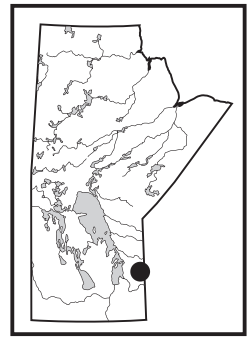
GS-11 Stratigraphic and structural setting of gold mineralization in the Lily Lake area, Rice Lake greenstone belt, Manitoba (NTS 52L11, 14)

by S.D. Anderson



Anderson, S.D. 2007: Stratigraphic and structural setting of gold mineralization in the Lily Lake area, Rice Lake greenstone belt, Manitoba (NTS 52L11, 14); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 114–128.

Summary

Bedrock geological mapping in the Lily Lake area of the Rice Lake greenstone belt has resulted in an improved understanding of the stratigraphy and structure of the Neoarchean Edmunds assemblage, as well as the nature and setting of its contained gold occurrences. In the study area, the Edmunds assemblage consists predominantly of turbiditic siliciclastic rocks that overlie arc-rift volcanic and volcaniclastic rocks of the Gem assemblage along a well-exposed depositional contact. Gold mineralization is hosted by a distinctive association of rock types that include thick-bedded, pebbly quartz greywacke, magnetite iron formation, tonalite-clast–bearing conglomerate, and mafic extrusive and intrusive rocks. These rocks were likely deposited in a very dynamic marginal-marine setting, characterized by voluminous clastic sedimentation, active mafic magmatism and episodic exhalitive activity. Map patterns and younging criteria indicate the presence of tight, upright macroscopic folds, which are extensively overprinted and disrupted by shear fabrics and Z-asymmetric folds that record progressive dextral-transcurrent shear deformation late in the regional orogenic history. The overprinting structures are particularly pervasive and intense within a 500–1000 m thick, east-trending zone that is referred to as the Lily–Banksian deformation corridor. Significant gold occurrences are localized within or along the margins of this corridor, and include three distinct styles of mineralization: shear-hosted quartz-sulphide veins; fault-controlled stockwork-breccia veins and silica-sulphide replacements; and sulphidized iron formation. The tectonic setting, lithostratigraphy and style of these gold occurrences are analogous to economically important lode-gold districts in the Archean Superior and Hearne cratons.

Introduction

The Lily Lake area is located approximately 155 km northeast of Winnipeg in the southeastern portion of the Archean Rice Lake greenstone belt, near the interface between the mainly metavolcanic Uchi Subprovince and the mainly metasedimentary English River Subprovince of the western Superior Province (Figure GS-11-1). During the 2007 field season, three weeks of bedrock geological mapping (1:20 000 scale) were completed in the Lily Lake area in order to refine and expand upon the geological mapping completed in 2006 (Anderson, 2006a, b), which was mainly focused at Gem Lake. The objectives of this study are to document the stratigraphy and structure of the Lily Lake area and gain insight into the nature and setting of its contained gold occurrences. Impetus for this work was provided by the recent discovery of the Roberto gold deposit on the Éléonore property in the James Bay district of Quebec, which is hosted by metasedimentary rocks of the Opinaca Subprovince, near the interface with the mainly metavolcanic La Grande Subprovince, in a setting that is analogous to the English River–Uchi interface in Manitoba. Although traditionally considered less prospective than the adjacent metavolcanic rocks, the discovery of this metasediment-hosted deposit, which is reported to contain an indicated and inferred gold resource of 2.76 million ounces (Simoneau et al., 2007), evidences significant exploration potential.

Regional geology

The Lily Lake area is located in the southeastern portion of the Archean Rice Lake greenstone belt, near the southern margin of the volcano-plutonic Uchi Subprovince of the western Superior Province. In Manitoba, the Rice Lake belt is flanked to the north by the ca. 3.0 Ga continental North Caribou Terrane and to the south by ca. 2.69 Ga metasedimentary rocks and granitoid plutons of the English River Subprovince (Figure GS-11-1). The southern boundary of the North Caribou Terrane is defined by the Wanipigow Fault, which is an east-southeast-trending, subvertical, crustal-scale structure that can be traced along strike for more than 170 km to Red Lake, Ontario. The Uchi–English River boundary is defined by the Manigotagan Fault, which is a similarly oriented structure that can be traced for more than 400 km along strike and is continuous with the Sydney Lake–Lake St. Joseph Fault in Ontario.

Supracrustal rocks in the southeastern portion of the Rice Lake belt constitute several distinct lithotectonic assemblages (*see* Figure GS-11-1; e.g., Poulsen et al., 1996; Bailes et al., 2003), which are interpreted to record continental- and oceanic-arc magmatism, and synorogenic sedimentation within an interpreted north-verging subduction-accretion complex that developed over a 300 Ma time period along the southern margin of the North Caribou Terrane (e.g., Stott and Corfu, 1991; Percival et al., 2002, 2006).

The Garner assemblage consists of a north-younging succession of ca. 2.87–2.9 Ga continental-arc

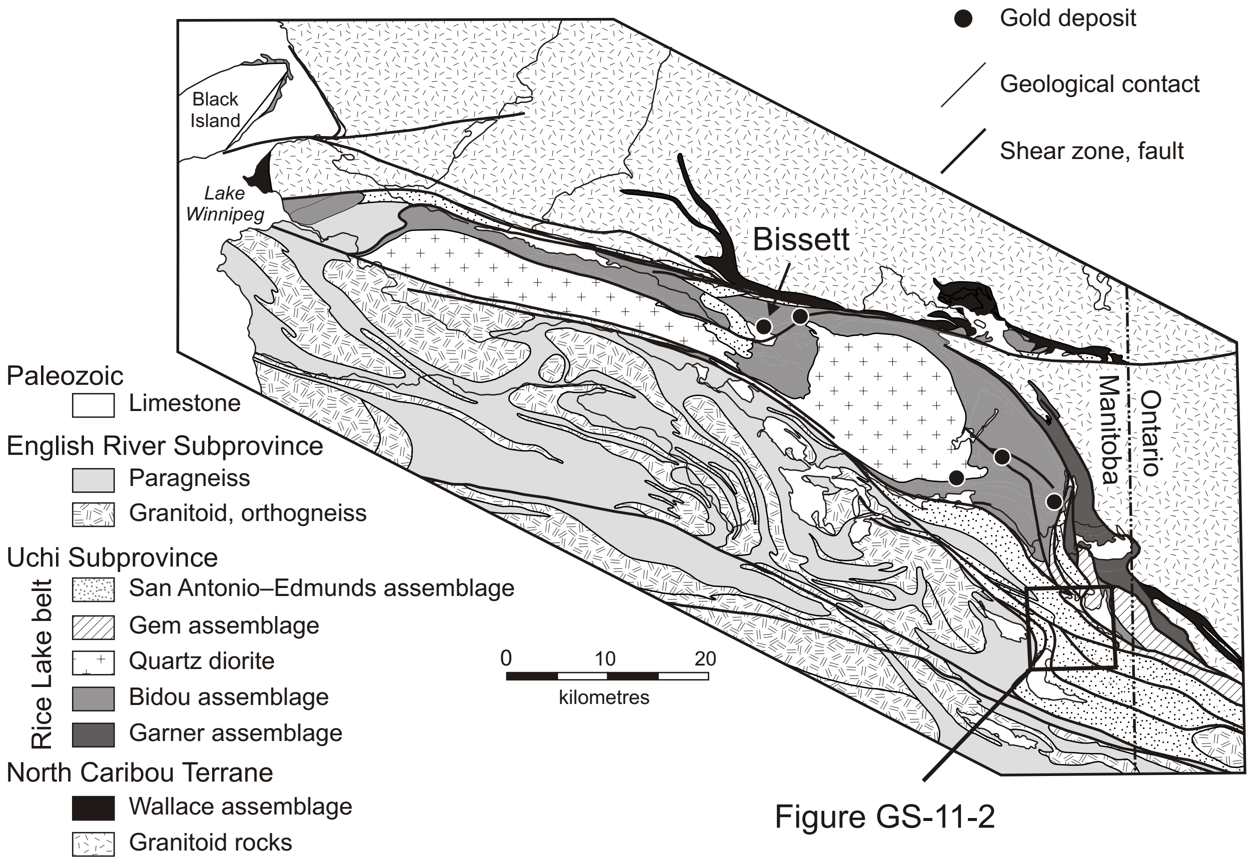


Figure GS-11-1: *Simplified regional geology of the Rice Lake greenstone belt, showing the principal lithotectonic assemblages and the location of Figure GS-11-2.*

volcaniclastic rocks and plume-related magmatic rocks (Hollings et al., 1999; Anderson, 2006a) that defines the northeastern margin of the Rice Lake belt, and is juxtaposed to the west across the Beresford Lake Shear Zone with the Neoarchean Bidou, Gem and Edmunds assemblages. The Bidou assemblage defines a macroscopic anticlinal culmination in the core of the Rice Lake belt (the Beresford anticline) and is intruded by several synvolcanic tonalite and granodiorite plutons, of which the ca. 2.73 Ga (Turek et al., 1989) Ross River pluton is the most prominent example. The lower portion of the assemblage consists mainly of mid-ocean-ridge (MORB)–like tholeiitic basalt flows, whereas the upper portion consists of a 2.5 km thick succession of ca. 2.73 Ga (Turek et al., 1989) volcaniclastic dacite, which is interpreted to represent an upward transition from back-arc to oceanic-arc magmatism (e.g., Poulsen et al., 1996; Bailes et al., 2003).

