GS-8 Uranium-lead geochronology of basement units in the Wuskwatim–Tullibee lakes area, northeastern Kisseynew Domain, Manitoba (NTS 63O)

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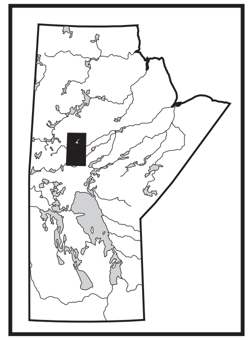

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Summary

This report presents U-Pb sensitive high-resolution ion microprobe (SHRIMP) geochronological results from four high-grade samples of proposed Archean inliers within the Kisseynew Domain. A sample of tonalite from the Burntwood River, near the mouth of the Muskoseu River, is interpreted to have crystallized between 2.8 and 2.9 Ga; it also contains inherited zircon up to 3.4 Ga in age. A third population of zircon from the tonalite indicates zircon growth between 2.5 and 2.55 Ga, speculatively associated with granulite-grade metamorphism. Immediately overlying the tonalite is quartzite, which is interpreted to be in unconformable contact with the tonalite basement. The detrital zircon with the youngest reproducible age is dated at 2.53 Ga, with other detritus yielding minimum dates as old as 3.32 Ga. Uranium-lead results from a charnockite within the Wuskwatim Lake inlier are interpreted to indicate crystallization between 2.64 and 2.66 Ga, with inheritance between 2.7 and 3.24 Ga. All three of these samples also record peak Trans-Hudson metamorphism with zircon growth at 1801 ±13 Ma (tonalite), 1806 ±5 Ma (quartzite) and 1804 ±29 Ma (charnockite). Zircons recovered from a tonalite gneiss near an iron formation west of Tullibee Lake does not preserve evidence of an Archean history. All but one zircon yielded a weighted mean age of 1809 ±3 Ma, identical (within error) to the Paleoproterozoic ages observed in the Archean samples. Only one zircon yielded a slightly older date of 1877 ±22 Ma.

Introduction

Recent work by the Manitoba Geological Survey (MGS) and the Geological Survey of Canada (GSC) as part of the Targeted Geoscience Initiative III (TGI-3) program has identified structural windows of Archean orthogneiss in what was previously mapped as part of a sea of Paleoproterozoic Burntwood metaturbidites. Subsequent aeromagnetic surveys have identified other positive anomalies consistent with those observed in the Archean basement inliers. Details on the rock types, structure and metamorphism have been described in earlier reports and are illustrated in Figure GS-8-1 (Growdon et al., 2006; Percival et al., 2006; Zwanzig et al., 2006). In summary, basement orthogneiss is exposed in the core of several structural culminations at Wuskwatim Lake and a few kilometres to the northwest on the Burntwood River. Samarium-Neodymium tracer isotopic work on a charnockite from Wuskwatim Lake yielded a model age of 3.1 Ga (Percival et al., 2006). On the Burntwood River, near the Muskoseu River, an unconformity is exposed between quartz-rich metasedimentary rocks and a foliated tonalite with a model age of 3.3 Ga (Zwanzig et al., 2006). Detrital zircon geochronology (SHRIMP) on an arkosic quartzite from the Burntwood River yielded a provenance profile dominated by 2.7 Ga detritus (Zwanzig et al., 2006). Based on certain similarities of rock types and detrital provenance (yet differences in geochemistry), it has been suggested that this sequence of supracrustal rocks may be correlative with the Ospwagan Group and the orthogneiss may be correlative with a westward extension of the Superior Province basement (Percival et al., 2006; Zwanzig et al., 2006).

This report presents new SHRIMP U-Pb results for the Wuskwatim charnockite, the Muskoseu tonalite and unconformably overlying quartzite, and a tonalite at Tullibee Lake.

Analytical methods

Procedures followed for SHRIMP zircon U-Pb analysis are those described by Stern (1997), with standards and U-Pb calibration methods from Stern and Amelin (2003). The internal features of the zircons (such as zoning, structures and alteration) were characterized with backscattered electrons (BSE) utilizing a Cambridge Instruments scanning electron microscope. Analyses were conducted using an ^{16}O primary beam. Details of the specific analytical and instrumental conditions and the U-Pb calibration error can be found in the footnotes of DRI2007002[2]. Offline data processing was accomplished using the SQUID program (Ludwig, 2001) and customized in-house software. Isoplot v. 2.49 (Ludwig, 2003) was used to generate concordia plots and calculate weighted means. All ages in the text and the ellipses

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[2] MGS Data Repository Item DRI 2007002, containing the data or other information sources used to compile this report, is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/freedownloads.htm, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Science, Technology, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada.

