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Detrital zircon geochronology of the Paleoproterozoic Hurwitz and Kiyuk groups, western Churchill Province, Nunavut

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Abstract: U-Pb ages of detrital zircons from the Paleoproterozoic Hurwitz Group establish depositional age limits for the upper part of the group (Watterson and Tavani formations) and document significant changes in sediment provenance through time. The lower Hurwitz Group (sequences 1 and 2) was deposited after 2.45 Ga, but before 2.11 Ga. Detrital zircons from Sequence 1 range in age from 2.73 to 2.66 Ga, characteristic of local basement rocks of the Hearne Domain. In contrast, the upper Hurwitz Group (sequences 3 and 4) has a broad-spectrum provenance dominated by 2.4 to 1.9 Ga zircons and a significant population at ca. 2.6 Ga. A weighted mean age of the youngest detrital zircon from the Tavani Formation provides a revised maximum depositional age of 1.911 ± 0.007 Ga. The most likely source for the 2.4 to 1.9 Ga zircons is the Taltson-Thelon Orogen, approximately 500 km to the west of the Hurwitz Basin. Zircon grains of similar age in the unconformably overlying Kiyuk Group suggest reworking and redeposition of Hurwitz Group during Trans-Hudson-related deformation.

Résumé : Des âges U-Pb obtenus sur des zircons détritiques du Groupe de Hurwitz (Paléoprotérozoïque) fournissent des limites temporelles pour le dépôt de la partie supérieure du groupe (formations de Watterson et de Tavani) et permettent de documenter d'importants changements de la provenance des sédiments en fonction du temps. La partie inférieure du Groupe de Hurwitz (séquences 1 et 2) a été déposée après 2,45 Ga mais avant 2,11 Ga. L'âge des zircons détritiques de la séquence 1 varie de 2,73 à 2,66 Ga, soit une fourchette d'âges caractéristique des roches du domaine de Hearne qui constituent le socle à cet endroit. Par contraste, la partie supérieure du Groupe de Hurwitz (séquences 3 et 4) contient des zircons de provenance très variée, qui ont livré pour la plupart des âges s'échelonnant de 2,4 à 1,9 Ga, mais dont une population significative date d'environ 2,6 Ga. Un âge moyen pondéré pour le plus jeune zircon détritique extrait de la Formation de Tavani a fourni un nouvel âge maximal de dépôt de 1,911 ± 0,007 Ga. La source la plus vraisemblable des zircons âgés de 2,4 à 1,9 Ga est l'orogène de Taltson-Thelon, à environ 500 km à l'ouest du bassin de Hurwitz. La présence de zircons d'un âge similaire dans le Groupe de Kiyuk, qui repose en discordance sur le Groupe de Hurwitz, suggère qu'il y a eu remaniement et resédimentation de ce dernier pendant la déformation associée à l'orogène trans-hudsonien.

INTRODUCTION

Establishing the time of deposition, as well as the source regions contributing to sedimentary sequences, is key to evaluating tectonic controls on basin formation and evolution. This is a particular challenge for Precambrian basins that typically preserve limited, or no, biostratigraphic control. The depositional ages of many of the extensive Paleoproterozoic intracratonic sedimentary basins of the Canadian Shield remain very poorly established, and the relationships of their sequence stratigraphy to specific tectonic events are correspondingly poorly known. In this paper the authors present U-Pb SHRIMP (Sensitive High Resolution Ion Micro Probe) ages for detrital zircons from the Hurwitz Group and Kiyuk Group, Paleoproterozoic intracratonic successions in the northwestern Canadian Shield. These data establish estimates for the maximum depositional age of the succession that help place their development within the broader tectonic setting of the assembly of Laurentia.

The Hurwitz Group was originally interpreted to represent a passive margin to foredeep developed on the Archean Hearne Domain within the broad tectonic context of the Trans-Hudson Orogen (Bell, 1970; Lewry et al., 1985; Young, 1988). In this model, lower units were interpreted as the deposits of an intracratonic basin associated with a rift–passive margin sequence that developed during opening of the Manikewan Ocean (Stauffer, 1984), and the upper units were related to foredeep-forebulge migration associated with Superior-Hearne collision (Trans-Hudson Orogeny). The lower units, in particular glaciogenic deposits of the Padlei Formation, were correlated with the Huronian and the Snowy Pass supergroups (Young, 1988). This model was subsequently invalidated based on a baddeleyite age of 2.111 ± 0.001 Ga (Patterson and Heaman, 1991) for gabbro sills within the lower Hurwitz Group (but not the upper Hurwitz Group). The basin was reinterpreted to have developed in response to a protracted break-up of a proposed Archean supercontinent between 2.45 Ga and 2.1 Ga (Aspler and Chiarenzelli, 1996, 1997; Aspler et al., 2001).

The protracted break-up model assumed that the Hurwitz Group was a broadly conformable sequence that entirely predated 2.11 Ga, the minimum age constraint imposed by the gabbro sills. However, U-Pb SHRIMP ages of detrital zircons indicate that there was a protracted hiatus in deposition of the Hurwitz Group that was accompanied by a profound change in its provenance (Davis et al. 2000; Aspler et al. 2001).

One of the difficulties in interpreting the data set of detrital ages reported by Davis et al. (2000) was that the precision on the youngest detrital grain in the upper Hurwitz Group, and by inference the maximum depositional age estimate of the succession, was insufficient to constrain different tectonic scenarios. To address this, additional work has been completed that improves the precision on the maximum age estimate of the upper Hurwitz Group previously reported in Davis et al. (2000) and Aspler et al. (2001).

REGIONAL GEOLOGICAL SETTING

The Hurwitz Group is a succession of continental siliciclastic and marine carbonate rocks up to 8.5 km thick, preserved as erosional remnants of basement-cover infolds across the Hearne Domain of the western Churchill Province, west of Hudson Bay (Figure 1; Lord, 1953; Wright, 1967; Bell, 1970; Eade, 1974; Aspler et al. 2001). The western Churchill Province is predominantly composed of Neoarchean rocks that were variably reworked during assembly of Laurentia at 1.9–1.75 Ga (Hoffman, 1988). The region is divided into the Rae and Hearne domains by the Snowbird tectonic zone, a major intracrustal geophysical lineament that records Neoarchean and Paleoproterozoic histories (e.g. Hanmer et al., 1995).

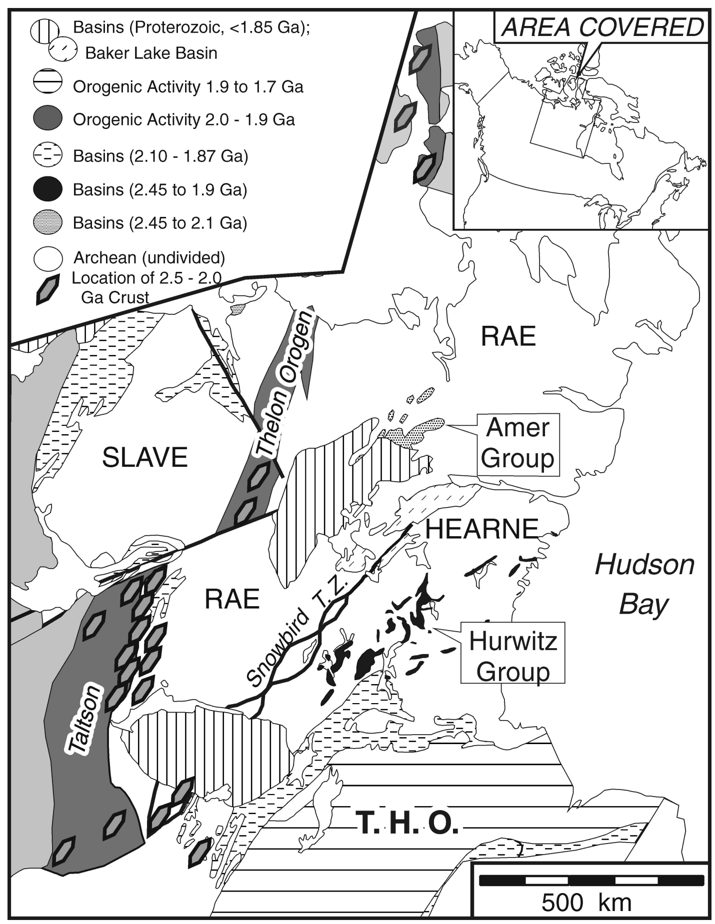

Figure 1. Map of principal tectonic elements of northwestern Laurentia (after Hoffman, 1988). Rocks of the Hurwitz Group are indicated by black fill pattern. Locations of potential source rocks for upper Hurwitz sequences with ages between 2.5 Ga and 2.0 Ga are indicated by symbols (after Aspler and Chiarenzelli, 1998). T.H.O — Trans-Hudson Orogen.

The western boundary of the western Churchill Province is the Taltson-Thelon zone, a major plutono-metamorphic belt that developed during collision of the Slave and Buffalo Head terrane with the Rae at 2.0–1.9 Ga (e.g. Hoffman, 1989; Henderson and Loveridge, 1990; McDonough et al., 2000; McNicoll et al., 2000). To the east and southeast lies the Trans-Hudson Orogen that represents the orogenic suture between the western Churchill and Superior cratons at 1.86–1.76 Ga. The Hurwitz group occurs in the Hearne Province.

STRATIGRAPHY OF THE HURWITZ AND KIYUK GROUPS

Aspler et al (2001) divided the Hurwitz Group into four large-scale sequences of unspecified order. A schematic stratigraphic section is presented in Figure 2 and detailed lithological descriptions are provided in Aspler and Chiarenzelli (1996, 1997, 2002) and Aspler et al. (1994, 2001). Sequences 1 and 2 are informally referred to as the lower Hurwitz Group and sequences 3 and 4 are referred to as the upper Hurwitz Group, with the boundary being at the contact between the Ameto and the Watterson formations. The Hurwitz Group unconformably overlies Archean rocks (ca. 2.8–2.5 Ga) and local wedges of litharenite and conglomerate of the Montgomery Lake Group (Aspler and Chiarenzelli, 1997). A maximum depositional age is provided by the 2.45 Ga Kaminak dyke swarm that cuts basement but not the Hurwitz Group (Heaman, 1997).

