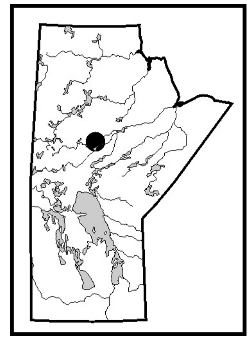
GS-11 Detrital zircon provenance of the Pipe Formation, Ospwagan Group, Thompson Nickel Belt, Manitoba, NTS 63O8

by N. Rayner[1], H.V. Zwanzig and J.A. Percival[1]



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Summary

Two samples of the Pipe Formation in the Thompson Nickel Belt were processed for U-Pb sensitive high-resolution ion microprobe (SHRIMP) ages of detrital zircons in an attempt to further constrain the age of deposition of the Ospwagan Group, which hosts the nickel deposits. A pelite from the Thompson mine and semipelite from the Pipe II pit both yielded a population of only Neoarchean grains with the primary age mode of ca. 2.7 Ga, similar to previous work on the entire Ospwagan Group sediment section. No Proterozoic grains were found to confirm the maximum age of deposition of <1974 Ma suggested by a single zircon grain in a previous study. The robust nature of the age distribution, however, suggests that detrital zircon modes are useful in distinguishing the Ospwagan Group from superficially similar rocks that may belong to a different sequence and are unlikely to contain nickel deposits.

Introduction

World-class nickel deposits make the Thompson Nickel Belt (TNB) an economically vital segment of the Superior Boundary Zone, where it adjoins the Trans-Hudson Orogen in Manitoba. The deposits occur in the highly metamorphosed and deformed Ospwagan Group sedimentary cover, which was folded with the remobilized Archean basement that extends into the Superior craton to the southeast. Most deposits are hosted in the Pipe Formation, a metapelite and iron formation unit in the central part of the Ospwagan Group. They are always associated and commonly in contact with ultramafic bodies that are interpreted to have been the source of the nickel for the deposits. Parts of the Pipe Formation are highly sulphidic and provided the sulphur for these magmatogenic deposits (Bleeker, 1990).

Despite considerable previous work, the age of the lower Ospwagan Group is poorly constrained between the youngest detrital zircon at ca. 2530 Ma (Hamilton and Bleeker, 2002) and intrusions crystallized at ca. 1.89 Ga (Zwanzig et al., 2003; Percival et al., 2004). A single grain of Paleoproterozoic zircon dated at ca. 1974 Ma was recovered from the upper part of the sequence by Hamilton and Bleeker (2002) along with a population of otherwise Neoarchean detrital grains with the primary age mode of ca. 2.7 Ga, but this Paleoproterozoic age needs confirmation. Other dating attempts also recovered large populations of only Archean zircons (N. Machado, pers comm, 2000; Zwanzig et al., 2001). The cited U-Pb geochronology and Nd isotope work of Zwanzig and Böhm (2002) show that the provenance of the sediments was the Archean Superior craton to the southeast of the TNB.

To this end, detrital zircon provenance profiles have been determined using the sensitive high-resolution ion microprobe (SHRIMP) for two new samples of the Pipe Formation. The majority of the data were collected in reconnaissance mode (six isotopes per four scans). This allowed analysis of a greater number of grains in a search for Paleoproterozoic detrital zircon. Ages of metamorphic overgrowths on the detrital zircons were also determined by SHRIMP and are consistent with high-grade metamorphism at ca. 1.78 Ga as reported by other workers (e.g., Bleeker, 1990a; Hamilton and Bleeker, 2002). New monazite ages determined by thermal ionization mass spectrometry (TIMS) are slightly younger.

A crystallization age of 1880 ±5 Ma for the ultramafic rocks, and therefore of the mineralization, was previously determined from zircon in a pyroxenite (Hulbert et al., 2005). Despite a similar approximate Re-Os age from sulphide ores (Hulbert et al., 2005), this has not been fully accepted by all geologists working in the TNB. To eliminate this disagreement, one of the new samples from the Pipe Formation was taken at the contact with a mineralized ultramafic body in hopes of finding zircon overgrowth formed during contact metamorphism on the detrital grains.