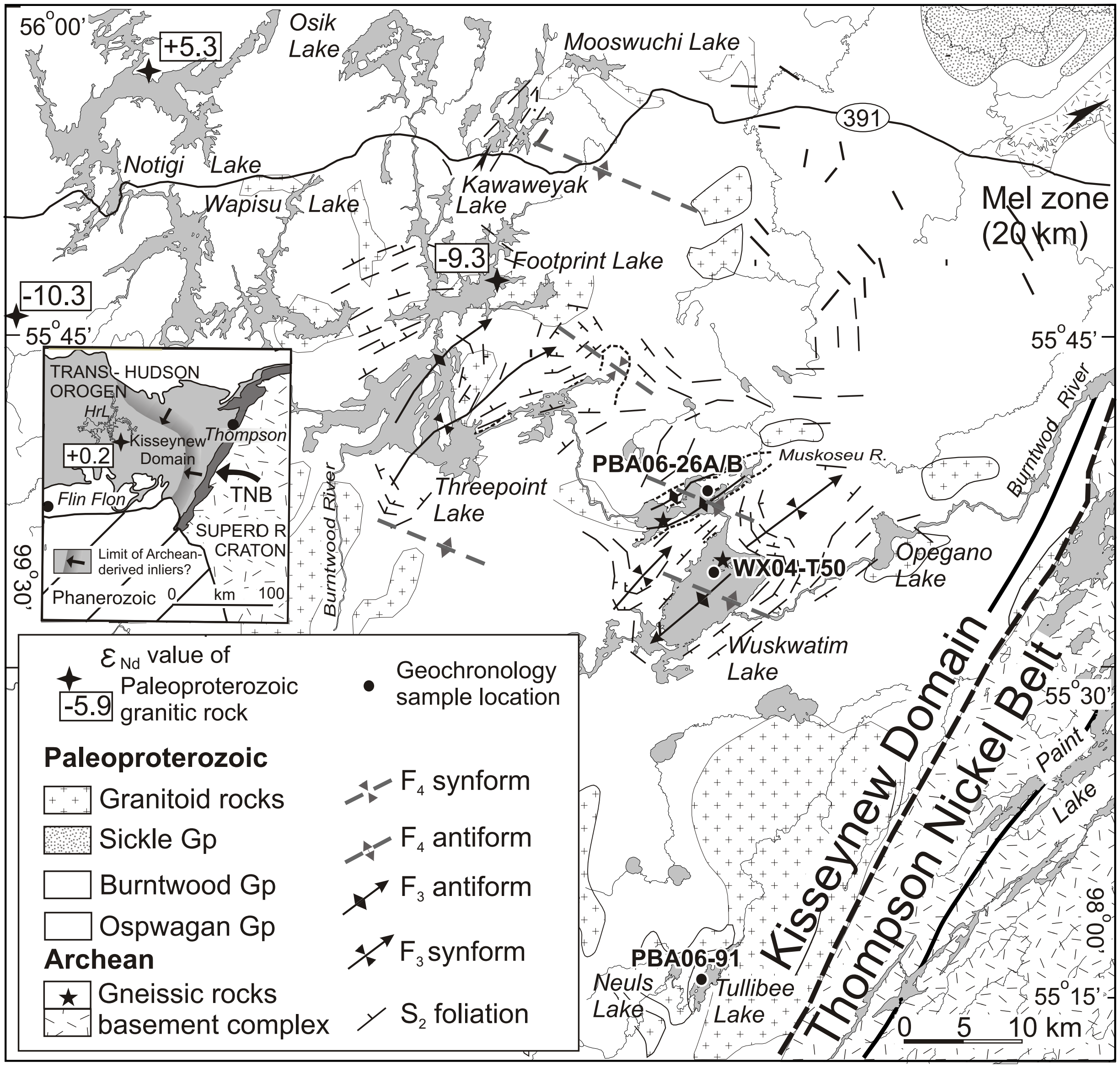

Figure GS-8-1: *Simplified geology of the Wuskwatim–Tullibee lakes area (*from *Percival et al., 2006).*

plotted in the figures have errors reported at the 2σ uncertainty level.

Sample details and results

Muskoseu tonalite (PBA06-26A)

At the locality near the Muskoseu River, a contact interpreted as an unconformity is exposed between the foliated tonalite and quartz-rich metasedimentary rocks (Figure GS-8-2a). The heterogeneous tonalitic unit comprises gneissic and foliated phases with orthopyroxene-clinopyroxene-hornblende-biotite-plagioclase-quartz assemblages. Sparse enclaves include garnet-orthopyroxene-biotite paragneiss and orthopyroxene-clinopyroxene-hornblende-plagioclase metabasite. Concordant leucosome and discordant leucogranite dikes are common.

Zircons recovered from the tonalite are highly variable in quality. They range from clear, colourless, high-quality prisms with few inclusions or fractures, to highly fractured and included prisms. The zircons show a weak cathodoluminescent response, but oscillatory zoning is visible in most grains. In a small number of grains, core-rim relationships are evident, in particular, clear rims surrounding poor-quality cores.

As has been observed in other high-grade rocks from the area, the U-Pb systematics of the older zircons are disturbed (Percival et al., 2005; Zwanzig et al., 2006). In a number of instances, replicate analyses on the same internal zone were not reproducible. Due to limited time constraints, it was not feasible to conduct replicate analyses on all the grains and therefore an unequivocal interpretation of any single age determination is not possible. By presenting and examining the data as concordia diagrams (Figure GS-8-3a) and probability

