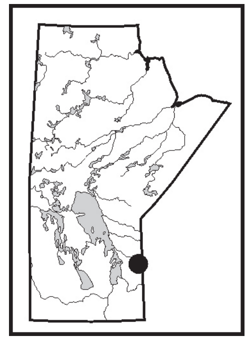
GS-11

Preliminary results and economic significance of geological mapping in the Gem Lake area, southeastern Rice Lake belt, Manitoba (NTS 52L11 and 14), with emphasis on the Neoarchean Gem assemblage

by S.D. Anderson



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Summary

The Gem assemblage is composed of a bimodal suite of primary and variably reworked volcanic and volcaniclastic rocks that ranges up to 2.0 km thick and includes pillowed to massive basalt, basaltic andesite and dacite flows; related fragmental volcanic rocks and subvolcanic intrusions; flow-banded rhyolite flows, monolithic breccias and pumiceous pyroclastic rocks; thick intercalations of heterolithic volcaniclastic rocks; and derived, well-bedded epiclastic rocks composed of volcanic conglomerate, sandstone, siltstone and chert. Rhyolite and high-silica rhyolite (69–81 wt.% SiO_2, anhydrous; 0.06–0.4 Zr/TiO_2) in the Gem assemblage exhibit transitional calcalkalic–tholeiitic affinities (Zr/Y 14.5–3.5) and high-field-strength-element signatures indicative of extension-related, within-plate volcanism. These rocks classify as FII- and FIIIa-type rhyolite in the scheme of Lesher et al. (1986). Basalt and basaltic andesite flows and sills (49–55 wt.% SiO_2, anhydrous; 0.007–0.02 Zr/TiO_2) exhibit transitional calcalkalic–tholeiitic affinities and plot between enriched mid-ocean ridge basalt (E-MORB) and typical arc-tholeiite on basalt discrimination diagrams. The Gem assemblage exhibits many of the hallmarks of oceanic or continental-arc volcanism in extensional tectonic regimes, and is provisionally interpreted to record the initiation of a ca. 2.72 Ga arc-rift basin (or basins) along the south margin (present coordinates) of the Rice Lake belt. These attributes indicate that, in addition to the demonstrated potential for orogenic lode-gold deposits, the Gem Lake area is prospective for VHMS deposits.

Introduction

The Rice Lake greenstone belt is situated in the western Uchi Subprovince of the Archean Superior Province, and consists mainly of Meso- and Neoarchean mafic to intermediate volcanic and volcaniclastic rocks of oceanic affinity, which constitute several distinct lithotectonic assemblages (e.g., Poulsen et al., 1996; Bailes et al., 2003). In Manitoba, the volcanoplutonic Uchi Subprovince is flanked to the north by the ca. 3.0 Ga North Caribou continental terrane and to the south by ca. 2.69 Ga paragneiss, orthogneiss and related granitoid plutons of the English River Subprovince (Figure GS-11-1). The Gem Lake area, which is located 45 km southeast of Bissett, Manitoba, represents the southeastern extremity of the Rice Lake belt.

In 2002, the Manitoba Geological Survey initiated a program of 1:20 000-scale bedrock mapping, structural analysis, lithogeochemistry, Nd-Sm isotope studies and U-Pb geochronology in the poorly understood Garner Lake–Gem Lake area, with the objective of unravelling the complex geology and structure, and improving the understanding of the tectonic evolution, metallogeny and economic potential of the Rice Lake belt. The results of fieldwork completed at Garner Lake have been summarized by Anderson (2002, 2003a, b).

Although previously unreported, approximately one week in each of the 2003, 2004 and 2005 field seasons was spent mapping in the Gem Lake area at a scale of 1:20 000, with particular emphasis on the Gem assemblage. As described by Weber (1971), the Gem assemblage consists of a distinctive suite of metavolcanic rocks that includes flow-banded, high-silica rhyolite flows and vent-proximal pyroclastic rocks. Percival et al. (2002) presented trace and rare earth element data from a single sample of the Gem assemblage rhyolite that indicate a geochemical affinity to extension-related, FII or FIII (Lesher et al., 1986) tholeiitic rhyolite. In contrast, felsic metavolcanic rocks elsewhere in the Rice Lake belt are typically FI dacite, and thus exhibit trace and rare earth element signatures indicative of calcalkaline-arc volcanism. Davis (1994) reported a U-Pb zircon age of 2722 ±2 Ma from the Gem assemblage rhyolite, which is significantly younger than the ca. 2.73 Ga ages obtained from felsic metavolcanic rocks elsewhere in the belt (e.g., Ermanovics and Wanless, 1983; Turek et al., 1989). Hence, there is evidence to suggest two distinct settings and ages of Neoarchean felsic volcanism in the Rice Lake belt. Given that extension-related FII and FIII rhyolite are important hosts to volcanic-hosted massive sulphide (VHMS) deposits (e.g., Lesher et al., 1986; Lentz, 1998; Syme, 1998; Syme et al., 1999), these data also suggest an unrecognized VHMS potential in the Gem assemblage, in addition to the demonstrated potential for orogenic lode-gold deposits.

In this context, the goals of the Gem Lake mapping were threefold: 1) to gain a better understanding of the rock types, stratigraphy, structure and deformation history

