GS-9

Thompson Nickel Belt–type units in the northeastern Kisseynew Domain, Manitoba (parts of NTS 63O)

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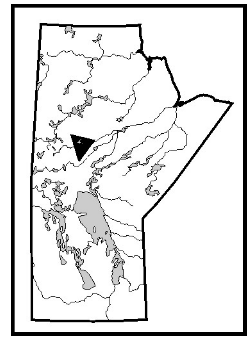

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Summary

Remapping a corridor from the Thompson Nickel Belt (TNB) 60 km west to Threepoint Lake (south of Nelson House) and a preliminary interpretation of geochemistry and Nd isotope data provide new evidence for an Archean age of crystallization and/or mantle extraction of biotite granulite facies orthogneiss in the northeastern part of the Kisseynew Domain. The gneiss occurs in local structural culminations mantled by, and probably interleaved with, heterogeneous paragneiss that may overlie it unconformably. A composite stratigraphic section through the narrow belts of this paragneiss comprises basal quartzite (containing only Archean detrital zircons) and minor calcsilicate gneiss, overlain by garnet-biotite gneiss and aeromagnetically prominent sulphide-facies iron formation. The succession has distinct similarities to the lower half of the cover rocks (Ospwagan Group) on the Archean basement in the TNB, but also some problematic differences. These narrow units are in fault contact with widespread juvenile Paleoproterozoic migmatite (Burntwood Group) derived from volcanic-arc sedimentary rocks. A preliminary interpretation suggests that a large region, which seems to be structurally underlain by these rocks, may be a major exploration frontier for Thompson-type nickel deposits. This assumes that the correlation of these rocks with the Ospwagan Group is confirmed by more rigorous examination, including planned analytical work and further mapping.

Introduction

A new aeromagnetic survey (Coyle and Kiss, 2006) and a geological mapping project (Percival et al., GS-8, this volume) were started west of the Thompson Nickel Belt (TNB) as a result of several recent observations. The recent findings include granite that is highly contaminated with Archean crust (Zwanzig et al., 2003), granulite-facies orthogneiss believed to be Archean basement, and supracrustal rocks with exclusively Archean detrital zircons (Percival et al., 2004, 2005). The project extends over a triangular area from Tullibee Lake in the south, along Highway 391 in the north and west to Threepoint Lake, more than 60 km west of the TNB. It covers much of the northeastern part of the Kisseynew Domain (KD) in the internal zone of Trans-Hudson Orogen (Figure GS-9-1). The general region is marked by a high-gravity anomaly (Viljoen et al., 1999)

The area, which was last mapped between 1971 and 1973 (Baldwin et al., 1979; Frohlinger and Kendrick, 1979; Kendrick, 1979a–c; Kendrick et al., 1979), has been considered until recently to be underlain solely by juvenile Paleoproterozoic greywacke-mudstone migmatite (Burntwood Group), local meta-arkose (Sickle Group) and granitoid rocks largely derived by partial melting of the metasedimentary rocks (e.g., White, 2005). A heterogeneous unit (mapped as unit 5 by Baldwin et al., 1979), containing amphibolite and paragneiss that includes sulphide-facies iron formation, grades into arkosic quartzite that was assigned to the Sickle Group. The quartzite, however, contains only Archean detrital zircons (Percival et al., 2004, 2005) that are uncommon in the Sickle Group (and its deep-marine facies, the Burntwood Group) because these groups have a provenance in the Paleoproterozoic arc terrane to the north. The quartzite and associated paragneiss appear to form an unrelated heterogeneous succession that can be compared to units in the TNB, which they resemble. The amphibolite appears to be largely intrusive. The small available exposures of these rocks were examined in detail and sampled to provide petrographic, geochemical, isotopic and structural data for the comparison.

The project area has less than 1% outcrop in the south and east, commonly separated by muskeg and low bush. Thus, the new mapping relies heavily on the recent aeromagnetic survey and on the few scattered clean outcrops along shorelines. Early results show that the Burntwood Group was mapped reliably, although the granitoid rocks are not sufficiently peraluminous to be S-type as suggested (but can be assigned a proper origin from archived samples). Moreover, 'unit 5' and the quartzite need to be remapped and resampled. To that end, an area measuring 6 km by 8 km was explored at Tullibee Lake (parts of NTS 63O2 and 7) and a 12 km wide corridor was remapped across the Wuskwatim–Threepoint lakes area (parts of NTS 63O10 and 11). Reconnaissance mapping was done along Highway 391, at Kawaweyak Lake (parts of NTS 63O7 and 8) and

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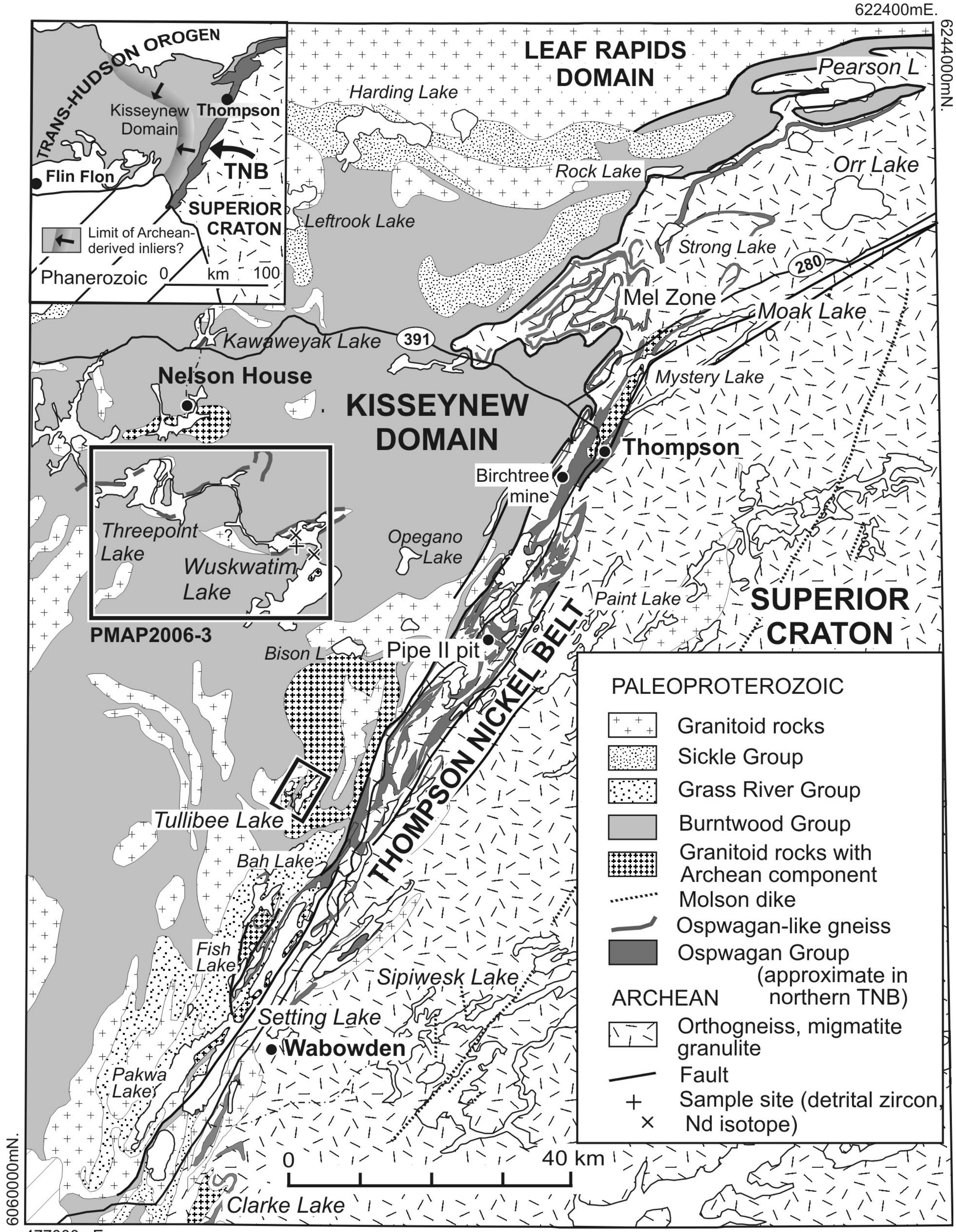

Figure GS-9-1: *Geology of the Thompson Nickel Belt and northeastern Kisseynew Domain, showing areas visited in 2006 with narrow belts of Ospwagan-like gneiss and sample sites for sensitive high-resolution ion microprobe (SHRIMP) detrital zircon ages and Nd isotope and geochemical data; large box shows area covered by Preliminary Map PMAP2006-3 (Zwanzig et al., 2006); inset map shows the limit of an area in the northeastern Kisseynew Domain that may contain northern Superior–type Archean crust, indicated also by highly contaminated granite.*

Notigi Lake (63O16). A day of helicopter work covered an area east and north of Tullibee Lake and at Opegano Lake.

The purpose of this new project is to compare the heterogeneous gneiss units and other rocks marked by magnetic anomalies (previously unit 5 and Sickle Group) along the Wuskwatim Lake corridor to similar rocks with proven mineral potential in the TNB. This work is designed to support and promote nickel exploration and possible gold exploration in the Thompson–Nelson House–Wabowden region. The general geology, structure and a preliminary field interpretation of the area are in a companion report (Percival et al., GS-8, this volume). Preliminary findings regarding metamorphic mineral assemblages, textures and relationships to structure and tectonostratigraphy are given in Growdon et al. (GS-10, this volume).

This report attempts to organize the various gneissic units that do not belong to the Burntwood Group greywacke-derived migmatite into a coherent tectonostratigraphy. The focus is on paragneiss units that resemble the Ospwagan Group, which hosts the nickel deposits in the TNB. Preliminary results are derived from petrography, geochemistry, Nd isotope geology and a review of detrital zircon geochronology. Time and budget constraints have limited this work to modal analysis and geochemistry of 11 samples, Nd isotope work on 7 new samples, and zircon geochronology replotted from one sample. Nevertheless, these limited data are tied into a rich database gathered over the past 8 years in the TNB, in the recently explored northern TNB extension and from some anomalous rocks on the margins of the TNB.

Preliminary tectonostratigraphy

Poor outcrop make an aeromagnetic interpretation critical in the northeastern KD. Therefore the regional distribution of units, which is the basis for a tectonostratigraphic interpretation, relies on the magnetic pattern and on ground truthing that was carried out during the 2006 field work. The magnetic units occur within narrow belts of paragneiss, less than 750 m wide and commonly exposed along shorelines parallel to strike, where full cross-sections are not available. Therefore, the unit-scale layering had to be inferred from numerous short shoreline sections, with structural interpretations being used to link them in a composite section.

