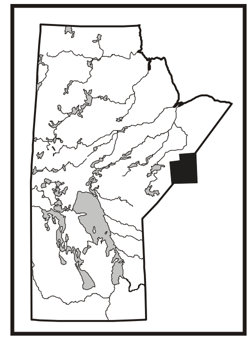
GS-21 GEOLOGICAL AND GEOCHRONOLOGICAL INVESTIGATIONS IN THE STULL LAKE-EDMUND LAKE GREENSTONE BELT AND GRANITOID ROCKS OF THE NORTHWESTERN SUPERIOR PROVINCE



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SUMMARY

Field and isotopic data on plutonic and supracrustal rocks from the northwestern Superior Province reveal three, fault-bounded crustal terranes that record the collision between reworked 3.6 Ga crust in the north and a less than 3 Ga protocraton at 2.72 to 2.71 Ga. In the south, the Munro Lake terrane comprises less than 2.86 Ga rift-margin sedimentary rocks and komatiite built on the reworked margin of the 3 Ga North Caribou terrane. Plutonic rocks at 2.84 and 2.72 Ga have 3 Ga Nd model ages, reflecting recycling of the North Caribou margin. To the north, in the Oxford Lake–Stull Lake terrane, ca. 2.83 Ga, submarine, depleted tholeiitic basalt was thrust (D_1), prior to ca. 2.73 Ga, onto the Munro Lake terrane. A 2.73 to 2.72 Ga, isotopically juvenile, continental-margin arc was built on the accreted crust and is cut by 2.72 to 2.71 Ga, early to syntectonic, isotopically juvenile plutons. To the north, across the northwest-trending North Kenyon Fault (a 1 to 2 km wide dextral strike-slip greenschist mylonite), 2.84 to 2.71 Ga plutonic rocks of the Northern Superior superterrane have 3.6 to 2.9 Ga Nd model ages and zircon inheritance to 3.57 Ga. Docking of this reworked Paleoarchean crust with the Oxford Lake–Stull Lake terrane resulted in 2.73 to 2.72 Ga arc volcanism, oblique convergence (D_2-D_3) and metamorphism at less than 2.72 Ga. Eruption of synorogenic, less than 2.71 Ga, alkaline and shoshonitic lavas with negative epsilon Nd (ε_{Nd}) values, and later deposition of continental sediments with local 3.6 Ga detrital zircons, reflects underthrusting and uplift of older continental crust across the Oxford Lake–Stull Lake terrane.

INTRODUCTION

Archean crust in the Superior Province of northern Manitoba and Ontario is tectonically segmented on a number of scales. Major crustal blocks are defined by northwest-trending, dextral-slip greenschist-facies shear zones, spaced 10 to 50 km apart. Granitoid rocks dominate these crustal domains and provide windows to understanding the crustal evolution and deformation history in these blocks. Supracrustal rocks preserved in greenstone belts are, in part, cut by the major shear zones, but also preserve an internal tectonic subdivision that predates shear-zone formation. Unravelling the volcanic and sedimentary record using field, geochronological and geochemical methods provides a valuable perspective on the early tectonic history of this area, and the fate of its mineral and metal endowment.

Geological mapping since 1995 (integrated within Western Superior NATMAP) provides 1:50 000 scale control along a northerly trending, across-strike transect along the northern Ontario–Manitoba border between Sachigo and Yelling lakes (Fig. GS-21-1; Stone and Pufahl, 1995; Stone et al., 1996; Stone and Halle, 1997; Stone et al., 1999a; Stone et al., 1999b). These results, plus a Nd isotopic and U-Pb (by sensitive high-resolution ion microprobe [SHRIMP]) isotopic survey of plutonic rocks between Sachigo Lake and Yelling Lake, reveal that fault-bounded, isotopically juvenile, 2.71 Ga crust separates the 3.0 Ga northern North Caribou margin in the south from the greater than 3 Ga Northern Superior superterrane in the north. Recent, detailed (1:20 000 scale) mapping of the Stull Lake–Edmund Lake (Fig. GS-21-2) and Knee Lake greenstone belts provides key structural, stratigraphic and geochronological constraints on the broad collision zone between these two protocratonic blocks (Corkery, 1996; Corkery et al., 1997; Corkery and Skulski, 1998; Corkery and Heaman, 1998; Corkery et al., 1999; Syme et al., 1997, 1998). These data are consistent with a three-fold subdivision of the northwestern Superior Province in the map area (Fig. GS-21-1): 1) Munro Lake terrane (*modified after* Thurston et al., 1991), the crustal block lying south of a splay of the Wolf Bay–Stull–Wunnumman Shear Zone in the southern Stull Lake–Edmund Lake greenstone belt and including the Sachigo Lake–Ponask Lake greenstone belt; 2) Oxford Lake–Stull Lake terrane (*modified after* Thurston et al., 1991), the area between the Wolf Bay–Stull–Wunnumman Shear Zone in the Stull Lake–Edmund Lake greenstone belt and the North Kenyon Fault; and 3) Northern Superior superterrane (Skulski et al., 1999), the area north of the North Kenyon Fault. This report focuses on the Sachigo Lake to Yelling Lake corridor, including a relatively in-depth look at the Stull Lake–Edmund Lake greenstone belt and new geological data from a north-trending transect along the Stull River from Kistigan Lake to Curran Robinson Lake (Fig. GS-21-2).

MUNRO LAKE TERRANE

Thurston et al. (1991) defined the Munro Lake terrane as a crustal block bound by the Gods Lake Narrows Shear Zone in the north (equivalent in the map area to a southwestern splay of the Wolf Bay–Stull–Wunnumman Shear Zone), and the equivalent of the South Pipestone Lake Shear Zone and its eastern extensions in the south (Parmenter et al., 1999). The Gods Lake Narrows Shear Zone is described as a D_2 shear zone with dominant dextral transcurrent shear and a south-over-north component (Corkery et al., 1999). The shear zone deforms an earlier D_1 shear-zone fabric, with south-over-north thrust displacement, that deforms less than 2711 Ma conglomerates (Corkery et al., 1999; Corkery et al., GS-22, this volume).

At the southern edge of the transect area and the Munroe Lake terrane, the Sachigo Lake–Ponask Lake greenstone belt includes relatively highly strained rocks that form three south-facing assemblages (Fig. GS-21-1; Stone et al., 1996, 1997). In the north, at Ponask Lake, a rift-margin assemblage is interpreted to consist of tonalitic basement with overlying less than 2865 Ma tonalite- and komatiite-bearing conglomerate (D.W. Davis and M. Moore, Geochronology in the western Superior Province, unpublished report, Royal Ontario Museum, 1991), siltstone-sandstone (locally quartz arenite), minor amounts of calc-silicate marble and talcose-tremolitic komatiite. On western Ponask Lake, mafic and intermediate to felsic, tuffaceous to fragmental rocks and 2857 Ma felsic intrusions (D.W. Davis and M. Moore, Geochronology in the western Superior Province, unpublished report, Royal Ontario Museum, 1991) may represent an arc assemblage. Pillowed basalt occurs at Sachigo Lake and north of Ponask Lake.

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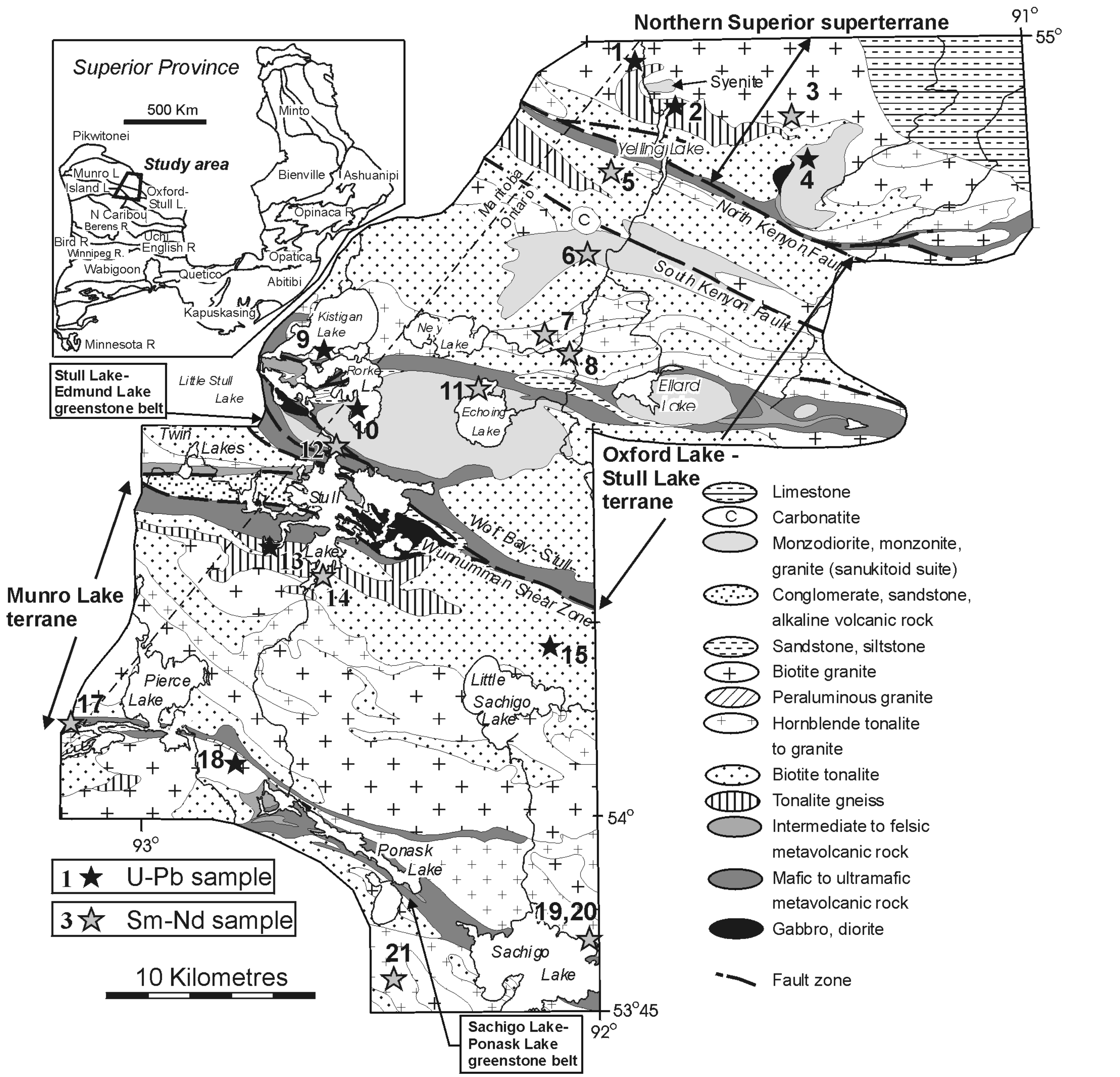