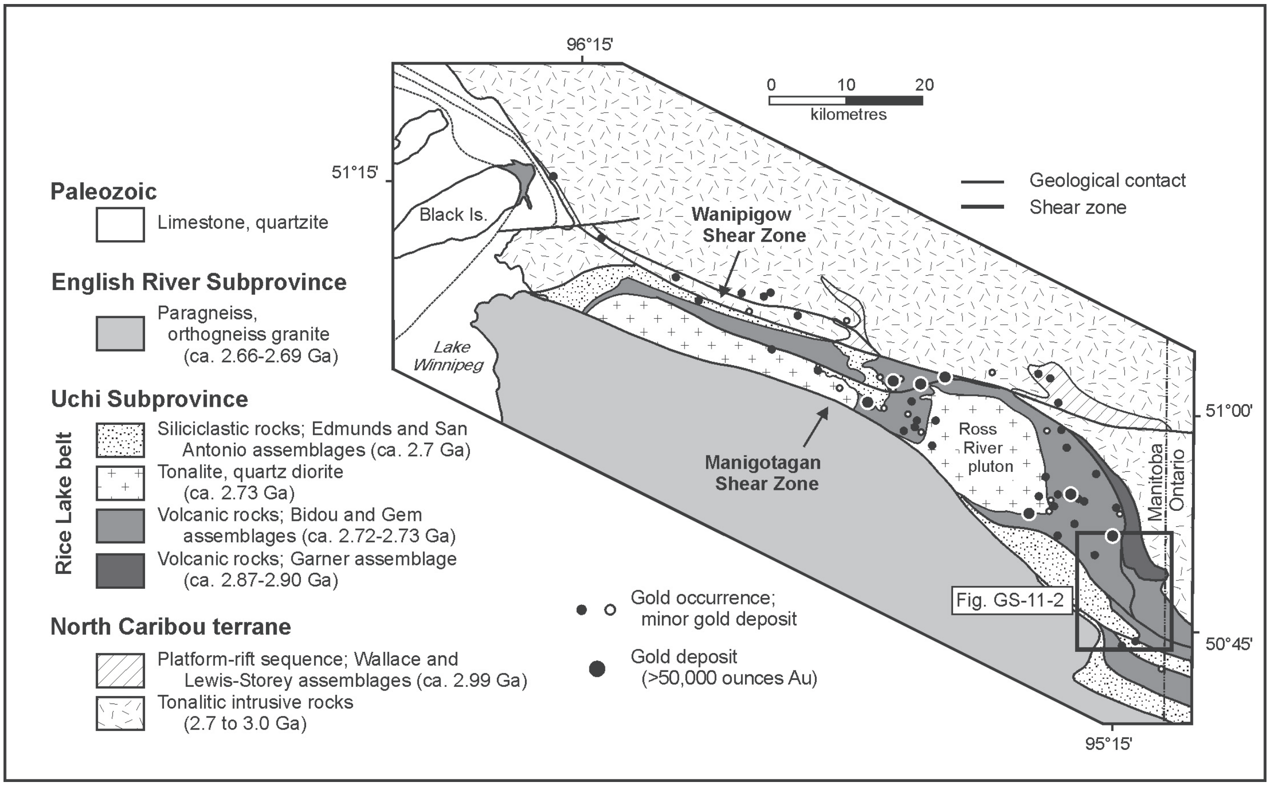

Figure GS-11-1: *Simplified geology of the Rice Lake belt, showing the location of Figure GS-11-2.*

of the Gem assemblage; 2) to determine the distribution, geochemical character and tectonic affinity of vent-proximal, rhyolitic volcanic rocks and assess their VHMS potential, and; 3) to update the lithostratigraphic, tectonic and metallogenic framework for the southeastern Rice Lake belt.

Toward these ends, the mapping was focused on shoreline bedrock exposures on Gem Lake, and the sporadic clean bedrock exposures created by recent logging activities east of the Manigotagan River between Beresford Lake and Gem Lake. A representative suite of least-altered volcanic rocks was collected and analyzed for a full suite of major, trace and rare earth elements (REE) by instrumental neutron activation and inductively coupled plasma–mass spectrometry. These high-quality data have been integrated with comparable data from samples collected by Corkery (1995), Bailes (1998) and Anderson (2002, 2003a) to facilitate geological correlations.

In this report, new data pertaining to the geology, structure and geochemistry of the ca. 2.72 Ga Gem assemblage are integrated with previous work and new data stemming from the mapping of Anderson (2003a, b) to provide an updated geological framework and preliminary insights into the possible tectonic evolution and economic potential of the Gem Lake area.

Local setting and previous work

The Gem Lake area was mapped at a regional scale by Stockwell (1945a, b) and Weber (1971), and more detailed mapping has also been completed at Stormy Lake (Owens and Seneshen, 1985; Owens, 1986; Seneshen, 1990), Beresford Lake (Brommecker, 1996), and Garner Lake (Anderson, 2003b). Supracrustal rocks in this portion of the Rice Lake belt extend east into the Bee Lake belt of northwestern Ontario, portions of which were recently mapped at 1:50 000 scale (Rogers, 2003).

Stratigraphic nomenclature

Weber (1971) provided the most comprehensive description of the Gem Lake area, including the only detailed description of the geology of Gem Lake. On the basis of this work, Weber (1971) subdivided the Rice Lake Group of Stockwell (1945b) into the mainly metavolcanic Bidou Lake and Gem Lake subgroups, and the metasedimentary Edmunds Lake Formation. The results of subsequent reconnaissance mapping and geochronology at Garner Lake (e.g., Brommecker et al., 1993; Davis, 1994; Poulsen et al., 1994) prompted Poulsen et al. (1996) to propose one additional unit, the mainly metavolcanic Garner Lake subgroup. As proposed by Poulsen et al. (1996), and subsequently adopted by Bailes et al. (2003), these units are herein referred to as the Garner, Bidou, Gem and Edmunds 'assemblages' (Figure GS-11-2). As shown in Figure GS-11-3, the various metavolcanic assemblages in the southeastern Rice Lake belt can be readily distinguished on the basis of geochemical attributes.

