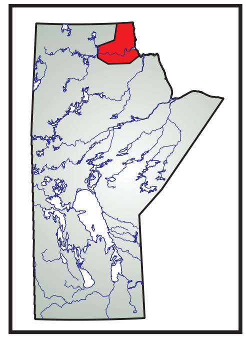
GS-2 Far North Geomapping Initiative: new U-Pb geochronological results from the Seal River region, northeastern Manitoba (parts of NTS 54L, M, 64I, P)

by N. Rayner[1]



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Summary

The Manitoba Geological Survey's Far North Geomapping Initiative includes collaboration with the Geochronology Laboratory of the Geological Survey of Canada under the Geo-mapping for Energy and Minerals (GEM) program. As part of this collaboration, this report presents new U-Pb zircon ages from 16 plutonic, volcanic and sedimentary rocks from the Seal River region in far northeast Manitoba. The U-Pb geochronological results presented here and interpreted in the accompanying report (Anderson et al., GS-1, this volume) record a protracted and complex geological history. Mesoarchean (2901 ±5 Ma; 2860 ±4 Ma) basement rocks along with remnants of older, Paleoarchean (3.5 Ga) material have been identified in a discrete crustal block (the Seal River Complex) in the central portion of the map area. Emplacement of a voluminous felsic plutonic suite occurred in the Neoarchean between 2570 Ma and 2550 Ma and coincides in time with the crystallization age of a rhyolite flow (2570 ±3 Ma) overlying the Seal River Complex. Of particular importance for regional tectonic correlations is a new chronology of four sedimentary sequences. Uranium-lead zircon ages indicate a Neoarchean depositional age (<2.70 Ga; >2.57 Ga) for the fluvial-alluvial sequence 1, which includes mineralized quartz pebble conglomerate. Provenance profiles also provide maximum depositional ages for overlying marginal marine to marine siliciclastic rocks of sequence 2 (<2.5 Ga), sequence 3 (<1.98 Ga) and sequence 4 (<1.88 Ga), and thus provide important new constraints for regional stratigraphic correlations and paleotectonic reconstructions.

Introduction

New mapping of Manitoba's far north was initiated in 2008 with a scoping study and continued with a focused effort in 2009 and 2010 to answer fundamental questions pertaining to the Precambrian geology and mineral potential of northern Manitoba. Manitoba's far north provides key exposures of metasedimentary cover successions, including rare exposures of metavolcanic rocks, and contains several important mineral occurrences. This report presents new U-Pb geochronological results from 16 samples collected during the 2008 and 2009 field seasons that provide absolute age constraints for the revised geological map of the Seal River region (see Anderson et al., GS-1, this volume; Anderson et al., 2010).

Regional geology

In northeastern Manitoba, the southeastern margin of the Hearne craton is divided into several geological domains distinguished by the proportions of cover and possible basement rocks, and to a lesser extent, by their structural trends and metamorphic grade. The area investigated in 2008 and 2009 includes portions of the Nejanilini and Seal River domains, and is bounded to the south by the Wathaman-Chipewyan plutonic complex (Figure GS-2-1). The Nejanilini Domain is dominated by granulite-grade metaplutonic rocks, with minor enclaves of metasedimentary rocks, and is interpreted to include vestiges of the Meso- to Neoarchean basement of the Hearne craton. The Seal River Domain, in contrast, is characterized by the presence of widespread metasedimentary rocks of generally lower metamorphic grade (the Great Island Group of Schledewitz, 1986), which is newly subdivided into four chronologically distinct sequences (Anderson et al., GS-1, this volume).

Within the Seal River Domain, Mesoarchean and Neoarchean basement rocks at the Hearne craton margin are composed of multicomponent orthogneiss and heterogeneous biotite (±hornblende) granite–granodiorite that are discordantly cut by dikes of biotite granodiorite, hornblende diorite, feldspar porphyry and diabase, collectively referred to as the Seal River intrusive complex by Anderson et al. (2009a, b), but is now referred to as the Seal River Complex (Anderson et al., GS-1, this volume). Separating these dominantly plutonic rocks from younger siliciclastic sequences are mafic to felsic volcanic, volcaniclastic and epiclastic rocks of the Sosnowski Lake assemblage, which were described in detail by Anderson et al. (2009a) based on mapping in the Great Island area. This assemblage is in turn unconformably overlain by structurally complex, though relatively intact, synclinal basins filled with continental and marine siliciclastic rocks previously referred to as the Great Island Group (Schledewitz, 1986; Anderson et al., 2009a), but is now subdivided into four chronologically distinct sequences (1–4) based on new mapping in the eastern Seal River Domain (Anderson

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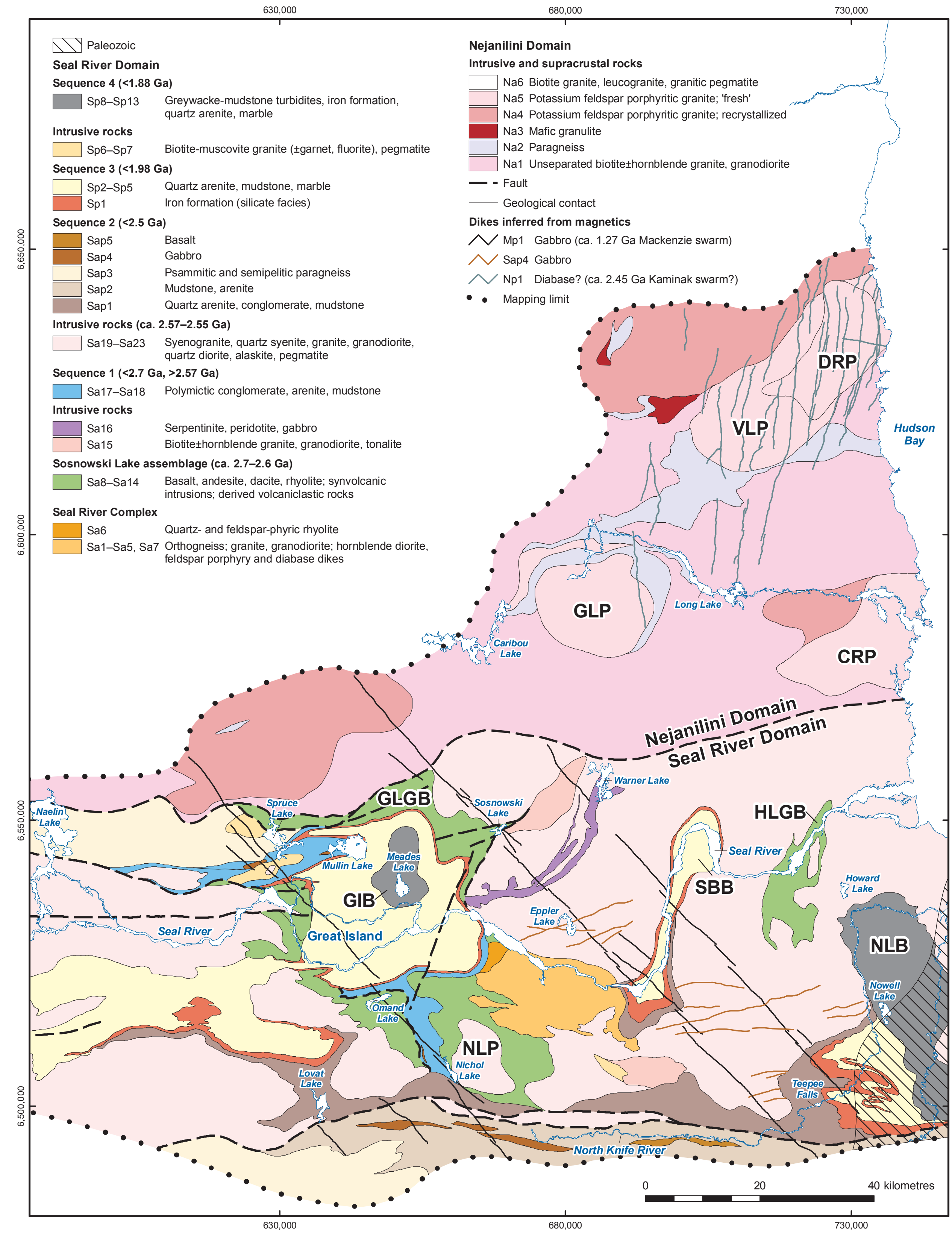