As described by Anderson (2005), the Gem assemblage is interpreted to record the initiation of an arc-rift basin within the Bidou oceanic arc (i.e., a possible fore-arc rift; Poulsen et al., 1996). The lower portion of the assemblage consists of a ca. 2.72 Ga (Davis, 1994), subaerial to shallow subaqueous, rhyolitic vent complex composed of high-silica rhyolite flows, coarse flow-lobe breccia units and hypabyssal intrusions (cryptodomes), with minor pumiceous pyroclastic rocks and derived epiclastic rocks. The rhyolite flows and pyroclastic rocks classify as FII- and FIIIa-type rhyolite in the scheme of Lesher et al. (1986), with high-field-strength-element signatures indicative of extension-related, within-plate volcanism (Anderson, 2005). The vent complex is overlain by a thick, possibly rift-fill succession of heterolithic volcaniclastic rocks that includes minor flow-banded to massive dacite and rhyolite flows, gabbro sills, pillowed basalt and basaltic andesite flows, and well-stratified epiclastic rocks.

The Edmunds assemblage concordantly overlies the Bidou and Gem assemblages, and is composed of a thick succession of basinal siliciclastic rocks that consist mainly of monotonous greywacke-mudstone turbidite, with subordinate units of coarse quartz greywacke, polymictic conglomerate and discontinuous layers of chert and iron formation. South of Gem Lake, pillowed basalt flows and dacitic volcaniclastic rocks that were previously considered part of the Gem assemblage (Weber, 1971) are interstratified with the Edmunds assemblage at a variety of scales (e.g., Weber, 1987), indicating that basin infilling was accompanied by mafic and possibly felsic magmatism. Uranium-lead dating of detrital zircons and crosscutting plutons (e.g., Corfu et al., 1995; Davis, 1996) constrain deposition to ca. 2.71–2.70 Ga, coeval with accretion-related orogenesis along the margin of the North Caribou Terrane. These rocks likely represent distal equivalents to the fluvial-alluvial clastic rocks of the ca. 2.70 Ga San Antonio assemblage, which unconformably overlie the Bidou assemblage and occur in discrete, possibly fault-bounded basins adjacent to the Wanipigow Fault.

The English River Subprovince flanks the Uchi Subprovince to the south and consists of ca. 2.69 Ga paragneiss, orthogneiss and granitoid plutons that formed during high-T–low-P regional metamorphism of a thick succession of ca. 2.7 Ga marine turbiditic sedimentary rocks (Corfu et al., 1995) that are the distal equivalents to the Edmunds assemblage. Along the south margin of the Rice Lake belt, high-grade paragneiss is tectonically juxtaposed with lower grade rocks of the Rice Lake belt along greenschist-facies (i.e., retrograde) high-strain zones (e.g., McRitchie and Weber, 1971), which include the Manigotagan Fault and subsidiary structures.

Local geology

The geology of the Lily Lake area has been investigated by Wright (1932), Stockwell (1938), Russell (1952), Weber (1971, 1987) and Anderson (2006a, b). As described by Anderson (2006a), the Lily Lake area is underlain mainly by marine sedimentary rocks of the Edmunds assemblage, which lie in depositional contact to the north with the underlying arc-rift volcanic and volcaniclastic rocks of the Gem assemblage (Figure GS-11-2). In the study area, the top of the Gem assemblage is

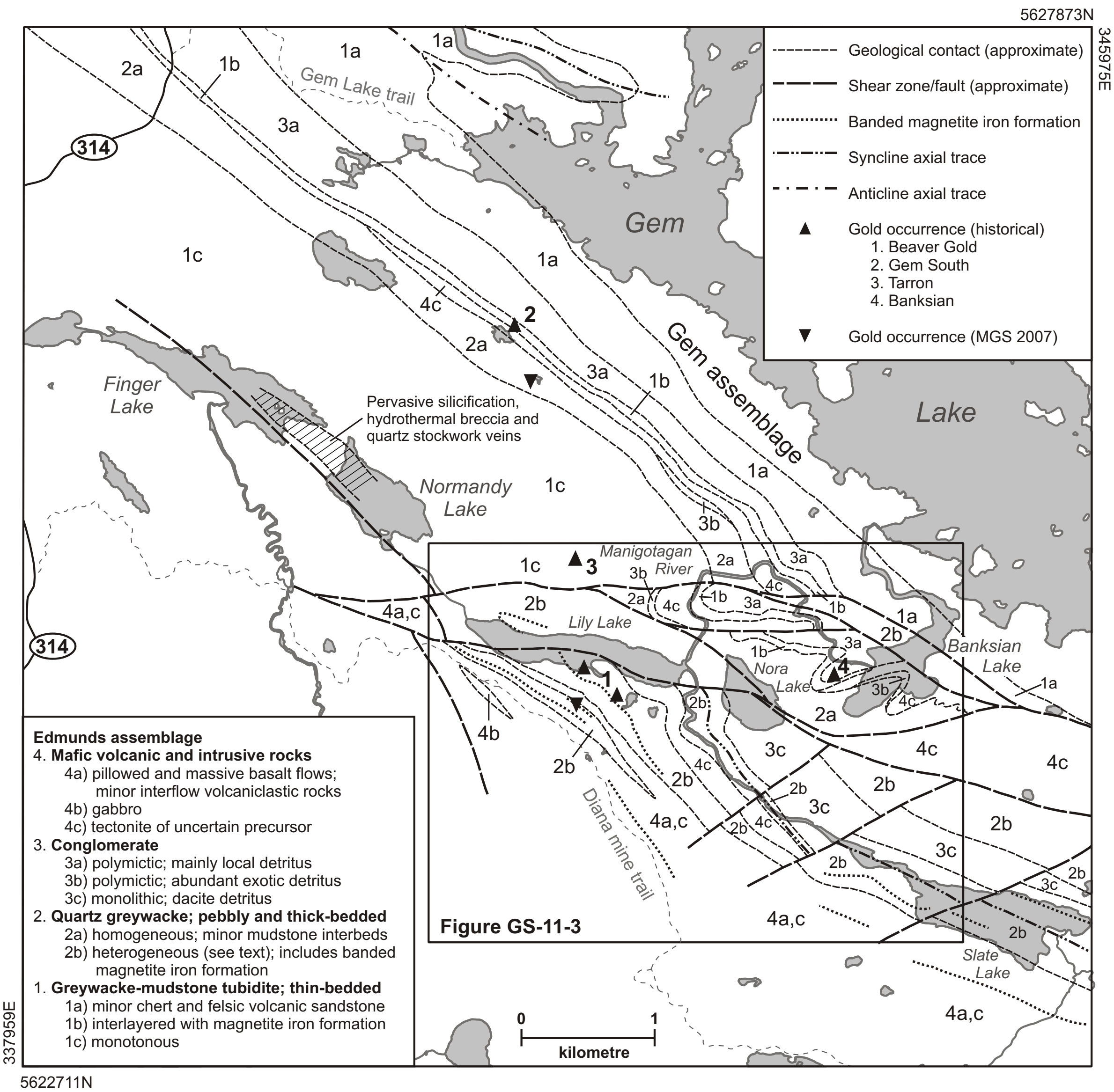


Figure GS-11-2: *Simplified geology of the Edmunds assemblage in the Lily Lake area, southeastern Rice Lake greenstone belt, showing the location of Figure GS-11-3 and the gold occurrences described in the text. For simplicity, the internal geology of the Gem assemblage, which lies in depositional contact with the Edmunds assemblage along the southwest shoreline of Gem Lake, is not shown.*