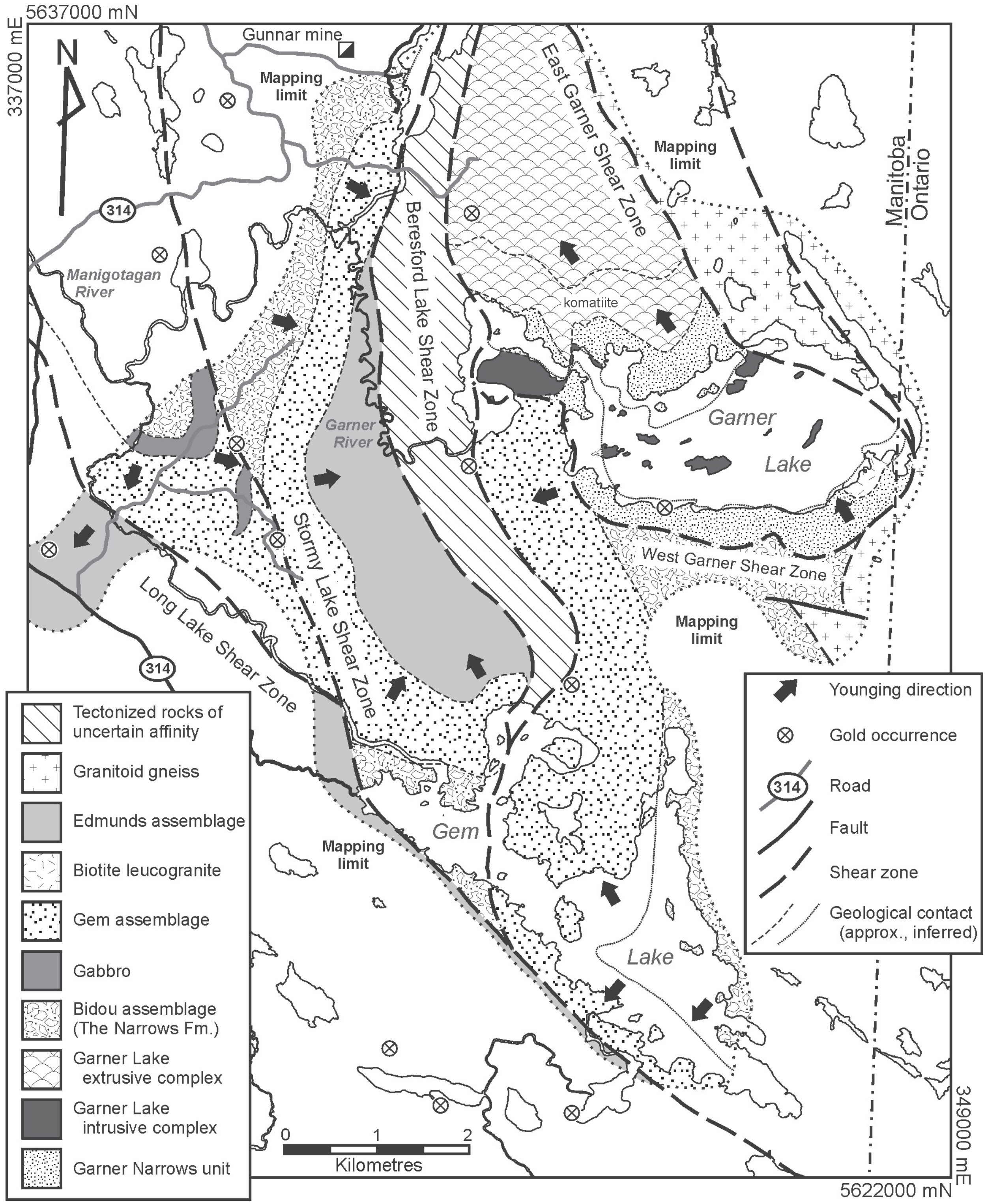

Figure GS-11-2: *Simplified geology of the Garner Lake–Gem Lake area, southeastern Rice Lake belt. The map pattern of the Gem assemblage west of the Manigotagan River is from Seneshen (1990).*

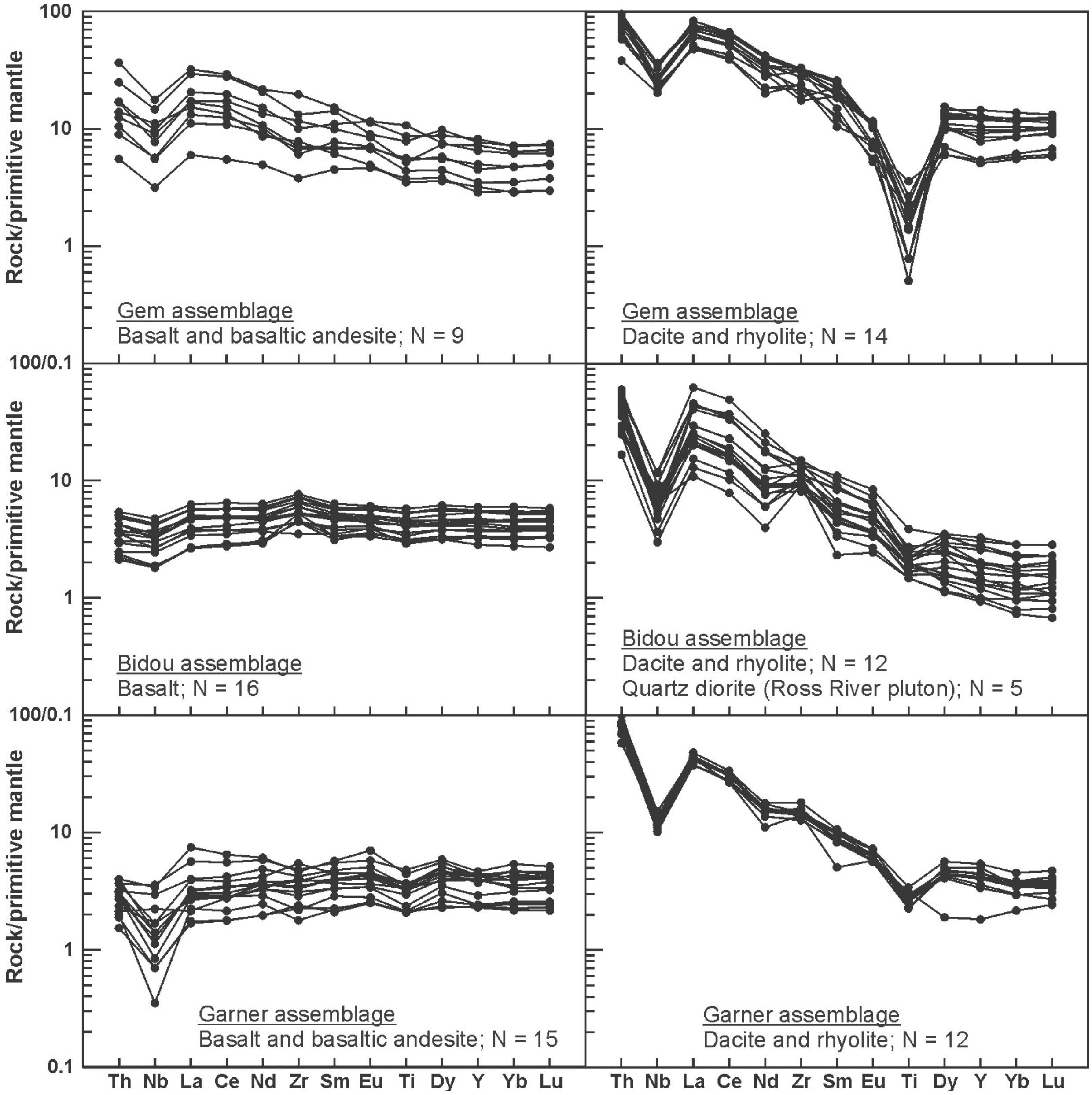

Figure GS-11-3: *Primitive-mantle–normalized (Sun and McDonough, 1989) extended-element diagrams for samples of mafic and felsic metavolcanic rocks in the southeastern Rice Lake belt.*

These assemblages provide a punctuated record, spanning roughly 200 m.y., of magmatism, sedimentation and orogenic activity in the western Uchi Subprovince. Broadly comparable assemblages have been documented in the Red Lake and Birch-Uchi belts in northwestern Ontario (*see* Stott and Corfu, 1991; Sanborn-Barrie et al., 2001) and provide a basis for regional-scale tectonostratigraphic correlations within the western Uchi Subprovince.

Garner assemblage

The Mesoarchean (ca. 2.87–2.90 Ga) Garner assemblage, which was previously included in the Gem and Edmunds assemblages (Weber, 1971), was subdivided by Anderson (2003a, b) into the Garner Narrows unit and the Garner Lake intrusive and extrusive complexes. The Garner Narrows unit is thought to form a conformable, north-younging stratigraphic succession that consists of a basal unit of polymictic volcanic conglomerate, overlain to the north by a thick package of calcalkalic felsic volcaniclastic rocks, and capped by a thin (~50 m) unit of magnetite iron formation. Uranium-lead analyses of zircon from a sample of dacitic crystal tuff indicate emplacement between ca. 2883 and 2898 Ma (Anderson, 2003a). The Garner Narrows unit is intruded by peridotite, pyroxenite and gabbro of the Garner Lake intrusive complex, the latter of which includes dikes and irregular pods of pegmatitic leucogabbro and quartz diorite that yielded U-Pb zircon ages of 2870 ±1 Ma (Anderson, 2003a), and 2871 ±1 Ma and 2871 ±2 Ma (Davis, 1994). The Garner Lake extrusive complex disconformably overlies the Garner Narrows unit and consists of a north-facing succession, more than 2.5 km thick, of subaqueous ultramafic to mafic volcanic flows and related subvolcanic intrusive rocks, with minor interflow sedimentary rocks. From south to north, the flows range in composition from basaltic komatiite (12–18 wt.% MgO, anhydrous) and minor ultramafic komatiite (18–32 wt.% MgO, anhydrous) to mainly Mg-tholeiitic basalt of primitive-arc or MORB affinity (Figure GS-11-3). These flows are interpreted to be comagmatic with the underlying Garner Lake intrusive complex (e.g., Brommecker et al., 1993).