A relatively good composite section (Figure GS-9-2) was assembled where the Burntwood River is widened by flooding near its exit into Wuskwatim Lake (Zwanzig et al., 2006). A short section that is oblique to the northwest shore of Wuskwatim Lake provided additional samples along 200 m of discontinuous shoreline exposure. Another composite section was assembled on Threepoint Lake.

Local sections of nickel belt-like paragneiss

The best composite sedimentary section is intermittently exposed on small islands and along the south shore of the flood-widened Burntwood River northwest of Wuskwatim Lake (Percival et al., GS-8, this volume, Figure GS-8-4a). Orthopyroxene-biotite-grade paragneiss mantles the southeastern contact of a belt of granulitic multicomponent orthogneiss that is 250 to 600 m wide. The steeply dipping southeastern contact is tentatively interpreted as an unconformity, and the paragneiss is interpreted to face southeast and to be structurally overlain by the Burntwood Group. The succession is 500 to 600 m wide, with arkosic quartzite adjoining the orthogneiss and a prominent linear magnetic anomaly marking the upper part of the section. The top is confined to low ground and features only locally exposed sulphidic schist and gneiss.

This sequence is followed by bedded quartz-rich gneiss with calcsilicate minerals in a section that may be 150 m thick. About 70 m to the southeast is garnet-biotite schist that is interpreted to be Burntwood Group greywacke gneiss. Near the sulphidic paragneiss where the river enters the lake, a protomylonite is interpreted to have been Burntwood Group rocks that were deformed in a major early fault zone that was subsequently reactivated in a late-kinematic shear zone.

A similar paragneiss section is exposed on the north side of the belt of orthogneiss on the south shore of the flooded area, 4 to 5.5 km west of the river exit. The shoreline exposes mainly arkosic quartzite, interpreted as the base of a north-facing succession. The quartzite is a maximum of 100 m thick, but much thinner at the west end of the belt where mylonitic quartzite is interlayered with sheared garnet-biotite gneiss. Minor chert and lean sulphide-facies iron formation are exposed within 100 m of the orthogneiss. The entire belt of paragneiss is only 400 m wide at this location despite presumed large-scale folding (Percival et al., GS-8, this volume Figure GS-8-4a). At the east end of the belt, sulphide-facies iron formation occurs with garnet-biotite gneiss 250 m above (north of) the quartzite. This locality marks the west end of a strong linear magnetic anomaly that extends more than 10 km northeast and is interpreted to be caused by thicker unexposed iron formation (Zwanzig et al., 2006). The iron formation–bearing section appears to be underlain at the shore to the south by a thin unit of diopside calcsilicate gneiss.

Outcrops on a small island at the west end of the widened river area indicate that a second belt of orthogneiss lies northwest of the paragneiss section. Orthogneiss exposed on the south and west shores of the island and quartzite exposed on the northeast corner suggest that another narrow belt of heterogeneous paragneiss occurs to the northwest (above the assumed unconformity). A strong linear magnetic anomaly, about 7.5 km long, indicates the

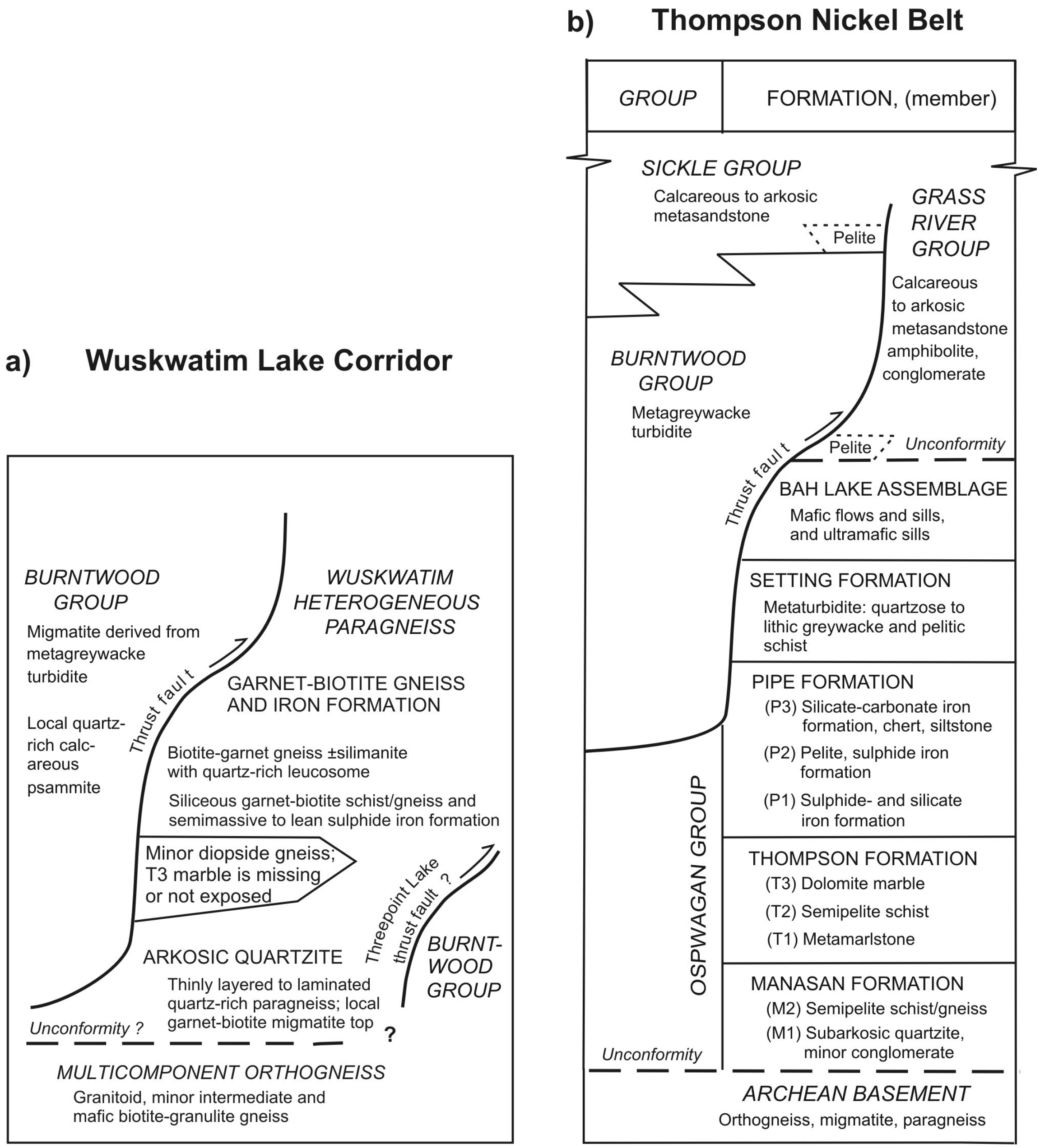

Figure GS-9-2: *Simplified composite tectonostratigraphic section in the Wuskwatim Lake corridor, northeastern Kisseynew Domain, compared to the type section of the Ospwagan Group in the Thompson Nickel Belt.*

presence of iron formation. A third linear anomaly over areas of flooding and drift 1 to 2 km to the northwest may represent a similar unexposed section of paragneiss.

The paragneiss and iron formation also occur on the northwest shore of Wuskwatim Lake. Bedding strikes locally at high angles to the northeast-trending shoreline, but strike is variable, suggesting that the section is near the hinge of a large fold. Highly pelitic gneiss north of sulphide-facies iron formation is followed by weakly calcareous psammitic gneiss and typical Burntwood Group migmatite. This section is therefore interpreted to be the same as the upper part of the main southeast-facing sequence near the Burntwood River exit, but lying in the northwest-facing limb of a synform that separates these localities. The magnetic anomaly of this succession extends for 10 km in Wuskwatim Lake along the northwest shore. It is separated from the nearest exposure of multicomponent orthogneiss by a calculated true thickness of 850 m of unexposed rock with the magnetic signature of the orthogneiss, which suggests only a thin sequence of paragneiss along the shore.

A section of paragneiss that also resembles the Ospwagan Group in the TNB was traced intermittently for 7.5 km in small exposures along the northwest shore of Threepoint Lake at the mouth of the Rat River and on an island in the lake. This succession, which is underlain and overlain by the Burntwood Group in the west, is overturned and faces the pluton that intrudes it in the main part of the lake (Zwanzig et al., 2006).

Multicomponent orthogneiss

The orthogneiss has a tonalitic to granodioritic and less commonly granitic composition, with minor layers and enclaves of mafic granulite and amphibolite boudins recognizable as mafic dikes. Orthopyroxene-bearing felsic phases weather light brown and range from uniform to gneissic, some with thin concentrations of biotite in the foliation. The moderately to strongly developed foliation is evidence of high strain. The gneiss contains local isoclinal, intrafolial folds and is generally intruded by sheets of pegmatite that locally cut its gneissic layering (Figure GS-9-3a). These features are all similar to TNB basement gneiss. Therefore, the contact with the sedimentary rocks is interpreted as an unconformity. If so, protracted deformation and metamorphism have likely transposed any angular discordance that was present at this unconformity.

Units of orthogneiss consist of assemblages including quartz, plagioclase, finely perthitic microcline, biotite, magnetite, ±clinopyroxene ±orthopyroxene ±garnet ±titanite ±monazite ±zircon and, in mafic to intermediate compositions, ±amphibole. Orthopyroxene crystals are generally only 1 to 2 mm long. They are interpreted as Paleoproterozoic in age, unlike the prominent clusters of grains that are commonly more than 10 mm long in the Archean granulite basement on the southeast side of the TNB. Moreover, unlike the Archean orthopyroxene, they are not generally retrogressed to amphibole as in the basement of the central TNB. Instead, they have thin rims and cracks filled with bastite that make them appear rusty brown on many outcrops.

Arkosic quartzite

Quartzitic paragneiss weathers from almost white to pale brown or buff. It is interpreted to lie unconformably on the multicomponent orthogneiss (Percival et al., GS-8, this volume, Figure GS-8-2d). Where this is interlayered with quartzite, there is strong deformation to obscure the relationship. The unit thickness ranges from less than 1 m to somewhat less than 100 m. The top appears to be interlayered with garnet-biotite migmatite at the base of the pelitic unit. The quartzite is locally cut by concordant or boudinaged mafic to intermediate dikes and widely cut by pegmatite or granite. Arkosic quartzite is massive, or more generally layered at the centimetre scale and laminated at the millimetre scale. This structure is interpreted as highly flattened, transposed bedding (Figure GS-9-3b). Biotite-rich partings are common, and thin interbeds of pelite converted to schist occur especially in the upper part of the unit. These features resemble the Manasan quartzite in the TNB, but the upward gradation into semipelite with abundant sillimanite (M2 member) is not apparent.