*Figure GS-21-1: Location map and geological map of the Sachigo Lake to Yelling Lake corridor. Inset map shows location within the northwestern Superior Province. Geological map shows principal terranes, geological units (*adapted from *Stone et al., 1999a), location of the Stull Lake–Edmund Lake greenstone belt, major shear zones and granitoid sample locations. Granitoid sample sites analyzed for both U-Pb and Sm-Nd for are shown as black stars; sites where only Sm-Nd isotopic data were collected are shown as grey stars.*

Hornblende-biotite tonalite gneiss occurs near the northern margin of the Munroe Lake terrane (Fig. GS-21-2). The contact between tonalite gneiss and basalt of the Hayes River Group (Stull Lake–Edmund Lake greenstone belt) in southern Stull Lake is obscured by glacial cover. The southernmost exposures of basalt are tectonically flattened, amphibolite-grade metabasalt. The tonalite gneiss is cut by multiple generations of syn- to post-tectonic granite pegmatite dykes and crosscut by boudinaged and tectonically dismembered mafic dykes. To the south, making up the central part of the Munroe Lake terrane, is a wide zone of moderately foliated biotite tonalite with enclaves of tonalite gneiss, amphibolite and hornblende tonalite. This tonalite is thought to be basement to the Sachigo–Ponask belt (Stone et al., 1996, 1997). The tonalite is intruded sequentially by intermediate hornblende tonalite to quartz diorite with lensoid inclusions of diorite and amphibolite, megacrystic hornblende granite, and massive to weakly foliated leucocratic biotite granite with inclusions of tonalite (Stone et al., 1996).

OXFORD LAKE–STULL LAKE TERRANE

This section focuses primarily on the Stull Lake–Edmund Lake greenstone belt and the internal and external granitoid plutons and major structures that define this terrane near the Ontario–Manitoba border.

Stull Lake–Edmund Lake Greenstone Belt

The Stull Lake–Edmund Lake greenstone belt comprises four tectonostratigraphic assemblages and four suites of internal plutonic rocks that record a complex history of ductile deformation and tectonic

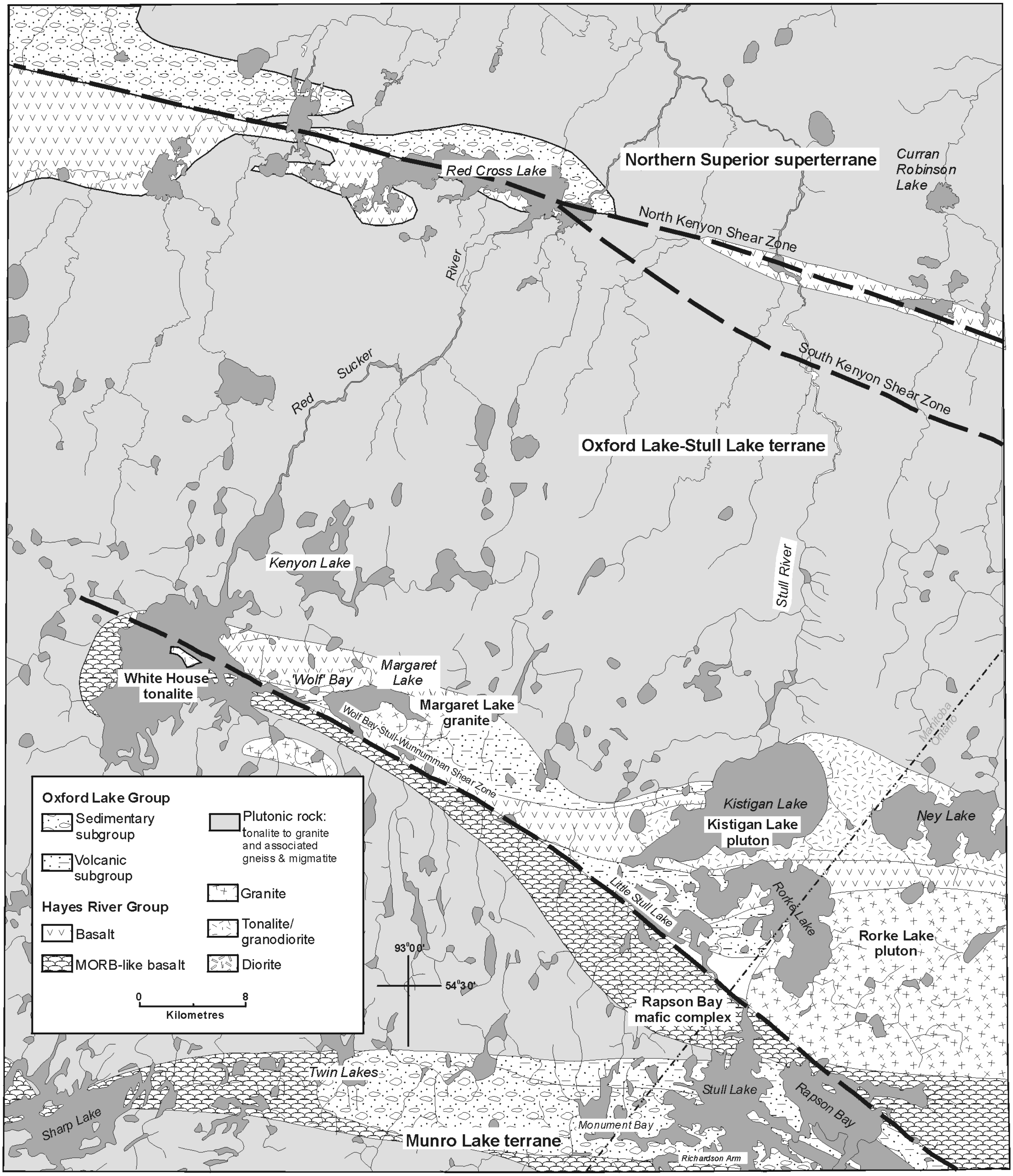

*Figure GS-21-2: Geological map of the Stull Lake–Edmund Lake greenstone belt, Oxford Lake–Stull Lake terrane (*adapted from *Corkery and Heaman, 1998).*

segmentation along the Wolf Bay–Stull–Wunnumman Shear Zone (WSWSZ; Fig. GS-21-2, -3). Available field, geochemical and geochronological constraints (Corkery and Heaman, 1998; Corkery and Skulski, 1998) allow us to subdivide the supracrustal rocks into a provisional tectonostratigraphy (pending ongoing geochronological studies at the Geological Survey of Canada [GSC] and Royal Ontario Museum [ROM]). These include:

1) south of the WSWSZ, greater than 2734 Ma Hayes River Group submarine tholeiitic basalt with depleted trace-element signatures;
2) north of the WSWSZ, greater than 2728 Ma Hayes River Group submarine tholeiitic basalt and andesite with flat light rare-earth element (LREE)–enriched, primitive-mantle–normalized patterns and positive Th/Nb values;
3) north of the WSWSZ, ca. 2741 to 2726 Ma Oxford Lake volcanic subgroup, calc-alkaline to shoshonitic, intermediate to felsic fragmental volcanic rocks and volcanic-derived sedimentary rocks; and
4) Oxford Lake sedimentary subgroup, fluvial-clastic sandstone and polymictic conglomerate.

Hayes River Group

Tholeiitic, sparsely vesicular, aphyric pillow basalt intruded by up to 50% gabbro sills forms the Rapson Bay mafic complex of the Hayes River Group, south of the WSWSZ (Fig. GS-21-3). This complex can be traced from Stull Lake in Ontario to the southern shore of Edmund Lake in Manitoba (Corkery and Skulski, 1998; Corkery and Heaman, 1998). The pillow basalt and gabbroic rocks are characterized by LREE- and large-ion lithophile element (LILE)–depleted, primitive-mantle–normalized profiles, similar to modern ocean-floor basalt (Corkery and Skulski, 1998). In the Edmund Lake area, a minimum age on the Rapson Bay mafic complex is provided by the crosscutting 2734 ± 2 Ma White House tonalite (Heaman and Corkery, 1998; Fig. GS-21-2).

Pillowed and massive tholeiitic basalt and rare andesite north of the WSWSZ are interbedded sporadically with oxide-facies banded iron-formation. The basalt includes LREE-enriched varieties with large negative Nb anomalies, as well as rare depleted tholeiitic basalt and basalt with flat primitive-mantle–normalized patterns (Corkery and Skulski, 1998). In the Edmund Lake area, LREE-enriched basalt has a minimum age defined by the crosscutting 2728 ± 2 Ma Margaret Lake granite (Fig. GS-21-2; Corkery and Heaman, 1998). The Hayes River Group volcanic rocks in the Stull Lake–Edmund Lake greenstone belt are chemically similar to diverse Hayes River Group basalt, found in the Knee Lake area, that is locally associated with 2.83 Ga rhyolite (Syme et al., 1998).