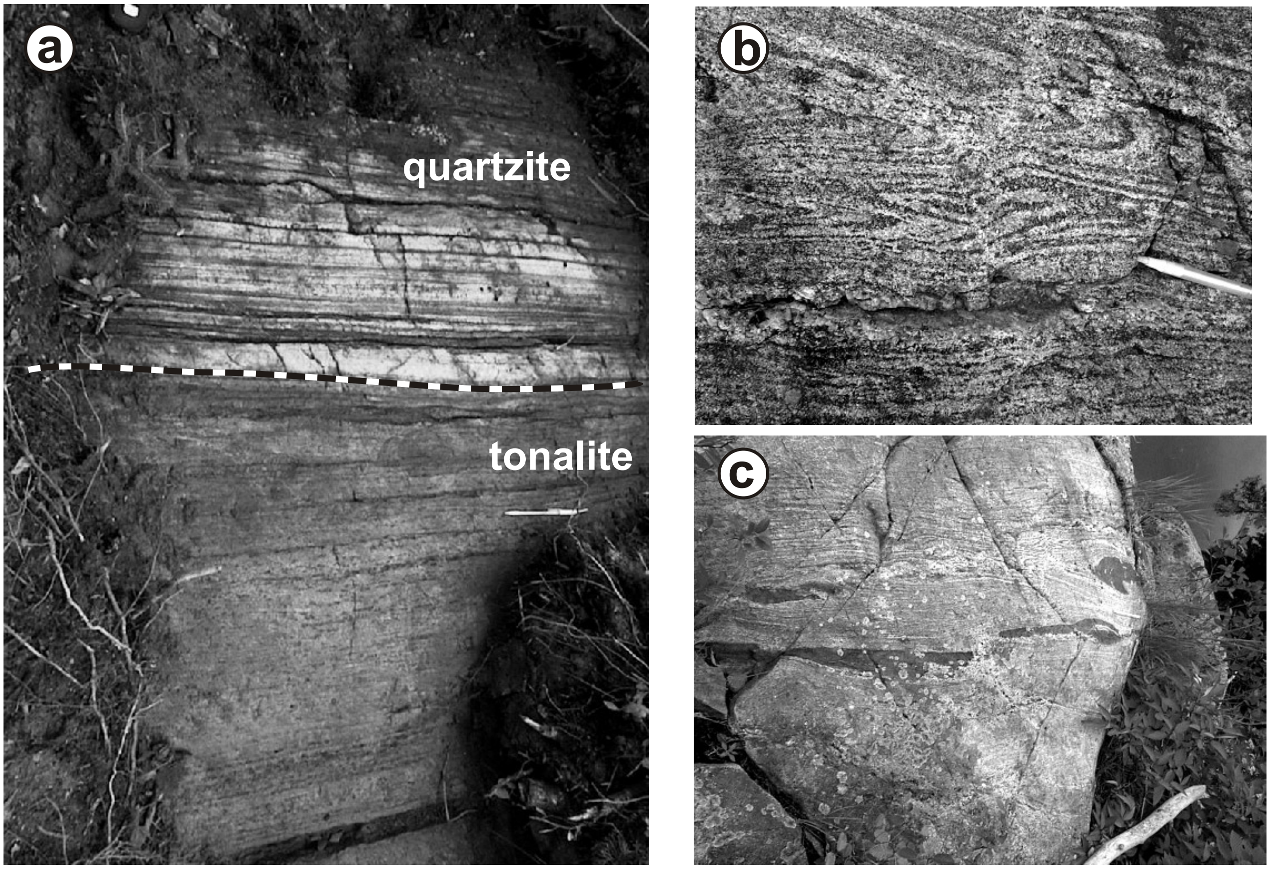

Figure GS-8-2: *Photographs of rocks sampled for U-Pb geochronology:* ***a)*** *Muskoseu River tonalite (PBA06-26A) and overlying quartzite (PBA06-26B); 16 cm pen for scale;* ***b)*** *detail of Tullibee tonalite gneiss (PBA06-91); 1 cm wide pen for scale;* ***c)*** *Tullibee tonalite gneiss (PBA06-91 with mafic enclaves); 16 cm pencil for scale.*

density diagrams with overlaid histograms (Figure GS-8-3b), the authors were best able to identify the prominent age modes and tentatively interpret these dates.

Beginning with the youngest results, three analyses of unzoned to faintly sector-zoned zircon give a mean age of 1801 ±13 Ma (2σ, mean square of weighted deviates (MSWD) = 0.61, probability of fit = 54%). This date is interpreted to represent the timing of Trans-Hudson metamorphism and is consistent with monazite results in the region (Growdon et al., 2006).

The remaining older zircons yielded $^{207}Pb/^{206}Pb$ ages ranging from 2392 to 3417 Ma. There is no clear relationship between zircon morphology and age. Replicate analyses of grains that at first yielded Paleoproterozoic or Neoarchean dates subsequently yielded older dates (e.g., grains 1, 5, 64, 68). The dominant age mode is between 2.8 and 2.9 Ga (Figure GS-8-3b). The authors interpret the crystallization age of the tonalite to be within this range, but cannot constrain it further due to the non-reproducibility of the results. The older age modes at ca. 2.95 and 3.4 Ga are interpreted as inherited components. The oldest $^{207}Pb/^{206}Pb$ date was determined from one of the poor-quality cores described earlier. Another prominent cluster of data is found in the range of 2.50–2.55 Ga, separated from the older population by an indistinct swath of results. A pronounced peak in the cumulative probability curve is shown at ca. 2.7 Ga (Figure GS-8-3b). This is based on a single, non-reproduced, precise analysis and does not necessarily indicate a geologically significant age. The authors would propose that the 2.5–2.55 Ga zircon growth and resetting of older zircons occurred due to granulite-grade metamorphism at this time or slightly later. The 1.8 Ga zircons described earlier are not affected by the U-Pb isotopic disturbance that is thought to be associated with granulite-grade metamorphism; consequently, the authors infer that the high-temperature metamorphism occurred before 1.81 Ga.

