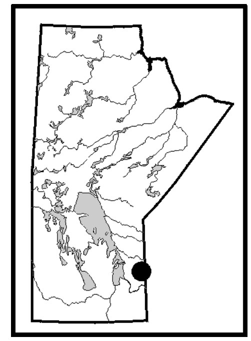

GS-27 PRELIMINARY REPORT ON THE GEOLOGY AND STRUCTURE OF THE GARNER LAKE AREA, SOUTHEAST RICE LAKE GREENSTONE BELT (NTS 52L14), MANITOBA

by S.D. Anderson

Anderson, S.D. 2002: Preliminary report on the geology and structure of the Garner Lake area, southeast Rice Lake greenstone belt (NTS 52L14), Manitoba; *in* Report of Activities 2002, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 234–249.

SUMMARY

The Rice Lake greenstone belt, located in the western portion of the Archean Uchi Subprovince, is the most significant lode-gold district in Manitoba, with more than 1.7 million ounces of past gold production. In 2002, the Manitoba Geological Survey initiated a multidisciplinary program of targeted 1:20 000-scale bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology in the Rice Lake belt. The objective of this program is to further refine the stratigraphic, structural and tectonic framework of the belt, with particular emphasis on gold metallogeny. Fieldwork in 2002 focused on detailed mapping and sampling of a roughly 12 km transect across the southeast portion of the Rice Lake belt, utilizing exposures along the Gem Lake logging road and the shoreline of Garner Lake.

Four distinct tectonostratigraphic domains have been identified across the transect, each of which is bounded by major ductile shear zones that trend north or northwest. One of these domains includes the 'Garner narrows[1] assemblage', herein proposed for the north-facing sequence of arkosic wacke, andesitic volcanic rocks, iron formation and komatiitic flows that is exposed through the narrows in Garner Lake. This assemblage, the age of which is currently being investigated by U-Pb zircon geochronology, is similar to Mesoarchean (ca. 2.99 Ga) rift sequences elsewhere in the Uchi Subprovince.

In contrast to previous interpretations, overprinting relationships clearly indicate that the major domain-bounding shear zones postdate the regional D_2 deformation; however, the implications of this distinction for gold exploration remain unclear. To this end, a major focus of future work will be to document the stratigraphic and structural setting of gold occurrences in the Garner Lake area in the context of the framework outlined in this report. This information will provide insight into the mineralization process and controls, and constrain predictive models for gold in the southeast Rice Lake belt.

INTRODUCTION

The Rice Lake greenstone belt is the most significant lode-gold district in Manitoba, with hundreds of documented gold occurrences (e.g., Stockwell, 1940; Theyer and Yamada, 1989; Theyer and Ferreira, 1990; Theyer, 1991, 1994a, b; Richardson and Ostry, 1996) and historic production of approximately 1.73 million ounces of gold from several past-producing mines, including 1.42 million ounces from the San Antonio mine at Bissett (Whiting and Sinclair, 1990). Studies conducted under the auspices of the Canada-Manitoba Partnership Agreement on Mineral Development and the Western Superior NATMAP project have provided important new insights into the complex stratigraphic, structural and metallogenic evolution of the Rice Lake belt. Recent bedrock mapping, U-Pb geochronology and geochemistry have established, for example, the local presence of Mesoarchean (ca. 2.9 Ga) quartzite–iron formation–komatiite rift sequences, in addition to the more extensive Neoarchean (ca. 2.73 Ga) volcanic-arc successions (Fig. GS-27-1; e.g., Poulsen et al., 1996; Sasseville and Tomlinson, 1999, 2000; Percival et al., 2001, 2002). In this regard, it is now apparent that the tectonostratigraphy of the Rice Lake belt is analogous to that in the adjacent Red Lake greenstone belt in northwestern Ontario (e.g., Poulsen et al., 1996; Sanborn-Barrie et al., 2000, 2001).

Aside from contributing significantly to the understanding of the Rice Lake belt, these studies have also revealed challenging problems and directions for further research. For example, despite the correlative tectonostratigraphy in the Red Lake and Rice Lake belts, the vast majority of gold production (>20 million ounces) in the former has been derived from Mesoarchean hostrocks; in contrast, gold production in the latter came mainly from Neoarchean rocks. Moreover, although the importance of structural controls on the distribution of gold mineralization in the Rice Lake belt has been clearly demonstrated (e.g., Stockwell, 1940; Stephenson, 1972; Lau, 1988; Brommecker et al., 1989; Brommecker, 1991; Poulsen et al., 1996), the structural geology and deformation history of large areas of the belt remain poorly understood.

[1] unofficial place name

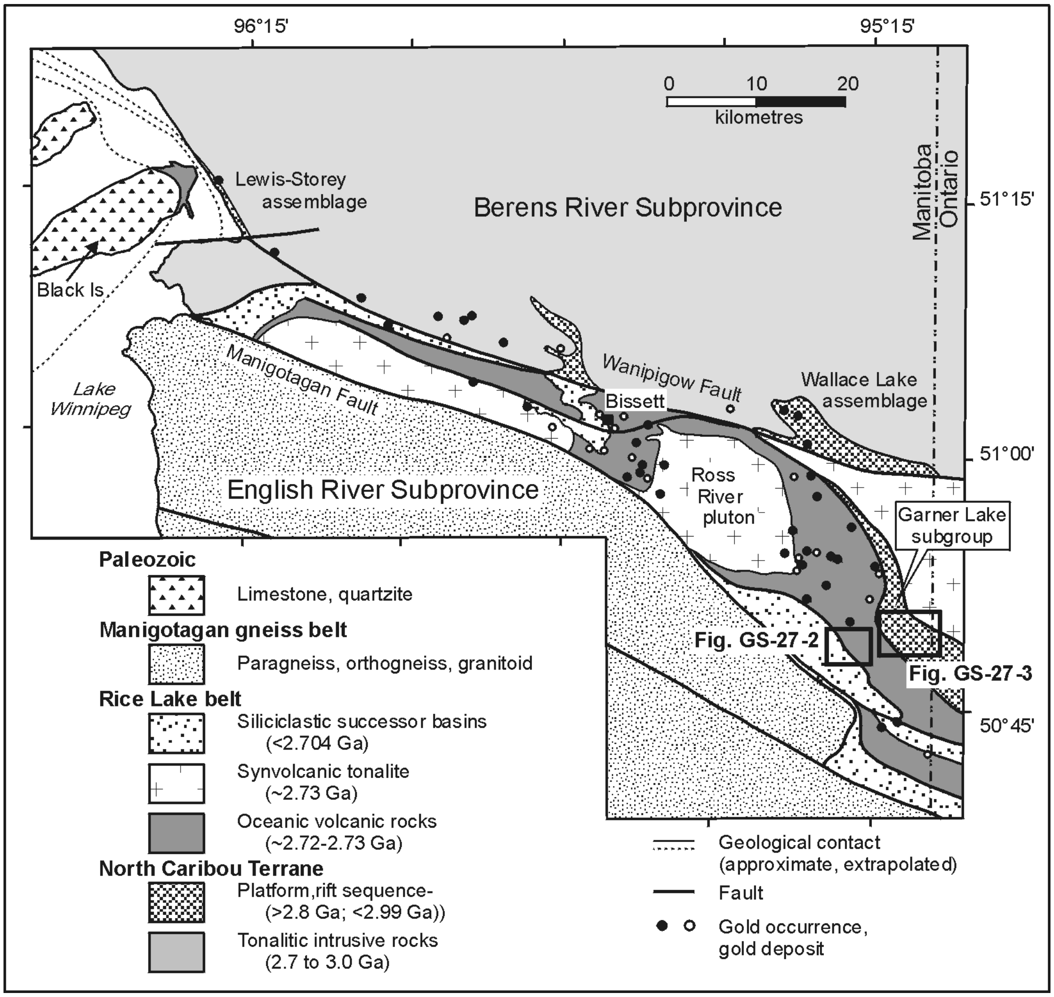

Figure GS-27-1: Simplified geology of the Rice Lake belt (after Richardson and Ostry, 1996). The locations of Figures GS-27-2 and GS-27-3 are indicated.

