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Ancient (Meso- to Paleoarchean) crust in the Rae Province, Canada: Evidence from Sm–Nd and U–Pb constraints

R.P. Hartlaub[a,*], T. Chacko[a], L.M. Heaman[a], R.A. Creaser[a],
K.E. Ashton[b], A. Simonetti[a]

[a] *Department of Earth and Atmospheric Sciences, University of Alberta,*
1-26 ESB, Edmonton, AB, Canada T6G 2E3
[b] *Saskatchewan Geological Survey, 2101 Scarth Street, Regina, SK, Canada S4P 3V7*

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Abstract

New Sm–Nd and U–Pb data indicate that a block of ancient Mesoarchean and Paleoarchean crust (3.0–3.9 Ga) is present along the southwestern margin of the Rae Province, Canada. Consequently, the Rae Province can be divided into an ancient (>3.0 Ga) southwestern component and a more juvenile (<3.0 Ga) northeastern component. Evidence for episodic reworking of the evolved southwestern component is recorded in the Sm–Nd and U–Pb signatures of younger Archean and Paleoproterozoic intrusive rocks and sediments. Nd model ages range from 2.7 to 3.3 Ga, with the oldest signatures occurring along the western end of the Beaverlodge Belt, Saskatchewan. Xenocrystic zircons with ages of ca. 2.3, 3.0, 3.2–3.3 and >3.6 Ga were discovered in two Paleoproterozoic granites.

Keywords: Rae Province; Geochronology; Crustal recycling; Xenocrystic zircon; Archean

1. Introduction

The Rae Province, northwestern Canada (Fig. 1), comprises the western part of the Churchill craton, one of the largest exposures of Archean crust in the world. The remote and inaccessible location of this craton in northern Canada has resulted, however, in only limited scientific study of this significant piece of Earth's early crust. The majority of the craton has been mapped at a reconnaissance scale, but detailed work has recently been completed near the southwestern margin of the craton along the northern shore of Lake Athabasca (Ashton and Card, 1998; Hartlaub and Ashton, 1998; Hartlaub, 1999; Ashton et al., 2000, 2001). The aforementioned mapping was accompanied by isotopic and geochemical study of the Archean and Paleoproterozoic plutonic and sedimentary rocks. These studies recognized a quartzite dominated supracrustal package termed the Murmac Bay Group which locally overlies ca. 3.0 Ga granite basement. Meta-sandstone from the upper part of Murmac Bay Group contains detrital zircon as young as 2.33 Ga, and is locally injected by granites as old as 2.32 Ga (Hartlaub, unpublished data). Both quartzite and meta-sandstone from the Murmac Bay Group contain abundant detrital zircon grains with U–Pb ages greater than 3.6 Ga (Hartlaub et al., 2004). A Lu–Hf isotope study of these ancient detrital zircons (Hartlaub et al., in press) indicates that many of the grains were eroded from a

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[*] Corresponding author. Tel.: +1 780 492 2778;
fax: +1 780 492 2030.
E-mail address: hartlaub@ualberta.net (R.P. Hartlaub).

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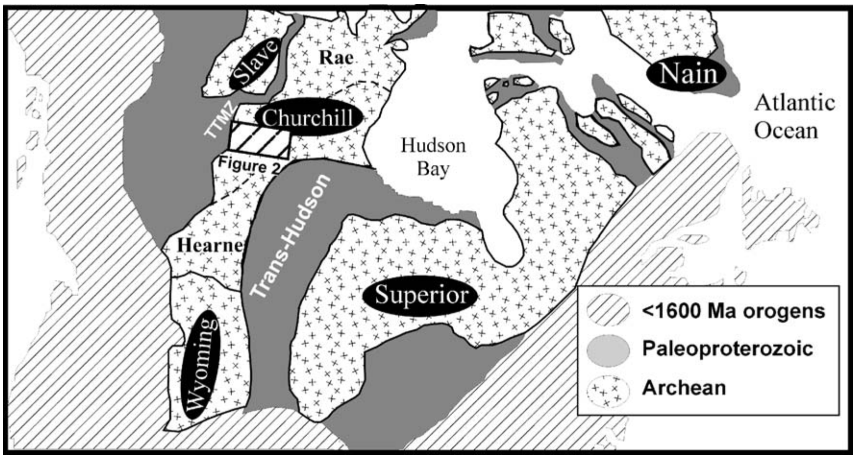

Fig. 1. Simplified geological map of North America highlighting the major Archean cratons. The striped box indicates the area of Fig. 2. The overlying Proterozoic and younger sedimentary basins have been removed. TTMZ, Taltson-Thelon Magmatic Zone.

crustal source with a history dating back to the Hadean (>4.0 Ga). Because of the extreme rarity of early Archean crust, one of the goals of this paper is to identify regions of the Rae Province that may represent source areas for this ancient detritus. In addition, by subdividing the Rae Province according to radiogenic isotopic signatures, the location of possible Archean sutures may be delineated.

U–Pb crystallization ages provide a first-order glimpse at the crustal signature of the Rae Province; however Sm–Nd isotopes are also utilized herein because a wide variety of rocks can be analyzed more rapidly and the isotope system is resistant to resetting (Barovich and Patchett, 1992). There are relatively few Sm–Nd isotopic data published for the Rae Province, especially when compared to the quantity of results from the adjacent Superior and Slave cratons. A reconnaissance study of the northern Rae Province indicates that the oldest Nd isotopic signatures were located along its western margin (Thériault et al., 1994). We collected samples along a 200 km East-West transect across the southern Rae Province, north of Lake Athabasca in Saskatchewan, in order to expand the Nd isotope database southward (Fig. 1). In addition to Sm–Nd isotope study, the crystallization ages for selected plutonic samples have been determined using thermal ionization mass spectrometry (TIMS) and Laser Ablation MC-ICP-MS U–Pb techniques. When combined with the previously published work, the Nd isotopic signatures and U–Pb crystallization ages allow us to make several first order conclusions about the crustal structure of the Rae Province. The primary conclusions is that one or more fragments of older ($\geq$2.9 Ga) crust exist along the western margin of the younger ($\leq$2.9 Ga) Rae Province. Ancient detrital zircons and Nd model ages indicate that the oldest components of these crustal fragments have crystallization ages >3.6 Ga.

2. Regional geology

The western margin of the Rae Province (Fig. 1) is a tectonically complex zone that has been overprinted by a ca. 2.3 Ga orogen (Bostock and van Breemen, 1994; Hartlaub, 2004) and the enigmatic 1.9–2.0 Ga Taltson-Thelon Magmatic Zone (Hoffman, 1989). The Taltson-Thelon Magmatic Zone is variably interpreted to represent a post-collisional S-type intracontinental batholith superimposed on a pre-collisional I-type continental magmatic arc (Hoffman, 1989) or a zone of intracontinental deformation and magmatism (Chacko et al., 2000; De et al., 2000). The Beaverlodge Belt, Saskatchewan, Canada (Fig. 2), is a sub-domain of the Rae Province delineated by marginal shear zones and an abundance of Archean to Paleoproterozoic sedimentary rocks. The prodigious U and Au production of the western Beaverlodge Belt spurred a recent effort to reassess the geology and mineral potential of the belt. This work included detailed new mapping, geophysics and geochemistry (Ashton and Card, 1998; Hartlaub and Ashton, 1998; Hartlaub, 1999; Ashton et al., 2000, 2001). At least three Paleoproterozoic supracrustal packages, the ca. 2.3 Ga Murmac Bay Group (Hartlaub, unpublished data), the ca. 1.83 Ga Martin Group (Hartlaub, unpublished data), and the ca. 1.81–1.66 Ga Athabasca Group (Rayner et al., 2003), are exposed within the belt. Circa 3.0, 2.6, and 2.3 Ga granite suites are also locally exposed within the belt (Hartlaub et al., 2004).

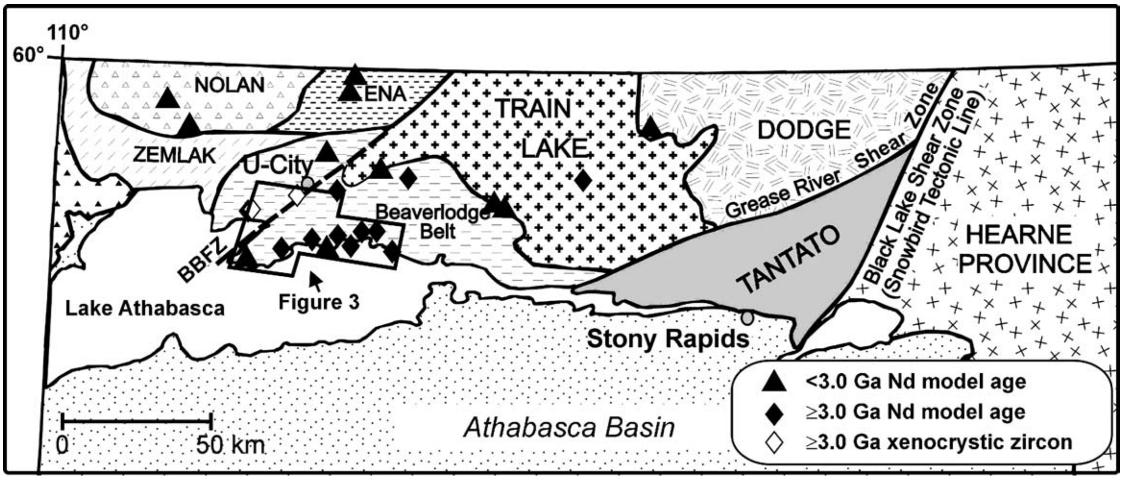

Fig. 2. Simplified geological map of northwestern Saskatchewan. Old (>3.0 Ga) Nd TDM ages, xenocrystic zircons, and ancient detrital zircons highlight an area of Meso- to Paleoarchean crust. BBSZ, Black Bay shear zone; U-City, Uranium City.