Muskoseu quartzite (PBA06-26B)

The sample is a quartz-rich rock with centimetre-scale layering defined by biotite-rich seams (Figure GS-8-2a). The proposed unconformable contact with basement is defined by a change to homogeneous, orthopyroxene-bearing tonalitic rocks. Zircons recovered from the quartzite are similar in appearance to those from the tonalite. A population of clear, colourless, high-quality prisms is present as distinct grains and rarely as overgrowths around a second population of light- to medium-brown, highly fractured, subrounded prisms. In contrast to the tonalite sample,

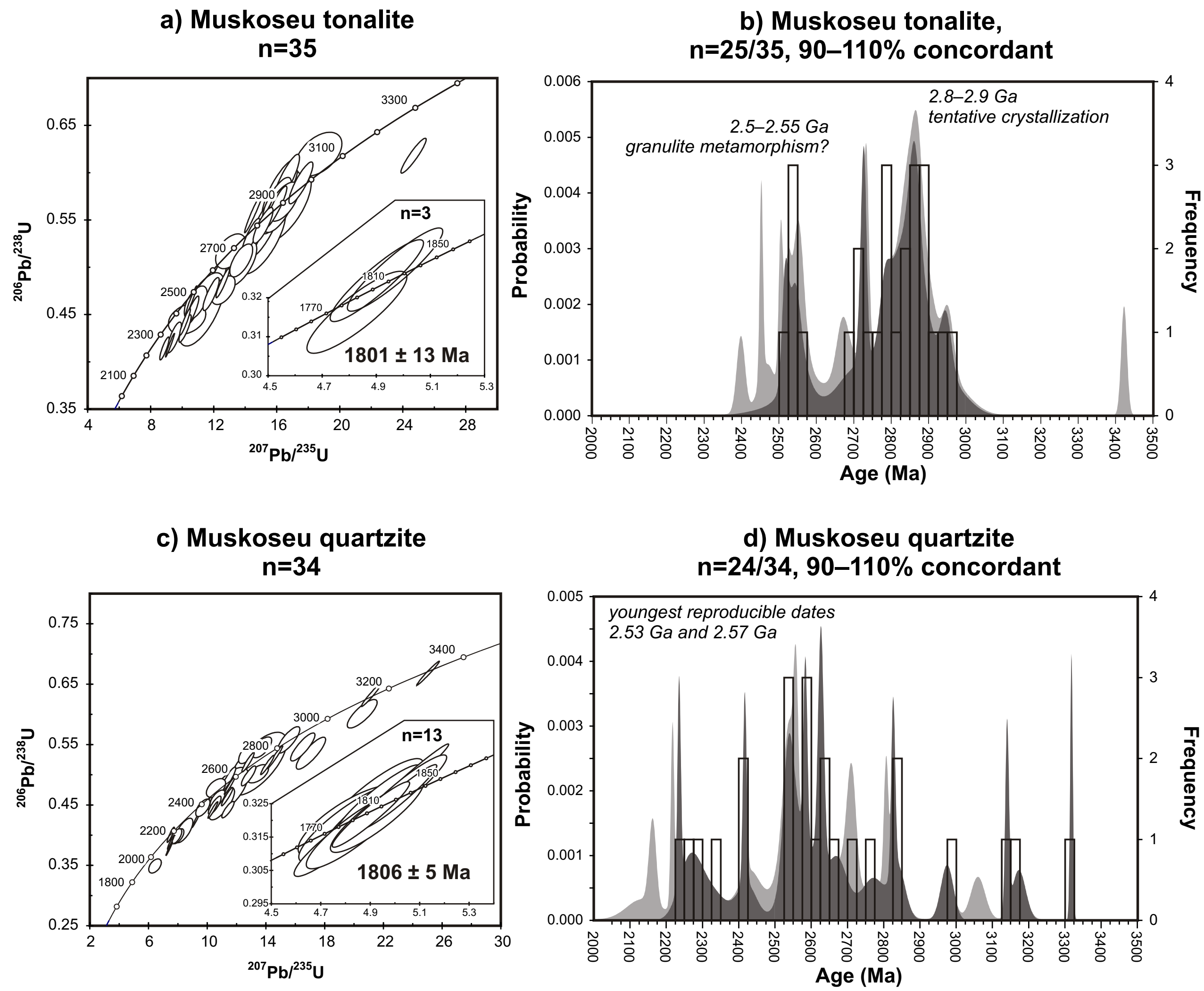

***Figure GS-8-3:** Sensitive high-resolution ion microprobe (SHRIMP) U-Pb results for Muskoseu tonalite and overlying quartzite: **a)** Muskoseu tonalite concordia diagram, all data; **b)** Muskoseu tonalite probability density diagram with overlaid histogram; light grey shaded curve represents the probability density of the entire dataset (n = 35); dark grey shaded curve and histogram only illustrate results between 90 and 110% concordant and do not include replicate analyses (n = 25); **c)** Muskoseu quartzite concordia diagram, all data; **d)** Muskoseu quartzite probability density diagram with overlaid histogram; colour scheme as in **b)**.*