Sequence 1 consists of predominantly siliciclastic rocks (Noomut, Padlei, and Kinga formations) deposited in shallow-water marine to fluvial environments. The Padlei Formation comprises conglomerate and sandstone, including horizons of probable glaciogenic origin (Young and McLennan, 1981; Aspler and Chiarenzelli, 1997). The Kinga Formation includes sandstone and conglomerate interpreted to be fluvial deposits, with locally preserved dolostone intercalations indicating short--lived marine incursions (Maguse member). Extensive ripple-marked quartz arenite in the upper (Whiterock) member is interpreted to have been deposited in broad, shallow lakes (Aspler et al., 1994). The Kinga Formation is capped by a discontinuous unit, less than 25 m thick, of bedded chert and chert breccia, originally interpreted as silcrete by Bell (1970), but reinterpreted as hot-spring sinter deposits by Aspler and Chiarenzelli (1997).

Sequence 2 is represented by the Ameto Formation, a succession of fine-grained siliciclastic rocks that mark a period of basin-deepening, with local areas of magmatism. Sequences 1 and 2 are cut by the ca. 2.11 Ga Griffin (formerly Hurwitz) gabbro units, which are interpreted to have been intruded after lithification of the sedimentary rocks (Aspler et al., 2002b).

Sequence 3 is a mixed siliciclastic-carbonate succession interpreted to have been deposited on an emergent, shallow marine ramp (Watterson Formation) that was buried by deltaic, fluvial, and lacustrine deposits (Ducker and lower Tavani formations). Sequence 4 (upper Tavani Formation) is characterized by stromatolitic dolostone and sandstone that mark a marine transgression and return to mixed siliciclastic-carbonate shelf deposition. Sequence 3 unconformably overlies Archean rocks in western and northern Hurwitz Basin; elsewhere it disconformably overlies the lower Hurwitz Group with no indication of significant erosion, tilting, or weathering (Aspler and Chiarenzelli, 2002).

The Kiyuk Group is a continental deposit made up of a fining-upward succession of conglomerate, arkose, and intraformational breccia (Aspler et al. 2002a). These rocks unconformably overlie the entire Hurwitz Group. The Kiyuk Group has most recently been interpreted as continental rift deposits, attending late-stage opening of the Manikewan Ocean (Aspler et al. 2002a).

SAMPLE DESCRIPTION

Detrital zircons were separated and analyzed from three samples of the lower Hurwitz Group: one from the Padlei Formation, one from the Maguse member of the Kinga Formation, and one from the Whiterock member of the Kinga Formation. Sample locations are found in Table 1. The Padlei Formation sample is from an arkosic conglomerate collected from the southeast side of Mackenzie Lake, part of a sequence of interbedded conglomerates and sandstones of probable fluvial origin referred to previously as the 'Mackenzie Lake metasediments' (Aspler et al., 2000). Clasts in the conglomerate are well rounded and predominantly quartzose sandstone Crossbedding at the sample locality indicates unimodal transport to the southwest. Detrital zircon grains generally are large and well to very well rounded, with only a few euhedral grains. Magnetite is the other ubiquitous heavy mineral phase in this sample. The sample from the Whiterock member is a kyanite-bearing quartz arenite from the southern end of Mackenzie Lake. Heavy-mineral banding, well developed at the sample locality, outlines tectonically folded bedding and crossbedding. This sample yielded detrital zircons with a wide variety of grain morphologies, including some large tabular euhedral grains in the more magnetic fractions, and smaller, generally well-rounded grains in the less magnetic fractions. The sample from the Maguse member is a medium-grained quartz arenite with jasper granules from the northeast end of Kaminak Lake. The sample was collected several metres above an erosional unconformity above mafic volcanic rocks of the Kaminak greenstone belt. Trough crossbedding at the sample site indicates paleoflow toward the southeast. Detrital zircons are widely varied in size, colour, and morphology.

Two samples of the upper Hurwitz Group were investigated; one each from the Waterson and Tavani formations. Additionally, one sample from the K2 subunit of the Kiyuk Group was investigated. The sample of the Waterson Formation is from an outcrop of very fine grained, carbonate-cemented quartz wacke, from near the middle of formation. Zircons are small (typically less than 100 microns), and euhedral to moderately rounded . A medium- to coarse-grained, sublithic wacke, collected near the base of the Tavani

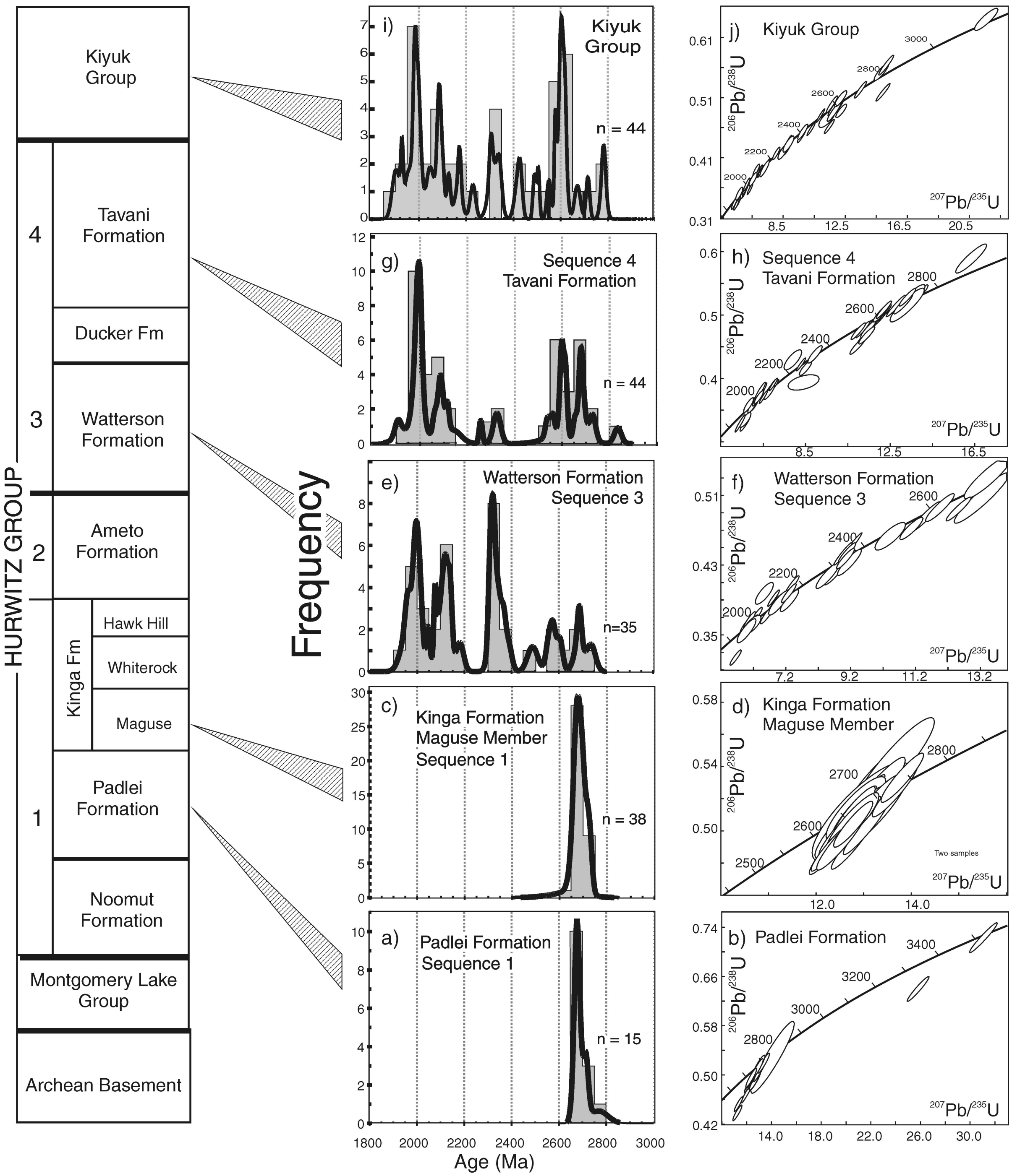

Figure 2. *Schematic stratigraphic column showing relationships between Kiyuk, Hurwitz, and Montgomery Lake groups. U-Pb zircon age data are shown in cumulative probability plots, histograms (bin width — 50 Ma), and on concordia diagrams. Arrows indicate approximate stratigraphic position of analyzed samples. Data used in cumulative probability diagrams and histograms were screened at <5% discordance.*

formation, contains heavy-mineral bands with large, well rounded detrital zircons. The sample of the Kiyuk Formation is a fine-grained arkose.

ANALYTICAL METHODS

U-Pb isotopic data were acquired using the Geological Survey of Canada Sensitive High Resolution Ion Micro Probe (SHRIMP II). Analytical methods are provided in greater detail in Stern (1997) and Stern (1998). Zircons were separated from 1 to 2 kg samples using standard crushing, heavy liquid, and magnetic separation techniques, then mounted and polished along with grains of Kipawa zircon standard in a 2.5 cm epoxy disc. Back-scatter electron and cathodoluminescence images were made using a scanning electron microscope to fully characterize the internal structures of the grains and aid in beam positioning. Bias in the measured Pb/U values was corrected relative to the Kipawa zircon standard ($^{206}Pb/^{238}U$ age = 993Ma) using a linear calibration curve determined between $^{206}Pb^+/^{238}U^+$ and $^{254}U^+/^{238}U^+$. Final U-Pb ages are reported with 1 sigma errors in Table 1 and shown at two-sigma in concordia diagrams.