Geological background

The TNB forms the southeastern external zone of the Trans-Hudson Orogen in Manitoba (Figure GS-11- 1). It comprises a basement of polydeformed Archean orthogneiss and migmatite, tightly folded with the Ospwagan Group cover sequence that is believed to have been deposited during the Paleoproterozoic on an outer shelf and upper slope environment (Zwanzig et al., work in progress, 2006). The Superior Boundary Zone along the TNB is tectonically unique in having experienced

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, nrayner@nrcan.gc.ca

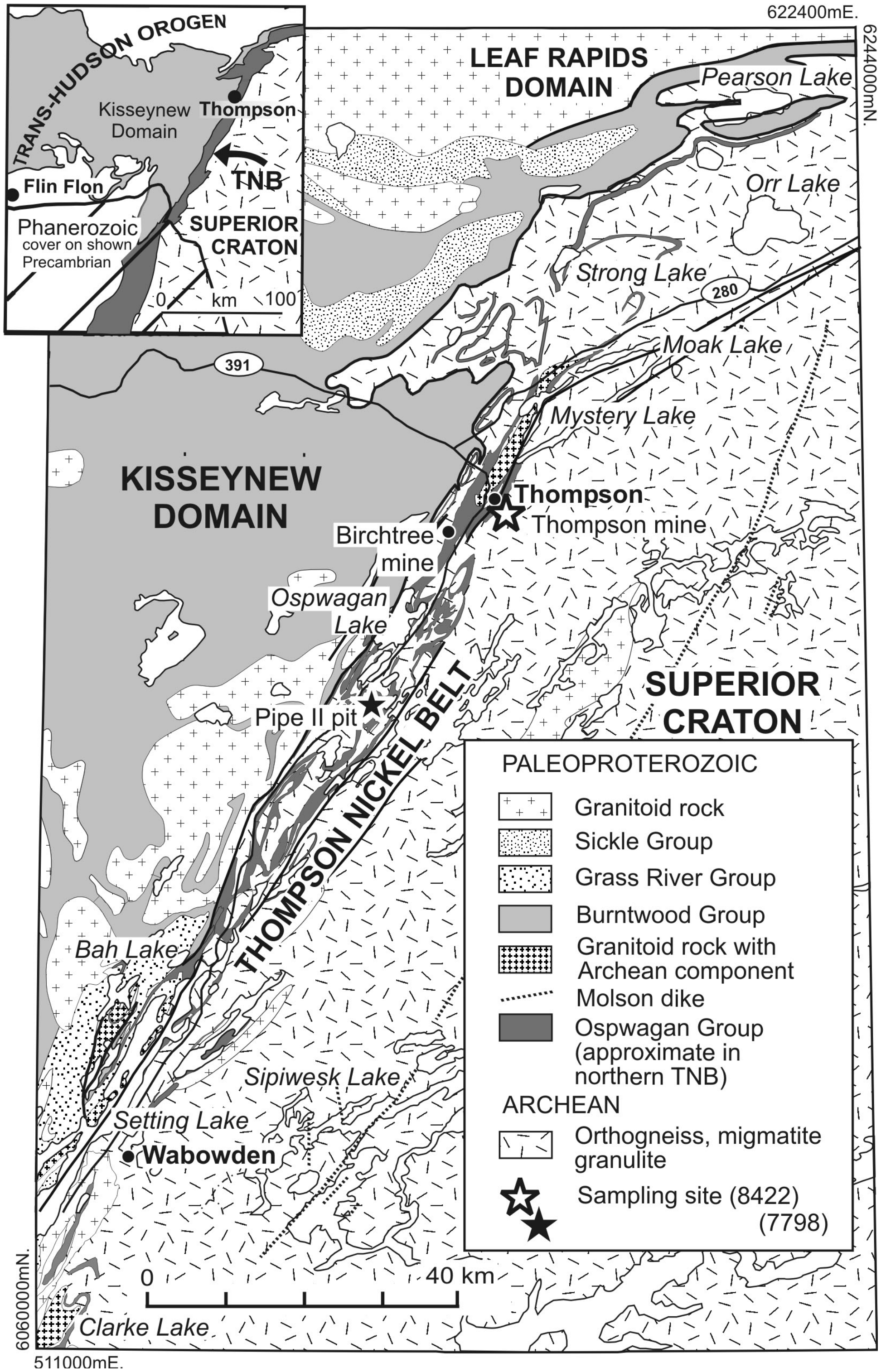


Figure GS-11-1: *Simplified geological map of the Thompson Nickel Belt showing the locations of detrital zircon samples.*

1890 to ca. 1880 Ma felsic calcalkaline plutonism and deformation, interpreted to have taken place in a continental arc setting (Percival et al., 2004, 2005). The 1883 Ma Molson mafic dike swarm (Heaman et al., 1986) was intruded within, and southeast of, the TNB. A fringing, coarse siliciclastic overlap succession between the TNB and the internal zone of Trans-Hudson Orogen (Grass River Group of Zwanzig, 1997) is estimated to have been deposited between 1.85 and 1.83 Ga, similar to its correlatives (the Missi and Sickle groups). This is interpreted to mark the onset of collision with the Superior craton (White et al., 2002; Zwanzig and White, 2002) and the structural juxtaposition with the Burntwood Group that underlies much of the Kisseynew Domain in the internal zone. The intrusion of stitching alkaline to sanukitoid plutons at 1835 Ma supports the proposed age of collision (Zwanzig et al., 2003). Intense syn- to postcollisional deformation involved thrusting from the internal zone followed by the formation of fold nappes (Bleeker, 1990a, b; Zwanzig and Böhm, 2002) and granite to syenite intrusion. Tight upright folds formed during later metamorphism and intracontinental transpression lasting to 1770 Ma and younger (Bleeker, 1990a, b). Metamorphic grade ranges from middle amphibolite to biotite-granulite facies. The thermotectonism has so modified the TNB that no single rigorous model for its age and origin exists.