there is an approximate relationship between morphology and age, with the high-quality prisms routinely yielding ages consistent with Trans-Hudsonian metamorphism. The analysis of 13 zircon overgrowths or distinct prisms gave a weighted mean $^{207}Pb/^{206}Pb$ age of 1806 ±5 Ma (2σ, MSWD = 1.2, probability of fit = 26%; Figure GS-8-3c), which was interpreted as the time of metamorphism. These zircons exhibit faint concentric zoning and have Th/U ratios between 0.02 and 0.43. From the low-quality zircon population, interpreted to be detrital, 27 analyses were carried out on 20 separate zircon grains. Of the seven grains with replicate analyses, only three grains gave reproducible ages. Uranium-lead SHRIMP results for the detrital zircons are affected by the disturbance of the U-Pb systematics typically observed in granulite-grade rocks discussed previously. All non-reproduced dates should be considered as minimum ages. In the instance of multiple analyses from single zircon grains, the oldest of the replicate analyses is considered the minimum age. The detrital ages range from 2132 to 3318 Ma (DRI2007002; Figure GS-8-3c, d). The youngest reproducible zircon dates are ca. 2.53 Ga (grain 61) and 2.57 Ga (grain 30). The significance of these dates is ambiguous—they might correspond to the youngest detrital zircons or might be related to the ca. 2.5 Ga metamorphism proposed for the underlying tonalite described earlier. The significance of any of the younger early Paleoproterozoic ages is uncertain and should not be taken to represent the maximum age of deposition of the quartzite.

Wuskwatim charnockite (WX04-T050)

A sample of massive, brown-weathering, coarse-grained, orthopyroxene-biotite granite (charnockite) was collected on Wuskwatim Lake from a locally gneissic unit that includes schlieren of older gneiss. Previous Sm-Nd analyses indicated an evolved source with a model age of 3.1 Ga (Percival et al., 2006). Zircons recovered from the sample are mainly poor-quality, highly fractured prisms with numerous inclusions and some altered domains. A smaller proportion of the zircons, observed both as discrete crystals and overgrowths, are high-quality, clear, colourless zircon, typically unzoned in BSE images.

Thirty-four analyses were carried out on 26 individual zircon grains (DRI2007002; Figure GS-8-4). Six analyses from the clear, colourless zircons yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 1804 ±29 Ma (2σ, MSWD = 0.14, probability of fit = 98%), interpreted to represent the timing of a late Trans-Hudson metamorphic overprint. One analysis (9216-37.2) gave a slightly older age of 1888 Ma, but this is likely due to overlap of the analytical spot onto an older core (9216-37.1). Zircon of pre–Trans-Hudson age exhibits the non-reproducible behaviour described earlier. Ages range from 2234 to 3248 Ma, with two dominant populations (Figure GS-8-4b). No distinction can be made between these two groups based on U concentration or Th/U ratio. Of the younger subset of data, zircon that is unzoned and between 2560 and 2662 Ma in age gives a weighted mean $^{207}Pb/^{206}Pb$ age of 2641 ±23 Ma (n = 10, MSWD = 0.44, probability of fit = 92%). By incorporating the five next-oldest analyses of faintly zoned to zoned zircon, it is possible to calculate a statistically indistinguishable weighted mean $^{207}Pb/^{206}Pb$ age of 2666 ±27 Ma (MSWD = 1.6, probability of fit = 6%). The current dataset, with its large errors and non-reproducible behaviour, is not adequate to convincingly state whether the difference in zonation pattern represents a true difference in age. Therefore, this population is best constrained in the age range of 2.64–2.66 Ga. The oldest population of zircon ranges in age from 3091 to 3248 Ma. The weighted mean $^{207}Pb/^{206}Pb$ age of the six oldest analyses (excluding one replicate analysis, 9216-43.1) is 3238 ±15 Ma (MSWD = 0.24, probability of fit = 94%). Two interpretations of the Archean dates from the charnockite are possible. In the first interpretation, the granite was intruded at 3.24 Ga and subsequently metamorphosed to granulite grade between 2.64 and 2.66 Ga. Alternatively, this is a magmatic charnockite crystallized between 2.64 and 2.66 Ga with 3.24 Ga inheritance. The latter interpretation is preferred due to the apparent freshness of the unit; however, the isolated nature of the outcrop (on a poorly exposed island in Wuskwatim Lake) limits the utility of field relationships to resolve this question.

Tullibee Lake tonalite gneiss (PBA06-91)

The Tullibee Lake sample is a finely laminated tonalitic gneiss containing pyroxene and cut by mafic dikes. During remapping, it was assumed to be of Molson age (1880–1884 Ma; Heaman et al., 1986; Hulbert et al., 2005; Figure GS-8-2b, c). The tonalite gneiss coincides with a positive aeromagnetic anomaly. This association with presumed older dikes and aeromagnetic highs led to the hypothesis of this rock type being Archean basement. Isotopic and geochronological studies on a nearby granodiorite gneiss yielded an ε_{Nd} value of –13 (*illustrated in* Percival et al., 2005), suggesting the presence of Archean rocks. The recovered zircon is typically slightly rounded and ranges in size from ~30 to 210 µm. Morphologies range from equant to prismatic. Most of the zircons are simply terminated, though some of the more equant grains are multifaceted. Approximately half of the grains are clear and colourless; the remainder range from light to very dark brown. Opaque inclusions are present in many grains. These inclusions are commonly surrounded by radial fractures. The intense brightness of these inclusions suggests high-density minerals such as uraninite and/or thorite.