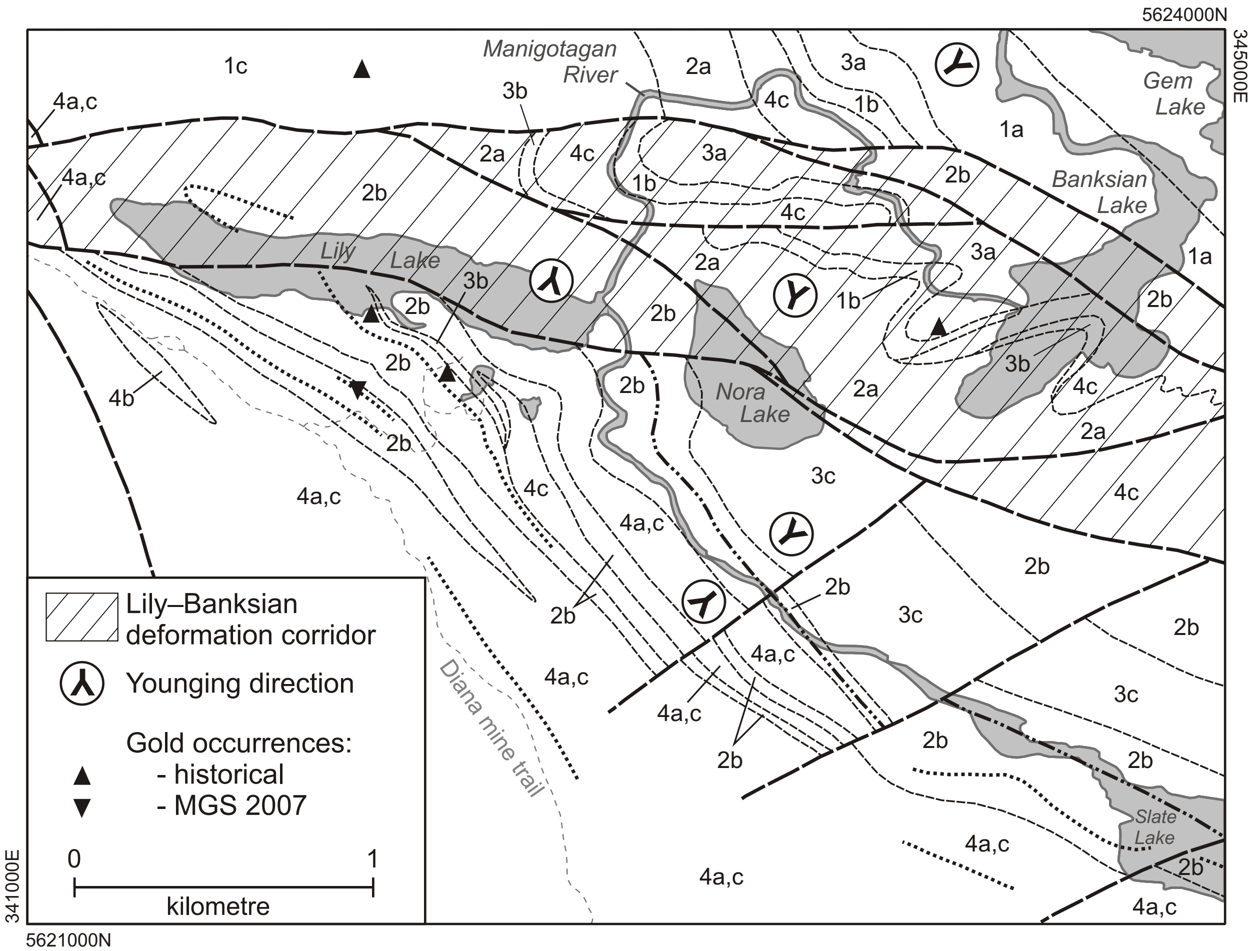


Figure GS-11-3: Detailed geology of the Edmunds assemblage in the Lily–Banksian lakes area. See Figure GS-11-2 for explanation of unit codes and map symbols.

defined by an approximately 200 m thick package of felsic volcaniclastic rocks, with minor intercalated pillowed basaltic andesite flows and derived epiclastic rocks. These rocks are well exposed along the top of the high outcrop ridge that extends along the southwest shoreline of Gem Lake, and lie in sharp depositional contact to the southwest with the Edmunds assemblage. Massive dacitic crystal tuff, which weathers light grey-green to buff, is the predominant rock type and contains minor intercalations of monolithic breccia, tuff-breccia and lapilli tuff. The basaltic andesite flows are dark green to light grey-green, fine to medium grained, and aphyric to sparsely plagioclase phyric. Massive and pillowed flows range up to 40 m thick and characteristically contain 1–5% round to slightly elongate quartz amygdules that range up to 7.0 cm in size, suggesting a shallow-water eruptive setting.

South of Gem Lake, map patterns and younging criteria in the Edmunds assemblage indicate the presence of tight, upright macroscopic folds, which are extensively overprinted and disrupted by shear fabrics and Z-asymmetric folds that record progressive dextral transcurrent shear deformation associated with regional late-orogenic shortening. The overprinting structures are particularly pervasive and intense within a 500–1000 m thick zone that trends in an easterly direction through Lily Lake and Banksian Lake, and is thus referred to as the Lily–Banksian deformation corridor (Figure GS-11-3). North of the deformation corridor, the Edmunds assemblage consists of a generally southwest-younging succession on the south limb of the regional-scale Beresford anticline. South of the deformation corridor, younging criteria in the Edmunds assemblage define the axial trace of a macroscopic isoclinal syncline that trends along the Manigotagan River from Lily Lake to Slate Lake and is thus referred to as the Slate Lake syncline. Metamorphic mineral assemblages throughout the study area indicate low to middle greenschist-facies regional metamorphism.

Lithostratigraphy north of the Lily–Banksian deformation corridor

North and east of Lily Lake, on the south limb of the Beresford anticline, the Edmunds assemblage consists of a distinctive and internally consistent stratigraphic succession that has been mapped continuously along strike for approximately 9.5 km. This succession ranges up to 2.2 km thick and consists, from base to top, of 1) thin-bedded greywacke-mudstone turbidite; 2) locally derived, polymictic pebble conglomerate; 3) thin-bedded greywacke-mudstone turbidite and magnetite iron formation; 4) mafic tectonite of uncertain precursor; 5) tonalite-clast–bearing conglomerate; 6) thick-bedded pebbly greywacke turbidite; and 7) thin-bedded greywacke-mudstone turbidite (Figure GS-11-4). With the exception of the mafic tectonite, this association of rock types corresponds closely to the classical facies association proposed by Walker (1978) for a submarine-fan depositional setting.

The base of the Edmunds assemblage consists of a 200–400 m thick turbidite succession composed of interbedded greywacke and graphitic mudstone (unit 1a). The basal contact with the Gem assemblage is well exposed in several locations and is defined by a unit of thin-bedded to laminated cherty mudstone of variable thickness, suggesting that basin infilling was preceded by a relatively sediment-starved, quiescent interval. Individual greywacke beds are typically fine grained, 2–10 cm thick and normally graded, with sharp basal contacts. Rare examples of complete (‘ABCDE’) Bouma sequences (Figure GS-11-5a) indicate deposition from turbidity currents, likely in a mid-fan setting. Included in this succession are rare interlayers of pebble conglomerate, white-grey felsic volcanic sandstone and laminated black chert, which are typically 0.5–1.5 m thick and point to episodic variations in sediment influx.

The turbidite succession is overlain by a 150–400 m thick unit of polymictic, pebble to cobble conglomerate (unit 3a). The conglomerate is generally massive, poorly sorted and matrix supported, suggesting deposition from slump-related, submarine debris flows. Well-rounded to subangular clasts are typically 2–15 cm across and consist mainly of grey, aphyric to sparsely feldspar-phyric, felsic volcanic material, which was likely derived from the underlying Gem assemblage; exotic clasts (e.g., quartzite, tonalite, vein quartz) are absent. The matrix consists of fine- to medium-grained feldspathic greywacke that lacks coarse detrital quartz.