Despite these problems, the Ospwagan Group is known to lie unconformably on the Superior Province basement. A regional compilation (Thompson Nickel Belt Geology Working Group, 2001a, b, c, d) confirms the original subdivision of the group into five conformable formations (Bleeker, 1990b; Bleeker and Macek, 1998) that can be recognized along at least 200 km of strike length. Although strongly deformed and attenuated, the sequence is generally coherent and can be crossed from the basal unconformity into the synclinal core of the large regional folds (Bleeker, 1990a, b; Zwanzig, 1998). The sequence consists of clastic and chemical sedimentary rocks capped by mafic volcanic rocks. Detailed sections of Ospwagan Group rocks were established on clean exposures on the shoulders of the Pipe II pit and Thompson pits (Figure GS-11-2), and from lakeshore exposures (Bleeker and Macek, 1988; Bleeker, 1990b; Zwanzig, 1997, 1999). From these separate exposures, an almost complete lithostratigraphic succession has been reconstructed as summarized in Figure GS-11-2.

Sample details

Detrital zircons were recovered from two Ospwagan Group samples. The first is a Pipe Formation semipelite (PBA03-35, Geological Survey of Canada [GSC] lab number 7798), collected from the shoulder of the Pipe II pit. The 6 cm wide sample was sawn out of a section through approximately 10 semipelite beds (Figure GS-11-3). Zircons recovered from sample 7798 vary from large euhedral prisms to well-rounded ovoid grains to small euhedral to subhedral prisms. All morphologies exhibit moderate to strong oscillatory zoning and most have very thin (<5 µm), high U rims. The rims are too narrow to be dated by the ion probe but based on their appearance and ubiquity they likely represent Hudsonian metamorphic growth.

The second sample is a pelite, also from the Pipe Formation, in contact with a mineralized ultramafic intrusive body (provided by Inco Limited, sample number 768262, GSC lab number 8422). The sample is from the hangingwall side of an ultramafic unit in the north end of the Thompson mine, 2500 ft. level. This sample was initially collected in an attempt to indirectly determine the age of ultramafic magmatism by dating U-bearing metamorphic minerals that were thought to have formed during contact metamorphism. While the authors did not succeed in constraining the age of contact metamorphism, the results from this sample provide constraints on the detrital population and Trans-Hudson metamorphism. Zircons recovered from sample 8422 are mainly prismatic