AGE AND PROVENANCE OF DETRITAL ZIRCONS

Hurwitz Group: Sequence 1

U-Pb ages of zircons from three samples of the lower Hurwitz Group define a narrow range, with 94% of the analyses between 2.73 and 2.66 Ga (Figure 2 a, b, c, d). These ages are characteristic of local basement rocks, such as those in the Kaminak greenstone belt (Davis et al., 2004). A subordinate component of pre-3.0 Ga zircon in the Padlei sample (two grains: 3.432 ± 0.007 Ga and 3.529 ± 0.007 Ga (Table 1), taken from near the northwestern limit of Hurwitz Basin, represent the only grains with a provenance exotic to the local basement. The well-rounded morphology of many of the zircons, particularly in the Padlei Formation conglomerate, suggests that they may have been reworked from an older, texturally mature source, as also indicated by the rounded quartzite clasts in the conglomerate. The detrital zircon age-profile is similar to that obtained for the Happy Lake quartzite, a putative outlier of Kinga Formation, located about 40 km northeast of the Maguse member sample site from this study (Rainbird et al., 2002).

Upper Hurwitz Group: Sequence 3

In marked contrast to sequence 1, two samples from sequence 3 of the upper Hurwitz Group are characterized by detrital zircons ranging in age from ca. 2.83 Ga to 1.91 Ga (Figure 2e, f, g, h). In the quartz wacke sample from the Watterson Formation, 84% of the 36 grains (35 on plot) analyzed are Paleoproterozoic, with significant peaks on a probability distribution plot at 2.35 to 2.31Ga, 2.15 to 2.10 Ga, and 2.00 to 1.95 Ga (Figure 2e). Rocks of similar ages are common in the southwestern Rae Province, Thelon-Taltson magmatic zone and Buffalo Head Terrane (*see* compilations in van Breemen et al., 1992; Aspler and Chiarenzelli, 1998; McNicoll, et al., 2000). In particular, the most common detrital ages of 2.35 to 2.31 Ga are similar to the age of basement gneisses from the southern part of the Taltson magmatic zone (McNicoll et al., 2000) and the adjacent southwestern Rae Province (Figure 1; van Breemen and Bostock, 1994; Bostock et al., 1987; van Schmus et al., 1986; R. Hartlaub, pers. comm., 2002). The remaining grains define peaks at both 2.58 and 2.70 Ga, common ages of magmatic rocks in the western Churchill Province. The youngest $^{207}Pb/^{206}Pb$ age at 1.960 ± 0.022 Ga (- 2.9 % discordant) provides an estimate of the maximum depositional age.

The majority of the 50 zircons analyzed from the lower Tavani sandstone are Paleoproterozoic (Fig. 2g, Table 1). The most prominent peak on the cumulative probability plot, representing 25% of the analyses, is at 2.00 to 1.99 Ga. Rocks within this age range include the Deskenatlata igneous suite from the northern end of Taltson magmatic zone (van Breemen et al., 1992), and mylonitic gneisses from the Thelon Orogen (van Breemen et al., 1987a, b). There are several grains showing ages between 2.05 and 2.09 Ga, which are ages that have been recorded in the Buffalo Head Terrane (Villeneuve et al., 1993). Significant populations at ~2.59 and ~2.68 Ga are common ages for rocks from the Slave and western Churchill provinces.

The youngest $^{207}Pb/^{206}Pb$ age for zircon in the Tavani Formation was previously reported as 1.907 ± 0.024 Ga in Davis et al. (2000). The imprecision in the resulting maximum depositional age estimate of the sequence meant that the relationship of the basin to complex tectonic events that occurred in the area between 1.92 and 1.83 Ga could not be constrained. For this reason additional analyses have been carried out, comprising a total of 12 analyses of three locations on the youngest grain (Grain 49, Table 1; Figure 3). In order to perform as many analyses as possible on a single grain, replicate analyses within one spot were performed.

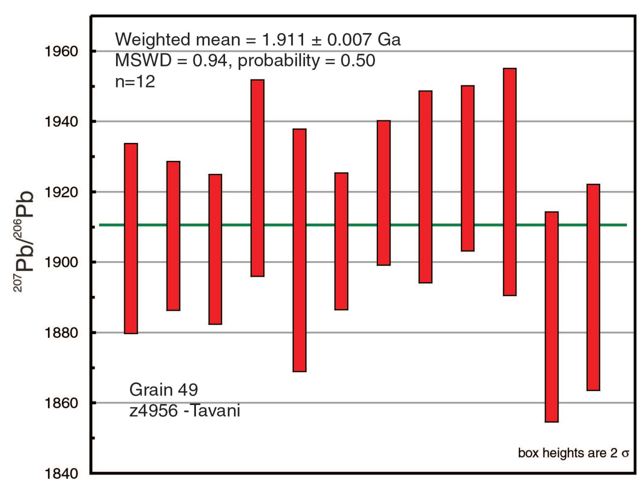

Figure 3. *Weighted average age of youngest grain recovered from sample of Tavani Formation (IsoplotEx 2.49; Ludwig, 2001).*

Table 1. U-Pb analytical data.

Analyses	U (ppm)	Th (ppm)	$\frac{Th}{U}$	Pb* (ppm)	^{204}Pb (ppb)	$\frac{^{204}Pb}{^{206}Pb}$	$\pm\frac{^{204}Pb}{^{206}Pb}$	$f(206)^{204}$	$\frac{^{208*}Pb}{^{206*}Pb}$	$\pm\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{206*}Pb}{^{238}U}$	$\pm\frac{^{206}Pb}{^{238}U}$	$\frac{^{207*}Pb}{^{235}U}$	$\pm\frac{^{207}Pb}{^{235}U}$	$\frac{^{207*}Pb}{^{206*}Pb}$	$\pm\frac{^{207}Pb}{^{206}Pb}$	Apparent Age $\frac{^{207}Pb}{^{206}Pb}$	Apparent Age $\pm\frac{^{207}Pb}{^{206}Pb}$	Apparent Age Disc. (%)
Padlei Formation - Z5200			**Location UTM 15: 361523E 6947486N**					**(NAD 27)**											
1.1	78	54	0.692	41	1	0.000026	0.000034	0.00046	0.1960	0.0033	0.4383	0.0064	11.2491	0.1866	0.1862	0.0012	2708	11	13.5
2.1	48	36	0.750	28	1	0.000036	0.000059	0.00062	0.2014	0.0036	0.4897	0.0092	12.5730	0.2826	0.1862	0.0019	2709	17	5.2
3.1	86	111	1.286	54	0	0.000010	0.000010	0.00017	0.3503	0.0027	0.4722	0.0090	12.0550	0.2471	0.1851	0.0010	2699	9	7.6
4.1	67	52	0.779	41	0	0.000010	0.000010	0.00017	0.2159	0.0021	0.5104	0.0083	12.8882	0.2299	0.1832	0.0010	2682	9	0.9
5.1	73	69	0.951	46	0	0.000008	0.000036	0.00014	0.2644	0.0030	0.5134	0.0084	12.9476	0.2467	0.1829	0.0014	2679	13	0.3
6.1	80	146	1.831	57	0	0.000010	0.000010	0.00017	0.4990	0.0035	0.4899	0.0069	12.4282	0.1985	0.1840	0.0011	2689	10	4.4
7.1	110	85	0.776	64	3	0.000064	0.000027	0.00111	0.2092	0.0025	0.4851	0.0069	12.1961	0.1932	0.1823	0.0010	2674	9	4.7
8.1	99	59	0.594	56	0	0.000010	0.000010	0.00017	0.1684	0.0015	0.4880	0.0064	12.6006	0.1948	0.1873	0.0012	2718	11	5.8
9.1	125	101	0.809	73	1	0.000010	0.000010	0.00017	0.2192	0.0016	0.4879	0.0064	12.2994	0.1849	0.1828	0.0011	2679	10	4.4
10.1	86	70	0.817	81	3	0.000048	0.000027	0.00084	0.2072	0.0022	0.7231	0.0122	31.0757	0.5611	0.3117	0.0014	3529	7	0.6
11.1	56	51	0.924	35	0	0.000010	0.000010	0.00017	0.2583	0.0033	0.5107	0.0110	13.1574	0.3018	0.1869	0.0011	2715	10	2.0
12.1	94	58	0.620	55	3	0.000076	0.000026	0.00132	0.1786	0.0019	0.4938	0.0075	12.3957	0.2062	0.1821	0.0009	2672	8	3.2
13.1	97	131	1.343	67	1	0.000024	0.000019	0.00042	0.3772	0.0026	0.5149	0.0069	12.9524	0.1947	0.1825	0.0010	2675	9	-0.1
14.1	78	64	0.828	49	0	0.000010	0.000010	0.00017	0.2302	0.0033	0.5193	0.0082	13.3700	0.2366	0.1867	0.0012	2714	11	0.6
15.1	104	115	1.108	61	0	0.000010	0.000010	0.00017	0.3128	0.0029	0.4524	0.0061	11.3341	0.1727	0.1817	0.0010	2668	9	9.8
16.1	50	59	1.182	33	0	0.000010	0.000010	0.00017	0.3205	0.0030	0.5160	0.0080	12.9957	0.2379	0.1827	0.0015	2677	13	-0.2
17.1	68	89	1.313	46	1	0.000026	0.000040	0.00046	0.3613	0.0035	0.5098	0.0083	12.8524	0.2424	0.1829	0.0014	2679	13	0.9
18.1	87	54	0.613	70	0	0.000010	0.000010	0.00017	0.1717	0.0016	0.6397	0.0101	25.8112	0.4404	0.2926	0.0014	3432	7	7.1
20.1	4	224	61.610	31	0	0.000010	0.000010	0.00017	17.1791	0.3188	0.5287	0.0292	14.0847	0.8770	0.1932	0.0044	2770	37	1.2
21.1	114	142	1.243	74	0	0.000010	0.000010	0.00017	0.3399	0.0031	0.4956	0.0078	12.3695	0.2206	0.1810	0.0012	2662	11	2.5
Kinga Formation - Maguse Member Z5201					**Location UTM 14: 535647E 6801233N**					**(NAD 27)**									
1.1	45	17	0.366	26	0	0.000010	0.000010	0.00017	0.1023	0.0023	0.5082	0.0099	12.9115	0.3117	0.1843	0.0022	2692	20	1.6
2.1	55	44	0.793	33	0	0.000010	0.000010	0.00017	0.2257	0.0033	0.5007	0.0097	12.6604	0.2838	0.1834	0.0017	2684	15	2.5
3.1	134	102	0.756	81	1	0.000012	0.000023	0.00021	0.2148	0.0018	0.4991	0.0070	12.4419	0.1896	0.1808	0.0008	2660	8	1.9
4.1	66	58	0.873	42	0	0.000010	0.000010	0.00017	0.2428	0.0024	0.5184	0.0075	13.4131	0.2203	0.1877	0.0011	2722	10	1.1
6.1	94	82	0.880	59	0	0.000010	0.000010	0.00017	0.2507	0.0026	0.5126	0.0074	12.8154	0.2151	0.1813	0.0012	2665	11	-0.1
7.1	124	103	0.831	78	1	0.000010	0.000010	0.00017	0.2309	0.0020	0.5170	0.0068	13.3261	0.1908	0.1870	0.0008	2716	7	1.1
9.1	38	32	0.838	24	0	0.000010	0.000010	0.00017	0.2344	0.0034	0.5151	0.0098	13.1992	0.2869	0.1859	0.0016	2706	14	1.0
10.1	73	38	0.518	42	3	0.000099	0.000051	0.00172	0.1414	0.0025	0.5071	0.0072	12.9393	0.2143	0.1851	0.0013	2699	11	2.0
11.1	64	23	0.358	36	0	0.000010	0.000010	0.00017	0.0987	0.0028	0.5053	0.0092	12.7677	0.2771	0.1832	0.0018	2682	16	1.7
12.1	82	42	0.515	47	0	0.000010	0.000010	0.00017	0.1425	0.0018	0.5016	0.0082	13.0380	0.2336	0.1885	0.0011	2729	9	4.0
13.1	39	19	0.475	23	2	0.000104	0.000083	0.00181	0.1289	0.0046	0.5070	0.0105	12.7667	0.3268	0.1826	0.0023	2677	21	1.2
14.1	60	40	0.660	34	1	0.000028	0.000032	0.00049	0.1863	0.0029	0.4884	0.0077	12.2919	0.2181	0.1825	0.0012	2676	10	4.2
15.1	86	50	0.581	48	0	0.000002	0.000029	0.00004	0.1594	0.0019	0.4888	0.0069	12.2801	0.1929	0.1822	0.0010	2673	9	4.0
16.1	51	31	0.603	31	0	0.000010	0.000010	0.00017	0.1708	0.0021	0.5250	0.0081	13.6558	0.2383	0.1887	0.0012	2730	10	0.4
17.1	57	50	0.877	35	0	0.000010	0.000010	0.00017	0.2404	0.0031	0.4938	0.0091	12.5296	0.2595	0.1840	0.0014	2689	12	3.8
18.1	69	42	0.604	41	0	0.000016	0.000029	0.00028	0.1698	0.0021	0.5041	0.0071	12.7810	0.2070	0.1839	0.0012	2688	10	2.1
19.1	8	5	0.622	5	2	0.000682	0.000352	0.01182	0.1453	0.0154	0.5036	0.0187	12.3143	0.7199	0.1773	0.0072	2628	69	0.0
20.1	66	26	0.400	39	0	0.000010	0.000010	0.00017	0.1098	0.0016	0.5330	0.0076	13.8135	0.2245	0.1880	0.0011	2724	10	-1.1
Kinga Formation - Maguse Member Z5204					**Location UTM 14: 365695E 6906440N**					**(NAD 27)**									
2.1	38	29	0.748	23	1	0.000047	0.000072	0.00082	0.2058	0.0037	0.5019	0.0094	12.5235	0.2743	0.1810	0.0017	2662	16	1.5
3.1	14	4	0.272	8	0	0.000010	0.000010	0.00017	0.0812	0.0030	0.5140	0.0159	12.9916	0.4419	0.1833	0.0020	2683	18	0.4
4.1	20	7	0.330	12	0	0.000010	0.000010	0.00017	0.0920	0.0024	0.5407	0.0148	13.6207	0.4335	0.1827	0.0024	2678	22	-4.1