Bidou assemblage

The Bidou assemblage occupies the core of the Rice Lake belt and is intruded by ca. 2.73 Ga (Turek et al., 1989) quartz diorite of the Ross River pluton. The assemblage consists of a thick (≥5.5 km) sequence of subaqueously deposited supracrustal rocks, which Campbell (1971) subdivided into seven conformable formations. The lower portion of the Bidou assemblage consists of laterally continuous units of massive and pillowed, MORB-like (Figure GS-11-3) tholeiitic basalt flows (the Unnamed, Tinney Lake and Gunnar formations), alternating with units of well-bedded feldspathic greywacke, siltstone and chert, with minor intercalations of mafic to intermediate volcaniclastic rocks (the Stovel Lake and Dove Lake formations). The Gunnar Formation is overlain by the Stormy Lake Formation, which consists mainly of thick-bedded feldspathic greywacke and siltstone, with minor intercalated pillowed basalt, felsic volcaniclastic rocks, laminated chert and thin units of iron formation. The Narrows Formation defines the top of the Bidou assemblage, and consists of a 2.5 km thick succession of coarse, heterolithic volcaniclastic rocks composed mainly of calcalkaline plagioclase-phyric dacite. With the apparent exception of the upper portion of The Narrows Formation, all of these units are intruded by tholeiitic gabbro sills.

Turek et al. (1989) reported a U-Pb zircon age of 2731 ±3 Ma for dacite in The Narrows Formation, as well as overlapping ages of 2728 ±8 Ma and 2731 ±13 Ma for porphyritic dikes that crosscut pillowed basalt in the lower portion of the Bidou assemblage and are presumed to be associated with the Ross River pluton. These dates provide a minimum age for the lower portion of the Bidou assemblage and suggest that the Ross River pluton and The Narrows Formation are comagmatic.

Gem assemblage

As described by Weber (1971), the Gem assemblage overlies The Narrows Formation and consists of primary and variably reworked mafic to felsic volcanic flows and pyroclastic rocks that, at Gem Lake, include a distinctive package of high-silica, flow-banded rhyolite and vent-proximal pyroclastic rocks unique in the Rice Lake belt. Weber (1971) subdivided the Gem assemblage into the mainly metavolcanic Banksian Lake Formation and the mainly metasedimentary Rathall Lake Formation. The Banksian Lake Formation was interpreted to consist of a fully differentiated (basalt to rhyolite) volcanic cycle that, on the basis of contact relationships observed along the Manigotagan River, was thought to disconformably overlie the ca. 2.73 Ga Bidou assemblage. This portion of the Banksian Lake Formation was subsequently renamed the 'Manigotagan River Formation' by Seneshen and Owens (1985), and was interpreted to mark a conformable transition from subaerial felsic volcanism in the Bidou assemblage to basinal marine sedimentation in the Edmunds assemblage. Davis (1994), however, obtained a U-Pb zircon age of 2722 ±2 Ma from quartz-phyric rhyolite breccia at Gem Lake, which suggests that a significant depositional hiatus may have separated Bidou and Gem volcanism, and thus supports the original interpretation of Weber (1971). In this report, the Manigotagan River Formation is considered to be laterally equivalent to lithologically and geochemically similar rocks at Gem Lake; hence, these rocks are herein collectively referred to as the Gem assemblage. The Rathall Lake Formation of Weber (1971) consists of discontinuous units of locally derived boulder conglomerate, feldspathic greywacke and arkose that typically crop out along the contact between the Gem assemblage and the overlying Edmunds assemblage. These rocks are herein tentatively correlated with the coarse, subaerial siliciclastic rocks of the San Antonio assemblage (*see* below).

Edmunds assemblage

The Edmunds assemblage is at least 2.5 km thick and is composed of basinal siliciclastic rocks that consist mainly of monotonously bedded greywacke-mudstone turbidites, with subordinate units of polymictic conglomerate and quartz greywacke, and discontinuous layers of laminated chert and iron formation. Unlike similar rocks in the Bidou and Gem assemblages, these rocks are devoid of gabbro sills, and the conglomerate layers contain abundant, well-rounded granitoid clasts. The base of the Edmunds assemblage is marked by a 1.2 km thick coarsening-upward cycle, suggesting deposition in a progradational subaqueous fan. Seneshen (1986) described a gradational and conformable contact relationship with underlying felsic pyroclastic rocks of the Gem assemblage. At Gem Lake, however, thinly bedded greywacke-mudstone turbidites and chert at the base of the succession lie in sharp, apparently discordant, contact with pillowed felsic flows and coarse flow breccias of the Gem assemblage, which are intruded by distinctive plagioclase-porphyritic gabbro sills. The overlying turbidites are completely devoid of these sills, but contain thin

(<1.0 m) beds of polymictic pebble to cobble conglomerate in which porphyritic gabbro constitutes up to 30% of the clast population. These relationships indicate a significant depositional hiatus and erosional unconformity at the base of the Edmunds assemblage.

The youngest detrital zircons obtained from two samples of greywacke collected near the base of the Edmunds assemblage, west of Gem Lake, yielded slightly discordant $^{207}Pb/^{206}Pb$ ages of 2712 and 2705 Ma (Davis, unpublished data, 1994). In Ontario, correlative rocks were intruded by calcalkalic plutons at 2698 Ma (Corfu et al., 1995), and exhibit evidence of ductile deformation prior to emplacement of the Wingiskus Lake granodiorite pluton (Rogers, 2001) at 2696 Ma (McNicoll and Rogers, unpublished data, 2001). These data constrain deposition of the Edmunds assemblage to the ca. 2.71–2.70 Ga time interval. In the central portion of the Rice Lake belt, fluvial and alluvial siliciclastic rocks of the San Antonio assemblage unconformably overlie the Bidou assemblage and contain detrital zircons as young as 2.704 Ga (Percival et al., 2002). These rocks are considered to represent the proximal equivalents to the more distal, deep-marine Edmunds assemblage.