In order to address these and other outstanding problems, the Manitoba Geological Survey (MGS) has initiated a multiyear, multidisciplinary project with the objective of further refining the stratigraphic, structural and tectonic framework of the Rice Lake belt, with particular emphasis on gold metallogeny and the recently documented Mesoarchean rift sequence. This collaborative project will mainly involve targeted 1:20 000-scale bedrock mapping, structural analysis and lithogeochemistry (S. Anderson, C. Beaumont-Smith and T. Corkery, MGS), in conjunction with the focused application of U-Pb geochronology (C. Böhm; University of Alberta).

In the summer of 2002, fieldwork focused on detailed mapping and sampling of a roughly 12 km transect across the southeast portion of the Rice Lake belt, utilizing exposures along the Gem Lake logging road and the shoreline of Garner Lake (Fig. GS-27-1, GS-27-2, GS-27-3). Due to the combination of complex stratigraphy and structure, a lack of comprehensive mapping coverage and the evidence for a thick package of komatiitic volcanic rocks (Brommecker et al., 1993), the Garner Lake area has been considered key to unravelling the complex geological history of the Rice Lake belt (e.g., Poulsen et al., 1994; Corkery, 1995, 1999). This mapping, the preliminary results of which are summarized below, will be complemented by U-Pb geochronology and lithogeochemistry to provide an updated geological framework for ongoing investigations in the southeast Rice Lake belt.

REGIONAL SETTING

The Archean Rice Lake greenstone belt is located in the westernmost exposed portion of the volcanoplutonic Uchi Subprovince of the Superior Province. In Manitoba, the Uchi Subprovince is flanked to the north by the North Caribou Terrane (Berens River Subprovince) and to the south by the Manigotagan gneiss belt of the English River Subprovince

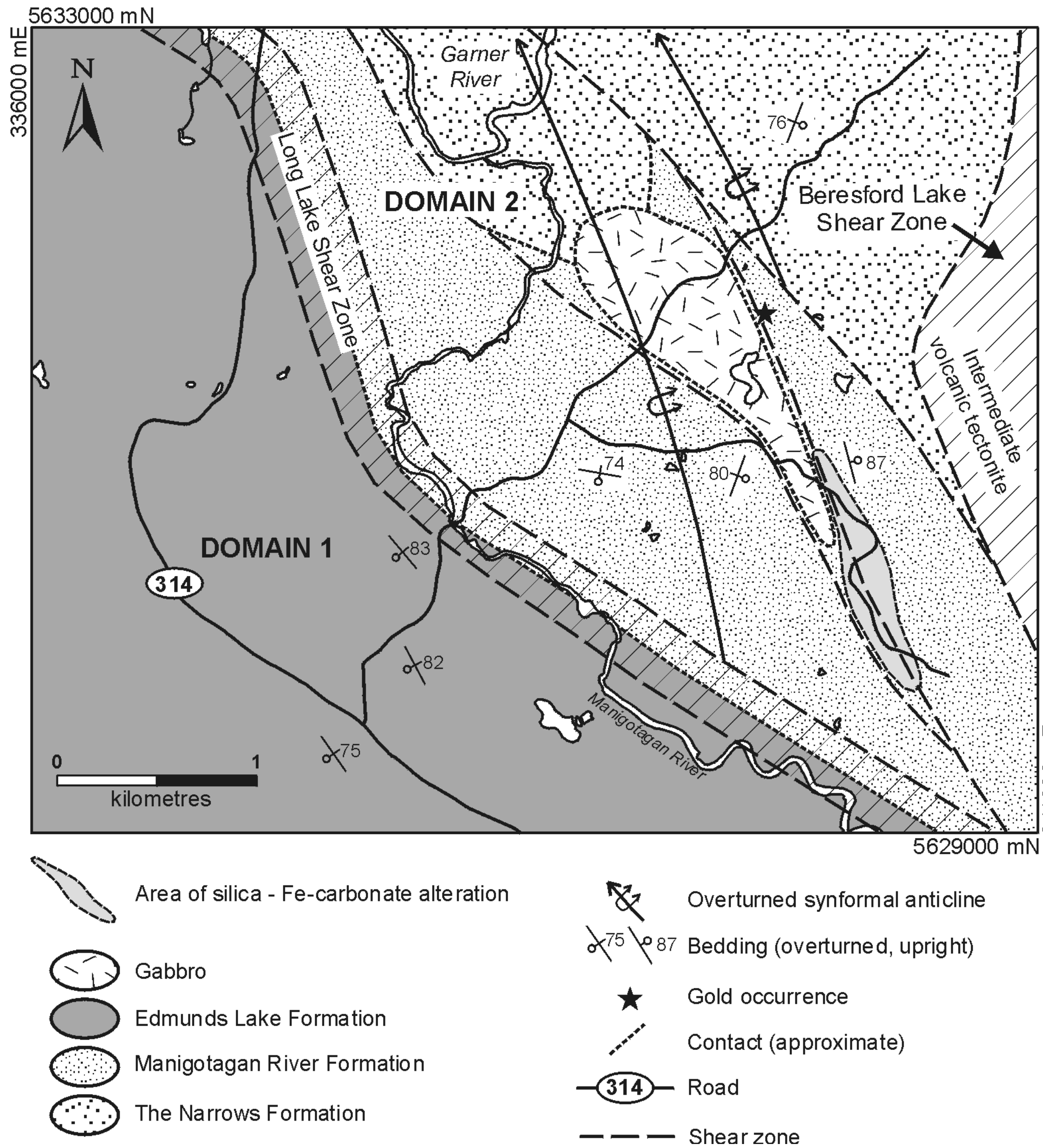

Figure GS-27-2: Simplified geology in the area of the Gem Lake logging road.

(Fig. GS-27-1).

The North Caribou Terrane (Thurston et al., 1991), which is bounded to the south by the regional-scale Wanipigow Fault, comprises ca. 3.0 Ga (Mesoarchean) basement plutonic rocks of mainly tonalitic composition, unconformably overlain by a ca. 2.9 Ga platform-rift sequence, and intruded by voluminous ca. 2.7 Ga (Neoarchean) granitoid plutons. The platform-rift sequence, as represented by the Lewis-Storey (Percival et al., 2001) and Wallace Lake assemblages (McRitchie, 1971; Sasseville and Tomlinson, 2000), is discontinuously exposed along the southern margin of the North Caribou Terrane (Fig. GS-27-1). The sequence typically consists of basal quartz arenitic rocks overlain by intercalated banded iron formation and komatiitic volcanic rocks, and is thought to record continental rifting at the southwest margin of the North Caribou Terrane (Percival et al., 2002).

The Manigotagan gneiss belt, which is bounded to the north by the regional-scale Manigotagan Fault, consists of paragneiss, orthogneiss and granitoid plutons. These rocks were derived, at least in part, from siliciclastic sequences in the adjacent Rice Lake belt, and underwent regional deformation and metamorphism at ca. 2.69 Ga, during the Kenoran orogeny.

