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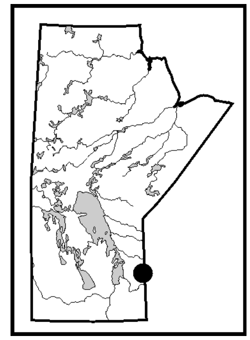
The publisher/department name in the bibliographic reference cited immediately below the title of each GS report should read **Manitoba Industry, Economic Development and Mines** instead of **Manitoba Industry, Trade and Mines**.

GS-24 Geology and structure of the Garner Lake area, southeast Rice Lake greenstone belt, Manitoba (NTS 52L14)

by S.D. Anderson



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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 in order to further refine the stratigraphic, structural and tectonic framework, with the ultimate goal of providing the exploration community with an enhanced, belt-specific, predictive framework for orogenic lode-gold deposits. Fieldwork in 2003 focused on extending detailed mapping coverage outward from the roughly 12 km transect that was mapped across the southeastern portion of the Rice Lake belt in 2002.

Exposures in the Garner Lake area record roughly 200 m.y. of magmatism, sedimentation and tectonothermal activity along the southern margin of the North Caribou Terrane, and provide key constraints for the gold-metallogenic evolution of the Rice Lake belt. Mesoscopic deformation structures indicate a complex, multiphase sequence of deformation, which is divisible into six distinct phases. The Beresford Lake Shear Zone (BLSZ), which represents a potentially significant metallogenic feature in the southeast Rice Lake belt, records a complex movement history that likely includes D_3 northeast-over-southwest dip-slip, D_4 dextral strike-slip and D_5 sinistral strike-slip. Mapping of the BLSZ in 2003 has led to the discovery of several occurrences of crustiform-banded ankerite veins, which are hosted by thick zones of intense chlorite-sericite-ankerite alteration and locally overprinted by silica-sulphide replacements. Although assay results are pending, the mineralogy, paragenesis and setting of these veins are closely analogous to those hosting spectacular high-grade gold mineralization in the Red Lake mine in Ontario. The presence of this style of mineralization, which has not been documented previously, further underscores the tremendous exploration potential of the Rice Lake belt.

Introduction

The Rice Lake belt is the most significant lode-gold district in Manitoba, with hundreds of documented occurrences and historic production of approximately 1.73 million ounces from several past-producing mines, including 1.42 million ounces from the San Antonio mine at Bissett. The Rice Lake gold metallogeny project was initiated in 2002 by the Manitoba Geological Survey with the objective of updating the stratigraphic, structural and tectonic framework of the Rice Lake greenstone belt, with particular emphasis on the metallogeny of orogenic lode-gold deposits. This multiyear, multidisciplinary project involves targeted 1:20 000-scale bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology, with the goal of providing the exploration community with an enhanced predictive framework for orogenic lode-gold deposits in the Rice Lake belt.

Fieldwork in years one and two of this project focused on the Garner Lake area in the southeastern portion of the Rice Lake belt (Fig. GS-24-1). Large portions of this area, which previous workers have considered key to unravelling the complex geological history of the Rice Lake belt (e.g., Corkery, 1995), have never been mapped in detail. At Garner Lake, reconnaissance-scale lithogeochemistry and U-Pb geochronology indicate the presence of thick successions of komatiitic volcanic rocks (Brommecker et al., 1993) and pre–2.87 Ga felsic volcanic rocks (Poulsen et al., 1993) that were previously unrecognized, and indicate a significantly more complex geological history for the southeast Rice Lake belt than has previously been contemplated. Fieldwork in year two of the project focused on extending the detailed mapping coverage outward from the roughly 12 km transect that was mapped in 2002 (Anderson, 2002) across the southeastern portion of the Rice Lake belt (Fig. GS-24-2). This mapping, the results of which are outlined in this report and on preliminary map PMAP2003-1, will be complemented by ongoing U-Pb geochronology and lithogeochemistry to provide an updated geological framework for continuing metallogenic investigations in the Rice Lake belt.

Regional setting

In the Superior Province of Manitoba, the Uchi Subprovince, which includes the Rice Lake greenstone belt, is flanked to the north by the North Caribou Terrane (Berens River Subprovince) and to the south by the Manigotagan

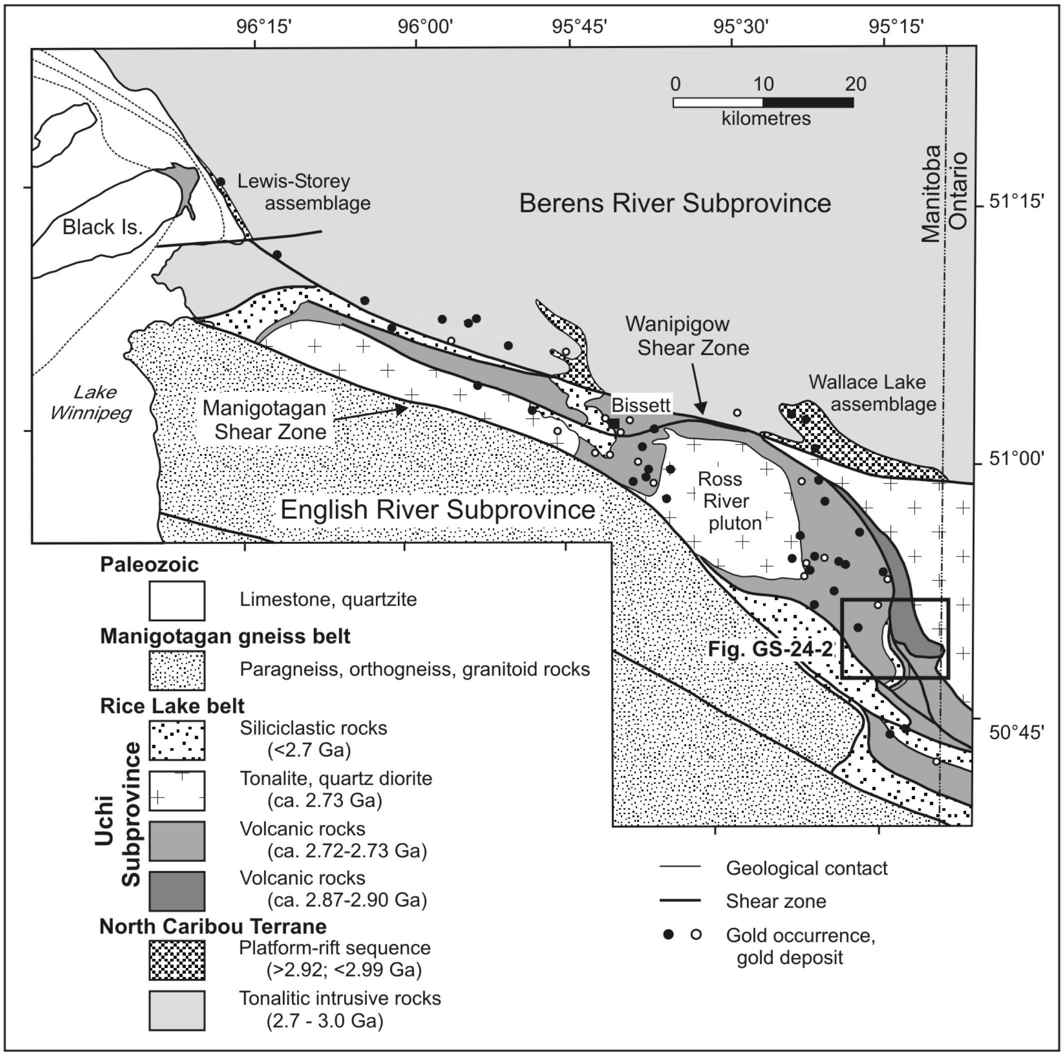

Figure GS-24-1: Simplified geology of the Rice Lake belt, showing the location of Figure GS-24-2.

gneiss belt of the English River Subprovince (Fig. GS-24-1). The North Caribou Terrane (Thurston et al., 1991) comprises ca. 3.0 Ga (Mesoarchean) basement plutonic rocks of mainly tonalitic composition, nonconformably overlain by a ca. 2.92 to 2.99 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 (Sasseville and Tomlinson, 2000), typically consists of basal quartz arenitic rocks overlain by intercalated iron formation and komatiitic volcanic rocks, and is thought to record continental rifting at the southwestern margin of the North Caribou Terrane (Percival et al., 2002). This sequence is discontinuously exposed along the southern margin of the North Caribou Terrane (Fig. GS-24-1), and is tectonically juxtaposed with the Rice Lake belt to the south along the regional-scale Wanipigow Shear Zone. The Manigotagan gneiss belt, which is bounded to the north by the regional-scale Manigotagan Shear Zone, consists of paragneiss, orthogneiss and granitoid plutons. These rocks were derived, at least in part, from <2.705 Ga siliciclastic sequences in the adjacent Rice Lake belt, and were regionally deformed and metamorphosed during the ca. 2.7 Ga (e.g., Corfu and Andrews, 1987) Kenoran Orogeny.