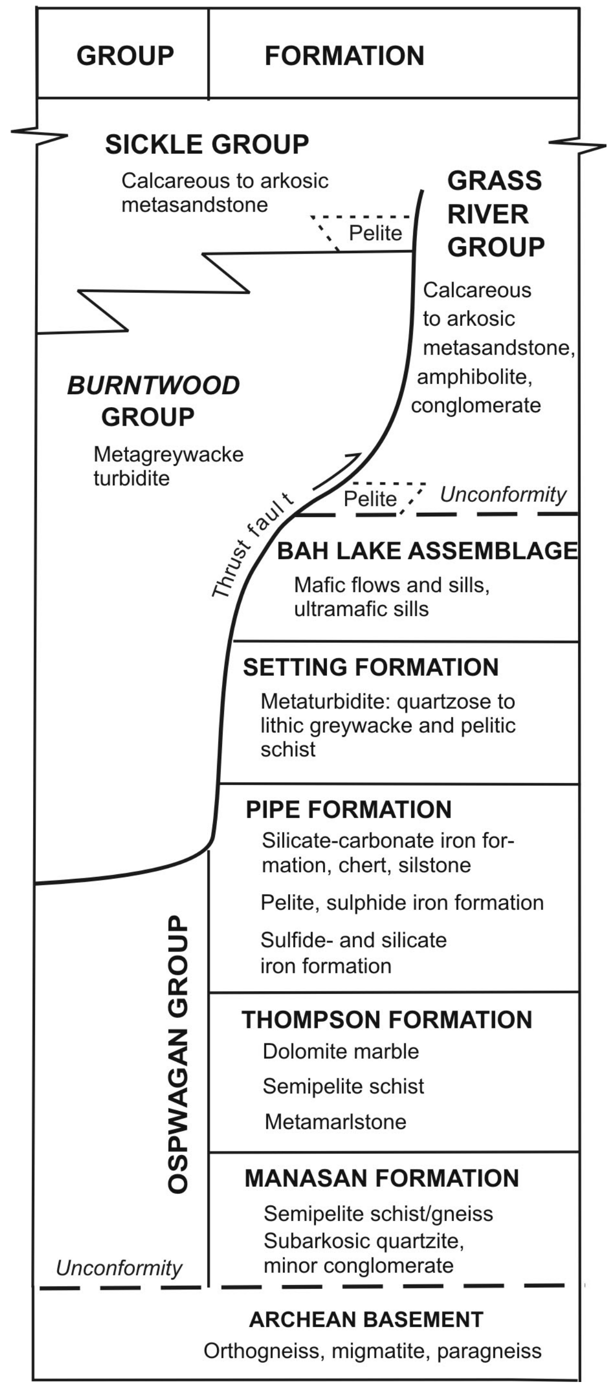


Figure GS-11-2: *Succession of supracrustal rocks in the Thompson Nickel Belt and adjacent part of the Kisseynew Domain.*

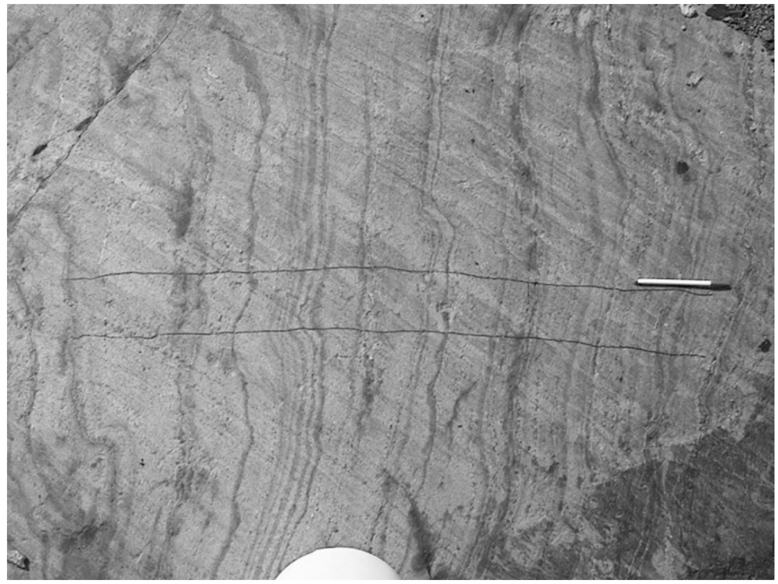


***Figure GS-11-3:** Photograph of sample site at Pipe II pit showing Pipe Formation semipelite with planned cutting lines indicated (16 cm pen for scale).*

with oscillatory-zoned, high U overgrowths and low U, unzoned cores. The monazite is pale yellow and platy with few inclusions or fractures. Biotite and other minerals that were adhered to the margins of the monazite were removed with brief air abrasion.

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, alteration, etc.) were characterized with backscattered electrons (BSE) utilizing a Cambridge Instruments scanning electron microscope (Figure GS-11-4). Analyses were conducted using an $^{16}O^-$ primary beam. Details on the spot size, the primary beam intensity, the species, the number of scans and the U-Pb calibration error can be found in the footnotes of tables 1 and 2 in DRI2006004[2]. Off-line data processing was accomplished using 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 plotted in the figures have errors reported at the 2σ uncertainty level.

Monazite ages determined by isotope dilution thermal ionization mass spectrometry (ID-TIMS) at the Geochronology Laboratory, Geological Survey of Canada follow the sample dissolution and chemical methods as described in Parrish et al. (1987) and Davis et al. (1998). Individual grains were spiked with a mixed ^{205}Pb-^{233}U-^{235}U tracer solution calibrated to ±0.1% against a gravimetric solution and dissolved in high-pressure bombs in 6 N HCl. Data reduction and error propagation follow methods outlined in Roddick (1987). Uranium and lead isotopic ratios were measured using a Thermo Triton™ mass spectrometer operated in static multicollection mode. The ^{205}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb isotopes were measured simultaneously in Faraday collectors, with ^{204}Pb in an axial ion counting secondary electron multiplier. A Pb mass fractionation correction of 0.10 ±0.04%/amu was applied as determined by replicate analyses of the NBS981 standard. Uranium fractionation was corrected using the ^{233}U-^{235}U double spike and was typically in the range of 0.12%/amu.

Results

The primary goal of studying sample 7798 was to try to confirm the presence of Paleoproterozoic material in the Ospwagan Group as suggested by the single zircon identified by Hamilton and Bleeker (2002), rather than to precisely constrain the age and composition of the Archean zircons. For this reason, only a small number of grains (n=13) were analyzed using the typical ten isotopes per five scans routine of SHRIMP dating. The majority of the data (n=80) were collected in reconnaissance mode (six isotopes per four scans). This allowed analysis of a greater number of grains, but the dataset is of lower precision and does not include Th compositional data.