To the east of the Beaverlodge Belt, the Train Lake and Dodge Domains are dominated by Neoarchean granites that may represent the deeper crustal levels of granite-geenstone belts (Ashton and Card, 1998). West of the Beaverlodge Belt, the Zemlak, Nolan and Ena Domains are granitoid-rich crustal blocks of unknown tectonic setting that are distinguished from one another on the basis of lithological and structural differences.

3. Sample selection

Samples of all the known suites of plutonic rocks were selected from recently mapped areas of the Beaverlodge Belt. To achieve a more regional perspective on crustal evolution in this region, two different approaches were taken: (1) ca. 2.3 Ga supracrustal rocks from the region were collected in order to ascertain the average crustal residence time of their source rocks. Interpretation of Nd data from sedimentary rocks may be complicated because detritus from diverse crustal sources may become mixed within a single depositional basin, the distance that sediment was transported may be significant, and cannibalistic recycling of early sediments may occur (Patchett et al., 1999). Despite these complexities, the crustal residence times of sedimentary rocks are still valuable in resolving questions of sediment source and for tracing regions of potential ancient crust (Jahn and Condie, 1995; Böhm et al., 2000). (2) Granitoid samples were collected on a reconnaissance transect extending at least 50 km to the north, east, and west of the Beaverlodge Belt. These granitoid rocks included both well studied rocks with known crystallization ages, as well as reconnaissance samples of granitoids with suspected Archean age.

Although abundant quartz-rich sedimentary rocks are exposed in the Beaverlodge Belt, only rocks that contain adequate amounts of minerals (e.g. biotite, hornblende, apatite, zircon) that concentrate low abundance trace elements, such as Sm and Nd, were collected. In addition, mafic and ultramafic rocks were not analyzed because of the difficulty in calculating meaningful Nd model ages for rocks with high Sm/Nd ratios.

3.1. *Circa 3.0 Ga granite basement (RH98-LBG, RH00-6336, RH98-125)*

Three samples of Mesoarchean granitic basement (Hartlaub et al., 2004) were collected from the Uranium City area; one sample each from the 3060 ± 40 Ma Lodge Bay Granite, the 2999 ± 7 Ma Cornwall Bay Granite, and an undated basement dome (Hartlaub et al., 2004). These granites unconformably underlie the ca. 2.3 Ga Murmac Bay Group.

3.2. *Neoarchean granitoids*

Several ca. 2.6 Ga granitoids were selected from within and adjacent to the Beaverlodge Belt. As described by Hartlaub et al. (2004) and Card (2001), these granitoids vary in composition from granodiorite to granite and generally contain up to 30% hornblende and/or orthopyroxene ± biotite. A >40 km^2 area of granite along the northern margin of the Beaverlodge Belt, termed the Prince Lake-Stephen's Lake granites, was selected for both Sm–Nd and U–Pb geochronology. This orange to white granite is coarse-grained and locally contains metamorphic orthopyroxene and migmatitic layering. Orthopyroxene, where present, is partly replaced by metamorphic biotite, garnet and hornblende. A poorly constrained 2440 ± 57 Ma U–Pb zircon age (Bickford et al., 1987) was reported for the Stephens Lake portion of this granite.

In addition to dated Neoarchean granites, reconnaissance sampling of granitoid rocks was conducted northwestwards from the Beaverlodge Belt towards the Taltson-Thelon Magmatic Zone (TTMZ, Fig. 1). Because most felsic magmatism in the core of the Rae Province appears to have occurred at ca. 2.6 Ga (Davis et al., 2000), most of the samples of undated granitoid obtained here are likely of this age.

3.3. Circa 1.9–2.0 Ga granites

Pink leucogranite that intrudes Archean basement is abundant within the Uranium City area. One of these granites has a poorly defined U–Pb age of 1994 ± 37 Ma (Persons, 1988). The pink Uranium City Granite (RH01-06) was collected within the town site of Uranium City (Fig. 3), and appears typical of this leucogranite suite. The Uranium City Granite is homogeneous with no visible inclusions or xenoliths. The Feil Lake Granodiorite (4701-299) was collected from the western end of the Beaverlodge Belt (Ashton et al., 2001), 15 km west of the Uranium City Granite. The Feil Lake Granodiorite is foliated to gneissic, and grades into a migmatite that has injected hosting paragneisses. It contains 1–2% chlorite after biotite, 0–2% epidote in veins and as alteration, and trace muscovite-sericite in fractures and as feldspar alteration. Because leucogranites commonly contain abundant xenocrystic zircon (Miller et al., 2003), and the identification of xenocrystic zircon can help unravel the nature and extent of buried ancient crust, we decided to examine the U–Pb systematics of a large quantity of individual zircons.

3.4. Supracrustal rocks

Several samples of meta-sedimentary rocks were chosen for Sm–Nd isotopic analysis in order to determine the average crustal residence age of their source rocks; this included three pelitic to psammitic rocks from the Beaverlodge Belt and one pelite from close to the western margin of the Rae Province at Taylor Lake (RH01-20). Although none of these meta-sediments have been directly dated, those collected from the Beaverlodge Belt are interpreted to range in age from ca. 2.3 Ga to Neoarchean (Heaman et al., 2003; Hartlaub et al., 2004). A single sample of intermediate volcanic rock that is intermixed with these sediments was also taken from the Beaverlodge Belt (RH98-439). A sample of quartzofeldspathic gneiss from the Beaverlodge Belt (RH98-90) could have either a sedimentary or an igneous origin.

4. Methodology

4.1. U–Pb ID-TIMS geochronology

Samples were crushed and milled using a jaw crusher and Bico disk mill. The resulting powder was passed across a Wilfley Table to obtain a concentrate of high

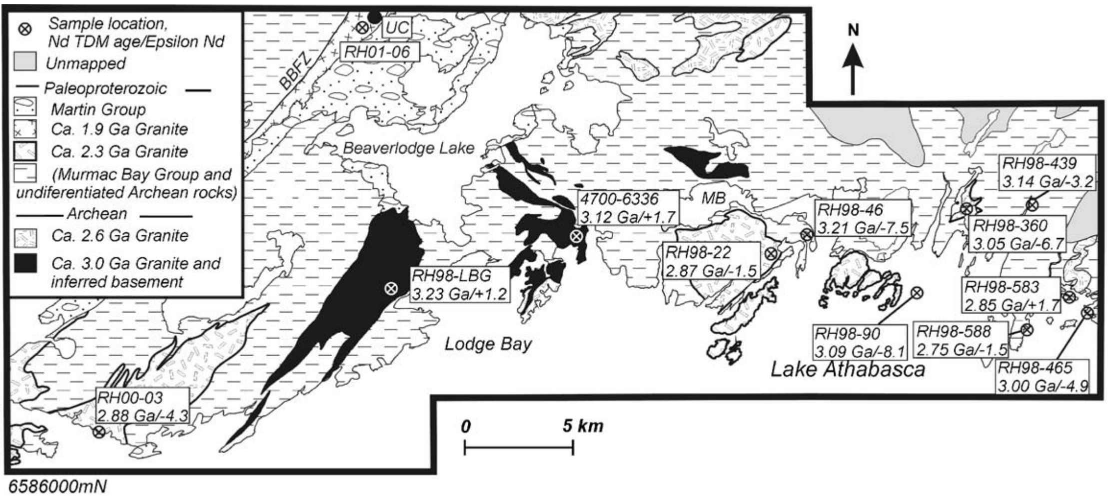

Fig. 3. Detailed geological sketch map of the region around Uranium City, Saskatchewan. The location of samples that are described in the text and detailed in Tables 1–3 are highlighted on this map. BBFZ, Black Bay Fault Zone; UC, Uranium City.

density minerals. This separate was passed through a 70-mesh sieve to obtain uniformly fine-grained material. Highly magnetic particles were removed by dropping the sample in front of a high-strength magnetic field. A final separate consisting entirely of heavy minerals was ensured by flotation of the sample in the heavy liquid methyl iodide. The >3.2 g/cm^3 heavy mineral separate was then split into magnetic fractions by passing the material through a Frantz isodynamic separator. With the aid of a binocular microscope, individual fractions of zircon, monazite, and titanite were hand picked from this separate. Some fractions were air abraded (Krogh, 1982) in order to remove zircon overgrowths, near-surface imperfections, and alteration.