Figure GS-2-1: *Simplified geology of the Seal River region in northern Manitoba (from Anderson et al., 2010). Abbreviations: CRP, Caribou River pluton; DRP, Dickins River pluton; GIB, Great Island basin; GLGB, Garlinski Lake greenstone belt; GLP, Gross Lake pluton; HLGB, Howard Lake greenstone belt; NLB, Nowell Lake basin; NLP, Nichol Lake pluton; SBB, Seal Bend basin; VLP, Vinsky Lake pluton.*

et al., GS-1, this volume). These rocks are thought to be partly correlative with the ca. 2.5–1.9 Ga Hurwitz Group in Nunavut (Aspler et al., 2001; Davis et al., 2005) and the comparatively well-dated ca. 2.1–1.9 Ga Wollaston Supergroup in Saskatchewan (Yeo and Delaney, 2007; Tran et al., 2008). As described by Anderson et al. (GS-1, this volume), intrusive rocks ranging in composition from granite to peridotite are a significant component of the Seal River Domain and provide important constraints on the relative chronology of the principal map units.

Analytical methods

Heavy minerals were separated from most rock samples by standard crushing, grinding and heavy liquid techniques, followed by the sorting of heavy minerals using a Frantz isodynamic separator. Electric-pulse disaggregation (EPD; Rudashevsky et al., 1995) was employed to comminute two of the samples. Zircons analyzed by isotope dilution–thermal ionization mass spectrometry (ID-TIMS) were treated with the chemical abrasion method (Mattinson, 2005) before being submitted for U-Pb chemistry. Dissolution of zircon in concentrated HF, extraction of U and Pb, and mass spectrometry followed the methods described by Parrish et al. (1987). Data reduction and numerical propagation of analytical uncertainties follow Roddick (1987). Analytical blanks for Pb were 1 pg. Results are presented in Table GS-2-1.

Prior to sensitive high-resolution ion microprobe (SHRIMP) analysis, the internal features of the zircons (zoning, structures, alteration, etc.) were characterized with backscattered electrons (BSE) using a Zeiss Evo® scanning electron microscope. Detailed SHRIMP analytical procedures and U-Pb calibration details are given in Stern (1997) and Stern and Amelin (2003). The ion microprobe results were collected on seven separate epoxy mounts with varying instrumental conditions. Specific analytical details for each sample are given in the footnotes of the data table found in Data Repository Item DRI2010004[2]. An O^- primary beam was used in all analytical sessions with an intensity ranging from 3 to 12 nA. The count rates of ten isotopes of Zr+, U+, Th+ and Pb+ were sequentially measured over five scans with a single electron multiplier. The 1σ external errors of $^{206}Pb/^{238}U$ ratios reported in the data table incorporate an error between 1.0 and 1.6% in calibrating the standard zircon (Stern and Amelin, 2003). No fractionation correction was applied to the Pb-isotope data; the common Pb correction used the Pb composition of the surface blank (Stern, 1997). Isoplot v. 3.00 (Ludwig, 2003) was used to generate concordia plots and calculate weighted means. AgeDisplay (Sircombe, 2004) was used to generate probability density diagrams. All ages quoted in the text are given at 2σ.

Results

Seal River Complex

The Seal River Complex is well exposed in shoreline outcrops on the Seal River downstream from Great Island and displays evidence of multiphase diking that is not observed elsewhere in the map area. The distinctive aeromagnetic signature of the complex is suggestive of a discrete crustal block that has been enveloped by younger granitoid intrusions. As described by Anderson et al. (GS-1, this volume), the Seal River Complex is thought to represent a remnant of older crust within the southern margin of the Hearne craton.

Sample 96-09-1177: granodiorite gneiss

This sample was collected from a 5 m thick sheet of homogeneous granodiorite in an outcrop of multicomponent orthogneiss at the type locality of the Seal River Complex downstream from Great Island. Based on crosscutting relationships, this orthogneiss is interpreted as the oldest map unit in the complex. Abundant, elongate to stubby prisms were recovered from the sample, which was disaggregated using the electric-pulse disaggregation (EPD) method. Twenty-one zircons were analyzed by SHRIMP and the weighted mean $^{207}Pb/^{206}Pb$ age of 19 of these analyses is 2901 ±5 Ma, which is interpreted as the crystallization age of the granodiorite (Figure GS-2-2a). The youngest (2803 Ma) and oldest (2930 Ma) results were excluded from the calculation of the mean and are interpreted to reflect minor Pb loss and inheritance, respectively.

Sample 96-08-43-1: biotite granodiorite

The older orthogneiss component of the Seal River Complex is crosscut by irregular dikes and thick sheets of texturally heterogeneous, light pink biotite±hornblende granite and granodiorite, which are in turn crosscut by dikes of light grey biotite granodiorite. A sample of a discordant dike of biotite granodiorite was collected from an outcrop along the north shore of the Seal River, at the type locality east of Great Island. A relatively homogeneous population of euhedral, prismatic zircons were recovered from this sample. Based on their relatively simple appearance, TIMS analyses were carried out on five single-grain fractions treated using the chemical abrasion method (Mattinson, 2005). Three of the five fractions yield concordant or near-concordant results of 2861 Ma, 2858 Ma and 3458 Ma (Figure GS-2-2b). The

[2] MGS Data Repository Item DRI2010004, 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/web/freedownloads.html, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Innovation, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, Manitoba R3G 3P2, Canada

Table GS-2-1: Isotope dilution–thermal ionization mass spectrometry (ID-TIMS) U-Pb results.

							Isotopic Ratios[6]								Ages (Ma)[8]						
Fract.[1]	Description[2]	Wt. (ug)	U (ppm)	Pb[3] (ppm)	$^{206}Pb/^{204}Pb$[4]	Pb[5] (pg)	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{235}U$	±1 σ absolute	$^{206}Pb/^{238}U$	±1 σ absolute	Corr.[7] Coeff.	$^{207}Pb/^{206}Pb$	±1 σ absolute	$^{206}Pb/^{238}U$	±2 σ	$^{207}Pb/^{235}U$	±2 σ	$^{207}Pb/^{206}Pb$	±2 σ	% Disc
96-08-43-1 (Z9851) biotite granodiorite, UTM: zone 14, 687408E 6521150N																					
Z1A	Clr, Or, Pr, Eu	3	120	76	3924	3	0.11	15.67880	0.01768	0.55661	0.00050	0.93559	0.20430	0.00009	2852.6	4.1	2857.4	2.2	2860.8	1.4	0.4
Z1C	Clr, Or, Pr, Eu	2	198	109	3243	3	0.03	14.65485	0.01677	0.52038	0.00047	0.93480	0.20425	0.00009	2700.8	4.0	2793.1	2.2	2860.5	1.4	6.8
Z1D	Clr, Or, Pr, Eu	2	148	98	2599	4	0.17	15.65165	0.01856	0.55668	0.00052	0.92828	0.20392	0.00010	2852.9	4.3	2855.8	2.3	2857.8	1.5	0.2
Z1E	Clr, Or, Pr, Eu	1	165	120	5642	1	0.05	23.46733	0.02720	0.64605	0.00061	0.94741	0.26345	0.00011	3212.8	4.8	3246.5	2.3	3267.4	1.3	2.1
Z1F	Clr, Or, Pr, Eu	5	303	252	27152	2	0.07	29.07763	0.03210	0.70847	0.00062	0.94756	0.29767	0.00012	3452.7	4.7	3456.1	2.2	3458.2	1.2	0.2
96-08-26 (Z9850) charnockite gneiss, UTM: zone 14, 635721E 6562214N																					
Z1	Clr, Co, Pr, fIn	6	221	122	25026	2	0.16	11.07744	0.01217	0.48144	0.00042	0.94756	0.16688	0.00007	2533.6	3.7	2529.7	2.0	2526.5	1.3	-0.3
Z1B	Clr, Co, Pr, fIn	6	113	59	8264	3	0.12	10.77927	0.01191	0.47051	0.00041	0.94529	0.16616	0.00007	2485.8	3.6	2504.3	2.1	2519.3	1.3	1.6
Z1C	Clr, Co, Pr, fIn	4	171	90	21992	1	0.15	10.67641	0.01170	0.46753	0.00041	0.94729	0.16562	0.00006	2472.7	3.6	2495.4	2.0	2513.9	1.3	2.0
Z2	Clr, Co, St, rIn	3	182	88	10849	1	0.12	9.49369	0.01054	0.43826	0.00039	0.94440	0.15711	0.00006	2342.8	3.5	2386.9	2.0	2424.8	1.4	4.0
Z3	Clr, Br, St, rIn	4	131	68	9473	1	0.14	10.58601	0.01219	0.46533	0.00043	0.93424	0.16499	0.00007	2463.1	3.8	2487.5	2.1	2507.5	1.5	2.1
Z4	Clr, Co, Rnd	2	175	81	6525	1	0.13	8.84968	0.01018	0.42173	0.00038	0.93199	0.15219	0.00007	2268.3	3.5	2322.6	2.1	2370.7	1.5	5.1