Oxford Lake volcanic subgroup

The White House tonalite and Margaret Lake granite are synvolcanic with Oxford Lake Group volcanism, and their age and field setting establishes that the Oxford Lake Group was built on a basement of Hayes River Group basalt (Corkery and Heaman, 1998). Four marine lithological associations are identified in the Oxford Lake volcanic subgroup on Little Stull Lake, including: Lodge Bay aphyric, intermediate to felsic tuff and breccia; Sickle Bay greywacke turbidite, argillite and oxide-facies iron-formation; Minnow Bay feldspar±quartz–phyric, intermediate to felsic tuff and breccia; and hornblende-phyric, high-K andesite, trachybasalt, trachyte and derived volcanogenic and epiclastic sedimentary rocks (Fig. GS-21-3; Corkery and Skulski, 1998; Stone et al., 1999a).

Corkery and Skulski (1998) reported a maximum age of 2726 ± 2 Ma (inheritance to 2751 ± 2 Ma) for a Lodge Bay aphyric rhyolite tuff interbedded with fine-grained, reworked, volcanogenic sedimentary rocks on Little Stull Lake. The Lodge Bay volcanic sequence is cut by a 2717 ± 1 Ma feldspar±quartz–phyric tonalite (Fig. GS-21-3; D.W. Davis and M. Moore, Geochronology in the western Superior Province, unpublished report, Royal Ontario Museum, 1991), thus bracketing deposition of aphyric volcanic rocks, argillite and iron-formation between 2726 Ma and 2717 Ma. The aphyric volcanic sequence is calc-alkaline and characterized by LREE- and LILE-enriched, and heavy rare-earth element (HREE)–depleted primitive-mantle–normalized profiles with

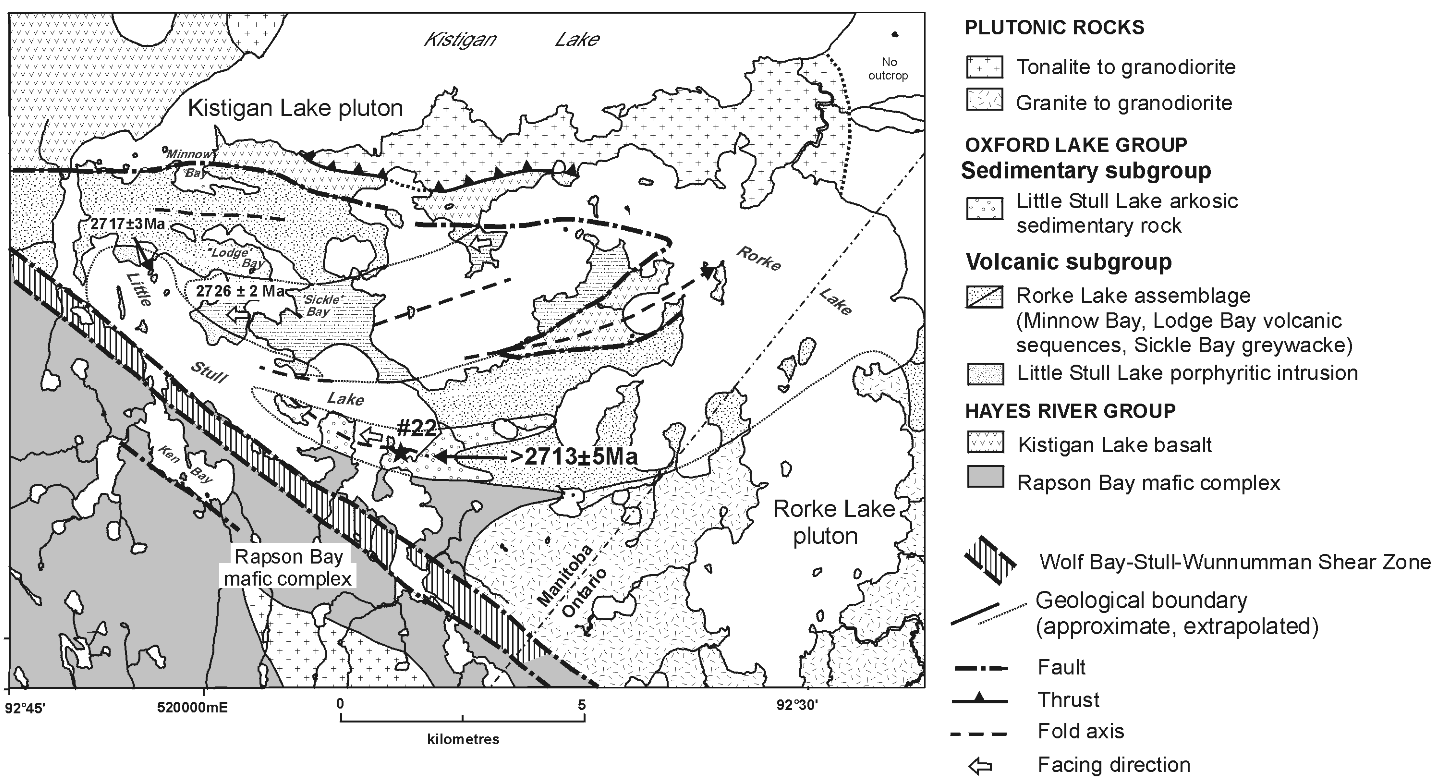

*Figure GS-21-3: Geological map of the Stull Lake segment of the Stull Lake–Edmund Lake greenstone belt (*adapted from *Corkery and Skulski, 1998 and Stone et al., 1999a). Black star indicates location of Oxford Lake sedimentary subgroup arkose sample (no. 22) for SHRIMP geochronology.*

negative Nb anomalies (Corkery and Skulski, 1998). Dacitic tuff, at Ellard Lake to the east (Fig. GS-21-1), has a U-Pb age of 2732 ± 1 Ma (Stone et al., 1999b) and is correlative with the Oxford Lake volcanic subgroup.

The Minnow Bay feldspar-phyric and quartz-feldspar–phyric andesite to rhyolite and associated sedimentary rocks are interpreted to be in fault contact with the Lodge Bay sequence (Corkery and Skulski, 1998). A minimum age on the Minnow Bay sequence is given by the crosscutting 2717 Ma feldspar±quartz–phyric tonalite (Fig. GS-21-3). The Minnow Bay sequence is calc-alkaline and shows trace-element signatures similar to those of the aphyric Lodge Bay sequence.

Intermediate to mafic fragmental rocks, which are locally hornblende-phyric on Rorke Lake (Fig. GS-21-3), include tuff, lapilli tuff and tuff breccia interlayered with reworked volcaniclastic and epiclastic rocks. Similar hornblende-phyric, mafic volcanic rocks and feldspar-phyric felsic volcanic rocks on Stull Lake, south of the WSWSZ, are mildly alkaline and include trachybasalt and trachyte (Fig. GS-21-3; Stone et al., 1999a). A sample of hornblende-phyric amygdaloidal trachybasalt from Stull Lake is characterized by pronounced enrichment in Th, LREE and LILE relative to other volcanic rocks in the Oxford Lake Group (Corkery and Skulski, 1998).

Oxford Lake sedimentary subgroup

Crossbedded and graded arkose, arkosic wacke and polymictic conglomerate constitute the Oxford Lake sedimentary subgroup and are exposed both north and south of the WSWSZ on Little Stull Lake and Stull Lake (Corkery and Skulski, 1998; Stone et al., 1999a). On Little Stull Lake, crossbedded arkose (foresets up to 5 cm) is overlain by polymictic, volcanic-derived conglomerate. On Stull Lake, polymictic conglomerate includes clasts of iron-formation, volcanic rocks, plutonic rocks and previously foliated granitoid and mylonitic rocks. This conglomerate overlies trachybasalt and trachyte (Stone et al., 1999a), and it is uncertain whether the interface between them marks an unconformity or, as suggested by Stone et al. (1999a), a conformable package of the Oxford Lake Group sedimentary subgroup. Large-scale (>2 cm), trough-type crossbedding, channel-facies conglomerate, and pebble lag deposits characterize the sedimentary subgroup and are characteristic of fluvial-clastic sedimentary rocks (Corkery and Skulski, 1998). The change in depositional setting from marine in the Oxford Lake volcanic subgroup (ca. 2726 Ma) to fluvial-subaerial in the sedimentary subgroup (<2713 Ma; *see* below), and the presence of polymictic conglomerate with clasts of underlying rock types in the latter, is evidence of an unconformable contact between the volcanic and sedimentary subgroups.

Internal Plutons

Four suites of internal plutons are recognized in the Stull Lake–Edmund Lake greenstone belt. These include 1) synvolcanic (Hayes River Group) gabbro and anorthositic gabbro plutons; 2) syn- to late volcanic (Oxford Lake volcanic subgroup), porphyritic tonalite, granodiorite and granite; 3) pre- to syntectonic (Oxford Lake volcanic subgroup) hornblende–biotite–K-feldspar porphyritic granodiorite; and 4) a sanukitoid suite.

Up to 50% of the Hayes River Group south of the WSWSZ on Little Stull Lake consists of synvolcanic gabbro sills that constitute the Rapson Bay mafic complex (Fig. GS-21-2; Corkery et al., 1997). These gabbroic rocks are associated with the tholeiitic basalt that extends from Rapson Bay in Ontario to southern Edmund Lake in Manitoba. The gabbro sills are medium grained, equigranular and locally plagioclase-phyric. An 800 m wide sill on Ken Bay in Little Stull Lake retains decimetre-scale layering of melagabbro, leucogabbro and anorthositic gabbro (Fig. GS-21-3).

Syn- to late volcanic plutons include the 2734 ± 2 Ma White House tonalite and the 2728 ± 2 Ma Margaret Lake granite (Corkery and Heaman, 1998) in the Edmund Lake area, and the 2717 ± 3 Ma feldspar±quartz–phyric tonalite on Little Stull Lake (Fig. GS-21-2; Corkery et al., 1997). The White House tonalite is a strongly foliated and recrystallized intrusion, dominated by fine-grained, equigranular biotite tonalite, that intrudes the Hayes River tholeiitic basalt described above (Corkery and Heaman, 1998). The tonalite is calc-alkaline and has primitive-mantle–normalized LREE enrichment and negative Nb anomalies similar to those found in felsic volcanic rocks of the Oxford Lake Group. The Margaret Lake granite is a fine- to medium-grained, equigranular, biotite leucogranite that is weakly foliated to nonfoliated (Corkery, 1996). The Little Stull Lake porphyritic intrusion is a tabular, 5 km long, composite intrusion of feldspar-phyric tonalite to quartz-feldspar–phyric trondhjemite. The pluton is moderately foliated, and the intensity of deformation increases toward the WSWSZ, which locally defines its western boundary.