The combined SHRIMP results (typical and reconnaissance modes) for sample 7798 are presented in DRI2006004, Table 1 and plotted in Figure GS-11-5. All

[2] MGS Data Repository Item DRI2006004, containing the sensitive high-resolution microprobe (SHRIMP) U-Pb detrital results for sample 7798, Pipe Formation, Pipe II pit, and the SHRIMP and thermal ionization mass spectrometry (TIMS) data for sample 8422, Pipe Formation, Thompson mine, 2500 ft. level used to compile this report, is available on-line to download free of charge at 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.

data are included in the concordia diagram; however, 12 of the analyses are excluded from the cumulative probability curve as they are greater than 5% discordant. The $^{207}Pb/^{206}Pb$ age of discordant zircons cannot be relied upon to provide an accurate representation of the age of the detritus; discordant results can only be considered as minimum ages. Concordant ages range from 2595 to 2934 Ma and have a dominant mode at ca. 2700 Ma. Of the 82 concordant zircons, only four give ages in excess of 2825 Ma. The data clearly show that no Proterozoic grains were present in the sample population and that the primary age mode is the same as for the previous work (Hamilton and Bleeker, 2002).

The original aim for sample 8422 was to determine the timing of contact metamorphism. Evaluating the detrital population was not a high-priority objective and therefore detrital ages were determined on only a small number of grains. This was done in reconnaissance mode and in this instance a U-Pb calibration was not conducted. For this reason only, $^{207}Pb/^{206}Pb$ ages are available and it is not possible to evaluate the degree of concordance of the results. The ages reported here assume concordance. The detrital ages range from 2555 to 2748 Ma, with the prominent mode (n=4) at 2660 Ma (Figure GS-11-6a).

Eight high U, oscillatory-zoned zircon rims from sample 8422 were analysed using the ion probe. The data are presented in DRI2006004, Table 2 and shown graphically in Figure GS-11-6b. The weighted mean $^{207}Pb/^{206}Pb$ age of the rims is 1777 ±17 Ma (2σ, mean standard weighted deviate [MSWD] = 1.4, probability = 0.21).

The zircon metamorphic ages are also supported by monazite TIMS results. Three monazite fractions are between 0.2 and 0.4% discordant, and range from 1769 to 1773 Ma. The three fractions do not overlap within error, suggesting some geological scatter. The results can be found in DRI2006004, Table 2 and Figure GS-11-6b.

Discussion

Detrital zircons from two samples of the Pipe Formation — one at the Pipe II pit, the other at the Thompson mine — contain only Archean zircons. No Paleoproterozoic zircons were identified that would help constrain the maximum age of deposition. Instead, the age of the detritus indicates a source from the Superior craton to the east. The zircons range in age from 2555 to 2934 Ma across both samples, with the dominant age mode at ca. 2.7 Ga. While only a small subset of zircons from the Thompson mine pelite was analyzed, a preliminary conclusion is that the provenance of the pelite and the Pipe II pit semipelite are similar. The single mode at 2.7 Ga is the same as that determined from the Ospwagan Group in earlier studies of a considerably larger combined population that sampled the Ospwagan Group from the bottom to the top (N. Machado, pers comm, 2000; Zwanzig et al., 2001; Hamilton and Bleeker, 2002). These data also provide a maximum age of sedimentation of 2529 Ma from the majority of the sequence or ca. 1974 Ma from a sample high in the stratigraphy (Hamilton and Bleeker, 2002). The unimodal age distribution, which extends laterally along the TNB and vertically throughout the Ospwagan Group, indicates a Neoarchean provenance, probably