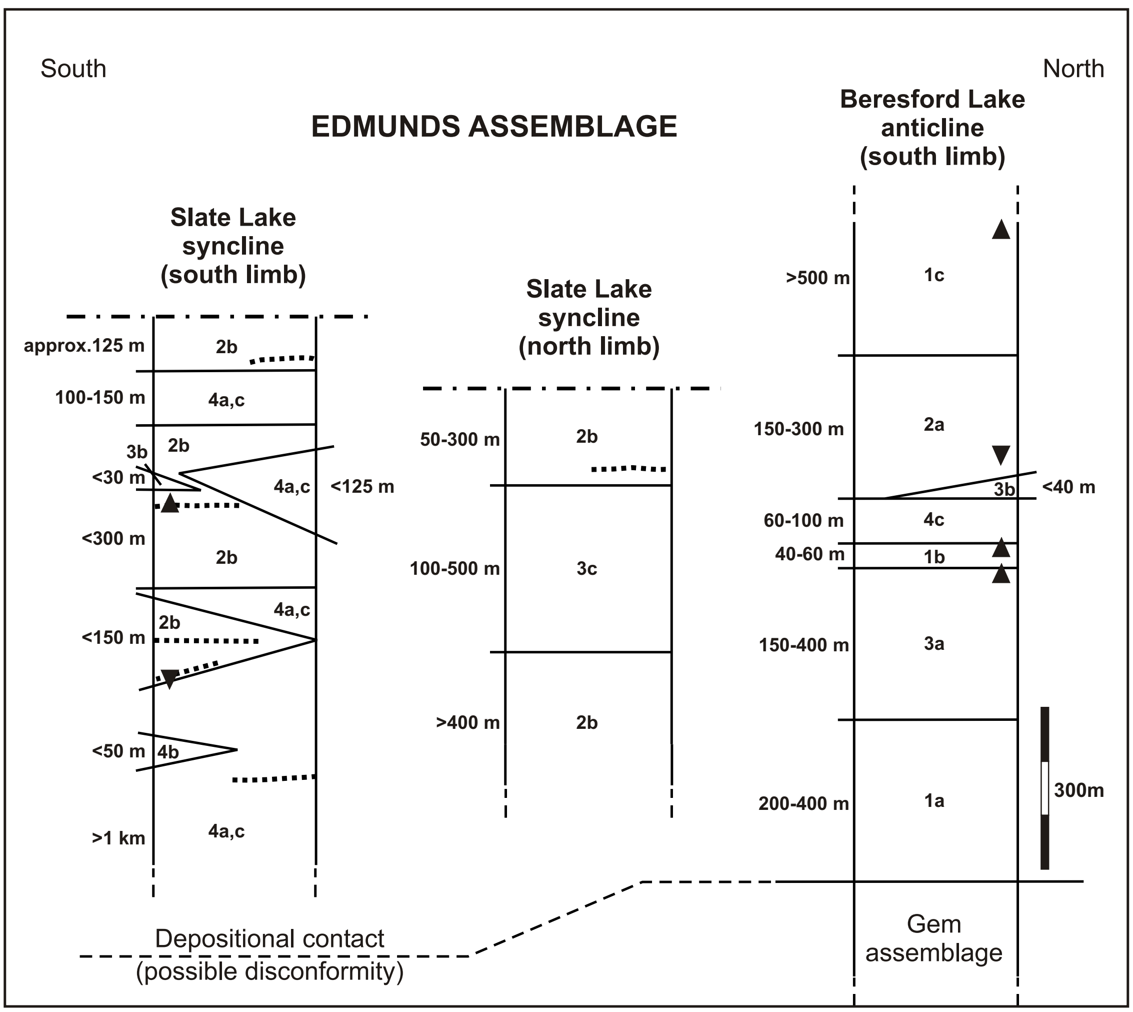


Figure GS-11-4: Simplified stratigraphic columns showing the lithostratigraphy of the Edmunds assemblage in the Lily Lake area, southeastern Rice Lake greenstone belt. See Figure GS-11-2 for explanation of unit codes.

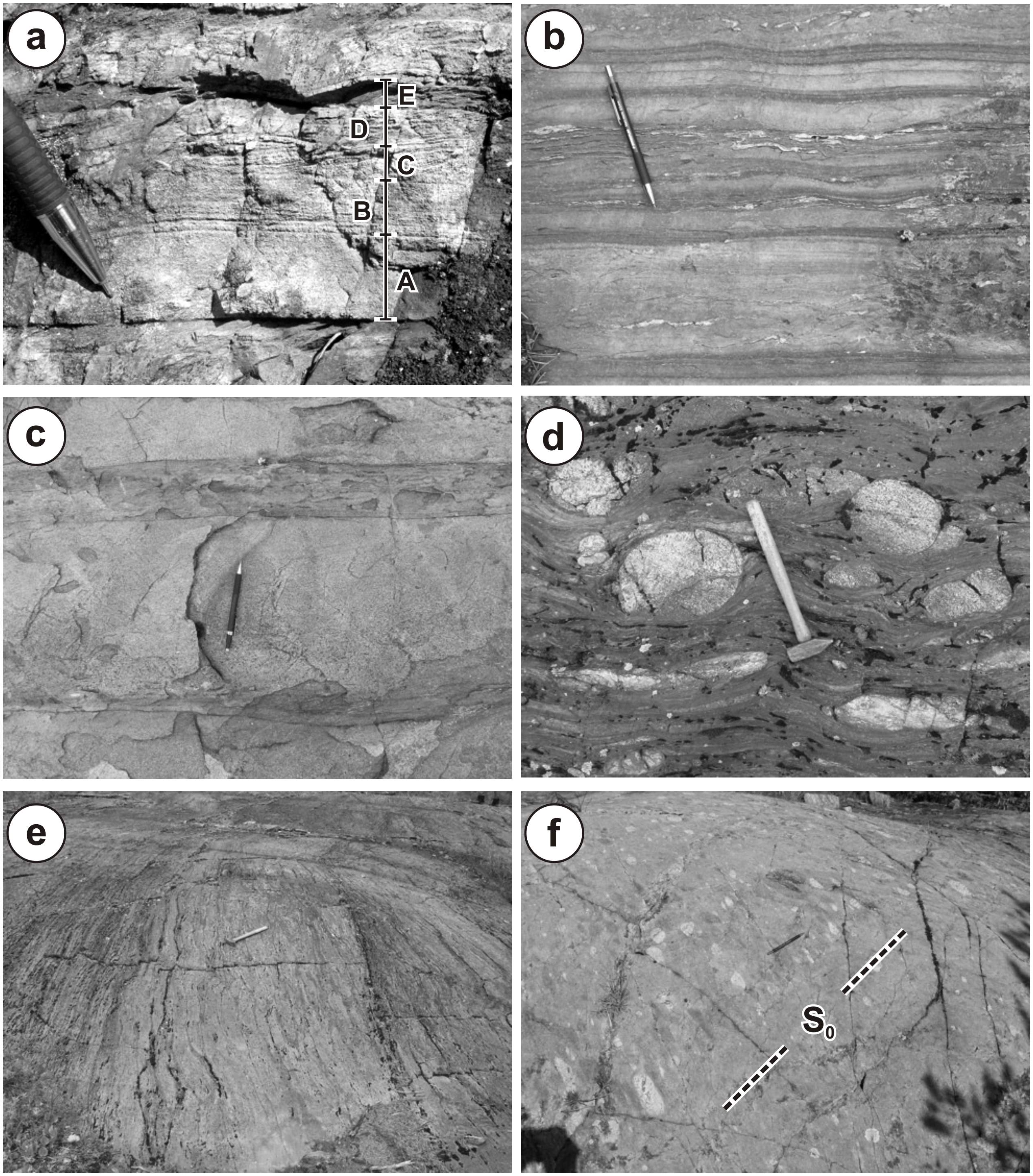


***Figure GS-11-5:** Outcrop photographs of rock types in the Lily Lake area, southeastern Rice Lake greenstone belt: **a)** turbidite exhibiting 'ABCDE' Bouma sequence, southwest of Gem Lake; **b)** greywacke-mudstone turbidite with interlayered magnetite iron formation, southwest of Gem Lake; **c)** pebbly quartz greywacke bed showing normal grading, Lily Lake; **d)** tonalite-boulder conglomerate, north of Lily Lake; **e)** pillow structures preserved in low-strain domain in mafic tectonite, southwest of Lily Lake; **f)** faintly stratified dacite conglomerate, south of Nora Lake.*

The conglomerate is overlain by a distinctive, 40–60 m thick interval of thinly bedded greywacke-mudstone turbidite, which is rhythmically interstratified with magnetite iron formation and includes minor beds of laminated cherty mudstone (unit 1b; Figure GS-11-5b). The individual turbidite units are generally 1–5 cm thick and composed of fine- to medium-grained greywacke that grades continuously upwards into laminated mudstone ('AE' turbidite). The mudstone beds are overlain by laminated beds of magnetite iron formation that range up to 10 cm thick. The resulting, 2–15 cm thick, greywacke–mudstone–iron formation 'triplets' are locally organized into fining- and thinning-upward cycles, ranging from 0.2 to 1.0 m thick, within larger fining- and thinning-upward cycles that range from 5 to 10 m thick. These features are indicative of mixed clastic and chemical sedimentation in a sediment-starved lower-fan setting. Similar rocks have been described in a submarine-fan succession along the southern margin of the Beardmore-Geraldton greenstone belt (Barrett and Fralick, 1989), near the interface between the Wabigoon and Quetico subprovinces. As described by Klein (2005), the iron formation units likely result from basinal (below wave base) chemical precipitation, with iron and silica sourced mainly from submarine hydrothermal activity.

In the northwestern portion of the mapped area, the turbidite–iron formation unit is overlain by a succession of thick-bedded quartz greywacke and mudstone that ranges from 150 to 300 m thick and contains minor beds of pebble conglomerate (unit 2a). The greywacke is buff to pale grey, medium to very coarse grained, and typically contains 10–30% detrital quartz. Individual beds range from 0.2 to 2.0 m thick and generally exhibit normal size-grading from coarse- or very coarse grained pebbly greywacke at the base to fine-grained greywacke at the top (Figure GS-11-5c). The beds are planar-tabular, with sharp and scoured basal contacts; crossbedding is absent. The fine-grained greywacke grades upward into brown mudstone interbeds that range up to 15 cm thick and generally account for 5–10% of the outcrops. These features indicate deposition via turbidity currents, likely in a mid-fan setting. Medium- to coarse-grained greywacke also forms massive beds up to 3 m thick, which were likely deposited from higher density grain flows. The pebble conglomerate layers are 20–50 cm thick and include subangular to well-rounded clasts of vein quartz and medium-grained tonalite, indicating a significant change in sediment provenance (*see* below).