Along the south margin of the Rice Lake belt, greenschist-facies supracrustal rocks are tectonically juxtaposed and locally interleaved with ca. 2.69 Ga (Corfu et al., 1995) paragneiss, orthogneiss and related granitoid plutons of the English River Subprovince along a series of greenschist-facies high-strain zones (e.g., McRitchie and Weber, 1971), which include the regional-scale Manigotagan Shear Zone and subsidiary structures. The paragneiss records high-temperature, low-pressure regional metamorphism of ca. 2.71–2.70 Ga metasedimentary rocks (Corfu et al., 1995) that are the distal equivalents to the Edmunds assemblage.

Structure and metamorphism

In the Garner Lake–Gem Lake area, map patterns are segmented into a series of northwest-trending, relatively low-strain lithostructural panels by a network of ductile and ductile-brittle high-strain zones (Figure GS-11-2). Of these, the Beresford Lake Shear Zone (BLSZ) represents the most significant and apparently long-lived structural discontinuity (e.g., Brommecker, 1996; Anderson, 2003a). East of the BLSZ, north-younging rocks of the Mesoarchean Garner assemblage are juxtaposed to the south across the West Garner Shear Zone (WGSZ) with a west-younging panel of the Neoarchean Gem assemblage, which is underlain by a thick, west-younging package of dacitic volcanic rocks that are tentatively correlated with the Bidou assemblage. These rocks are juxtaposed to the east, across the East Garner Shear Zone, with an extensive granitoid domain of uncertain age and affinity. West of the BLSZ, macroscopic map patterns and younging criteria in the Neoarchean succession, comprising the Bidou, Gem and Edmunds assemblages, define the regional-scale Beresford Lake anticline (BLA), which is the dominant structural feature in the core of the Rice Lake belt. The BLA is truncated by the BLSZ at Beresford Lake. Along strike to the northwest, this shear zone coincides with and overprints the northeast limb of the anticline. The southwest limb of the BLA is overprinted by the Long Lake Shear Zone and is transected and offset in a right-lateral sense by the Stormy Lake Shear Zone. The latter structure was referred to as the Dove Lake Shear by Campbell (1971) and the South Carbonate Shear by Brommecker (1996).

As described by Anderson (2003a, 2004), mesoscopic overprinting relationships indicate six distinct generations of ductile deformation structure in the eastern portion of the Rice Lake belt. The BLA is a tight, upright F_3-generation fold that trends northwest and is overturned to the southwest. From northwest to southeast, the hinge of the BLA exhibits a systematic change in orientation from moderately northwest-plunging, through subhorizontal, to steeply southeast-plunging, and is thus doubly plunging on a regional scale. The BLA is associated with a regionally developed, axial-planar S_3 flattening fabric that dips subvertically. In relatively low-strain structural domains, the S_3 fabric is consistently overprinted at a shallow anticlockwise angle by a penetrative, regional, S_4 crenulation cleavage. The resulting L^3_4 intersection lineation plunges steeply and is pervasive in the Rice Lake belt. Both of these fabrics are overprinted at a clockwise angle by a variably developed shear-band or fracture cleavage that is attributed to D_5 deformation and exhibits a consistent dextral sense of asymmetry or offset. In the southeastern portion of the Rice Lake belt, all of these fabrics are overprinted by open, east- or northeast-trending F_6 folds.

The BLSZ truncates the F_3 BLA west of Beresford Lake and is folded by macroscopic F_6 folds at Gem Lake (Figure GS-11-2), and records at least two increments of ductile, non-coaxial deformation. In both the BLSZ and WGSZ, early zones of cohesive mylonite and ultramylonite contain steeply plunging stretching and quartz-ribbon lineations, and preserve kinematic evidence of northeast-over-southwest, dip-slip shear. These fabrics are overprinted by chloritic mylonite and tectonite that contain shallow lineations and well-developed kinematic indicators on horizontal surfaces, which indicate transcurrent shear deformation. These fabrics are attributed to the regional D_4 and D_5 deformations, respectively, and are presently thought to record successive increments of a progressive deformation associated with orogen-scale dextral transpression in the western Uchi Subprovince.

Metamorphic mineral assemblages in the Garner Lake–Gem Lake area generally indicate low- to middle-greenschist–facies regional metamorphism, although supracrustal rocks along the northeastern margin of the belt locally contain middle- to upper-amphibolite–facies assemblages. In the interest of brevity, the prefix 'meta' is omitted from the descriptions below.

Gem assemblage

The following description of the Gem assemblage is based on a detailed examination of shoreline bedrock exposures on Gem Lake, coupled with widely spaced traverses in the poorly exposed area to the north and northwest. The Gem assemblage is composed of a bimodal suite of intercalated mafic and felsic volcanic and volcaniclastic rocks that exhibit distinctive textural, lithological and geochemical attributes as compared to compositionally similar rocks in the underlying Bidou assemblage. On the basis of these attributes, three separate lithostructural panels of Gem assemblage rocks have been identified in the Gem Lake area. Although similar in terms of overall composition and geochemistry, each of these panels exhibits important differences in internal stratigraphy and rock-type associations, which remain poorly understood. For this reason, the internal stratigraphy of the Gem assemblage has not been subdivided in detail, and this report provides only generalized descriptions of each of the panels.

Distribution

West of the BLSZ, the Gem assemblage has been documented on both the east and west limbs of the BLA, and forms laterally continuous units up to at least 1.5 km thick that are bound at the base by dacitic volcaniclastic rocks of the Bidou assemblage and at the top by greywacke-mudstone turbidite of the Edmunds assemblage (Figure GS-11-2). Younging criteria indicate a consistent, outward younging direction from the core of the BLA. These units were previously referred to as the Banksian Lake Formation by Weber (1971), and correspond to the Manigotagan River Formation of Seneshen and Owens (1985) and Anderson (2003a, b).

East of the BLSZ, the Gem assemblage extends northward from Gem Lake to the western basin of Garner Lake (Figure GS-11-2), and likewise appears to be stratigraphically underlain by dacitic volcanic and volcaniclastic rocks that are tentatively correlated with The Narrows Formation of the Bidou assemblage. Sparse bedforms and younging criteria indicate a west-younging stratigraphic succession that is at least 2.0 km thick and is structurally truncated to the west, north and south by D_4-D_5 shear zones. At Gem Lake, this succession is folded by an open, Z-asymmetric F_6 fold. Portions of this succession, which includes the Banksian Lake and Rathall Lake Formations of Weber (1971), were provisionally referred to as the 'Garner River unit' by Anderson (2003a, b). South of Gem Lake, the Edmunds and Gem assemblages exhibit a complex map pattern (e.g., Weber, 1971) that appears to result from a combination of fold repetition and structural imbrication along late high-strain zones or faults.

