear Zone in the Trans-Hudson Orogen (Figure GS-7-1). As presently understood, the belt is 5–8 km wide and strikes eastward for more than 80 km, from west of Eden Lake to east of the Rat River. It is located above a collisional suture zone that marks the end of northward subduction beneath the Lynn Lake and adjacent greenstone belts. The EDC is believed to be the exhumed remains of a deep-seated section of the subduction front. Deformation in the EDC alternates between high-strain and low-strain belts. High-strain belts include annealed fault breccia, ductile shearing and mylonization, as well as younger shearing, brittle fracturing and stockwork breccia units. The deformation corridor hosts abundant intrusions ranging from ultramafic to felsic and spanning a minimum age range of 1870–1800 Ma. The most important features of the EDC are the varied styles of mineralization and hydrothermal alteration that have been documented along the belt over the past 3 years. Mineralization includes rare earth metal–rich carbonatite bodies, Ni-Cu-PGE sulphides, sulphide-facies iron formation, rare metal pegmatite bodies, Th-U radiometric occurrences, and various forms of hydrothermal alteration. This is the reason for the parallel reference to the EDC as the Eden polymetallic mineral belt. Airborne, high-resolution, multi-parameter geophysical surveys and systematic geological work are recommended for the belt.

Introduction

Regional scoping studies and targeted detailed exploration programs carried out in the Leaf Rapids area of the Trans-Hudson Orogen during 2002, 2003 and 2004 have led to recognition of an intense deformation belt extending from west of Eden Lake to east of the Rat River, referred to hereafter as the 'Eden deformation corridor' (EDC). As presently understood, the deformation zone is approximately 5–8 km in width and more than 80 km in length. The deformation is partitioned into belts of high and low strain. High-strain belts display ductile and mylonitic deformation of metawacke, metaturbidite, iron formation, and felsic, intermediate, mafic and ultramafic intrusive and volcanic rocks. They are locally intruded by undeformed intrusions, such as the Eden Lake Carbonatite Complex (ELC), that provide time control on the end of ductile deformation (Mumin, 2002a). All early-formed rocks within the corridor have been subject to amphibolite-facies metamorphism. The EDC runs parallel to and southeast of the fertile, east-trending, transcurrent Johnson Shear Zone that extends for more than 100 km along the Lynn Lake greenstone belt to the north (Beaumont-Smith, 2000; Beaumont-Smith and Edwards, 2000; Rogge et al., 2003).

The most significant feature of the EDC is the extraordinary variety and widespread nature of associated mineralization and hydrothermal alteration, leading to the reference to this structural zone as the 'Eden polymetallic mineral belt' (EPMB). This report describes the nature of the EDC and gives a brief description of 10 different styles of mineralization and alteration that are presently known to occur. Comparison with the Johnson Shear Zone and its various styles of alterations, including newly observed Fe-oxide breccia, is also briefly discussed. The paper concludes with speculation on the origin of this previously unrecognized deformation corridor and mineral belt, and comments on its potential to host various styles of mineralization.

Regional geology

The Eden deformation corridor occurs within the Leaf Rapids Domain of the Trans-Hudson Orogen, and is located north of the Kisseynew Domain and Rusty Lake greenstone belt, and south of the Chipewyan Batholith and Lynn Lake greenstone belt. The Trans-Hudson Orogen constitutes a major Paleoproterozoic tectonic collage of varied terrains that amalgamated with the Hearne craton in a north-vergent series of collisional events, and eventually sutured to the northwestern Archean Superior Province. The collage includes early island-arc terrains, accretionary prisms,

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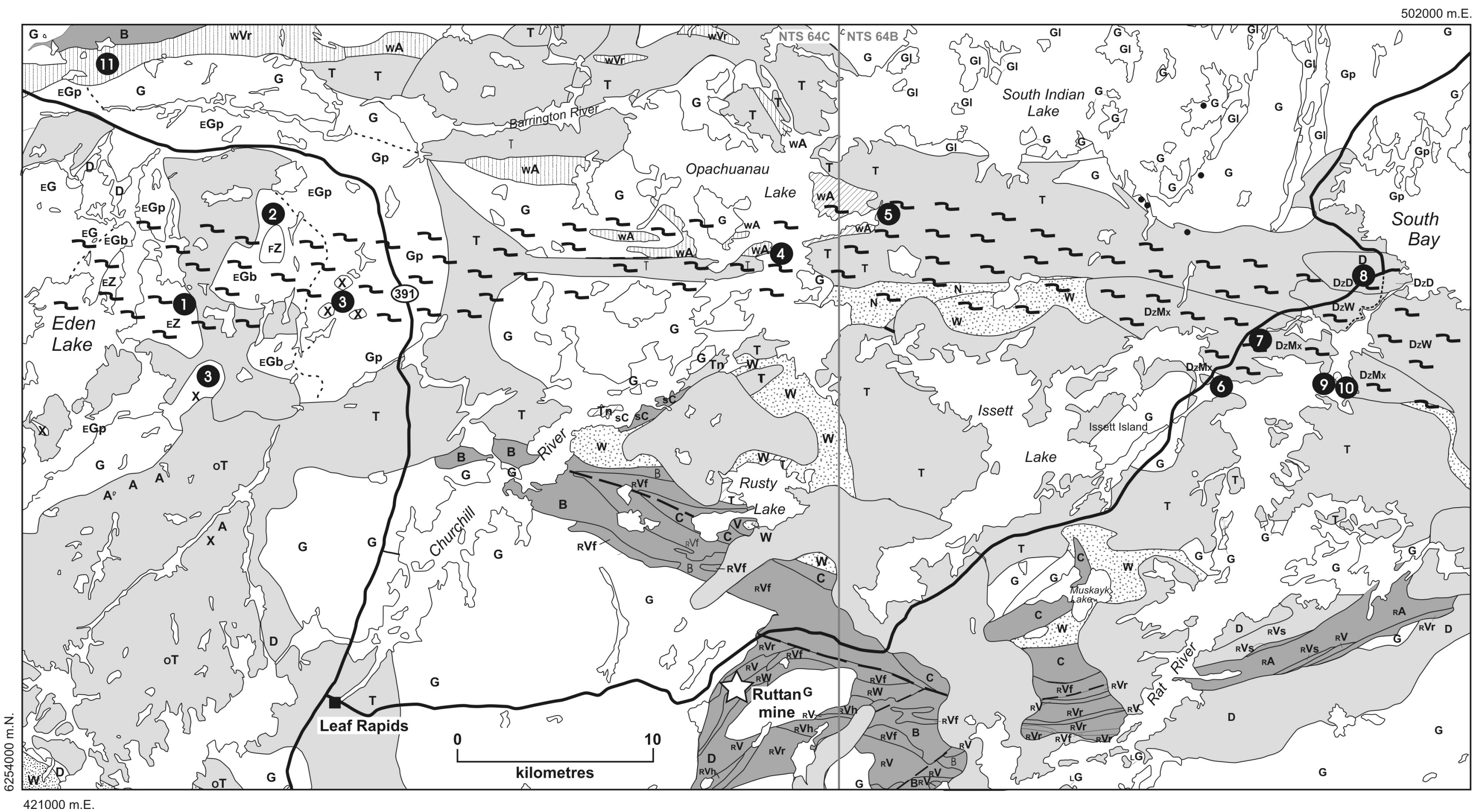

Figure GS-7-1: *Geology of the Eden Lake–South Bay area* (after *Manitoba Energy and Mines, 1986a, b*), *showing the Eden deformation corridor and locations discussed in the text.*