All additional work on mineral fractions was performed in an ultraclean U–Pb Laboratory at the University of Alberta Radiogenic Isotope Facility. All fractions were cleaned in heated dilute nitric acid and washed repeatedly with H_2O and acetone in order to remove particles that could be adhering to grain surfaces. The cleaned fractions were weighed using a Mettler UTM-2 ultra-microbalance. Zircon fractions were loaded into pre-cleaned Teflon TFE dissolution vessels and immersed in a 10:1 mixture of 48% HF:7N HNO_3 and a measured amount of ^{205}Pb–^{235}U tracer solution. Uranium and lead were purified from fractions weighing more than 5 μg using the anion exchange chromatography methods described by Heaman et al. (2002). Two drops of 0.2 N H_3PO_4 acid were added to sample aliquots and then dried down in pre-cleaned beakers. Uranium and lead were loaded together onto a Re filament following the Si-gel technique of Cameron et al. (1969). Isotopic ratios were measured in single collector mode on a VG354 mass spectrometer using either a Faraday cup or Daly photomultiplier detector, depending on signal strength. The 1σ errors reported in Table 1 were calculated using an in-house program that numerically propagates all known sources of uncertainty. The composition of common lead in the samples was determined using the model of Stacey and Kramers (1975). Regression calculations and age uncertainties were determined using Isoplot Version 3.0 (Ludwig, 2003).

4.2. U–Pb laser ablation MC-ICP-MS geochronology

Due to the complex xenocrystic zircon populations that may occur in leucocratic granites (e.g. Miller et al., 2003), a selection of grains was dated by laser ablation multicollector Inductively Coupled Plasma Source Mass Spectrometry (LA-MC-ICP-MS). The Nu Plasma MC-ICP-MS utilized in this study has three ion multipliers which enabled simultaneous collection of ^{207}Pb, ^{206}Pb and ^{204}Pb. ^{235}U, ^{238}U and ^{203}Tl ion signals were measured on Faraday collectors. A New Wave Research 213 nm Nd:YAG laser unit was employed to ablate 40 μm spots on zircon grains mounted in epoxy. Data acquisition consisted of a 1 s integration for a total of 30 s. Measured ratios were corrected for machine drift by bracketing analyses with a known in-house standard. An external reproducibility (2σ) of $\leq$1% for ^{207}Pb/^{206}Pb and 3–4% for ^{206}Pb/^{238}U was achieved (Simonetti et al., 2005). Individual spot ages were calculated with Isoplot Version 3.0 (Ludwig, 2003) using a lower intercept of 0 Ma. Additional details regarding U–Pb dating by LA-MC-ICP-MS at the University of Alberta are given by Simonetti et al. (2005).

4.3. Sm–Nd geochemistry

Sm–Nd samples were crushed and finely powdered in a tungsten-carbide shatterbox. Rock powder was mixed to ensure sample homogeneity and 0.05–0.6 g, dependent on Sm concentration, of the powder was added to a pre-cleaned Savillex vial. A mixed ^{149}Sm–^{150}Nd spike, HF and HNO_3 were then added to the sample vial. The vial was placed on a hot plate at 150 °C for 6 days to ensure complete dissolution of all mineral grains. Samples were dried down and then converted to a 0.75 N HCl solution. This solution was centrifuged and loaded onto a cation column for REE separation. The collected REE solution was dried down and then converted to a 0.025 N HCl solution. This solution was added to HDEHP columns to separate the Sm and Nd. The Sm and Nd were dried down and then converted to a nitric acid solution that was loaded onto separate Re filaments. Isotope ratios were measured entirely with Faraday collectors on a Micromass Sector 54 Thermal-Ionization Mass Spectrometer. All reported depleted mantle model ages (T_{DM}) are based on the mantle evolution model of Goldstein et al. (1984). Additional details of Sm–Nd geochemistry methods and standard values are reported by Unterschutz et al. (2002).

5. U–Pb TIMS results

5.1. Prince Lake Granite (RH99-869)

The Prince Lake Granite contains numerous brown, prismatic, slightly resorbed zircons. All seven analyses consisted of single grains of near identical initial appearance. The similar U contents (280–700 ppm), Th/U ratios (0.16–0.45), and ^{207}Pb/^{206}Pb ages (2330–2567 Ma) (Table 1) and prismatic grain shape is consistent with a

Table 1
U–Pb TIMS results

Sample description[a]	Weight (mg)	Concentrations (ppm)				Isotopic ratios[b]				Apparent ages (Ma)				PD[c]
		U	Th[d] model	Pb rad.	Th/U ratio	Pb (pg)[e]	^{206}Pb/^{204}Pb	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb	
Prince Lake Granite (RH99-869)														
Zr, abr (1)	0.005	696	110	298	0.16	44	2128	0.4116 ± 7	9.136 ± 18	0.1610 ± 1	2222.4 ± 3.3	2351.7 ± 1.9	2465.8 ± 1.0	11.66
Zr, abr (1)	0.004	392	131	146	0.33	65	513	0.3468 ± 7	7.104 ± 17	0.1486 ± 2	1919.1 ± 3.1	2124.5 ± 2.4	2329.6 ± 2.3	20.34
Zr, abr (1)	0.002	325	145	172	0.45	30	729	0.4746 ± 12	11.188 ± 33	0.1710 ± 2	2503.8 ± 5.3	2538.9 ± 2.8	2567.1 ± 2.3	2.97
Zr, abr (1)	0.003	406	149	212	0.37	17	2074	0.4770 ± 9	11.149 ± 23	0.1695 ± 1	2514.3 ± 3.9	2535.7 ± 1.9	2552.9 ± 1.0	1.83
Zr, abr (1)	0.003	284	114	147	0.40	18	1571	0.4676 ± 8	10.775 ± 22	0.1671 ± 1	2473.0 ± 3.6	2504.0 ± 1.9	2529.1 ± 1.1	2.67
Zr, abr (1)	0.002	269	80	139	0.30	8	2404	0.4810 ± 10	11.303 ± 25	0.1705 ± 1	2531.4 ± 4.2	2548.4 ± 2.1	2562.0 ± 1.1	1.44
Zr, abr (1)	0.002	644	213	320	0.33	5	8111	0.4591 ± 12	10.417 ± 27	0.1646 ± 1	2435.6 ± 5.2	2472.6 ± 2.4	2503.2 ± 0.8	3.24
Uranium City Granite (RH01-06)														
Zr (1)	0.001	248	75	108	0.30	15	440	0.4006 ± 8	9.720 ± 25	0.1760 ± 3	2171.6 ± 3.8	2408.6 ± 2.4	2615.6 ± 2.5	19.96
Zr, abr (1)	0.001	1899	935	609	0.49	81	619	0.2961 ± 5	4.494 ± 10	0.1101 ± 2	1672.1 ± 2.2	1729.9 ± 1.9	1800.4 ± 2.7	8.08
Zr, abr (1)	0.002	423	42	162	0.10	26	585	0.3787 ± 7	7.779 ± 17	0.1490 ± 2	2070.1 ± 3.2	2205.8 ± 2.0	2334.4 ± 2.0	13.22
Zr, abr (1)	0.000	2035	180	714	0.09	13	689	0.3566 ± 6	5.823 ± 13	0.1185 ± 2	1965.9 ± 3.0	1949.9 ± 2.0	1932.9 ± 2.7	−.98
Zr, abr (1)	0.001	88	34	51	0.38	11	274	0.5047 ± 20	14.788 ± 68	0.2125 ± 4	2633.8 ± 8.6	2801.7 ± 4.9	2922.4 ± 3.4	12.10
Zr, abr (1)	0.001	321	234	171	0.73	10	452	0.4409 ± 12	11.491 ± 41	0.1890 ± 4	2354.5 ± 5.4	2563.8 ± 3.3	2733.8 ± 3.1	16.53
Zr, abr (1)	0.001	192	49	108	0.25	4	2187	0.4899 ± 9	17.006 ± 30	0.2518 ± 1	2570.3 ± 3.7	2935.2 ± 1.7	3195.9 ± 0.8	23.66
Feil Lake Granite (4701-299)														
Zr, abr (1)	0.001	290	42	107	0.14	4	1118	0.3592 ± 9	6.002 ± 22	0.1212 ± 3	1978.3 ± 4.3	1976.1 ± 3.3	1973.8 ± 4.5	−0.3
Zr, abr (1)	0.001	519	145	256	0.28	2	4353	0.4391 ± 8	13.594 ± 23	0.2245 ± 2	2346.7 ± 3.4	2721.8 ± 1.6	3013.4 ± 1.0	26.3
Zr, abr (1)	0.001	191	77	96	0.41	1	4276	0.4362 ± 11	12.990 ± 32	0.2160 ± 2	2333.5 ± 4.8	2678.9 ± 2.3	2951.1 ± 1.2	24.9
Zr (1)	0.001	733	241	295	0.33	13	1045	0.3632 ± 7	6.801 ± 14	0.1358 ± 2	1997.5 ± 3.1	2085.8 ± 1.8	2174.2 ± 2.0	9.4
Zr (1)	0.001	994	363	335	0.37	6	1576	0.3039 ± 5	6.109 ± 12	0.1458 ± 1	1710.8 ± 2.7	1991.7 ± 1.7	2297.2 ± 1.3	29.0

[a] Abbreviations: Zr, zircon; abr, air abraded following the techniques of Krogh (1982). The number in parentheses identifies the number of grains or grain fragments analyzed.

[b] Atomic ratios corrected for 2.0 pg Pb and 0.5 pg U in blanks, fractionation, and initial common Pb (Stacey and Kramers, 1975). Uncertainties are reported at 1σ.

[c] PD refers to the percent discordance along a chord to the origin.

[d] Model Th concentration calculated from ^{208}Pb/^{206}Pb ratio and ^{207}Pb/^{206}Pb age.