In the area northeast of Lily Lake and extending towards Banksian Lake, the base of the thick-bedded quartz greywacke succession is locally marked by a distinctive unit of tonalite-clast–bearing cobble to boulder conglomerate (unit 3b). This unit ranges up to 40 m thick locally and forms lenticular bodies of apparently limited strike length. The conglomerate is poorly sorted and matrix supported, and ranges from massive to faintly stratified. In the westernmost outcrops, well-rounded (in many cases nearly spherical) to subrounded cobbles and boulders of tonalite predominate, and range up to 50 cm across (Figure GS-11-5d). The matrix consists of brown, fine-grained greywacke. These features indicate deposition from slump-related submarine debris flows composed of fluvially transported detritus. Toward the southeast, the proportion of tonalite clasts decreases and the conglomerate contains abundant clasts of porphyritic andesite and dacite, black aphyric rhyolite and vein quartz, with local beds of pebbly quartz greywacke. This conglomerate, together with the overlying quartz greywacke succession, records a major influx of fluvial sediment into the submarine fan, with a change to a more deeply eroded, and likely more distant, source area.

The thick-bedded quartz greywacke succession is overlain by a monotonous succession of greywacke-mudstone turbidite that is at least 500 m thick (unit 1c). This succession is composed of thinly interbedded greywacke and graphitic mudstone, and is thus substantially similar to the rocks at the base of the Edmunds assemblage. This succession is dominated by AE turbidite units, suggesting deposition in a mid- to lower-fan setting.

Throughout much of the map area, the interface between units 1b and 2a is marked by a laterally continuous, 60–100 m thick unit of rusty brown to green mafic tectonite of uncertain precursor (unit 4c). Most outcrops consist of strongly foliated chloritic mylonite and phyllonite. In places, however, this unit includes a dark green to brown, fine- to medium-grained, apparently massive and equigranular rock that exhibits a faint subophitic to ophitic texture defined by 0.5–1.5 mm feldspar crystals in a matrix of chlorite and actinolite. Other outcrops consist of a light green to grey porphyritic rock, which contains subhedral, 2–5 mm plagioclase phenocrysts (10–20%) in a fine-grained feldspathic and chloritic matrix. In one location, this unit varies from dark green-brown and equigranular on the northeast, to light green-grey and porphyritic on the southwest, perhaps as a result of *in situ* differentiation. Most outcrops are moderately to strongly magnetic and contain finely disseminated sulphides, consisting mainly of pyrrhotite and pyrite, with traces of chalcopyrite. In the absence of clear textural indications of alternative origins, these aspects are interpreted to indicate an intrusive origin for this unit. Texturally similar mafic sills are observed in the underlying map units.

Lithostratigraphy south of the Lily–Banksian deformation corridor

The stratigraphy of the Edmunds assemblage is considerably more complex in the area southeast of Lily Lake (Figures GS-11-3, -4). Here, the principal rock types include monolithic dacite conglomerate and variably tectonized mafic volcanic and intrusive rocks, which define lenticular units that are intercalated on scales ranging from metres to several hundreds of metres with internally complex units of mixed clastic and chemical (exhalitive iron formation) sedimentary rocks. The sedimentary units are cut by mafic dikes and sills of similar texture and geochemical signature to intercalated mafic flows. This, in conjunction with evidence of depositional contact relationships observed in the field, indicates that this section is most likely a stratigraphic succession, as opposed to a thrust imbricate. Hence, the apparently abrupt lateral and vertical facies changes that characterize this succession are interpreted to result from primary depositional processes within a very dynamic, marginal-marine depositional environment characterized by active mafic volcanism, episodic exhalitive activity and voluminous clastic sedimentation. This succession is at least 1.5 km thick on the south limb of the Slate Lake syncline, and younging criteria consistently indicate tops to the northeast. On the north limb of the syncline, the succession is approximately 800 m thick and exhibits consistent younging to the southwest.

South limb

On the south limb of the Slate Lake syncline, the base of the section is marked by a thick (>1 km) succession of variably tectonized mafic volcanic flows and intrusive rocks. Mafic tectonite (unit 4c) predominates in the upper (northeastern) portion of the succession, and consists of chlorite-carbonate phyllonite that is anastomosed around relatively low-strain domains in which primary textures are locally preserved (Figure GS-11-5e). Most of this succession appears to consist of pillowed and massive basalt flows (unit 4a). The basalt weathers buff to rusty brown to green and is grey-green on fresh surfaces. Most specimens are fine grained, aphyric and nonamygdaloidal, although sparse feldspar phenocrysts (1–2%; 2–5 mm) and quartz amygdules (1–3%; 1–5 mm) are observed locally. Pillows preserved in low-strain enclaves within the tectonite are wispy to bun shaped and less than 2.0 m in maximum dimension, with chloritic selvages <1.5 cm thick and <5% interpillow material (mainly carbonate). Individual flows range up to at least 10 m thick and are locally capped by 0.5–3.0 m thick layers of flow-top breccia. Massive flows range up to 5 m thick and locally transition upward into pillowed and/or brecciated flow tops. In these locations, it is apparent that strain was strongly partitioned into less-competent breccia layers between the individual flows. The basalt flows are intruded by dikes and sills of fine- to medium-grained, locally plagioclase-porphyritic gabbro; individual gabbro sills range up to at least 50 m thick (unit 4b). Discordant dikes of gabbro up to 3 m thick form a significant component (approx. 5–10%) of some outcrops, and are also observed to cut the overlying clastic sedimentary rocks. The available geochemical data (five samples) indicate two distinct types of lava: calcalkaline basaltic andesite of oceanic-arc affinity and tholeiitic basalt of transitional oceanic-arc–E-MORB affinity (Anderson, unpublished data, 2006).

Towards the northeast, the mafic volcanic rocks are intercalated with clastic and chemical sedimentary rocks, which locally form heterogeneous, well-stratified units up to 300 m thick (unit 2b). Thick-bedded quartz greywacke, which is texturally similar to that described previously (unit 2a), is the predominant rock type and is intercalated with lenticular strata of polymictic conglomerate, thin-bedded greywacke-mudstone turbidite, and graphitic mudstone. This unit also contains minor strata of monolithic dacite conglomerate, banded magnetite-chert iron formation, feldspathic greywacke, mafic volcanic sandstone and laminated black chert. Individual quartz greywacke beds range up to 1.5 m thick and are separated by thin (<10 cm) beds of fine-grained greywacke or mudstone. These beds characteristically exhibit normal size grading and well-developed basal lag deposits composed of angular mudstone rip-up clasts, and more rounded lithic clasts and quartz pebbles. Lenticular layers of polymictic conglomerate range up to 25 m thick and contain unsorted, typically subangular to well-rounded, matrix-supported clasts, which range in size up to 25 cm, in a very coarse grained, quartz-rich matrix. Clast types include porphyritic to aphyric dacite, black aphyric rhyolite, quartz-feldspar porphyry, vein quartz, magnetite iron formation, tonalite and orthoquartzite. The latter two clast types do not appear to be of local provenance, and suggest a probable source area in the ca. 3.0 Ga North Caribou Terrane. This inference is supported by the predominance of ca. 2.92–3.01 Ga detrital zircons in a sample of this material collected in 2006 for detrital zircon U-Pb analysis (Anderson, unpublished data, 2007).

North limb

The lithostratigraphy on the north limb of the Slate Lake syncline is dominated by a remarkably homogeneous unit of monolithic dacite conglomerate (unit 3c) that can be traced along strike for 3.0 km and increases in thickness from 100 m in the southeast to just over 500 m in the northwest. Along the upper and lower contacts, this conglomerate is locally heterolithic and contains minor interbeds of polymictic pebble conglomerate and thin-bedded feldspathic greywacke and graphitic mudstone of unit 2b. Dacite conglomerate layers, which do not exceed 10 m thick, are also present on the south limb of the fold, and thus provide a stratigraphic link across the hinge of the fold. This conglomerate is massive to very faintly stratified, unsorted and matrix supported, and is composed almost exclusively of buff to light green–weathering, plagioclase-phyric dacite clasts, with rare clasts of slightly darker green plagioclase-phyric andesite (Figure GS-11-5f). The dacite clasts range in shape from well rounded to subangular, and in size up to 1.5 m (typically 5–10 cm). No examples of obviously second-cycle (i.e., volcaniclastic) clasts were observed. The matrix consists of medium- to coarse-grained feldspathic wacke that contains 30–40% subhedral feldspar crystals <1.5 mm in size; coarse detrital quartz is absent from the matrix. These features, coupled with the significant stratigraphic thickness, are interpreted to indicate that the dacite conglomerate on the north limb of the syncline was deposited via an uninterrupted series of large-volume, subaqueous debris flows sourced from a rapidly eroding volcanic arc.