Notes:
[1] Z = zircon fraction. All fractions were composed of a single grain, chemically abraded for 4 hours following the method of Mattinson (2005).
[2] Zircon descriptions: Co = colourless, Br = brown, Or = orange, Clr = clear, fIn = few inclusions, rIn = rare inclusions, Eu = euhedral, Pr = prismatic, St = stubby prism, Rnd = round
[3] Radiogenic Pb
[4] Measured ratio, corrected for spike and fractionation
[5] Total common Pb in analysis corrected for fractionation and spike
[6] Corrected for blank Pb and U and common Pb, errors quoted are 1σ absolute; procedural blank values for this study: 0.1 pg U and 1 pg Pb;
Pb blank isotopic composition is based on the analysis of procedural blanks; corrections for common Pb were made using Stacey-Kramers compositions.
[7] Correlation coefficient
[8] Corrected for blank and common Pb, errors quoted are 2σ in Ma
The error on the calibration of the Geological Survey of Canada ^{205}Pb-^{233}U-^{235}U spike utilized in this study is 0.22% (2σ).

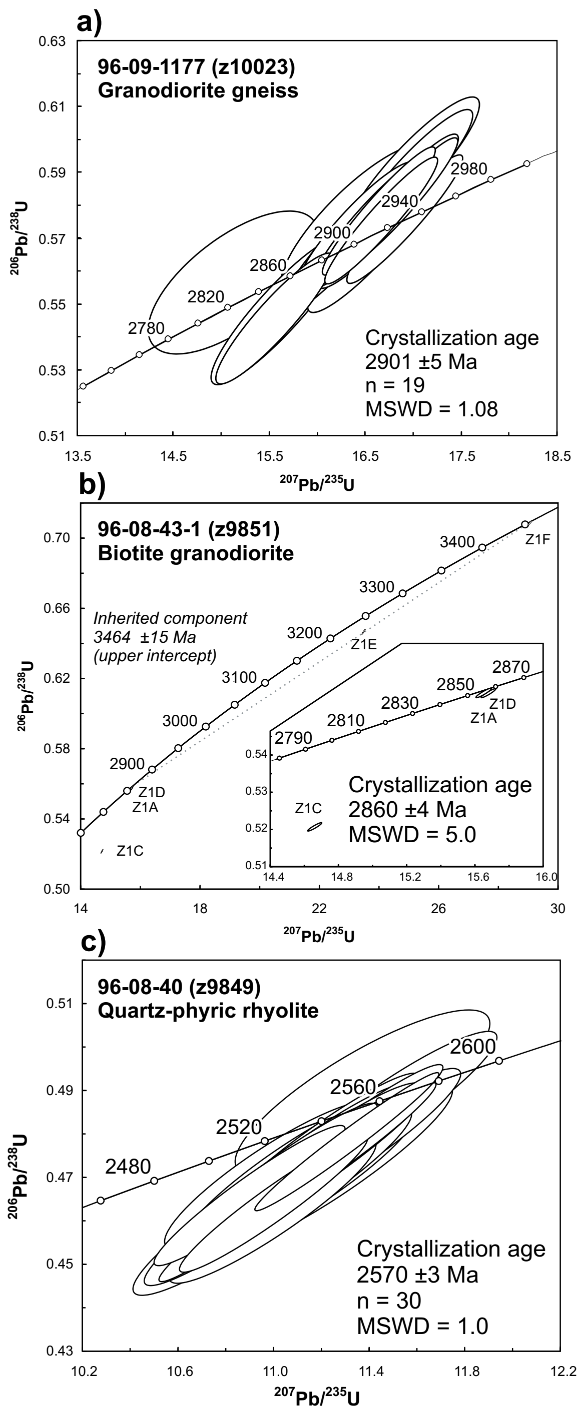

***Figure GS-2-2:** Uranium-lead zircon geochronological results from the Seal River Complex (ellipses on concordia diagrams are plotted at the 2σ uncertainty level; MSWD = mean square of weighted deviates; Geological Survey of Canada lab numbers are given in parentheses for each sample): **a)** concordia diagram showing sensitive high-resolution ion microprobe (SHRIMP) results from sample 96-09-1177; **b)** concordia diagram showing isotope dilution–thermal ionization mass spectrometry (ID-TIMS) results from sample 96-08-43-1; inset illustrates a magnified view of the three fractions used to calculate the weighted mean age; **c)** concordia diagram showing SHRIMP results from sample 96-08-40.*

$^{207}Pb/^{206}Pb$ age for one of the discordant analyses is identical within error to those of the two younger concordant results. The weighted mean $^{207}Pb/^{206}Pb$ age of these three analyses is 2860 ±4 Ma (Figure GS-2-2b, inset) and is interpreted to represent the crystallization age of the granodiorite, while the Mesoarchean result is interpreted to represent an inherited component. The fifth fraction yields a discordant $^{207}Pb/^{206}Pb$ age of 3267 Ma, which falls approximately along a chord between the magmatic and inherited components. Although a core-rim relationship was not clearly observed, this result might indicate the presence of two components within the single analyzed grain.

Sample 96-08-40: quartz-phyric rhyolite

A distinctive rhyolite flow at Thibeault Lake contains blue-quartz phenocrysts and very fine scale compositional layers, interpreted to represent flow banding. As described by Anderson et al. (GS-1, this volume), this rhyolite is interpreted to represent the extrusive equivalent to high-level feldspar±quartz porphyry dikes that cut adjacent rocks of the Seal River Complex. Abundant zircons characterized by extensive fractures, inclusions and alteration were recovered. Due to the poor quality of the zircons, the ion microprobe was employed to target the highest-quality portions of grains. All thirty analyzed zircons yielded consistent results and a weighted mean $^{207}Pb/^{206}Pb$ age of 2570 ±3 Ma (mean square of weighted deviates [MSWD] = 1.0), which is interpreted as the crystallization age of the rhyolite (Figure GS-2-2c).

Sosnowski Lake assemblage

The Sosnowski Lake assemblage was defined by Anderson et al. (2009a) to consist mostly of subaqueous mafic to intermediate lava flows and related intrusions, with minor intermediate to felsic volcanic rocks and thick successions of unseparated volcaniclastic and epiclastic rocks. Two samples of sandstone and one of quartz porphyry were analyzed to constrain the age of volcanism and sedimentation.