The supracrustal rocks of the Rice Lake belt consist mainly of tholeiitic and calcalkaline arc volcanic rocks of basaltic to rhyolitic composition, intercalated with thick synvolcanic mafic sills and minor derived volcaniclastic and epiclastic sedimentary rocks (e.g., Bailes et al., 2003). In the southeast Rice Lake belt, the supracrustal rocks are subdivided into the Neoarchean (ca. 2.72–2.73 Ga) Bidou (basalt-dacite) and Gem (basalt-andesite-dacite-rhyolite) assemblages, and the Mesoarchean (ca. 2.87–2.90 Ga) Garner (komatiite-basalt-dacite) assemblage (e.g., Poulsen et al., 1996; Bailes et al., 2003). These rocks are intruded by tonalite, quartz diorite and granodiorite plutons, some of which may be synvolcanic (e.g., the ca. 2.73 Ga Ross River pluton; Turek et al., 1989). Basinal siliciclastic rocks that contain

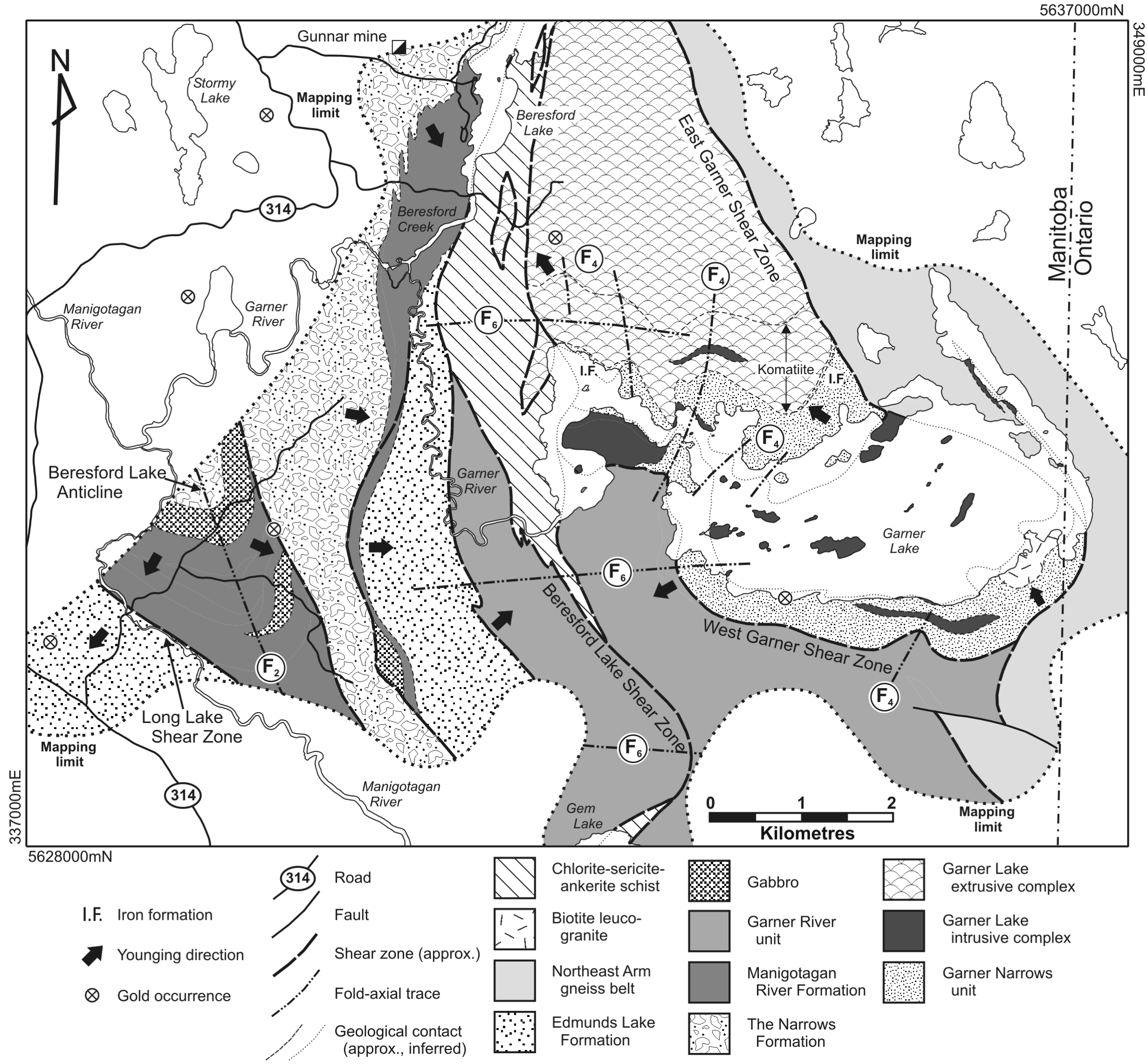

Figure GS-24-2: Simplified geology of the Garner Lake area. The iron formation indicated by I.F. is referred to in the text as subunit 1d.

<2.705 Ga detrital zircons (Davis et al., 1994; Percival et al., 2002) unconformably overlie the Bidou and Gem assemblages, and represent the youngest supracrustal rocks in the Rice Lake belt.

General geology and stratigraphy

The geology of parts of the Garner Lake area has been previously mapped by Stockwell (1945), Scoates (1971), Weber (1971), Owens and Seneshen (1985) and Brommecker (1991, 1996). Metamorphic mineral assemblages throughout the map area indicate lower to middle greenschist facies regional metamorphism, with local middle to upper amphibolite facies assemblages present along the margins of intrusive bodies and along the eastern margin of the supracrustal belt. The geology and stratigraphy of the Garner Lake area (Table GS-24-1) are described below in order of decreasing known or apparent age. The unit numbers correspond to those on PMAP2003-1.

Garner Narrows unit (unit 1)

The Garner Narrows unit comprises an east-trending package of volcanic conglomerate (subunit 1a), dacitic volcanic rocks (subunit 1b), and iron formation (subunit 1d) that is mainly exposed along the south and north shores of Garner Lake (Fig. GS-24-2). Contact relationships indicate a conformable, north-younging stratigraphic succession, the

Table GS-24-1: Summary of geological map units in the Garner Lake area.

LATE NEOARCHEAN	
Post–2.7 Ga plutonism and deformation	
13)	Diorite
12)	Chlorite-sericite±ankerite schist (Beresford Lake Shear Zone)
11)	Biotite leucogranite
Northeast Arm gneiss belt	
10)	Granodiorite, quartz diorite, tonalite, granite; gneissic equivalents; amphibolite
Post–2.7 Ga sedimentation	
Edmunds Lake Formation	
9)	Bedded greywacke, mudstone, polymictic conglomerate, quartzose arenite, chert
	Unconformity
EARLY NEOARCHEAN	
Ca. 2.71–2.73 Ga volcanism, sedimentation and plutonism	
8)	Feldspar±quartz porphyry
7)	Gabbro
Garner River unit	
6)	Andesite volcanic breccia, tuff breccia, lapilli tuff; derived epiclastic rocks
Manigotagan River Formation	
5)	Massive to pillowed basalt or andesite flows (quartz amygdaloidal), volcanic breccia; derived epiclastic rocks; chert
The Narrows Formation	
4)	Dacite volcanic breccia, tuff breccia, lapilli tuff, crystal tuff; volcanic conglomerate
	Tectonic contact
MESOARCHEAN	
Ca. 2.87 Ga ultramafic to mafic plutonism and volcanism	
Garner Lake extrusive complex	
3)	Komatiite to Mg-tholeiite flows, breccia; synvolcanic gabbro; minor iron formation, chert
Garner Lake intrusive complex	
2)	Peridotite, pyroxenite, serpentinite; gabbro; quartz diorite, tonalite
	Intrusive contact
Ca. 2.88–2.90 Ga volcanism and sedimentation	
Garner Narrows unit	
1)	Polymictic volcanic conglomerate; dacite volcanic breccia, tuff breccia; magnetite-facies iron formation

Note: The relative ages of units 5 and 6 are unknown; these units may, in part, be lateral equivalents.

thickness of which probably exceeds 1.5 km. This unit is intruded by the Garner Lake intrusive complex (unit 2) and, to the north, appears to be disconformably overlain by ultramafic and mafic volcanic rocks of the Garner Lake extrusive complex (unit 3). To the south, the Garner Narrows unit is juxtaposed with the Garner River unit (unit 6) along a generally northwest-trending, D_3 high-strain zone (the West Garner Shear Zone [WGSZ]; Anderson, 2002).