Field estimates of quartz content are 60–80%, with the remainder being feldspar, biotite (<10%) ±magnetite ±garnet ±sillimanite/hornblende ±calcite ±various accessory minerals (locally including zircon).

Preliminary detrital zircon results reported in Percival et al. (2005) suggest that the arkosic quartzite from this section contains only or mainly Archean detritus. These results are reviewed later in this paper.

Garnet-biotite gneiss and migmatite

The rocks lying directly on quartzite form only a few small outcrops. They include garnet-biotite migmatite that locally resembles greywacke-derived Burntwood Group paragneiss. A felsic variety is estimated to have about equal parts of quartz and plagioclase, 10 to 15% K-feldspar and up to 15% biotite plus chlorite, with local altered orthopyroxene and minor calcite and epidote. This may be a much-abbreviated upper part of the Manasan Formation (M2), but this is a very unreliable correlation. The unit is generally highly sheared.

Diopside gneiss

A 50 cm thick unit of diopside calcsilicate gneiss, which is interpreted to be sedimentary in origin, occurs within biotite±garnet±orthopyroxene gneiss. The layer is exposed on the north shore of the widened Burntwood River and may be part of a thicker unit underlying the river. It is pale grey-green and comprises mainly clinopyroxene and lesser plagioclase and minor calcite. This unit is of particular interest because similar layers occur in the Thompson Formation, a prominent stratigraphic marker in the Ospwagan Group in the TNB.

Quartzose garnet-biotite gneiss and iron formation

This marker unit forms the upper exposed part of the paragneiss succession in several of the sections. It comprises rusty- to grey–weathering, siliceous and pelitic, garnet-biotite schist and gneiss that contain one to several interbeds of sulphide-facies iron formation. In its rare exposures, the iron formation forms prominent rusty-weathering subunits 1 to 3 m thick (Figure GS-9-3c). They are highly magnetic, with about 30% pyrrhotite±magnetite. An angular boulder of graphitic massive sulphide at one of the magnetic anomalies (Percival et al., GS-8, this volume) is similar to iron formation (P1) at the base of the Pipe Formation in the TNB.

The dark grey to brown, siliceous schist and gneiss that host the iron formation have thin primary layering defined by variations in biotite content. The average garnet content is generally <10% and the grains are

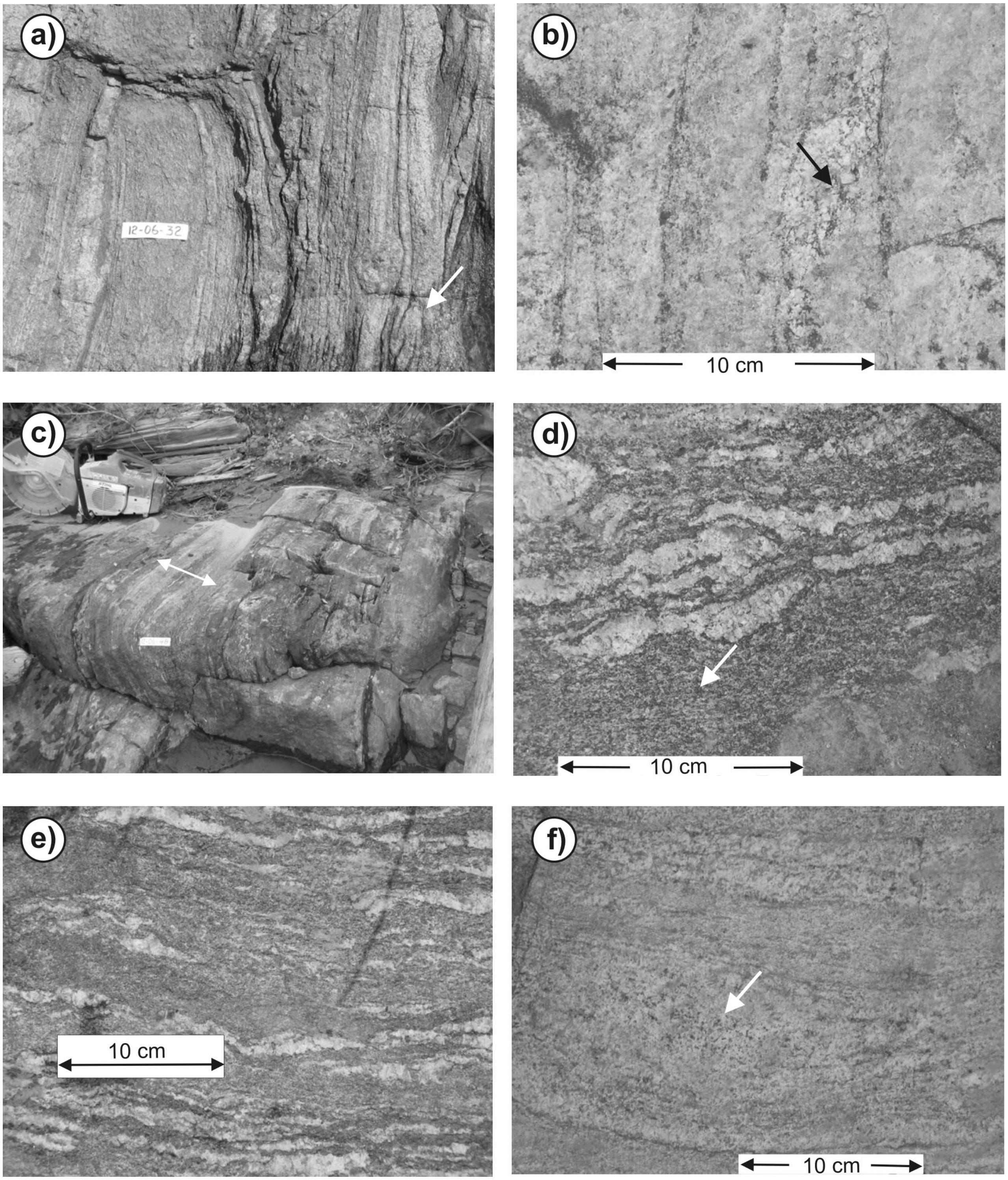

Figure GS-9-3: *Typical units in the Wuskwatim Lake area, northeastern Kisseynew Domain:* ***a)*** *layered multicomponent biotite-granulite gneiss, showing local isoclinal intrafolial folds (arrow); tape is 10 cm long;* ***b)*** *arkosic quartzite with thin biotite-rich partings as remnants of bedding and yielding only Archean detrital zircons; note pegmatite at arrow; c) sulphide-facies iron formation with quartz-rich garnet-biotite gneiss interlayer (arrow);* ***d)*** *quartz-rich veins in biotite-garnet gneiss, similar to photo (e) but formed from Archean detritus; garnets (arrow) are dark;* ***e)*** *Burntwood Group greywacke-mudstone-derived metatexite with quartz-rich leucosome; and* ***f)*** *calcareous quartz-rich metapsammite with lenses (near scale bar) and layers of calcsilicate minerals (top) including calcite.*

<3 mm in diameter in all but some of the iron-rich layers. Sillimanite±muscovite is a prominent component in sparse pelitic beds near the top and bottom of the unit. The rock is locally sulphidic and graphitic. It includes garnet-rich and mafic layers of silicate-facies iron formation that are on the order of 50 cm thick. Other prominent interbeds are very quartz rich and probably derived from impure chert. Veins of leucosome contain mainly quartz in this rock type. Layers or lenses of calcsilicate rock are locally present.

There are metagabbro layers elsewhere in the unit. If the correlation with the lower Pipe formation is valid, this is the most likely stratigraphic level for ultramafic sills and nickel deposits.

Biotite-garnet gneiss

This garnet-rich rock, which is the highest in the exposed section, forms a thin unit structurally overlain by the Burntwood Group. It is a grey-weathering pelitic unit that contains up to 25% garnet porphyroblasts. One locality has a layer with 50% garnet, up to 8 mm in diameter. Otherwise, the rock is generally uniform, with only rare 8 cm beds containing smaller garnets than normal. The rock has 20 to 40% quartz-feldspar leucosome or quartz veins (Figure GS-9-3d).

Burntwood Group

The Burntwood Group is the most widespread unit in the northeastern part of the KD. It forms a monotonous succession of medium grey– to reddish brown–weathering, turbidite-derived greywacke-mudstone migmatite. This unit is typically graphitic and magnetite free with only rare pyrrhotite; as a consequence, it provides a magnetically quiet background in the Wuskwatim Lake corridor. In the field, however, it can be mistaken for units in the heterogeneous paragneiss succession or some units in the Ospwagan Group (Zwanzig and Böhm, 2002).

In the Wuskwatim Lake area, primary bedding has been structurally transposed and metamorphosed into migmatite layering. Remnants of bedding are best defined by garnet size: 2 to 3 mm in the psammitic lower parts of the beds and up to 10 mm (10–20%) in the upper pelitic parts of the beds. The biotite- and garnet-rich metapelite can contain abundant K-feldspar. Granitoid leucosome in the normal stromatic migmatite (metatexite) constitutes 10 to 50% of the rock in lits that have a local maximum thickness of 2 to 50 cm (Figure GS-9-3e). The leucosome in the Wuskwatim Lake area is unusual in that it contains abundant garnet and commonly large cordierite porphyroblasts ±sillimanite ±orthopyroxene ±spinel. Less common diatexite has lost all primary structure during transformation to 60 to 90% coarse crystal–charged partial-melt rock.

Calcareous psammite

Isotopic analyses presented later in this paper show that, adjacent to the heterogeneous paragneiss, the Burntwood Group contains an unusual formation of quartz-rich calcareous psammitic gneiss. This light grey–weathering, highly felsic rock shows remnants of bedding and lamination defined by increased biotite content (Figure GS-9-3f). The unit is about 10 m thick on Wuskwatim Lake, where it occurs between the greywacke migmatite and the unrelated biotite-garnet gneiss. The directly overlying rocks to the northwest are relatively garnet rich and more uniformly pelitic than elsewhere. About 150 m of the same calcarious psammite occur also in the southeast-facing section south of the widened Burntwood River. This thicker unit contains more interbedded garnet-biotite gneiss with quartz-rich leucosome.