The ca. 2.72 to 2.73 Ga (Turek et al., 1989) supracrustal rocks of the Rice Lake greenstone belt consist mainly of tholeiitic and calc-alkaline volcanic rocks of basaltic to rhyolitic composition, intercalated with thick synvolcanic mafic sills and minor derived volcaniclastic and epiclastic sedimentary rocks. These volcanic rocks are intruded by

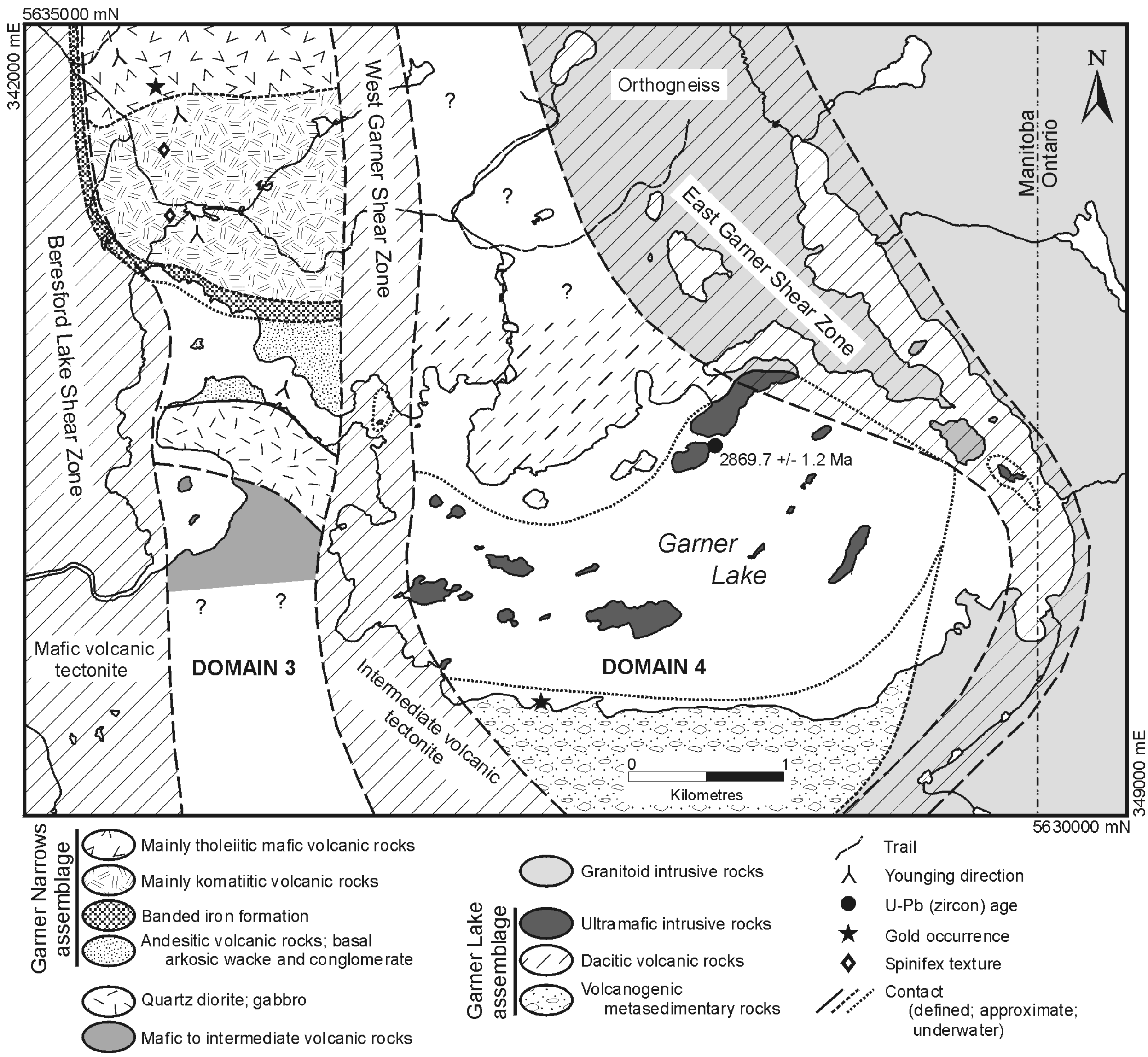

Figure GS-27-3: Simplified geology of the Garner Lake area, modified in part from Brommecker et al. (1993).

synvolcanic tonalite, quartz diorite and granodiorite plutons (e.g., the 2.73 Ga Ross River pluton; Turek et al., 1989), and are unconformably overlain by less than 2.704 Ga (Davis et al., 1994; Percival et al., 2002) basinal siliciclastic rocks.

Brommecker et al. (1993) described a thick sequence of basalt, komatiite and iron formation in the area north of Garner Lake, and speculated that the interior portion of the Rice Lake belt may also contain fault-bounded packages of the Mesoarchean rift sequence. This theory was supported by a 2.87 Ga U-Pb zircon date obtained from the nearby Garner Lake layered ultramafic body (Poulsen et al., 1993), which Brommecker et al. (1993) considered to intrude the basal portion of the komatiite-bearing sequence. On this basis, Poulsen et al. (1996) subsequently defined the Garner Lake subgroup (Fig. GS-27-1), which they considered to be correlative with the Mesoarchean rocks at Wallace Lake. As demonstrated below, however, the geological picture in the Garner Lake area is significantly more complex than previously thought, and the local geological framework proposed by Poulsen et al. (1996) requires significant revision.

GENERAL GEOLOGY, STRATIGRAPHY AND METAMORPHISM

Four distinct stratigraphic-structural domains have been identified along the Gem Lake road–Garner Lake transect, each of which contains a distinctive association of rock types, locally with significant differences in the style and sequence of deformation. They trend north or northwest and are each bounded by major ductile shear zones. These domains, numbered 1 through 4 from west to east across the study area (Fig. GS-27-2, GS-27-3), are described in detail below.

Domain 1

Domain 1 consists of greywacke-mudstone turbidite of the Edmunds Lake Formation (Fig. GS-27-2). These rocks contain detrital zircons as young as 2.704 Ga (Davis et al., 1994), and regional stratigraphic relationships indicate that they unconformably overlie the ca. 2.73 Ga volcanic rocks of the Rice Lake belt.

This domain is bounded to the northeast by a 500 m thick ductile shear zone herein referred to as the 'Long Lake Shear Zone', after the location where it was originally described by Zwanzig (1971). The regional metamorphic mineral assemblage in these rocks consists of biotite-chlorite±hornblende and rare garnet, consistent with middle to upper greenschist facies peak metamorphic conditions.

Edmunds Lake Formation

The Edmunds Lake Formation consists of monotonously bedded greywacke-siltstone turbidite, with minor conglomerate, mudstone, chert and iron formation. Bedding in these rocks dips steeply northeast. Well-developed graded beds, channels, crossbedding and load structures indicate that these rocks face southwest, although local reversals are observed and indicate the presence of F_1 isoclinal folds. In general, the section appears to coarsen stratigraphically upward, with thin-bedded mudstone, iron formation and chert more common lower in the section, and thick-bedded greywacke and conglomerate more prevalent higher in the section. The greywacke is typically medium grained and contains less than 10% detrital quartz. Individual beds range up to 50 cm thick and exhibit normal size-grading and abundant slump-folds. Lenticular beds of polymictic conglomerate range up to 3 m thick and contain unsorted, typically subangular to well-rounded clasts that range in size up to 20 cm. In marked contrast to conglomerate in the underlying volcanic successions, clasts of phaneritic plutonic rock are an important component of the Edmunds Lake Formation conglomerate.