The basal portion of the Garner Narrows unit contains a section of polylithic volcanic conglomerate, more than 500 m thick, which is typically massive and unstratifed, with angular to well-rounded, matrix-supported clasts that range up to 50 cm across. The matrix consists of dark grey, medium- to coarse-grained, pebbly volcanic sandstone that lacks coarse detrital quartz. The clasts consist mainly of texturally variable intermediate volcanic detritus. No clasts of the adjacent dacite were observed in this conglomerate. The northern contact of the conglomerate is well exposed in one location, and is marked by a 30 to 50 cm thick layer of bedded volcanic sandstone that lies in sharp, apparently conformable contact with massive, light grey, dacite tuff. Graded beds and channels in the sandstone indicate stratigraphic younging toward the dacite (north).

The dacitic volcanic rocks crop out along the north and, to a lesser extent, south shores of Garner Lake, and form a section more than 1 km thick. The predominant rock types are volcanic breccia and tuff-breccia, with subordinate lapilli tuff and crystal tuff. The breccia is 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 (typically 1–5 cm).

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. Although typically unstratified, these rocks locally contain diffuse intercalations of lapilli tuff and tuff (Fig. GS-24-3). In Garner Narrows, these rocks also locally contain sections, less than 5 m thick and trending east-west, of thinly layered quartz arenite, iron carbonate and fine-grained ferruginous argillite (subunit 1c).

Toward the west, the dacitic volcanic rocks are more tuffaceous and feldspar phyric, with up to 15% subhedral plagioclase crystals that range up to 3 mm across. A sample of the relatively coarse, plagioclase-phyric tuff was collected in 2002 for U-Pb geochronology, with the goal of constraining the age of the volcanic rocks. Analysis of three single zircon grains and two fractions of two zircons yielded no concordant U-Pb ages, and failed to provide an unambiguous age for the dacitic volcanism. Nevertheless, the U-Pb data indicate that the dacite tuff was most likely emplaced between ca. 2883 and 2898 Ma (C. Böhm and L. Heaman, unpublished data, 2003).

The dacitic volcanic rocks are overlain to the north by a laterally discontinuous section of thinly layered magnetite-facies iron formation (subunit 1d; Fig. GS-24-2). In western Garner Lake, this subunit can be traced along strike for more than 700 m, and ranges up to 50 m thick. The contact with the underlying dacite was observed in one location, and is very sharp and planar. To the east, the iron formation is considerably less thick, not as laterally continuous and includes magnetite, silicate and local sulphide facies. In both locations, however, the iron formation separates dacitic volcanic rocks from overlying spinifex-textured komatiite flows, and likely marks a potentially significant depositional hiatus.

Garner Lake intrusive complex (unit 2)

The Garner Lake intrusive complex intrudes the Garner Narrows unit and crops out only on islands and small shoreline exposures in Garner Lake (Fig. GS-24-2). The main body of the complex, which underlies the main basin of Garner Lake, consists of 100 to 400 m thick, alternating layers of serpentinized peridotite and clinopyroxenite (subunit 2a) that strike generally east and northeast, and dip moderately to the north (Scoates, 1971). This portion of the complex was not examined in detail during the present mapping program, and the interested reader is referred to Scoates (1971) for a more detailed description.

In the northern 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 (subunit 2b), through medium- to coarse-grained leucogabbro (subunit 2c), to pegmatitic leucogabbro (subunit 2d). 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. Dikes of pegmatitic leucogabbro appear to be generally concordant with the igneous layers in the ultramafic rocks, and likely represent a late-stage magmatic segregation phase that formed, largely in situ, in the upper portion of the Garner Lake intrusive complex (Scoates, 1971). A sample of the pegmatitic material, processed for U-Pb geochronology, contained colourless to brown zircons with high Th/U ratios characteristic of zircons crystallized from mafic magmas (Davis et al., 1994). These zircons yielded a U-Pb zircon date

Figure GS-24-3: Layered dacitic lapilli tuff and tuff of the Garner Narrows unit, north shore of Garner Lake.

of 2871 ±1 Ma, which is considered to closely approximate the age of the Garner Lake intrusive complex, thus confirming a pre–2.87 Ga age for the Garner Narrows dacitic volcanic rocks.

Based on preliminary mapping in the western portion of Garner Lake, Anderson (2002) described the 'Garner Narrows assemblage', which was interpreted to include a basal unit of 'arkosic wacke', conformably overlain to the north by felsic volcanic rocks, iron formation and komatiitic flows. To the south, this assemblage was interpreted to nonconformably overlie a large body of melanocratic gabbro that contains irregular segregation pods of coarse-grained to pegmatitic quartz diorite and tonalite (subunit 2e; Fig. GS-24-4). A sample of the pegmatitic quartz diorite, collected to test these interpretations via U-Pb zircon analysis, yielded an emplacement age of 2870 ±1 Ma (C. Böhm and L. Heaman, unpublished data, 2003). This age, which overlaps within error that obtained from the pegmatitic leuco-gabbro in the main body of the Garner Lake intrusive complex (i.e., 2871 ±1 Ma), is also essentially identical to the 2871 ±2 Ma age obtained from zircons in the adjacent 'arkosic wacke' unit (Davis et al., 1994). These data, in conjunction with the regional contact relationships to the adjacent ca. 2883 to 2898 Ma dacite, indicate that the 'arkosic wacke' (Anderson, 2002) or 'grit' (Davis et al., 1994) must represent cataclastically deformed and altered tonalite or quartz diorite, which is likely comagmatic with the Garner Lake intrusive complex. These data have significantly clarified the complex geology and structure of the Garner Narrows area.

Garner Lake extrusive complex (unit 3)

The Garner Narrows unit is disconformably overlain by a north-facing succession of ultramafic to mafic volcanic flows, more than 2.0 km thick, that is intercalated with rare, thin layers of chert and iron formation, and intruded by voluminous gabbroic sills. Lithogeochemical data (Brommecker et al., 1993) indicate that several intercalated, compositional varieties of flow are present, including calcalkalic basalt, tholeiitic andesite, high-Mg tholeiitic basalt and komatiite (21–25% MgO, anhydrous). In general, the komatiitic rocks predominate in the southern portion of the section, whereas the tholeiitic rocks predominate farther to the north. In the field, these rocks were subdivided into mainly komatiitic (subunit 3a) and mainly Mg-tholeiitic (subunit 3b) map units.

The komatiite (subunit 3a) weathers dark green to black to rusty brown, and is typically massive, with a fine- to coarse-grained, ophitic texture. These rocks typically contain less than 35% fine-grained plagioclase, which is interstitial to acicular crystals of actinolite (after pyroxene). Spinifex texture occurs in irregular zones that exhibit gradational contacts with the massive, ophitic-textured komatiite. Randomly oriented, acicular crystals of actinolite (after pyroxene) range up to 5 cm long, and commonly form radiating clusters up to 10 cm across (Fig. GS-24-5). Spinifex also occurs in distinct, 10 to 15 cm thick layers within the massive komatiite. Brommecker et al. (1993) provided descriptions of spinifex, autobreccia and polysuture textures in the komatiite, which confirm a volcanic flow origin. In the southern portion of this subunit, komatiite contains irregular bodies and crosscutting dikes of serpentinized peridotite and pyroxenite, which lends support to the theory that the Garner Lake intrusive complex represents the subvolcanic source for the komatiitic flows (e.g., Brommecker et al., 1993).

The Mg-tholeiite flows (subunit 3b) weather light green-grey to emerald green, and are characterized by a fine- to

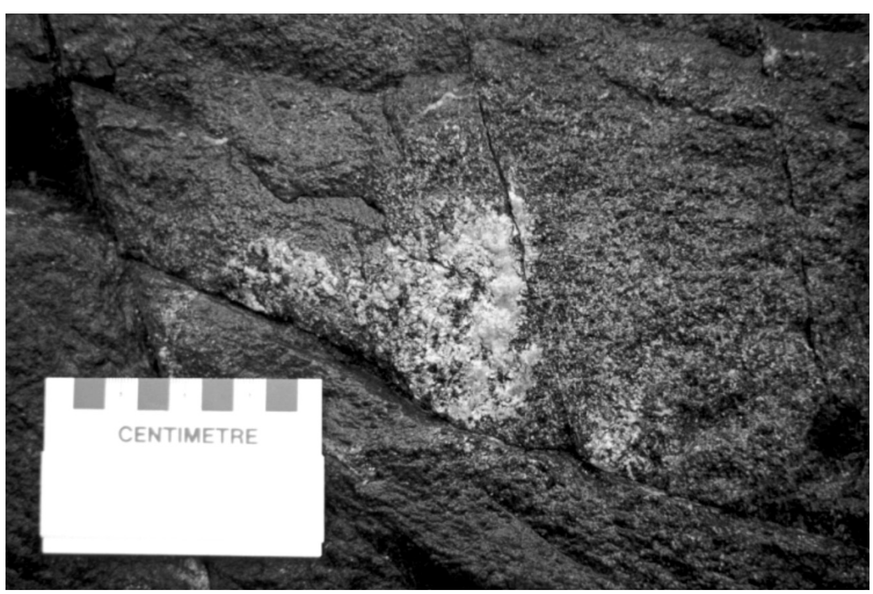

Figure GS-24-4: Irregular segregation pod of blue-quartz diorite in melanocratic gabbro of the Garner Lake intrusive complex, south shore of Garner Narrows.