Sample 97-09-280: volcanic sandstone

A sample from a felsic volcanic sandstone interlayer within pillowed and massive basalt flows at the type locality of the Sosnowski Lake assemblage southwest of Sosnowski Lake was collected to constrain the age of the source felsic volcanic rocks. Abundant prismatic zircons that vary from well faceted to slightly resorbed were recovered (Figure GS-2-3a, inset). Sixty-five detrital zircons were analyzed by ion microprobe and yielded a relatively simple provenance profile with a dominant mode at 2.7 Ga and three subordinate modes at 2.82, 3.2 and 3.4–3.45 Ga (Figure GS-2-3a). The youngest detrital grain with reproducible analyses yields an age of 2705 ±5 Ma (n = 2), which is consistent with the dominant

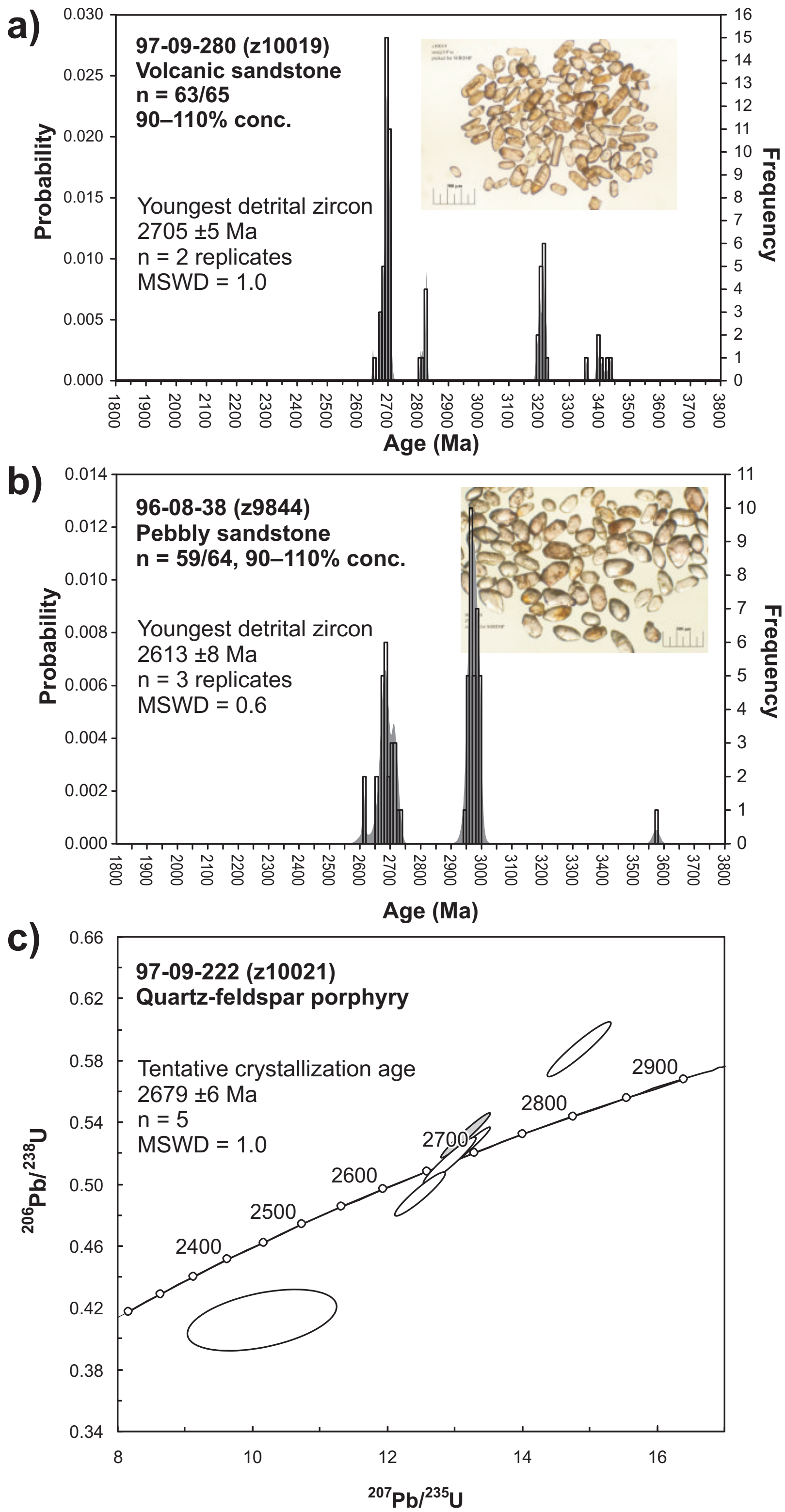

Figure GS-2-3: *Uranium-lead geochronological results from the Sosnowski Lake assemblage (dark grey curves and histograms represent data that is within 10% of concordia; MSWD = mean square of weighted deviates; probability density diagrams do not include replicate analyses; ellipses on concordia diagrams are plotted at the 2σ uncertainty level):* ***a)*** *probability density diagram showing sensitive high-resolution ion microprobe (SHRIMP) results for sample 97-09-280;* ***b)*** *probability density diagram showing SHRIMP results for sample 96-08-38;* ***c)*** *concordia diagram showing SHRIMP results from sample 97-09-222; grey ellipse is excluded from the calculation of the weighted mean. Scale bar on inset photographs is 300 µm.*

detrital population; this is interpreted to represent the most likely age of felsic volcanism in the Sosnowski Lake assemblage north of the Seal River.

Sample 96-08-38: pebbly sandstone

The Sosnowski Lake assemblage southeast of Omand Lake includes distinctive units of polymictic conglomerate and sandstone that are interstratified with intermediate volcaniclastic rocks of apparently local derivation, but contain abundant well-rounded cobbles and boulders of apparently 'exotic' quartzite. A sample of pebbly sandstone from one of the conglomerate units was collected for analysis. Abundant detrital zircons, many strongly rounded and frosted by mechanical abrasion during transport, were recovered (Figure GS-2-3b, inset) and 64 were analyzed by SHRIMP. The provenance profile is dominated by two populations at 2.7 Ga and 2.97 Ga (Figure GS-2-3b); the younger peak is thought to be representative of the locally sourced felsic volcanic detritus, whereas the older peak may be representative of the dominant source of detritus in the sandstone precursor to the exotic quartzite. A single, ancient, 3.58 Ga zircon was identified as well as two younger 2.6 Ga zircons. Three replicates on a single grain (#61) were used to constrain the age of the youngest detrital zircon, and thus the maximum age of deposition, to 2613 ±8 Ma.

Sample 97-09-222: quartz-feldspar porphyry

A sample of a small plug of hypabyssal quartz-feldspar porphyry east of Omand Lake was collected to constrain the age of felsic volcanism in the southern portion of the Sosnowski Lake assemblage. This porphyry is interpreted to be broadly coeval with adjacent felsic volcanic rocks, and appears to be unconformably overlain to the west by coarse fluvial-alluvial conglomerate of sequence 1. Eleven poor-quality zircons were recovered from this sample. Only six zircons were of suitable quality for ion microprobe analysis, and despite a wide range in U concentrations (114–1085 ppm), all six grains gave similar ages (Figure GS-2-3c). The weighted mean $^{207}Pb/^{206}Pb$ age of five of these analyses (excluding a single, young, high-U analysis) is 2679 ±6 Ma, which could be interpreted to represent the crystallization age of the hypabyssal intrusion or the age of xenocrystic zircons. Regardless of interpretation, the 2.68 Ga date is thought to closely approximate the age of felsic volcanism in this portion of the Sosnowski Lake assemblage.

Sequence 1

Sedimentary rocks of sequence 1 consist of a lower unit of interstratified arenite and polymictic conglomerate and an upper unit of quartz arenite, with only minor interbeds of conglomerate and mudstone. These rocks define a narrow, north-trending, half-graben south of Great Island that is fault-bounded to the west and unconformably overlies felsic volcaniclastic rocks of the Sosnowski Lake assemblage to the east. To the south and north, this basin is truncated by unconformities at the base of sequence 2 and sequence 3, respectively. Possible correlative rocks are also exposed in an anticlinal culmination in the area south of Spruce Lake, where they are crosscut by a variety of intrusive rocks that are not observed in the overlying rocks of sequences 2 or 3, likewise indicating an unconformable contact relationship.