Table 1. (cont.)

Analyses	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	^{204}Pb (ppb)	$^{204}Pb/^{206}Pb$	± $^{204}Pb/^{206}Pb$	$f(206)^{204}$	$^{208*}Pb/^{206*}Pb$	± $^{208}Pb/^{206}Pb$	$^{206*}Pb/^{238}U$	± $^{206}Pb/^{238}U$	$^{207*}Pb/^{235}U$	± $^{207}Pb/^{235}U$	$^{207*}Pb/^{206*}Pb$	± $^{207}Pb/^{206}Pb$	Apparent Age $^{207}Pb/^{206}Pb$	Apparent Age ± $^{207}Pb/^{206}Pb$	Apparent Age Disc. (%)
5.1	35	16	0.465	20	0	0.000010	0.000010	0.00017	0.1281	0.0021	0.5070	0.0088	12.8778	0.2525	0.1842	0.0014	2691	12	1.8
6.1	45	38	0.826	28	0	0.000010	0.000010	0.00017	0.2331	0.0026	0.5082	0.0107	12.8550	0.3002	0.1835	0.0015	2684	13	1.3
7.1	129	136	1.049	85	1	0.000013	0.000023	0.00023	0.2879	0.0022	0.5203	0.0074	13.0428	0.2032	0.1818	0.0009	2670	8	-1.2
8.1	27	12	0.452	15	0	0.000021	0.000087	0.00037	0.1247	0.0044	0.5138	0.0099	12.8383	0.3143	0.1812	0.0023	2664	21	-0.3
9.1	93	73	0.786	55	0	0.000010	0.000010	0.00017	0.2164	0.0018	0.4908	0.0073	12.7409	0.2110	0.1883	0.0011	2727	9	5.6
10.1	96	41	0.430	54	0	0.000002	0.000023	0.00004	0.1198	0.0020	0.5063	0.0072	12.7220	0.1987	0.1822	0.0009	2673	8	1.2
11.1	57	27	0.476	33	0	0.000010	0.000010	0.00017	0.1341	0.0022	0.5101	0.0083	13.0157	0.2370	0.1851	0.0012	2699	11	1.5
12.1	21	9	0.412	12	0	0.000010	0.000010	0.00017	0.1108	0.0042	0.5294	0.0116	13.2028	0.3362	0.1809	0.0019	2661	18	-2.9
13.1	55	50	0.903	35	3	0.000116	0.000054	0.00201	0.2484	0.0038	0.5099	0.0086	13.0620	0.2633	0.1858	0.0017	2705	15	1.8
14.1	9	4	0.500	5	0	0.000010	0.000010	0.00017	0.1359	0.0062	0.5119	0.0154	12.9427	0.5131	0.1834	0.0041	2684	37	0.7
16.1	123	58	0.476	70	2	0.000042	0.000045	0.00072	0.1296	0.0025	0.5022	0.0070	12.8360	0.2118	0.1854	0.0013	2701	12	2.9
17.1	51	18	0.361	28	2	0.000100	0.000053	0.00173	0.0996	0.0028	0.5053	0.0102	12.8286	0.2923	0.1842	0.0015	2691	14	2.0
18.1	106	96	0.905	64	0	0.000010	0.000010	0.00017	0.2504	0.0021	0.4913	0.0070	12.4062	0.1931	0.1831	0.0009	2681	8	3.9
19.1	64	21	0.330	35	3	0.000097	0.000047	0.00169	0.0906	0.0028	0.5006	0.0079	12.7251	0.2410	0.1844	0.0016	2693	14	2.8
20.1	69	55	0.803	42	0	0.000010	0.000010	0.00017	0.2220	0.0020	0.5086	0.0077	12.7235	0.2189	0.1815	0.0012	2666	11	0.6
21.1	44	39	0.876	28	1	0.000063	0.000050	0.00109	0.2441	0.0043	0.5114	0.0082	12.8016	0.2398	0.1815	0.0014	2667	13	0.2
22.1	52	42	0.823	32	1	0.000066	0.000073	0.00114	0.2329	0.0041	0.5061	0.0088	12.6440	0.2740	0.1812	0.0020	2664	18	0.9
Watterson Formation - Z5946 Location UTM 15: 535647E 6817200N (NAD 27)																			
1.1	1177	176	0.149	456	4	0.000010	0.000010	0.00017	0.0435	0.0006	0.3839	0.0055	6.7935	0.1014	0.1283	0.0004	2075	5	-0.9
2.1	421	199	0.474	161	11	0.000089	0.000020	0.00154	0.1396	0.0014	0.3515	0.0044	5.9306	0.0896	0.1224	0.0009	1991	12	2.5
3.2	209	218	1.043	96	43	0.000652	0.000098	0.01130	0.3552	0.0059	0.3615	0.0055	6.1578	0.1395	0.1236	0.0019	2008	27	1.0
3.3	632	921	1.456	276	7	0.000042	0.000016	0.00073	0.4377	0.0024	0.3240	0.0044	5.6534	0.0882	0.1266	0.0008	2051	11	11.8
4.1	262	177	0.676	111	3	0.000032	0.000026	0.00055	0.1932	0.0020	0.3732	0.0053	6.6299	0.1085	0.1288	0.0009	2082	12	1.8
5.1	487	437	0.896	263	4	0.000024	0.000014	0.00041	0.2584	0.0021	0.4461	0.0106	9.1018	0.2231	0.1480	0.0006	2323	7	-2.4
7.1	244	197	0.809	121	4	0.000044	0.000020	0.00075	0.2317	0.0021	0.4195	0.0066	8.5043	0.1469	0.1470	0.0008	2312	10	2.3
9.1	162	106	0.655	78	24	0.000408	0.000062	0.00707	0.1968	0.0044	0.4179	0.0074	8.4883	0.1794	0.1473	0.0014	2315	16	2.8
10.1	668	228	0.342	288	2	0.000007	0.000008	0.00012	0.0970	0.0012	0.4075	0.0052	7.4012	0.1062	0.1317	0.0007	2121	9	-3.9
11.1	399	235	0.589	197	23	0.000154	0.000026	0.00266	0.1849	0.0059	0.4293	0.0090	8.7411	0.1971	0.1477	0.0009	2319	10	0.7
13.1	147	226	1.539	99	1	0.000021	0.000024	0.00036	0.4391	0.0046	0.4858	0.0084	11.5200	0.2205	0.1720	0.0011	2577	10	0.9
14.1	264	159	0.603	130	2	0.000019	0.000017	0.00033	0.1693	0.0020	0.4332	0.0075	9.1622	0.1861	0.1534	0.0013	2384	15	2.7
15.1	89	52	0.584	35	0	0.000010	0.000010	0.00017	0.1750	0.0042	0.3547	0.0069	5.9886	0.1461	0.1225	0.0015	1992	23	1.8
16.1	102	67	0.650	42	0	0.000010	0.000010	0.00017	0.2010	0.0045	0.3617	0.0067	6.0742	0.1476	0.1218	0.0017	1983	25	-0.4
17.1	603	202	0.336	249	7	0.000034	0.000011	0.00059	0.0995	0.0008	0.3896	0.0049	7.1505	0.0988	0.1331	0.0006	2140	8	0.9
18.1	293	133	0.453	124	1	0.000011	0.000012	0.00020	0.1296	0.0014	0.3894	0.0055	7.0598	0.1159	0.1315	0.0009	2118	12	-0.1
19.1	715	181	0.253	284	15	0.000062	0.000013	0.00107	0.0742	0.0009	0.3840	0.0053	6.9103	0.1087	0.1305	0.0008	2105	10	0.5
20.1	36	44	1.248	24	0	0.000010	0.000010	0.00017	0.3579	0.0050	0.5071	0.0145	13.2395	0.4234	0.1894	0.0021	2737	19	3.4
21.1	460	19	0.041	177	2	0.000010	0.000010	0.00017	0.0115	0.0005	0.3922	0.0048	6.8247	0.0911	0.1262	0.0005	2046	7	-4.2
23.1	329	158	0.481	161	4	0.000030	0.000014	0.00052	0.1375	0.0013	0.4430	0.0065	8.9653	0.1413	0.1468	0.0006	2309	7	-2.4
24.1	75	60	0.799	41	0	0.000013	0.000087	0.00023	0.2231	0.0049	0.4631	0.0079	10.4205	0.2354	0.1632	0.0021	2489	22	1.4
25.1	358	140	0.392	196	25	0.000165	0.000042	0.00285	0.1089	0.0023	0.4960	0.0080	11.9525	0.2224	0.1748	0.0013	2604	12	0.3
26.1	504	109	0.217	191	5	0.000028	0.000014	0.00049	0.0627	0.0011	0.3718	0.0049	6.2878	0.0954	0.1226	0.0007	1995	11	-2.2
27.1	150	77	0.513	65	1	0.000010	0.000010	0.00017	0.1482	0.0026	0.3893	0.0063	7.3131	0.1426	0.1363	0.0013	2180	16	2.8
28.1	507	195	0.384	240	11	0.000056	0.000012	0.00097	0.1099	0.0011	0.4357	0.0057	9.1149	0.1339	0.1517	0.0008	2365	9	1.4
29.1	422	186	0.442	165	1	0.000005	0.000011	0.00008	0.1275	0.0016	0.3632	0.0049	6.1597	0.0987	0.1230	0.0009	2000	13	0.1
30.1	162	86	0.530	69	0	0.000002	0.000046	0.00004	0.1550	0.0038	0.3868	0.0071	6.9846	0.1585	0.1310	0.0015	2111	20	0.1
31.1	444	221	0.497	219	1	0.000003	0.000007	0.00005	0.1439	0.0012	0.4441	0.0058	9.0881	0.1355	0.1484	0.0008	2328	10	-1.8