Figure GS-24-5: Spinifex texture in komatiite flow of the Garner Lake extrusive complex, 300 m north of the west basin of Garner Lake.

medium-grained, subophitic texture. Pillowed flows predominate over massive flows, and both are typically aphyric and nonamygdaloidal. The pillows are bun shaped and range in size from 0.1 to 1.0 m across. The pillows have well-defined, less than 3 cm thick, dark green to black, aphanitic selvages, with local calcsilicate alteration. The cores of the pillows are locally strongly epidotized, and often contain up to 20% light grey to pink variolites up to 3 cm in diameter. In rare instances, the pillow cores are also plagioclase phyric, with up to 5% plagioclase crystals. Pillow tops in three locations indicate that these rocks young to the north.

Iron formation and chert (subunit 3c) are relatively minor constituents of the mafic volcanic sections. These layers range up to a maximum of 2 m thick, and are typically laterally discontinuous. Magnetite-facies iron formation appears to predominate in the Mg-tholeiitic rocks. All of these rocks are intruded by voluminous gabbro sills (subunit 3d), which range up to 40 m thick and appear to account for at least 40% of the section. The gabbro is light green and fine to medium grained, and typically has a massive subophitic texture, with a characteristic glomeroporphyritic texture defined by equant aggregates of actinolite up to 10 mm across.

The Narrows Formation (unit 4)

The Narrows Formation (Campbell, 1971) consists of a succession of ca. 2731 Ma (Turek et al., 1989) dacitic volcaniclastic and epiclastic rocks, more than 2.5 km thick, that is intruded by thick gabbro sills (unit 7). In the map area, volcanic conglomerate (subunit 4c) appears to predominate in the northwestern portion of the unit, whereas volcanic breccia and tuff-breccia (subunits 4a and 4b) predominate in the southeast. Subunit 4a becomes increasingly prevalent toward the south, and includes rocks that Weber (1971) assigned to the Gem Lake subgroup (Gem assemblage; Poulsen et al, 1996; Bailes et al., 2003). These rocks conformably overlie epiclastic sedimentary rocks of the Stormy Lake Formation (Campbell, 1971) of the Bidou assemblage, and are conformably overlain by the Manigotagan River Formation (Seneshen and Owens, 1985).

The volcanic conglomerate contains subangular to well-rounded clasts that are typically less than 50 cm in maximum dimension, but locally range up to more than 2.0 m across. The clasts consist almost exclusively of various textural varieties of light grey to buff, aphanitic to plagioclase- and/or quartz-phyric, dacitic volcanic rock. The matrix of the conglomerate is medium- to coarse-grained feldspathic sandstone, which typically lacks coarse detrital quartz. The conglomerate is locally weakly stratified, and contains a diffuse layering that dips steeply to the west-northwest. This subunit contains interlayers of coarse-grained feldspathic sandstone, as well as thinly layered, light green to grey, feldspar-phyric tuff. Younging criteria in two locations indicate tops to the east.

Subunits 4a and 4b consist predominately of dacite volcanic breccia, with subordinate tuff-breccia and lapilli tuff, and rare layers of volcanic conglomerate and sandstone. The volcanic breccia is monolithic, unsorted and generally massive, with angular to subrounded clasts of aphanitic to plagioclase- and/or quartz-phyric, highly siliceous, dacitic volcanic rock. In subunit 4a, the clasts are sparsely feldspar phyric, and generally weather light grey to buff-white, whereas subunit 4b tends to contain more coarsely feldspar-phryic clasts that weather light green or grey. These differences may reflect a change in composition up section and toward the south, from dacite through to rhyodacite.

The proportion of feldspar phenocrysts in the clasts ranges up to 20%. Quartz phenocrysts are generally rare, although they locally account for 1 to 2% of individual clasts. Subunit 4a also contains well-layered intervals of monolithic lapilli tuff and crystal tuff that range up to more than 30 m thick.

Manigotagan River Formation (unit 5)

The Manigotagan River Formation (Seneshen and Owens, 1985) includes a distinctive assemblage of diverse rock types that forms a laterally continuous, mappable unit separating The Narrows and Edmunds Lake formations. The Manigotagan River Formation consists of basalt and andesite flows, associated volcanic fragmental rocks and derived epiclastic sedimentary rocks. Gabbro sills (unit 7) are particularly abundant in this unit, and range up to more than 30 m thick. Younging criteria indicate that the Manigotagan River Formation is folded into a tight anticline, the eastern limb of which is displaced to the south by a later shear zone (Fig. GS-24-2). This fold is interpreted to represent the hinge of the regional F_2 Beresford Lake anticline. To the east, the Manigotagan River Formation is discontinuously exposed along the contact between The Narrows and Edmunds Lake formations (Fig. GS-24-2). It is unclear at present whether the discontinuous nature is simply a reflection of poor exposure, or if it results from primary depositional or later structural processes.

The basalt flows are dark green to grey and aphyric to coarsely plagioclase phyric, whereas the andesite flows weather buff or light grey and are typically aphyric. These flows are fine to medium grained, and include both massive and pillowed sections that range up to 20 m thick. The plagioclase-phyric basalt contains 25 to 40% euhedral plagioclase crystals <5 mm in size. A characteristic feature of both the andesite and basalt flows is the presence of 1 to 5%, round to slightly elongate, evenly distributed, quartz-filled amygdales <1.5 cm in size (Fig. GS-24-6). Well-formed, bun-shaped pillows range up to 0.5 m in size and are intercalated locally with thin layers of flow-top breccia and minor agglomerate. Agglomerate is monolithic, with <5% matrix material, and very angular, wispy, interlocking clasts of fine-grained, locally feldspar-phyric basalt. The fragmental volcanic rocks are relatively minor, and consist mainly of light grey to green breccia and lapilli tuff containing fragments that are texturally similar to the associated flows.

The volcanic rocks are intercalated with polylithic volcanic conglomerate (subunit 5c), with subordinate thin-bedded sections of chloritic volcanic greywacke, siltstone and mudstone (subunit 5d). In proximity to the mafic flows, these rocks are crosscut by dark green mafic dikes, <2 m thick with well-developed chilled margins (subunit 5e), that are interpreted as subvolcanic feeder dikes for the mafic flows. The conglomerate contains subrounded to well-rounded clasts that are typically 10 to 30 cm in diameter but locally range up to 2.0 m. 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, as well as distinctive, dark grey to black, pyritic, siliceous clasts (<1%). The matrix consists of dark grey to green, coarse-grained chloritic sandstone that lacks detrital quartz. The greywacke beds are fine to medium grained and range up to 1.0 m thick, with locally well-developed normal grading and channels. The basal portions of coarse-grained greywacke beds locally contain up to 2% detrital quartz. A distinctive feature of the thin-bedded sections are thin layers (<15 cm) of laminated black chert. As described by Seneshen and Owens (1985), the crossbedded volcanic greywacke is locally intimately intercalated with the pillowed, vesicular mafic flows. A

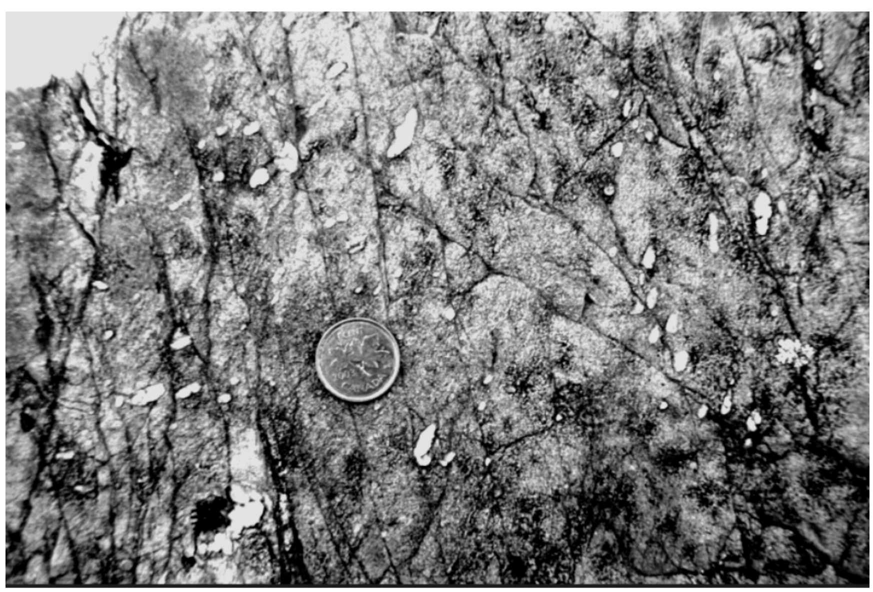

Figure GS-24-6: Quartz amygdules in a massive andesite flow, Manigotagan River Formation, southeast of the confluence of Beresford Creek and the Garner River.

sample of greywacke collected from the Manigotagan River Formation near the southern end of Beresford Lake contains detrital zircons as young as 2725 Ma (Davis et al., 1994), and thus provides a maximum age limit for the mafic and intermediate volcanism.