[e] Total common lead in analysis.

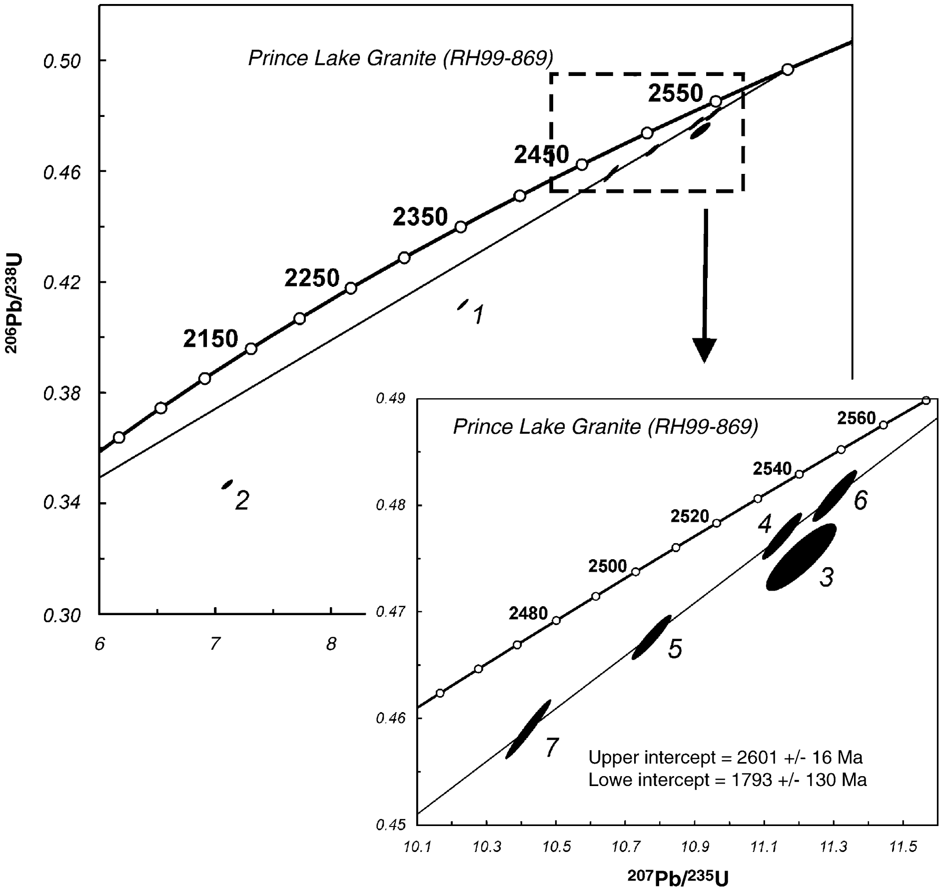

Fig. 4. U–Pb concordia diagram for the Prince Lake Granite.

single population of igneous zircon. Although all grains underwent air abrasion prior to analysis, a much higher degree of air abrasion was used for grains 3–7. These highly abraded cores have a lower weight and less common lead than the weakly abraded grains (Table 1). Discounting analysis 3, which has more common lead and higher errors than analyses 4–7, a discordia line derived by the highly abraded grains has an upper intercept age of 2601 ± 16 Ma and a lower intercept age of 1793 ± 130 Ma (MSWD = 0.22; Fig. 4). The upper intercept is interpreted to represent the crystallization age of the granite, whereas the lower intercept, which is identical to lower intercepts found in other Neoarchean granites from the area (Hartlaub et al., 2004), broadly corresponds to a period of Paleoproterozoic metamorphism.

5.2. *Feil Lake Granodiorite (4701-299)*

This sample contains a mixed zircon population consisting of colourless and slightly brown prismatic to acicular grains. Backscatter electron images reveal highly altered grains with cores and overgrowths, as well as relatively pristine acicular grains (Fig. 5A–D). Analysis no. 1 represents an abraded clear and colourless acicular zircon (e.g. Fig. 5D) grain that has a slightly lower Th/U ratio (0.14) than the other grains in the sample (Table 1). The concordant ^{207}Pb/^{206}Pb age of 1974 ± 5 Ma for this grain is considered a good estimate of the crystallization age for this granodiorite. Analyses no. 2 and 3 consist of brown abraded prismatic grains. These two grains likely represent xenocrystic zircons from a protolith with a crystallization age of >3.0 Ga. Analyses 4 and 5 were not abraded and therefore represent complex mixtures of rim and core material with increased discordance.

5.3. *Uranium City Granite (RH01-06)*

The Uranium City Granite contains a mixed population of zircon grains that range from resorbed rounded varieties to colourless prismatic grains. Although the majority of grains are colourless, rare yellow grains are

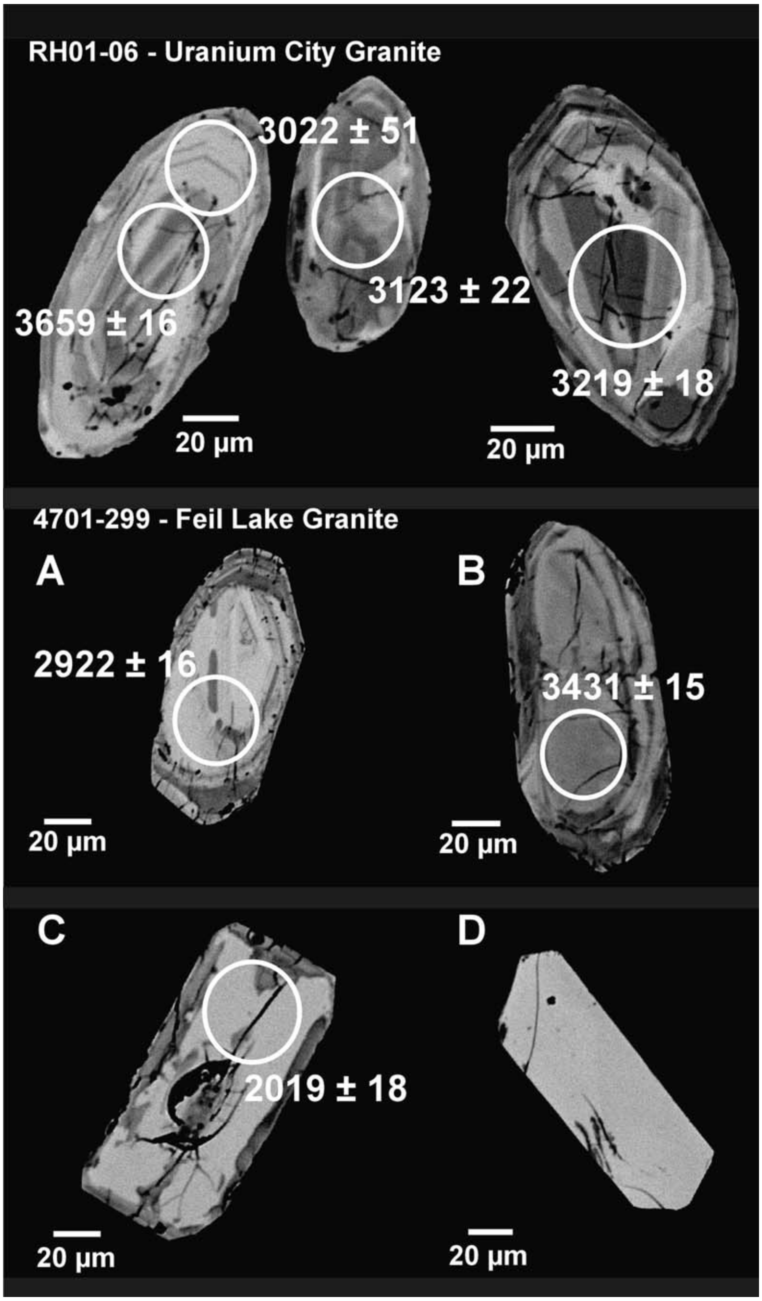

Fig. 5. Backscatter electron images of zircon from leucogranites. The U-City Granite (RH01-06) contains zircon with Paleoarchean xenocrystic cores that are surrounded by oscillatory zoned overgrowths. The Feil Lake Granodiorite (4701-299) contains massive prismatic Paleoproterozoic zircon (C and D) in addition to grains with cores and overgrowths (4701-299) (A and B). Laser spot locations with associated ages (in Ma) are highlighted.

present and many grains are cloudy. Backscatter electron images of zircon from the sample indicate that the majority of grains contain massive structureless cores that have been overgrown by oscillatory zoned zircon (Fig. 5, top). These cores likely represent a xenocrystic component to the zircon in this sample. Analyses nos. 1, 3 and 7 (Table 1, Fig. 6) consist of single colourless ovoid zircons. Nos. 1 and 7 are exceptionally clear grains whereas no. 3 is slightly cloudy. Analysis no. 2 is a very cloudy abraded prismatic zircon. Analysis no. 4 consists of a single exceptionally clear and colourless blocky zircon that was moderately abraded. Analyses no. 5 and

6 are both clear prismatic zircon but no. 5 was heavily abraded to a sphere, whereas no. 6 was only moderately abraded.