Sample 97-09-89: quartz pebble conglomerate

East of Omand Lake, the lower unit of sequence 1 contains interlayers of supermature quartz pebble conglomerate that locally contain anomalous concentrations of Au, U and LREE, presumably associated with accumulated heavy minerals. A sample of fuchsitic quartz pebble conglomerate from this location was collected to constrain the depositional age. The recovered zircons range from colourless through pale yellow/brown to pink and are large and morphologically diverse, with variably rounded, prismatic to equant habits (Figure GS-2-4, lower, inset). The detrital sources identified in this sample are unique, dominated by 3.4 and 3.5 Ga zircons with a significant proportion of grains older than 3.6 Ga (Figure GS-2-4, lower). The oldest detrital zircon recognized is 3801 Ma. Four zircons yielded ages of ca. 3.0 Ga and two others yielded ages of ca. 3.2 Ga. A single zircon dated at ca. 2.7 Ga constrains the maximum age of deposition of the conglomerate.

Intrusive rocks

The Seal River Domain includes a wide variety of granitoid intrusive rocks that are known or inferred to intrude supracrustal rocks of the Sosnowski Lake assemblage and sequence 1, but are not observed to cut the unconformably overlying rocks of sequences 2–4. A representative selection of these granitoid intrusions were sampled for analysis.

Sample 97-09-134: syenogranite

This sample was collected from an outcrop on the Seal River upstream from Great Island, in the central portion of a large syenogranite and quartz syenite pluton that intrudes the Sosnowski Lake assemblage to the east and sequence 1 to the north (Figure GS-2-1). A population of simple, prismatic, oscillatory zoned zircons was recovered and 17 grains were analyzed by ion microprobe. The weighted mean $^{207}Pb/^{206}Pb$ age of all the analyses is 2570 ±5 Ma (Figure GS-2-5a), which is interpreted as the crystallization age. Given the crosscutting relationships, this age is also interpreted to represent the minimum age of the Sosnowski Lake assemblage and sequence 1, the latter of which is thus constrained between 2.7 Ga and 2.57 Ga. The crystallization age of the syenogranite is identical, within error, to the quartz-phyric rhyolite (sample 96-08-40; Figure GS-2-2c) that overlies the Seal River Complex.

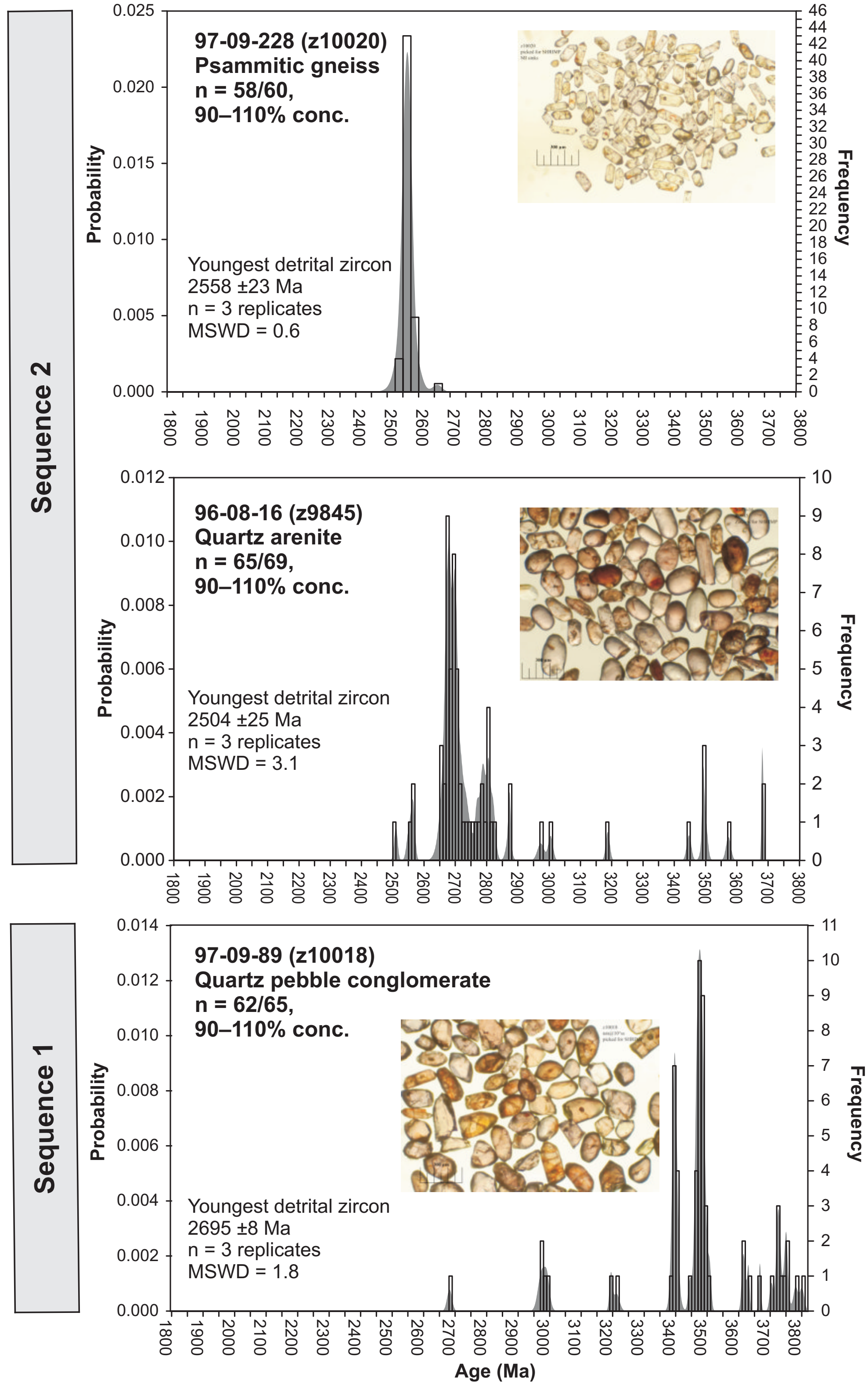

Figure GS-2-4: *Uranium-lead geochronological results from sedimentary sequences 1 and 2 (dark grey curves and histograms represent data that is within 10% of concordia; MSWD = mean square of weighted deviates; probability density diagrams do not include replicate analyses):* ***(lower)*** *probability density diagram showing sensitive high-resolution ion microprobe (SHRIMP) results for sample 97-09-89, from sequence 1 east of Omand Lake;* ***(middle)*** *probability density diagram showing SHRIMP results for sample 96-08-16, from sequence 2 at Teepee Falls on the North Knife River;* ***(upper)*** *probability density diagram showing SHRIMP results for sample 97-09-228, from sequence 2 west of Spruce Lake. Scale bar on inset photographs is 300 µm.*