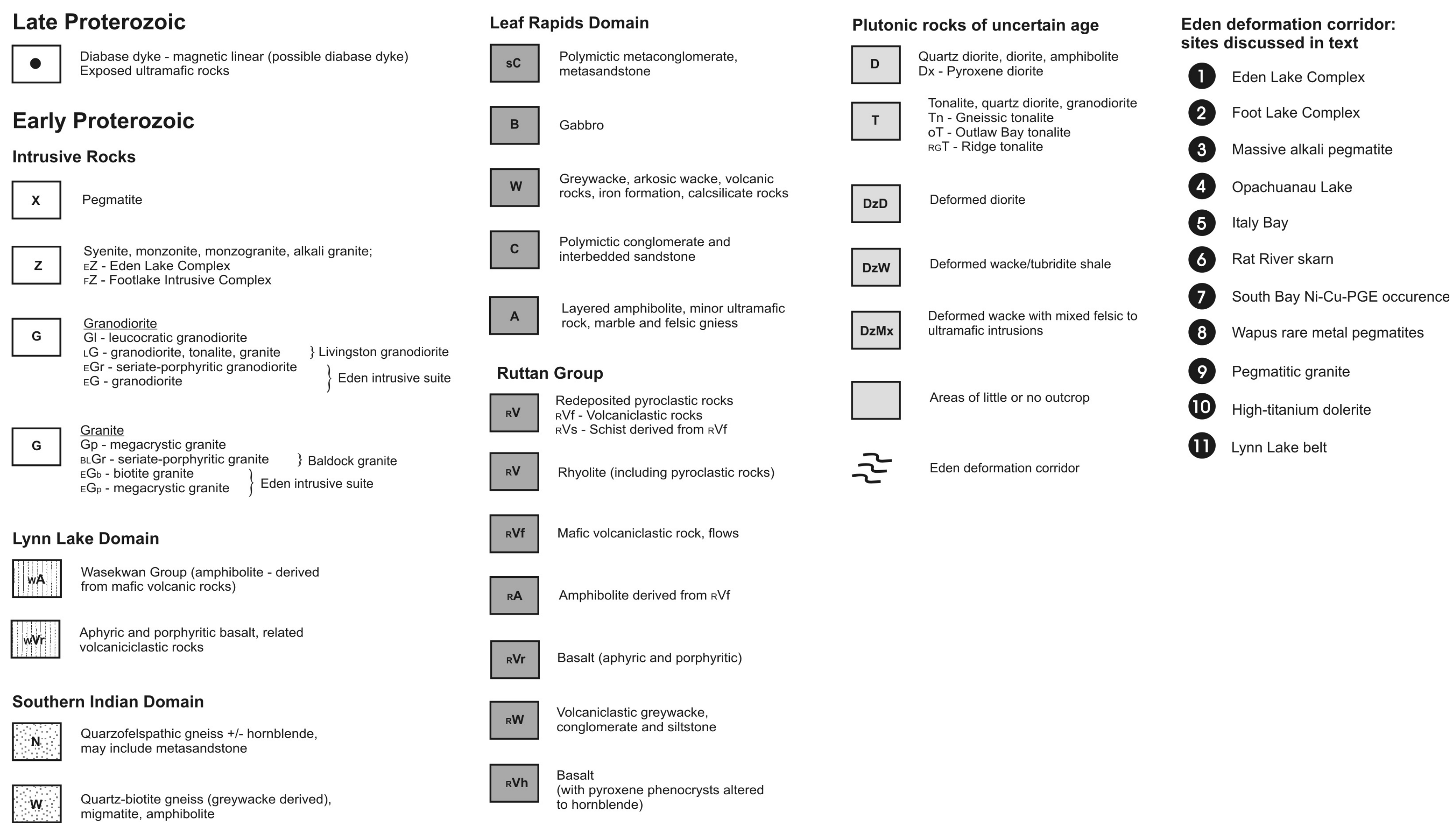

***Figure GS-7-1:** Geology of the Eden Lake–South Bay area (after Manitoba Energy and Mines, 1986a, b), showing the Eden deformation corridor and locations discussed in the text.* (continued) continental orogenic belts, arc- and continental-rift environments, collisional suture zones and granitoid gneiss belts (Lewry and Collerson, 1990). These continental and protocontinental rift- and orogenic-belt environments constitute a number of geotectonic terrains capable of hosting a variety of igneous and hydrothermal styles of mineralization. However, high-grade metamorphism, scarcity of outcrop, remoteness and limited access to much of the Trans-Hudson Orogen have left most of it relatively unexplored and little investigated. In the present study, a series of previously unrelated investigations, including a scoping study for Fe-oxide Cu-Au (IOCG) mineralization, prove to be linked by a common geotectonic feature, allowing the authors to partially fill knowledge gaps in a small part of the Trans-Hudson Orogen.

Eden deformation corridor

The Eden deformation corridor is an approximately 5–8 km wide east-west corridor with a subvertical to north-dipping deformation fabric. It extends from west of Eden Lake to east of the Rat River diversion channel south of South Bay (Figure GS-7-1). The EDC is bordered to the southeast by tonalite and granodiorite that separate it from the Rusty Lake greenstone belt, and to the southwest by granodiorite, tonalite and massive feldspar pegmatite bodies. The northern boundary is constrained by a series of porphyritic granodiorite, monzogranite and diorite intrusions. Large areas of these bounding intrusions are also disrupted by the deformation. Both the western and eastern extents of the deformation corridor remain undelimited.

The Eden deformation corridor disrupts metawacke and metaturbidite, and is intruded subparallel to the foliation by abundant felsic, mafic and ultramafic rocks of varying affinities. Mafic intrusive phases analyzed to date include diorite, gabbro-diabase, high-Ti dolerite, Fe tholeiite, komatiitic basalt compositions and ultramafic rocks. Injection-type migmatite is common, but no evidence for in situ partial melting has been observed (using the criteria of Sawyer, 1999). In the central part of the EDC, extending through Opachuanau Lake, a deformed supracrustal belt of metavolcanic rocks is exposed, juxtaposed and/or overlying metasedimentary rocks. The belt also hosts a suite of early predeformation to syntectonic intrusions that include granodiorite (porphyritic), diorite and biotite granite, and a compositional range of other felsic, mafic and ultramafic intrusions.

Deformation across the 5–8 km wide corridor occurs as intercalated subparallel zones of high and low strain that vary from less than 1 m to hundreds of metres in width. Deformation includes ductile-deformed tectonite units, mylonitized rocks and annealed fault breccia (Figures GS-7-2, -3). Younger, higher level shearing, brittle fracturing and tectonic-breccia zones are superimposed on the early ductile deformation in narrow to wide zones (Figures GS-7-4, -5).

The low-strain zones in the northeastern part of the presently documented EDC locally include some steeply dipping granitic to dioritic sheet intrusions with faint to well-developed mineral foliation(s) and some local magmatic layering. The foliation in the porphyritic, felsic to intermediate intrusions is defined by the preferred orientation of subhedral K-feldspar megacrysts and mafic microgranular enclaves, and satisfies criteria for a magmatic origin (cf. Vernon, 1986; Paterson et al., 1998). Earlier phases of diorite may also display a magmatic foliation but also have a weak solid-state mineral foliation overprinting them (Figures GS-7-6, -7). The mafic enclaves are typical of cogenetic enclaves and point, along with the presence of some rapakivi-like crystals, to coeval emplacement and mingling of mafic and felsic magmas (Baxter and Feely, 2002). Late-stage granitic dikes that locally display magmatic layering are either parallel to or cut across the igneous fabric of the earlier intrusions. They are themselves intruded by an array of massive granitic dikes that locally contain magnetite. These intrusions share some characteristics of syntectonic intrusions (Corriveau and van Breemen, 2000). If further studies were to support such a syntectonic emplacement, these intrusions could provide some important time and tectonic constraints on the evolution of the EDC (cf. Paterson and Tobish, 1988; Pavlis, 1996; Corriveau et al., 1998).

Late- to post-tectonic intrusions in the Eden deformation corridor

The EDC hosts a suite of late- to post-tectonic intrusions that range from those with a weak fabric to others with no evidence of deformation. These late intrusions cut the strong deformation and previously mentioned rocks of the EDC. In some regions, such as Eden Lake, large, late intrusive complexes displace and obliterate most evidence of a preexisting east-west deformation corridor.

Presently recognized late- to post-tectonic intrusions within the corridor include marginal tonalite-granodiorite complex along the South Indian Lake road; two-mica alkaline pegmatoid granite exposed in the Rat River; rare metal pegmatite (Figures GS-7-8, -9); granitic pegmatite (Figure GS-7-10); quartz-feldspar pegmatite (Figure GS-7-11); massive two-feldspar alkali pegmatite (Figure GS-7-12); potassic, muscovite-rich granite, northeastern Italy Bay,

Figure GS-7-2: *Intense deformation of diorite with abundant injection migmatite, in the EDC approximately 3 km southwest of the Wapus rare metal pegmatite showing.*

Figure GS-7-3: *Annealed fault breccia in metasedimentary rocks near the South Bay Ni-Cu-PGE occurrence.*

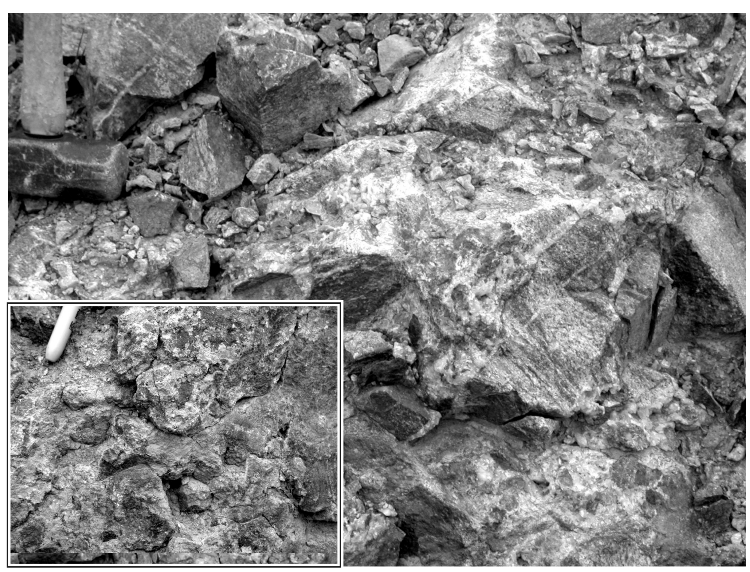

Figure GS-7-4: *Quartz stockwork veining in tectonic breccia associated with the Rat River skarn. Inset shows K-feldspar±hematite stockwork breccia veining.*

Figure GS-7-5: *Cataclastic shearing of metasedimentary rocks in the central EDC, near the South Bay Ni-Cu-PGE occurrence.*

Figure GS-7-6: *Diorite cut by a diabase dike, which is then cut by granitic pegmatite, Wapus rare metal pegmatite field.*

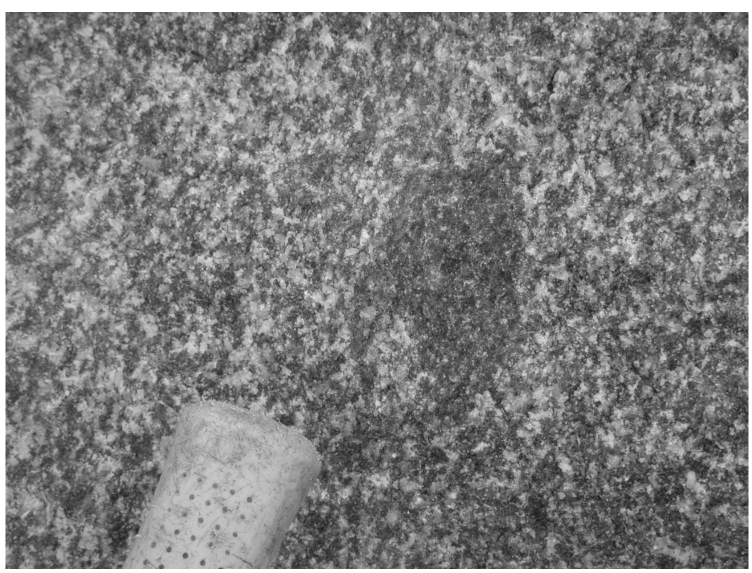

Figure GS-7-7: *Diorite with a weak fabric and mafic inclusion, Wapus rare metal pegmatite field.*

Figure GS-7-8: *Saccharoidal albite-rich pegmatite, Wapus rare metal pegmatite field.*