Correlation with Ospwagan Group stratigraphy

The lithology of several units in the Wuskwatim Lake corridor resembles that in the lower part of the Ospwagan Group in the TNB (Figure GS-9-2):

- The multicomponent orthogneiss may be equivalent to the TNB basement gneiss (but its age of crystallization has yet to be determined).
- The arkosic quartzite resembles the M1 member of the Manasan Formation and, if the proposed unconformity is confirmed by geochronology, would be the same as the unconformity at the base of the Manasan Formation in the TNB.
- A thin layer of diopside gneiss stratigraphically above the quartzite may represent a calcsilicate layer correlative with part of the Thompson Formation in the TNB.
- The garnet-biotite gneiss and sulphide-facies iron formation and overlying biotite-garnet gneiss are similar to the P1 and P2 members in the Pipe Formation. Garnet is much more abundant and sillimanite is scarce, but this may be a result of the higher metamorphic grade.

The general structural stacking order of units is similar to that in the TNB, with Burntwood overlying the older rocks. In the Wuskwatim paragneiss succession, however, several units are lacking and there may be an extra unit in the Burntwood Group:

- A full equivalent to the Thompson Formation that includes marble is not found in the heterogeneous paragneiss succession on Wuskwatim Lake or the Burntwood River to the north. The only calcareous rock appears to be a thin diopside gneiss layer. A thicker, weakly calcareous unit, which occurs higher in the structural stack, is associated with the allochthonous Burntwood Group. This is a serious problem in the correlation because the calcsilicate and marble are the best marker units in the Ospwagan Group.

Nevertheless, calcsilicate rocks that look similar to the Thompson Formation were found on a reconnaissance into Kawaweyak Lake (Percival et al., GS-8, this volume). These occur adjacent to prominent sulphide-facies iron formation in a presently unknown stratigraphic order. The carbonate is generally low weathering and may simply not be exposed in most areas.

- The prominent M2 member (Pipe Formation pelite) is seen only locally, but this may be due to lack of exposure of this unit, which also weathers recessively.
- The presence of calcareous quartz-rich paragneiss in the Burntwood Group is unusual with respect to the group's regional composition. This unit is possibly part of a different tectonic assemblage.
- The upper part of the section is missing and basement is missing in some areas, but this can be explained by faulting.

Thus, at the current state of understanding, each argument for or against correlation can be countered with an ad hoc explanation.

In order to test the proposed correlation more rigorously, geochemistry and Nd isotope geology are applied. These methods have been used successfully in mapping the northern extent of the TNB (Zwanzig and Böhm, 2002, 2004; Zwanzig et al., work in progress, 2006). Some preliminary results obtained using this technique at Wuskwatim Lake are discussed below.

Geochemistry and isotope geology

Significant differences in the source area of the detritus for the Ospwagan Group and younger arc-related rocks (Burntwood, Grass River and Sickle groups) have provided a useful geochemical distinction between these different assemblages of clastic rocks (Zwanzig et al., work in progress, 2006). They can be distinguished using geochemical diagrams of selected major and trace elements, normalized by the average composition of the most widespread pelitic unit in the TNB, the P2 member of the Pipe Formation. This technique is applied to the heterogeneous paragneiss assemblage at Wuskwatim Lake using data fields from the TNB for comparison.

Routine sampling with sledge hammers was carried out during the mapping and important units were cut by saw on shore outcrops. Samples were crushed in mild steel and given standard analysis using x-ray fluorescence (XRF) for major elements and inductively coupled plasma mass spectrometry (ICP-MS) for trace elements to provide a complete geochemical fingerprint. The work was done to 'standard' precision at Activation Laboratories Ltd. in Ancaster, Ontario, and data are presented in Table GS-9-1, along with existing analyses from the TNB taken from Zwanzig et al. (work in progress, 2006) and D. Peck (pers. comm., 2003).

Fields of existing data from Ospwagan Group sedimentary rocks in the TNB and Burntwood Group paragneiss collected regionally in the KD (Figures GS-9-4a, -4b) are compared to multi-element plots of paragneiss from Wuskwatim Lake (Figure GS-9-4c, -4f). Amphibolite is compared to a primitive-mantle-normalized field of plots from synkinematic dikes and similar amphibolite from the TNB margin and elsewhere in the KD (Figure GS-9-4g).

The plots suggest that parts of the section of heterogeneous high-grade metasedimentary rocks on Wuskwatim Lake share geochemical characteristics with the Ospwagan Group. Other parts of the section may have a volcanic-arc-related provenance with some similarity to the Burntwood Group, rather than the typical Archean craton–derived Ospwagan Group. Particularly indicative of an arc-related provenance are the prominent negative Zr and K anomalies that are typical of all arc assemblages, including those in the Paleoproterozoic Trans-Hudson Orogen and in the Archean Superior Province. The positive slope from the large ion lithophile elements (LILE) to heavy rare earth elements (HREE) of the P2-normalized analyses (Figure GS-9-4c) is inconsistent with provenance from the peneplaned Archean Superior craton that was the source of the Ospwagan Group and produced a flat P2-normalized plot (Zwanzig et al., work in progress, 2006). The higher P_2O_5 contents are also typical of Kisseynew basin compositions (Figure GS-9-4d). The plots resemble light rare earth element– and alkali element–depleted basement orthogneiss and 'anomalous' paragneiss in the northern extension of the TNB (Figure GS-9-4e). A sample of diopside calcsilicate gneiss has the immobile element pattern of more aluminous but otherwise similar rock from the Thompson Formation in the TNB (Figure GS-9-4f). Samples of Thompson diopside calcsilicate that have the same low Al_2O_3 content as the unit northwest of Wuskwatim Lake also have the same low alkali element content and similar low contents of V, Cr and Ni (Table GS-9-1) typical of continent-derived sedimentary rocks. An amphibolite body in the Burntwood Group is similar to synkinematic diabase dikes elsewhere in the KD (Figure GS-9-4g)

Based on bulk chemical characteristics alone, possible alternative sediment sources may include provenance from

1) the Superior craton, which provides a link with the Ospwagan Group, but this is not well expressed;
2) the juvenile internal zone of Trans-Hudson Orogen, which also fed the Burntwood Group;
3) Archean rocks that are known to exist locally in parts of the internal zone, based on the presence of contaminated arc-volcanic rock;
4) older, more depleted Archean basement occurring in the northern extension of the TNB, where it retains much of its arc signature but may have lost Th, U,

Table GS-9-1: Analytical data for rock samples from Wuskwatim Lake in the northeastern Kisseynew Domain and, for comparison, from the Thompson Nickel Belt (Zwanzig et al., work in progress, 2006).

Sample	12-06-31-3	12-06-31-4	12-06-34-1	12-06-43-1	12-06-43-3	12-06-43-5	12-06-43-6	12-06-42-1	PBA04-18	38-88-12	38-88-14	SP-02-02B	98-46
Rock type	Intermediate granulite	Felsic gneiss	Garnet-biotite gneiss	Garnet-biotite gneiss	Psammite + calcite	Biotite-garnet gneiss	Biotite-garnet gneiss	Amphibolite	Calc-silicate	*Diopside gneiss	*Skarn (calc-silicate)	*Skarn + diopside	Mg-rich gabbro dike
Area	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Pipe 2 pit	Pipe 2 pit	Thompson S pit	Minago River
Unit	Orthogneiss		?	Burntwood Gp		Ospwagan-like		Dike?	T?	Thompson Formation			Molson
SiO_2	66.17	68.04	66.89	59.14	76.58	68.55	56.46	49.28	50.00	50.40	55.70	51.22	50.91
Al_2O_3	16.13	15.88	14.56	16.19	9.11	11.40	17.95	12.90	6.00	2.77	4.21	12.65	5.83
Fe_2O_3	3.72	3.21	4.79	12.13	2.77	11.18	12.39	15.12	2.50	3.85	1.84	4.02	7.85
MnO	0.04	0.03	0.06	0.40	0.03	0.15	0.14	0.25	0.05	0.09	0.05	0.08	0.15
MgO	1.99	1.17	2.81	4.00	1.27	3.17	3.89	4.73	14.50	15.20	14.01	10.14	16.87
CaO	3.76	3.03	2.60	2.07	4.91	1.50	2.53	12.11	22.40	23.42	20.28	12.64	17.18
Na_2O	3.62	4.35	2.95	2.59	0.59	0.90	2.87	1.41	0.10	0.21	0.21	0.31	0.59
K_2O	2.64	2.95	4.31	1.82	0.78	1.89	2.18	0.14	0.70	0.40	2.92	5.33	0.12
TiO_2	0.50	0.46	0.53	1.15	0.30	0.99	1.23	2.48	0.51	0.15	0.17	0.50	0.48
P_2O_5	0.17	0.12	0.19	0.08	0.08	0.09	0.05	0.25	0.09	0.23	0.05	0.08	0.03
LOI	1.55	1.13	0.66	-0.34	3.02	0.80	0.08	1.01	2.20	3.59	1.00	2.86	3.92
Total	100.3	100.4	100.3	99.2	99.4	100.6	99.8	99.7	96.9	96.7	99.4	99.8	100.0
V	56	36	59	251	45	194	304	507	34	93	-60	44	251
Cr	40	< 20	130	220	60	160	230	70	33	25	20	44	583
Co	9	6	13	35	5	23	41	42	6			10	71
Ni	40	< 20	70	80	< 20	80	120	50	<10	18	9	<20	241
Cu	50	< 10	10	20	20	30	20	310	13	7	8	<10	315
Zn	40	50	70	120	60	90	120	110	96	216	157	67	35
Ga	21	21	20	22	10	16	24	23	9			16	
Ge	< 1	1	1	2	1	2	3	2				2	
Rb	57	57	122	81	46	73	98	1	48	12	26	111	3
Sr	555	301	250	130	119	60	149	245	58	57	55	105	
Y	9.0	8.0	25.0	26.0	15.0	23.0	28.0	48.0	15.0			19.0	15.3
Zr	205	292	148	138	77	169	107	166	117			167	27
Nb	6.0	6.0	11.0	8.0	3.0	7.0	8.0	11.5	17			8.5	<1
Sb	0.9	1.4	14.5	< 0.5	4.3	3.1	16.1	7.6	-0.2			0.3	
Cs	< 0.5	< 0.5	< 0.5	1.0	< 0.5	1.3	0.9	0.1	0.6			2.1	
Ba	1467	1446	969	481	863	367	339	42	216	85	216	749	19
La	42.70	96.40	42.80	21.60	15.70	23.30	18.30	9.69	22.00			31.43	7.52