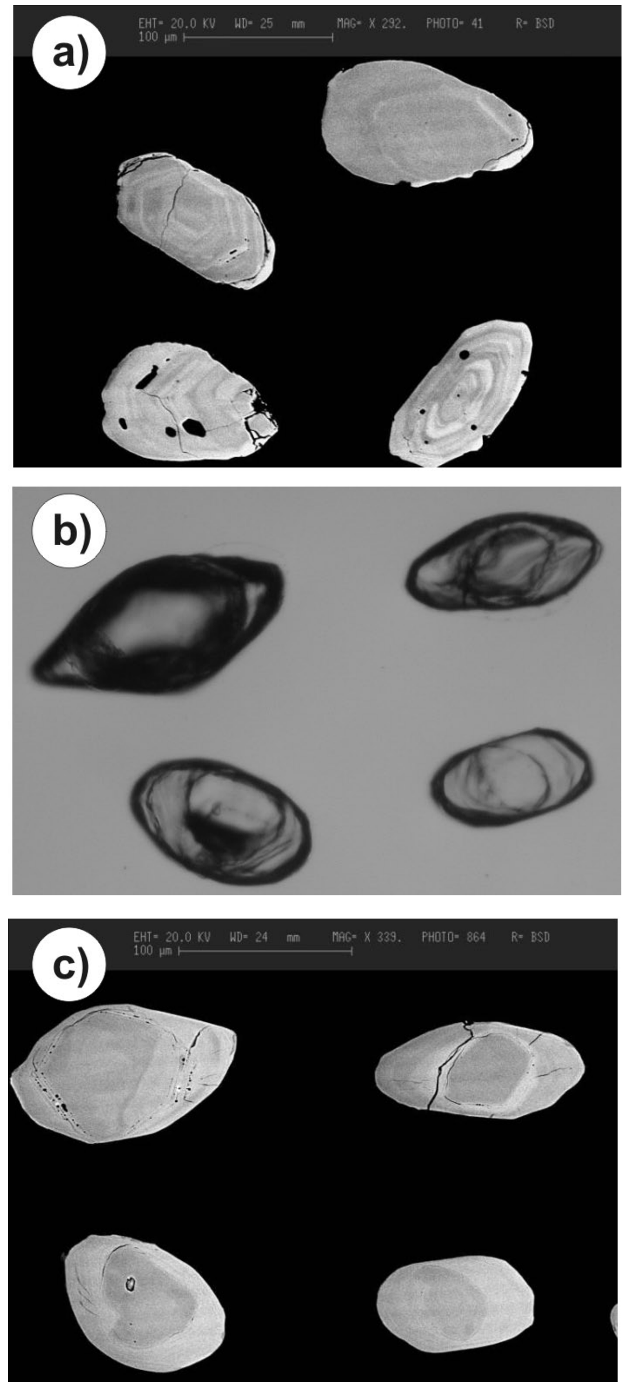


*Figure GS-11-4: Zircon images: **a)** backscattered electron (BSE) image of representative zircon grains from sample 7798 (Pipe II pit). Note thin, high U (bright in BSE) overgrowths on the two upper grains. **b)** Transmitted light image of representative zircon grains from sample 8422 (Inco pelite). Note thick overgrowths around rounded cores. **c)** BSE image of zircons shown in b).*