The Kistigan Lake pluton is a large pre- to syntectonic hornblende–biotite–K-feldspar porphyritic granodiorite to hornblende-biotite tonalite that intrudes, and is in fault contact with (*see* below), the northern margin of the greenstone belt along the south shore of Kistigan Lake (Fig. GS-21-2, -3). This well foliated plutonic body is subdivided into three phases (Corkery et al., 1997): a predominant, coarse-grained, equigranular tonalite to granodiorite phase; a finer grained, mafic tonalite to quartz diorite marginal phase; and a local, K-feldspar megacrystic (1–7 cm), medium- to coarse-grained granodiorite.

The Rorke Lake pluton is a relatively massive, K-feldspar megacrystic granodiorite and hornblende-biotite granodiorite that intrudes the greenstone belt in the Rorke Lake area (Fig. GS-21-2, -3). This pluton is part of a monzodiorite-monzonite-granite sanukitoid suite (Stone et al., 1997). The sanukitoid bodies are typically late, oval-shaped, zoned plutons that have mafic marginal zones (diorite, monzodiorite and monzonite) containing crustal xenoliths, grading into more differentiated granodiorite and granite in the core. The geochemistry of this suite is characterized by high Mg#s, high Cr and Ni concentrations, and enrichment in LREE and LILE relative to other granitoid rocks (cf. Stern and Hanson, 1991).

Structural History of the Stull Lake–Edmund Lake Greenstone Belt

The Stull Lake–Edmund Lake greenstone belt is cut by the WSWSZ, a large northeast-trending deformation zone that divides the belt into two domains: a southern domain dominated by depleted tholeiitic mafic volcanic rocks of the Hayes River Group, and a northern domain comprising tholeiitic Hayes River volcanic rocks and fault-bounded panels of the younger Oxford Lake volcanic subgroup (Fig. GS-21-2; Corkery et al., 1997; Corkery and Skulski, 1998; Jiang and Corkery, 1998). The Oxford Lake sedimentary subgroup is an element common to both sides of the deformation zone. Jiang and Corkery (1998) recently summarized the structural evolution of the greenstone belt and recognized four sets of ductile structures.

Structures belonging to D_1 are confined to tholeiitic gabbro and basalt of the Hayes River Group on the south shore of Edmund Lake (Fig. GS-21-3; Jiang and Corkery, 1998). These structures comprise a shallow-dipping S_1 foliation and shallow-plunging L_1 stretching lineation in deformed gabbro and basalt. The S_1 foliation is a shape fabric in deformed gabbro and a compositional, tectonic layering of mylonitized gabbro and basalt that represents the C-foliation in ductile shear zones. The sense of shear in these early deformation zones is not evident. These early structures are overprinted by the D_{2-4} structures described below.

Structures belonging to D_2 reflect regional isoclinal folding, with map-scale F_2 folds in the Little Stull Lake area that primarily control the map pattern (Fig. GS-21-3; Jiang and Corkery, 1998). The F_2 folds have gentle plunges, are slightly overturned to the southeast, and have east-northeast trends that curve into parallelism close to the southeast-trending D_3 WSWSZ. Map-scale F_2 structures include an anticline in the Oxford Lake sedimentary subgroup, an anticline in the Minnow Bay sequence, and a syncline and anticline in the Sickle Bay–Lodge Bay sequences. Jiang and Corkery (1998) described S_2 as a differentiated crenulation cleavage that overprints S_1 cleavage in the Rapson Bay mafic complex.

The D_3 deformation reflects noncoaxial dextral transpression along the regional WSWSZ (Fig. GS-21-2). Jiang and Corkery (1998) suggested that it is a continuation of D_2, reflecting an evolution from folding to dextral transpression. This large structure, and kinematically similar small-scale shear zones in the Rapson Bay mafic complex, strike 110 to 130° and have S-C structures and other kinematic indicators that indicate a dextral sense of shear (Corkery and Skulski, 1997; Jiang and Corkery, 1998). Lineations within the WSWSZ and parallel allied structures are subhorizontal, whereas they are steeper and more variable in less deformed wall rocks.

Structures belonging to D_4 reflect north-south compression. They are characterized by 1) small-scale, cleavageless Z-folds of D_3 mylonite in the WSWSZ, with geometries that are inconsistent with dextral transpression, and 2) S-folds along southern Kistigan Lake, which cannot be attributed to parasitic F_2 or D_3 drag folds (Jiang and Corkery, 1998). On Kistigan Lake, a shallow north-dipping D_4 shear zone, with a mylonitic foliation and a north-plunging L_4 stretching lineation, separates the Kistigan Lake pluton to the north from Hayes River Group basalt, suggesting north-side-up thrusting.

Granitoid Plutons North of the Stull Lake–Edmund Lake Greenstone Belt

Three lithological suites of rocks dominate the plutonic domain that extends from north of the Stull Lake–Edmund Lake greenstone belt to the North Kenyon Fault (Fig. GS-21-1). An early complex orthogneiss, generally of tonalitic composition, is intruded by a younger, foliated, biotite tonalite-granodiorite that is, in turn, intruded by biotite granite, hornblende-bearing granite and associated late aplitic and pegmatitic dykes.

The early gneiss complex occurs both as the dominant rock type over kilometre-scale sections of the Stull River transect and as xenoliths in younger intrusive rocks. It generally occurs as a centimetre- to decametre-scale layered biotite or rarely hornblende tonalite gneiss. Fine- to medium-grained grey quartzofeldspathic bands form original restite, with 5 to 20% leucocratic mobilizate. A *lit* injection of light grey biotite tonalite forms the youngest phase of the early gneiss. In several locations, the dominant mafic mineral is hornblende or a retrograded mix of biotite, chlorite and hornblende remnants. The distribution of mafic minerals as clots in many locations is interpreted to indicate a younger period of metamorphism that postdates the early migmatite development.

Granodiorite to biotite tonalite is the dominant rock type along both the Stull River transect and the 1:50 000 scale corridor near the provincial border. These plutonic massifs vary from coarse- to medium-grained biotite granodiorite, locally microcline megacrystic, to medium- to fine-grained tonalite. This unit intrudes and truncates the gneissic layering and isoclinal folding in the early gneiss complex. However, there is local preservation of hornblende and an indication of late retrograde metamorphism similar to that observed in the gneiss.

Medium- to coarse-grained biotite granite forms from a few per cent up to (rarely) 50% of outcrops. Fine-grained aplitic and pegmatitic dykes are also common.

The early gneiss is generally well foliated to strongly lineated and was migmatitic prior to tonalite injection. However, both of these units share a strong east-west fabric throughout most of the Stull River transect, indicating at least two metamorphic events. The younger granite suite generally occurs as straight-walled intrusions that truncate the east-west fabric with a weak foliation.

In the area of the South and North Kenyon faults (Fig. GS-21-1), all units are strongly sheared and a fabric trending 300 to 310° transposes or overprints all earlier fabrics. The South Kenyon Fault is believed to be a splay of the North Kenyon Fault, and is a north-northwest-trending, 480 km long, subvertical deformation zone characterized by broad, greenschist facies, 1 to 2 km wide mylonite zones (Osmani and Stott, 1988; Stone et al., 1999b).

NORTH KENYON FAULT AND THE NORTHERN SUPERIOR SUPERTERRANE

The region north of the North Kenyon Fault comprises five plutonic suites (Stone et al., 1999b). A belt-like domain of medium-grained biotite tonalite gneiss, locally containing plagioclase porphyroclasts, is exposed north of Yelling Lake (Fig. GS-21-1). Well foliated biotite monzogranite is the most abundant rock type in this area and occurs as strongly foliated, K-feldspar megacrystic syenogranite on the north shore of Curran Robinson Lake in the west (Fig. GS-21-2). A sample of sheared granodiorite within the North Kenyon Fault at Yelling Lake is dated at 2722 ± 2 Ma (Fig. GS-21-1; Stone et al., 1999b), providing a maximum age on shear-zone deformation. Large tabular bodies of hornblende tonalite curve into parallelism with the North Kenyon Fault as the boundary of the fault is approached, reflecting an apparent dextral sense of drag. An oval-shaped pluton of well foliated hornblende–biotite–K-feldspar megacrystic granodiorite, belonging to the sanukitoid suite, intrudes biotite tonalite and biotite granite east of Yelling Lake (Fig. GS-21-1).

The North Kenyon Fault on Yelling Lake comprises a 1 km wide protomylonite to mylonite zone within granodiorite (Osmani and Stott, 1988). The rock matrix is reported to be extensively altered to chlorite and epidote, and feldspar augen are saussuritized. Asymmetrical quartz aggregates with subhorizontal long axes in the granodiorite suggest dextral noncoaxial flow (Osmani and Stott, 1988). Planar fabric within the mylonite dips northerly, and stretching lineations are mainly subhorizontal, although steep down-dip lineations are locally present (Stone et al., 1999a).

GEOCHRONOLOGICAL AND ND ISOTOPIC RESULTS

New geochronological and Nd isotopic data are summarized here from both the Stull Lake–Edmund Lake greenstone belt and a regional survey of granitoid rocks extending from south of the WSWSZ, near Sachigo Lake, to near the North Kenyon Fault in the Yelling Lake area. Zircons from sedimentary and plutonic rocks were analyzed with the GSC's SHRIMP II facility, using extraction and analytical methods described in Stern (1997). The Sm-Nd isotopic data on volcanic and plutonic rocks were collected in the geochronological laboratories of the GSC using methods described in Skulski et al. (1996).