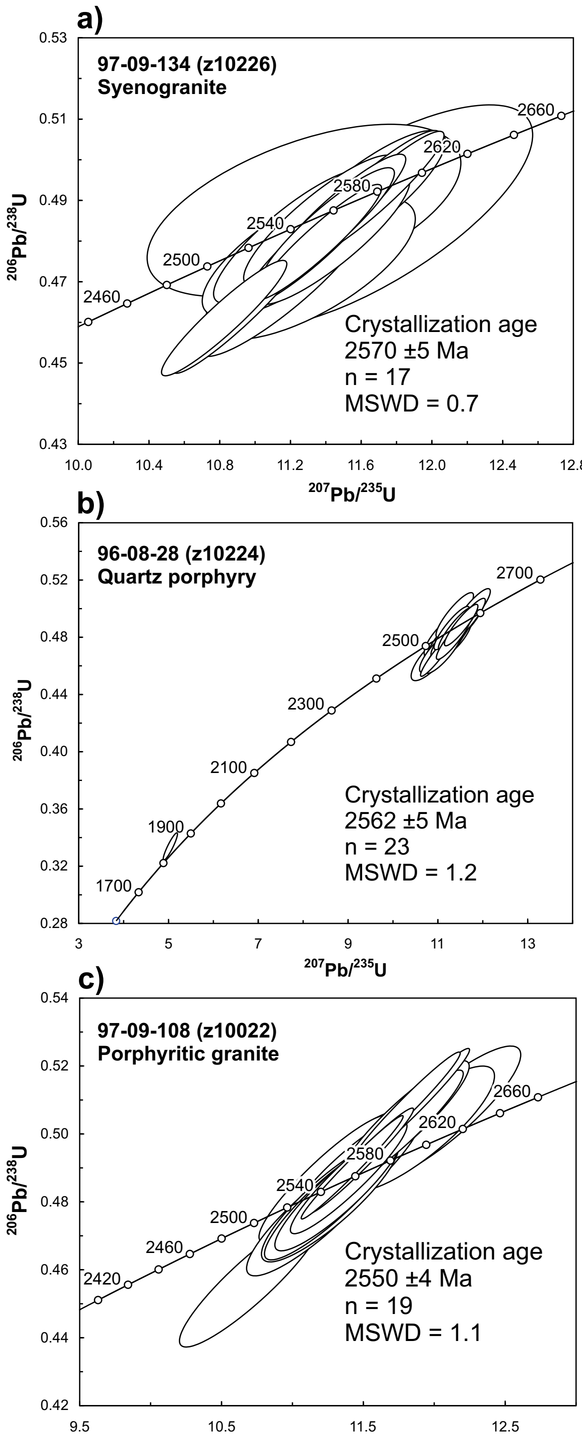

Figure GS-2-5: *Uranium-lead geochronological results from a selection of Archean granitoid intrusions from the Seal River Domain (ellipses on concordia diagrams are plotted at the 2σ uncertainty level; Geological Survey of Canada lab numbers are given in parentheses for each sample; MSWD = mean square of weighted deviates):* ***a)*** *concordia diagram showing sensitive high-resolution ion microprobe (SHRIMP) results from sample 97-09-134,* ***b)*** *concordia diagram showing SHRIMP results from sample 96-08-28,* ***c)*** *concordia diagram showing SHRIMP results from sample 97-09-108.*

Sample 96-08-28: quartz porphyry

This sample was collected from a large outcrop of quartz porphyry within a succession of interlayered arenite and polymictic conglomerate of sequence 1 south of Spruce Lake. Abundant, simple, prismatic and well-faceted zircons were recovered and analyzed by ion microprobe. Twenty-three low-U zircons yield a weighted mean $^{207}Pb/^{206}Pb$ age of 2562 ±5 Ma (Figure GS-2-5b), which is interpreted as the emplacement age of the quartz porphyry. This age overlaps, within error, the crystallization age of the syenogranite intrusion to the south (sample 97-09-134; Figure GS-2-5a) and thus confirms the ca. 2.57 Ga minimum age of deposition for sequence 1. A single high-U overgrowth on one of the zircons (962 ppm U, Th/U = 0.02) is interpreted to represent a Paleoproterozoic (ca. 1.80 Ga) metamorphic overprint that is rarely recorded by zircons in the study area.

Sample 97-09-108: porphyritic granite

Plutons composed of unseparated granite, granodiorite and lesser quartz diorite intrude the Sosnowski Lake assemblage and, at least locally, define the margins of both the Garlinski Lake and Howard Lake greenstone belts (Figure GS-2-1). These plutons also appear to be extensive beyond the margins of these belts, where they appear to include older gneissic components. A sample of homogeneous porphyritic granite northeast of Sosnowski Lake, close to the boundary zone with the Nejanilini Domain, was collected for analysis and was disaggregated using the EPD method. The zircons recovered from the granite are simple, clear, colourless, well-faceted prisms with few fractures or inclusions. Nineteen zircons were analyzed by ion microprobe and combined to a weighted mean $^{207}Pb/^{206}Pb$ age of 2550 ±4 Ma (Figure GS-2-5c). This is the youngest intrusive rock documented within the Seal River Domain.

Sequence 2

Sequence 2 consists mostly of quartz arenite and varicoloured mudstone, with subordinate gabbro sills and amygdaloidal basalt flows that transition southward into andalusite-bearing paragneiss, schist and minor amphibolite that are intruded by synmetamorphic biotite–muscovite–garnet±fluorite granite and related pegmatite. To the north, sequence 2 unconformably overlies Neoarchean (≥2.55 Ga) orthogneiss, volcanoplutonic rocks and granitoid intrusions, as well as fluvial-alluvial siliciclastic rocks of sequence 1. Sequence 2 is distinguished from sequence 1 by the presence of coeval mafic flows and related intrusions, and the lack of coarse polymictic conglomerate. Sequence 2 is also thought to include the strongly transposed psammitic and semipelitic paragneiss between Spruce Lake and Naelin Lake, which was provisionally considered part of the 'Omand Lake assemblage' by Anderson et al. (2009a).

Sample 96-08-16: quartz arenite

A sample of pebbly quartz arenite from a large outcrop near the base of sequence 2 at Teepee Falls on the North Knife River was collected for analysis. Large, prismatic zircons, ranging from colourless to pale yellow/brown to pink, are predominantly well-rounded and frosted from mechanical abrasion during transport (Figure GS-2-4, middle, inset). The detrital zircon provenance profile is dominated by 2.7 Ga zircons with a subordinate population of 2.8 Ga zircons and scattered results between 3.7 Ga and 2.9 Ga (Figure GS-2-4, middle). Though much less abundant, the distribution of results older than 2.9 Ga in this sample is similar to that obtained from the quartz pebble conglomerate of sequence 1. Four zircons yielded ages of ca. 2.56–2.50 Ga, which are representative of the granitoid intrusions described earlier. Three replicate analyses on the youngest detrital zircon yields a mean $^{207}Pb/^{206}Pb$ age of 2504 ±25 Ma constraining the maximum age of deposition.

Sample 97-09-228: psammitic paragneiss

A sample of sequence 2 sillimanite-bearing psammitic paragneiss was collected 2 km west of the location where interbedded arenite and conglomerate of sequence 1 are discordantly cut by 2.56 Ga quartz porphyry (sample 96-08-28; Figure GS-2-5b). A homogeneous population of well-faceted, prismatic zircons was recovered and analyzed by ion microprobe (Figure GS-2-4, upper, inset). All but one of the 60 analyzed zircons defines a single statistical population centred at 2.56 Ga (Figure GS-2-4, upper). The youngest detrital zircon is dated at 2558 ±23 Ma, based on three replicate analyses of a single grain. A single detrital zircon records a slightly older age of 2.66 Ga. Given the proximity to the dated 2.56 Ga quartz porphyry, the unimodal population of 2.56 Ga detrital zircons in the paragneiss sample is interpreted to indicate a very local source and thus a depositional contact relationship with sequence 1.

Sequences 3 and 4

Sedimentary rocks of sequences 3 and 4 define a series of prominent synclinal basins that, from west to east, include the Great Island, Seal Bend and Nowell Lake basins, and are the defining characteristic of the southeastern margin of the Hearne craton in Manitoba. Sequence 3 includes a basal silicate facies iron formation, overlain by a thick succession of interlayered arenite, mudstone and minor lenses of dolomitic marble that likely records deposition in a marine-deltaic setting. Sequence 4 includes a lower section of dolomitic marble, calcsilicate rocks and oxide-facies iron formation, overlain by a thick succession of greywacke-mudstone turbidites, with minor iron formation, thought to represent a basinal-marine depositional setting. Sequences 3 and 4 were referred to as the 'lower' and 'upper' Great Island Group, respectively, by Anderson et al. (2009a); the contact between these sequences is interpreted to be an angular unconformity.

Sample 96-08-15: quartz arenite

A sample of quartz arenite was collected from near the base of sequence 3 downstream from Teepee Falls on the North Knife River, in close proximity to the basal contact of flat-lying Ordovician sedimentary rocks of the Hudson Bay Basin. A heterogeneous population of well-faceted to well-rounded zircons was recovered (Figure GS-2-6, lower, inset). Many of the zircon grains are stained orange by iron oxide precipitate along fractures, perhaps as a result of Ordovician weathering. Sixty-four detrital zircons were analyzed by ion microprobe and define a prominent mode at 2.56 Ga, with a subordinate mode at 2.7 Ga and rare results older than 2.8 Ga (Figure GS-2-6, lower). The dominant 2.56 Ga mode is consistent with the ages of the granitoid intrusions described earlier. Two detrital zircons confirm a Paleoproterozoic depositional age for this sequence, the youngest of which yields a mean $^{207}Pb/^{206}Pb$ age of 2049 ±19 Ma.