Domain 2

Domain 2 contains rocks of the Narrows Formation (Campbell, 1971; Weber, 1971) and the overlying Manigotagan River Formation (Owens and Seneshen, 1985; Seneshen and Owens, 1985), which represent the uppermost formations of the ca. 2.73 Ga (Turek et al., 1989) Bidou Lake subgroup. Although regional stratigraphic relationships point to a conformable relationship between these formations, the contact appears to be mainly tectonic in the mapped area. Domain 2 is bounded to the northeast by the ca. 2 km thick Beresford Lake Shear Zone, and to the southwest by the Long Lake Shear Zone (Fig. GS-27-2). Regional metamorphic mineral assemblages in these rocks comprise fine-grained chlorite-biotite±actinolite±sericite, consistent with lower greenschist facies peak metamorphic conditions.

Narrows Formation

The section of Narrows Formation exposed along the Gem Lake road consists of volcanic conglomerate, volcanic breccia and tuff breccia, intercalated with minor units of intermediate volcanic sandstone. Light grey to buff, aphanitic to plagioclase- and/or quartz-phyric, dacitic volcanic rock is the predominant clast type in the coarse fragmental rocks. The matrix consists of fine- to coarse-grained, plagioclase-crystal–rich, tuffaceous sandstone that contains up to 10% detrital quartz. The volcanic conglomerate is heterolithic and typically matrix supported, with well-rounded to subangular clasts that range in size up to 2 m, whereas the volcanic breccia is monolithic and clast supported, with angular to subrounded clasts generally less than 30 cm in size. A diffuse layering that dips steeply to the west-northwest is locally evident, and is defined by subtle variations in clast size and proportion of matrix. Load casts and channels observed in two locations indicate tops to the east-southeast.

Manigotagan River Formation

The Manigotagan River Formation, as originally defined by Seneshen and Owens (1985), is thought to mark the transition between the underlying Narrows Formation and the Edmunds Lake Formation. The section through the Manigotagan River Formation provided by the Gem Lake road is broadly similar to that described by Seneshen and Owens (1985), although considerably thicker due to structural thickening in the hinge of a macroscopic synformal anticline (Fig. GS-27-2). The hinge of this fold also contains a large body of medium-grained, homogeneous, leucocratic gabbro that discordantly intruded the Manigotagan River Formation (Fig. GS-27-2).

The section comprises mainly dark green to grey, aphyric to coarsely plagioclase-phyric, mafic to intermediate volcanic rocks, which include massive and pillowed flows, lapilli tuff, breccia and pillow breccia. The flows contain up to 5% round, quartz-filled amygdales, less than 0.5 cm in size, and locally display well-formed pillows less than 0.5 m in size. The volcanic rocks are intercalated with thick units of heterolithic volcanic conglomerate, with subordinate, thin-bedded units of fine-grained, chloritic, volcanic sandstone and mudstone, and minor chert. The finer grained clastic rocks contain well-developed graded bedding, with local load casts and channels. The conglomerate contains a diffuse metre-scale layering defined by variations in the proportion and size of clasts (Fig. GS-27-4). Typically, the clasts are subrounded to well rounded, equant and 10 to 30 cm in diameter, but locally range up to 2 m in maximum dimension. Texturally heterogeneous, generally plagioclase-phyric, intermediate volcanic rock accounts for more than 90% of the clast population, with minor clasts of mafic volcanic and sedimentary rock. The matrix consists of dark grey to green, coarse-grained chloritic sandstone that lacks detrital quartz.

Domain 3

Domain 3 contains the ‘Garner narrows assemblage’ (GNA), which is herein proposed for the generally west-trending, consistently north-facing sequence of rocks that is well exposed through the area of the narrows between the east and west portions of Garner Lake (Fig. GS-27-3). To the south, the GNA lies in apparent nonconformable contact with quartz diorite, which is flanked to the south by a thick package of mafic to intermediate volcanic rocks.

The northern, mafic volcanic portion of the GNA has previously been described by Brommecker et al. (1993), who documented the presence of komatiitic flows and suggested a possible correlation with Mesoarchean rift-sequence rocks elsewhere in the Uchi Subprovince. As described in detail below, the 2002 mapping has shown that the GNA contains all of the essential components that typify Mesoarchean rift sequences.

Domain 3 is bounded on the west by the Beresford Lake Shear Zone, and on the east by the approximately 500 m thick West Garner Shear Zone (the Garner Shear Zone of Poulsen et al., 1994). Metamorphic mineral assemblages comprise biotite-chlorite-actinolite±hornblende and rare garnet, consistent with middle to upper greenschist facies peak metamorphism.

Mafic to intermediate volcanic rocks

The southernmost portion of Domain 3 is underlain by a more than 1 km thick package of dark green to grey, mafic to intermediate volcanic rocks (Fig. GS-27-3). These rocks are typically aphyric to coarsely plagioclase-phyric, with up to 25% subhedral plagioclase crystals that are less than 0.5 cm in size and evenly distributed in an aphanitic to fine-grained matrix. The predominant rock type is monolithic tuff breccia that contains up to 50% angular to subrounded, plagioclase-phyric clasts that range in size up to 25 cm (generally 5–10 cm). The tuff breccia contains a diffuse layering and is locally intercalated with thin units of chloritic lapilli tuff; however, these rocks lack unambiguous younging criteria.

Figure GS-27-4: Metre-scale layering in volcanic conglomerate of the Manigotagan River Formation, exposed along the south branch of the Gem Lake logging road. This outcrop is located in the hinge of the macroscopic anticline shown in Figure GS-27-2. Note the orthogonal relationship between the layering and the regional S_2 foliation (parallel to pencil).

Quartz diorite and gabbro

To the north, the mafic to intermediate volcanic rocks lie in contact with an approximately 600 m thick body of quartz diorite and minor gabbro (Fig. GS-27-3). The gabbro is dark grey to green with a fine- to medium-grained, equigranular, ophitic texture and 20 to 50% plagioclase. The quartz diorite is dark grey, medium to coarse grained and texturally similar to the gabbro, although it contains greater than 50% plagioclase and up to 10% blue quartz. Coarse-grained to locally pegmatitic quartz diorite, which contains coarse-grained blue quartz and acicular hornblende crystals up to 2 cm in length, occurs in irregular patches and dike networks cutting the finer grained quartz diorite and gabbro, particularly near the northern contact. These rocks are crosscut by light grey to pink, fine- to medium-grained granodiorite dikes that range up to 1.5 m thick.

The southern contact of the quartz diorite has not been observed, and is therefore open to interpretation. An early, west-trending, high-strain zone is well exposed immediately south of the inferred contact (Fig. GS-27-3), which may indicate a wholly tectonic contact relationship. The apparent absence of granodiorite dikes in the volcanic rocks to the south may lend support to this interpretation. Alternatively, the contact may be intrusive and only slightly modified by later shearing. Additional mapping will be required to differentiate between these, or other, possibilities. The northern contact of the quartz diorite is comparatively well exposed, and is described below.

Garner narrows assemblage

Arkosic wacke and pebble conglomerate

The base of the GNA is marked by a distinctive unit of light grey to green, arkosic wacke and pebble conglomerate that ranges from 5 to 30 m thick. Typically, this unit consists of medium- to coarse-grained, pebbly arkosic wacke (Fig. GS-27-5) that contains up to 25% blue quartz. The blue quartz forms angular to subrounded, equant grains, less than 1 cm in size, that are evenly distributed in a fine- to medium-grained feldspathic matrix containing up to 30% chlorite, biotite, sericite and magnetite. These rocks are typically quite homogeneous on the scale of individual outcrops, although variations in the abundance and size of quartz grains in some outcrops locally define a very subtle, diffuse layering that parallels the strike of the unit. A coarser fragmental texture is apparent in many locations, and is defined by pebble- and cobble-sized clasts of phaneritic tonalite, evenly distributed in a finer grained matrix of chlorite, biotite and magnetite.