Twenty-four analyses were performed on 17 separate zircon grains spanning the range of morphologies. The weighted mean $^{207}Pb/^{206}Pb$ age from 20 of the analyses is 1809 ±3 Ma. Both apparent cores and rims were targeted for analysis, but no difference in age or composition was observed (Figure GS-8-5).

The four excluded analyses were replicates from a single zircon, grain 87 (Figure GS-8-5 inset), and a weighted mean of the three oldest analyses yielded a $^{207}Pb/^{206}Pb$ age of 1890 ±8 Ma (MSWD = 0.92, probability of fit = 40%). Grain 87 is morphologically distinct from the other grains, having a very irregular habit and interior alteration pattern.

Such a young dominant population of zircons from this sample was unexpected, given the presence of crosscutting mafic dikes and the magnetic signature of the area. Geochronological results from the three previous samples indicate that a metamorphic overprint at ca. 1.81 Ga is common in this region. If the 1809 Ma date from the Tullibee tonalite gneiss is also interpreted as metamorphic, the only constraint on any older components is the single grain dated at 1877 Ma. In this instance, it should only be considered a minimum age due to the apparent pervasiveness of the Paleoproterozoic overprint. The authors propose that any primary igneous zircons from the tonalite were either very rare or were resorbed during Trans-Hudson overprint; consequently, the age of this unit cannot be further constrained at this time.

Discussion

Results from earlier mapping, aeromagnetic surveys and geochronology studies led to the interpretation that the northeastern Kisseynew Domain is interleaved with or underlain by Superior basement and possibly Ospwagan Group cover (Percival et al., 2006; Zwanzig et al., 2006; this study). Although the presence of Archean basement is suggested from previous isotopic tracer work (Percival et al., 2006), the U-Pb results presented here provide rigorous confirmation. Questions remain, however, about the nature of the basement. Is the basement contiguous, or

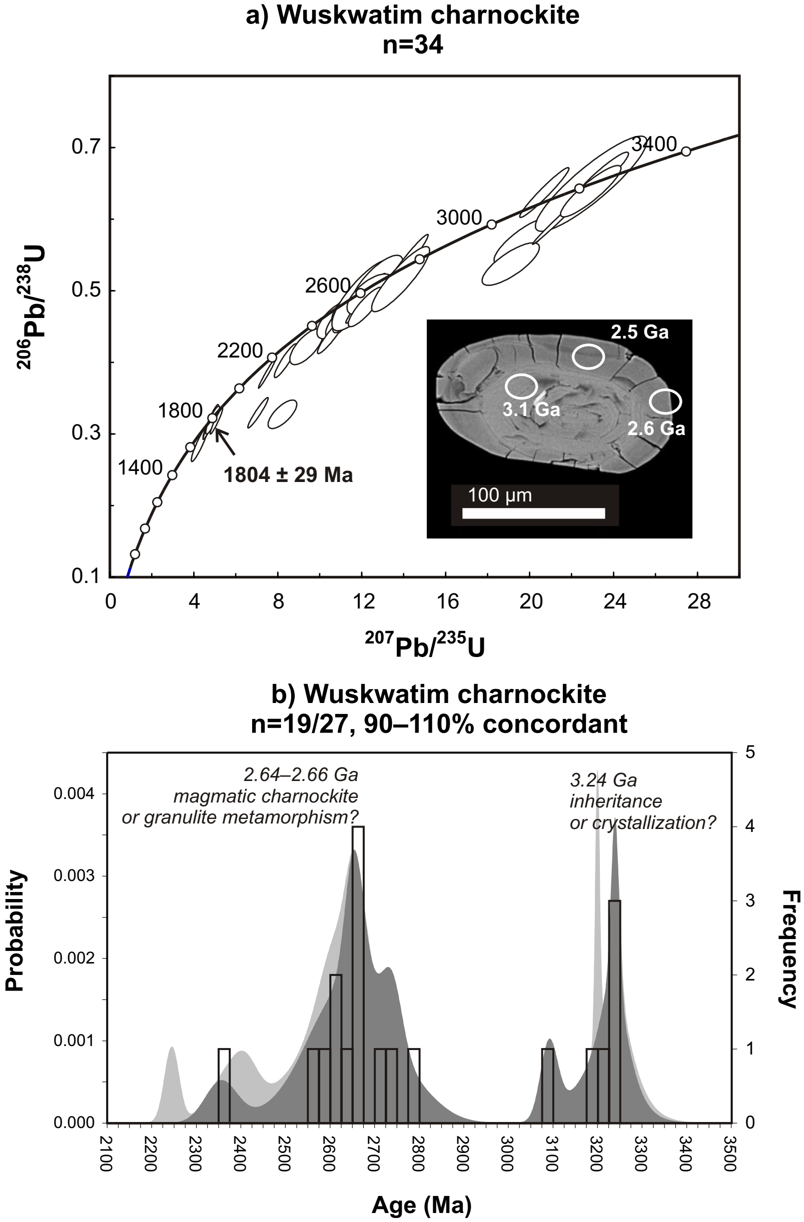

Figure GS-8-4: *Sensitive high-resolution ion microprobe (SHRIMP) U-Pb results for the Wuskwatim charnockite:* ***a)*** *concordia diagram, all data; inset is a backscattered electron (BSE) image of grain 9 illustrating analytical sites and spot ages, including a 3.1 Ga core and non-reproducible overgrowth dates;* ***b)*** *probability density diagram with overlain histogram; light grey shaded curve represents the probability density of the entire dataset (n = 27); dark grey shaded curve and histogram only illustrate results between 90 and 110% concordant and do not include replicate analyses (n = 19).*

a rifted fragment? If rifted, is it possible to discriminate between those of Superior craton affinity or slivers of other exotic blocks (i.e., Sask craton, Hearne margin and Wollaston Domain)?