Sample 96-08-29: quartz arenite

A sample of massive to faintly stratified, medium- to coarse-grained quartz arenite was collected from higher up-section in sequence 3, on the north channel of the Seal River at Great Island. Zircons recovered from this sample range from colourless to pale yellow and are typically rounded to subrounded (Figure GS-2-6, middle, inset). Most of the results fall within the range of 2.3–2.5 Ga, with sporadic older results up to 2.75 Ga (Figure GS-2-6, middle). The youngest detrital zircon with reproducible analyses is dated at 1984 ±14 Ma (weighted mean $^{207}Pb/^{206}Pb$ age of grain 100, four replicates), which is considered the maximum depositional age of sequence 3.

Sample 96-08-32: greywacke turbidite

A sample of coarse lithic greywacke was collected from near the base of sequence 4 in the Great Island basin east of Meades Lake and is the stratigraphically highest analyzed sample in the Seal River Domain. Well-faceted, prismatic zircons characterized by numerous fractures dominate the detrital zircon population; however, a subordinate population of well-rounded grains was also identified (Figure GS-2-6, upper, inset). The provenance profile of the greywacke exhibits a more limited range of ages compared to samples from the underlying sequences, with a prominent mode centred at 2.53 Ga and sporadic younger ages (Figure GS-2-6, upper). Maximum age of deposition of the greywacke is constrained by four replicate analyses on a single grain that yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 1879 ±19 Ma.

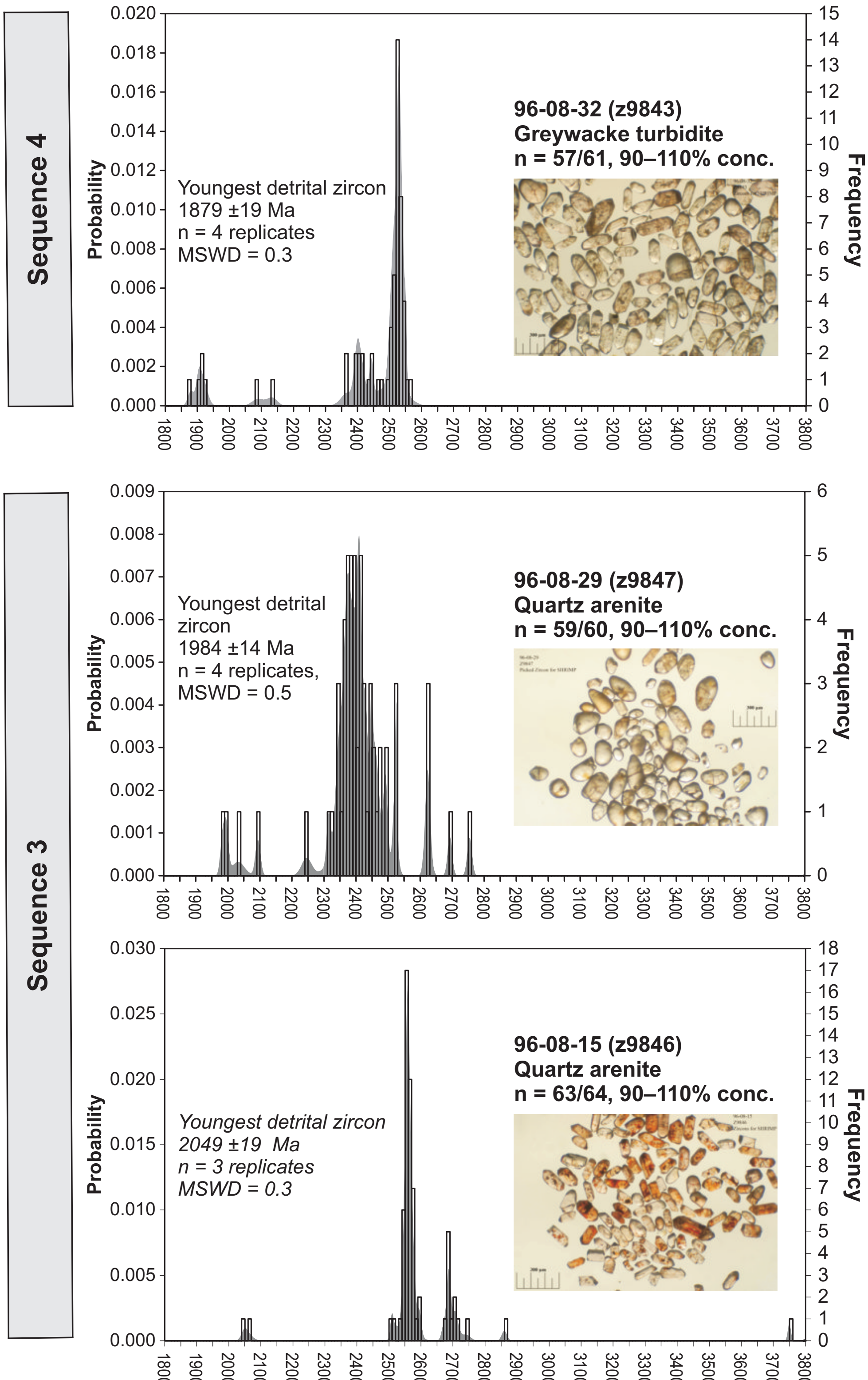

Figure GS-2-6: *Uranium-lead geochronological results from sequences 3 and 4 (dark grey curves and histograms represent data that is within 10% of concordia; probability density diagrams do not include replicate analyses; MSWD = mean square of weighted deviates):* ***(lower)*** *probability density diagram showing sensitive high-resolution ion microprobe (SHRIMP) results for sample 96-08-15 from sequence 3 downstream from Teepee Falls on the North Knife River;* ***(middle)*** *probability density diagram showing SHRIMP results for sample 96-08-29 from sequence 3 on the north side of Great Island;* ***(upper)*** *probability density diagram showing SHRIMP results for sample 96-08-32 from sequence 4 east of Meades Lake. Scale bar on inset photographs is 300 µm.*

Nejanilini Domain

The Nejanilini Domain is dominated by metaplutonic rocks with minor enclaves of mafic granulite and paragneiss. Only a single sample from this domain, collected in 2008, has been analyzed to date. This domain was a major focus of the 2010 mapping campaign and three additional samples have been submitted for geochronological analysis to resolve the age and possible correlation of the principal map units.

Sample 96-08-26: charnockitic gneiss

A sample of charnockitic gneiss composed of honey-brown to green feldspar, quartz, hornblende and magnetite was collected from the south margin of the Nejanilini Domain northeast of Spruce Lake. Clear colourless zircons were recovered from the sample and separated into four distinct morphologies: elongate prisms; stubby prisms; stubby rounded grains; and turbid, rounded zircons. Single-grain fractions of each of these morphologies were analyzed by TIMS after treatment by chemical abrasion (Mattinson, 2005). Despite their simple appearance, most of the fractions yielded discordant results. The elongate zircon population (Z1) yielded the three most concordant fractions (Figure GS-2-7). The best estimate of the crystallization age of the granite is interpreted to be the $^{207}Pb/^{206}Pb$ age of the most concordant fraction, 2526.5 ±1.3 Ma. Other more discordant fractions yield $^{207}Pb/^{206}Pb$ ages between 2519 and 2371 Ma. All six fractions are approximately collinear and yield a lower intercept of 1737 ±200 Ma, (MSWD = 87) when the upper intercept is anchored at the interpreted crystallization age of 2526 Ma. This may reflect the Paleoproterozoic metamorphic overprint recorded by zircon in sample 96-08-28 (Figure GS-2-5b). As described by Anderson et al. (GS-1, this volume), the significance of this result is unclear in the context of the available U-Pb ages and field relationships in the Nejanilini Domain. Further analyses are planned to resolve this problem.