Nd Isotopic Composition of Granitoid Rocks

Figure GS-21-4 shows Nd model ages (DePaolo [1981] depleted-mantle model) of granitoid rocks along the Sachigo Lake to Yelling Lake corridor. Differences in Nd model ages are apparent between the three crustal domains, indicating distinct crustal histories. In the Munro Lake terrane, Nd model ages range from 3.02 Ga in tonalite gneiss south of the Stull Lake belt to 2.92 Ga in hornblende-biotite tonalite north of the Sachigo Lake–Ponask Lake greenstone belt. In contrast, Nd model ages in the Oxford Lake–Stull Lake terrane are largely Neoarchean and range from 2.80 Ga in hornblende-biotite granodiorite of the sanukitoid suite to 2.77 Ga in moderately foliated hornblende-biotite granodiorite that flanks the Stull Lake–Edmund Lake greenstone belt. Older Nd model ages of 2.94 Ga are found in biotite tonalite in the northern parts of the

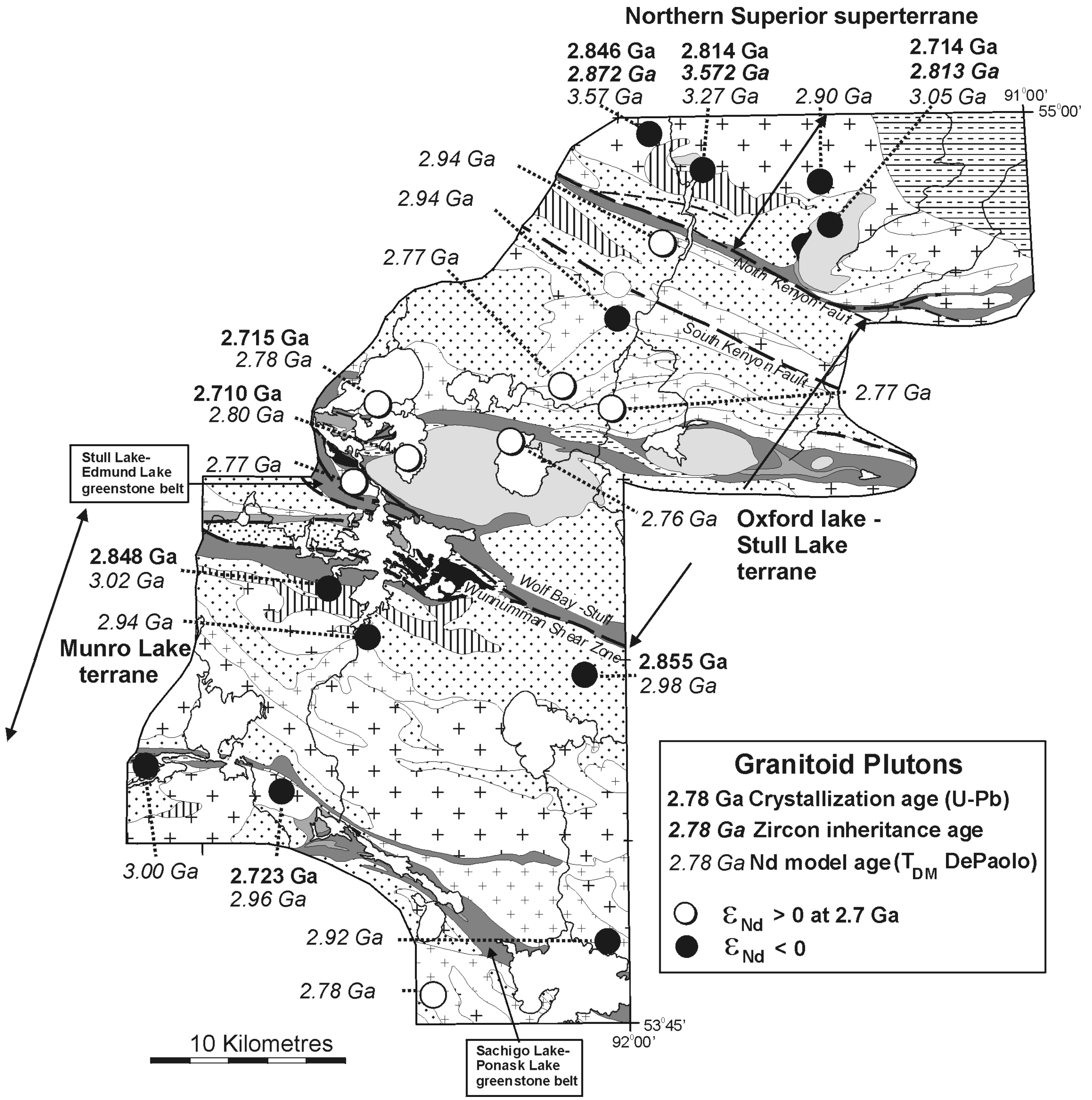

Figure GS-21-4: Summary of new U-Pb SHRIMP ages and Nd model ages for the Sachigo Lake to Yelling Lake corridor. U-Pb zircon SHRIMP ages are shown in bold and include crystallization ages (normal type) and maximum age of inheritance (bold italic type). Nd model ages (DePaolo [1981] depleted-mantle model) of whole-rock plutonic samples are shown in italic type. Sample locations are shown on Figure GS-21-1; rock types for dated samples are given in Figures GS-21-6 to -8.

terrane. Paleoarchean to Mesoarchean Nd model ages are found across the North Kenyon Fault in the Northern Superior superterrane. These range from 3.57 to 2.90 Ga in foliated biotite granite, to 3.27 Ga in tonalite gneiss, and 3.05 Ga in foliated hornblende-biotite granodiorite of the sanukitoid suite.

Nd Isotopic Composition of Volcanic Rocks

Eleven whole-rock samples of volcanic rocks were analyzed for their Nd isotopic composition in the Stull Lake–Edmund Lake greenstone belt (Fig. GS-21-5). Three tholeiitic basalt samples from the Hayes River Group south of the WSWSZ are depleted in incompatible LREE and have relatively high initial ε_{Nd} values, ranging from +3.8 to +0.5, that reflect derivation from a depleted-mantle source (generally accepted to be greater than +2.0 at ca. 2.7 Ga). These results are consistent with an ocean-floor or thin continental margin origin for this submarine mafic volcanic sequence.

Three samples of Hayes River Group basalt from north of the WSWSZ, characterized by LREE enrichment and negative Nb anomalies, have ε_{Nd} values ranging from +2.3 to -0.6. These lower ε_{Nd} values may reflect recycling of older continental crust in a subduction-zone setting.

A sample of 2726 Ma aphyric dacite from the Lodge Bay sequence of the Oxford Lake volcanic subgroup has an ε_{Nd} value of +1.4. The

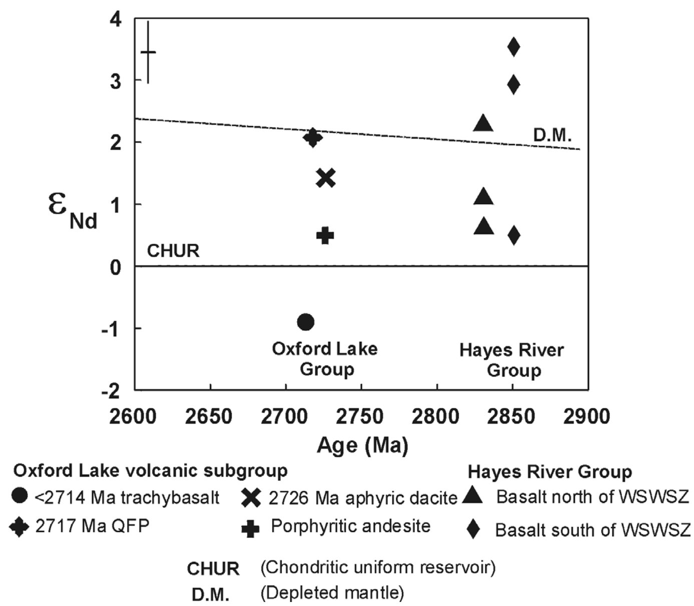

Figure GS-21-5: Epsilon Nd (ϵ_{Nd}) value versus age for whole-rock volcanic samples from the Stull Lake–Edmund Lake greenstone belt.

slightly younger 2717 Ma porphyritic tonalite intrusion on Little Stull Lake also has a positive ϵ_{Nd} value of +2. These data suggest that calc-alkaline, LREE-enriched magmas with negative Nb anomalies did not interact significantly with older continental crust. This observation is consistent with the field observation that synvolcanic intrusions (2734–2728 Ma) on Edmund Lake cut relatively juvenile mafic crust of the Hayes River Group.

Hornblende-phyric high-K andesite north of the WSWSZ, and trachybasalt underlying conglomerate of the Oxford Lake sedimentary subgroup south of the WSWSZ, are characterized by low ϵ_{Nd} values of +0.5 and -0.9, respectively. These low ϵ_{Nd} values may reflect a fundamental change in the source of high-K magmatism that involves the recycling of older continental crust.

In general, pre-2717 Ma volcanic rocks of the Stull Lake–Edmund Lake greenstone belt have relatively juvenile Nd isotopic compositions, as do the internal granitoid plutons that cut the belt. These data suggest that the volcanic belt developed on either a thin continental margin or in an oceanic setting. A major change in the Nd isotopic composition of mildly alkaline and high-K volcanic rocks occurs just prior to the deposition of synorogenic conglomerate of the Oxford Lake sedimentary subgroup. This change is recorded in the first appearance of Mesoarchean and Paleoarchean detrital zircons in late sedimentary rocks of the Stull Lake–Edmund Lake greenstone belt (below) and from correlative units in the Oxford Lake–Stull Lake terrane to the west.

U-Pb Geochronology

Eight samples of granitoid rocks were dated, using the SHRIMP, to investigate the crystallization ages of, and possible zircon-inheritance patterns from, widely spaced representative units with contrasting Nd model ages (Fig. GS-21-4). In addition, detrital zircons from a sample of crossbedded arkose from the Oxford Lake sedimentary subgroup were dated with the SHRIMP as well.