Garner River unit (unit 6)

The name 'Garner River unit' is herein proposed for the thick package of intercalated intermediate volcanic and epiclastic rocks that extends southward from Garner Lake to the northern portion of Gem Lake. These rocks lie in tectonic contact to the north with rocks of the Garner Narrows unit and the Garner Lake intrusive complex along the D_3 WGSZ (Fig. GS-24-2), and are intruded to the southeast by granodiorite that may be related to the Reahill Lake pluton (Rogers, 2001) that extends into the Bee Lake belt in Ontario. To the west, the Garner River unit is juxtaposed with the Edmunds Lake Formation. In this location, bedding in the Edmunds Lake Formation consistently faces south on the regional S_2, whereas that in the Garner River unit faces north, indicating a tectonic contact. The thickness of this unit is unknown due to structural complexities, but probably exceeds 1.0 km. Weber (1971) included large portions of this unit in either the Edmunds Lake Formation or the Gem Lake subgroup. As outlined in a later section of this report, however, several field criteria distinguish these rocks from the Edmunds Lake Formation. In addition, these rocks are also quite distinct from the flow-banded rhyolite flows and coarsely quartz-phyric felsic volcaniclastic rocks that characterize the Gem Lake subgroup at Gem Lake, the latter of which was the source of the 2722 ±2 Ma U-Pb zircon date that constrains the age of the subgroup (e.g., Davis et al., 1994).

The predominant rock types in the Garner River unit are andesitic breccia and tuff-breccia, with subordinate lapilli tuff and crystal tuff (subunit 6c). These rocks typically weather to various shades of green or grey or buff, and are dark green to grey on fresh surfaces. They are characteristically feldspar phyric, with 15 to 25% euhedral plagioclase crystals, less than 5 mm in size, that are evenly distributed in an aphanitic to fine-grained, feldspathic matrix. The breccia is typically monolithic, and contains up to 50% angular to subrounded, unsorted clasts of feldspar-phyric andesite that are <40 cm and generally 5 to 10 cm in size (Fig. GS-24-7). The presence of various textural varieties of feldspar-phyric andesite locally imparts a polylithic appearance to these rocks. The tuff-breccia contains a diffuse layering and is locally intercalated with thin layers of lapilli tuff. These rocks lack unambiguous younging criteria.

The far northeastern and southwestern portions of this unit contain thick sections of remarkably homogeneous and massive, fine-grained, intermediate volcanic sandstone (subunit 6a) that weathers buff or grey, with a dark grey fresh surface. These rocks locally contain a faint stratification defined by beds of coarse-grained pebbly sandstone that range up to 10 cm thick. These beds locally contain up to 2% detrital quartz pebbles ranging up to 0.5 cm in diameter. Subunit 6c is spatially associated with up to 200 m thick sections of thin-bedded, buff- to grey–weathering, feldspathic greywacke and siltstone, with minor pebble to cobble, polylithic volcanic conglomerate. The greywacke beds, which are typically less than 10 cm thick, are very fine to medium grained and contain 10 to 30% broken plagioclase crystals, 0.5 to 3 mm in size, with <5% quartz. Normal-graded beds are common, and delineate both small- and large-scale younging reversals in the Garner River unit.

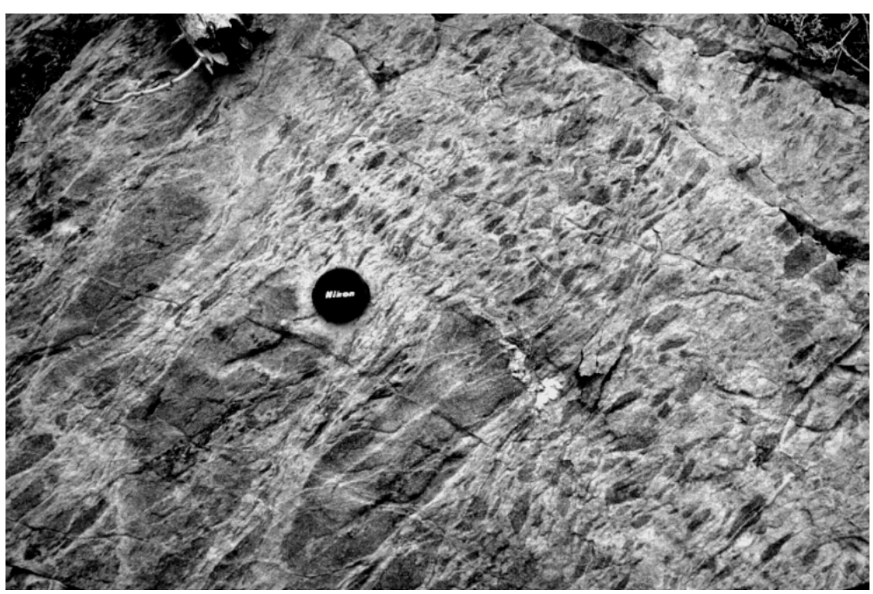

Figure GS-24-7: Andesitic volcanic breccia of the Garner River unit, roughly midway between western Garner Lake and Gem Lake.

Gabbro (unit 7)

Gabbro is an important constituent of The Narrows and Manigotagan River formations in the map area. The gabbro forms laterally extensive sills that range up to more than 60 m thick. These sills typically weather to light grey-green, and have a medium- to coarse-grained, massive, equigranular, subophitic texture. In general, the sills are leucocratic and contain between 60 and 80% plagioclase. The gabbro is locally strongly magnetic, with up to 3 to 5% modal magnetite. Gabbro sills were not observed in the Edmunds Lake Formation.

Feldspar±quartz porphyry (unit 8)

The Garner Lake extrusive complex is intruded by numerous dikes of feldspar±quartz porphyry. These dikes range up to 5 m thick, and typically exhibit sharp parallel contacts. The rock contains up to 15%, <5 mm, euhedral, blocky plagioclase phenocrysts, locally with 10 to 15%, <3 mm, anhedral, equant quartz phenocrysts. These crystals are evenly distributed in a light grey, very fine grained to aphanitic feldspathic matrix that contains <5% very fine grained aggregates of biotite and chlorite. The dikes also locally contain approximately 1% finely disseminated pyrite. In most locations, the dikes contain a penetrative L>S fabric, and are strongly boudinaged within high-strain zones that cut the host mafic to ultramafic volcanic rocks. The relative age of the feldspar porphyry is based on the 2731 Ma U-Pb zircon age obtained by Turek et al. (1989) for similar dikes that cut the Bidou assemblage approximately 3 km to the northwest. It is entirely possible, however, that the dikes in the Garner Lake extrusive complex are significantly older.

Edmunds Lake Formation (unit 9)

The Edmunds Lake Formation (Campbell, 1971) crops out on both limbs of the F_2 Beresford Lake anticline in sections that are >1.0 km thick and dip steeply northeast and southwest (Fig. GS-24-2). In general, both sections appear to coarsen stratigraphically upward, with thin-bedded siltstone, greywacke, mudstone and chert (subunit 9a) predominating lower in the section, thick-bedded greywacke (subunit 9b) or quartzose arenite (subunit 9c) constituting the middle portion of the section, and polymictic conglomerate and quartzose arenite (subunit 9d) more prevalent higher in the section. Well-developed younging criteria indicate that these rocks generally face outward from the core of the F_2 anticline, although local reversals are observed, and indicate the presence of isoclinal folds that are parasitic to the macroscopic F_2 closure.