Structural geology

As described by Anderson (2004), mesoscopic overprinting relationships indicate at least six generations of ductile deformation structure in the eastern portion of the Rice Lake greenstone belt. In the Lily Lake area, however, evidence of this deformation history is typically obscured by a pervasive and intense structural overprint associated with late-orogenic transcurrent shear deformation. Nevertheless, map patterns, younging criteria and bedding-cleavage relationships indicate the presence of an early macroscopic syncline, which is correlated with the F_3-generation folds described regionally. The northern limb of this syncline is shared with the F_3 Beresford anticline, which is the dominant structural feature in the core of the Rice Lake belt. On a regional scale, the F_3 folds define tight, upright, doubly plunging structures that trend northwest and are overturned to the southwest. These folds are associated with a regionally developed, axial-planar, S_3 flattening fabric and cleavage that dips subvertically and contains a steeply plunging L_3 elongation lineation. The S_3 fabric locally intensifies into a penetrative transposition fabric, which is particularly well developed along the axial trace of the F_3 syncline on the Manigotagan River between Lily Lake and Slate Lake (Figure GS-11-6a).

In the central portion of the belt at Rice Lake (*see* Anderson, 2004), the S_3 fabric is consistently overprinted at a counterclockwise angle by a finely spaced S_4 crenulation cleavage, and both of these fabrics are overprinted at a clockwise angle by a variably developed S_5 shear band or fracture cleavage that exhibits a consistent dextral sense of asymmetry or offset. In the Lily Lake area, both of these fabrics are at least locally well developed (Figure GS-11-6b, -6c), but appear to be associated with the progressive development of the discrete high-strain zones and Z-asymmetric folds formed during dextral transcurrent shear deformation (i.e., the D_4 and D_5 deformation structures recognized at Rice Lake probably result from separate increments of a regionally progressive dextral transcurrent deformation). South of Lily Lake, the macroscopic F_3 folds are extensively overprinted and disrupted by D_4-D_5 high-strain zones and Z-asymmetric folds. The high-strain zones range up to several hundreds of metres thick and consist of chloritic or sericitic mylonite and ultramylonite (Figure GS-11-6d) that contain steeply dipping mylonitic foliations and shallow-plunging quartz-ribbon and slickenline lineations (Figure GS-11-6e). Kinematic indicators, which include porphyroclast systems, S-C fabrics, shear bands and asymmetric boudin trains, consistently indicate dextral strike-slip shear. Mesoscopic and macroscopic Z-asymmetric folds (F_4-F_5) are pervasive in the Lily Lake area, and are particularly intense in the west-trending Lily–Banksian deformation corridor (Figure GS-11-6f). These folds are gentle to tight, with steeply inclined, east-northeast-trending axial planes and steeply plunging hinges. Axial-planar fabrics are only locally developed and, in these locations, consist of a finely spaced crenulation cleavage. Chevron-style Z-folds are common. Rare tight to isoclinal, similar-style Z-folds are also observed, particularly in the mafic tectonite.

Brittle faults are the latest structures observed in the Lily Lake area. These faults strike northwest or northeast and dip subvertically. Offsets are generally right lateral on the northwest-trending faults and mainly left lateral on the northeast-trending faults, which is suggestive of a conjugate relationship. Apparent displacements range up to several hundreds of metres. Where exposed, the faults are characterized by sharp slip surfaces and narrow (<50 cm) zones of cohesive fault breccia and cataclasite, with minor irregular seams of purple or black pseudotachylite. The wallrocks are commonly bleached, with moderate to strong silicification and diffuse arrays of quartz-filled extension fractures.

Exploration history

From 1925 to the present, the Lily Lake area has seen extensive, though intermittent, prospecting activity. Many of the known mineral occurrences in the area were initially staked in 1926 following the discovery of the Diana deposit, which is located 5 km southeast of Lily Lake at Kickley Lake. To date, four significant gold occurrences have been identified in the Lily Lake area (Figure GS-11-2). Prior to 1984, exploration activity was restricted mainly to surficial prospecting for vein-hosted mineralization, and this work lead to the discovery of the Beaver Gold and Banksian occurrences. In 1984, Nelson Baker Geological Services Ltd. completed a reconnaissance rock-chip geochemical survey that covered Gem Lake and extended to the north shore of Lily Lake (Assessment File 93615, Manitoba Science, Technology, Energy and Mines, Winnipeg). This survey identified two areas of significantly anomalous gold and arsenic in bedrock, which are now known as the Gem South and Tarron occurrences.

The Beaver Gold occurrence, discovered by surface prospecting in about 1940, is located on the south shore of Lily Lake. The geology of this occurrence is described by Russell (1952), Theyer and Gaba (1986) and Theyer (1987, 1994). Prior to 1986, the most extensive exploration of the occurrence was reported by Starbird Mines Ltd. in 1959 (A.F. 91322) and Rock Ore Exploration and Development Ltd. in 1976–1977 (A.F. 94291). In 1986, Canhorn Mining Corp. completed an airborne

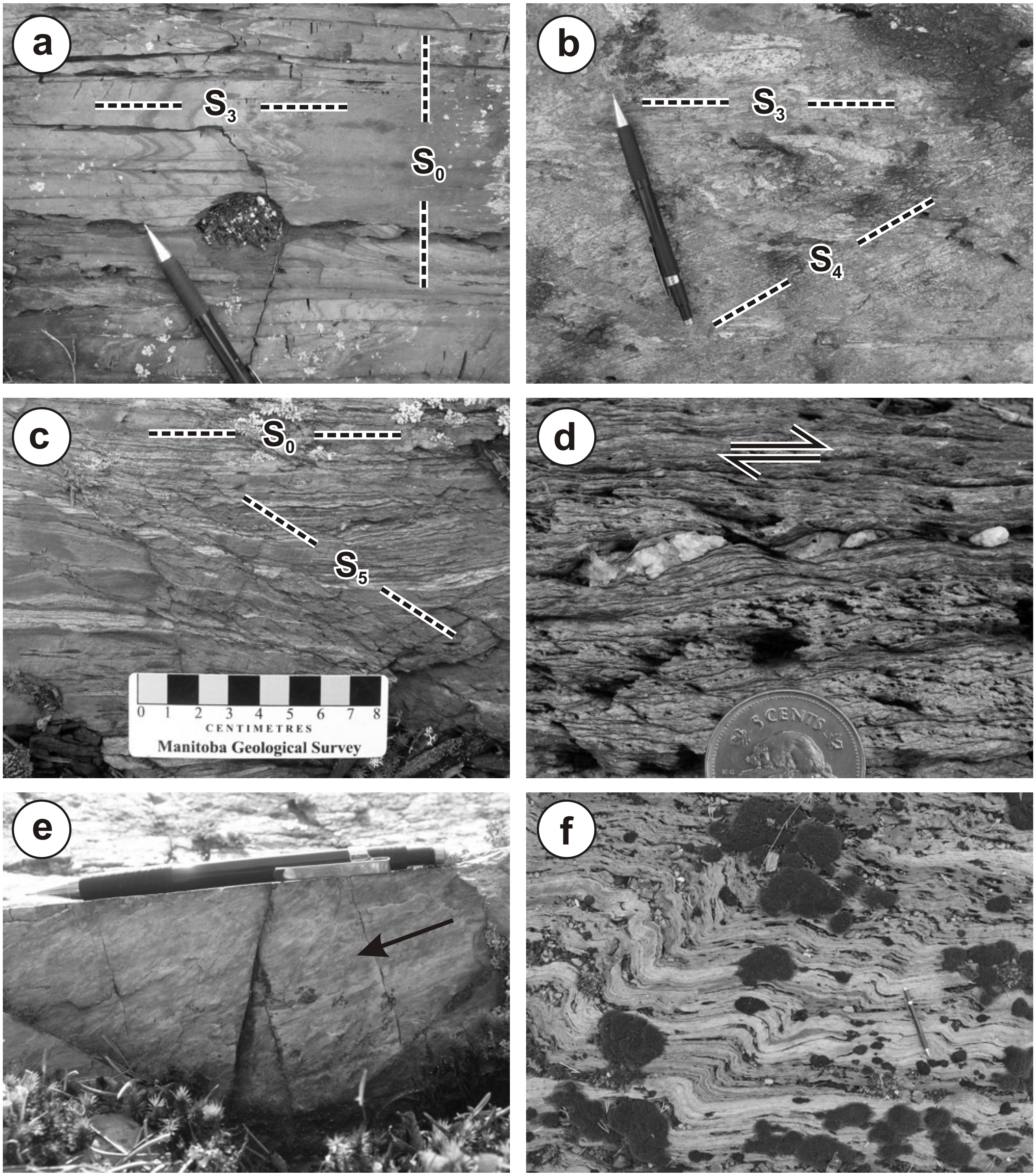


***Figure GS-11-6:** Outcrop photographs of deformation structures in the Lily Lake area, southeastern Rice Lake greenstone belt: **a)** spaced S_3 crenulation cleavage and transposition fabric in the hinge of the Slate Lake syncline, Slate Lake; **b)** S_3 flattening fabric (defined by elongate clasts) overprinted by finely spaced S_4 crenulation cleavage, north of Slate Lake; **c)** S_5 shear-band cleavage overprinting S_0-S_3, west of Gem Lake; **d)** S_4-S_5 mylonitic foliation and asymmetric quartz boudins (dextral) in high-strain zone, Gem Lake; **e)** shallow-plunging quartz ribbon lineation in S_4-S_5 mylonite, north of Lily Lake; f) Z-asymmetric F_4-F_5 folds in mafic tectonite, Banksian Lake.*