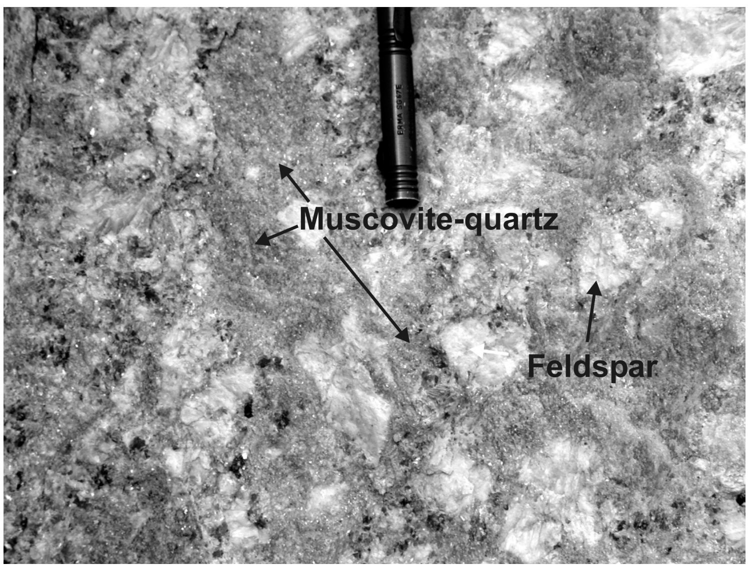

Figure GS-7-9: *Muscovite-quartz after microcline–type alteration in a complex pegmatite, Wapus rare metal pegmatite field.*

Figure GS-7-10: *Well-zoned granitic pegmatite, Wapus rare metal pegmatite field.*

Figure GS-7-11: *Rhythmically banded quartz+ two-feldspar pegmatite, Foot Lake Complex.*

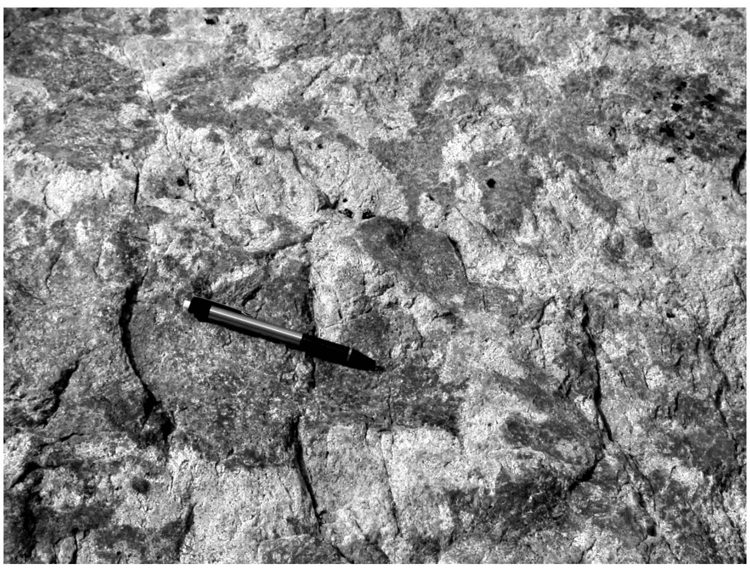

Figure GS-7-12: *Amoeboid two-feldspar alkaline pegmatite, Eden Lake south.*

Opachuanau Lake; fine- to medium-grained felsite, southern Italy Bay (Figure GS-7-13); plagioclase (Na-rich) porphyry, northeastern Italy Bay (Figure GS-7-14); diabase; gabbro; high-Ti dolerite; Fe tholeiite; komatiitic basalt; pyroxenite; unclassified ultramafic rocks; biotite granite (ELC); fluorite-magnetite alkali granite (ELC); monzonite (ELC); syenite (ELC; Figures GS-7-15, -16); varied mafic rocks of the ELC (Figure GS-7-16); lamprophyre (ELC; Figure GS-7-16); and carbonatite (ELC; Figure GS-7-17).

The Eden deformation corridor refers to rocks solely or primarily associated with the Eden Lake Carbonatite Complex, although they may eventually be found elsewhere along the belt. The most important aspect of the syn- to post-tectonic intrusions is their association with a wide range of magmatic and/or hydrothermal styles of mineralization and hydrothermal alteration.

Polymetallic mineralization along the Eden deformation corridor

Ten styles of mineralization and/or hydrothermal alteration have been recognized to date along the Eden deformation corridor. Most are associated with igneous activity along the deformation zone, and range from early-metamorphosed and -deformed bodies to late, well-preserved zones. Mineralization and alteration include the Eden Lake REE-Y-Th-U-PO_4–rich carbonatite complex (Figure GS-7-17); the South Bay Ni-Cu-PGE occurrence (Figures GS-7-18, -19); the Wapus rare metal Li-Cs-Ta (LCT)–type pegmatite field (Figures GS-7-8, -9, -10); the

Figure GS-7-13: *Contact between igneous felsite and banded volcanic-volcaniclastic sequence, Opachuanau supracrustal sequence, Italy Bay.*

Figure GS-7-14: *Na-rich plagioclase porphyry with epidote and pyrite alteration, Italy Bay.*

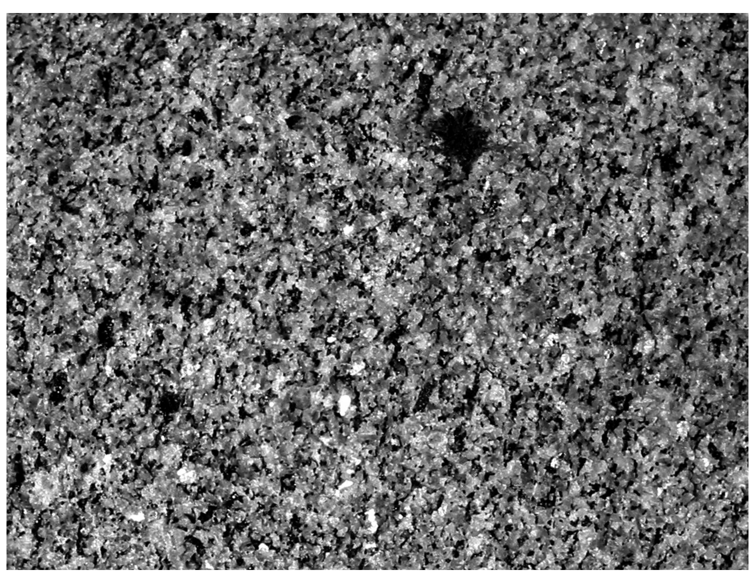

Figure GS-7-15: *Aegirine-augite syenite, Eden Lake. Field of view = 7 cm.*

Figure GS-7-16: *Altered and disaggregated mafic-lamprophyre dike hosted in syenite, Eden Lake.*

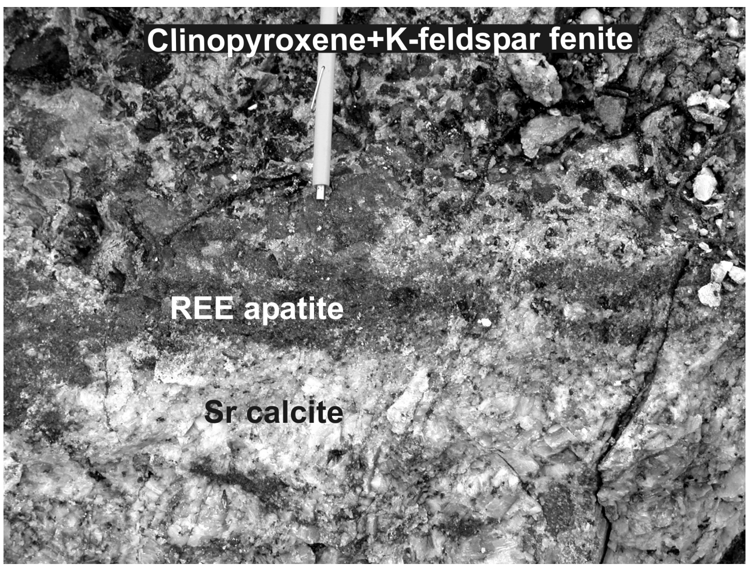

Figure GS-7-17: *Eden Lake carbonatite with Sr-calcite, apatite and pyroxene+potassium-feldspar fenite bands.*