Table GS-9-1: Analytical data for rock samples from Wuskwatim Lake in the northeastern Kisseynew Domain and, for comparison, from the Thompson Nickel Belt (Zwanzig et al., work in progress, 2006). *(continued)*

Sample	12-06-31-3	12-06-31-4	12-06-34-1	12-06-43-1	12-06-43-3	12-06-43-5	12-06-43-6	12-06-42-1	PBA04-18	38-88-12	38-88-14	SP-02-02B	98-46
Rock type	Intermediate granulite	Felsic gneiss	Garnet-biotite gneiss	Garnet-biotite gneiss	Psammite + calcite	Biotite-garnet gneiss	Biotite-garnet gneiss	Amphibolite	Calc-silicate	*Diopside gneiss	*Skarn (calc-silicate)	*Skarn + diopside	Mg-rich gabbro dike
Area	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Wuskwatim	Pipe 2 pit	Pipe 2 pit	Thompson S pit	Minago River
Unit	Orthogneiss		?	Burntwood Gp		Ospwagan-like		Dike?	T?			Thompson Formation	Molson
Ce	73.20	172.00	86.50	49.20	30.10	44.70	41.30	26.10	38.00			57.49	19.96
Pr	7.32	17.40	9.49	5.85	4.00	5.22	4.92	4.08	4.50			6.44	3.00
Nd	22.70	52.80	32.20	20.40	14.30	18.30	18.00	20.40	17.00			25.16	15.07
Sm	3.90	7.90	6.40	4.60	3.10	3.90	4.30	6.02	3.00			4.16	4.40
Eu	1.62	1.68	1.15	1.30	1.06	0.94	1.56	2.10	0.53			0.96	1.16
Gd	2.20	4.10	5.30	4.20	2.70	3.70	4.10	7.18	2.50			3.94	3.73
Tb	0.30	0.50	0.80	0.80	0.40	0.70	0.80	1.32	0.36			0.56	0.56
Dy	1.70	1.90	4.70	4.60	2.60	4.00	4.70	8.25	2.20			3.02	2.91
Ho	0.30	0.30	0.90	0.90	0.50	0.80	1.00	1.67	0.45			0.60	0.55
Er	0.90	0.70	2.30	2.70	1.40	2.40	2.90	4.87	1.20			1.79	1.42
Tm	0.13	0.09	0.30	0.41	0.20	0.37	0.44	0.70	0.19			0.28	0.18
Yb	0.80	0.60	1.80	2.70	1.30	2.40	3.10	4.58	1.30			1.70	1.13
Lu	0.12	0.09	0.26	0.43	0.20	0.37	0.49	0.69	0.18			0.25	0.15
Hf	4.80	7.50	4.10	3.70	2.10	4.60	3.00	4.60	3.30			4.62	1.07
Ta	0.20	0.20	0.50	0.50	0.30	0.40	0.40	0.79	1.10			0.83	0.40
Tl	0.30	0.30	0.70	0.30	0.30	0.30	0.50	< 0.05	0.30			0.57	
Pb	21.00	21.00	27.00	12.00	20.00	9.00	11.00	< 5	3.00			5.25	
Th	8.40	36.40	18.50	5.80	3.20	8.60	3.80	0.30	4.90			11.80	0.28
U	0.60	0.80	0.80	1.30	1.40	0.60	0.80	0.23	3.10			1.38	0.20

*** unpublished data for comparison**
Major elements in weight percent, trace elements in ppm.

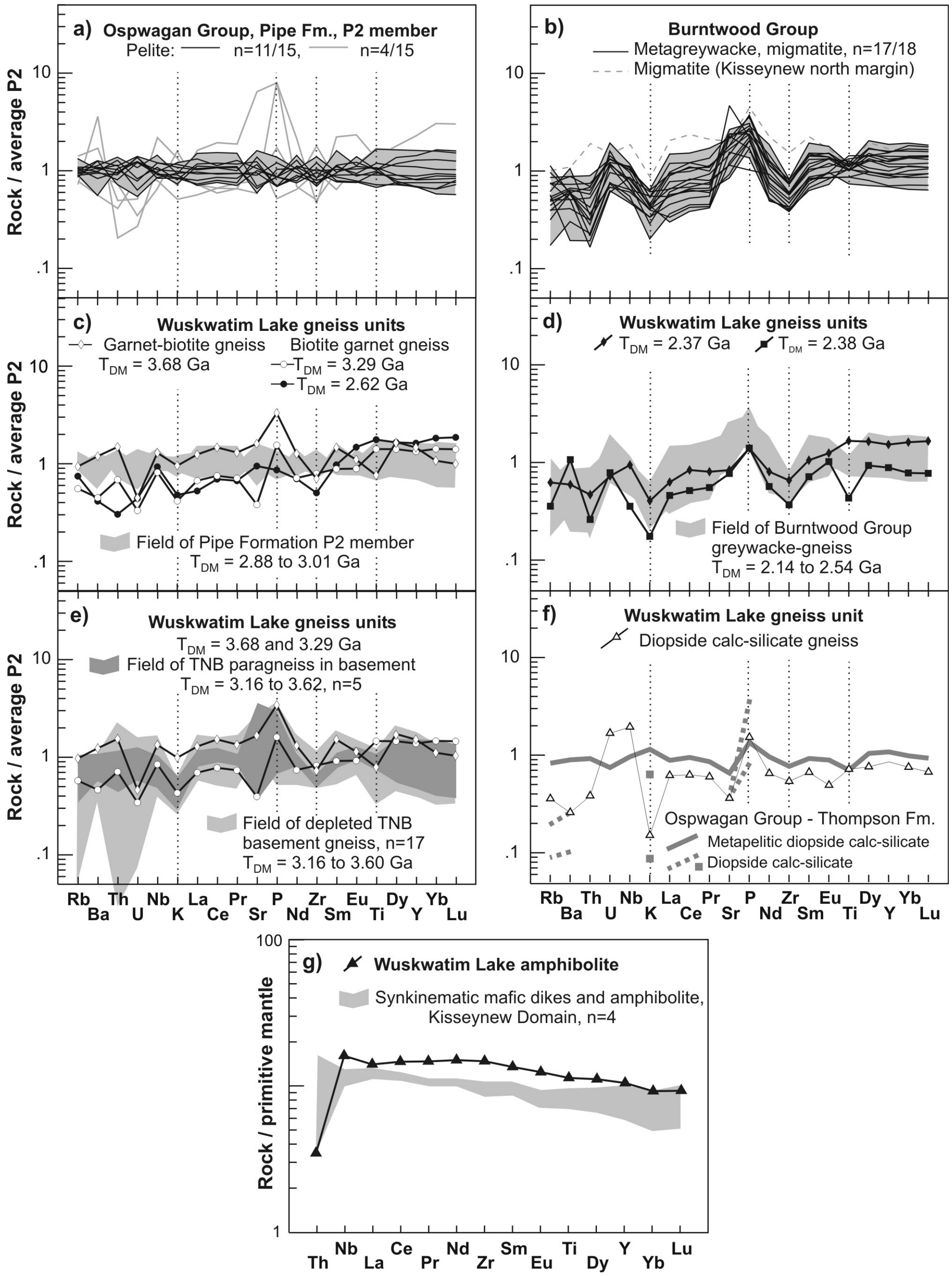

Figure GS-9-4: *Multi-element plots of Ospwagan Group sedimentary rocks from the Thompson Nickel Belt and Burntwood Group from the Kisseynew Domain (plots a, b), Wuskwatim Lake (plots c–f), and primitive-mantle-normalized amphibolite units compared to an analysis from Wuskwatim Lake (plot g):* ***a)*** *the most abundant pelite (P2 member) in the TNB, normalized with the average of the 11 most common of its own compositions (highlighted field) out of a total of 15 analyses (outliers in grey lines);* ***b)*** *Burntwood Group (P2 normalized), showing all but outliers in highlighted field;* ***c)*** *pelitic gneiss from Wuskwatim Lake (P2 normalized) compared to the field of P2;* ***d)*** *garnet-biotite gneiss and calcareous quartz-rich gneiss (P2 normalized) compared to the field of the Burntwood Group;* ***e)*** *pelitic gneiss with high Nd model ages (T_{DM}) from Wuskwatim Lake (P2 normalized) compared to the fields of depleted basement gneiss from the TNB (pale shade) and to 'anomalous' paragneiss from the outer margins of the TNB (dark grey);* ***f)*** *diopside calcsilicate gneiss (P2 normalized) compared to plots of three isolated beds of similar rock in the Thompson Formation, one bed relatively pelitic (solid grey line) and two partly analyzed beds (dotted partial lines) with similar major-element geochemistry to the diopside calcsilicate;* ***g)*** *amphibolite from the analyzed section on Wuskwatim Lake (primitive-mantle normalized) compared to the field of synkinematic diabase sheets and equivalent amphibolite from the TNB margin and elsewhere in the KD.*

and K during deep crustal metamorphic processes (Figure GS-9-4e); and

5) various terranes providing a mixture of detritus.

More information is clearly required to distinguish these possibilities. Some of this has been provided by preliminary Nd isotope data and one recalculated detrital zircon spectrum.

Seven new samples were analyzed for Nd isotope ratios at the University of Alberta geochronology laboratory (Table GS-9-2). The data were used to calculate depleted-mantle model ages of mantle-crust separation (for an explanation of this method, *see* Zwanzig and Böhm, 2002). The Nd model (T_{CHUR}) ages are also given in Figure GS-9-4, where they divide the six sedimentary samples into three groups: those with Mesoarchean model ages, one with a late Neoarchean model age and those with Paleoproterozoic model ages. The youngest set is interpreted as part of the Burntwood Group or as sedimentary rocks with a similar provenance (Figure GS-9-4d), consistent with alternative 2 (above). Surprisingly, this includes the calcareous quartz-rich unit that is not generally part of the Burntwood Group and was initially thought to be correlative with the Thompson Formation.

Rocks with Mesoarchean model ages may have a provenance in Mesoarchean basement rocks on the northern margin of the TNB (Zwanzig and Böhm, 2004) and apparently in deeply exposed crust, such as in the core of the dome containing the Mel zone and near Orr Lake (Figure GS-9-1; Zwanzig and Böhm, 2002, 2004). Such paragneiss units also occur on the periphery of the TNB (near the Birchtree mine and on Paint Lake) and interlayered with the orthogneiss basement (at the Soab mine and east of Strong Lake). These samples are consistent with alternative 4 (above), but do not distinguish between an Archean and a Proterozoic age of deposition (discussed later in the paper). The deeper seated, chemically similar basement also has the same range of Nd model ages as the pelite on Wuskwatim Lake (Figure GS-9-4e). Additional clues to the origin of these rocks are provided by detrital zircon ages (below).