Munro Lake terrane

Three rocks were dated in the Munro Lake terrane, two samples of tonalite gneiss and a moderately foliated K-feldspar–biotite granodiorite (Fig. GS-21-4). Ten zircon grains from a biotite tonalite gneiss from south of the WSWSZ (sample 15; UTM 15, 560500E, 5907700N) have a U-Pb age of 2855 ± 5 Ma (Fig. GS-21-6a). This rock has a Nd model age of 2.98 Ga (initial ϵ_{Nd} of +0.15), although it shows no evidence of inherited zircons of this age. A tonalite gneiss from south of the Stull Lake–Edmund Lake greenstone belt (sample 13; UTM 15, 519752E, 6022590N) has an age of 2848 ± 7 Ma (10 zircons analyzed) and a 3.02 Ga Nd model age (initial ϵ_{Nd} of -0.28; Fig. GS-21-6b). The Nd data suggest that ca. 3 Ga crust may have been implicated in the source of tonalitic magmas. Data from other parts of the Munroe Lake terrane show similar results. To the west, in the Munro Lake terrane south of the Knee Lake greenstone belt, a felsic gneiss has an age of 2883 Ma (Corkery et al., 1999). Synvolcanic quartz porphyry, which cuts mafic rocks in the Ponask Lake belt, is dated at 2857 ± 2 Ma (D.W. Davis and M. Moore, Geochronology in the western Superior Province, unpublished report, Royal Ontario Museum, 1991) and is contemporaneous with tonalite gneiss to the north. Early quartz-rich conglomerate in the Ponask Lake belt that rests unconformably on tonalite (Stone et al., 1996) has a unimodal detrital zircon age of 2865 ± 1 Ma (D.W. Davis and M. Moore, Geochronology in the western Superior Province, unpublished report, Royal Ontario Museum, 1991), 10 m.y. older than the biotite tonalite gneiss dated here.

A K-feldspar–biotite granodiorite (sample 18; UTM 15, 513200E, 5992150N), which intrudes the Ponask Lake–Sachigo Lake greenstone belt, has a U-Pb age of 2721 ± 6 Ma (Fig. GS-21-1, -6c). This rock has a 2.96 Ga Nd model age (initial ϵ_{Nd} value of -0.70), which may reflect an older ca. 3 Ga crustal source beneath the Munro Lake terrane.

Oxford Lake–Stull Lake terrane

Uranium-lead ages were obtained by SHRIMP for the Kistigan Lake and Rorke Lake plutons and for a sample of crossbedded arkose from the Oxford Lake sedimentary subgroup in the Stull Lake–Edmund Lake greenstone belt (Fig. GS-21-3, -4). Eleven zircons from a hornblende–biotite–K-feldspar granodiorite phase of the Kistigan Lake pluton (sample 9; UTM 15, 524789E, 6051127N) give a U-Pb age of 2715 ± 8 Ma (Fig. GS-21-1, -7a). A single zircon core had a $^{207}Pb/^{206}Pb$ age of 2747 Ma that, along with the 2.78 Ga Nd model age (initial ϵ_{Nd} of +1.61), indicates a juvenile source for the Kistigan Lake pluton. The age of this pluton also provides a maximum age estimate for D_4 thrusting of the Kistigan Lake pluton onto Hayes River basalt.

Ten zircons from a hornblende-biotite granodiorite phase of the Rorke Lake sanukitoid (sample 10; UTM 15, 531286E, 6043247N) give a U-Pb age of 2710 ± 6 Ma (Fig. GS-21-1, -7b). The absence of inherited zircons in this rock and a Nd model age of 2.77 Ga (initial ϵ_{Nd} of +1.15) lend further support to a juvenile source for this pluton. From crosscutting relationships, the age of the Rorke Lake pluton provides a minimum age for the Minnow Bay volcanic sequence, and a maximum age for the WSWSZ that cuts its southern margin.

Twenty-two detrital zircons from a sample of crossbedded arkose in the Oxford Lake sedimentary subgroup on Little Stull Lake (sample 22; UTM 15, 523010E, 6044495N) were analyzed with the SHRIMP (Fig. GS-21-3, -7c). Zircons in this sample range in age from 2905 ± 8 Ma to 2713 ± 5 Ma, the latter being a U-Pb age of five spots on a single zircon that constrains the maximum age of sedimentation. The sample also contains detrital zircons of 2842 ± 9 Ma, similar in age to tonalite gneiss in the Munro Lake terrane and Hayes River felsic volcanism at Knee Lake (ca. 2830 Ma; Corkery et al., GS-22, this volume), and younger detrital zircons of 2740 to 2720 Ma that may reflect derivation from sources in the underlying Oxford Lake volcanic subgroup. Detrital zircons in the fluvial-clastic facies of the Oxford Lake sedimentary subgroup in the Knee Lake greenstone belt range in age from 3647 Ma to 2711 ± 2 Ma on Gods Lake, and from 2798 Ma to 2707 +9/-8 Ma on southern Knee Lake (Corkery et al., GS-22, this volume), and thus provide similar maximum age constraints on sediment deposition. From the detrital zircon data, a maximum age for D_2 folding of the Oxford Lake sedimentary subgroup on Little Stull Lake is 2713 ± 5 Ma.

A number of lines of evidence are consistent with deposition of the

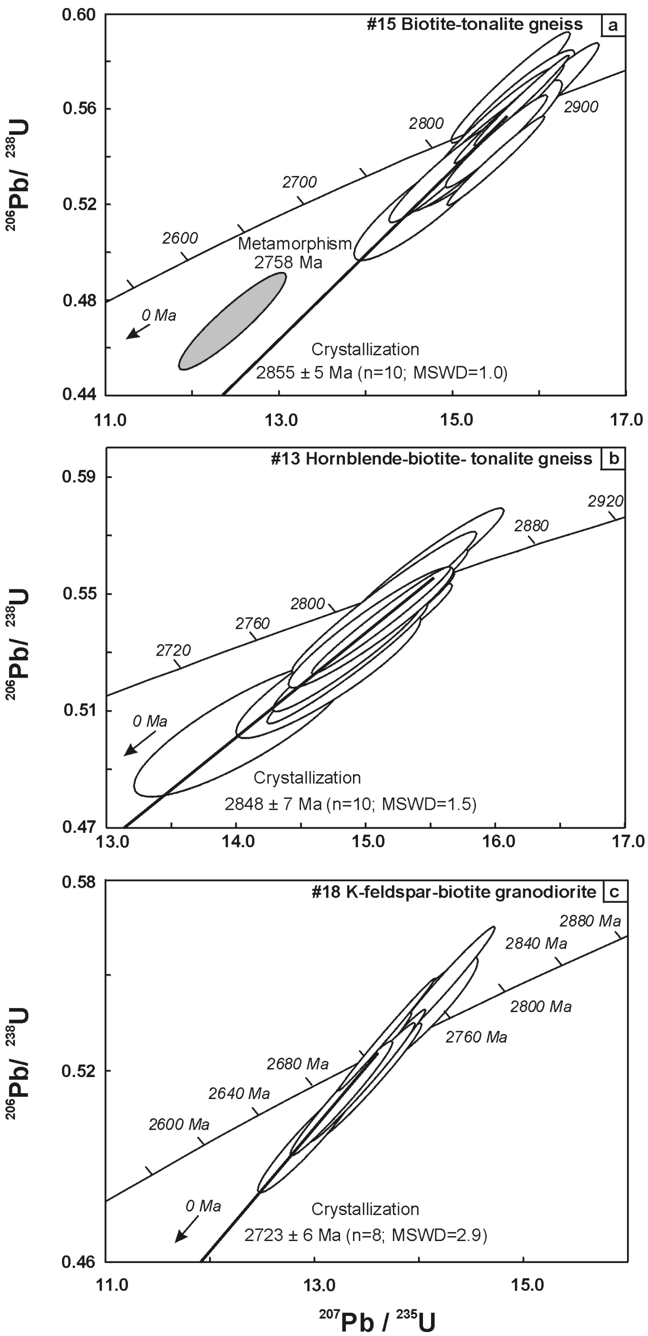

Figure GS-21-6: U-Pb concordia diagram of SHRIMP zircon data from plutonic rocks in the Munro Lake terrane. Sample locations are shown on Figure GS-21-1 (UTM coordinates in text). In all three diagrams, the crystallization age is given for regression through spot analyses (number of spots = n) that is forced through a zero-age intercept (MSWD is mean standard weighted deviation of regression). Filled (grey) ellipse in (a) is a single $^{207}Pb/^{206}Pb$ age determination on a metamorphic overgrowth in biotite tonalite gneiss.

sedimentary subgroup after emplacement of the 2710 ± 6 Ma Rorke Lake pluton. Mesoarchean detrital zircons in arkose (ca. 2.9 Ga) and low ϵ_{Nd} values in trachybasalt (-0.9) that underlies the conglomerate both indicate proximity of older continental crust, at less than 2713 ±5 Ma. This crust was not present when the 2710 ± 6 Ma Rorke Lake pluton (ϵ_{Nd} = +1.1) and earlier magmas were emplaced in the belt. Underthrusting of Mesoarchean crust beneath the Stull Lake belt after 2710 Ma could account for the contaminated nature of the high-K volcanic rocks, the change from marine to fluvial depositional setting, and the presence of previously deformed plutonic clasts in conglomerate of the Oxford Lake sedimentary subgroup.

Northern Superior superterrane

Three plutonic rocks from the Northern Superior superterrane that were dated using the SHRIMP show evidence of zircon inheritance and younger metamorphic events (Fig. GS-21-1, -4).