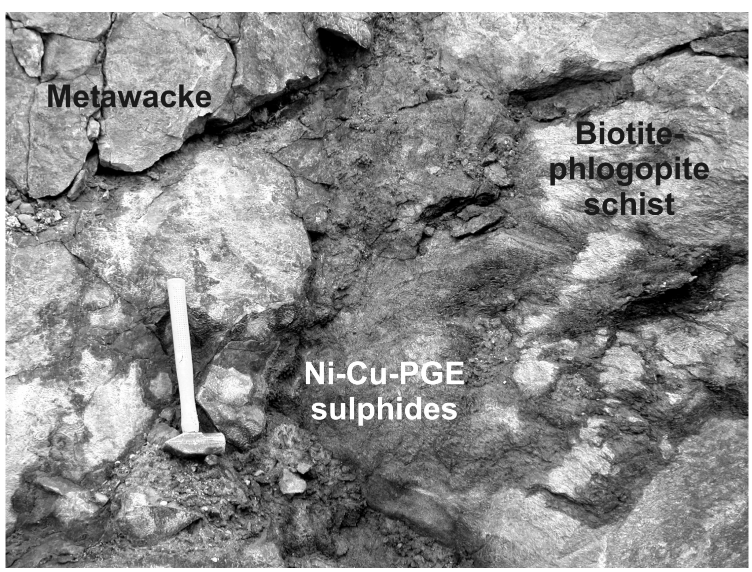

Figure GS-7-18: *South Bay Ni-Cu-PGE occurrence.*

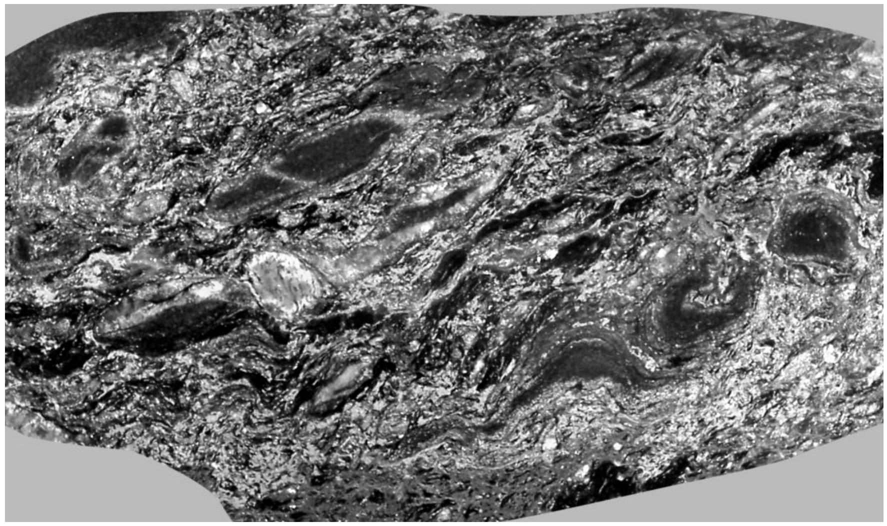

Figure GS-7-19: *Polished slab of high-grade* durchbewegung-*textured (penetrative deformation) Ni-Cu-PGE–rich sulphides from the South Bay occurrence. Clasts of tonalite, metasedimentary rock, quartz vein, and mafic schist in anastomosing sulphide matrix.*

Rat River skarn (Figures GS-7-20, -21); fertile(?) granite bodies; the Foot Lake Complex radiometric occurrence; the Opachuanau Lake garnet-actinolite amphibolite (Figures GS-7-22, -23, -24); the Italy Bay radiometric anomaly; the South Bay albite zone (Figure GS-7-25); and sulphide-facies iron formations.

Eden Lake REE-Y-Th-U-PO_4–rich Carbonatite Complex

The Eden Lake Carbonatite Complex (ELC) intrudes and almost completely obliterates the western portion of the Eden deformation corridor (EDC). Consequently, the EDC was not previously recognized in spite of significant work in the area. Nevertheless, there was enough evidence for previous investigators to recognize that the ELC lies at the intersection of major east-, north- and northeast-trending structures (Mumin, 2002a).

The Eden Lake Carbonatite Complex is an alkaline complex, exposed over an area greater than 30 km^2, that is derived from the upper mantle–lower crust and dominated by syenite, monzonite and alkali granite. A significant portion of the complex lies beneath Eden Lake or glacial cover, making accurate estimates of its limits difficult. The central part of the complex encompasses an approximately 8 km^2, REE-mineralized and fenite-altered region whose economic potential is currently being investigated. This core region is characterized by a shattered-carapace stockwork of magmatic intrusions and hydrothermal veining with progressive intrusion of rocks ranging from ultramafic and mafic compositions to monzonite, syenite, fluorite-magnetite alkali granite, aplite and quartz-feldspar pegmatite (McRitchie, 1988; Halden and Fryer, 1999; Mumin, 2002a; Mumin and Camier, 2003). Carbonatite dikes and veins intrude the complex in intimate association with mafic, monzonite, syenite and alkali granite phases (Figures GS-7-15, -17).

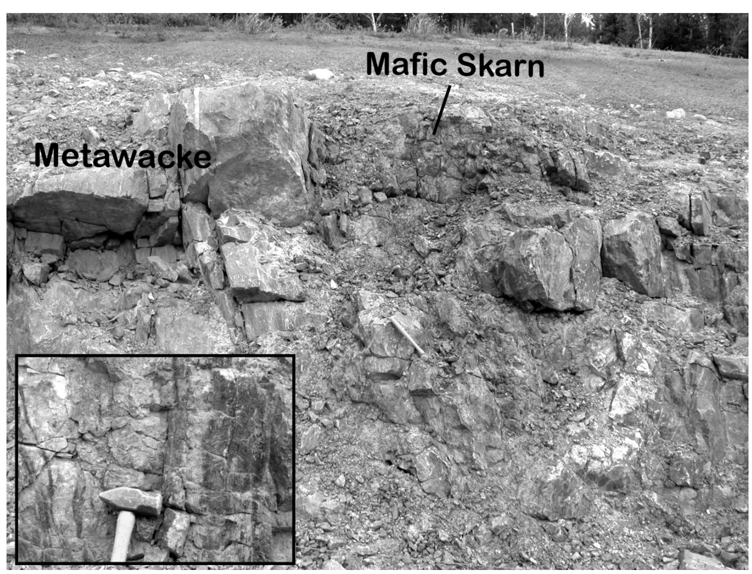

Figure GS-7-20: *Rat River skarn with altered mafic volcanic rocks. Inset is a close-up of banded skarn.*

Figure GS-7-21: *Shearing and hydrothermal alteration of metasedimentary rocks to phyllosilicate schist, Rat River skarn.*

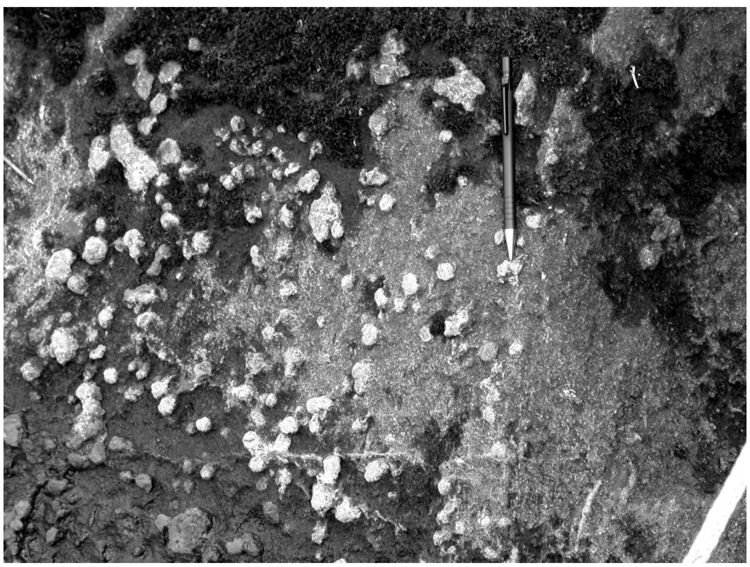

Figure GS-7-22: *Mafic actinolite-garnetite, Opachuanau supracrustal sequence, Italy Bay.*

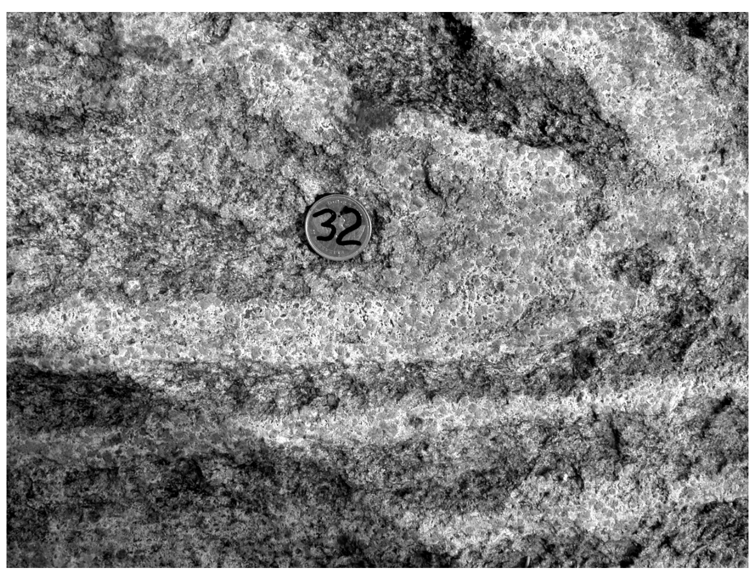

Figure GS-7-23: *Garnetite, Opachuanau supracrustal sequence, Italy Bay (Quarter for scale).*

Figure GS-7-24: *Mafic actinolite-garnetite, Opachuanau supracrustal sequence, Italy Bay.*

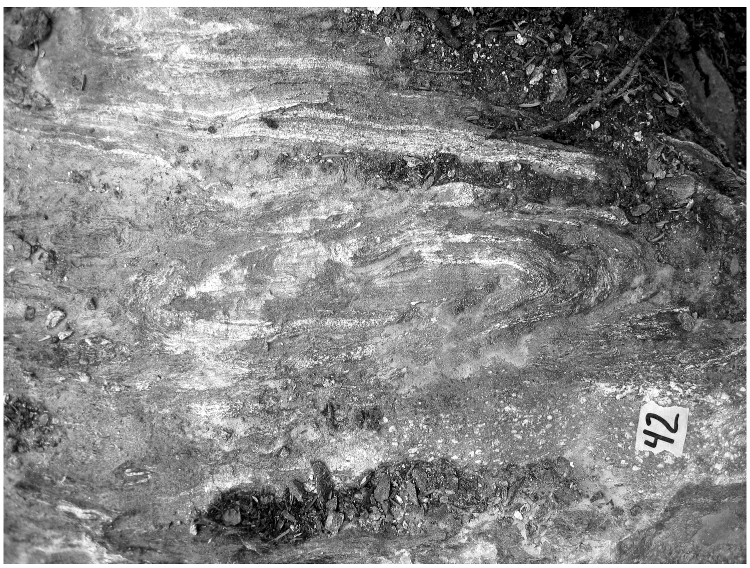

Figure GS-7-25: *Spotted-albite alteration of deformed metasedimentary rocks and mafic intrusions, South Bay drill-road exposure.*

Fenitic alterations are widespread and include clinopyroxene-feldspar veining and pervasive alteration; REE-apatite-clinopyroxene veins; carbonate–K-feldspar zones; carbonate-syenite alteration; and high-grade REE veins comprising allanite, britholite, garnet, albite, clinopyroxene, apatite, titanite and fluorite. Carbonatite dikes, veins and irregular bodies are ubiquitously enriched in reddish brown REE-rich apatite. Assays from mineralized rocks returned values up to 169 000 ppm total REE in high-grade veins and 19 300 ppm total REE from apatite-rich segregations in carbonatite dikes.