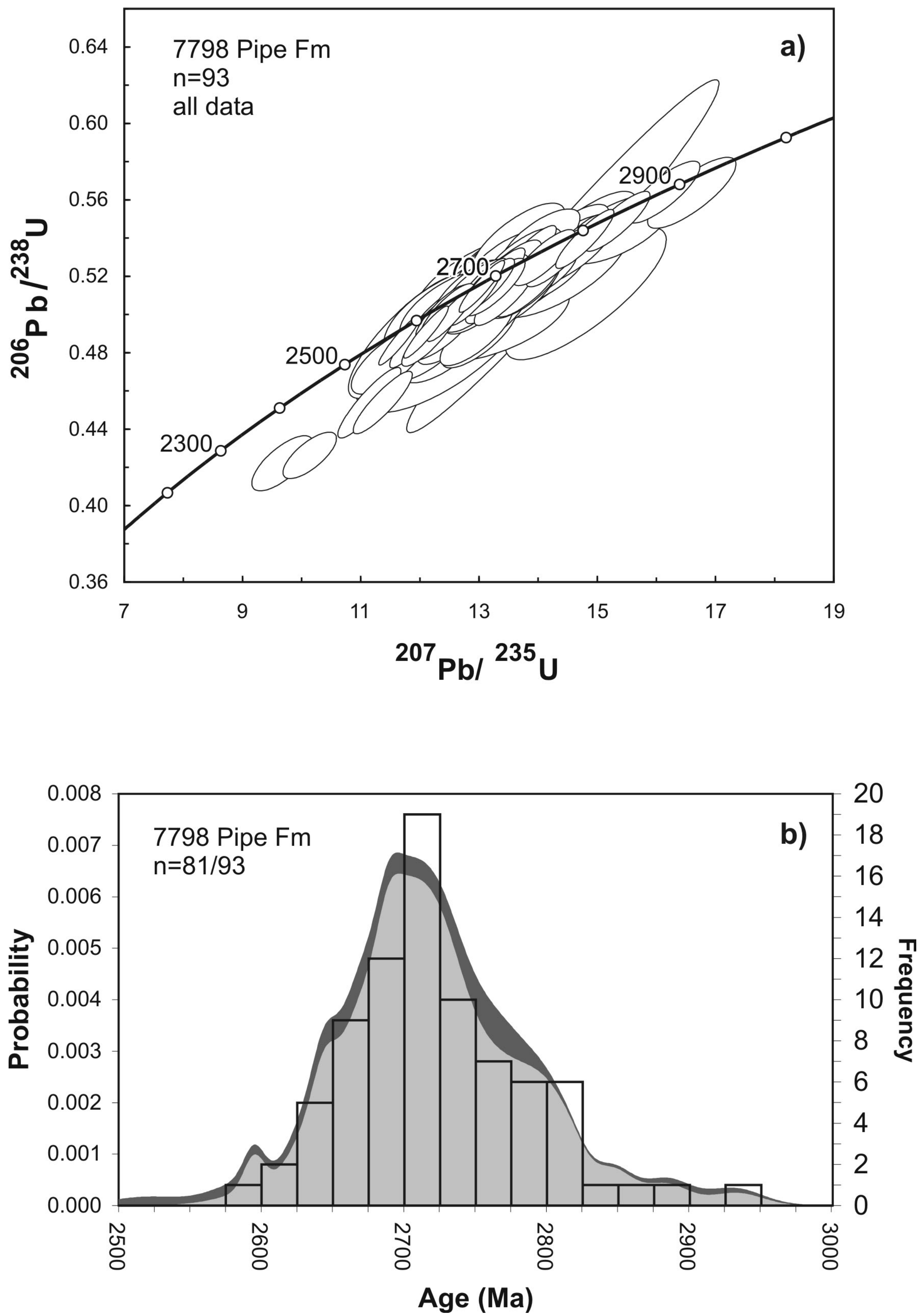
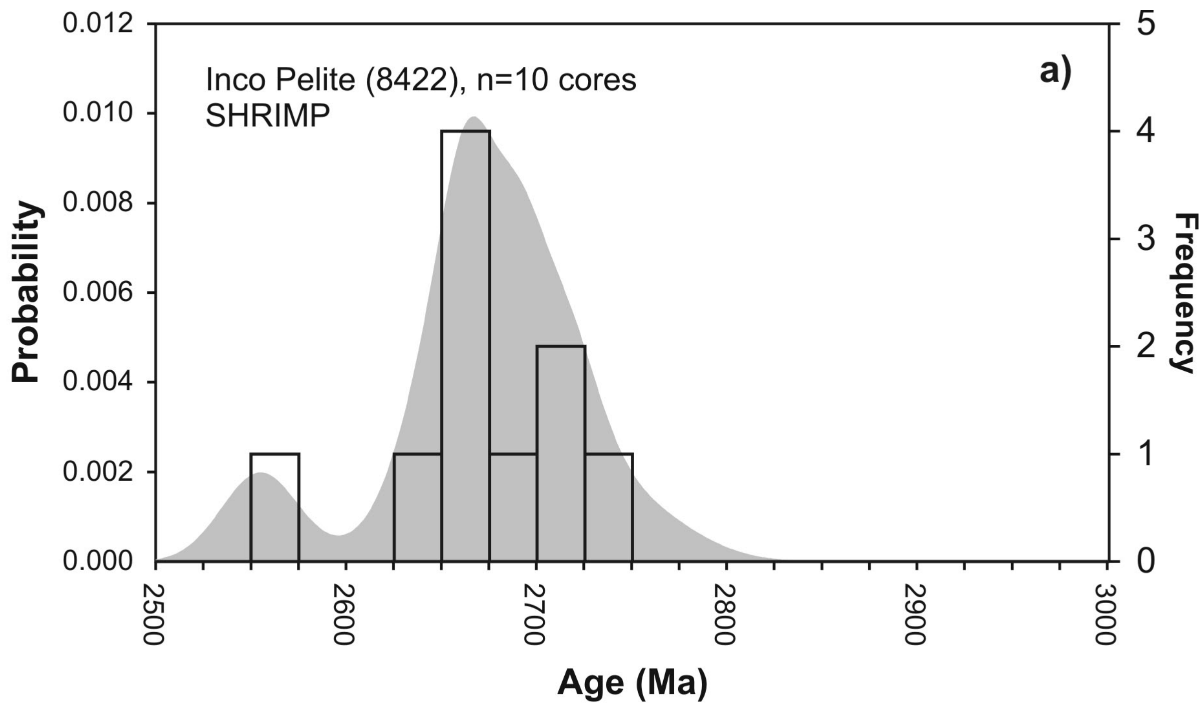


Figure GS-11-5: a) *Concordia diagram illustrating detrital zircon results for sample 7798 (Pipe II pit). All data (n = 93) are plotted regardless of degree of concordance. Ellipses are plotted at the 2σ uncertainty level.* ***b)*** *Cumulative probability curve and overlying histogram for detrital zircon results for sample 7798. All data is shown by the dark grey curve. Light grey curve and histogram are defined by data that is less than 5% discordant (n = 81).*