A sample of biotite monzogranite from northwest of Yelling Lake (sample 1; UTM 15, 569300E, 6090850N) has a complex geological history preserved in the zircon. Fifteen analyses of optically zoned interiors of zircon grains give a U-Pb crystallization age of 2846 ± 5 Ma (Fig. GS-21-1, -8a). A single, possible inherited core has a $^{207}Pb/^{206}Pb$ age of 2872 Ma. This rock has a Nd model age of 3.57 Ga (initial ϵ_{Nd} value of -6.2) and must have been derived by partial melting of Paleoarchean crust. Although Paleoarchean zircons were not observed in this sample, the tonalite gneiss to the south (*see* next paragraph) does contain inherited components of Paleoarchean age. Some of the grains have distinctive, thin, discontinuous, and unzoned overgrowths that have uniformly low Th/U values of approximately 0.038, characteristic of metamorphic zircon. Three of these overgrowths have $^{207}Pb/^{206}Pb$ ages in the range 2760 to 2717 Ma and give a minimum age of metamorphism of ca. 2717 Ma.

A biotite tonalite gneiss at the northern tip of Yelling Lake (sample 2; UTM 15, 576200E, 6085300N), which is cut by 2722 Ma granodiorite to the south, contains a complex history of zircon inheritance and metamorphic overgrowths for which SHRIMP dating is perfectly suited (Fig. GS-21-1, -8b). Zircons from this rock contain an abundance of inherited cores mantled by thick, optically zoned overgrowths and, in some cases, thin, unzoned, discontinuous rims. Nine analyses of zoned mantles give a U-Pb age of 2814 ± 4 Ma, interpreted to be the crystallization age of the igneous protolith. The $^{207}Pb/^{206}Pb$ ages of inherited cores range from 3572 to 3209 Ma. Two analyses of thin, unzoned rims give $^{207}Pb/^{206}Pb$ ages of 2744 and 2741 Ma. These rims are interpreted to represent metamorphic zircon growth, with a minimum age of 2741 Ma. The tonalite gneiss has a Nd model age of 3.27 Ga (initial ϵ_{Nd} value of -5.30). Both the direct evidence for zircon inheritance and the Nd isotopic data clearly indicate an ancient crustal source of early Mesoarchean to Paleoarchean age for this gneiss.

There is no evidence that Paleoarchean crust was implicated in either the magmatic source region or the sediment source in the adjacent Oxford Lake–Stull Lake terrane or terranes to the south, prior to deposition of the Oxford Lake sedimentary subgroup after ca. 2.71 Ga. At Gods Lake to the southwest, 3.6 Ga detrital zircons are found in less than 2711 Ma Oxford Lake sedimentary rocks (Corkery et al., GS-22, this volume) and 3.5 Ga detrital zircons are found in the less than 2709 Ma Cross Lake Group to the west (Corkery et al., 1992). The Northern Superior superterrane (Skulski et al., 1999) is interpreted to include the crust north of the North Kenyon Fault and to extend northwestward to the Assean Lake Block, where 3.54 Ga tonalite gneiss occurs within a crustal domain containing widespread Nd model ages of greater than 3.5 Ga (Böhm et al., 2000).

Zircons from a sample of a hornblende–biotite–K-feldspar granodiorite sanukitoid pluton east of Yelling Lake (sample 4; UTM 15, 595700E, 6077700N) were dated with the SHRIMP (Fig. GS-21-1, -8c). Eleven analyses of zoned grains, which either lack inherited cores or represent zoned mantles on cores, give a U-Pb age of 2714 ± 8 Ma, interpreted as the crystallization age of the pluton. Inherited zircons in this rock have $^{207}Pb/^{206}Pb$ ages ranging from 2813 to 2720 Ma. The Nd model age of this pluton is 3.06 Ga (initial ϵ_{Nd} value of -1.71) and, together with the zircon data, reflects recycling of Mesoarchean or older crust in its magmatic source region.

The absence of metamorphic zircon overgrowths in the sanukitoid pluton is interpreted to indicate that metamorphism in the Northern

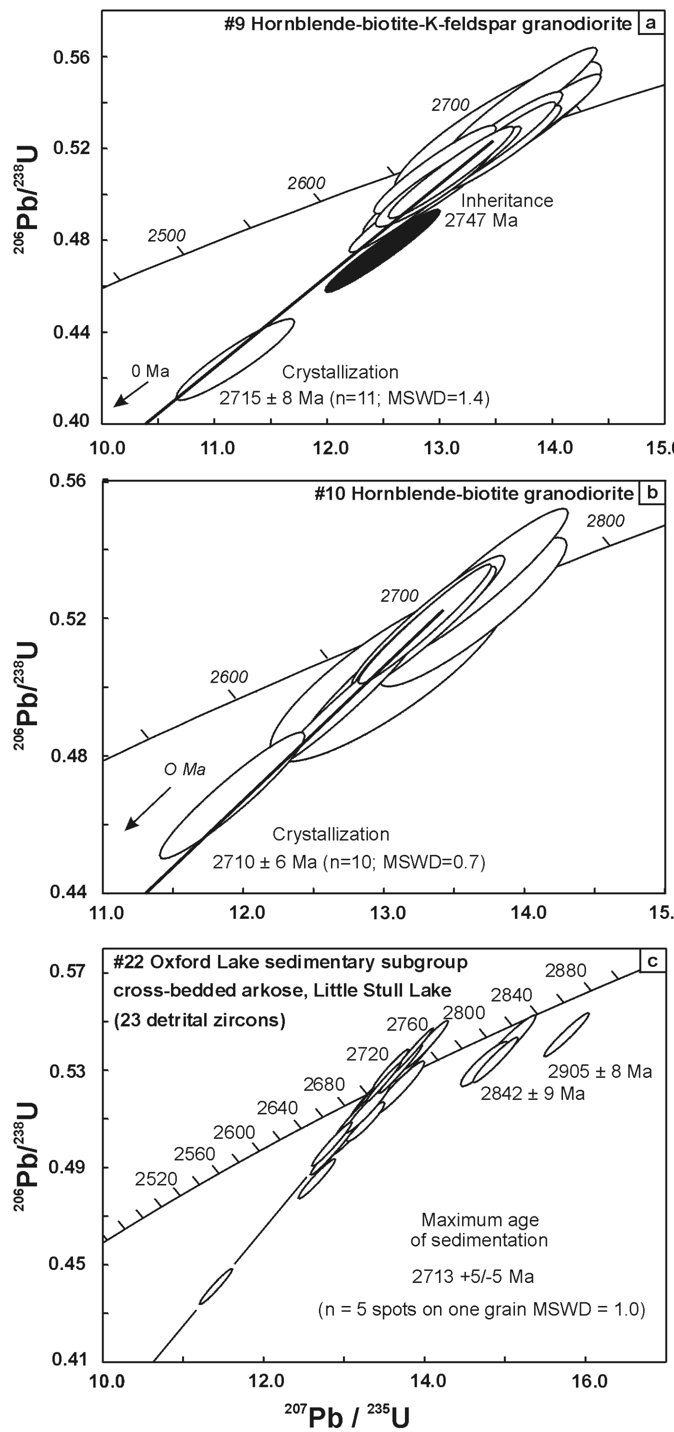

Figure GS-21-7: U-Pb concordia diagram of SHRIMP U-Pb zircon data from plutonic and sedimentary rocks in the Oxford Lake–Stull Lake terrane. Sample locations are shown on Figures GS-21-1 and -3 (UTM coordinates in text). In (a) and (b), the crystallization age is given for a regression forced through the origin, and the number of analyses and MSWD are given in parentheses. Filled (black) ellipse in (a) is a single $^{207}Pb/^{206}Pb$ age determination on an inherited zircon core. Twenty-three detrital zircon analyses are shown in (c). Five spots on the youngest grain were regressed (free regression) to yield a maximum age of sedimentation.

Superior superterrane can be bracketed between ca. 2.74 Ga (age of overgrowths in tonalite gneiss) and 2.71 Ga (age of sanukitoid). As mentioned earlier, the North Kenyon Fault cuts a 2722 Ma granodiorite at Yelling Lake, and movement along this fault could have been related closely in time with regional metamorphism of the Northern Superior superterrane.

TECTONIC SYNTHESIS

The data presented here provide important constraints for the tectonic evolution of the northwestern Superior Province.

Quartzite, marble and komatiite in the Sachigo Lake–Ponask Lake greenstone belt, although undated, were likely deposited after 2.865 Ga, the age of detrital zircons in basal conglomerate at Ponask Lake. These sedimentary rocks are interpreted to represent the vestiges of a northern platform sequence on the ca. 3 Ga North Caribou protocraton. Evidence of this 3 Ga protocraton is found in the older Nd model ages of plutonic rocks in the Munro Lake terrane.

Depleted submarine basalt of the Hayes River Group either represents slivers of exotic ocean-floor crust or continental margin obducted during D_1 deformation at Edmund Lake, or juvenile continental crust telescoped prior to 2734 Ma, the age of the crosscutting tonalite. The presence of both depleted basalt and possible contaminated arc basalt in the Hayes River Group on Kistigan lake may be an indication that these different volcanic rocks formed on the thin margin of the North Caribou protocontinent. A pre–Oxford Lake volcanic subgroup angular unconformity at Knee Lake (Syme et al., 1998), and occurrence of D_1 fabrics that is restricted to Hayes River basalt at Edmund Lake, may be evidence that this ca. 2.83 Ga continental-margin crust was tectonically shortened before Oxford Lake time (>2.73 Ga). Deposition of Oxford Lake volcanic and sedimentary rocks in a marine setting suggests that the earlier tectonic shortening was an accretionary event, and not the closure of an ocean basin.

Oxford Lake volcanism, at 2.73 to 2.72 Ga, is widespread within the Oxford Lake–Stull Lake terrane and extends as far west as Cross Lake. This calc-alkaline volcanic episode is interpreted to reflect the development of a continental-margin arc prior to collision of the Northern Superior superterrane. The transition from juvenile magmatic sources at 2.71 Ga, when the Rorke Lake pluton was emplaced in the Stull Lake belt, to crustally contaminated sources for continental alkaline volcanism at less than 2.71 Ga, when the Oxford Lake sedimentary subgroup was deposited, is interpreted to record the thrusting of the North Caribou craton beneath the Stull Lake–Edmund Lake belt. The driving force for this deformation was the oblique collision and regional metamorphism of the Northern Superior superterrane at ca. 2.72 to 2.71 Ga that is recorded in D_{2-4} structures. Erosion of both uplifted Northern Superior superterrane crust and the telescoped northern North Caribou margin provided sedimentary detritus for possible transtensional molasse basins along dextral strike-slip faults such as the WSWSZ, where mildly alkaline volcanic rocks erupted.