The ELC is late in the tectonic history of the EDC and was not subject to the regional high-grade metamorphism and deformation, although shear zones of minor extent occur locally. The complex, however, is the shattered carapace that formed over a large rising pluton and, as such, forms a mega-stockwork of multiple intrusive injections of magma and hydrothermal veining, superimposed upon each successively earlier phase. Stockwork, fault, fracture and shear orientations preserve evidence of three major tectonic lineaments, oriented north, northeast, and east. The latter is of particular interest, as it is believed to be late-stage evidence of the EDC in the Eden Lake region and illustrates that this alkaline complex is likely not anorogenic, as previously proposed by Halden and Fryer (1999) on the basis of the A-type affinity of the granitoid bodies (Figure GS-7-26). It is no coincidence to find a large plutonic complex (such as the ELC) situated at the intersection of crustal lineaments, as these result in zones of maximum crustal weakness. In the summer of 2004, clear evidence of early and severe, pre-ELC deformation was observed on an island at the inlet to Kwaskwaypichikun Bay. Intensely sheared and mylonitized porphyritic granodiorite with an east-trending fabric is intruded by syenite, aplite and pegmatite of the ELC. This pre-ELC porphyritic granitoid is similar to, and could be the same age as, the 1870 Ma

Figure GS-7-26: *Diatreme-like breccia with a syenite-carbonatite matrix in an east-trending structure, central east grid area, Eden Lake.*

Eden Lake porphyritic granite near Provincial Road 391 east of Eden Lake (Turek et al., 2000). This contrasts with a younger age of 1800 Ma for ELC syenite (Böhm, unpublished data, 2003) and apparently brackets the timing of severe deformation within the Eden deformation corridor.

An intracontinental orogenic setting for the ELC could be of economic significance, as it shares similarities with the second largest light rare earth element deposit in China, the Maoniuping deposit. This 1.45 Mt carbonatite-hosted REE deposit belongs to a series of carbonatite and alkaline complexes emplaced in an intracontinental orogenic belt at the eastern margin of the Qinghai–Xizang–West Sichuan Plateau (*see* Wang et al., 2001; Xu et al., 2004). The largest REE deposit in China, and also the largest in the world, is the giant REE-Nb-Fe Bayan Obo deposit. At Bayan Obo, dolomitic marble has been mineralized by carbonatite-derived fluids. At Eden Lake, high-grade REE veins in syenite and monzonite are thought to originate, in a similar manner, from hydrothermal fluids derived from a source carbonatite melt (Mumin, 2002a; Mumin et al., 2003). Carbonatite dikes rich in rare earth elements have also been identified at Bayan Obo (Yang et al., 2003). Additional information on the ELC can be found in Mumin (2002a), Mumin and Camier (2003), and Mumin and Perrin (work in progress).

Wapus Li-Cs-Ta (LCT)–type rare metal pegmatite field

A rare metal pegmatite field with evidence of LCT (Li-Cs-Ta) subtype zoning (Trueman and Cerny, 1982) was discovered in 2004, situated near the northwestern part of the presently documented EDC. The pegmatite field is well exposed along the South Indian Lake road over a distance of 5–6 km, with the most interesting exposure in a roadcut approximately 3 km west-southwest of the old ferry landing on South Bay (Figures GS-7-8, -9, -10). The main hostrock for the pegmatite bodies is the large diorite intrusion briefly discussed above and exposed along the northern margin of the EDC and southwest corner of South Bay (Figures GS-7-6, -7). The southern margin of the diorite is deformed by the EDC (Figure GS-7-2), whereas the pegmatite bodies intrude well-preserved to sheared diorite and metasedimentary rocks, as well as intensely deformed rocks of the deformation corridor. The pegmatite bodies are late in the tectonic history of the belt and remain very well preserved.

As presently understood, the pegmatite bodies exposed within this field range from complex, zoned pegmatite with or without Ta±Be±Cs, to associated granitic pegmatite. They range up to 15 m in exposed thickness, are well zoned and have interesting mineralogy, including K-feldspar (up to 50 cm graphic crystals), albite (including aquamarine saccharoidal and megacrystic varieties), compositionally varied muscovite and other micas (e.g., biotite and/or phlogopite), quartz, beryl, tourmaline, garnet, pyrite-pyrrhotite-arsenopyrite, apatite, triphylite(?) and various unidentified oxides.

The pegmatite bodies are variably zoned, including the following presently recognized mineralogical variations: quartz and quartz-feldspar; fine- to medium-grained, white to aquamarine albitite; saccharoidal albite; megacrystic K-feldspar–muscovite±albite; megacrystic albite-quartz±beryl; muscovite–quartz–K-feldspar±albite; K-feldspar–muscovite±albite; and garnet-feldspar. Internal muscovitequartz after microcline (MQM)–type hydrothermal alterations are present in several of the exposed pegmatite bodies (Figure GS-7-9). Preliminary assays returned values of up to 435 ppm Ta from a grab sample of quartz-albite and black-oxide–bearing pegmatite. Grab samples of muscovite-rich material returned values up to 1.75 wt. % CsO. Further investigation of these pegmatite bodies is in progress.

A further suite of granitic pegmatite bodies, intruding predominantly metasedimentary rocks, was revealed by the 2004 drilling of the South Bay property. They range from less than 1 m to several metres in thickness and comprise quartz, K-feldspar, albite, muscovite, garnet, tourmaline, sulphides and unknown oxides. These pegmatite bodies also include some albitite. It is not known if they are related to the above-mentioned pegmatite bodies. A compositionally banded granitic pegmatite was also observed along the north shore of Italy Bay. Farther north, on the Churchill River, Corrigan and Rayner (2002) reported the presence of a Ta-bearing pegmatite with 57 ppm Nb and 27 ppm Ta.

South Bay Ni-Cu-PGE occurrence

A narrow but high-grade magmatic Ni-Cu-PGE zone occurs within the central part of the EDC corridor approximately 9 km west-southwest of the Rat River outlet from South Bay (Figure GS-7-18). Hostrocks for the occurrence include a swarm of mafic to ultramafic rocks of varying compositions that intrude, and/or are intercalated with, metawacke and metaturbidite as subparallel dikes to irregular bodies along a 3–4 km wide belt within the deformation corridor. The mafic rocks vary from those that are altered and deformed beyond recognition to well-preserved igneous rocks, including gabbro, diabase, high-Ti dolerite and various other compositions with mafic and ultramafic affinities. Nickel sulphides occur along the north contact of a biotite-phlogopite schist with a composition that plots within the field of komatiitic basalt. Emplacement within a major deformation zone can explain the alteration beyond recognition of the mafic hostrock to schist.

To date, high-grade assays were only obtained from a narrow zone of the South Bay roadcut showing (e.g., 2.14% Ni, 0.34% Cu and 1.30 g/t PGE, an average of 11 high-grade boulders recovered from the blast rubble, and 1.2% Ni, 0.21% Cu and 4.99 g/t PGE from a 1.5 m chip sample across the lower east side of the roadcut (Camier, 2004; Figure GS-7-19). Difficulties in tracing the mineralized zone can be attributed, at least in part, to the previously unrecognized severe and extensive deformation of the EDC. Elsewhere in the belt, well-preserved and young high-Ti dolerite exposed in the Rat River is quite interesting for its significant enrichment in PGE (70 ppb) and TiO_2 (3.31 wt. %), and is possible evidence of fertile magmas. Talc-altered ultramafic rocks returned values of 1200 ppm Ni (near Rat River) and 2100 ppm Ni (large boulder near Italy Bay). The South Bay Ni-Cu-PGE occurrence was under active exploration and investigation at the time of writing.

Rat River skarn

The Rat River skarn occurs near the southern boundary of the EDC, near the contact with the Issett Lake tonalite-granodiorite complex. The zone is well exposed in a roadcut approximately 59 km northeast of Leaf Rapids. It comprises metasedimentary rocks intruded by mafic and ultramafic dikes near the south end of the exposure. The roadcut exposes a well-altered sequence of diopside-epidote skarn-like alteration (Figure GS-7-20); talc-chlorite–altered ultramafic rocks; hydrothermal alteration of metasedimentary rocks to clay-mica-chlorite–rich rocks (Figure GS-7-21); clay-mica–altered tonalite dikes; and tectonic breccia with anastomosing feldspar-hematite veining and vuggy quartz stockwork (Figure GS-7-4). The alteration exposed in the roadcut apparently preserves evidence of a temperature gradient away from the contact of the EDC with marginal tonalite-granodiorite, from that which resembles a higher temperature skarn (metasomatism of Ca-rich rocks) to intermediate hydrothermal alterations and lower temperature vuggy quartz stockwork farthest from the contact. Deformation in the zone includes early ductile deformation of metasedimentary rocks, subsequent brittle-ductile shearing and a blocky tectonic breccia zone that hosts the vuggy quartz and/or feldspar stockwork.

Minor mineralization associated with this zone includes pyrrhotite-pyrite with trace to minor malachite, chalcopyrite and bornite. The talc-chlorite–altered ultramafic dike returned a value of 1200 ppm Ni in the only sample analyzed. Altered mafic and ultramafic rocks from the skarn zone returned values of up to 1800 and 1200 ppm Ni, respectively.

Fertile(?) granite

Undeformed and unmetamorphosed granite bodies intrude the EDC. Those recognized to date include a pink, potassic, locally pegmatitic, muscovite-rich granite exposed north of Italy Bay on Opachuanau Lake. It may be related to banded granitic pegmatite present along the north shoreline of Italy Bay, and may also be associated with nearby felsite (Figure GS-7-13). The alkali-rich granite contains 9.22 wt. % Na_2O+K_2O.

A pegmatoid granite with abundant muscovite and biotite forms the bulk of an island in the Rat River where it transects the EDC. The granite is coarse grained and pegmatoid over large areas. Granitic pegmatite masses are also exposed nearby, across the Rat River channel. There is some speculation that it may be the fertile granite responsible for the Wapus rare metal pegmatite field; however, at present there is no direct evidence to support this suggestion.