This unit is remarkably similar to the tonalitic ‘grit’, described by Percival et al. (2001, 2002), immediately below the basal unconformity of the Mesoarchean Lewis-Storey assemblage. They considered the grit to be a proximal erosional product of the immediately underlying tonalitic basement rocks. In the GNA, the coarse-grained, blue-quartz–bearing arkosic wacke lies in sharp contact with blue-quartz–bearing quartz diorite, which similarly suggests proximal derivation from the underlying plutonic rocks and therefore a nonconformable depositional relationship. Samples of the arkosic wacke and adjacent pegmatitic quartz diorite have been collected for U-Pb geochronology to test this hypothesis.

Andesitic volcanic rocks

The clastic unit lies in contact to the north with an approximately 800 m thick package of andesitic volcanic rocks. The contact between these units, as observed in three locations, is sharp and appears to be depositional (Fig. GS-27-6). The andesitic volcanic rocks are light green to grey, aphyric to plagioclase phyric and consist of intercalated tuff breccia, lapilli tuff and tuff, with minor units of thinly layered quartz arenite, iron carbonate and fine-grained ferruginous argillite. The fragmental volcanic rocks are monolithic and unsorted, with angular to subrounded clasts of light grey to green andesite that range in size up to 25 cm. Diffuse layering was observed in several locations, and trends generally east. The tuffaceous rocks are fine grained and homogeneous, with approximately 60% subhedral, felty-textured plagioclase laths, less than 1 mm in size, in an aphanitic feldspathic

Figure GS-27-5: Coarse-grained pebbly arkosic wacke at the base of the Garner narrows assemblage, south shore of Garner narrows.

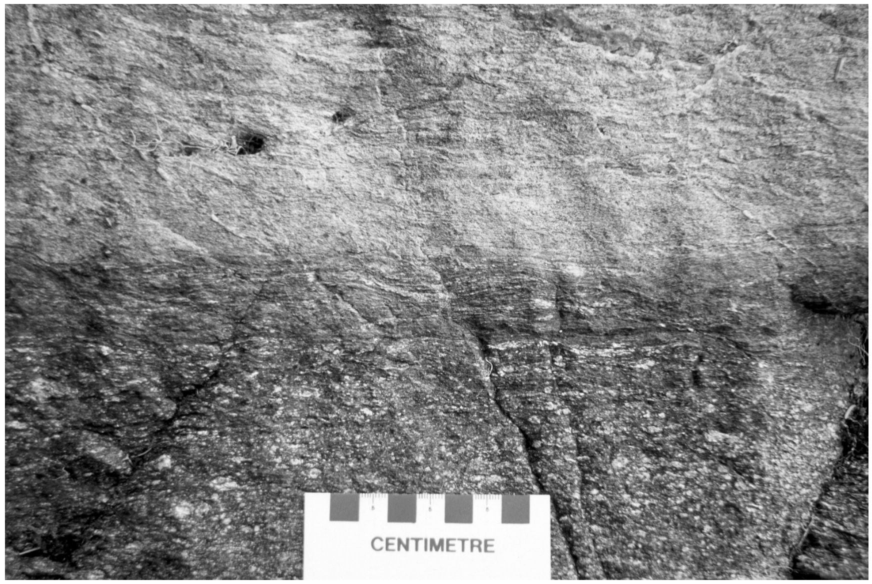

Figure GS-27-6: Sharp contact between dark grey, pebbly arkosic wacke and overlying, light grey-green, andesitic volcanic rocks of the Garner narrows assemblage, West Garner Shear Zone, north shore of Garner narrows.

matrix. A sample of relatively coarse plagioclase-phyric tuff was collected for U-Pb geochronology, with the goal of constraining the age of the andesitic volcanic rocks.

Banded iron formation

Through a gap in exposure less than 100 m wide, the andesitic volcanic rocks are flanked to the north by an approximately 150 m thick unit of banded oxide-facies iron formation (Fig. GS-27-3). These rocks consist of alternating layers, less than 10 cm thick, of light grey chert and fine-grained, granular magnetite, with accessory chlorite, quartz and biotite (Fig. GS-27-7). To the west, regional aeromagnetic data and field relationships indicate that the iron formation is transposed into the Beresford Lake Shear Zone (Fig. GS-27-3). To the east, the aeromagnetic signature becomes more diffuse, likely due to proximity to the Garner Lake ultramafic intrusive body.

Mafic volcanic rocks

As described by Brommecker et al. (1993), the iron formation is overlain by a thick (>1.5 km), north-facing section of predominantly massive and pillowed mafic flows, intercalated with rare, thin units of fine-grained sedimentary rocks and iron formation, and abundant gabbroic sills. Lithogeochemical data indicate that several, intercalated, compositional varieties of mafic flow are present, including calc-alkalic basalt, tholeiitic andesite, high-Mg tholeiitic basalt and komatiite (21–25% MgO, anhydrous; Brommecker et al., 1993). In general, the komatiitic rocks predominate in the southern portion of the section, whereas the tholeiitic rocks predominate farther to

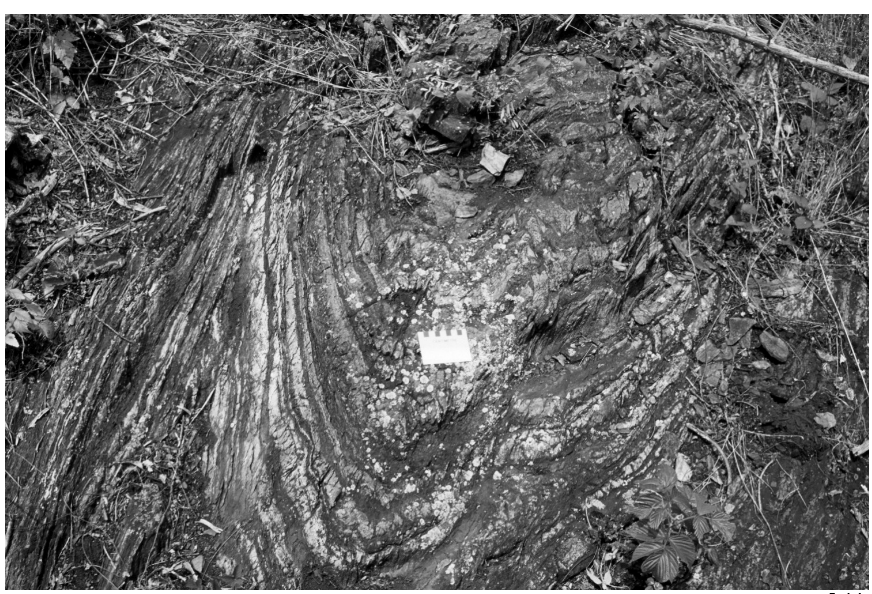

Figure GS-27-7: Banded iron formation in the Garner narrows assemblage (top of photo is north), north shore of Garner narrows. The east-trending layering in these rocks is folded by an F_3 fold, and transposed into a narrow D_3 shear zone along the west edge of the outcrop.

the north. Spinifex, autobreccia and polysuture textures are observed locally in the komatiitic rocks, thereby confirming their origin as volcanic flows (Brommecker et al., 1993).

Although several authors have indicated that the komatiite continues to the east across the trace of the West Garner Shear Zone (e.g., Corkery, 1995; Poulsen et al., 1996), the original work of Brommecker (1991) and Brommecker et al. (1993) provides little evidence to support this interpretation. The komatiitic section is therefore provisionally interpreted to be truncated at the West Garner Shear Zone (Fig. GS-27-3), pending additional mapping and lithogeochemical sampling in this key area.