The greywacke is fine to coarse grained and feldspathic, with 40% angular to subrounded feldspar grains <1.5 mm in size. These beds generally contain more than 5% detrital quartz. Individual beds range up to 50 cm thick and exhibit normal size-grading. The quartzose arenite forms a >300 m thick unit on the east limb of the anticline, and consists of light brown to grey, fine- to coarse-grained sandstone that contains 10 to 40% angular to subrounded, evenly distributed quartz grains <5 mm in size. The quartzose arenite is typically massive and homogeneous; however, diffuse layers of pebbly sandstone are locally abundant and contain angular rip-ups of light grey to greenish brown siltstone, as well as well-rounded quartz pebbles. These rocks are also locally interlayered with layers of dark grey, laminated siltstone <3 cm thick. Lenticular layers of polymictic conglomerate range up to more than 10 m thick and contain unsorted, typically subangular to well-rounded clasts that range in size up to 20 cm. The clasts are typically matrix supported, and include phaneritic-textured tonalite and granodiorite (Fig. GS-24-8).

Although the map of Weber (1971) indicates that large areas to the north and south of Garner Lake are underlain by interlayered greywacke and argillite of the Edmunds Lake Formation, the present mapping indicates that such sedimentary rocks represent only a very minor component of the bedrock in these areas. Moreover, these sedimentary rocks, which are now included in the Garner River unit, can be reliably distinguished from the Edmunds Lake Formation on the basis of four field criteria: 1) the greywacke beds contain <5%, and typically <2%, detrital quartz; 2) the conglomerate beds do not contain clasts of phaneritic plutonic rock; 3) the rocks are intruded by gabbro sills, and; 4) the rocks contain intercalated volcaniclastic material.

Northeast Arm gneiss belt (unit 10)

In the eastern portion of the map area, the supracrustal rocks are intruded by hornblende-biotite granodiorite, quartz diorite and tonalite (subunit 10a), and biotite±hornblende leucogranite (subunit 10b). Subsequent to emplacement, the plutonic rocks underwent high-temperature metamorphism and deformation, and have been inhomogeneously transposed into a northwest-trending belt of intercalated orthogneiss (subunits 10c, d) and amphibolite (subunit 10e), with minor unseparated enclaves of the adjacent supracrustal rocks. Crosscutting relationships in eastern Garner Lake clearly show that at least some of the granitoid plutons intruded the Garner Lake intrusive-extrusive complex prior to

Figure GS-24-8: Polymictic cobble conglomerate of the Edmunds Lake Formation, east limb of the Beresford Lake anticline, southwest of Garner Lake. Note cobble of medium-grained tonalite to the left of the lens cap.

development of the prominent gneissic fabric that characterizes the Northeast Arm gneiss belt. The interior portion of the gneiss belt contains thick packages of intercalated granitoid and gabbroic orthogneiss, as well as garnet-biotite-hornblende straight gneiss of uncertain derivation. The western margin of the belt is defined by a 100 to 300 m thick zone of amphibolite and amphibolite-facies tectonite (East Garner Shear Zone [EGSZ]; Anderson, 2002) that contains a penetrative and pervasive S-L fabric defined by acicular hornblende porphyroblasts. The presumably high metamorphic grade and state of strain recorded by these rocks indicate a significant gradient of decreasing finite strain and metamorphic grade toward the west, away from the margin of the supracrustal belt.

Biotite leucogranite (unit 11)

Small stocks and plutons of biotite leucogranite occur in the eastern portion of the map area, in close spatial association with the eastern margin of the supracrustal rocks (Fig. GS-24-2). The largest body of leucogranite is well exposed in the southeast portion of Garner Lake, where it discordantly intrudes the contact between the Garner Narrows unit and serpentinized peridotite of the Garner Lake intrusive complex. The leucogranite is light pink to grey-white, and is typically characterized by a fine- to medium-grained, equigranular phaneritic texture, with less than 10% very fine grained biotite. The pluton is remarkably homogeneous, lacks crosscutting dikes or xenoliths, and is distinguished from subunit 10b based on the absence of modal hornblende and gneissic fabrics. Nevertheless, it is entirely possible that these units are the same age. Along the margins, the pluton contains a moderate to strong L>S fabric that is coaxial to the regional S-L (D_2-D_3) fabric in the country rocks. A sample of this unit was collected during the 2003 field season for U-Pb geochronology, and would provide a maximum age for the regional D_2 deformation.

Chlorite–sericite±ankerite schist (unit 12)

In the central portion of the map area, the Beresford Lake Shear Zone (BLSZ) contains several distinct zones of chlorite–sericite±ankerite schist and mylonite. These zones range up to more than 100 m thick, and occur over a strike length of more than 9.0 km. On a large scale, these zones form an anastomosed network that contains lenticular domains of lesser deformed and altered wallrock. In the area to the west and northwest of Garner Lake, these domains consist mainly of pillowed Mg-tholeiite flows and strongly folded and boudinaged segments of magnetite-facies iron formation, which suggests derivation from the adjacent Garner Lake extrusive complex. The schist consists of strongly foliated, fine- to medium-grained chlorite and sericite, with subordinate ankerite, quartz, calcite, pyrite and chalcopyrite. The ankerite weathers to orange-brown, and occurs in the chlorite-sericite schist as euhedral crystals up to 5 mm across, or as irregular blebs that probably represent strongly boudinaged veinlets. Ankerite locally accounts for upwards of 50% of the schist, and the preferential weathering of the carbonate produces a deeply pitted outcrop surface. Strongly boudinaged and discontinuous veins of ankerite, with minor quartz, chlorite, sericite, calcite and pyrite, range up to 50 cm thick and are a characteristic feature of this unit.

Diorite (unit 13)

The BLSZ is spatially associated with a distinctive swarm of light grey, fine- to medium-grained diorite dikes that range up to 1.5 m thick. These dikes are typically hosted by chlorite-sericite schist, and discordantly cut the mylonitic foliation in the BLSZ. The contacts of the dikes are planar and parallel, and locally exhibit delicate apophyses that extend outward into the schist and are undeformed. The dikes characteristically have well-developed chilled margins up to 5 cm thick. The cores of the dikes exhibit an equigranular, subophitic texture and are locally weakly plagioclase porphyritic. In several locations, the central portions of these dikes also contain subrounded to angular xenoliths of quartz up to 10 cm across. A sample of the diorite collected in 2002 for U-Pb geochronology failed to provide any zircon. The sample did contain a moderate amount of titanite (C. Böhm and L. Heaman, unpublished data, 2003), however, which may be analyzed to help constrain the emplacement age and the timing of deformation in the BLSZ.

Structural geology

The 2003 mapping program has resulted in a significantly refined understanding of the structural geology in the Garner Lake map area, and indicates a substantially more complex sequence of deformation than had previously been contemplated. In this report, mesoscopic deformation structures in the Garner Lake area are subdivided, on the basis of overprinting relationships, into six generations (Table GS-24-2), which are interpreted to result from five discrete phases of ductile (D_1, D_2, D_3, D_4, D_5) and one phase of brittle-ductile (D_6) deformation. It is emphasized, however, that correlation of deformation structures in the mapped area is significantly complicated by several factors, including 1) the presence of several generations of late, nearly coaxial folds that have significantly reoriented earlier fabric elements, which are themselves nearly coaxial; 2) a relatively uniform metamorphic grade throughout much of the deformation history; 3) the general lack of primary anisotropy and younging criteria in most of the map units; and 4) the almost complete absence of demonstrably syn- or intradeformational dikes. In light of these factors, the deformation sequence outlined below should be considered provisional.

D_1 deformation

Structures of the D_1 deformation are only locally observed in the study area. The best examples occur west of the BLSZ, in rocks of the Manigotagan River and Edmunds Lake formations that contain a pronounced primary anisotropy. The S_1 fabric is an inhomogeneously developed, fine-grained, biotite-chlorite foliation that parallels the bedding planes. This fabric is best preserved in the hinges of F_2 folds and the microlithons between S_2 or S_3 crenulation cleavage planes. In the Manigotagan River Formation, F_2 folds locally overprint an early mylonitic foliation in narrow, bedding-parallel high-strain zones that contain lenticular, fault-fill–type quartz veins. As suggested by Brommecker (1991), these fabrics probably record bedding-parallel thrusting, possibly during intra-oceanic accretion and initial crustal thickening of the Rice Lake belt.

Table GS-24-2: Summary of deformation structures in the Garner Lake area.