Foot Lake complex radiometric occurrence

The Foot Lake Complex is located approximately 6 km east of Kwaskwaypichikun Bay of Eden Lake (Foot Lake is referred to as Spur Lake by Young and McRitchie, 1990). It is a late granitic intrusion that lacks evidence of high-grade metamorphism and deformation, and is emplaced within a regional biotite granite. The granite is intruded by abundant (clino?)pyroxene-bearing monzonite, quartz monzonite and syenite. Aplite and quartz-feldspar pegmatite also intrude the complex, and local patches of wispy pyroxene veining invade the above-mentioned rocks. Several exposures of two-feldspar alkali pegmatite occur southeast of Foot Lake. Together, the igneous and hydrothermal dikes and veins form a crude, large-scale intrusive stockwork reminiscent of the Eden Lake complex in a number of respects. Many of the quartz-feldspar pegmatite bodies have dramatic rhythmic zoning, a feature best explained by tensional fracturing and multiple injection of melt into the interior of the same dike (Figure GS-7-11).

The Foot Lake Complex is host to numerous localized zones of high radioactivity (Young and McRitchie, 1990); however, the nature and source of the radioactivity has not been determined. Elsewhere, in related alkali granite of the ELC, high radiometric readings were found to correlate with high concentrations of Zr and with high-grade REE-bearing veins**.** Combined with the Eden Lake complex to the west and possible similar intrusions to the east, these rocks form a suite of young granitic and alkaline intrusions characterized by intrusive stockwork, hydrothermal metasomatism and high radioactivity (McRitchie, 1989). No work is presently being carried out over the Foot Lake Complex, but it warrants further investigation for its U potential, possible carbonatite association or other mineralization related to felsic magmatic-hydrothermal activity.

Opachuanau garnetite-amphibolite

The Eden deformation corridor disrupts a suite of supracrustal metavolcanic rocks where it transects Opachuanau Lake on the Churchill River, approximately 40 km northeast of Leaf Rapids. The supracrustal belt in this region comprises felsic, intermediate, mafic and ultramafic volcanic rocks, and associated intrusions and metasedimentary rocks (Figures GS-7-13, -27), the dominant volcanic rock type being amphibolite. Exposures examined are all variably hydrothermally altered, metamorphosed and/or deformed. Large areas along the shoreline on both the east and west sides of the lake show evidence of severe ductile deformation with abundant boudinage of felsic veins and other more competent layers (Figure GS-7-28).

Along the west side of the lake, significant and locally pervasive epidote alteration is present in some amphibolite (Figures GS-7-28, -29). Local minor garnetite bands, including one with ~1% chalcopyrite are also present in amphibolite. On the east side of the lake in Italy Bay, garnetite and actinolite garnetite zones in amphibolite are widespread.

Figure GS-7-27: *Interlayered felsic-mafic volcanic tuff and/or volcaniclastic rocks, Opachuanau supracrustal sequence, Italy Bay.*

Figure GS-7-28: *Epidote-flooded amphibolite with boudinaged felsic veins, Opachuanau supra-crustal sequence.*

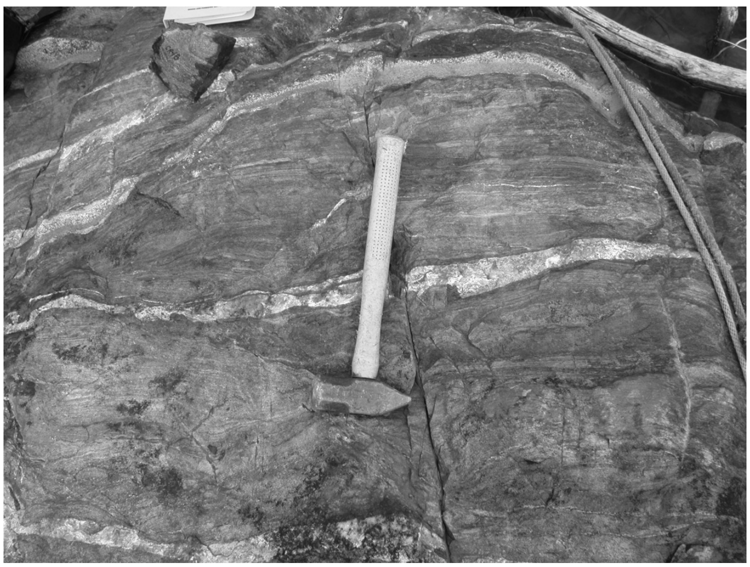

Figure GS-7-29: *Epidote-flooded amphibolite with quartz-feldspar veins, Opachuanau supra-crustal sequence.*

Examples include shoreline exposures in excess of 70 m. The garnetite contains up to 60% almandine garnet (Figures GS-7-22, -23) and actinolite garnetite examined contains up to 30% and 25% actinolite and garnet, respectively (Figure GS-7-24).

The presence of abundant garnet and actinolite in metamorphosed mafic rocks requires compositional modification of the rocks by hydrothermal leaching prior to metamorphism. In particular, leaching of Na, K and Mg±Ca of a mafic precursor leaves behind an Fe-rich aluminous composition that favours metamorphic formation of a garnet-amphibole±actinolite assemblage. The type of compositional modification required can result from hydrothermal alteration associated with volcanic-hosted massive sulphide– or sedimentary-exhalative (SEDEX)–type systems.

Italy Bay radiometric anomaly

A radiometric K, U and Th anomaly was identified 1–2 km east of Italy Bay, and targeted for follow-up investigation during the Manitoba hydrothermal Fe-oxide Cu-Au (IOCG)–Olympic Dam regional scoping study (Mumin 2002b; Mumin and Trott, 2003; Mumin and Perrin, work in progress). The site is interesting because of a high point-source U and Th anomaly and moderate to weak K anomaly, apparently hosted in tonalite. In light of the present investigation, it is also apparent that this radiometric source lies along a major crustal deformation zone. This site has not yet been visited on the ground, although the region along strike around Italy Bay and Opachuanau Lake has been scouted. Here, Ca, Na and K metasomatism have been documented and are relatively widespread. The alteration includes epidote flooding in amphibolite (Figure GS-7-28, -29), Na-rich porphyry with epidote and pyrite (Figure GS-7-14), and K-rich felsite of igneous origin with minor hematite and magnetite (Figure GS-7-13). At present, there is no direct evidence to link any of the alteration to IOCG-type mineralization, but these types of alteration are widespread around some IOCG systems (e.g., NICO and Sue-Dianne in the Great Bear Magmatic Zone, Northwest Territories; Goad et al., 2000a, 2000b). Further work is recommended for this region.

South Bay albite zone

Spotted albite was first recorded from drillcore during the 2004 winter drill program on the South Bay property (Camier, 2004), and is also well exposed under the winter drill road west of the South Bay road. Albite occurs as porphyroblastic, subhedral grains ranging from less than 1 mm to 7 mm in size. The occurrence of albite is widespread in banded zones throughout both the metasedimentary rocks and the mafic intrusions (Figure GS-7-25). The drill road also exposes an intercalated sequence of severely deformed mafic intrusive rocks and metawacke, with up to 40% porphyroblastic subhedral albite in centimetre- to metre-thick spotted bands over large sections of the exposed rocks. The albite porphyroblasts are preferentially oriented parallel to the axial plane of subvertical isoclinal folds with subvertical fold axes in the EDC. Adjacent vertical sheath folds and a locally well-developed vertical mineral lineation are also observed. The distribution of the albite porphyroblasts is compatible with a late-shearing metasomatic event. The source of this metasomatic alteration is presently unknown, although there are several possibilities, including 1) albite-amphibolite–facies metamorphism with a late-shearing Na-flushing front indicative of high-pressure and relatively low-temperature alteration, and 2) igneous intrusion–related alteration focused in an active shear zone. Considering its location in the central portion of a large deformation corridor, the syn- to late-deformation timing of the albite alteration and the presence of abundant late felsic to mafic intrusions within the EDC, both an igneous-related source for the alteration and deep-seated metasomatism are possible explanations.

Sulphide-facies iron formation

Several subparallel, east-southeast-striking and north-dipping bands of intermittent sulphide-facies iron formation were intersected during the 2004 winter drill program on the South Bay property. The iron formations are up to 60 m thick and locally contain up to 40% pyrrhotite, minor pyrite ± trace amounts of chalcopyrite in anastomosing veins and disseminations (Camier, 2004). The iron formations are hosted in metasedimentary rocks, and current drilling and geophysical surveys indicate that they may be fairly widespread within at least parts of the EDC. The sulphide iron formations are affected by deformation within the EDC, making their origin somewhat obscure. Both syn- and epigenetic origins are possible.

Johnson Shear Zone and granite-hosted Fe-oxide breccia

Detailed structural analysis and U-Pb geochronology of the Johnson Shear Zone and host Lynn Lake greenstone belt constrain the age of regional dextral transpression and shear-hosted Au mineralization to have taken place ca. 1819 Ma, which postdates the assembly of juvenile and contaminated volcanic arc belts and the emplacement of successor-arc plutons. The shear zone served as a conduit for the metamorphic fluids that led to Au mineralization (Beaumont-Smith and Böhm, 2003). It is crosscut by syenitic dikes, one of which yielded a titanite age of 1766 Ma. East of the Hughes Lake boat launch road, a medium-grained salmon pink granite was found to host a magnetite breccia with minor disseminated Fe sulphides (UTM Zone 14, 408213mE, 6294033mN, NAD 83). The breccia extends for a few metres and consists of sparse millimetre- to centimetre-wide veins of very fine grained magnetite. The host granite crosscuts folded zones of silicification and veins of epidote within the shear zone, and is itself locally sheared. Zones of alteration (sodic?) were also encountered at the intersection between the Hughes Lake boat launch road and Provincial Road 391. Although of minor extent, the presence of a granite-hosted magnetite breccia and alterations within a regional-scale shear zone bears similarities to Fe-oxide Cu-Au settings. This occurrence is another example of late intrusion–associated mineralization hosted within crustal-scale structures of the Trans-Hudson Orogen.