Domain 4

Domain 4 contains the 'Garner Lake assemblage', herein proposed for the thick package of intermediate to felsic, volcanic and volcaniclastic rocks exposed along the north and south shores of Garner Lake, and which includes the Garner Lake layered ultramafic intrusion (Scoates, 1971), exposed mainly on islands in Garner Lake (Fig. GS-27-3).

The regional metamorphic mineral assemblage in the volcanic rocks comprises biotite-chlorite±garnet±hornblende, indicating upper greenschist to lower amphibolite facies peak metamorphic conditions. As described by Scoates (1971), a narrow contact-metamorphic aureole is developed along the north and south contacts of the Garner Lake intrusion, in which the volcanic rocks are strongly recrystallized and contain a coarse biotite-hornblende-epidote±garnet mineral assemblage, locally with up to 10% concentrically zoned, epidote-rich hornfels spots less than 15 cm in diameter. The presence of this aureole indicates an intrusive contact relationship between the ultramafic intrusion and the adjacent volcanic rocks. The nature of the contact relationship between the country rocks north and south of Garner Lake remains unknown.

Domain 4 is bounded to the west by the West Garner Shear Zone. To the east, the rocks of the Garner Lake assemblage are cut by multiple generations of granitoid plutonic rock, which include granite, granodiorite, hornblende tonalite and quartz diorite, and are transposed into a thick belt of mainly granitic orthogneiss that marks the trace of the East Garner Shear Zone (Fig. GS-27-3). Crosscutting relationships clearly show that at least some of the granitoid dikes intruded the Garner Lake ultramafic intrusion, as well as the volcanic country rocks, prior to development of the main gneissic fabric in the East Garner Shear Zone. The interior portion of the shear zone contains thick packages of intercalated felsic and mafic orthogneiss and garnet-biotite-hornblende straight gneiss (Fig. GS-27-8). The presumably high metamorphic grade and state of strain recorded by these rocks indicate that a significant strain and metamorphic gradient probably exists in this direction. It is also possible that some of these rocks represent allochthonous tectonic inclusions in the East Garner Shear Zone.

Garner Lake assemblage

Volcanogenic metasedimentary rocks

The south shore of Garner Lake was only briefly examined during the 2002 field season. As described by previous authors (e.g., Brommecker et al., 1993; Corkery, 1995, 1999; Poulsen et al., 1996), the section in this area

Figure GS-27-8: Garnet-biotite-hornblende straight gneiss in the East Garner Shear Zone, central part of the large island in eastern Garner Lake (see Fig. GS-27-3). Top of photo is northeast.

appears to consist mainly of volcanogenic metasedimentary rocks, with heterolithic volcanic conglomerate predominating in the examined outcrops. These rocks contain subangular to subrounded, unsorted clasts of mafic and intermediate volcanic material that range in size up to 40 cm. These clasts locally have aspect ratios of greater than 30:1 on horizontal outcrop surfaces, indicative of very high finite strain in this area.

Dacitic volcanic rocks

Outcrops along the northern shore of Garner Lake contain a well-exposed section of light grey, dacitic volcanic rocks more than 1 km thick. The predominant lithology is volcanic breccia and tuff breccia, with subordinate lapilli tuff and crystal tuff. The volcanic breccia units are characterized by a coarse, monolithic fragmental texture defined by very angular to subrounded, generally equant, unsorted fragments that range in size up to 25 cm. The fragments are clast supported, typically with less than 15% very fine grained, siliceous matrix material. The fragments consist of light grey, homogeneous, aphanitic to fine-grained dacite that contains up to 5% evenly distributed, subhedral plagioclase and/or hornblende crystals less than 3 mm in size. A diffuse, generally east-trending layering is locally present, although unambiguous facing criteria are lacking.

Garner Lake layered ultramafic intrusion

The main body of the ultramafic intrusion consists of 100 to 400 m thick, alternating layers of orange-brown–weathering serpentinized peridotite and dark grey-black clinopyroxenite. The layers strike generally east and northeast, and dip moderately to the north (Scoates, 1971). In the northeast portion of the intrusion, the clinopyroxenite contains significant volumes of heterogeneous gabbro, which ranges in texture and composition from fine- to medium-grained melanocratic gabbro, through medium- to coarse-grained leucogabbro, to pegmatitic leucogabbro and hornblende quartz diorite. The pegmatitic leucogabbro occurs as irregular segregation pods with diffuse contacts in clinopyroxenite and melagabbro, or as narrow (<2 m thick) dikes, locally with sharp, parallel contacts. The pegmatitic dikes appear to be generally concordant with the bulk-scale layering in the ultramafic rocks, and may therefore be more correctly described as sills. These rocks likely represent a late-stage magmatic segregation phase (e.g., Scoates, 1971), which formed largely in situ in the upper portion of the Garner Lake layered ultramafic intrusive body.

A sample of the pegmatitic material, processed for U-Pb geochronology, was found to contain colourless to brown zircons with high Th/U ratios characteristic of zircons crystallized from mafic magmas (Poulsen et al., 1993; Poulsen et al., work in progress, 1998). These zircons yielded a U-Pb zircon date of 2869.7 ± 1.2 Ma, which is considered to closely approximate the age of the Garner Lake ultramafic intrusion. This date confirms a 2.87 Ga (Mesoarchean) minimum age for the volcanic country rocks in the Garner Lake assemblage. Although Brommecker et al. (1993) suggested that the Garner Lake layered intrusion may represent the subvolcanic source of the komatiitic flows northwest of Garner Lake, field relationships indicate that these rocks are separated by the West Garner Shear Zone. Therefore, a direct link between these rocks is presently considered unlikely.

STRUCTURAL ANALYSIS

Previous structural studies in the eastern portion of the Rice Lake belt (e.g., Weber, 1971; Zwanzig, 1971; Brommecker, 1991; Sasseville and Tomlinson, 1999, 2000) all described three main generations of deformation structure, including 1) an early, layer-parallel, S_1 fabric that is axial planar to rare isoclinal folds; 2) a regional, northwest-trending, penetrative S_2 foliation that contains a prominent, steeply plunging L_2 elongation lineation and is axial planar to macroscopic, upright, variably plunging F_2 folds; and 3) northeast-trending kink folds, locally associated with an S_3 crenulation cleavage.

Within this framework, Brommecker (1991) defined a series of north-trending D_1 high-strain zones, including the Beresford Lake Shear Zone, which were thought to record early, layer-parallel thrusting. These shear zones were thought to predate ductile D_2 deformation structures formed during regional southwest-directed shortening and out-of-sequence thrusting. The D_3 deformation structures, which are mainly brittle, were thought to have formed during dextral strike-slip shear along the Wanipigow and Manigotagan faults, in a regime of regional northwest-directed shortening.

The sequence of deformation proposed by Brommecker (1991) appears to be broadly consistent with the deformation structures observed along the Gem Lake road–Garner Lake transect. However, Brommecker's interpretation of the Beresford Lake Shear Zone as a D_1 structure is difficult to reconcile with mesoscopic and macroscopic overprinting relationships, which clearly indicate that the main shear fabric postdates the regional S_2-L_2

fabric, as well as the macroscopic F_2 folds. This distinction may have important implications for gold exploration in the area, since overprinting relationships described by Brommecker (1991) indicate a pre- to syn-D_2 timing of gold mineralization in the southeast Rice Lake belt.