The difficulty in constraining precise crystallization ages for the basement due to the isotopic disturbance of the zircons during >1.81 Ga granulite-facies metamorphism makes correlating basement ages with a specific craton challenging. Broadly speaking, the observed ages (2.8–3.4 Ga) are consistent with a Superior Province affinity (Figure GS-8-6). The presence of a 1.88 Ga isotopically contaminated plutonic suite (Percival et al., GS-7, this volume), as has been documented in the contiguous Superior Province (Percival et al., 2005), also argues for a correlation with that craton. Dates reported for the Sask craton are dominated by 2.45 Ga ages, with rocks as old as 3.1 Ga (Chiarenzelli et al., 1998; Ashton et al., 1999; Rayner et al., 2005). These dates do not appear to be consistent with those from the northeastern Kisseynew Domain; however, this may reflect limited exposure and sampling of the Sask craton at the surface. There are few lithological or age similarities with the Hearne margin

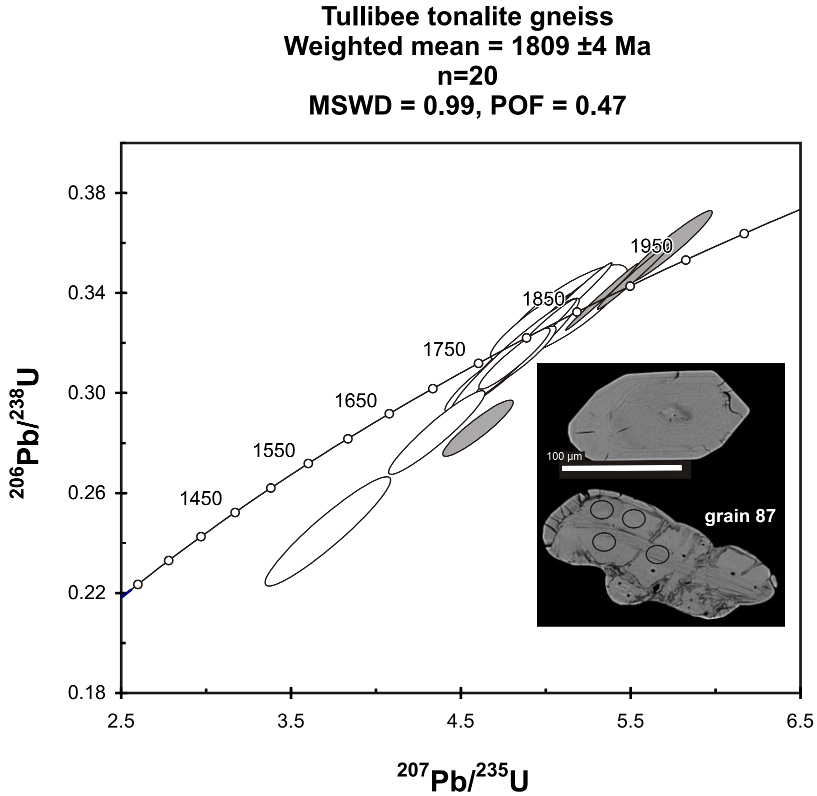

Figure GS-8-5: *Concordia diagram presenting sensitive high-resolution ion microprobe (SHRIMP) U-Pb results for Tullibee Lake tonalite gneiss; inset is a backscattered electron (BSE) image of a typical zircon from this sample (upper) and anomalous zircon grain 87 (lower) along with the locations of SHRIMP analyses. Data from grain 87 are shown by the light grey ellipses and are excluded from the calculation of the weighted mean.* See *text for discussion.*

in northeast Saskatchewan, where basement inliers are dominated by 2.57–2.59 Ga crystallization ages and basal Wollaston Domain detritus is dominated by 2.51–2.6 Ga zircon (Hamilton and Delaney, 2000).