Lithology and stratigraphy

On the western limb of the BLA, the Gem assemblage defines a homoclinal succession that ranges from 0.3 to 1.5 km thick and, as described by Seneshen (1990), includes a lower section of mainly mafic volcanic rocks, overlain by a medial section of intercalated mafic flows and epiclastic rocks, and an upper section of mainly felsic pyroclastic and derived epiclastic rocks. The mafic volcanic rocks are composed of basalt and basaltic andesite of transitional calcalkalic-tholeiitic affinity, and consist of massive or pillowed flows, intercalated with thick intervals of flow breccia and lapilli tuff. The basalt flows range from aphyric to very coarsely plagioclase phyric and are characteristically quartz amygdaloidal. Thick intercalations of mafic lapilli tuff were interpreted as subaqueously deposited tephra-fall deposits by Seneshen (1990). The epiclastic rocks consist of massive to thick-bedded volcanic conglomerate, with subordinate intervals of thin-bedded, chloritic greywacke-mudstone turbidite, interpreted by Seneshen (1990) to represent a progradational subaqueous-fan succession. The conglomerate is very heterolithic and contains well-rounded boulders up to 2.0 m in diameter, suggesting extensive subaerial reworking and a high-energy depositional setting. The greywacke beds exhibit well-developed normal grading, crossbeds and channels, and are locally interlayered with distinctive layers of black chert, suggesting periodic episodes of sediment starvation. Trough-crossbedded sandstone in pillow interstices and well-developed peperite textures indicate coeval mafic volcanism and high-energy sedimentation (Seneshen, 1986). The epiclastic rocks are intruded by abundant dikes and sills of aphanitic to fine-grained basalt that exhibit well-developed chilled margins and are locally amygdaloidal, suggesting shallow-level emplacement. The section is bounded by 10–50 m thick units of well-bedded rhyolitic volcaniclastic rocks, which characteristically contain plagioclase-phyric pumice clasts and are interpreted as subaqueously deposited pyroclastic flows (Seneshen, 1990).

On the eastern limb of the BLA, the Gem assemblage is displaced to the south, in a right lateral sense, by the Stormy Lake Shear Zone (Figure GS-11-2), and appears to range from less than 250 m thick at Gem Lake to more than 1.0 km thick along strike to the north at Beresford Lake. Felsic volcanic rocks predominate over mafic on this limb of the BLA, and the section is provisionally subdivided into a mainly felsic volcanic lower unit and a mainly epiclastic upper unit. The lower unit consists of massive to weakly stratified lapilli tuff and tuff-breccia, with minor intercalations of pillowed or massive, typically quartz-amygdaloidal felsic flows and associated flow breccias. The major and trace element chemistry of these rocks indicate that they are composed of rhyolite (69–74 wt.% SiO_2, anhydrous; Zr/TiO_2 0.05–0.2), which ranges from aphyric to coarsely plagioclase±quartz–

phyric. Distinctive sills of coarsely plagioclase-porphyritic gabbro intrude these rocks and range up to 150 m thick. The upper epiclastic unit appears to conformably overlie the lower unit and is marked at the base by a 30–40 m thick section of felsic volcaniclastic debris flows, in which distinctive layers of laminated grey-black chert cap a series of well-developed fining-upward cycles that range up to 10 m thick. The base of these intervals is marked by a 2–3 m thick layer of matrix-supported, heterolithic volcanic conglomerate, which contains angular to rounded clasts, up to 30 cm across, that include angular rip-ups of the adjacent black chert beds. Upsection, these rocks grade into thick-bedded, feldspathic greywacke-mudstone turbidites that contain subordinate layers of felsic lapilli tuff, heterolithic pebble conglomerate and chert, and are intruded by abundant gabbro sills. This unit is at least 500 m thick at the south end of Beresford Lake, but pinches out approximately 2.5 km along strike to the south. South of this point, pillowed felsic flows and coarse flow breccias in the lower unit of the Gem assemblage lie in direct contact to the east with thinly bedded greywacke-mudstone turbidites of the Edmunds assemblage.

As described by Weber (1971), the Gem assemblage east of the BLSZ consists mainly of variably reworked, heterolithic volcaniclastic rocks, which are intercalated with pillowed to massive basalt, basaltic andesite and dacite flows; related fragmental volcanic rocks and subvolcanic intrusions; flow-banded rhyolite flows and pumiceous pyroclastic rocks; and derived, well-bedded epiclastic rocks composed of volcanic conglomerate, sandstone, siltstone and chert. At Gem Lake, the Gem assemblage ranges up to least 2.0 km thick. In the southeastern portion, the base of the assemblage is marked by a 300–400 m thick unit of massive to flow-banded rhyolite flows, intercalated with coarse, monolithic flow breccias and intervals of massive to well-bedded lapilli tuff and tuff. In general, there appears to be an upward transition in this section from light grey rhyolite flows and flow breccias (Figure GS-11-4a), which typically exhibit gossanous weathered surfaces and moderate to intense sericite-pyrite alteration, to dark grey or black, spectacularly flow-banded rhyolite flows (Figure GS-11-4b) that typically lack alteration. Individual flows, or flow complexes, range up to 125 m thick and can be traced along strike for over 500 m, whereas the apparently concordant zone of sericite-pyrite alteration may extend more than 2.0 km along strike. Along the southwestern shoreline of Gem Lake, flow-banded black rhyolite is overlain to the southwest by a weakly stratified, 50–60 m thick unit of monolithic matrix-supported breccia that contains very angular to subrounded clasts of flow-banded rhyolite ranging up to 1.5 m across. Along strike in the central portion of Gem Lake, this unit includes a 30–40 m thick section of well-bedded rhyolitic volcanic sandstone and siltstone (Figure GS-11-4c), which contains distinctive layers of black chert (exhalite?) that range up to 1.0 m thick. These epiclastic rocks are overlain by an ~200 m thick unit of heterolithic breccia and lapilli tuff, which is composed mainly of clasts of aphyric, locally quartz-amygdaloidal basalt and basaltic andesite (Figure GS-11-4d). Along strike toward the northwest, the mafic breccia is overlain by an ~100 m thick unit of massive to weakly stratified monolithic breccia, composed of closely packed angular fragments of buff to grey, coarsely quartz-phyric rhyolite. The breccia contains minor intercalations of lapilli tuff and massive rhyolite (flow?), and locally contains highly elongate wispy fragments of dark grey to brown quartz-phyric pumice, which range up to 5 cm long and account for up to 30% of the rock (Figure GS-11-4e). This unit may represent a subaerially deposited, welded rhyolite ignimbrite, and is the source of the 2722 ±2 Ma U-Pb zircon age obtained by Davis (1994).

Upsection, these rocks are overlain by a very heterogeneous, ~1.5 km thick package that consists mainly of heterolithic volcaniclastic rocks with minor intercalations of massive to flow-banded dacite and rhyolite, pillowed basalt flows and flow breccias, and well-bedded epiclastic rocks. The volcaniclastic rocks range from massive to thinly bedded and typically contain angular to well-rounded (Figure GS-11-4f) fragments, which characteristically include aphyric to coarsely quartz-phyric rhyolite, quartz-amygdaloidal basalt, flow-banded black rhyolite and plagioclase±quartz–phyric pumice. The heterolithic clast population and rounded clast shapes are indicative of significant subaerial transport and reworking. Well-developed bedforms and the presence of pillowed flows indicate a subaqueous depositional setting, which was likely proximal to a subaerially exposed, bimodal volcanic centre.