In the present study, mesoscopic deformation structures in the Garner Lake area are subdivided, on the basis of overprinting relationships, into four generations, which are interpreted to result from four discrete phases of ductile (D_1, D_2, D_3) and brittle-ductile (D_4) deformation. The major domain-bounding shear zones, including the Beresford Lake Shear Zone, are interpreted to have formed during the D_3 deformation phase, although it is still possible that an early movement history within these zones has been completely obliterated by subsequent deformation.

Deformation D_1

Structures attributed to D_1 deformation are only locally preserved in the study area. The hinges of F_2 folds and the microlithons between S_2 crenulation cleavage planes locally contain a penetrative S_1 foliation defined by a preferred orientation of fine-grained biotite and chlorite. This fabric is particularly evident in the Edmunds Lake Formation, in areas where it is oriented slightly oblique to bedding (S_0) and is crenulated by S_2. In these rocks, local reversals in younging direction that are not associated with a corresponding change in S_0-S_2 vergence indicate the presence of isoclinal F_1 folds. An early (pre-S_2) fabric defined by aligned plagioclase crystals is also locally evident in the large gabbroic intrusive body in the Manigotagan River Formation, although this may represent an igneous flow texture.

Deformation D_2

Structures attributed to D_2 deformation are regionally developed in the study area (e.g., Brommecker, 1991; Poulsen et al., 1996). The S_2 planar fabric is typically penetrative, finely spaced and defined by a preferred orientation of fine-grained biotite, chlorite and amphibole. In fragmental rocks, the S_2 foliation is defined by strongly flattened clasts (Fig. GS-27-4). Typically, the S_2 foliation dips steeply northeast or southwest and contains a downdip to steeply northwest-plunging mineral and stretching lineation (Fig. GS-27-9a), defined by the long axes of elongate mineral grains and stretched clasts (Fig. GS-27-10). The axial ratios of stretched clasts generally define oblate ellipsoids, consistent with flattening strains.

The S_2 foliation is axial planar to open to isoclinal, upright F_2 folds. In the Edmunds Lake Formation, S_0-S_2 intersection lineations indicate that the F_2 folds plunge steeply to the northwest. Regional-scale F_2 folds with amplitudes ranging up to several kilometres have been mapped northwest of the study area, and include the map-scale Beresford Lake anticline that defines the map pattern in the central portion of the Rice Lake belt (e.g., Campbell, 1971; Brommecker, 1991). A consistent S_0-S_2 angular relationship in the Edmunds Lake Formation along the Gem Lake road similarly indicates the presence of macroscopic F_2 folds southwest of the study area.

Discrete zones of syn-D_2 high strain are characterized by a penetrative mylonitic S_2 foliation that largely obliterates primary features in the rocks. This foliation contains a prominent L_2 mineral and stretching lineation, with local development of L>S tectonite in which the X:Y axial ratios of stretched clasts exceed 10:1. Isoclinal, rootless and intrafolial F_2 folds are common in these zones, and result from progressive folding and transposition during D_2 shearing. Particularly good examples of D_2 high-strain zones are found in Domain 3 along the southern contact of the quartz diorite (Fig. GS-27-3) and in dacitic volcanic rocks of Domain 4. Sense of shear indicators in the D_2 high-strain zones, as viewed in the X-Z plane of the strain ellipsoid, include shear bands, σ-porphyroclasts and asymmetric quartz boudins that consistently indicate northeast-side-up shear (Fig. GS-27-11). As suggested by Brommecker (1991), the geometry of D_2 deformation structures in the southeast Rice Lake belt appears to be compatible with regional southwest-directed shortening.

Deformation D_3

Ductile structures attributed to the D_3 deformation have a heterogeneous distribution and geometry. Outside of the major domain-bounding shear zones, the regional S_2 foliation is locally overprinted by a weak, steeply northwest-dipping S_3 crenulation cleavage that is defined by fine-grained, foliated chlorite and biotite. This cleavage is axial planar to steeply northwest-plunging, open, parallel-style F_3 folds (Fig. GS-27-9b) and crenulations.

Toward the margins of the major north-trending shear zones, the S_3 fabric intensifies and the F_3 folds become progressively more tight, asymmetric and similar in style. Along the margins of the Beresford Lake and West Garner shear zones, east-trending primary layering and the S_2-L_2 fabric are strongly transposed into tight to isoclinal F_3 folds that trend north and are markedly S-asymmetric (Fig. GS-27-12). In the interior of the shear zones, these folds are transposed by thick zones of chlorite-biotite schist and chloritic mylonite that contain intrafolial, S-asymmetric

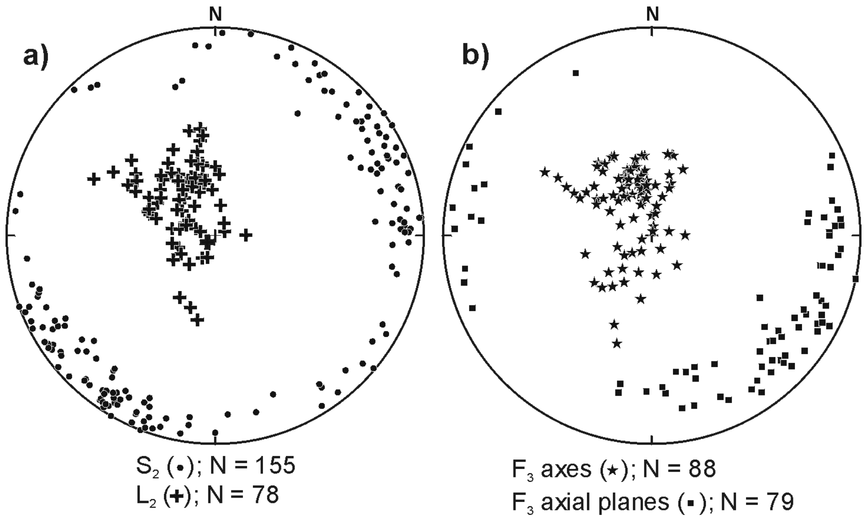

Figure GS-27-9: Lower hemisphere, equal area stereographic projections of the main deformation structures in the Garner Lake area: A) S_2 foliation (poles) and L_2 lineation; B) F_3 fold axes and poles to F_3 axial planes.

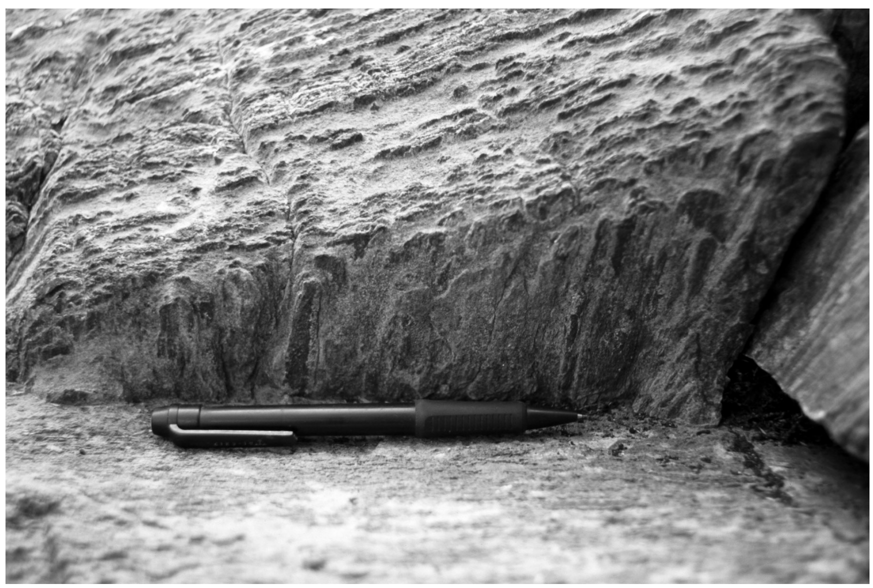

Figure GS-27-10: L_2 stretching lineation in intermediate volcanic rocks near the eastern margin of the West Garner Shear Zone (looking northwest), south shore of Garner narrows.