Table 1. (cont.)

Analyses	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	^{204}Pb (ppb)	^{204}Pb/^{206}Pb	± ^{204}Pb/^{206}Pb	f(206)^{204}	^{208*}Pb/^{206*}Pb	±^{208}Pb/^{206}Pb	^{206*}Pb/^{238}U	±^{206}Pb/^{238}U	^{207*}Pb/^{235}U	±^{207}Pb/^{235}U	^{207*}Pb/^{206*}Pb	±^{207}Pb/^{206}Pb	Apparent Age ^{207}Pb/^{206}Pb	Apparent Age ±^{207}Pb/^{206}Pb	Apparent Age Disc. (%)
32.1	49	26	0.535	30	0	0.000010	0.000010	0.00017	0.1443	0.0030	0.5314	0.0125	13.4328	0.3698	0.1834	0.0021	2683	19	-2.4
33.1	241	65	0.269	122	6	0.000063	0.000023	0.00109	0.0786	0.0015	0.4721	0.0064	11.0730	0.1793	0.1701	0.0012	2559	12	2.6
34.1	298	836	2.809	262	2	0.000020	0.000011	0.00034	0.8769	0.9095	0.4944	0.0068	12.5282	0.1929	0.1838	0.0010	2687	9	3.6
37.1	502	299	0.595	249	7	0.000036	0.000016	0.00062	0.1679	0.0017	0.4375	0.0059	9.0422	0.1393	0.1499	0.0009	2345	10	0.2
38.1	626	19	0.030	219	2	0.000013	0.000012	0.00022	0.0093	0.0006	0.3594	0.0047	6.1408	0.0915	0.1239	0.0007	2013	10	1.7
39.1	243	132	0.542	115	2	0.000023	0.000023	0.00040	0.1525	0.0022	0.4201	0.0064	8.6845	0.1566	0.1499	0.0012	2345	13	3.6
40.1	507	485	0.957	255	69	0.000394	0.000071	0.00683	0.3467	0.0047	0.3976	0.0062	6.5391	0.1406	0.1193	0.0015	1945	23	-10.9
41.1	361	37	0.103	144	3	0.000022	0.000015	0.00039	0.0308	0.0008	0.3978	0.0055	7.2945	0.1152	0.1330	0.0008	2138	11	-1.0
42.1	742	319	0.430	299	95	0.000403	0.000034	0.00698	0.1538	0.0018	0.3670	0.0049	6.0812	0.0927	0.1202	0.0007	1959	11	-2.9
Tavani Formation - Z5945				**Location UTM 15: 559250E 6833150N**				**(NAD 27)**											
1.1	127	53	0.422	45	0	0.000010	0.000010	0.00017	0.1210	0.0021	0.3294	0.0063	5.6487	0.1226	0.1244	0.0010	2020	14	9.1
2.1	140	65	0.462	55	0	0.000010	0.000010	0.00017	0.1329	0.0018	0.3648	0.0053	6.1729	0.0989	0.1227	0.0007	1996	10	-0.4
3.1	75	67	0.897	48	0	0.000004	0.000030	0.00008	0.2502	0.0025	0.5204	0.0071	13.1401	0.2201	0.1832	0.0015	2682	13	-0.7
4.1	73	35	0.480	44	1	0.000021	0.000037	0.00036	0.1326	0.0024	0.5280	0.0100	13.7280	0.2860	0.1886	0.0013	2730	11	-0.1
5.1	89	77	0.857	38	0	0.000010	0.000010	0.00017	0.2405	0.0023	0.3638	0.0049	6.1528	0.0945	0.1227	0.0007	1995	10	-0.3
6.1	121	60	0.494	68	1	0.000010	0.000010	0.00017	0.1403	0.0015	0.4959	0.0068	12.0208	0.1816	0.1758	0.0009	2614	8	0.7
7.1	135	182	1.356	91	0	0.000006	0.000023	0.00010	0.3779	0.0021	0.5034	0.0066	12.2162	0.1733	0.1760	0.0007	2616	7	-0.5
8.1	222	59	0.265	123	1	0.000010	0.000010	0.00017	0.0752	0.0007	0.5140	0.0066	12.9618	0.1807	0.1829	0.0008	2679	7	0.2
9.1	170	52	0.307	90	1	0.000010	0.000010	0.00017	0.0868	0.0009	0.4872	0.0070	11.6935	0.1778	0.1741	0.0006	2597	5	1.5
10.1	187	129	0.692	91	1	0.000015	0.000011	0.00027	0.1957	0.0013	0.4222	0.0052	8.2876	0.1104	0.1424	0.0006	2256	7	-0.6
11.1	140	44	0.315	52	1	0.000012	0.000025	0.00020	0.0924	0.0019	0.3580	0.0049	6.0744	0.0974	0.1231	0.0009	2001	13	1.4
12.1	99	65	0.658	55	1	0.000025	0.000015	0.00043	0.1838	0.0016	0.4772	0.0065	11.2018	0.1689	0.1703	0.0008	2560	8	1.8
13.1	175	182	1.042	113	1	0.000012	0.000024	0.00021	0.2731	0.0077	0.5158	0.0133	13.3068	0.4066	0.1871	0.0025	2717	23	1.3
14.1	72	42	0.583	34	0	0.000003	0.000027	0.00005	0.1670	0.0021	0.4161	0.0057	8.4971	0.1465	0.1481	0.0013	2324	15	3.5
15.1	85	53	0.617	47	1	0.000029	0.000019	0.00051	0.1693	0.0024	0.4745	0.0067	10.9978	0.1730	0.1681	0.0009	2539	9	1.4
16.1	153	82	0.534	82	1	0.000010	0.000010	0.00017	0.1516	0.0017	0.4703	0.0092	11.3742	0.2360	0.1754	0.0009	2610	8	4.8
17.1	184	54	0.293	69	1	0.000010	0.000010	0.00017	0.0826	0.0009	0.3583	0.0051	6.0815	0.0933	0.1231	0.0005	2001	7	1.4
18.1	212	150	0.707	95	1	0.000010	0.000010	0.00017	0.2034	0.0018	0.3891	0.0047	7.0460	0.0923	0.1313	0.0005	2116	7	-0.1
19.1	139	75	0.542	83	0	0.000007	0.000010	0.00012	0.1517	0.0016	0.5189	0.0065	13.0531	0.1821	0.1825	0.0009	2675	8	-0.7
20.1	58	36	0.628	31	0	0.000010	0.000010	0.00017	0.1765	0.0023	0.4526	0.0073	10.9942	0.2010	0.1762	0.0012	2617	11	8.0
21.1	93	45	0.481	36	0	0.000010	0.000010	0.00017	0.1353	0.0020	0.3590	0.0067	6.0326	0.1333	0.1219	0.0012	1984	18	0.3
22.1	187	123	0.659	85	1	0.000012	0.000050	0.00021	0.1861	0.0052	0.3937	0.0061	8.4078	0.3691	0.1549	0.0061	2401	68	10.9
23.1	100	110	1.096	61	0	0.000010	0.000010	0.00017	0.3026	0.0025	0.4785	0.0070	11.4770	0.1872	0.1740	0.0010	2596	10	2.9
24.1	139	114	0.821	62	0	0.000010	0.000010	0.00017	0.2343	0.0016	0.3794	0.0053	6.7240	0.1044	0.1285	0.0007	2078	10	0.2
25.1	290	131	0.452	122	1	0.000010	0.000010	0.00017	0.1305	0.0012	0.3890	0.0047	6.9182	0.0924	0.1290	0.0006	2084	8	-1.6
26.1	89	132	1.471	45	1	0.000050	0.000037	0.00086	0.4227	0.0040	0.3789	0.0061	6.7936	0.1299	0.1301	0.0011	2099	15	1.3
27.1	181	91	0.503	85	0	0.000005	0.000032	0.00009	0.1408	0.0040	0.4294	0.0079	7.9002	0.2095	0.1335	0.0023	2144	30	-7.4
28.1	147	63	0.431	60	1	0.000022	0.000021	0.00039	0.1232	0.0016	0.3791	0.0071	6.4105	0.1309	0.1226	0.0008	1995	11	-3.9
28.2	388	122	0.316	151	1	0.000010	0.000010	0.00017	0.0903	0.0012	0.3721	0.0051	6.2337	0.0936	0.1215	0.0005	1979	8	-3.1
29.1	145	82	0.568	60	0	0.000010	0.000015	0.00017	0.1625	0.0014	0.3707	0.0051	6.5073	0.0989	0.1273	0.0006	2061	8	1.4
30.1	185	87	0.472	104	1	0.000017	0.000016	0.00029	0.1308	0.0015	0.5035	0.0072	12.0952	0.1999	0.1742	0.0011	2599	11	-1.2
31.1	62	52	0.835	24	0	0.000010	0.000010	0.00017	0.2502	0.0045	0.3347	0.0058	5.6572	0.1331	0.1226	0.0017	1994	25	6.7
32.1	65	42	0.654	35	0	0.000010	0.000010	0.00017	0.1810	0.0023	0.4679	0.0068	11.3944	0.1911	0.1766	0.0012	2621	11	5.6
33.1	169	76	0.452	60	1	0.000022	0.000015	0.00038	0.1303	0.0018	0.3291	0.0069	5.4104	0.1229	0.1192	0.0008	1945	11	5.7
33.2	169	101	0.599	70	2	0.000044	0.000024	0.00077	0.1662	0.0021	0.3728	0.0058	6.3001	0.1130	0.1226	0.0009	1994	13	-2.4
33.3	150	84	0.559	53	2	0.000040	0.000053	0.00069	0.1620	0.0035	0.3204	0.0054	5.4052	0.1253	0.1224	0.0017	1991	25	10.0
34.1	89	79	0.893	39	0	0.000006	0.000043	0.00011	0.2617	0.0043	0.3714	0.0060	6.2719	0.1322	0.1225	0.0014	1993	21	-2.2