Because of its distinct morphology and near concordance, the 1933 Ma ^{207}Pb/^{206}Pb age for analysis no. 4 likely represents the crystallization age for the Uranium City Granite. The large proportion of xenocrystic zircon in the Uranium City and Feil Lake Granites is consistent with their formation in a low-temperature crustal setting (Chappell et al., 2004). The 1933 Ma crystallization age corroborates the date for the petrologically similar Feil Lake Granodiorite, and is consistent with magmatism in the Uranium City area coeval with magmatism in the Taltson Magmatic Zone (Fig. 1). Elsewhere in the Uranium City area, a gold-bearing pink leucogranite has a poorly defined U–Pb age of 1994 ± 37 Ma (Persons, 1988). The similar morphology and chemical composition (Table 1) of analyses 1, 3 and 7 is consistent with their derivation from a common source rock. A discordia line through these analyses and no. 4 has an upper intercept age of 3899 ± 97 Ma. Although the upper intercept has a large error, it has some geological significance because it suggests that Paleoarchean crust was involved in the formation of this granite. Such crust has been suspected in the region since the discovery of >3.7 Ga ages from detrital zircons in a quartzite 10 km to the northeast (Hartlaub et al., 2004).

6. U–Pb laser ablation MC-ICP-MS results

In order to better constrain the complex xenocrystic zircon components of the Feil Lake Granodiorite and Uranium City Granite, laser ablation MC-ICP-MS analysis of large zircon populations was conducted. All analyses were done on the cores of grains in order to avoid discordance and areas characterized by younger overgrowths.

Twenty three zircons from the Uranium City Granite were analyzed in this study (Fig. 6, Table 2). The ^{207}Pb/^{206}Pb minimum ages for these grains range from 2174 to 3659 Ma (Table 2). Twenty grains from the Feil Lake Granodiorite were also analyzed, and range in age from 1897 to 3776 Ma (Fig. 6, Table 2). In addition to the ca. 1.9 Ga zircons we interpret to represent igneous crystallization ages, a large number of the zircons group around 2.3 and 3.0–3.3 Ga. These xenocryst populations match the age of dated granites from the study area (Hartlaub, 2004; Hartlaub et al., 2004). The >3.6 Ga zircon xenocrysts have a similar age as the upper intercept from TIMS dating of this sample, and together they corroborate the initial evidence for Paleoarchean crust in the area that was reported by Hartlaub et al. (2004). Although the Uranium City and Feil Lake Granites may have acquired xenocrystic zircon from partial melting of sediments, the good match between ages of exposed granite and xenocrystic zircon is consistent with local derivation for these xenocrysts.

7. Sm–Nd results

7.1. Circa 3.0 Ga basement granite

The two dated 3.0 Ga basement granite samples (RH98-LBG, RH00-6336) have low concentrations of Sm (1–2 ppm) and Nd (6–16 ppm) (Table 3). The nearly identical T_{DM} and U–Pb crystallization ages for the granites, combined with their +1.2 and +1.7 epsilon Nd at crystallization ($\varepsilon\mathrm{Nd}_{\mathrm{T}}$), indicate that these granites are broadly juvenile in composition. The relatively homogeneous zircon populations of the basement granites (Hartlaub et al., 2004) are consistent with this conclusion. Because granites related to differentiation of mafic and ultramafic complexes are volumetrically minor (Pitcher, 1997), it is unlikely that the ca. 3.0 Ga granites are directly mantle-derived. It is possible, however, that the source rocks for the granites were mantle-derived mafic to intermediate igneous rocks of nearly the same age. The 3.3 Ga T_{DM} and negative εNd at 3.0 Ga for the undated sheared basement granite (RH98-125, Table 3) indicates that this granite was either contaminated by older material or is slightly older than ca. 3.0 Ga. The second interpretation would be consistent with the abundance of 3.2–3.3 Ga xenocrystic zircon identified in the Paleoproterozoic granites from the area. Another undated and sheared granite (RH99307a, Table 3) structurally underlies Proterozoic quartzite and may also represent ca. 3.0 Ga granite. The Sm and Nd concentrations of this rock are similar to dated ca. 3.0 Ga granite.

7.2. Neoarchean granitoids

All of the dated Neoarchean granitic rocks from this study have uniform Nd model ages ranging from 2.8 to 3.0 Ga and $\varepsilon\mathrm{Nd}_{\mathrm{T}}$ ranging from −1.2 to +1.7 (Table 3). All seven undated granites of probable Neoarchean age have similar Sm and Nd concentrations (Table 3) and Nd model ages (2.8–3.0 Ga). The $\varepsilon\mathrm{Nd}_{\mathrm{T}}$ for six of the seven granites at 2600 Ma is almost identical with a range between −0.1 and +1.3. The Nd isotopic evolution of both the Neoarchean and ca. 3.0 Ga basement granites are plotted as envelopes on the time versus ^{143}Nd/^{144}Nd plot (Fig. 7). The two episodes of magmatism have distinct isotopic evolution envelopes, consistent with a predominantly juvenile source for both granite suites. A

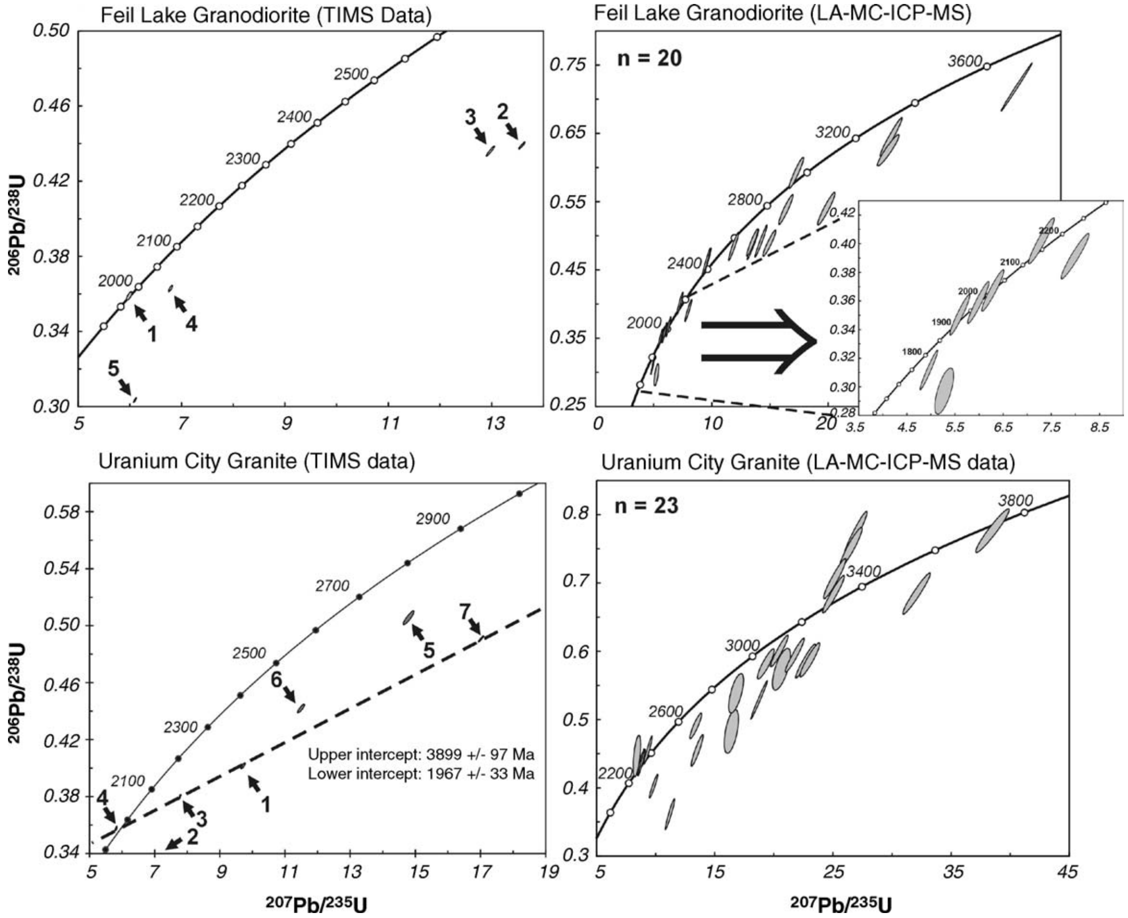

Fig. 6. U–Pb concordia diagrams for the Feil Lake Granodiorite (top) and the Uranium City Granite (bottom).

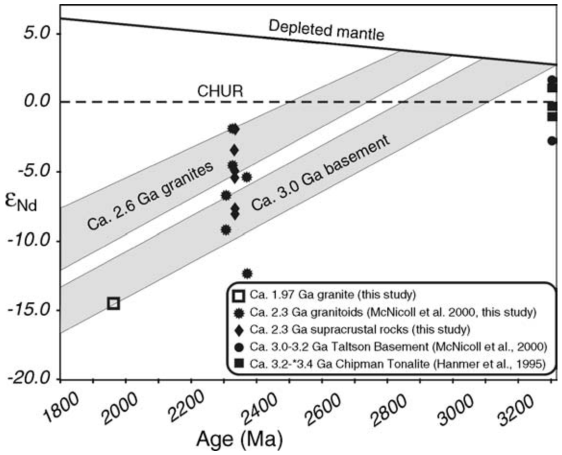

Fig. 7. Comparison plot of Rae Province sediments and granitoids with the Nd evolution trends for ca. 2.6 and 3.0 Ga (Mesoarchean) granites from this study. Plotted ca. 2.6 Ga granites are restricted to those outside the region of ancient crust. Depleted mantle trend is based on the evolution model of Goldstein et al. (1984).

single foliated granitoid gneiss that has a slightly lower εNd_T of −1.2 at 2600 Ma (RH01-10), may have either crustal contamination or a >2.6 Ga crystallization age.