Deformation phase	Shortening direction	Deformation structures	Regional structure	Tectonic significance
D1	?	S1 parallel to primary layering; narrow, bedding-parallel, high-strain zones		Intraoceanic accretion? initial crustal thickening
D2	NE-SW	Regional NW- to NNW-trending S2; L2 stretching lineation; upright macroscopic F2 folds	Beresford Lake anticline	Collisional tectonics; crustal thickening
D3	NE-SW	Regional NW- to WNW-trending S3; L2-3 lineation; northeast-side-up high-strain zones (BLSZ, EGSZ, WGSZ)	Initial increments of deformation in the WSZ and MSZ?	Sinistral transpression; main-stage collisional orogenesis; southwest tectonic transport
D4	E-W (local)	Upright, north-trending F4 folds; S4 shear-band cleavage in west margin of the BLSZ	Dextral reactivation of BLSZ	Continued regional sinistral transpression?
D5	NW-SE	S5 mylonite in WNW- to NNW-trending, ductile-brittle high-strain zones; L5 lineation; F5 folds; BLSZ, LLSZ	Dextral reactivation of the WSZ and MSZ	Orogen-scale dextral transpression; terminal collision of the Kenoran Orogen
D6	N-S	Conjugate shear-fractures and kink-folds	Macroscopic E- trending open folds	Late-stage orogen-normal movements

Abbreviations: BLSZ, Beresford Lake Shear Zone; EGSZ, East Garner Shear Zone; LLSZ, Long Lake Shear Zone; MSZ, Manigotagan Shear Zone; WSZ, Wanipigow Shear Zone; WGSZ, West Garner Shear Zone

D_2 deformation

Structures attributed to D_2 deformation are regionally developed in the southeast Rice Lake belt (e.g., Brommecker, 1991; Poulsen et al., 1996). Due to the increased intensity of D_3 strain toward the east, however, the D_2 structures tend to be better preserved west of the BLSZ. In this area, the S_2 planar fabric is typically penetrative, finely spaced and defined by a preferred orientation of fine-grained biotite, chlorite and amphibole. In coarse-grained fragmental volcanic and sedimentary rocks, the S_2 foliation is defined by strongly flattened clasts. Typically, the S_2 foliation dips steeply east-northeast or west-southwest and contains a downdip to steeply northwest-plunging mineral and stretching lineation defined by the long axes of elongate mineral grains and stretched clasts. The axial ratios of the clasts generally define oblate ellipsoids, consistent with flattening strains.

The S_2 foliation is axial planar to open to isoclinal, upright F_2 folds that plunge subvertically. Macroscopic F_2 folds with amplitudes ranging up to several kilometres have been mapped northwest of the study area, and include the regional Beresford Lake anticline that controls the map pattern in the central portion of the Rice Lake belt (e.g., Campbell, 1971; Brommecker, 1991). In the Edmunds Lake Formation, local reversals in younging direction that are not associated with a corresponding change in S_0-S_3 vergence indicate the presence of large-amplitude isoclinal folds that are likely also of the F_2 generation. Similar relationships are observed south of Garner Lake in the thin-bedded greywacke-siltstone packages of the Garner River unit. In these locations, the S_2 flattening fabric is oriented subparallel to bedding.

The regional distribution of the S_2-L_2 fabric indicates that the tectonostratigraphic assembly of the Rice Lake belt probably occurred during, or prior to, the early increments of D_2 deformation. The D_2 deformation structures indicate northeast-southwest shortening of the Rice Lake belt, possibly during the onset of main-stage collisional orogenesis and major crustal thickening.

D_3 deformation

Structures of the D_3 deformation are also regionally developed in the southeast Rice Lake belt, and exhibit a marked eastward increase in intensity toward the Northeast Arm gneiss belt. In the area west of the BLSZ, the S_3 fabric consists of a pervasive, finely spaced crenulation or fracture cleavage that trends northwest to north-northwest and dips subvertically. This cleavage overprints S_2 and maintains a consistent, counter-clockwise-oblique angular relationship to bedding on both limbs of the F_2 Beresford Lake anticline (i.e., S_3 transects F_2). The S_3 cleavage contains a very prominent intersection lineation ($L^2{}_3$) that plunges to the northwest at steep to moderate angles, and locally contains a weak L_3 mineral lineation defined by fine- to medium-grained biotite and hornblende. Mesoscopic, open to tight, Z-asymmetric folds are associated with the S_3 cleavage and plunge steeply to the northwest.

East of the BLSZ, S_3 constitutes a regionally pervasive and penetrative foliation defined by a preferred alignment of biotite, hornblende and sericite, and by strongly flattened primary features, including clasts, pillows and variolites. The S_3 foliation contains a very prominent, downdip mineral, stretching and intersection lineation that appears to represent a composite L_2-L_3 linear fabric. The D_3 high-strain zones are characterized by a penetrative mylonitic S_3 foliation that largely obliterates primary features in the rocks. These zones locally contain a prominent tectonite layering that parallels S_3 and contains a pervasive, intense, L_3 mineral and stretching lineation. In many locations, these zones constitute L>S tectonite in which the axial ratios of stretched clasts define markedly prolate ellipsoids. Isoclinal, rootless and intrafolial F_3 folds are common in these zones, and record progressive folding and transposition during D_3 shear. Sheath folds are common and plunge subvertically. Major D_3 high-strain zones are developed along the west margin of the Northeast Arm gneiss belt (EGSZ), as well as along the northeast contact of the Garner River unit (WGSZ). The earliest increment of shear within the BLSZ probably also occurred during D_3 deformation, as evidenced by the local preservation of a penetrative S_3-L_3 fabric in relatively low-strain enclaves within the shear zone. A characteristic feature of the D_3 high-strain zones is the presence of shear bands, σ-porphyroclasts and asymmetric quartz boudins that consistently indicate northeast-side-up shear (Fig. GS-24-9).

The geometry of the D_3 deformation structures indicates northeast-southwest shortening and southwest-directed tectonic transport of the southern margin of the North Caribou Terrane over the Rice Lake belt. On a regional scale, the D_3 structural geometry would be compatible with a regime of sinistral transpression during main-stage collisional orogenesis.

D_4 deformation

Along the western margin of the BLSZ, the S_3 crenulation cleavage is overprinted by a pervasive, spaced, shear-band

Figure GS-24-9: Ultramylonite in the West Garner Shear Zone, 500 m south of Garner Lake, looking southeast (in the X-Z plane). Northeast-side-up shear indicated by asymmetric quartz boudins and shear bands.

cleavage that trends north to north-northwest and dips subvertically. The sense of asymmetry of the shear bands is consistently dextral. This cleavage, which is herein assigned to D_4 deformation, locally intensifies into narrow zones of chloritic mylonite that strike north-northwest and contain very well developed asymmetric fabrics that also indicate dextral shear. These fabrics are not observed in the adjacent BLSZ, where asymmetric fabrics indicate sinistral strike-slip shear associated with the D_5 deformation (*see* below). In this regard, these D_4 structures appear to preserve evidence of post-D_3–pre-D_5 dextral shear within the BLSZ.

East of the BLSZ, D_3 high-strain zones are overprinted by open to tight, parallel- to similar-style folds that plunge steeply and have generally south-trending axial planes. The asymmetry of these folds appears to depend on the orientation of the D_3 tectonite fabric, with S- and Z-asymmetric folds formed in northwest- and northeast-trending tectonite, respectively. East-trending tectonite contains symmetric folds. Along the eastern margin of the BLSZ, these folds are transposed by sinistral D_5 mylonite (*see* below), and are therefore also attributed to D_4 deformation. In the central portion of the Garner Lake extrusive complex, northwest-trending D_3 fabrics and high-strain zones are crosscut by a series of widely spaced, <5 m thick, chloritic shear zones that trend north-northeast and dip subvertically. Asymmetric fabrics and offsets of markers indicate dextral shear. Although the relative timing of these shear zones with respect to the D_5 deformation is unknown, they are similar in terms of style and kinematics to those described west of the BLSZ and are thus tentatively assigned to the D_4 deformation.

Overall, the geometry of the D_4 structures suggests roughly east-west shortening of the D_3 structures. This shortening may have occurred during the waning stages of the main-stage collisional orogenesis.

D_5 deformation

Structures attributed to the D_5 deformation are spatially associated with a series of ductile to brittle-ductile shear zones that significantly influence the map pattern in the southeast Rice Lake belt. These shear zones range up to 1.0 km thick and generally trend west-northwest to north-northwest, with subvertical dips. These shear zones are characterized by greenschist-facies mylonitic fabrics that contain very well developed S-C fabrics, shear bands, foliation fish and asymmetric quartz boudins. Shallow-plunging ridge-in-groove and rare stretching lineations indicate predominantly strike-slip shear. Asymmetric fabrics in the north-northwest-trending BLSZ record sinistral strike-slip shear (Fig. GS-24-10), whereas those in the west-northwest-trending Long Lake Shear Zone (LLSZ) record dextral strike-slip shear. In the EGSZ, narrow zones of retrogressed cataclastic gneiss and greenschist-facies mylonite also consistently record dextral strike-slip shear. Large outcrops near the mouth of the Garner River in Garner Lake clearly illustrate the progressive transposition of D_2-D_3-D_4 fabrics along the eastern margin of the BLSZ. Here, west-trending D_3 tectonite and symmetrical, open to tight, north-trending F_4 folds are progressively transposed over approximately 150 m into chlorite-sericite schist and mylonite of the BLSZ. The D_5 mylonite contains trains of open to isoclinal, S-asymmetric F_5 folds, with clear evidence for progressive folding and transposition in a kinematic regime of sinistral strike-slip shear.