geophysical survey on a large claim group that extended from the south shore of Lily Lake to the west end of Anderson Lake (A.F. 94605, 94606) and included the Beaver Gold occurrence. In 1987, under an option agreement with Canhorn Mining Corp., Mutual Resources Ltd. investigated the Beaver Gold occurrence in detail (A.F. 94588) and identified four zones of gold mineralization hosted by a variably silicified, sulphidized and sericitized unit of greywacke turbidite, bounded by boulder conglomerate and banded-magnetite iron formation (unit 2b). This unit was traced for 850 m along strike and returned up to 12 410 ppb Au over 1.0 m in channel samples. In this interval, visible gold is observed in thin, lenticular veins of smoky grey to black quartz that exhibit narrow wallrock sulphidization haloes containing up to 20% arsenopyrite. In 1988, Mutual Resources Ltd. completed three diamond-drill holes (totalling 304.8 m) to test the occurrence, the best result of which was 5420 ppb Au over 1.47 m in DDH88-3 (A.F. 94589). In 1996, Asquith Resources Inc. acquired the claim group and completed three additional diamond-drill holes (totalling 331.1 m), the best result of which was 9460 ppb Au and 6000 ppm As over 40 cm in LL96-2, within a 14 m thick interval of quartz-veined greywacke with patchy arsenopyrite mineralization (A.F. 94566).

The Gem South occurrence is situated roughly midway between Gem Lake and Normandy Lake, and was identified in 1984 by the reconnaissance rock-chip geochemical survey completed by Nelson Baker Geological Services Ltd., which returned values as high as 630 ppb Au and 10 000 ppm As over the occurrence. In 1984–1985, Amalgamated Mining Development Corp. Ltd. investigated this occurrence through prospecting and rock-chip geochemical sampling, as well as magnetometer, VLF-EM and pulse-EM surveys. This work outlined a northwest-trending zone of stratabound disseminated arsenopyrite mineralization and sparse quartz-arsenopyrite veins associated with interlayered turbidite and magnetite iron formation (unit 1b). This zone was traced for 900 m along strike and surface samples returned values up to 710 ppb Au. Two diamond-drill holes (84-1 and 85-1) were completed to test a 90 m strike length of the anomalous zone. The best results were obtained from DDH84-1, which intersected 13.1 m of arsenopyrite mineralization that contained several narrow intercepts with up to 24 406 ppm As and 2560 ppb Au (A.F. 93616).

The Tarron occurrence is located north of the central portion of Lily Lake, and was discovered in 1985 by exploration crews from OreQuest Consultants Ltd., who were prospecting the area of an anomalous rock-chip sample (2140 ppb Au, 1594 ppm As) collected in 1984 by Nelson Baker Geological Services Ltd. The 1985–1986 work program, undertaken by OreQuest Consultants Ltd. on behalf of Tarron Resources Ltd., involved geological mapping, prospecting, bedrock geochemical sampling and VLF-EM and magnetometer surveys on two claims that extended from Lily Lake to Banksian Lake (A.F. 93110). In the location of the anomalous rock-chip sample, a prospecting crew identified a system of thin (<30 cm) quartz-arsenopyrite veins hosted by sheared and folded greywacke (unit 1c), which returned values up to 42 130 ppb Au in grab samples. Theyer (1987) examined the Tarron occurrence and described fracture-controlled tourmaline mineralization within zones of bleached and silicified wall rock several metres thick. In 1998, Asquith Resources Inc. followed up this work with a program of prospecting, rock geochemical sampling, geological mapping and ground magnetometer surveying north of Lily Lake in the area of the Tarron occurrence (A.F. 94538, 94541), and confirmed the presence of gold values up to 27 100 ppb in quartz veins.

The historical Banksian occurrence, which was described by Russell (1952) and Theyer (1994), is located near the southwest shore of Banksian Lake and consists of several shallow trenches that expose a series of discontinuous blue-black quartz veins hosted by pyrite and arsenopyrite-bearing chlorite schist and iron formation (unit 1b). This occurrence was sampled in 1985 by OreQuest Consultants Ltd. on behalf of Tarron Resources Ltd., and returned values up to 4660 ppb Au in grab samples (A.F. 93110).

Mineralization and alteration

The historical gold occurrences described above, coupled with two new gold occurrences identified by the MGS in 2007, comprise three distinct styles of mineralization: 1) strongly deformed quartz-sulphide veins associated with ductile shear zones; 2) late stockwork-breccia veins and silica-sulphide replacements associated with brittle faults; and 3) sulphidized iron formation.

Shear-hosted quartz-sulphide veins

Gold mineralization at the Tarron, Beaver Gold and Banksian occurrences consists of variably deformed quartz-sulphide veins associated with discrete, generally bedding-parallel, ductile-brittle shear zones. The host rocks typically consist of thick-bedded quartz greywacke (Tarron and Beaver Gold) or iron formation (Banksian). The shear zones dip steeply north or northeast and are characterized by narrow zones of chloritic or sericitic mylonite that contain shallowly plunging slickenline or quartz-ribbon lineations and ubiquitous dextral kinematic indicators. Within these zones, the quartz veins are highly attenuated, boudinaged and folded (Figure GS-11-7a), and rarely exceed 50 cm in thickness, with maximum strike lengths of 25 m. The wallrocks adjacent to the shear zones contain variably transposed Z-folds and local crosscutting arrays of quartz-filled extension fractures. The vein quartz is distinctly grey or black, with a dense 'cherty' texture. Accessory minerals include ankerite, sericite, chlorite, feldspar and calcite. Most veins contain trace to 5% pyrite and arsenopyrite, with the best gold values associated with finely disseminated needles of arsenopyrite. Wallrock alteration haloes are typically narrow (<1 m) and consist of proximal silica-sericite/chlorite-ankerite-sulphide that grades outwards to distal chlorite/sericite-calcite. At the Tarron occurrence, concordant zones of moderate to strong quartz-feldspar alteration are overprinted by brittle, tourmaline-filled fracture arrays. The general characteristics of these auriferous veins are indicative of classical 'mesothermal' or 'orogenic' lode-gold deposits.

Fault-controlled stockwork-breccia veins and silica-sulphide replacements

In 2007, the MGS identified a new gold occurrence southwest of Gem Lake and approximately 450 m southeast of the Gem South occurrence. The occurrence is hosted by thick-bedded quartz greywacke (unit 2a), approximately 100 m stratigraphically above the laterally continuous iron formation (unit 1b) and mafic tectonite (unit 4c). In this area, younging reversals indicate the presence of a macroscopic isoclinal fold closure, which is likely parasitic to the regional-scale Beresford F_3 anticline. The occurrence consists of patchy, irregular zones of moderate to intense silica-sericite-sulphide alteration associated with stratabound arrays of quartz-filled extension fractures, as well as bedding-discordant, northwest-trending faults (Figure GS-11-7b). The zones of most intense alteration, which rarely exceed 1.0 m in thickness, are associated with faults that contain narrow seams of silica-cemented breccia and cataclasite with ghost-like fragments of altered wallrock and 2–5% finely disseminated pyrite and arsenopyrite. Wallrock alteration grades outward from proximal silica-sulphide to distal sericite-silica±sulphide over 0.5–1.0 m. In some cases, the wallrock alteration is sharply bounded by discrete slip surfaces, indicating that fault movement outlasted alteration and vein emplacement. A grab sample of proximal silica-sulphide alteration from one of these faults returned 350 ppb Au and 3270 ppm As.