Discussion

The Eden deformation corridor (EDC) and polymetallic mineral belt forms an approximately 5–8 km wide belt that extends in an easterly direction from Eden Lake for a presently documented minimum distance of 80 km to beyond the Rat River. The western and eastern limits of the belt remain undelimited. Deformation is intense but variable across the belt in alternating higher and lower strain zones. In some areas, well-preserved igneous and metasedimentary rocks lie juxtaposed to equivalent rocks that are deformed beyond recognition. Deformation includes ductile flow, boudinage and mylonitization intercalated with narrow bands of felsic veins. Narrow to wide zones of annealed fault breccia are also present. These early-deformed rocks were disrupted by younger and structurally higher level tectonization that may be synchronous with D_6 deformation at Lynn Lake (Beaumont-Smith and Edwards, 2000). This produced brittle-ductile to brittle shearing and fracturing, schist, mica-clay alteration, fault gouge and tectonic breccia zones with open stockwork veining.

Geotectonic history and setting of the Eden deformation corridor

A sequence of events is preserved in rocks of the EDC, allowing a reconstruction of at least part of its geotectonic history. Oldest rocks of the belt appear to be metasedimentary rocks (wacke and turbidite). They are intruded by an early suite of ultramafic, mafic and felsic rocks, at least some of which are probable feeders for a former, overlying, supracrustal volcanic belt. At present, the supracrustal volcanic rocks are only confirmed in the Opachuanau Lake region. Evidence of early brittle or brittle-ductile faulting is preserved in the annealed fault breccias. These zones appear to have been tectonized at higher levels within the crust, prior to the high-grade metamorphism and intense deformation that characterizes the EDC. This high-grade deformation and metamorphism necessarily occurred during deep burial. A long period of subsequent uplift, exhumation and extension followed, with intrusion of abundant felsic, intermediate, alkaline, mafic and ultramafic rocks. High-Ti dolerite intrudes a late, pegmatoid, mica-rich granite exposed on an island in the Rat River, demonstrating the long history of pre-, syn- and post-deformation emplacement of mafic rocks into the structural corridor.

The interesting variety of geotectonic features and compositional variations that characterize the Eden deformation corridor seemingly defy simple explanation. Nevertheless, the observations can be explained in several ways. The spotted albite zone in association with mylonitized rocks observed southwest of South Bay suggests that sodic alteration took place along the EDC during the later stages of shearing. Furthermore, albite-amphibolite–facies metamorphism is indicative of high-pressure, low-temperature conditions. The EDC may be the exhumed, relatively deep levels of a subduction front beneath an island-arc complex. The Opachuanau supracrustal volcanic suite may be an arc remnant that was in the process of suturing to and partially subducting beneath a growing Hearne cratonic margin. The abundance of intrusions into the EDC and the widespread evidence of extensional features indicate that the subduction front must have been subject to a period of extension, a natural consequence of rollback and collapse of a subducting slab. The transition from compressional to extensional tectonics would cause pressure release on a regional scale. It is of interest to note that the EDC is located above a crustal-scale ramp, the Granville Lake structural zone, a few kilometres north of a dramatic crustal offset between the lower crust of the Lynn Lake arc and the crustal root beneath the Kisseynew Domain (cf. White et al., 2000, Figure 3). This crustal break is interpreted to have been preserved since 1.8 Ga and may have been instrumental in the formation of a major fault zone. Collapse of the subducting slab and rollback can also bring hot mantle beneath an arc that is undergoing extension and possible thinning. The evidence for hot thin crust beneath this portion of the Trans-Hudson Orogen has been recently discussed by Zwanzig (2004). A broad range of upper-mantle and crustal melts is plausible in this type of setting, and a rifting arc would have provided conduits for ascending magmas of varying composition into the already complex subduction front.

It is most interesting that deep crustal seismic profiles across the giant Olympic Dam deposit in Australia reveal a dramatic crustal break and offset directly beneath the deposit, and place the Olympic Dam deposit in an orogenic setting (Lyons et al., 2004). This fundamental new information about the Olympic Dam deposit presents a striking parallel with the geotectonic setting for the Eden deformation corridor.

Island-arc complexes associated with the EDC may include the Lynn Lake greenstone belt, situated immediately to the north, as well as the Opachuanau supracrustal suite. The Rusty Lake greenstone belt to the south is only separated from the EDC by late intrusion of the Issett Lake tonalite suite, and may therefore be more closely linked to the EDC than is apparent from surface geological mapping. Further evidence of former regional north-dipping subduction has been presented by Zwanzig (1990), White et al. (2000) and Zwanzig and Böhm (2002) along the northern margin of the Kisseynew Domain. Here, accretionary sedimentary rocks are disrupted by a series of north-dipping thrust sheets. Ductile deformation with high-grade metamorphism suggest that the EDC exposes a deeper section of the subduction front, whereas the northern margin of the Kisseynew Domain displays evidence of a somewhat higher level section of a sediment-dominated accretionary complex.

Economic considerations

A range of geological and tectonic features, and styles of mineralization and alteration is spatially and genetically associated with a previously unrecognized geotectonic belt southeast of and parallel to the Au-mineralized Johnson Shear Zone. The belt has been named the Eden deformation corridor (EDC) and hosts the Eden polymetallic mineral belt. It is located structurally above a major collisional suture zone that marked the end of northward subduction beneath the Lynn Lake and adjacent greenstone belts. A variety of igneous and/or hydrothermal styles of mineralization and alteration is documented along this belt, and it is probable that others have yet to be recognized. The limits and extent of this belt remain unknown, but the magnitude of the structure (approx. 5-8 km in width and a minimum of 80 km in strike length) suggests that it may extend well beyond Eden Lake to the west and Rat River–South Bay to the east. There is even the possibility that this structural belt may be associated with some of the tectonic belts that run parallel to and north of the Superior Boundary Zone, a distance of several hundred kilometres. Moreover, Paleoproterozoic terranes that formed through lateral accretion of magmatic arcs at the margin of an Archean craton and that host orogenic Au occurrences and A-type magmatic suites are key targets for IOCG deposits. This type of setting has recently been inferred for the Hiltaba intrusive suite of the Gawler craton and the giant 2880 Mt Olympic Dam Cu-Au-Ag-U IOCG deposit (Ferris and Schwarz, 2003). At Olympic Dam, the Fe-oxide breccia that hosts the orebody is fully enclosed within the A-type Roxby Downs granite, a member of the craton-wide felsic to mafic Hiltaba intrusive suite (Haynes et al., 1995; Reynolds, 2000). The Hiltaba suite forms, with the Gawler Range volcanic rocks, a very fertile ca. 1.59 Ga intracontinental back-arc extensional setting (Skirrow et al., 2002; Ferris and Schwarz, 2003). East of the Olympic Dam Cu-Au province is the orogenic Au province of the central Gawler craton (Ferris and Schwarz, 2003).

The EDC remains essentially unexplored, with the exception of ongoing work at the Eden Lake Carbonatite Complex and the South Bay Ni-Cu-PGE occurrence. Based on the geotectonic setting, alteration and mineralization observed within the belt, the Eden deformation corridor and polymetallic mineral belt is presently considered prospective for the following styles of mineralization:

- Rare earth metal carbonatite (e.g., Eden Lake Carbonatite Complex)
- Rare metal pegmatite bodies (e.g., Wapus rare metal pegmatite field)
- Magmatic Ni-Cu-PGE (e.g., South Bay Ni-Cu-PGE occurrence; high-Ti dolerite with anomalous PGE values)
- Sn, W, U and/or Th associated with felsic intrusions (e.g., Foot Lake Complex; other potassic and alkaline intrusions)
- IOCG-type deposits (e.g., Eden Lake Carbonatite Complex and other targets along the belt)
- Lode Au: major geotectonic structural belt associated with subduction and widespread sulphidic shear zones, compositionally varied intrusions, and parallel to the fertile Johnson Shear Zone
- Iron formation–hosted Au (e.g., sulphide-facies iron formations and sulphidic shears in a major deep-seated geotectonic belt)
- SEDEX deposits: sulphide-facies iron formations in a rifted, sediment-hosted, intrusion-rich accretionary fore-arc(?) basin
- Volcanogenic massive sulphides (e.g., garnet-actinolite amphibolite of the Opachuanau supracrustal suite).

Considering the potential mineral endowment of the EDC, detailed geological mapping and sampling are warranted along the entire length of the corridor to help document its potential and direct further work. Such work also needs to be carried out along eastward and westward extensions of the belt. Significant challenges arise in exploring the region, however, due to the lack of access in many areas, lack of significant outcrop over large tracts and the difficulties that arise when trying to interpret rocks that have been subjected to very high degrees of metamorphism, deformation and/or hydrothermal alteration. At present, the best access routes through the corridor are Eden Lake, Provincial Road 391, the Churchill River and the South Bay road. In areas of little outcrop, geochemistry, including Enzyme Leach[SM] and geobotanical methods, may be effective in helping to select targets.

A regional, high-resolution, airborne geophysical survey appears necessary and warranted. Given the types of mineralization and alteration that have been documented, the survey should include multiparameter magnetic, radiometric and electromagnetic components. A government or government-industry collaborative survey of this type may prove to be highly effective in stimulating new exploration along this prospective belt. In conjunction with the geophysics, certain types of satellite remote sensing might detect geochemical anomalies in vegetation, soils and/or outcrop; given the potential for anomalous mineralization to occur along the belt, this type of database might be helpful.

Multiparameter exploration, including geological, geophysical and geochemical surveys, and sustained effort are recommended for exploration of this region in order to determine the full economic potential of the belt.

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References

Baxter, S. and Feely, M. 2002: Magma mixing and mingling textures in granitoids: examples from the Galway Granite, Connemara, Ireland; Mineralogy and Petrology, v. 76, p. 63–74.

Beaumont-Smith, C.J. 2000: Structural analysis of the Johnson Shear Zone in the Gemmell Lake–Dunphy Lakes area, Lynn Lake greenstone belt (parts of NTS 64C/11, /12); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 57–63.