The two samples with young model ages are clearly Proterozoic and consistent with alternative 2 (Figure GS-9-4d). One sample of garnet-biotite gneiss with a model age of 2.62 Ga may have a mixed provenance consistent with alternative 5.

Detrital zircon ages

Preliminary detrital zircon results for an arkosic quartzite from the section on the Burntwood River northwest of Wuskwatim Lake (Geological Survey of Canada lab number 8334) were reported in Percival et al. (2005). Initial results, which indicated exclusively Archean zircons, were based on a very small dataset (n = 5) derived from grains that gave reproducible sensitive high-resolution ion microprobe (SHRIMP) results. Most of the grains analyzed (n = 26) were considered unreliable due to either nonreproducible replicates within individual grains or very significant signal variations during a single analysis, leading to extremely large analytical uncertainties. The difficulty of within-analysis analytical scatter has been overcome by processing the raw data using the SQUID program (Ludwig, 2001), which employs a robust regression method (two-peak interpolations) that is less sensitive to outliers. Using this method, the authors were able to present the entire set of results (Table GS-9-3, Figure GS-9-5).

The difficulty of nonreproducible ages remains: of the nine grains where replicate analyses were carried out, only four have reproducible ages. The $^{207}Pb/^{206}Pb$ ages range from 2325 to 3328 Ma, and a significant number are greater than 5% discordant. If a zircon is concordant or nearly so, its $^{207}Pb/^{206}Pb$ age represents the age of the detritus; however, for discordant analyses, the $^{207}Pb/^{206}Pb$ age can only be considered a minimum. Only zircons less than 5% discordant are plotted on the histogram and shown as the light grey cumulative probability curve (Figure GS-9-5b). Excluded from this dataset are replicate, concordant results; in these instances, the oldest of the replicates was plotted. For reference, the entire dataset, regardless of concordance and including replicate analyses, is shown by the dark grey cumulative probability curve. The concordant results indicate a well-defined mode at 2.7 Ga (n = 6), sporadic values between 2.8 and 3.2 Ga (n = 8) and another mode at 3.3 Ga (n = 7). Despite the fact that they are concordant, it is possible that replicate analyses on the grains in the 2.8 to 3.2 Ga range would not give reproducible ages due to Pb loss. Therefore, these ages should not necessarily be considered a representative age of detritus. The cluster of results at 2.7 Ga and ca. 3.3 Ga would indicate that these are meaningful populations. This expanded dataset supports the conclusion of Percival et al. (2005) that the detrital population of sample 8334 is broadly similar to that of the Ospwagan Group, in that it is exclusively Archean in age. Nevertheless, the prevalence of very ancient zircons in this sample is distinct from other samples. Detrital studies of the Pipe Formation (sample 7798) and the Thompson pelite (sample 8422) have not uncovered any zircons older than 2.95 Ga (Rayner et al., GS-11, this volume). Hamilton and Bleeker (2002) reported only one zircon grain older than 2.85 Ga (3150 Ma). More than half of the concordant zircons from sample 8334 are older than 3.1 Ga and roughly one-third are ca. 3.3 Ga.

Although they are derived from the basal quartzite of the heterogeneous paragneiss succession, these detrital ages are consistent with alternative 4 suggested by the geochemical data.

Table GS-9-2: Sm-Nd analytical data from the Wuskwatim Lake area, northeastern Kisseynew Domain.

Sample	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	Uncert. (±2σ)	T_{DM}	$\sim T_{Ma}$	ε_{NdT}	$^{145}Nd/^{144}Nd$	Rock type	Area	Easting	Northing	Comment
12-06-31-3	3.07	19.72	0.094	0.511	0.000	3.15	1900	-13.3	0.348	Intermediate granulite	Burntwood R.	528822	6164551	Paragneiss
12-06-31-4	6.03	44.27	0.082	0.510	0.000	3.27	2700	-5.5	0.348	Felsic gneiss	Burntwood R.	528822	6164551	Basement(?)
12-06-34-1	5.69	29.07	0.118	0.511	0.000	3.68	1900	-16.0	0.348	Garnet-biot. gneiss+Su	Burntwood R.	526263	6163968	Prob. Pipe Fm.
12-06-43-1	4.00	19.24	0.126	0.512	0.000	2.37	1900	0.7	0.348	Garnet-biotite gneiss	Wuskwatim L.	529097	6161648	Burntwood Gp.
12-06-43-3	2.71	13.53	0.121	0.512	0.000	2.38	1900	0.3	0.348	Calcsilicate	Wuskwatim L.	529097	6161648	Burntwood Gp.(?)
12-06-43-5	2.91	13.27	0.133	0.511	0.000	3.29	1900	-8.6	0.348	Biotite-garnet gneiss	Wuskwatim L.	529092	6161646	Poss. Pipe Fm.
12-06-43-6	3.30	14.71	0.136	0.512	0.000	2.62	1900	-1.1	0.348	Biotite-garnet gneiss	Wuskwatim L.	529097	6161648	Uncertain affinity

Table GS-9-3: Sensitive high-resolution ion microprobe (SHRIMP) U-Pb data for zircon from arkosic quartzite (Geological Survey of Canada lab number 8334).

Spot name	U (ppm)	Th (ppm)	$\frac{Th}{U}$	Pb* (ppm)	^{204}Pb (ppb)	$\frac{^{204}Pb}{^{206}Pb}$	± $\frac{^{204}Pb}{^{206}Pb}$	f(206)^{204}	$\frac{^{208}Pb^*}{^{206}Pb^*}$	± $\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{207}Pb^*}{^{235}U}$
Grains with reproducible replicates:											
8334-57.1	65	107	1.7	45	14	52.24E-	10.64E-	0.009	0.467	0.005	11.910
8334-57.2	86	154	1.8	73	21	51.94E-	71.35E-	0.008	0.527	0.008	13.998
8334-114.1	84	49	0.6	67	1	14.65E-	16.65E-	0.000	0.158	0.002	25.739
8334-114.2	105	84	0.8	87	13	22.44E-	43.65E-	0.003	0.222	0.004	23.737
8334-124.1	110	57	0.5	90	2	24.85E-	30.45E-	0.000	0.144	0.002	25.541
8334-124.2	121	47	0.4	87	3	42.15E-	13.95E-	0.000	0.107	0.002	22.687
8334-103.1	68	122	1.9	50	10	36.14E-	91.05E-	0.006	0.533	0.008	12.698
8334-103.2	80	151	2.0	53	16	52.74E-	12.54E-	0.009	0.552	0.009	11.530
Grains with non-reproducible replicates:											
8334-98.1	362	305	0.9	267	10	53.85E-	10.15E-	0.000	0.240	0.001	20.509
8334-98.2	448	108	0.3	292	14	61.35E-	14.25E-	0.001	0.070	0.001	19.556
8334-122.1	50	80	1.7	41	2	81.25E-	35.55E-	0.001	0.447	0.005	15.704
8334-122.2	88	150	1.8	72	10	23.34E-	55.15E-	0.004	0.498	0.006	16.010
8334-118.1	101	49	0.5	79	1	14.25E-	14.05E-	0.000	0.130	0.002	24.304
8334-118.2	33	12	0.4	18	15	11.43E-	20.14E-	0.019	0.109	0.004	13.949
8334-59.1	129	116	0.9	62	8	18.84E-	45.15E-	0.003	0.268	0.003	7.856
8334-59.2	77	71	1.0	39	9	35.04E-	74.05E-	0.006	0.253	0.005	8.972
8334-59.3	98	79	0.8	51	15	41.14E-	65.25E-	0.007	0.237	0.004	11.164
8334-64.1	135	92	0.7	65	1	14.85E-	23.06E-	0.000	0.205	0.002	8.392
8334-64.2	56	45	0.8	38	4	15.14E-	28.75E-	0.002	0.224	0.004	19.075
Grains without replicates:											
8334-109.1	132	177	1.4	97	7	11.84E-	33.85E-	0.002	0.399	0.008	15.180
8334-110.1	185	101	0.6	121	11	13.44E-	22.75E-	0.002	0.148	0.004	15.523
8334-116.1	137	72	0.5	101	1	18.65E-	19.25E-	0.000	0.142	0.001	23.185
8334-117.1	156	80	0.5	93	4	65.95E-	24.05E-	0.001	0.156	0.002	13.606
8334-119.1	103	134	1.3	83	2	39.05E-	76.86E-	0.000	0.368	0.003	20.903
8334-123.1	182	181	1.0	105	10	14.14E-	29.35E-	0.002	0.283	0.004	11.050
8334-21.1	61	56	1.0	40	3	98.75E-	48.35E-	0.001	0.267	0.007	13.309
8334-24.1	66	40	0.6	51	17	48.04E-	77.15E-	0.008	0.172	0.005	21.617
8334-25.1	49	22	0.5	37	17	61.64E-	93.45E-	0.010	0.123	0.002	23.455
8334-26.1	270	101	0.4	124	16	16.94E-	34.05E-	0.002	0.111	0.002	9.994
8334-27.1	73	96	1.4	54	14	44.04E-	92.05E-	0.007	0.393	0.004	13.390
8334-36.1	60	61	1.0	41	16	56.54E-	88.15E-	0.009	0.262	0.008	14.030
8334-44.1	130	143	1.1	72	11	24.44E-	43.25E-	0.004	0.311	0.003	9.927
8334-44.1	140	117	0.9	107	14	19.74E-	40.85E-	0.003	0.238	0.002	21.064
8334-55.1	83	72	0.9	52	13	36.24E-	65.25E-	0.006	0.236	0.004	14.196
8334-58.1	86	38	0.5	62	10	20.64E-	39.35E-	0.003	0.113	0.004	22.891
8334-60.1	119	195	1.7	80	8	16.94E-	44.25E-	0.002	0.487	0.004	11.841
8334-65.1	74	111	1.6	53	2	70.45E-	31.25E-	0.001	0.417	0.011	13.543
8334-70.1	30	41	1.4	23	7	54.94E-	14.94E-	0.009	0.435	0.011	15.510
8334-89.1	40	51	1.3	38	10	42.24E-	88.15E-	0.007	0.348	0.004	24.987
8334-91.1	67	86	1.3	63	8	20.54E-	53.75E-	0.003	0.337	0.003	27.105
8334-92.1	141	124	0.9	110	11	14.74E-	23.25E-	0.002	0.249	0.004	20.671

Notes (see Stern, 1997):
* refers to radiogenic Pb (corrected for common Pb)
Spot name follows the convention x-y.z; where x = sample number, y = grain number and z = spot number.
Uncertainties reported at 1σ (absolute) and are calculated by numerical propagation of all known sources of error
f(206)^{204} refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb method;
common Pb composition used is the surface blank (4/6: 0.05770; 7/6: 0.89500; 8/6: 2.13840) (cont.)