Table 1. (cont.)

																	Apparent Age		
Analyses	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	^{204}Pb (ppb)	^{204}Pb/^{206}Pb	± ^{204}Pb/^{206}Pb	f(206)^{204}	^{208*}Pb/^{206*}Pb	± ^{208}Pb/^{206}Pb	^{206*}Pb/^{238}U	±^{206}Pb/^{238}U	^{207*}Pb/^{235}U	±^{207}Pb/^{235}U	^{207*}Pb/^{206*}Pb	±^{207}Pb/^{206}Pb	^{207}Pb/^{206}Pb	±^{207}Pb/^{206}Pb	Disc. (%)
35.1	74	64	0.860	31	2	0.000082	0.000045	0.00143	0.2475	0.0035	0.3580	0.0058	5.8064	0.1178	0.1177	0.0012	1921	19	-2.7
35.2	115	100	0.866	41	0	0.000010	0.000010	0.00017	0.2591	0.0046	0.2970	0.0062	4.8389	0.1288	0.1182	0.0017	1929	25	13.1
35.3	125	138	1.103	43	1	0.000032	0.000123	0.00056	0.3197	0.0108	0.2760	0.0059	4.5575	0.1509	0.1198	0.0027	1953	41	19.6
36.1	75	65	0.872	47	0	0.000010	0.000010	0.00017	0.2502	0.0019	0.5144	0.0085	12.7783	0.2281	0.1802	0.0009	2654	8	-0.8
37.1	95	86	0.914	42	2	0.000054	0.000030	0.00094	0.2707	0.0024	0.3743	0.0051	6.3163	0.1034	0.1224	0.0009	1991	14	-2.9
38.1	65	44	0.668	28	0	0.000010	0.000010	0.00017	0.1941	0.0021	0.3807	0.0068	6.3612	0.1253	0.1212	0.0008	1974	12	-5.4
39.1	74	82	1.107	34	0	0.000010	0.000010	0.00017	0.3193	0.0176	0.3732	0.0187	6.4144	0.4482	0.1247	0.0053	2024	78	-1.0
40.1	71	54	0.761	37	0	0.000015	0.000031	0.00025	0.2162	0.0027	0.4381	0.0069	8.9510	0.1719	0.1482	0.0014	2325	16	-0.7
41.1	208	129	0.619	123	1	0.000010	0.000011	0.00018	0.1758	0.0016	0.5084	0.0070	12.2070	0.1845	0.1741	0.0009	2598	8	-2.0
42.1	213	174	0.817	91	1	0.000012	0.000009	0.00021	0.2373	0.0017	0.3650	0.0044	6.1638	0.0856	0.1225	0.0007	1993	10	-0.7
43.1	193	244	1.265	97	1	0.000010	0.000010	0.00017	0.3695	0.0027	0.3906	0.0050	6.9781	0.0988	0.1296	0.0006	2092	8	-1.6
44.1	41	50	1.215	28	0	0.000010	0.000010	0.00017	0.3469	0.0048	0.5175	0.0079	13.1191	0.2263	0.1839	0.0012	2688	11	0.0
45.1	57	87	1.539	47	0	0.000010	0.000038	0.00017	0.4269	0.0062	0.5891	0.0115	16.3317	0.3680	0.2011	0.0018	2835	15	-5.3
46.1	94	72	0.765	60	1	0.000015	0.000017	0.00025	0.2109	0.0020	0.5282	0.0071	13.3233	0.1990	0.1830	0.0010	2680	9	-2.0
47.1	101	57	0.565	41	0	0.000010	0.000010	0.00017	0.1598	0.0016	0.3705	0.0050	6.2934	0.1062	0.1232	0.0010	2003	15	-1.4
47.2	214	152	0.713	96	1	0.000010	0.000010	0.00017	0.2069	0.0016	0.3945	0.0050	6.6725	0.0952	0.1227	0.0006	1995	9	-7.4
48.1	28	4	0.130	14	0	0.000010	0.000010	0.00017	0.0385	0.0051	0.4688	0.0149	11.1237	0.5413	0.1721	0.0057	2578	56	3.9
49.1	167	76	0.458	65	1	0.000010	0.000010	0.00017	0.1325	0.0019	0.3621	0.0047	5.8273	0.0916	0.1167	0.0009	1907	13	-4.5
49.1.2	147	64.6	0.4544	54	1	0.000020	0.000019	0.00035	0.1323	0.0017	0.3396	0.0061	5.4679	0.1068	0.1168	0.0007	1908	11	1.2
49.1.3	134	58.7	0.4512	48	1	0.000015	0.000024	0.00026	0.1339	0.0018	0.334	0.0065	5.3664	0.1121	0.1165	0.0007	1904	11	2.4
49.1.4	120	51.9	0.4453	42	0	0.000005	0.000015	0.00008	0.1301	0.0016	0.3251	0.0073	5.2826	0.1302	0.1179	0.0009	1924	14	5.7
49.1.5	110	46.9	0.4393	37	1	0.000036	0.000037	0.00062	0.1282	0.0027	0.3094	0.0083	4.9714	0.1469	0.1165	0.0011	1904	17	8.7
49.2	162	69	0.4393	60	0	0.000002	0.000018	0.00004	0.1348	0.0016	0.3439	0.0065	5.5321	0.1123	0.1167	0.0006	1906	10	0.0
49.2.2	157	65.5	0.4302	57	0	0.000004	0.000018	0.00008	0.1345	0.0016	0.3393	0.0069	5.5003	0.1193	0.1176	0.0007	1920	10	1.9
49.2.3	143	56.8	0.4105	51	0	0.000010	0.000010	0.00017	0.1231	0.0016	0.3363	0.0082	5.4571	0.1439	0.1177	0.0009	1922	14	2.7
49.3	170	85.8	0.5215	62	1	0.000028	0.000017	0.00049	0.1509	0.0030	0.3361	0.0064	5.4696	0.1136	0.1180	0.0008	1927	12	3.1
49.3.2	157	79	0.5203	57	0	0.000000	0.000029	0.00001	0.1535	0.0021	0.3339	0.0087	5.4227	0.1551	0.1178	0.0011	1923	16	3.4
49.3.3	143	72	0.5207	51	3	0.000074	0.000037	0.00128	0.1493	0.0023	0.3282	0.0086	5.2170	0.1488	0.1153	0.0010	1885	15	2.9
49.3.4	128	64	0.5175	44	0	0.000010	0.000010	0.00017	0.1505	0.0018	0.3161	0.0093	5.0487	0.1586	0.1158	0.0009	1893	15	6.5
50.1	30	17	0.581	12	1	0.000148	0.000104	0.00257	0.1713	0.0064	0.3716	0.0101	6.1306	0.2282	0.1197	0.0027	1951	40	-4.4
Kiyuk Group - K2 Unit Z5944				**Location UTM 15: 425150E 6704200N**					**(NAD 27)**										
1.1	133	172	1.2973	62	0	0.000010	0.000016	0.00017	0.3812	0.0024	0.1051	0.0016	0.3575	0.0044	6.3595	0.0883	2084	9	5.5
2.1	362	223	0.6147	176	0	0.000003	0.000009	0.00005	0.1768	0.0018	0.1222	0.0020	0.4249	0.0054	8.7603	0.1277	2341	10	2.5
3.1	158	163	1.0327	75	1	0.000010	0.000010	0.00017	0.2977	0.0024	0.1118	0.0018	0.3879	0.0051	6.9650	0.0993	2101	8	-0.6
4.1	316	357	1.1313	168	1	0.000010	0.000010	0.00017	0.3213	0.0052	0.1194	0.0029	0.4205	0.0067	8.5090	0.1751	2309	20	2.0
5.1	203	179	0.8807	86	1	0.000010	0.000010	0.00017	0.2560	0.0013	0.1036	0.0014	0.3565	0.0042	5.9909	0.0790	1984	8	0.9
5.2	256	211	0.8247	110	1	0.000017	0.000022	0.00029	0.2389	0.0023	0.1059	0.0020	0.3655	0.0054	6.1573	0.1034	1988	12	-1.0
5.2	233	192	0.8241	94	1	0.000010	0.000010	0.00017	0.2355	0.0028	0.0991	0.0021	0.3468	0.0053	5.8125	0.1057	1979	14	3.0
6.1	116	69.9	0.6023	66	1	0.000022	0.000012	0.00039	0.1650	0.0013	0.1361	0.0022	0.4966	0.0065	11.9665	0.1676	2604	6	0.2
7.1	432	171	0.3948	228	2	0.000010	0.000010	0.00017	0.1108	0.0007	0.1347	0.0019	0.4801	0.0057	10.9083	0.1377	2506	5	-0.9
10.1	409	151	0.3693	148	0	0.000003	0.000005	0.00005	0.1060	0.0006	0.0987	0.0013	0.3437	0.0041	5.5976	0.0698	1928	5	1.2
11.1	103	128	1.2489	50	0	0.000010	0.000010	0.00017	0.3553	0.0023	0.1087	0.0018	0.3820	0.0052	6.7987	0.1034	2085	10	0.0
12.1	332	204	0.6132	190	2	0.000017	0.000007	0.00030	0.1797	0.0011	0.1429	0.0020	0.4878	0.0057	12.2401	0.1773	2671	12	4.1
13.1	456	256	0.561	232	8	0.000046	0.000007	0.00080	0.1672	0.0007	0.1331	0.0019	0.4464	0.0057	9.6920	0.1403	2429	9	2.0
14.1	169	245	1.4553	86	1	0.000010	0.000010	0.00017	0.4214	0.0029	0.1108	0.0016	0.3828	0.0047	6.8150	0.0914	2086	7	-0.1
15.1	96.5	108	1.1147	40	0	0.000010	0.000010	0.00017	0.3250	0.0032	0.0977	0.0021	0.3351	0.0056	5.3686	0.1038	1898	14	1.9
17.1	277	74.7	0.2698	167	1	0.000009	0.000019	0.00015	0.0711	0.0017	0.1457	0.0040	0.5531	0.0074	14.8404	0.2387	2781	12	-2.0