The geometry and kinematics of the greenschist-facies shear zones in the map area indicate that they likely formed

Figure GS-24-10: Sinistral shear bands in greenschist-facies mylonite of the Beresford Lake Shear Zone, Garner River.

in response to the northwest-southeast shortening and dextral transpression that marks the terminal collision of the Kenoran Orogeny in the western Superior Province. On a regional scale, the greenschist-facies dextral mylonite that characterizes the Manigotagan and Wanipigow shear zones probably also formed during D_5 deformation.

D_6 deformation

The D_6 deformation structures are mainly brittle-ductile in character, and are heterogeneously developed. These structures typically comprise conjugate kink-fold and shear-fracture sets, which overprint earlier, north-trending fabrics in the BLSZ and WGSZ. The shear fractures locally contain seams of fine-grained cataclasite <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. On a macroscopic scale, several of the D_5 shear zones, including the BLSZ, are folded by broad open folds that trend east-west and do not have an associated axial-planar fabric. The geometry of these folds appears to be compatible with north-south shortening, possibly during D_6 deformation.

Economic considerations

Exploration targets

Perhaps the most significant exploration targets to come out of the 2003 field season are the thick zones of chlorite–sericite±ankerite alteration that characterize the regional-scale BLSZ between the south end of Beresford Lake and the northwest arm of Gem Lake. In particular, these alteration zones were found to contain strongly boudinaged ankerite veins that range up to 1.5 m thick and contain >90% ankerite, with subordinate quartz, chlorite, sericite, calcite and pyrite. Texturally, the veins consist of massive, coarsely crystalline ankerite, with local preservation of <1.0 cm thick crustiform bands of ankerite around angular inclusions of wallrock. In several locations, including southern Beresford Lake, western Garner Lake and northwestern Gem Lake, these veins are selectively replaced by dense, smoky grey silica (Fig. GS-24-11) that contains 1 to 2% finely disseminated pyrite, locally with subordinate chalcopyrite. The silica replacements range from patchy to pervasive within the veins, and are typically crosscut by brittle quartz-filled fractures. Locally, the late quartz veins define zones of stockwork quartz-chlorite-pyrite veins, up to 3 m wide, that cut the ankerite veins and the host chlorite-sericite-ankerite-pyrite schist. Several of the silica-replaced, crustiform-banded ankerite veins have been sampled for assay and trace-element analysis. The ankerite veins, and the regional Fe-carbonate alteration zones that host them, are substantially similar to those that host high-grade gold mineralization in the Red Lake gold camp of Ontario (e.g., Poulsen et al., 1994).

Timing of gold mineralization – constraints on metallogenesis

One of the primary goals of the Rice Lake gold metallogeny project is to provide the exploration community with practical constraints on the timing, distribution and structural setting of orogenic lode-gold deposits in the Rice Lake belt. To this end, time was spent this summer conducting brief, field-based examinations of virtually all of the most

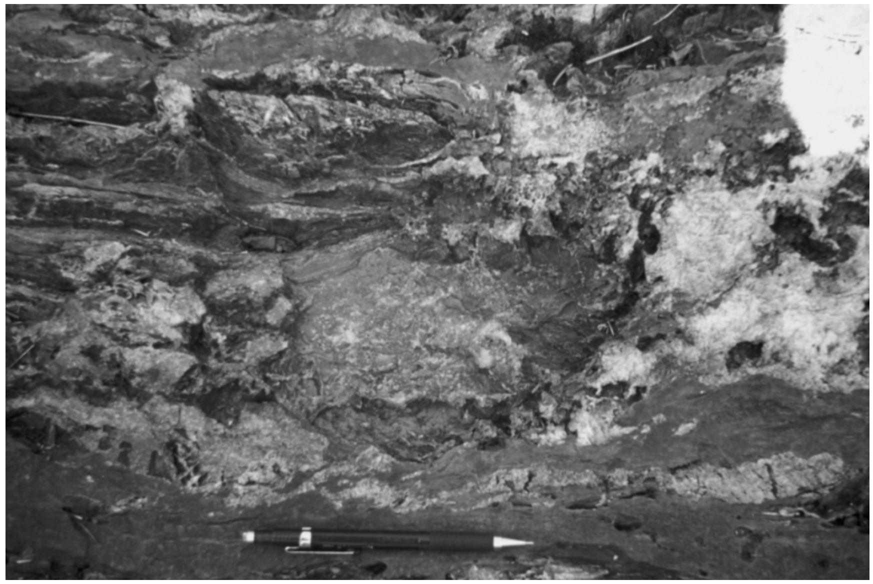

Figure GS-24-11: Boudinaged ankerite vein, selectively replaced by smoky grey silica, in the Beresford Lake Shear Zone, southeast shore of Beresford Lake.

significant gold deposits and occurrences in the Rice Lake belt. In many instances, these examinations were conducted in the company of the current property owner, which allowed for stimulating 'on-the-outcrop' discussions regarding currently favoured exploration models and the gold metallogeny in the Rice Lake belt. One recurring theme in many of these conversations was the idea that the gold mineralization is genetically related to, and largely synchronous with, emplacement of the Ross River pluton. This theory, which appears to be largely predicated on the observation that most of the significant gold deposits in the belt are spatially associated with the pluton, is worthwhile examining in the context of the regional structural model presented herein, as well as the presently available relative and absolute chronological constraints.

Currently, the best estimate of the age of the Ross River pluton is 2728 ±8 Ma, which is based on the analysis of four multigrain zircon fractions separated from a sample of quartz diorite that was collected from the southeastern margin of the pluton (Turek et al., 1989). On the basis of its intrusive relationship with ca. 2730 Ma felsic volcanic rocks of the Bidou assemblage (e.g., Turek et al., 1989; Bailes et al., 2003), the pluton is presently considered synvolcanic. On a regional scale, the Bidou assemblage is conformably overlain by siliciclastic rocks of the Edmunds Lake Formation, which bound the Rice Lake belt to the south and contain detrital zircons as young as 2.705 Ma (Davis et al., 1994).

Gold mineralization in the Rice Lake belt is invariably hosted by quartz±carbonate (calcite–ankerite), chlorite, sericite, tourmaline, pyrite, chalcopyrite and/or arsenopyrite veins that exhibit a high degree of structural control and are generally hosted by discrete, linear, ductile or ductile-brittle shear zones (e.g., Brommecker, 1991; Poulsen et al., 1996). In many localities, these shear zones discordantly cut a regional S-L fabric in the country rocks that, in at least the southeastern portion of the belt, represents a composite D_2-D_3 fabric that formed under greenschist to amphibolite-facies metamorphic conditions, at midcrustal depths. Based on a detailed analysis of gold-bearing shear zones in the southeast Rice Lake belt, Brommecker (1991) concluded that gold mineralization was likely synmetamorphic and associated with regional northeast-southwest shortening during the main pulse of ductile deformation in the belt (i.e., D_2-D_3, this study). From the standpoint of gold-metallogenic models, it is important to emphasize that the Edmunds Lake Formation contains the D_2-D_3 fabrics, as well as shear-hosted auriferous quartz veins.

These constraints require the following sequence of events: 1) ca. 2.728 Ga intrusion of the Ross River pluton into the Bidou assemblage; 2) cooling of the pluton, perhaps during regional exhumation of the Bidou assemblage; 3) conformable and nonconformable deposition of the Edmunds Lake Formation over the Bidou assemblage and Ross River pluton subsequent to 2.705 Ga; 4) crustal thickening and burial of the Edmunds Lake Formation to midcrustal depths prior to, or during, D_2-D_3 regional deformation; 5) development of ductile and ductile-brittle shear zones (syn-D_3?); and 6) emplacement of auriferous quartz veins.

In this context, it is clear that the Ross River pluton must predate final emplacement of gold mineralization in many of the most significant gold deposits discovered to date in the Rice Lake belt by at least 15 m.y., and most likely by more than 30 m.y. Equally clear is the fact that the metallogeny of lode-gold mineralization in the Rice Lake belt cannot be fully explained in the context of simplistic syngenetic models. Any attempt to construct a comprehensive, practical, gold metallogenic model for the Rice Lake belt should endeavour to include all available chronological constraints, and must take into account the significant time gap that existed between arc magmatism and final emplacement of auriferous quartz veins.

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