Table GS-9-3: Sensitive high-resolution ion microprobe (SHRIMP) U-Pb data for zircon from arkosic quartzite (Geological Survey of Canada lab number 8334). ***(continued)***

Spot name	± ^{207}Pb/^{235}U	^{206*}Pb/^{238}U	± ^{206}Pb/^{238}U	Corr. Coeff.	^{207*}Pb/^{206}Pb*	± ^{207}Pb/^{206}Pb	Apparent ages (Ma) ^{206}Pb/^{238}U	± ^{206}Pb/^{238}U	^{207}Pb/^{206}Pb	± ^{207}Pb/^{206}Pb	Disc. (%)
Grains with reproducible replicates											
8334-57.1	0.228	0.470	0.007	0.827	0.235	0.002	2484	33	2687	18	8.2
8334-57.2	0.378	0.543	0.008	0.558	0.249	0.002	2795	34	2716	37	-2.8
8334-114.1	0.457	0.692	0.012	0.964	0.184	0.002	3390	45	3305	7	-2.5
8334-114.2	0.368	0.636	0.009	0.944	0.273	0.004	3172	37	3311	8	4.4
8334-124.1	0.469	0.687	0.011	0.882	0.246	0.001	3370	43	3305	14	-1.9
8334-124.2	0.621	0.615	0.017	0.985	0.246	0.001	3091	66	3291	7	6.5
8334-103.1	0.294	0.501	0.008	0.669	0.148	0.002	2617	33	2688	28	2.7
8334-103.2	0.387	0.433	0.011	0.755	0.218	0.004	2319	49	2769	36	19.4
Grains with non-reproducible replicates											
8334-98.1	0.286	0.605	0.008	0.938	0.173	0.001	3052	32	3157	8	3.5
8334-98.2	0.313	0.604	0.008	0.821	0.186	0.003	3044	32	3086	15	1.4
8334-122.1	0.339	0.555	0.011	0.912	0.274	0.006	2847	45	2868	14	0.7
8334-122.2	0.275	0.545	0.009	0.918	0.239	0.003	2803	36	2930	11	4.5
8334-118.1	0.419	0.660	0.011	0.959	0.253	0.008	3268	42	3288	8	0.6
8334-118.2	0.515	0.461	0.009	0.556	0.274	0.006	2443	42	2978	49	21.9
8334-59.1	0.150	0.384	0.005	0.741	0.175	0.002	2097	25	2325	22	10.9
8334-59.2	0.315	0.410	0.011	0.749	0.185	0.002	2215	49	2442	39	10.3
8334-59.3	0.398	0.434	0.013	0.811	0.154	0.001	2323	56	2713	34	16.8
8334-64.1	0.140	0.395	0.006	0.940	0.206	0.002	2145	28	2393	10	11.6
8334-64.2	0.691	0.556	0.020	0.981	0.211	0.002	2850	82	3177	11	11.5
Grains without replicates											
8334-109.1	0.336	0.534	0.011	0.935	0.193	0.004	2757	46	2877	13	4.4
8334-110.1	0.393	0.535	0.013	0.960	0.271	0.001	2761	55	2910	11	5.4
8334-116.1	0.455	0.641	0.010	0.825	0.185	0.002	3194	41	3260	17	2.1
8334-117.1	0.327	0.508	0.008	0.660	0.202	0.002	2650	34	2777	30	4.8
8334-119.1	0.451	0.619	0.013	0.977	0.148	0.002	3107	52	3152	7	1.4
8334-123.1	0.196	0.457	0.006	0.775	0.187	0.004	2425	28	2610	19	7.6
8334-21.1	0.359	0.521	0.010	0.728	0.191	0.005	2702	43	2702	31	-0.0
8334-24.1	0.660	0.620	0.011	0.563	0.267	0.001	3110	42	3203	40	3.0
8334-25.1	0.475	0.636	0.011	0.849	0.254	0.002	3173	43	3291	17	3.7
8334-26.1	0.155	0.420	0.006	0.875	0.159	0.004	2259	26	2584	13	14.4
8334-27.1	0.409	0.518	0.013	0.815	0.253	0.008	2689	55	2722	29	1.2
8334-36.1	1.088	0.534	0.039	0.935	0.213	0.001	2758	163	2747	45	-0.4
8334-44.1	0.157	0.421	0.006	0.902	0.220	0.007	2263	27	2569	11	13.5
8334-44.1	0.398	0.602	0.010	0.895	0.235	0.002	3036	41	3210	13	5.7
8334-55.1	0.281	0.511	0.009	0.872	0.187	0.004	2659	38	2840	16	6.8
8334-58.1	0.966	0.656	0.017	0.619	0.159	0.004	3250	67	3205	52	-1.4
8334-60.1	0.260	0.465	0.009	0.908	0.187	0.004	2462	41	2695	15	9.4
8334-65.1	0.349	0.529	0.010	0.720	0.171	0.001	2735	41	2706	30	-1.1
8334-70.1	0.627	0.516	0.019	0.913	0.253	0.006	2681	81	2967	27	10.7
8334-89.1	0.572	0.665	0.012	0.772	0.267	0.003	3285	46	3322	23	1.1
8334-91.1	0.851	0.718	0.016	0.732	0.184	0.003	3489	62	3328	33	-4.6
8334-92.1	0.427	0.628	0.011	0.853	0.188	0.003	3140	44	3112	17	-0.9

* refers to radiogenic Pb (corrected for common Pb)
Discordance relative to origin = 100 * (1-(^{206}Pb/^{238}U age)/(^{207}Pb/^{206}Pb age))
Calibration standard 6266; U = 910 ppm; Age = 559 Ma; ^{206}Pb/^{238}U = 0.09059
Error in ^{206}Pb/^{238}U calibration 1.25%
Th/U calibration: F = 0.03446*UO + 0.868

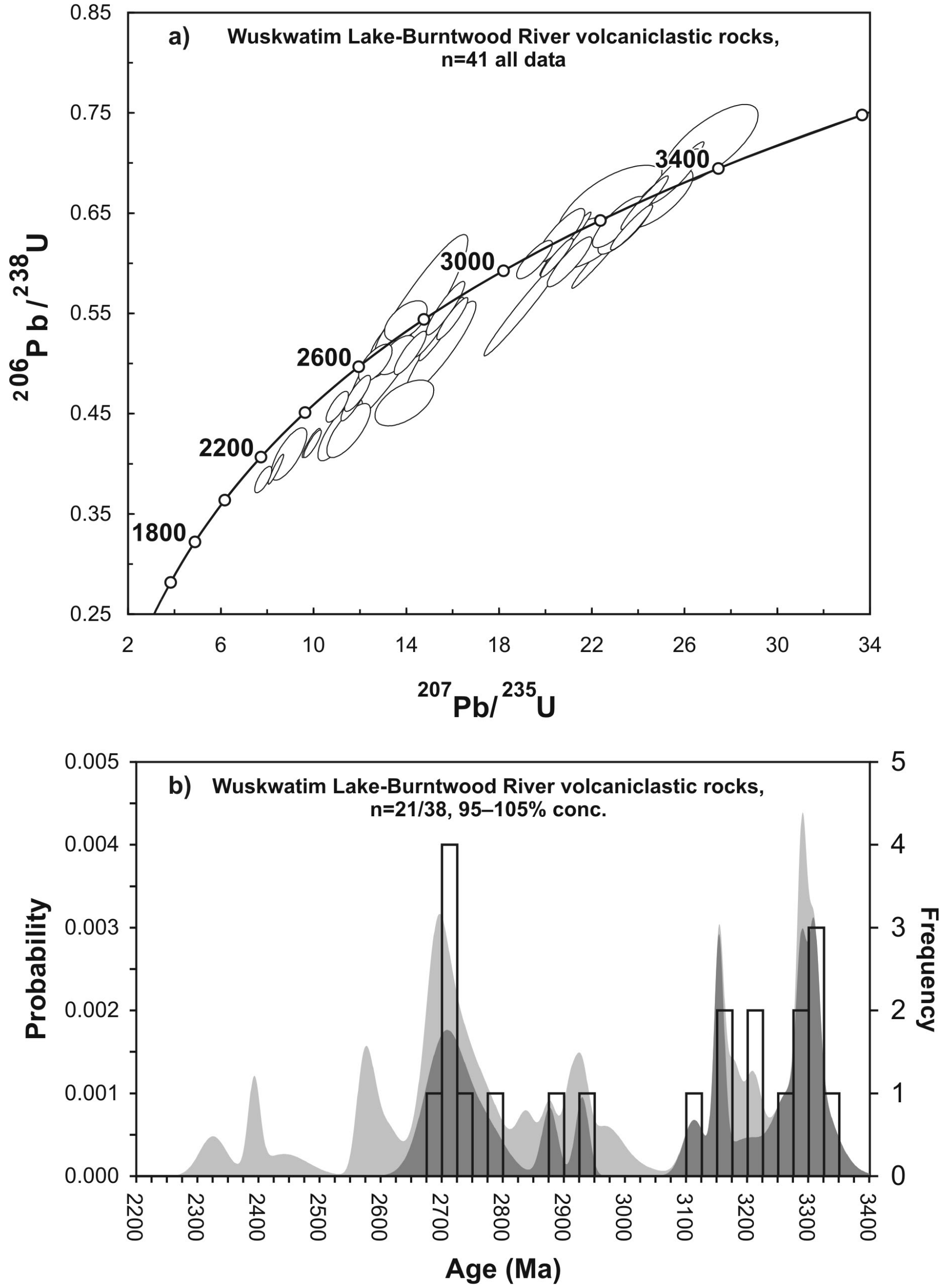

Figure GS-9-5: ***a)*** *Concordia diagram illustrating detrital zircon results for arkosic quartzite sample (Geological Survey of Canada lab number 8334). All data (n = 41), including duplicate analyses, are plotted regardless of degree of concordance. Ellipses are plotted at the 2σ uncertainty level.* ***b)*** *Cumulative probability curve and overlying histogram for detrital zircon results for sample 8334. All data (excluding concordant, duplicate results) are shown by the light grey curve. Dark grey curve and histogram are defined by data that are less than 5% discordant and do not include duplicates (n = 21).*

Discussion

Field and laboratory work in the Wuskwatim Lake corridor since 2004 have now clearly established the presence of granitoid orthogneiss with an Archean age of crystallization and/or mantle extraction, and paragneiss with Archean detritus in the Kisseynew Domain (KD) up to 60 km west of the Thompson Nickel Belt (TNB). In the 2006 field season, an area more than 12 km long and 4 km wide was delineated in the flood-widened Burntwood River northwest of Wuskwatim Lake where the orthogneiss is interleaved with paragneiss, yielding only Archean detrital zircons and Archean Nd model ages similar to the Ospwagan Group in the TNB. Their contact is interpreted to be an unconformity. A complex domal structure underlies Wuskwatim Lake and features similar multicomponent orthogneiss with biotite-granulite mineral assemblages and Archean model ages, and similar Ospwagan-like paragneiss along its northwestern margin. Narrow belts of such heterogeneous paragneiss are traced intermittently for 40 km west-northwest past Threepoint Lake. Other such belts may lie north of Highway 391 (Percival et al., GS-8, this volume). Their origin as Archean basement gneiss is supported by their strong fabric and the presence of early mafic enclaves, as well as better preserved mafic dikes and boudins that are interpreted to be Paleoproterozoic. These are also typical features of the basement gneiss in the TNB.