Table 1. (cont.)

Analyses	U (ppm)	Th (ppm)	Th/U	Pb* (ppm)	^{204}Pb (ppb)	^{204}Pb/^{206}Pb	± ^{204}Pb/^{206}Pb	f(206)^{204}	^{208*}Pb/^{206*}Pb	± ^{208}Pb/^{206}Pb	^{206*}Pb/^{238}U	± ^{206}Pb/^{238}U	^{207*}Pb/^{235}U	± ^{207}Pb/^{235}U	^{207*}Pb/^{206*}Pb	± ^{207}Pb/^{206}Pb	Apparent Age ^{207}Pb/^{206}Pb	Apparent Age ± ^{207}Pb/^{206}Pb	Disc. (%)
18.1	444	176	0.3971	184	1	0.000010	0.000010	0.00017	0.1132	0.0008	0.1103	0.0017	0.3870	0.0050	7.0475	0.0986	2126	7	0.8
19.1	273	84.5	0.309	144	1	0.000008	0.000007	0.00013	0.0854	0.0006	0.1346	0.0020	0.4868	0.0058	11.7107	0.1523	2601	6	1.7
20.1	189	52.7	0.2791	69	1	0.000010	0.000010	0.00017	0.0807	0.0010	0.1016	0.0020	0.3514	0.0047	5.9680	0.0940	2003	12	3.1
21.1	213	86.3	0.4058	96	0	0.000003	0.000019	0.00005	0.1219	0.0015	0.1253	0.0023	0.4171	0.0052	8.0566	0.1188	2228	11	-0.8
22.1	196	158	0.8079	115	1	0.000010	0.000010	0.00017	0.2250	0.0018	0.1354	0.0020	0.4862	0.0060	11.6576	0.1523	2596	6	1.6
24.1	724	698	0.9637	306	8	0.000037	0.000006	0.00065	0.2862	0.0012	0.1034	0.0034	0.3483	0.0094	5.8453	0.1606	1981	5	2.8
25.1	72.3	57.6	0.7978	46	0	0.000010	0.000010	0.00017	0.2266	0.0018	0.1486	0.0026	0.5230	0.0071	13.4819	0.1991	2716	8	0.1
26.1	583	14.6	0.025	289	1	0.000004	0.000004	0.00007	0.0070	0.0002	0.1372	0.0043	0.4885	0.0056	11.5815	0.1373	2577	3	0.5
27.1	81.7	52.6	0.6436	33	0	0.000015	0.000029	0.00025	0.1842	0.0029	0.1016	0.0027	0.3551	0.0067	5.9964	0.1318	1993	17	1.7
28.1	115	66.3	0.578	50	0	0.000010	0.000010	0.00017	0.1621	0.0015	0.1091	0.0018	0.3892	0.0050	6.7641	0.1080	2043	14	-3.7
29.1	295	230	0.7791	138	1	0.000010	0.000010	0.00017	0.2244	0.0013	0.115	0.0017	0.3993	0.0050	7.4666	0.1012	2172	6	0.3
30.1	142	77.4	0.544	81	1	0.000014	0.000010	0.00024	0.1541	0.0012	0.1415	0.0022	0.4996	0.0063	12.0774	0.1633	2609	6	-0.1
31.1	82.8	189	2.2887	44	0	0.000010	0.000044	0.00017	0.6469	0.0070	0.099	0.0020	0.3501	0.0054	5.6696	0.1144	1918	20	-0.9
32.1	149	80.1	0.5381	84	0	0.000006	0.000017	0.00010	0.1522	0.0014	0.1402	0.0023	0.4958	0.0062	12.0624	0.1724	2620	10	0.9
33.1	189	110	0.5815	93	1	0.000010	0.000010	0.00017	0.1644	0.0012	0.1234	0.0020	0.4362	0.0056	8.8084	0.1227	2305	7	-1.2
34.1	452	147	0.3245	245	1	0.000007	0.000005	0.00011	0.0902	0.0007	0.138	0.0024	0.4965	0.0067	12.0708	0.1708	2619	5	0.8
36.1	132	97	0.7334	77	1	0.000010	0.000010	0.00017	0.2020	0.0014	0.1356	0.0021	0.4924	0.0063	11.7060	0.1606	2581	6	0.0
37.1	182	69.6	0.3822	69	1	0.000015	0.000012	0.00025	0.1099	0.0015	0.1025	0.0021	0.3564	0.0048	6.0360	0.0892	1998	8	1.6
38.1	232	59.6	0.2566	105	1	0.000010	0.000010	0.00017	0.0711	0.0021	0.1198	0.0041	0.4326	0.0067	8.8417	0.1797	2326	19	0.3
39.1	944	632	0.6698	741	5	0.000010	0.000010	0.00017	0.1802	0.0030	0.1722	0.0039	0.6401	0.0092	21.5844	0.3785	3150	13	-1.3
40.1	175	214	1.2248	73	0	0.000010	0.000010	0.00017	0.3517	0.0027	0.0953	0.0016	0.3318	0.0045	5.4825	0.0877	1954	12	5.4
41.1	132	41	0.3105	77	1	0.000016	0.000020	0.00029	0.0911	0.0013	0.1522	0.0033	0.5188	0.0073	14.9359	0.2278	2896	7	7.0
42.1	230	201	0.8717	137	0	0.000002	0.000020	0.00004	0.2458	0.0030	0.1372	0.0030	0.4865	0.0082	11.7790	0.2254	2612	12	2.1
43.1	111	147	1.325	66	0	0.000009	0.000025	0.00015	0.3730	0.0026	0.1275	0.0025	0.4531	0.0064	9.7661	0.1651	2416	13	0.3
44.1	715	50	0.0699	279	8	0.000034	0.000017	0.00059	0.0231	0.0009	0.1295	0.0061	0.3918	0.0068	7.2990	0.1530	2166	17	1.6
45.1	217	115	0.5326	123	1	0.000008	0.000010	0.00013	0.1476	0.0015	0.1382	0.0026	0.4988	0.0071	11.6432	0.1837	2551	9	-2.3
46.1	332	145	0.4355	170	11	0.000087	0.000016	0.00151	0.1341	0.0012	0.1409	0.0022	0.4576	0.0054	10.2987	0.1331	2489	7	2.4
47.1	107	121	1.1328	69	7	0.000155	0.000034	0.00269	0.3066	0.0027	0.1375	0.0024	0.5081	0.0067	12.2015	0.2001	2598	14	-1.9
48.1	99.5	63.6	0.6388	66	0	0.000010	0.000010	0.00017	0.1780	0.0016	0.1572	0.0031	0.5640	0.0083	15.1423	0.2432	2782	8	-3.6
49.1	384	257	0.6685	163	1	0.000010	0.000010	0.00017	0.1925	0.0030	0.1077	0.0025	0.3741	0.0057	6.5571	0.1308	2059	20	0.5
50.1	179	70.2	0.3921	92	2	0.000022	0.000013	0.00038	0.1164	0.0013	0.1372	0.0025	0.4619	0.0059	11.4759	0.1627	2655	8	7.8