Economic considerations

The mapping and U-Pb age results presented here and by Anderson et al. (GS-1, this volume) represent a significant advancement in the understanding of the complex nature, protracted evolution and diverse mineral potential of the southeastern Hearne craton margin, one of the last remaining frontier areas in Manitoba. Of particular economic importance are the Archean age constraints on an extensive and underexplored greenstone belt with known Au mineralization (the Sosnowski Lake assemblage), which is the only known example in Manitoba's far north. The geochronological results presented here support a revised stratigraphy of the Great Island Group (Schledewitz, 1986), comprising four diverse sedimentary sequences. Sequence 1 includes a fault-controlled fluvial-alluvial basin of Archean age south of Great Island that contains U-Au-LREE–mineralized quartz pebble conglomerate. The first absolute age constraints from Paleoproterozoic siliciclastic rocks of sequences 2–4 facilitate comparisons with better-studied and explored successions in Nunavut (Hurwitz Group) and Saskatchewan (Wollaston Group) and thus provide a substantially upgraded

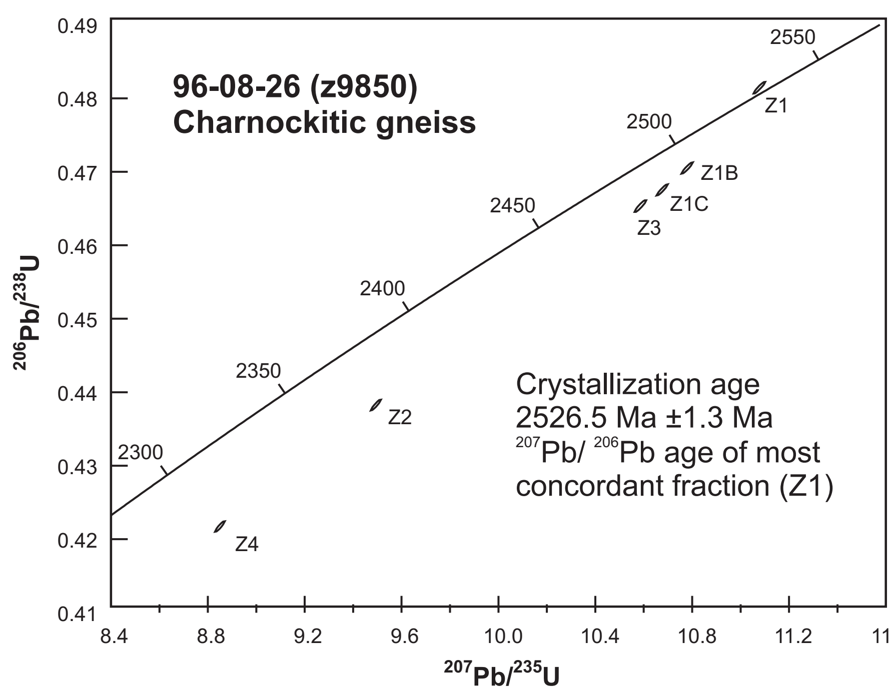

Figure GS-2-7: *Concordia diagram of U-Pb isotope dilution–thermal ionization mass spectrometry (ID-TIMS) results from sample 96-08-26 from the Nejanilini Domain (ellipses on the concordia diagram are plotted at the 2σ uncertainty level; Geological Survey of Canada lab number is given in parentheses).*

conceptual framework for mineral exploration in Manitoba's far north.

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References

Anderson, S.D., Böhm, C.O. and Syme, E.C. 2010: Precambrian geology of the Seal River region, Manitoba (parts of NTS 54L, M, 64I, P); Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Preliminary Map PMAP2010-1, scale 1:175 000.

Anderson S.D., Böhm, C.O., Syme, E.C., Carlson A. and Murphy L.A. 2009a: Bedrock geology of the Great Island area, Manitoba (parts of NTS 54L13, 54M4, 64I15, 16, 64P1, 2); Manitoba Innovation, Energy and Mines, Manitoba Geological Survey Preliminary Map PMAP2009-4, scale 1:75 000.

Anderson, S.D., Böhm, C.O., Syme, E.C., Carlson, A.R. and Murphy, L.A. 2009b: Far North Geomapping Initiative: geological investigations in the Great Island area, Manitoba (parts of NTS 54L13, 54M4, 64I15, 16, 64P1, 2); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 132–147.

Aspler, L.B., Wisotzek, I.E., Chiarenzelli, J.R., Losonczy, M.F., Cousens, B.L., McNicoll, V.J. and Davis W.J. 2001: Paleoproterozoic intracratonic basin processes, from breakup of Kenorland to assembly of Laurentia; Hurwitz Basin, Nunavut, Canada; Sedimentary Geology, v. 141–142, p. 287–318.

Davis, W.J., Rainbird, R.H., Aspler, L.B. and Chiarenzelli, J.R. 2005: Detrital zircon geochronology of the Paleoproterozoic Hurwitz and Kiyuk groups; Geological Survey of Canada, Current Research 2005-F1, 13 p.

Ludwig, K.R. 2003: User's manual for Isoplot/Ex rev. 3.00: a geochronological toolkit for Microsoft Excel; Berkeley Geochronology Center, Special Publication 4, Berkeley, 70 p.

Mattinson J.M. 2005: Zircon U–Pb chemical abrasion ("CA-TIMS") method: combined annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages; Chemical Geology, v. 220, p. 47–66.

Parrish, R.R., Roddick, J.C., Loveridge, W.D. and Sullivan, R.W. 1987: Uranium-lead analytical techniques at the geochronology laboratory, Geological Survey of Canada; *in* Radiogenic Age and Isotopic Studies: Report 1, Geological Survey of Canada. v. 87-2, p. 3–7.

Roddick, J.C. 1987: Generalized numerical error analysis with application to geochronology and thermodynamics; Geochimica et Cosmochimica Acta, v. 51, p. 359–362.

Rudashevsky, N.S., Burakov, B.E., Lupal, S.D., Thalhammer, O.A.R. and Saini-Eidukat, B. 1995: Liberation of accessory minerals from various rock types by electric-pulse disintegration—method and application; Transactions of the Institute of Mining and Metallurgy, v. 104, p. 25–29.

Schledewitz, D.C.P. 1986: Geology of the Cochrane and Seal rivers area; Manitoba Energy and Mines, Geological Report GR80-9, 139 p.

Sircombe, K. 2004: AgeDisplay: an EXCEL workbook to evaluate and display univariate geochronological data using binned frequency histograms and probability density distributions; Computers & Geosciences, v. 30, p. 21–31.

Stern, R.A. 1997: The GSC sensitive high resolution ion microprobe (SHRIMP): analytical techniques of zircon U-Th-Pb age determinations and performance evaluation; *in* Radiogenic Age and Isotopic Studies, Report 10, Geological Survey of Canada, Current Research 1997-F, p. 1–31.

Stern, R.A. and Amelin, Y. 2003: Assessment of errors in SIMS zircon U-Pb geochronology using a natural zircon standard and NIST SRM 610 glass; Chemical Geology, v. 197, p. 111–146.

Tran, H.T., Ansdell, K.M., Bethune, K.M., Ashton, K. and Hamilton, M.A. 2008: Provenance and tectonic setting of Paleoproterozoic metasedimentary rocks along the eastern margin of Hearne craton: constraints from SHRIMP geochronology, Wollaston Group, Saskatchewan, Canada; Precambrian Research, v. 167, p. 171–185.

Yeo, G.M. and Delaney, G.D. 2007: The Wollaston Supergroup, stratigraphy and metallogeny of a Paleoproterozoic Wilson cycle in the Trans-Hudson orogen, Saskatchewan; *in* EXTECH IV: Geology and Uranium EXploration TECHnology of the Proterozoic Athabasca Basin, Saskatchewan and Alberta; Geological Survey of Canada, p. 89–117, Bulletin 588 and Saskatchewan Geological Society, Special Publication 18 and Geological Association of Canada, Mineral Deposits Division, Special Publication 4, C.W. Jefferson and G.D. Delaney (ed.).