7.3. Ca. 1.9 Ga granite

The exceptionally leucocratic nature and low Sm (1.22 ppm) and Nd (8.63 ppm) concentrations of the Feil Lake Granodiorite is significantly different from the Neoarchean granitoids, but almost identical to known ca. 3.0 Ga granite (Table 3). Its Nd composition (T_{DM} of 3.18 Ga, $\varepsilon Nd_T = -14.3$) and the presence of entrained ≥3.0 Ga zircon xenocysts is consistent with our interpretation that this granite is entirely derived from Meso and Paleoarchean crust.

7.4. Supracrustal rocks

Supracrustal rocks from this study have a wide range of T_{DM} ages (2.75–3.21 Ga) and εNd_T values

Table 2
LA-MC-ICP-MS U–Pb results

^{206}Pb/^{238}U	±1σ	^{207}Pb/^{235}U[a]	±1σ	^{207}Pb/^{206}Pb	±1σ	Age[b] (Ma)	±2σ
Uranium City Granite (RH01-06)							
0.6838	0.0112	25.010	0.375	0.2653	0.0013	3278	16
0.7763	0.0130	38.465	0.577	0.3593	0.0018	3745	15
0.5879	0.0101	23.011	0.345	0.2840	0.0018	3384	19
0.7716	0.0134	26.865	0.403	0.2525	0.0013	3201	16
0.6849	0.0123	32.038	0.481	0.3391	0.0018	3659	16
0.5388	0.0119	16.774	0.252	0.2245	0.0037	3022	51
0.5820	0.0090	19.298	0.289	0.2403	0.0017	3123	22
0.7065	0.0119	25.114	0.377	0.2577	0.0014	3233	17
0.4032	0.0070	9.787	0.147	0.1759	0.0010	2616	19
0.4832	0.0131	16.375	0.246	0.2456	0.0014	3158	61
0.4377	0.0078	8.780	0.132	0.1455	0.0007	2294	17
0.5947	0.0100	21.738	0.326	0.2651	0.0014	3277	16
0.4558	0.0094	13.488	0.202	0.2137	0.0019	2941	29
0.5739	0.0125	20.627	0.310	0.2606	0.0014	3251	48
0.7518	0.0121	26.477	0.397	0.2554	0.0015	3219	18
0.5861	0.0101	22.661	0.340	0.2804	0.0014	3365	16
0.4563	0.0082	9.330	0.140	0.1482	0.0009	2326	21
0.4475	0.0123	8.378	0.126	0.1352	0.0008	2174	69
0.6008	0.0094	20.441	0.307	0.2467	0.0013	3164	16
0.4914	0.0077	13.367	0.201	0.1971	0.0013	2804	21
0.4387	0.0078	8.702	0.131	0.1438	0.0008	2274	19
0.3626	0.0090	11.171	0.168	0.2233	0.0026	3006	36
0.5294	0.0115	18.719	0.281	0.2572	0.0018	3225	22
Feil Lake Granite (4701-299)							
0.5920	0.0093	17.320	0.260	0.2121	0.0011	2922	16
0.3504	0.0058	5.609	0.084	0.1160	0.0006	1897	19
0.4622	0.0083	9.643	0.145	0.1513	0.0008	2361	17
0.4851	0.0084	11.924	0.179	0.1782	0.0009	2637	17
0.4877	0.0091	13.586	0.204	0.2018	0.0011	2843	17
0.4619	0.0083	9.578	0.144	0.1504	0.0008	2351	17
0.4909	0.0081	13.537	0.203	0.1999	0.0011	2826	17
0.5387	0.0089	16.415	0.246	0.2208	0.0012	2988	17
0.4927	0.0095	14.274	0.214	0.2097	0.0012	2907	18
0.3914	0.0065	8.003	0.120	0.1482	0.0008	2326	17
0.6252	0.0094	25.214	0.378	0.2923	0.0015	3431	15
0.6448	0.0116	25.444	0.382	0.2861	0.0015	3397	16
0.2972	0.0066	5.284	0.079	0.1289	0.0007	2084	54
0.3119	0.0056	4.967	0.075	0.1154	0.0006	1888	18
0.5401	0.0098	19.882	0.298	0.2663	0.0017	3288	20
0.4893	0.0078	15.001	0.225	0.2220	0.0012	2998	17
0.3673	0.0059	6.294	0.094	0.1241	0.0006	2019	18
0.4020	0.0066	7.301	0.110	0.1316	0.0007	2121	18
0.3590	0.0060	5.994	0.090	0.1210	0.0006	1972	18
0.7179	0.0143	36.248	0.544	0.3658	0.0019	3776	15

[a] Calculated value based on ^{238}U/^{235}U = 137.88.
[b] ^{207}Pb/^{206}Pb age assumes lead loss at 0 Ma.

at 2600 Ma (+2.3 to −4) (Fig. 7). This range of values likely reflects the variety of source rocks from which these samples were derived. The samples with the lowest εNd values are preferentially located in the western Beaverlodge Belt and may have been derived almost entirely from the Meso- to Paleoarchean basement in the area (Fig. 3). This is consistent with the predominance of Paleoarchean detrital zircons in two metasedimentary rocks in the area (Hartlaub et al., 2004).

Table 3
Sm–Nd results

Sample no.	Rock type	UTM (E)	UTM (N)	Sm (ppm)	Nd (ppm)	^{147}Sm/^{144}Nd	^{143}Nd/^{144}Nd	Uncert.	T_{DM}[a]	~TMa[b]	εNd_T
Circa 3.0 Ga basement granite											
RH98-LBG	Lodge Bay Granite	634800	6591125	1.04	5.86	0.1071	0.510887	0.000009	**3.23**	**3060**	**1.2**
RH00-6336	Cornwall Bay Granite	643625	6593625	2.13	15.69	0.0822	0.510455	0.000008	**3.12**	**3000**	**1.7**
RH98-125	Sheared granite	647875	6598750	1.71	9.97	0.1039	0.510748	0.000008	**3.33**	*3000*	**−1.0**
RH99-307a	Sheared granite	663700	6612400	1.54	9.60	0.0972	0.510841	0.000009	**3.02**	*3000*	**3.4**
Neoarchean granites											
RH98-583	Dead Man granite	665500	6592775	11.93	64.49	0.1119	0.511247	0.000008	**2.85**	**2639**	**1.7**
RH99-869	Prince Lake Granite	655675	6611450	6.75	37.03	0.1102	0.511170	0.000008	**2.92**	**2600**	**0.3**
4798-2085b*	Granodiorite	373116	6606407	2.02	13.03	0.0936	0.510898	0.000009	**2.86**	**2550**	**−0.1**
4798-2031c*	Granodiorite	374122	6602281	11.23	77.26	0.0879	0.510750	0.000008	**2.91**	**2550**	**−1.2**
4798-3029*	Granodiorite	403550	6613525	6.18	30.32	0.1232	0.511352	0.000009	**3.03**	2600	**−0.5**
4798-4012*	Granite	430735	6633875	7.23	40.98	0.1066	0.511063	0.000009	**2.97**	**2678**	**0.3**
RH01-08	Sheared leucogranite	643102	6623321	9.96	70.10	0.0859	0.510752	0.000008	**2.86**	*2600*	**0.3**
RH01-09	Granite w/inclusions	651832	6637204	12.64	83.98	0.0910	0.510875	0.000008	**2.83**	*2600*	**1.0**
RH01-10	Foliated granitoid gneiss	657764	6649286	6.38	39.02	0.0989	0.510899	0.000008	**2.99**	*2600*	**−1.2**
RH01-16	Megacrystic granodiorite	613430	6634746	6.56	45.26	0.0877	0.510780	0.000009	**2.86**	*2600*	**0.2**
RH01-17	Megacrystic granodiorite	603762	6643951	15.33	86.11	0.1076	0.511139	0.000008	**2.89**	*2600*	**0.6**
RH01-18	Sheared granite	580439	6706325	4.01	22.58	0.1073	0.511146	0.000009	**2.87**	*2600*	**0.8**
RH01-12	Granodiorite/tonalite	647274	6755121	11.09	59.86	0.1120	0.511180	0.000007	**2.95**	*2600*	**−0.1**
Paleoproterozoic granite											
RH98-022	Macintosh Bay monzogranite	652400	6594250	4.92	24.61	0.1210	0.511403	0.000006	**2.87**	**2300**	**−1.5**
RH98-360	Hayter Bay monzogranite	657625	6601250	5.24	34.53	0.0918	0.510705	0.000007	**3.05**	**2300**	**−6.7**
RH00-03	Gunnar monzogranite	623625	6584500	10.07	71.87	0.0847	0.510712	0.000009	**2.88**	**2300**	**−4.3**
4701-0299	Feil Lake Granodiorite	619280	6600800	1.22	8.63	0.0855	0.510470	0.000009	**3.18**	**1970**	**−14.3**
Circa 2.3 Ga supracrustal rocks											
RH98-46	Psammite	653400	6594950	5.43	30.86	0.1063	0.510885	0.000009	**3.21**	**2300**	**−7.5**
RH98-465	Pelite	652750	6597400	5.77	33.73	0.1034	0.510974	0.000009	**3.00**	**2300**	**−4.9**
RH98-439	Intermediate volcanic	654850	6598200	3.98	17.63	0.1366	0.511563	0.000008	**3.14**	**2300**	**−3.2**
RH98-588	Migmatitic psammopelite	666100	6592375	6.26	37.75	0.1002	0.511101	0.000008	**2.75**	*2300*	**−1.5**
RH98-90	Quartzofeldspathic gneiss	659550	6594960	5.30	38.14	0.0841	0.510519	0.000007	**3.09**	*2300*	**−8.1**
RH01-20	Psammopelite	568032	6722524	4.67	28.48	0.0991	0.510997	0.000009	**2.86**	*2300*	**−3.2**

All UTMs are recorded in zone 12 except sample numbers with a * which are recorded in zone 13.