Notes (see Stern, 1997 for analytical details):
Analyses identifcation: grain number.location.analysis number
Uncertainties reported at 1σ (absolute) and are calculated by numerical propagation of all known sources of error
Pb* - radiogenic Pb
Calibration standard : Kipawa - Age = 993.4 Ma; ^{206}Pb/^{238}U = 0.16655; error 1.1%; except for z5495- grain 49 replicates: z6266 - Age = 559 Ma; ^{206}Pb/^{238}U = 0.09059;# error 1.7%.
f206^{204} refers to mole fraction of total ^{206}Pb that is due to common Pb, calculated using the ^{204}Pb-method; common Pb composition used is the surface blank: 4/6: 0.05770; 7/6: 0.89500; 8/6: 2.13840
Discordance relative to origin = 100 * (1-(^{206}Pb/^{238}U age)/(^{207}Pb/^{206}Pb ages

Because Pb/U calibration is sensitive to local charging and analytical pit depth, the accuracy of the Pb/U calibration for some of these analyses is uncertain. However, the analytical conditions have no effect on the $^{207}Pb/^{206}Pb$ ratios on which the age determination is based. The best estimate of the youngest grain in the upper Hurwitz Group is revised to 1.911 ± 0.007 Ga; slightly younger than the youngest grains in the Watterson Formation.

The Tavani and Watterson samples are both characterized by ca. 2.5 to 2.0 Ga zircons. However, the proportions of individual age populations as reflected in the principal peaks on the probability diagram are different for the two samples (Figure 2e, g). The Tavani sample is dominated by 2.00 to 1.99 Ga zircons, whereas the underlying Watterson sample has more significant populations at 2.35 to 2.31 Ga and 2.15 to 2.10 Ga. This is interpreted as a change in the dominant crustal age of the source region during the deposition of Sequence 3. The change may reflect unroofing and erosion of rocks with different crustal ages in the source region over time, or a shift in the geographical source area with time. Available data on possible source regions within the Taltson-Thelon and western Rae provinces are insufficient to discriminate between these possibilities.

Kiyuk Group

Forty-five detrital zircons analyzed from the Kiyuk Group (K-2 member) yielded U-Pb ages ranging between 2.8 Ga and 1.9 Ga (Figure 2i, j). The range of ages is broadly similar to those documented in the upper Hurwitz group, with significant populations at ca. 1.99 to 2.0 Ga and 2.6 Ga. However, unlike the samples from the upper Hurwitz Group, the Kiyuk Group sample has a more evenly distributed range of ages, possibly indicative of better mixing of source components. This well mixed signature may reflect polycyclic deposition, for example, due to recycling of underlying Hurwitz Group sedimentary units. If this is the case, the primary source area of Kiyuk detrital zircon grains cannot be inferred. The youngest grain analyzed in the Kiyuk Group yielded an age of 1.898 ± 0.028 Ga, within error of the youngest grain from the upper Hurwitz Group.

DISCUSSION

The detrital zircon age data revise the age for the upper Hurwitz Group to be <1.960 ± 0.022 Ga for the Watterson Formation, and <1.911 ± 0.007 Ga for the Tavani Formation. These maximum depositional ages are significantly younger than the 2.11 Ga minimum age for underlying sequences 1 and 2, and indicate a hiatus of at least 150 Ma between the upper and lower Hurwitz Group (Davis et al. 2000; Aspler et al. 2001). The subtlety of such a significant time break within the succession was interpreted to reflect apparent tectonic stability within the basin during an interval of nondeposition from 2.11 to 1.96 Ga (Aspler et al., 2001).

A fundamental difference in the provenance of the Hurwitz Group is documented over the depositional hiatus, from Archean sources with a narrow range of crystallization ages, to mainly Proterozoic sources with a broader range of crystallization ages. The detrital zircons in the lower Hurwitz Group are similar in age to those of the immediately underlying rocks of the central Hearne supracrustal belt and their associated intrusions (e.g. Davis et al., 2004). The lack of age variation upsection among the samples of the lower Hurwitz Group analyzed here, suggests derivation from local sources developed during basin initiation followed by relative tectonic stability as portrayed by eventual widespread deposition of shallow-water quartz arenites of the Whiterock member (Aspler et al., 2001).

The change in provenance after ~1.96 Ga corresponds with development of the Thelon-Taltson Orogen on the western margin of the Rae Province, and opening of the Manikewan Ocean on the south-eastern margin of the Hearne Province. Sources for the Paleoproterozoic zircon grains within the upper Hurwitz Group strata are not known in the local basement; however, the ages are consistent with provenance from the southwestern Rae Province, Taltson-Thelon magmatic-orogenic belt and Buffalo Head Terrane, 500 to 800 km to the west (Aspler et al., 2001; Figure 1; references above). Crustal age domains between 2.5 and 2.0 Ga are uncommon elsewhere within Laurentia, and therefore constitute a relatively diagnostic provenance tracer. Correlation with a Taltson-Thelon source is further supported by the significant population mode at 2.00 to 1.93 Ga, the age of metamorphosed plutonic rocks within the orogen. Eastward transport of detritus across the Rae hinterland during uplift and denudation of the Taltson-Thelon Orogen fed material into Hurwitz Basin (Davis et al., 2000; Aspler et al., 2001), and possibly to a broader passive-margin sequence on the southeast margin of the Hearne Domain (e.g. Wollaston Supergroup; Yeo et al., 2002, Tran et al., 2003).

Although the maximum depositional age of 1.911 ± 0.007 Ga for the Tavani Formation would allow linking the upper Hurwitz Basin to the Trans-Hudson Orogen (Young, 1988; Bell, 1970; Lewry et al., 1985), this hypothesis is not favoured because the detrital zircon age population is uncharacteristic of the dominant crustal age spectra of the accreted La Ronge arc (Lucas et al., 1996). Zircons younger than 1.9 Ga are not represented in the Hurwitz Group as would be expected if sourced within the Trans-Hudson Orogen.

As discussed in Aspler et al. (2001), one of the outstanding issues in understanding the evolution of Hurwitz Basin between 2.11 and 1.9 Ga is reconciling the sedimentary facies and evidence for a cryptic time gap in the upper Hurwitz Group with evidence for high-pressure metamorphism and tectonic exhumation at ca. 1.9 Ga in the basement rocks of the northwestern Hearne Domain (Sanborne-Barrie et al., 2001; Berman et al., 2000; Berman et al., 2002). Although the extent and tectonic significance of these metamorphic events remain poorly known, initial deep-crustal metamorphism is documented as early as 1.917 Ga with subsequent rapid exhumation by 1.900 Ga in the Kramanituar complex within 100 km of the preserved Hurwitz Basin (Sanborne-Barrie et al., 2001).

Basement rocks underlying the upper Hurwitz Group apparently do not record this metamorphic event, so there is no direct relationship known between the two events.

It is now clear from the more precise maximum depositional age for the upper Hurwitz reported here that the Tavani Formation was deposited at the same time, or after the regional high-pressure metamorphism documented in the northwestern Hearne Domain. Ambiguity of this point in the earlier data set (Davis et al., 2000) could not exclude the possibility that the upper Hurwitz Group was deposited prior to the ~1.91 Ga metamorphism. The revised maximum age estimate for the Tavani Formation supports the Aspler et al. (2001) hypothesis that the upper Hurwitz Group was deposited *after* the 1.9 Ga high-pressure metamorphism along the northern margin of the Hearne Domain.

CONCLUSIONS

Detrital zircon geochronology of the Hurwitz Group indicates a profound break in the succession of more than 150 Ma. This interval defines a change from mainly Archean intrabasinal sources, to mainly Paleoproterozoic extrabasinal sources. The change can be explained as a response to uplift and erosion accompanying the Taltson-Thelon Orogen, which formed on the western margin of the Rae Domain ca. 2.0 to 1.9 Ga, several hundred kilometres to the west of Hurwitz Basin. In this scenario, sediment was transported eastward to be deposited in the shallow intracratonic depressions of Hurwitz Basin where it was reworked by a variety of shallow-water processes.

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