The extent of Archean gneiss in the northeastern KD crust is also monitored by the distribution of granite plutons with elevated Nd model ages. These plutons occur in the KD in a 20 km wide belt that adjoins the TNB (Percival et al., 2005) and swings northwest, from Tullibee Lake possibly to Highrock Lake, 140 km west of Thompson (inset map on Figure GS-9-1). In the western part of this area, such plutons occur at Nelson House and Eyinatik Lake, 60 and 110 km west of Thompson. They range from calcalkaline granite to mildly alkaline syenite, are typically foliated and contain porphyroclastic K-feldspar. Neodymium model (T_{CHUR}) ages range from 2.3 to 2.8 Ga, and ε_{Nd} from +0.2 to –10.9 (Percival et al., 2005 and GS-8, this volume). These characteristics indicate that the granite has a significant component of melted Archean crust. Southwest of this belt, three tested plutons have nearly juvenile Proterozoic model ages (Percival et al., GS-8, this volume; Zwanzig, unpublished data, 2005). A larger population of chemically analyzed plutons (Hollings and Ansdell, 2002) has a composition similar to these juvenile plutons and unlike the bodies with long crustal residence in the northeastern KD. Whereas the plutons in the southwest have a flat aeromagnetic signature similar to the Burntwood Group country rock, bodies contaminated with or consisting of remelted Archean crust are strongly magnetic (Viljoen et al., 1999). This allows a first estimate of the extent of Archean gneiss in the crust of the northeastern KD.

At the margin of the TNB, gneissic granodiorite to porphyroclastic syenite plutons range in age from about 1890 to 1835 Ma (Zwanzig et al., 2003; Percival et al., 2004, 2005), although the younger plutons in that area are nearly juvenile and the older bodies predate the Burntwood Group. Dating these plutons in the northeastern KD will indicate when Archean crust was available for partial melting. Absolute ages are also required to clearly distinguish Archean basement orthogneiss from highly deformed Proterozoic granitoid rocks that are nearly wholesale melts of Archean crust. This is imperative in identifying TNB crust in the KD.

Based on the assumption that the multicomponent orthogneiss is largely Archean, a composite tectonostratigraphic section has been compiled from the intermittently exposed belts of heterogeneous paragneiss that are about 500 m wide and mantle the orthogneiss (Figure GS-9-2a). This section comprises basal arkosic quartzite overlain by garnet-biotite±orthopyroxene migmatite and minor calcsilicate gneiss, followed by siliceous garnet-biotite gneiss with aeromagnetically prominent sulphide-facies iron formation. This is capped by biotite-garnet gneiss and structurally overlain by the Burntwood Group. The paragneiss succession is interpreted to be derived from arkosic sandstone grading rapidly into pelite and semipelite, somewhat similar to the Manasan Formation in the TNB. The overlying gneiss, derived from minor marlstone, clay-rich siliciclastic rocks, sulphide-facies iron formation, chert and rare silicate-facies iron formation, resembles the lower part of the Pipe Formation (P1-P2) in the middle of the Ospwagan Group, possibly with a trace of underlying Thompson Formation. The marble unit (T3), which is critical for a positive correlation, was not observed. Although this could rule out an Ospwagan Group correlation, this may simply result from lack of exposure of this typically poorly exposed unit. Thus, at the present state of knowledge, the correlation with the type section in the TNB is tempting but not definitive.

A comparison of geochemical patterns and Nd model ages between the heterogeneous paragneiss and the Ospwagan Group and 'anomalous' paragneiss in the TNB has established a link between the geology at Wuskwatim Lake and the northern margin of the TNB. This comparable margin includes some belts of paragneiss near the Mel zone and others extending northeast to Pearson Lake (Figure GS-9-1). Several exploration drillcores and small outcrops in that area feature orthogneiss with Nd model ages ranging from 3.2 to 3.6 Ga (Böhm et al., work in progress, 2006). These are interlayered with or adjoin 'anomalous' paragneiss with model ages of 3.1 to 3.6 Ga, similar to the rocks on Wuskwatim Lake. Their geochemical patterns are also very similar. They have similar depletion in rare earth and low field strength elements, and slightly different geochemical anomalies compared to typical rocks of the Ospwagan Group. Adjacent belts of stratigraphically recognizable Ospwagan Group at the northern end of the TNB have model ages of 2.8 to 3.0 Ga, similar to the main part of the TNB (Böhm et al., work in progress, 2006). Thus, the presence of the Ospwagan Group is not clearly established in the Wuskwatim Lake corridor but is suggested by the association with nearly identical rocks at the north end of the TNB. The data may also be interpreted in terms of an Archean origin for some of the paragneiss at Wuskwatim Lake and in the northern TNB.

The regional structure and stratigraphic sequence at Wuskwatim Lake, however, indicate that the metasedimentary rocks are most likely Paleoproterozoic. The unconformable relationship of the basal quartzite and the wide extent of the Burntwood Group above the proposed roof thrust, subparallel to the unconformity, argue strongly for a Proterozoic age. Moreover, the abundance of garnet and dominance of sulphide-facies iron formation in the type Ospwagan Group and the 'anomalous' paragneiss in the northern TNB are similar at Wuskwatim Lake. This suggests that there may be a sedimentary facies change in the Ospwagan Group in the north and west. Sulphide facies is more abundant and carbonate facies (Thompson Formation) is weakly developed or missing. A possible explanation is that these rocks were deposited farther into the marine basin or farther down the ancient continental slope.

The Mesoarchean model ages and the detrital zircon spectrum indicate that part of the source was Mesoarchean. The similar chemical composition, model ages and detrital zircon ages of the orthogneiss and paragneiss suggest that the basement was exposed to erosion adjacent to the basin. The basement may have been more highly stretched and uplifted than that of the TNB, or completely separated into an epicontinental terrane by rifting.

If the model age of 2.6 Ga for one sample of biotite-garnet gneiss is an indication of mixing of sediments from Archean and Proterozoic sources, the heterogeneous paragneiss succession may be younger than the Ospwagan Group and have some sediments supplied from a more juvenile part of the 1880 to 1990 Ma continental or fringing arc that has been suggested by Percival et. al. (2005).

An interesting structural feature of the Wuskwatim Lake corridor is that the Burntwood Group lies on Pipe Formation–type rocks from Threepoint Lake to Wuskwatim Lake (this report) and again at the Mel zone, thus extending for 60 km if the structure is continuous (Zwanzig and Böhm, 2002). This suggests that the contact is a flat in a large thrust or the base of a thrust nappe (Zwanzig and Böhm, 2002). Along the western fault boundary of the main TNB margin, the Burntwood Group contact cuts up the footwall section from the basement gneiss west of Thompson through the Ospwagan Group near Setting Lake (Macek et al., 2006). If this structure is continuous with the early fault at Wuskwatim Lake, then the Burntwood Group was structurally emplaced from a northerly direction. The same vergence is suggested by a small thrust at the Thompson South pit (Macek et al., 2005) and by a thrust placing basement gneiss on Bah Lake assemblage (uppermost Ospwagan Group) and the Grass River Group (Zwanzig, 1999). In the northeastern KD, the 'basement' orthogneiss occurs only intermittently within the overall belt of heterogeneous paragneiss. This suggests that it may occur as megaboudins within a large D_1 thrust sheet that was highly attenuated in a midcrustal environment during D_2 and possibly thrown into a large recumbent fold before being refolded in dome-and-basin structures, as suggested for the Mel zone. Structural reconstructions will shed additional light on the question of whether the 'basement' and paragneiss 'cover' exposed in the Wuskwatim Lake corridor 1) are autochthonous beneath the northeastern KD and contiguous with the TNB and Superior Province, 2) represent a rifted epicontinental fragment, or 3) constitute the core of a nappe likely rooted to the northeast.

Economic considerations

The presence of small mafic-ultramafic bodies in the Wuskwatim heterogeneous paragneiss, particularly at a stratigraphic level that most resembles the economically productive lower part of the Pipe Formation in the Thompson Nickel Belt (TNB), holds promise that these rocks may host Thompson-type nickel deposits. Ultramafic bodies are the source of the nickel and the sedimentary sulphides that provided the sulphur for these magmatogenic deposits (Bleeker, 1990). The wide probable extent of such rocks interleaved with the Burntwood Group in the northeastern Kisseynew Domain (KD) makes this region a major exploration frontier if the correlation with the Ospwagan Group can be confirmed. Uranium-lead zircon crystallization ages of the 'basement' orthogneiss are crucial for this task. Further detrital zircon age spectra are required for the upper exposed part of the sequence, as well as for similar gneiss at the north end of the TNB. Detrital zircon age modes from the Thompson mine and Pipe II pit do not match that of the basal quartzite at Wuskwatim Lake (Rayner et al., GS-11, this volume). Therefore, further laboratory work at the north end of the TNB is required for future exploration there and in the Wuskwatim Lake corridor. Given the complex nature of the zircons (Rayner et al., GS-11, this volume), this will require work on the sensitive high-resolution ion microprobe at the Geological Survey of Canada. The work should to be given a high priority in view of the needs of the communities of Thompson, Nelson House and Wabowden, as well as the continued economic strength of Manitoba.

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