By examining the correlation of the Muskoseu and Burntwood River sedimentary rocks (Figure GS-8-6c, b, respectively) with the Ospwagan Group (Figure GS-8-6a), it may be possible to shed light on the question of a continuous or rifted Superior craton. A stratigraphic and geochemical comparison of Ospwagan Group rocks from Thompson, Burntwood Group metasedimentary rocks and Muskoseu metasedimentary rocks suggests that the latter are broadly similar to the Ospwagan Group sedimentary rocks, with some problematic aspects (Zwanzig et al., 2006). That the Ospwagan Group is dominated by 2.7 Ga detritus, while the sedimentary rocks within the inliers regularly exhibit a significant, additional older detrital zircon component can be accounted for by changes in the source region (Figure GS-8-6). Similar detrital zircon ages have been documented in metasedimentary rocks of the Assean Lake Crustal Complex, a crustal block inferred to be exotic to the Superior craton prior to accretion to the margin at 2.6 Ga (Figure GS-8-6; Böhm et al., 2003). Another difference is that the isotopic disturbance in the basement and cover inlier samples is not observed in the Ospwagan Group rocks. This suggests a distinct metamorphic history for pre-Kisseynew Domain rocks west of Thompson. As the ca. 1.81 Ga zircons from the basement and cover samples exhibit 'normal' isotopic behaviour, the authors infer that a high-grade metamorphic event must have occurred before this time. If these rocks are correlative with the Ospwagan Group, they would have been deposited sometime after 1974 Ma (Hamilton and Bleeker, 2002), constraining an episode of high-grade metamorphism of the basement-cover assemblage to between 1.97 and 1.81 Ga. If the metamorphic event is also responsible for the granulite-grade assemblages in the Burntwood Group metasedimentary rocks and the formation of the structural culminations that preserve the basement rocks, the timing could be further constrained to between 1.83 and 1.81 Ga, the maximum age of deposition of the Burntwood Group (Percival et al., 2005, 2006; Growdon et al., 2006). If it can be demonstrated that detrital zircon from a basal sample of the Burntwood Group also exhibits the unusual analytical behaviour, this hypothesis would be strengthened. Should Burntwood Group zircon not exhibit this behaviour, an older, high-grade metamorphic event is needed to explain the data. A metamorphic event older than 1974 Ma would exclude a correlation with the Ospwagan Group *sensu stricto* and would be consistent with (but not exclusive to) earlier deposition on an isolated continental fragment.

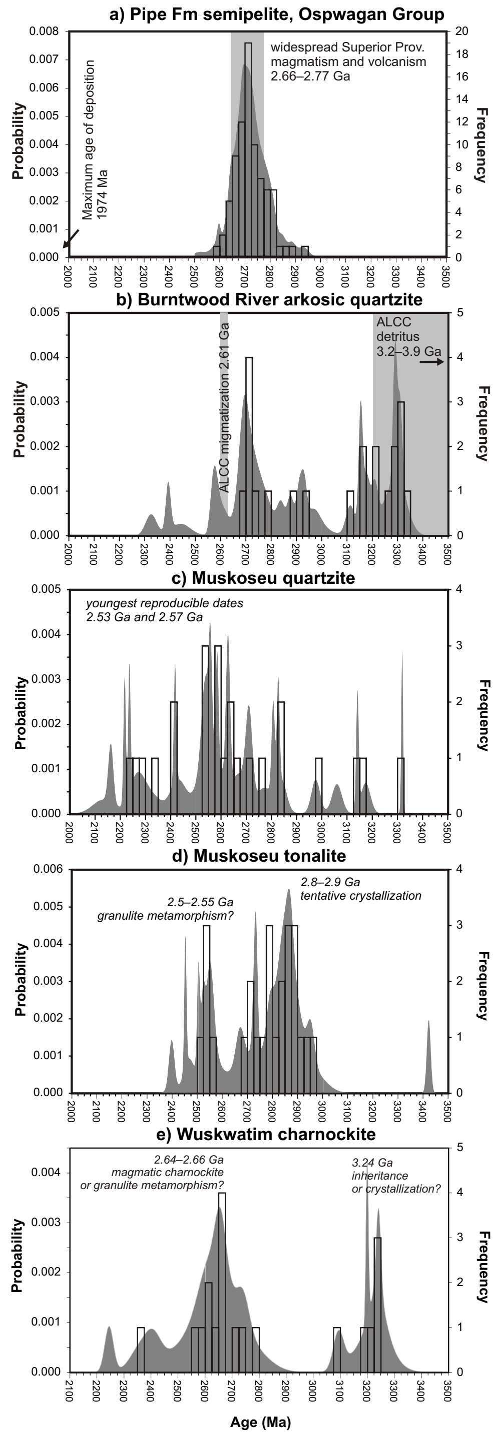

Figure GS-8-6: *Comparison of pre-Kisseynew Domain basement and cover ages with typical Superior craton and Ospwagan Group detrital zircon ages. Probability density curves illustrate the entire dataset, including replicate analyses and discordant results. Overlaid histograms do not include replicate analyses or discordant results. Sources of data:* ***a)*** *Rayner et al. (2005); maximum age of Ospwagan deposition data from Hamilton and Bleeker (2002); widespread Superior Province magmatism data from Corfu and Davis (1992);* ***b)*** *Zwanzig et al. (2006); abbreviation: ALCC, Assean Lake Crustal Complex; data from Böhm et al. (2003);* ***c), d), e)*** *this study.*

A greater understanding of early metamorphic events and the processes involved in the isotopic disturbance observed in pre–1.81 Ga zircon grains from the Kisseynew Domain inliers is required, as the current evidence does not rule out the possibility that these supracrustal rocks correspond to an early cover sequence preserved on a rifted Superior margin fragment.

Economic considerations

Uranium-lead zircon geochronology results presented provide compelling evidence of Archean basement rocks present in the northeastern quadrant of the Proterozoic Kisseynew Domain. This raises the possibility of enhanced diamond potential if the Archean mantle lithosphere is preserved. Although a definitive correlation between Ospwagan-type supracrustal rocks within the Kisseynew Domain and Ospwagan Group *sensu stricto* has not been made, the possibility of Thompson-type orebodies is still present. Although the details differ, the general lithological association of basement and supracrustal rocks (including iron formation and mafic sills) in the Wuskwatim Lake–Burntwood River area and possibly the Tullibee–Neuls lakes area is similar to that observed in the Thompson Nickel Belt.

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