Geochemistry

Felsic volcanic rocks in the Gem assemblage consist mainly of rhyolite and high-silica rhyolite (69–81 wt.% SiO_2, anhydrous; 0.06–0.4 Zr/TiO_2; Figure GS-11-5a), with minor dacite, that exhibit transitional calcalkalic-tholeiitic affinities (Zr/Y 14.5–3.5). Primitive-mantle–normalized profiles are characterized by strongly enriched light REE, with moderate negative Nb and Eu anomalies, very prominent negative Ti anomalies, and weakly fractionated, strongly enriched heavy REE (Figure GS-11-3). Chondrite-normalized multi-element profiles exhibit strongly enriched and fractionated light REE, with relatively flat, weakly fractionated heavy REE and moderate negative Eu anomalies (Eu/Eu^* 0.4–0.9). The high-field-strength-element signatures indicate an affinity to extension-related, within-plate volcanism (Figure GS-11-5b, c). Elevated Y and Yb contents, with correspondingly low Zr/Y and $[La/Yb]_N$ ratios, classify these rocks as FII- and FIIIa-type rhyolites (Figure GS-11-5d–f) in the scheme of

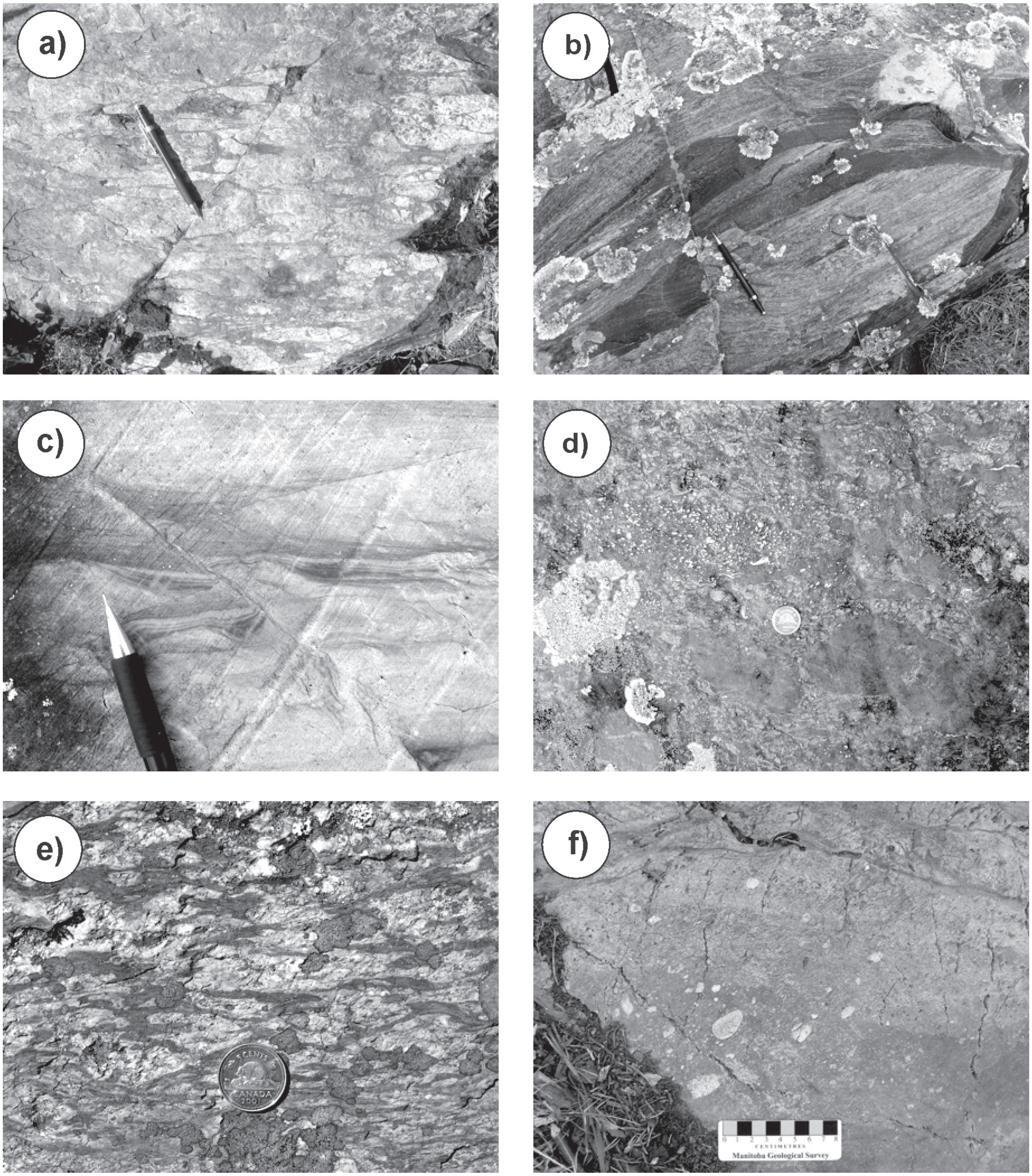

Figure GS-11-4: *Outcrop photographs of the Gem assemblage in the central portion of Gem Lake:* ***a)*** *altered monolithic flow breccia composed of light grey rhyolite;* ***b)*** *unaltered, flow-banded, dark grey rhyolite;* ***c)*** *thinly bedded volcanic sandstone, siltstone and chert (note crossbeds above the tip of the pencil);* ***d)*** *heterolithic mafic breccia with fragments of quartz-amygdaloidal basalt;* ***e)*** *quartz-phyric rhyolite breccia with dark-coloured, welded pumice fragments;* ***f)*** *bedded heterolithic volcaniclastic rocks with well-rounded rhyolite clasts.*

Lesher et al. (1986).