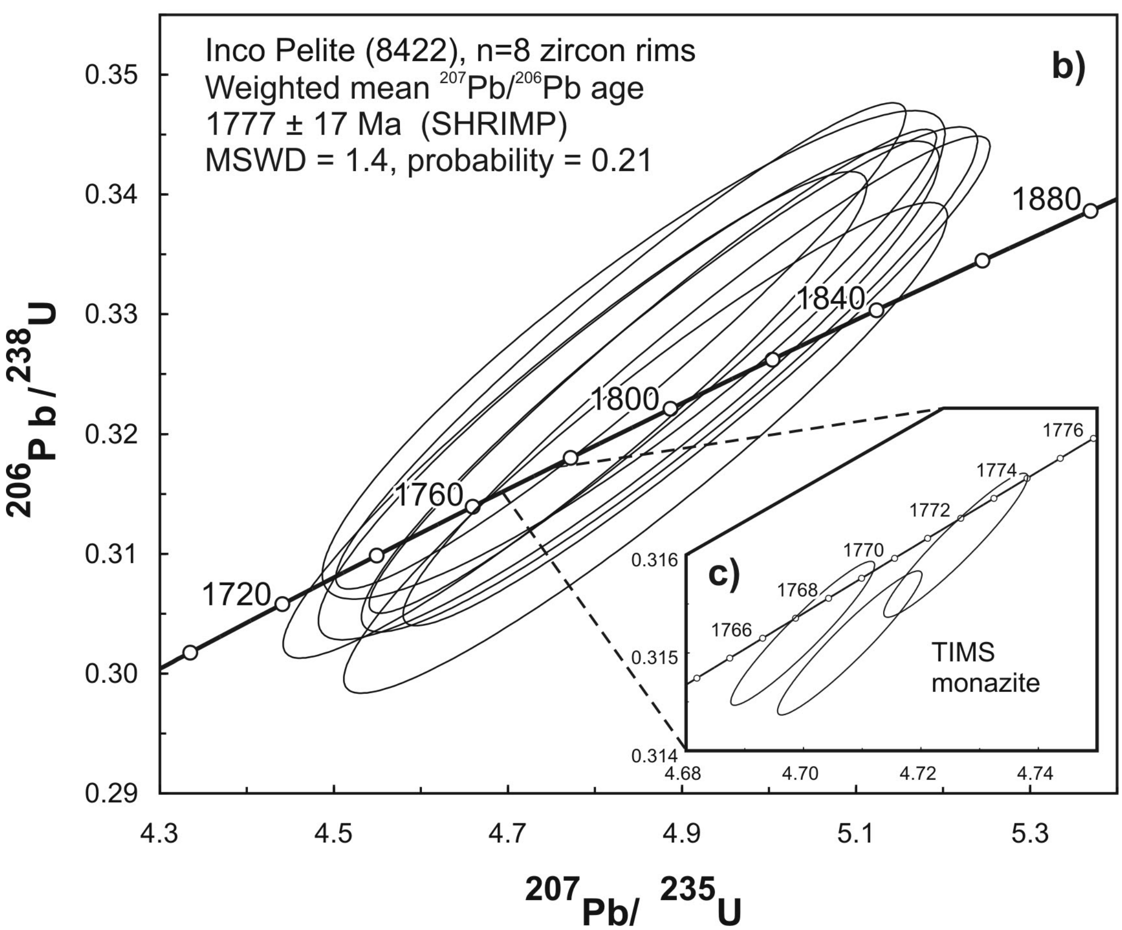


Figure GS-11-6: ***a)*** *Cumulative probability curve and overlying histogram for detrital zircon cores from sample 8422 (pelite, Inco, Thompson mine). All data are included in the plot and are assumed to be concordant.* ***b)*** *Concordia diagram illustrating the timing of metamorphism in sample 8422. Dominant image displays sensitive high-resolution ion microprobe (SHRIMP) results from high-U, low-Th/U overgrowths; inset presents monazite thermal ionization mass spectrometry (TIMS) results.*

from a single terrane. The robust nature of the age distribution suggests that detrital zircon modes are useful in distinguishing the Ospwagan Group from superficially similar rocks that may belong to a different sequence (*see also* Zwanzig et al., GS-9, this volume).

The timing of peak metamorphism with growth of monazite and zircon rims in the Pipe II pit area is ca. 1770 Ma. The rims exhibit low Th/U typical of metamorphic zircon but display oscillatory zoning, which suggests a fluid-mediated reaction. The presence of coeval, late-tectonic pegmatite at Thompson (Machado et al., 1987; Bleeker, 1990a) and across the orogen (Chiarenzelli et al., 1998, Rayner et al., 2005) is consistent with a fluid-rich environment.

Economic considerations

The simple, robust distribution of detrital zircon ages can help to distinguish the nickel-hosting Ospwagan Group from other similar-looking rocks in northern Manitoba and thus delimit areas for further nickel exploration.

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