Figure GS-27-11: Penetrative S_2 foliation in andesitic tuff of the Garner narrows assemblage (looking southeast), north shore of Garner narrows. The asymmetric quartz boudins to the left of the pencil indicate northeast-side-up shear.

Figure GS-27-12: Asymmetric F_3 folds along the eastern margin of the Beresford Lake Shear Zone, western Garner Lake at the mouth of the Garner River. Note the sinistral shear bands in the left-centre portion of the photograph. Pencil points north.

isoclinal folds. Shear bands and asymmetric quartz boudins in these zones consistently indicate sinistral strike-slip shear (Fig. GS-27-13).

Collectively, these features indicate that the major north-trending, domain-bounding shear zones formed during D_3 deformation through progressive F_3 folding and transposition in a regime of sinistral shear. Northwest-directed shortening during the D_3 deformation, as proposed by Brommecker (1991), would be kinematically compatible with sinistral shear in the north-trending Beresford Lake and West Garner shear zones. The Long Lake Shear Zone, which contains dextral shear-sense indicators, trends generally west-northwest, and would thus be favourably oriented for dextral strike-slip shear during D_3 deformation.

Deformation D_4

The D_4 deformation structures are mainly brittle in character, and are heterogeneously developed. These structures typically comprise conjugate kink-fold and shear-fracture sets, which overprint D_3 structures in the Beresford Lake and West Garner shear zones. The shear fractures locally contain seams of fine-grained cataclasite less than 5 cm thick. The geometry and orientation of the conjugate fold and shear-fracture sets indicate that they formed in response to north-directed shortening of the D_3 shear zones.

Figure GS-27-13: D_3 high-strain zone cutting iron formation in the northwest corner of Garner Lake. The asymmetric quartz boudins indicate sinistral shear. Pencil points north.

EXPLORATION CONSIDERATIONS

Results of 2002 fieldwork

The Garner Lake area contains thick successions of mafic to felsic volcanic rocks, including komatiite, that record heterogeneous, penetrative structural preparation during the regional D_2 deformation phase. Previous work in the central portion of the Rice Lake belt (e.g., Brommecker, 1991) and the Red Lake belt (e.g., Dubé et al., 2001) has demonstrated an intimate spatial association between gold mineralization and syn-D_2 high-strain zones. In this regard, D_2 high-strain zones that cut the volcanic successions in the Garner Lake area should be considered highly prospective for shear-hosted gold mineralization. The Mellow Yellow and Garner gold occurrences, as outlined below, may be examples of such mineralization.

A zone of potential economic significance has been identified along the southeast branch of the Gem Lake logging road. In this area, intermediate volcanic rocks of the Manigotagan River Formation are intruded by an elongate body of leucocratic gabbro, and have been folded by a macroscopic F_2 anticline (Fig. GS-27-2). The eastern limb of this fold and the S_2 foliation have been strongly transposed by a series of discrete, northwest-trending, D_3 shear zones that dip subvertically. The shear zones are marked by zones of strongly foliated chlorite schist, less than 10 m thick, that contain variably boudinaged quartz-carbonate-chlorite veins up to 0.5 m thick. Asymmetric quartz boudins and a pervasive shear-band fabric indicate dextral shear. The shear zones appear to have formed preferentially along the margins of the leucogabbro, and merge into a zone, greater than 100 m thick, beyond the southeastern termination of the intrusion.

The volcanic country rocks in this location locally weather light grey or deep reddish brown and contain patchy, irregular zones of moderate to strong, pervasive, silica–Fe-carbonate alteration. The more strongly silicified rocks have a dense, cherty appearance, with a fine-grained sugary texture and prominent conchoidal fracture. These rocks locally contain fine-scale stockworks of Fe-carbonate veins, less than 5 mm thick, or pervasive networks of chloritic fractures. Fresh broken surfaces reveal 1 to 2% finely disseminated pyrite and arsenopyrite. Thin (<30 cm) quartz veins with chlorite and/or Fe-carbonate selvages, less than 2 cm thick, constitute up to 5% of the altered outcrops. A channel sample of strongly silicified rock with less than 5% quartz veins returned 79 ppb Au and 396 ppm As, whereas an approximately 35 cm thick quartz vein in the same outcrop returned 58 ppb Au and 2140 ppm As.

The alteration has been traced along strike for more than 1 km, and is open in all directions. The only known gold occurrence in the area lies approximately 1.2 km to the north-northwest along strike, near the eastern sheared contact of the leucogabbro (Fig. GS-27-2). The showing consists of a very narrow (<50 cm thick) quartz vein that strikes north-northwest and has been traced for more than 75 m along strike (Assessment File 94326, Manitoba Industry, Trade and Mines, Winnipeg). The vein contains quartz and subordinate carbonate, chlorite, tourmaline and pyrite, with erratic gold values up to 27.4 g/t (AF 94326). The highest gold values are located in a right-lateral jog in the quartz vein, perhaps indicating that the auriferous hydrothermal solutions were preferentially channelled into sites of dilation in a regime of dextral shear.

Future work

The Garner Lake area contains two known high-grade gold occurrences that are targeted for detailed examination in the 2003 field season. The objective of this work will be to document the stratigraphic and structural setting of the gold mineralization and, in the context of the framework outlined above, provide insights into the mineralization process and controls. This information will be utilized to constrain predictive models for gold mineralization in the southeast Rice Lake belt.

The Garner occurrence (Theyer and Ferreira, 1990) is located along the south shore of Garner Lake (Fig. GS-27-3), and is marked by eight shallow prospect pits that expose three subparallel quartz veins hosted in strongly foliated, light grey, sericite-chlorite schist. A brief examination of the veins in 2002 revealed coarse visible gold in two locations, in keeping with a grab-sample assay result of 61 g/t Au reported by Theyer and Ferreira (1990). In 1980, Esso Resources Canada Inc. completed seven drillholes, totalling 492 m, based on channel-sample results of 14.1 g/t Au across a 1.5 m width and over a length of 35 m along strike (Assessment File 93330, Manitoba Industry, Trade and Mines, Winnipeg). Although the results of this drilling were essentially negative, the structural attributes of this showing have never been examined in detail.

The second gold occurrence is the Mellow Yellow showing (Assessment File 93694, Manitoba Industry, Trade and Mines, Winnipeg), located approximately 1 km north of the western arm of Garner Lake (Fig. GS-27-3). The showing consists of thin, lenticular quartz veins and stringers in sheared gabbro that returned assays of up to 77.5 g/t Au from grab samples (AF 93694). Brommecker (1996) indicated that the showing is hosted by a strongly sheared gabbro sill, more than 25 m thick, in a northwest-facing section of massive tholeiitic mafic flows and minor iron formation, immediately adjacent to the upper contact of the underlying komatiitic volcanic rocks (Fig. GS-27-3). In this area, the rocks contain an early, layer-parallel foliation that is transposed to the west by the D_3 Beresford Lake Shear Zone. Near the showing, the early fabric is cut by a series of subsidiary D_3 shear zones and feldspar or quartz porphyritic dikes that generally trend north (Brommecker, 1996). Interestingly, the stratigraphic and structural setting of this gold occurrence are quite similar to those described by Dubé et al. (2001) for the Campbell–Red Lake deposit in the Red Lake belt.

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