Similar fault-controlled alteration and veining was described by Anderson (2006a) north of Gem Lake, and was also observed by the author on the neck of land separating Finger Lake and Normandy Lake (*see also* Russell, 1952). In the latter location, intensely silicified

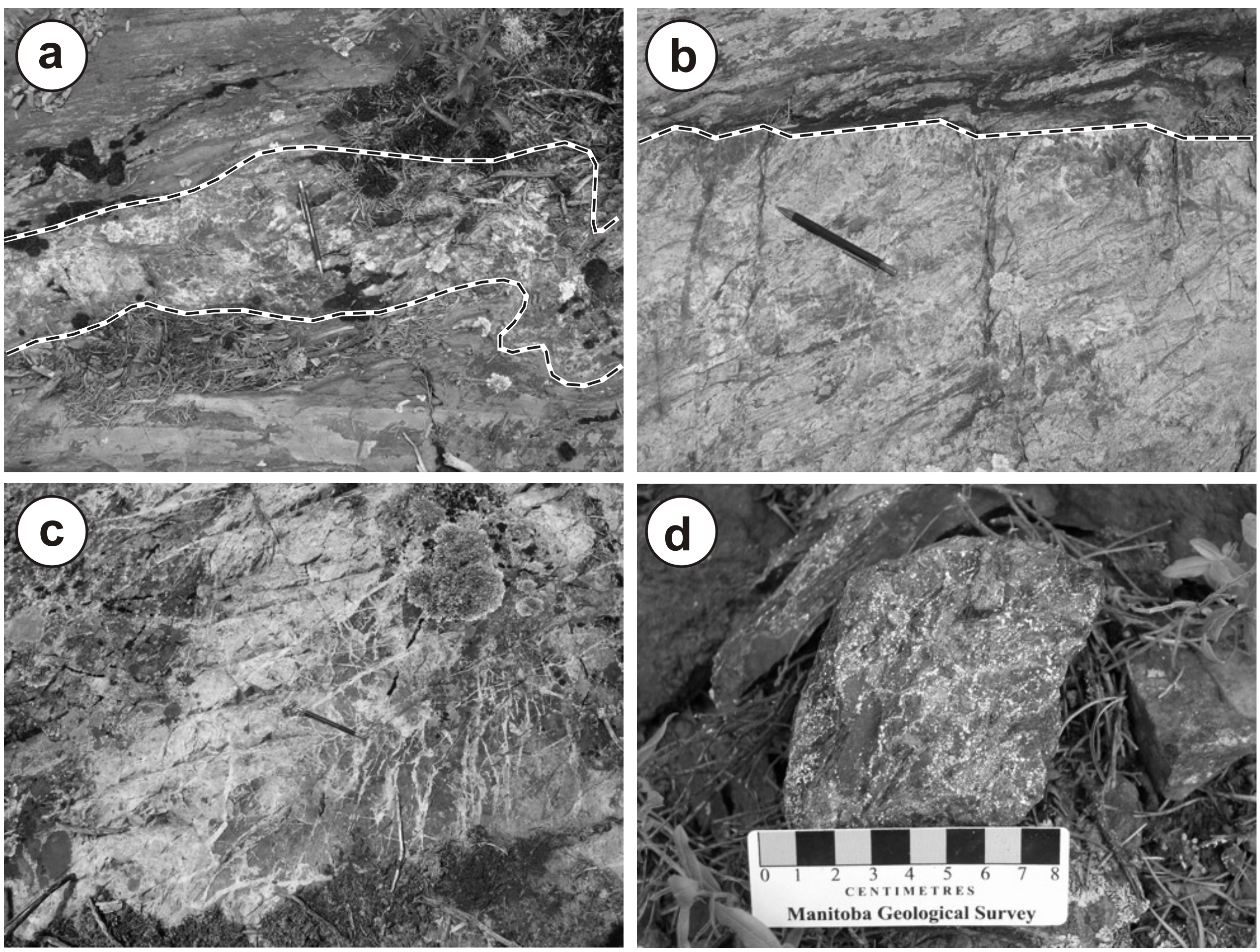


Figure GS-11-7: *Outcrop photographs of mineralization in the Lily Lake area, southeastern Rice Lake greenstone belt:* ***a)*** *shear-hosted quartz-arsenopyrite vein (outlined), north of Lily Lake;* ***b)*** *patchy, intense silica-arsenopyrite alteration associated with discordant fault (sharp slip surface indicated by dashed line), southwest of Gem Lake;* ***c)*** *quartz-vein stockwork and hydrothermal breccia, Normandy Lake; d) sulphidized iron formation, southwest of Lily Lake.*

hydrothermal breccia and peripheral stockwork quartz-vein arrays define a 200 m thick zone that can be traced on surface for at least 800 m along strike (Figure GS-11-7c). This zone is situated in the immediate hangingwall of a strongly sheared and faulted, north-west-trending contact between pillowed basalt flows (unit 4a) and greywacke-mudstone turbidite (unit 1c), which evidently served as a conduit for focused, high-volume discharge of hydrothermal fluids.

Sulphidized iron formation

In 2007, the MGS also identified a new gold occurrence south of Lily Lake and approximately 300 m west-southwest of the main Beaver Gold occurrence. The occurrence is hosted by a northwest-trending unit of interstratified quartz greywacke and polymictic conglomerate (unit 2b), approximately 10 m stratigraphically below the contact with an overlying unit of mafic tectonite (unit 4c). The hostrocks to the occurrence consist of a 3–4 m thick unit of magnetite iron formation that can be traced discontinuously along strike for 80 m. At the occurrence, the iron formation appears to abruptly terminate, perhaps indicating the presence of a crosscutting fault. Here, the iron formation is strongly silicified and chloritized, and contains up to 30% pyrite and arsenopyrite; quartz veins are absent (Figure GS-11-7d). The pyrite is coarsely crystalline and occurs as irregular veinlets and disseminations, whereas the arsenopyrite is very fine grained and forms near-solid blebs and disseminations. Hand-specimens are nonmagnetic, suggesting complete replacement of primary magnetite. A grab sample of this material returned 3550 ppb Au and 20 200 ppm As, with negligible Ag and base metals. The style and setting of this mineralization, coupled with the high Au:Ag ratio, are indicative of epigenetic, as opposed to syngenetic (i.e., stratiform), iron formation–hosted gold deposits (e.g., Kerswill, 1996). The stratabound disseminated arsenopyrite mineralization described at the Gem South occurrence is also suggestive of this deposit type.

In 1977, Rock Ore Exploration and Development Ltd. completed one diamond-drill hole (47-4-77) approximately 100 m along strike to the west of the new gold showing to test a weak EM conductor for massive base-metal–sulphide mineralization. Although the drill logs indicate several intervals of favourable alteration, quartz veining and disseminated sulphide mineralization, only two narrow intervals were sampled for gold assay (with negligible results).

Economic considerations

Gold occurrences in the Lily Lake area are hosted by a distinctive association of rock types that includes magnetite iron formation, tonalite-clast conglomerate, mafic volcanic rocks and quartz greywacke. Although this association is regionally extensive along the southern margin of the Rice Lake greenstone belt, the most significant gold occurrences are spatially associated with the west-trending Lily–Banksian deformation corridor, which disrupts the stratigraphic succession and records progressive dextral shearing and folding during late-orogenic transcurrent deformation. In terms of stratigraphic and structural setting, and style of mineralization, these occurrences are strongly analogous to epigenetic gold deposits in the Neoarchean Beardmore-Geraldton greenstone belt of the Superior Province (e.g., Lafrance et al., 2004) and the Neoarchean Rankin Inlet greenstone belt of the Hearne Province (i.e., the ‘Meliadine Trend’; *see* Carpenter and Duke, 2004). In both these belts, significant gold deposits are situated along a regional-scale interface between mafic metavolcanic rocks and metasedimentary rocks, and are hosted by chemically favourable rock types (principally iron formation) in areas of structural complexity resulting from discordant shears, folds or faults, or sheared lithological contacts. In this regard, future exploration in the Lily Lake area should be focused on delineating areas of structural complexity along and within the laterally extensive iron formation and mafic tectonite units identified in this study, utilizing detailed geological mapping and magnetometer surveys. As described by D. Busch (A.F. 94538, 94541), the sharply truncated and tightly folded iron formations indicated by magnetometer data at Lily Lake represent obvious exploration targets. Similar sites of favourable chemistry and structure also exist along the Manigotagan River between Lily Lake and Banksian Lake.

Also noteworthy is the fact that the regional tectonic setting and lithostratigraphy of the Lily Lake area are substantially similar to those in the area of the Éléonore property in the James Bay district of Quebec. Here, the approximately 2.76 million ounce Roberto gold deposit (Goldcorp Inc., 2007) occurs in metasedimentary rocks of the Opinaca Subprovince, near the interface with the mainly metavolcanic La Grande Subprovince, in a setting that is analogous to the English River–Uchi interface in Manitoba. The hostrocks consist of thin-bedded turbiditic greywacke and minor polymictic conglomerate that, in the footwall of the deposit, contain abundant aluminosilicate mineralization and are intruded by numerous sill-like diorite intrusions. The auriferous zones consist of 2–5% arsenopyrite and pyrrhotite associated with transposed, stratabound, stockwork quartz veins and proximal quartz-actinolite-microcline-tourmaline alteration. Although the genesis of this deposit remains poorly understood, the Éléonore exploration model emphasizes the association of greywacke turbidite, diorite intrusions and aluminosilicate mineralization. Based on the regional mapping of McRitchie and Weber (1971), there appears to be several areas in the English River Subprovince in which these attributes coincide.

Acknowledgments

K. Reid and R. Moody are thanked for their capable field assistance. Logistical support was provided by D. Binne and N. Brandson. B. Lenton drafted the figures. M. Pacey assembled the digital database for the hand-held data acquisition system used in the field. C. Beaumont-Smith and T. Corkery reviewed the manuscript. P. Sargeant and M. Tuchscherer of Grandview Gold Inc. provided proprietary aeromagnetic data. K. Freisen of Inner City Youth Alive Inc. facilitated access to their Gem Lake cabin.

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