Mafic and intermediate flows and sills in the Gem assemblage are composed of basalt and basaltic andesite (49.8–55.4 wt.% SiO_2, anhydrous; 0.007–0.02 Zr/TiO_2) that exhibit transitional calcalkalic-tholeiitic affinities. Primitive-mantle–normalized extended-element profiles are characterized by enriched and fractionated light REE, with moderate negative Nb anomalies and weakly fractionated and enriched heavy REE (Figure GS-11-3). These rocks plot between E-MORB and

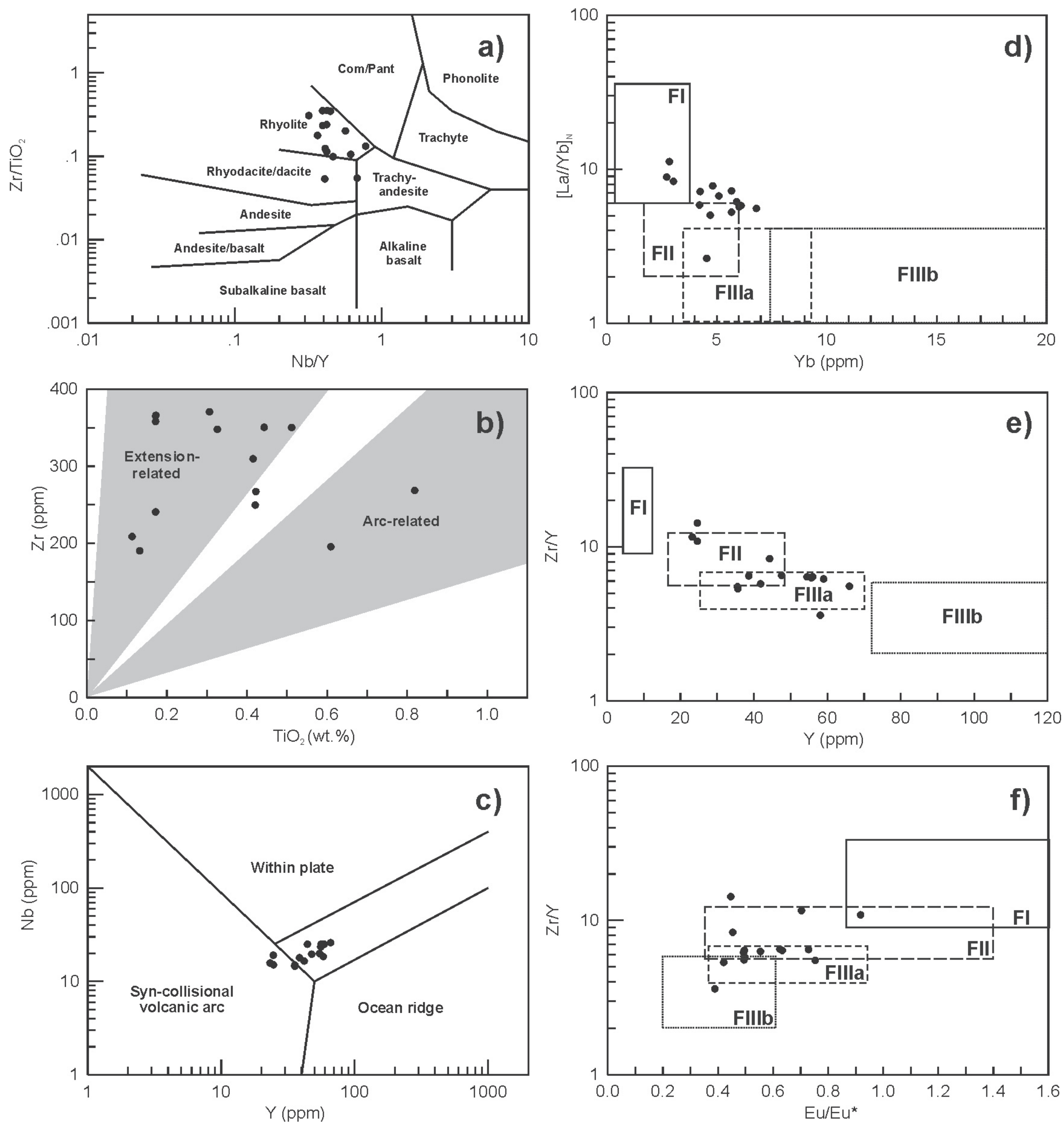

Figure GS-11-5: *Geochemical discrimination diagrams for samples of felsic volcanic rock in the Gem assemblage:* ***a)*** *Nb/Y vs. Zr/TiO_2 (Winchester and Floyd, 1977);* ***b)*** *TiO_2 vs. Zr (Syme, 1998);* ***c)*** *Y vs. Nb (Pearce et al., 1984);* ***d)*** *Yb vs. $[La/Yb]_N$;* ***e)*** *Y vs. Zr/Y; and* ***f)*** *Eu/Eu* vs. Zr/Y. The compositional fields for FI, FII, FIIIa and FIIIb rhyolite are from Lesher et al. (1986).*

typical arc-tholeiite on basalt discrimination diagrams, and are chemically similar to basaltic andesite flows in the Drumming Point sequence of the ca. 2.72 Ga Black Island assemblage (*see* Bailes and Percival, 2000; Bailes et al., 2003).

Paleotectonic setting

Seneshen (1986, 1990) interpreted the western panel of the Gem assemblage to record deposition in a subaerial to shallow-marine setting on the flanks of a subsiding volcanic edifice, during a regional transition from subaerial felsic volcanism to basinal marine sedimentation. As described by Seneshen (1986, 1990), this panel is characterized by rapid lateral and vertical facies transitions, with evidence of deep erosional scouring and high-energy sedimentation, coeval with bimodal, subaerial and subaqueous volcanism. Thin layers of laminated black chert in this panel indicate periodic episodes of sediment starvation. East of the Manigotagan River, similar layers appear to mark a regional transition from subaerial rhyolitic volcanism to subaqueous deposition of a thick succession of heterolithic volcaniclastic rocks, the accumulation of which was coeval with volumetrically minor bimodal volcanism. The felsic volcanic rocks are composed of transitional calcalkalic-tholeiitic dacite and rhyolite that exhibit an affinity to extension-related within-plate volcanism and are locally intercalated with MORB-like pillowed basalt flows. These features are hallmarks of oceanic or continental-arc volcanism in extensional tectonic regimes (e.g., Lentz, 1998; Syme et al., 1999). On this basis, the Gem assemblage is provisionally interpreted to record the initiation of a ca. 2.72 Ga arc-rift basin (or basins) along the southern margin (present coordinates) of a ca. 2.73 Ga calcalkaline arc represented by the Bidou assemblage.

Economic considerations

The association of extension-related volcanism and VHMS deposits has been well documented in the literature (e.g., Lentz, 1998; Syme, 1998; Syme et al., 1999) and represents a first-order criterion for identifying volcanic terranes of enhanced exploration potential. In the classification scheme of Lesher et al. (1986), felsic volcanic rocks in the Gem assemblage classify as FII- and FIIIa-type rhyolites, which are known to host several important VHMS deposits in the Archean greenstone belts of the Superior Province. At Gem Lake, these rocks contain laterally extensive zones of sericite-pyrite alteration that, in the eastern portion of Gem Lake, are situated in the footwall of a regional transition from subaerial volcanism to subaqueous deposition that is locally marked by layers of laminated black chert and sulphidic epiclastic rocks, which may represent paleoexhalative horizons. Altered sulphidic clasts (sericite-pyrite) are observed in heterolithic volcanic conglomerate layers in the medial portion of the Gem assemblage on the west limb of the BLA, indicating that the sericite-pyrite alteration observed at Gem Lake may be syngenetic. These attributes indicate that, in addition to the demonstrated potential for orogenic lode-gold deposits, the Gem Lake area is also prospective for VHMS deposits.

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