Beaumont-Smith, C.J. and Böhm, C.O. 2003: Tectonic evolution and gold metallogeny of the Lynn Lake greenstone belt, Manitoba (NTS 64C10, 11, 12, 14, 15 and 16); *in* Report of Activities 2003, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 39–49.

Beaumont-Smith, C.J. and Edwards, C.D. 2000: Detailed structural analysis of the Johnson Shear Zone in the west Gemmell Lake area (NTS 64C/11); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 64–68.

Camier, J. 2004: Technical report on the fall 2003 geological mapping and geochemical sampling and the 2004 winter drilling programs, South Bay Ni project, South Bay, Manitoba; internal technical report for Rare Earth Metals Corporation, Vancouver, British Columbia.

Corrigan, D. and Rayner, N. 2002: Churchill River–Southern Indian Lake Targeted Geoscience Initiative (NTS 64B, 64C, 64G, 64H), Manitoba: update and new findings; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 144–158.

Corriveau, L. and van Breemen, O. 2000: Docking of the Central Metasedimentary Belt to Laurentia in geon 12: evidence from the 1.17–1.16 Ga Chevreuil intrusive suite and host gneisses, Quebec; Canadian Journal of Earth Sciences, v. 37, p. 253–269.

Corriveau, L., Rivard, B. and van Breemen, O. 1998: Rheological controls on Grenvillian intrusive suites: implications for tectonic analysis; Journal of Structural Geology, v. 20, p. 1191–1204.

Ferris, G.M. and Schwarz, M.P. 2003: Proterozoic gold province of the central Gawler craton; MESA Journal, v. 30, p. 4–12.

Goad, R.E., Mumin, A.H., Duke, N.A., Neale, K.L. and Mulligan, D.L. 2000a: Geology of the Proterozoic iron oxide-hosted NICO cobalt-gold-bismuth, and Sue-Dianne copper-silver deposits, southern Great Bear Magmatic Zone, Northwest Territories, Canada; *in* Hydrothermal Iron Oxide Copper-Gold and Related Deposits: A Global Perspective, T.M. Porter (ed.), Australian Mineral Foundation, p. 249–267.

Goad, R.E., Mumin, A.H., Duke, N.A., Neale, K.L., Mulligan, D.L. and Camier, W.J. 2000b: The NICO and Sue-Dianne Proterozoic, iron-oxide-hosted polymetallic deposits, Northwest Territories: application of the Olympic Dam model in exploration; Exploration and Mining Geology, v. 9-2, p. 123–140.

Halden, N.M. and Fryer, B.J. 1999: Geochemical characteristics of the Eden Lake Complex: evidence for anorogenic magmatism in the Trans-Hudson Orogen; Canadian Journal of Earth Sciences, v. 36, p. 91–103.

Haynes, D.W., Cross, K.C., Bills, R.T. and Reed, M.H. 1995: Olympic Dam ore genesis: a fluid-mixing model; Economic Geology, v. 90, p. 281–307.

Lewry, J.F. and Collerson, K.D. 1990: The Trans-Hudson Orogen: extent, subdivision, and problems; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 1–14.

Lyons, P., Drummond, B.J., Goleby, B.R., Schwarz, M., Shearer, A.J., Fairclough, M.C. and Skirrow, R.G. 2004: General basement interpretation (^{18}S data); *in* Gawler Craton 2004: State of Play, Gawler Craton Seismic Workshop Notes, Adelaide, Australia, p. 53–61.

Manitoba Energy and Mines 1986: Granville Lake, NTS 64C; Manitoba Energy and Mines, Geological Services, Bedrock Geology Compilation Map Series, NTS 64C, scale 1:250 000.

Manitoba Energy and Mines 1986: Uhlman Lake, NTS 64B; Manitoba Energy and Mines, Geological Services, Bedrock Geology Compilation Map Series, NTS 64B, scale 1:250 000.

McRitchie, W.D. 1988: Alkaline intrusions of the Churchill Province: Eden Lake (64C/9); *in* Report of Activities 1988, Manitoba Energy and Mines, Minerals Division, p. 5–11.

McRitchie, W.D. 1989: Ground scintillometer reconnaissance of the Eden Lake aegirine-augite monzonite; *in* Report of Activities 1989, Manitoba Energy and Mines, Minerals Division, p. 7–12.

Mumin, A.H. 2002a: Discovery of a carbonatite complex at Eden Lake (NTS 64C9); *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 187–197.

Mumin, A.H. 2002b: Scoping study for hydrothermal iron-oxide copper-gold deposits (Olympic Dam–type), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 303–308.

Mumin, A.H. and Camier, J. 2003: Geology and rare earth metal mineralization of the Eden Lake carbonatite complex, Manitoba; technical report prepared for Rare Earth Metals Corporation, Vancouver, British Columbia, 82 p.

Mumin, A.H. and Trott, M. 2003: Hydrothermal iron-sulphide copper-graphite mineralization in the northern Kisseynew Domain, Trans-Hudson Orogen, Manitoba (NTS 63O and 64B): evidence for deep-seated IOCG (Olympic Dam)-style metal deposition? *in* Report of Activities 2003, Manitoba Industry, Economic Development and Mines, Manitoba Geological Survey, p. 79–85.

Mumin, A.H., Camier, J., Couëslan, C. and Trott, M. 2003: The extraordinary rare metal vein complex, Eden Lake, Manitoba (poster); Manitoba Mining and Minerals Convention 2003, Winnipeg, Manitoba.

Paterson, S.R. and Tobish, O.T. 1988: Using pluton ages to date regional deformations: problems with commonly used criteria; Geology, v. 16, p. 1108–1111.

Paterson, S.R., Fowler, T.K., Jr., Schmidt, K.L., Yoshinobu, A.S., Yuan, E.S. and Miller, R.B. 1998: Interpreting magmatic fabric patterns in plutons; Lithos, v. 44, p. 53–82.

Pavlis, T.L. 1996: Fabric development in syn-tectonic intrusive sheets as a consequence of melt-dominated flow and thermal softening of the crust; Tectonophysics, v. 253, p. 1–31.

Reynolds, L.J. 2000: Geology of the Olympic Dam Cu-U-Au-Ag-REE deposit; *in* Hydrothermal Iron Oxide Copper-Gold and Related Deposits: A Global Perspective, T.M. Porter (ed.), Australian Mineral Foundation, p. 93–104.

Rogge, D., Beaumont-Smith, C. and Halden, N.M. 2003: Application of data integration for deformation potential mapping using remotely acquired data sets within the Lynn Lake greenstone belt, northwestern Manitoba, Canada; Canadian Journal of Remote Sensing, v. 29, p. 458–471.

Sawyer, E.W. 1999: Criteria for the recognition of partial melting; Physics and Chemistry of the Earth, v. 24, p. 269–279.

Skirrow, R.G., Bastrakov, E., Raymond, O.L, Davidson, G. and Heithersay, P. 2002: The geological framework, distribution and controls of Fe-Oxide Cu-Au mineralisation in the Gawler Craton, South Australia; *in* Hydrothermal Iron Oxide Copper-Gold and Related Deposits: A Global Perspective, T.M. Porter (ed.), Australian Mineral Foundation, p. 33–47.

Trueman D.L. and Cerny P. 1982. Petrogenesis of granitic pegmatites; *in* Granitic Pegmatites in Science and Industry, P. Cerny (ed.), Mineralogical Association of Canada, Short Course Handbook, p. 463– 491.

Turek, A., Woodhead, J. and Zwanzig, H.V. 2000: U-Pb age of the gabbro and other plutons at Lynn Lake (part of NTS 64C); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 97–104.

Vernon, R.H. 1986: K-feldspar megacrysts in granites – phenocrysts, not porphyroblasts; Earth-Science Reviews, v. 23, p. 1–63.

Wang, D.H., Yang, J., Yan, S., Xu, J., Chen, Y., Pu, G. and Luo, Y. 2001: A special orogenic-type rare earth element deposit in Maoniuping, Sichuan, China: geology and geochemistry; Resource Geology, v. 51, p. 177–188.

White, D.J., Zwanzig, H.V. and Hajnal, Z. 2000: Crustal suture preserved in the Paleoproterozoic Trans-Hudson Orogen, Canada; Geology, v. 29, p. 527–530.

Xu, C., Zhang, H., Huang, Z., Liu, C., Qi, L., Li, W. and Guan, T. 2004: Genesis of the carbonatite-syenite complex and REE deposit at Maoniuping, Sichuan Province, China: evidence from Pb isotope geochemistry; Geochemical Journal, v. 38, p. 67–76.

Yang, X.-M., Yang, X.-Y., Zheng, X.-Y. and Le Bas, M.J. 2003: A rare earth element-rich carbonatite dyke at Bayan Obo, Inner Mongolia, North China; Mineralogy and Petrology, v. 78, p. 93–110.

Young, J. and McRitchie, W.D. 1990: REE investigations, Eden Lake intrusive suite (NTS 64C/9); *in* Report of Activities 1990, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 9–19.

Zwanzig, H.V. 1990: Kisseynew gneiss belt in Manitoba: stratigraphy, structure, and tectonic evolution; *in* The Early Proterozoic Trans-Hudson Orogen of North America, J.F. Lewry and M.R. Stauffer (ed.), Geological Association of Canada, Special Paper 37, p. 95–120.

Zwanzig, H.V. 2004: Hot, thin and mineral-rich evolution of the Paleoproterozoic Trans-Hudson Orogen in western Canada (abstract); Geological Association of Canada, Howard Street Robinson Distinguished Lecturer, 2004–2005, abstract available in this volume and online at URL <http://www.esd.mun.ca/~gac/OutReach/tour.htm#HSR> (accessed 25-Oct-04).

Zwanzig, H.V. and Böhm, C.O. 2002: Tectonostratigraphy, Sm-Nd isotope and U-Pb age data of the Thompson Nickel Belt and Kisseynew north and east margins (NTS 63J, 63O, 63P, 64A, 64B), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 102–114.