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REFERENCES

Böhm, Ch.O., Heaman, L.M., Creaser, R.A. and Corkery, M.T. 2000: Discovery of pre-3.5 Ga exotic crust at the northwestern Superior Province margin, Manitoba; Geology, v. 28, p.75–78.

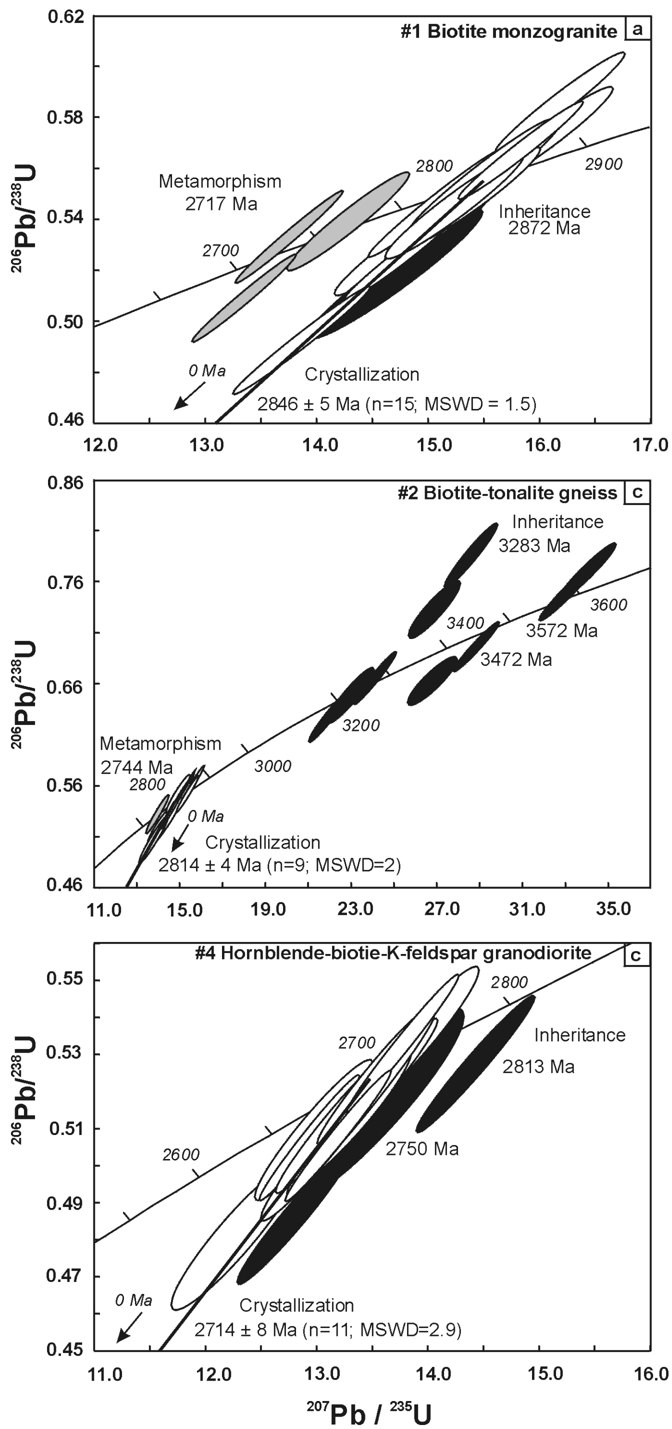

Figure GS-21-8: U-Pb concordia diagram of SHRIMP U-Pb zircon data from plutonic rocks in the Northern Superior superterrane. Sample locations are shown on Figure GS-21-1 (UTM coordinates in text). In all three diagrams, the crystallization age is given for a regression forced through the origin, and the number of analyses (open ellipse) and MSWD are given in parentheses. Filled (black) ellipses in all three diagrams are inherited zircon cores with selected $^{207}Pb/^{206}Pb$ ages. Filled (grey) ellipses in (a) and (b) are $^{207}Pb/^{206}Pb$ ages of metamorphic zircon overgrowths.

Corkery, M.T. 1996: Geology of the Edmund Lake area (53K/11NE); *in* Report of Activities 1996, Manitoba Energy and Mines, Geological Services, p. 11–13.

Corkery, M.T. and Skulski, T. 1998: Geology of the Little Stull Lake Area (part of NTS 53K/10 and 5); *in* Report of Activities 1998, Manitoba Energy and Mines, Geological Services, p. 111–118.

Corkery, M.T., Davis, D.W. and Lenton, P.G. 1992: Geochronological constraints on the development of the Cross Lake greenstone belt, northwest Superior Province, Manitoba; Canadian Journal of Earth Sciences, v. 29, no. 10, p. 2171–2185.

Corkery, M.T. and Heaman, L.M. 1998: Geology of the Edmund Lake area (NTS 53K/10 11NW); *in* Report of Activities 1997, Manitoba Energy and Mines, Geological Services, p. 103–110.

Corkery, M.T., Lin, S., Bailes, A.H. and Syme, E.C. 1999: Geological investigations in the Gods Lake Narrows area (parts of NTS 53L/9 and 53L/10); *in* Report of Activities 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 76–80.

Corkery, M.T., Skulski, T. and Whalen, J.A. 1997: Geology of the Little Stull Lake area (part of NTS 53K/10); *in* Report of Activities 1997, Manitoba Energy and Mines, Geological Services, p. 13–17.

DePaolo, D.J. 1981: Crustal growth and mantle evolution: inferences from models of element transport and Nd and Sr isotopes; Geochimica et Cosmochimica Acta, v. 44, p. 1185–1196.

Jiang, D. and Corkery, M.T. 1998: A preliminary structural analysis of the Edmund Lake–Little Stull Lake area, northwestern Superior Province, Manitoba; *in* Report of Activities 1998, Manitoba Energy and Mines, Geological Services, p. 119–126.

Osmani, I.A. and Stott, G.M. 1988: Regional scale shear zones in Sachigo Subprovince and their economic significance; *in* Summary of Field Work and Other Activities 1988; Ontario Geological Survey, Miscellaneous Paper 141, p. 53–67.

Parmenter, A.C., Lin, S. and Corkery, M.T. 1999: Structural study in the southeastern part of the Cross Lake greenstone belt, northwestern Superior Province, Manitoba; *in* Report of Activities 1999, Manitoba Industry, Trade and Mines, Geological Services, p. 81–83.

Skulski, T., Percival, J.A., Sanborn-Barrie, M., Whalen, J.B. and Stern, R.A. 1999: Archean crustal evolution in the northern Superior Province; *in* Tectonic and Magmatic Processes in Continental Growth: a Pan-LITHOPROBE Perspective, (ed.) J.A. Percival; LITHOPROBE Secretariat, University of British Columbia, LITHOPROBE Report No. 75.

Skulski, T., Percival, J.A. and Stern, R.A. 1996: Archean crustal evolution in the central Minto block, northern Quebec; *in* Radiogenic and Isotopic studies: Report 9; Geological Survey of Canada, Current Research 1995-F, p. 17–32.

Stern, R.A. 1997: The GSC sensitive high-resolution ion microprobe (SHRIMP): analytical techniques of zircon U-Th-Pb age determinations and performance evaluation; *in* Radiogenic and Isotopic studies: Report 10; Geological Survey of Canada, Current Research 1997-F, p. 1–32.

Stern, R.A. and Hanson, G.N. 1991: Archean high-Mg granodiorite: a derivative of light rare earth element-enriched monzonite of mantle origin; Journal of Petrology, v. 32, p. 201–238.

Stone, D. and Halle, J. 1997: Geology of the Sachigo, Stull and Yelling Lakes area: an overview; *in* Summary of Field Work and Other Activities 1997; Ontario Geological Survey, Miscellaneous Paper 168, p.67–71.

Stone, D. and Pufahl, P. 1995: Geology of the Stull Lake area; northern Superior Province, Ontario; *in* Summary of Field Work and Other Activities 1995; Ontario Geological Survey, Miscellaneous Paper 164, p. 48–51.

Stone, D., Halle, J. and Lange, M. 1996: Geology of the Ponask–Sachigo Lakes area, northern Superior Province, Ontario; *in* Summary of Field Work and Other Activities 1996; Ontario Geological Survey, Miscellaneous Paper 166, p. 57–59.

Stone, D., Halle, J. and Lange, M. 1999b: Geology of the Sherman River and Withers Lake areas, northern Superior Province, Ontario; *in* Summary of Field Work and Other Activities 1999; Ontario Geological Survey, Open File Report 6000, p. 22-1–22-7.

Stone, D., Halle, J., Lange, M. and Chaloux, E. 1999a: Geology of the Ellard Lake–Pasquatchai River and Stull Lake areas; northern Superior Province, Ontario; *in* Summary of Field Work and Other Activities 1998; Ontario Geological Survey, Miscellaneous Paper 169, p. 136–142.

Syme, E.C., Corkery, M.T., Bailes, A.H., Lin, S., Cameron, H.D.M. and Prouse, D. 1997: Geological investigations in the Knee Lake area, northwestern Superior Province (parts of 53L/15 and 53L/14); *in* Report of Activities 1997, Manitoba Energy and Mines, Geological Services, p. 37–46.

Syme, E.C., Corkery, M.T., Lin, S., Skulski, T. and Jiang, D. 1998: Geological investigations in the Knee Lake area, northern Superior Province (parts of 53L/15 and 53M/2); *in* Report of Activities, 1998, Manitoba Energy and Mines, Geological Services, p. 88–95.

Thurston, P.C., Osmani, I.A. and Stone, D. 1991: Northwestern Superior Province: review and terrane analysis; Chapter 5 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Pt. 1, p. 81–144.