[a] TDM calculated using the mantle evolution model of Goldstein et al. (1984).

[b] Ages in bold are approximate ages based on U–Pb dating (Hartlaub et al., 2004; Card, 2001). Ages in italics are assumed ages for the samples.

8. Discussion: crust formation and recycling in the Rae Province

8.1. Early Archean (3.9–3.3 Ga) crust

Paleoarchean crust is exceptionally rare in the rock record, yet provides the only direct evidence for Earth's earliest stages of formation (Condie, 1993). Estimates for the rate of crustal growth and recycling during Paleoarchean time are tied to the analysis of these ancient crustal remnants (Bowring and Housh, 1995). Great effort should be made, therefore, to find and describe this relict ancient crust. Evidence from the present work, and related studies (Hartlaub et al., 2004), indicate that Mesoarchean and possibly ancient (>3.6 Ga) crust exists along the western edge of the Beaverlodge Belt, Rae Province, Canada. In this area, the Uranium City Granite and Feil Lake Granodiorite both contain Paleoarchean xenocrystic zircons, and metasedimentary rocks have abundant >3.7 Ga detrital zircons (Hartlaub et al., 2004). These data, in conjunction with the depleted mantle Nd model ages reported in this study, suggest that a Meso- to Paleoarchean crustal block occurs at the western end of the Beaverlodge Belt.

The Black Bay shear zone (Fig. 2) is a several kilometer wide zone comprising both cataclastic rocks and older mylonitic gneisses (Bergeron, 2000). It is possible that the early component of this major shear zone represents the surface expression of a suture between a Paleo to Mesoarchean crustal block and Neoarchean crust. If this is the case then Paleoarchean crust may be exposed within this structural zone.

Elsewhere in the Churchill craton, evidence for ancient crust occurs primarily along the western margin of the Rae Province (Fig. 8, Table 4). Thériault et al. (1994) reported 3.0–3.9 Ga Nd model ages in the Queen Maud Block and immediately southeast of the MacDonald Fault (Fig. 8, Table 4). A 3300 Ma $^{207}Pb/^{206}Pb$ minimum age for a zircon xenocryst was reported from the Campbell Granite in this same area (Henderson and Loveridge, 1990). To the south, but also along the western margin of the Rae Province, McNicoll et al. (2000) reported numerous Mesoarchean Nd model ages within the basement to the Taltson Magmatic Zone (Table 4). Paleoarchean detrital zircons from Neoarchean supracrustal belts in the northern Rae Province (Eva Zaleski, pers. commun., 2001) also indicate that ancient crust must have been exposed at the surface by this time. The dashed line and cross-hatched area in Fig. 8 roughly separates the southwestern Rae Province, with abundant evidence for Meso and Paleoarchean crust, from the more juvenile northeastern Rae Province.

8.2. Circa 3.0–3.3 Ga crust

Circa 3.0–3.2 Ga crust appears to be widespread along the margins of the Rae Province (Fig. 8). In addition to crust of this age exposed in the Uranium City area (Hartlaub et al., 2004), a 3129 +13/−10 Ma tonalite gneiss is located along the western margin of the Rae Province, south of the McDonald fault (Henderson and Theriault, 1994). Also along the western margin of the Rae Province, 3.2–3.1 Ga granite and tonalite gneiss occurs as basement to the Taltson Magmatic Zone (McNicoll et al., 2000). The ca. 3.15–3.3 Ga Chipman Batholith is located along the Snowbird Tectonic Zone (Hanmer et al., 1994) at the boundary between the Rae and Hearne Provinces. The Nd isotopic composition of the 3.0 Ga crust in the Uranium City area suggests a relatively juvenile source (Fig. 7). However, other examples of ca. 3.0–3.3 Ga crust from the Rae Province appear to have more evolved isotopic compositions (Fig. 7). For example, a 3.08 Ga migmatitic tonalite gneiss from the Taltson Magmatic Zone basement has a T_{DM} of >3.7 Ga (McNicoll et al., 2000).

8.3. Neoarchean magmatism

Voluminous, variably deformed granitic rocks with U–Pb zircon ages between 2.58 and 2.64 Ga were first identified in the Rae Province by Ashton (1988). The regional extent and strictly felsic composition of these rocks was recognized shortly thereafter by LeCheminant and Roddick (1991). They also recognized the age and petrologic similarities between the Rae suite of granitoids and a granitic suite studied by van Breemen and Henderson (1988) in the Slave Province. The tectonic setting of these granitoids is one of the fundamental unknowns in the Rae Province (Relf and Hanmer, 2000; Davis et al., 2000). With the exception of those samples from this study that appear to be contaminated by ≥3.0 Ga crust in the Uranium City area, the known and suspected Neoarchean granitoids from the Rae Province ($n = 17$; this study; Dudas et al., 1991) have relatively similar εNd_T values that range between −1.2 and +1.7. This similarity in Nd compositions makes it difficult to explain their derivation as recycling of older crust. The consistent T_{DM} and εNd_T over such a large area of crust indicate a regional uniform reservoir. On the basis of a Sm–Nd isochron derived from these 17 samples, the reservoir would have had an initial $^{143}Nd/^{144}Nd$ ratio of approximately 0.50929 ± 0.00018 at 2.58 Ga corresponding to an εNd_T of ~0. The depleted mantle evolution model of Goldstein et al. (1984) predicts an εNd of +4.5 at 2580 Ma. Cousens et al. (2001) exam-

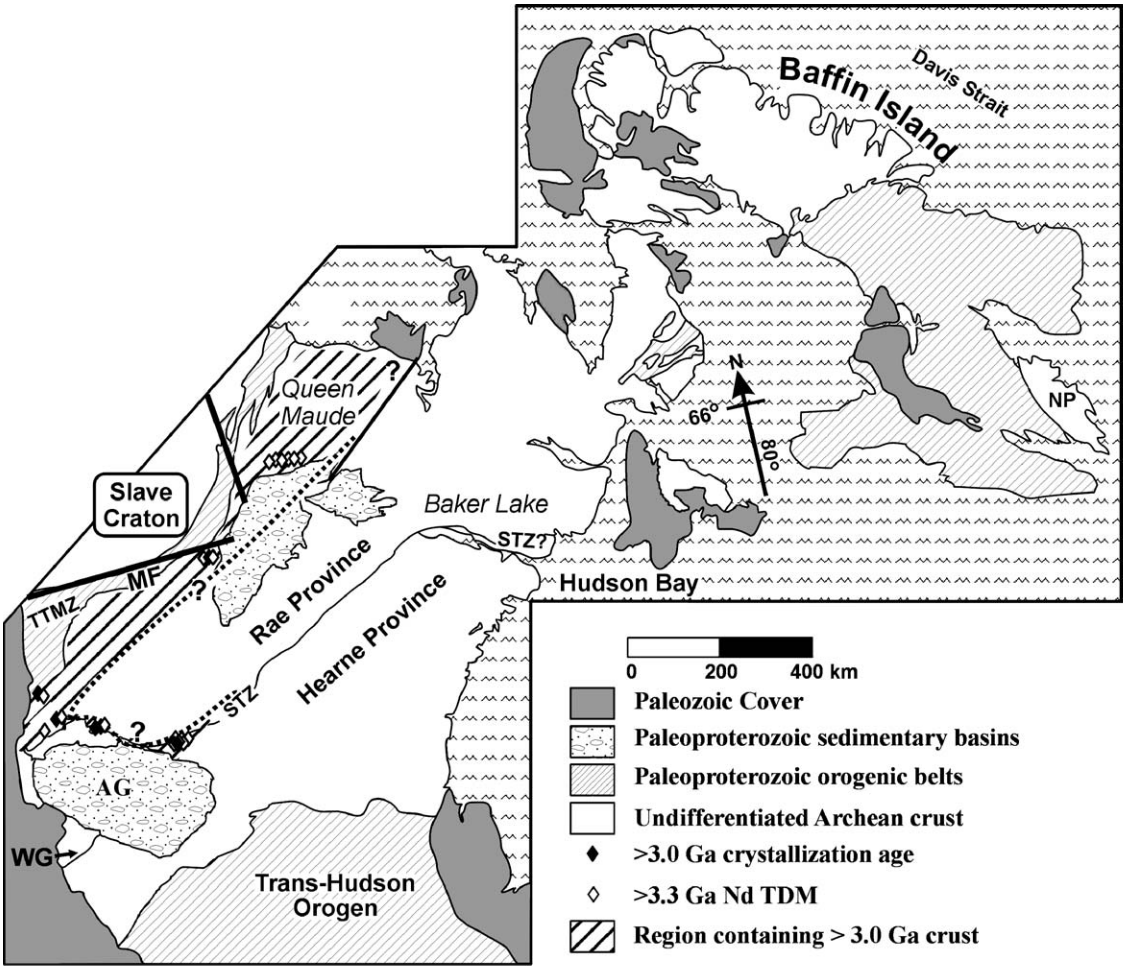

Fig. 8. Simplified geology of the Rae Province and bounding tectonic entities (modified after Jackson et al., 1990; Wheeler et al., 1996; Scott, 1999). Meso to Paleoarchean U–Pb crystallization ages and Nd TDMs from the Rae Province are highlighted and discussed in the text. The dashed line separates the evolved isotopic signature of the southwestern Rae Province from the more juvenile northeastern Rae Province. Data used in compilation is detailed in Table 4 (De et al., 2000; Dudas et al., 1991; Hanmer et al., 1994; Henderson and Theriault, 1994; McNicoll et al., 2000; Theriault, 1992; Thériault et al., 1994, this work). TDMs restricted to those samples with ^{147}Sm/^{144}Nd < 0.14. AG, Athabasca Group; MF, McDonald Fault; NP, Nain Province; STZ, Snowbird tectonic zone; TTMZ, Taltson-Thelon Magmatic Zone; WG, Western Granulite Domain.

ined the geochemistry and Nd isotopic composition of the Christopher Island Formation, a suite of Proterozoic ultrapotassic rocks injected and erupted over a 240,000 km^2 area of the Churchill craton. Based on their results they suggested that an enriched lithospheric mantle has existed beneath much of the Churchill craton since the Neoarchean. This enriched lithospheric mantle would have had εNd$_T$ of between −3 and +2 at 2600 Ma, similar to the average εNd of 0 for the Neoarchean granites in this study (Fig. 7). It is possible that an evolved mantle wedge was developed beneath the Churchill craton between 3.0 and 2.8 Ga. This mantle wedge would have been tapped during widespread Neoarchean magmatism.

8.4. *Proterozoic magmatism*

Voluminous ca. 2.3 Ga magmatic rocks occur along the entire western margin of the Rae Province (Hartlaub, 2004). The ca. 2.3 Ga plutons from the Beaverlodge Belt have Nd depleted mantle model ages (T_{DM}, Goldstein et al., 1984) that are considerably older (2.87–3.05 Ga) than their crystallization ages (Table 3). All three samples have negative initial εNd$_T$ values (−1.5 to −6.7). With the inclusion of three ca. 2.3 Ga intrusive rocks from the western margin of the Rae Province (McNicoll et al., 2000), this suite of magmatic rocks exhibit a significant variation in Nd values, with the majority of samples plotting within or below the Nd evolution enve-

Table 4
Sm–Nd compilation for Archean and probable Archean igneous rocks of the Rae Province

Sample no.	Reference	Rock type	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	±2σ	TDM[a]	Age[b] (Ga)
Baker Lake Region							
81SMA-K324	Dudas et al. (1991)	Felsic porhyry	0.0966	0.510998	11	2.80	∼2.7
82TX-S100-1	Dudas et al. (1991)	Leucocratic granite	0.1006	0.511009	5	2.89	2.61
80LAA-T36	Dudas et al. (1991)	Qtz-feldspar porhyry	0.1073	0.511116	22	2.91	2.61
83LAA-T188	Dudas et al. (1991)	Dacite porhyry	0.0978	0.510946	8	2.90	2.58
Queen Maude Block							
86-RF-48A	Thériault et al. (1994)	Opx-granitic gneiss	0.0711	0.509971	9	3.37	Undated
86-RF-49A	Thériault et al. (1994)	Migmatitic mafic gneiss	0.0967	0.510468	12	3.47	Undated
86-RF-54	Thériault et al. (1994)	Garnet granitic gneiss	0.1189	0.510907	8	3.58	Undated
86-RF-56C	Thériault et al. (1994)	Migmatitic granitic gneiss	0.0887	0.510425	4	3.30	Undated
86-RF-57A	Thériault et al. (1994)	Mylonitic mafic gneiss	0.1067	0.510701	5	3.46	Undated
86-RF-61B	Thériault et al. (1994)	Leucogranite	0.1381	0.511241	9	3.46	Undated
86-RF-62	Thériault et al. (1994)	Granite pegmatite	0.1043	0.510909	9	3.10	Undated
86-RF-63	Thériault et al. (1994)	Banded granitic gneiss	0.0906	0.510583	10	3.16	Undated
Western Rae Margin/Taltson Basement							
HBA-H-263	Thériault et al. (1994)	Granodiorite gneiss	0.0820	0.510336	6	3.24	Undated
HBA-W-213	Thériault et al. (1994)	Migmatitic granitic gneiss	0.0942	0.510815	7	2.96	Undated
HBA-B-385	Thériault et al. (1994)	Amphibolite gneiss	0.0961	0.510636	7	3.24	Undated
HBA-F-50A	Thériault et al. (1994)	Migmatitic granitic gneiss	0.1004	0.510656	5	3.33	Undated
HBA-F-414B	Thériault et al. (1994)	Paragneiss	0.0994	0.510655	8	3.30	Undated
HBA-W-70A	Thériault et al. (1994)	Tonalite gneiss	0.1107	0.510480	5	3.91	Undated
HBA-H-348B	Thériault et al. (1994)	Granitic gneiss	0.0692	0.510311	6	2.98	Undated
87BK-359	Thériault (1992)	Granitic gneiss	0.1219	0.511416	6	2.86	Undated
87BK-366	Thériault (1992)	Granitic gneiss	0.1046	0.511138	10	2.79	Undated
RT88-1	Thériault (1992)	Mixed gneiss	0.0826	0.510713	8	2.82	Undated
RT88-5	Thériault (1992)	Granitic gneiss	0.0952	0.510865	10	2.92	Undated
RT88-6	Thériault (1992)	Granitic gneiss	0.0919	0.510374	10	3.45	Undated
RT88-25	Thériault (1992)	Mixed gneiss	0.1230	0.511159	9	3.32	Undated
RT88-27	Thériault (1992)	Mixed gneiss	0.0823	0.510463	11	2.89	Undated
RT88-28	Thériault (1992)	Mixed gneiss	0.1205	0.510575	9	4.16	Undated
C233588	De et al. (2000)	Biotite gneiss	0.0985	0.510450	8	3.56	Undated
MSB-93-139	McNicoll et al. (2000)	Mimgatitic tonalite gneiss	0.1160	0.510737	6	3.73	3.08
MSB-94-47	McNicoll et al. (2000)	Tonalite gneiss	0.0775	0.510609	8	2.83	2.56
MSB-93-02	McNicoll et al. (2000)	Granodiorite gneiss	0.1156	0.510959	5	3.29	3.20
Western Granulite Domain							
CC-88-84B	Crocker et al. (1993)	Tonalitic gneiss	0.0800	0.510400	7	3.11	≥2.9 Ga
CC-88-3	Crocker et al. (1993)	Tonalitic gneiss	0.1096	0.510903	7	3.26	≥2.9 Ga

[a] All TDMs calculated using the mantle evolution model of Goldstein et al. (1984). Rocks with $^{147}Sm/^{144}Nd > 0.14$ are not included.
[b] U–Pb crystallization age.

lope for ca. 2.6 Ga granites (Fig. 7). The large range of Nd model ages and εNd values indicates that a significant component of Mesoarchean and Paleoarchean crust was recycled into these granites, either through contamination or direct partial melting.

The ca. 1.97 Ga Feil Lake Granodiorite has a crustal Nd signature ($T_{DM} = 3.18$ Ga, $\varepsilon Nd_T = -14.3$) that is best explained by partial melting of the local Paleoproterozoic to Paleoarchean basement. Granitoids from the 1.9 to 2.0 Ga Taltson Magmatic Zone have younger T_{DM} and higher εNd_T (1.94 Ga) values (−3.4 to −9.8) (De et al., 2000) than the Feil Lake Granodiorite. This difference can be explained by either a larger mantle component to the TMZ granites, or by their derivation from source rocks that have a younger average crustal residence time.

9. Conclusions

Evidence from the present work and previous studies (Thériault et al., 1994; McNicoll et al., 2000; Hartlaub et al., 2004) indicate that Mesoarchean and Paleoarchean crust exists along the southwestern margin of the Rae Province, Canada. One fragment of this ancient crust exists along the western margin of the Beaverlodge Belt. Circa 3.0 Ga granites in the Beaverlodge belt are relatively juvenile and do not appear to have mixed extensively with this older crust; however, granites of the same general age from the western margin of the Rae Province show extensive interaction with ancient crust. Much of the exposed Rae Province comprises Neoarchean granitoids (LeCheminant and Roddick, 1991; Ashton and Card, 1998); this suite has a relatively limited range of $\varepsilon\mathrm{Nd}_\mathrm{T}$ values suggesting derivation from a uniform crust or mantle reservoir. In contrast, ca. 2.3 and 1.9 Ga granites within southwestern Rae Province are partially to entirely derived from older Archean sources. These data suggest that crustal evolution in the southwestern Rae Province has been strongly influenced by episodic recycling of Meso to Paleoarchean crust, rather than simple growth by addition of juvenile material.

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