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Geochronology of the Back River volcanic complex, Nunavut–Northwest Territories

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Abstract

Five samples from the Back River volcanic complex of the eastern Slave Province provide age constraints on the stratigraphy of the area. Tuff from the Innerring sequence, at the stratigraphic base of the complex, is dated at 2708.5 ± 0.8 Ma. This age is 16 Ma older than a previously reported age of 2692 ± 2 Ma from rhyolite of the overlying Thlewycho sequence. An age determination on an intrusive rhyolite gives a poorly defined age between ca. 2660 Ma and 2690 Ma. A felsic sill that intrudes the Beechy Lake turbidite sequence, which in turn onlaps the volcanic complex, indicates an age of 2637 +8/-6 Ma. Detrital zircons from another section of Beechy Lake turbidite indicate that deposition postdated 2620 Ma, although the bulk of detritus was locally shed from the volcanic complex. A metagabbro dyke yielded baddeleyite, giving an age of 2586 ± 5 Ma.

Résumé

Dans la partie orientale de la Province des Esclaves, cinq échantillons prélevés dans le complexe volcanique de Back River ont permis de fournir à la stratigraphie régionale un cadre chronologique. Les tufs de la séquence d'Innerring à la base stratigraphique du complexe ont été datés à 2 708,5 ± 0,8 Ma. Cet âge est de 16 millions d'années plus ancien que celui des rhyolites de la séquence de Thlewycho sus-jacente qui ont été datées antérieurement à 2 692 ± 2 Ma. La datation d'une rhyolite intrusive a livré un âge mal défini se situant entre 2 660 Ma environ et 2 690 Ma. Un filon-couche felsique mis en place dans la séquence turbiditique de Beechy Lake, laquelle recouvre en avancée le complexe volcanique, a révélé un âge de 2 637+8/-6 Ma. Des zircons détritiques provenant d'une autre coupe de cette séquence turbiditique indiquent que la sédimentation a débuté après 2 620 Ma, bien que la plus grande partie des matériaux détritiques soient de source locale et proviennent du complexe volcanique. Un dyke de métagabbro renferme de la baddélyite ayant livré un âge de 2 586 ± 5 Ma.

INTRODUCTION

The Back River volcanic complex (**Fig. 1**) is an Archean stratovolcano, centred on 65° north latitude and 108° west longitude, that lies about 480 km northeast of Yellowknife, Northwest Territories. It constitutes the Back Group (Frith and Percival, 1978) of the Yellowknife Supergroup (Henderson, 1970). The complex is somewhat anomalous in the Slave Province because it has undergone only a low degree of deformation and is subhorizontal. It has generally low metamorphic grade (greenschist grade, but locally up to lower amphibolite grade). The southern half of the complex, which is exposed at the crest of a broad structural dome, is an eroded portion of the stratovolcano, possibly preserved in an upright position with sides steepened by regional deformation.

The complex comprises four volcanosedimentary sequences (Innerring, Thlewycho, Boucher-Regan, and Keish) that reflect the stages of growth and destruction of this Archean stratovolcano.

The Innerring sequence, which constitutes the oldest rocks of the complex, represents the upper part of an eroded early phase of the volcano. It includes andesite lava and tuff overlain by dacite lava and massive ash-flow tuff, and a rhyolite dome complex. All units have features consistent with subaerial deposition, except for laminated volcanic siltstone and black sulphide-rich slate and shale and iron-formation that locally mark the top of this sequence. A tuff on the northern side of the sequence (sample L1717-ZR-1, this report), yields U-Pb zircon igneous age of 2708 ± 0.8 Ma.

The Thlewycho sequence represents the main constructional phase of the stratovolcano. It forms an outward dipping, annular succession around the Innerring sequence, with an aggregate thickness of 2500–5000 m. Its stratigraphy, which changes dramatically around the volcano, varies from a) five cycles of andesitic to rhyolitic lava, followed by a succession of volaniclastic debris on the north side; to b) 30 subaerial, dominantly andesitic lava flows and rare pyroclastic and epivolcaniclastic units on the eastern side; to c) interlayered dacitic and andesitic lava and tuff overlain by a thick succession of voluminous, nonwelded, ash-flow tuff and volcaniclastic rocks around the southern side. Volcanism in this sequence ended with the eruption of large rhyolite/dacite dome/flow complexes (dated by U-Pb zircon at 2692 ± 2 Ma) around the periphery of the volcano (van Breemen et al., 1987; Lambert and Henderson, 1980). This is a common age for felsic volcanic rocks throughout the Slave Province (Villeneuve et al., 1997) and is similar to the age of upper Kam Formation of the Yellowknife Supergroup. The Innerring and Thlewycho sequences represent a complex history of lava effusion, mass wasting, and explosive eruption from numerous eruptive centres, and are interpreted as remnants of the main edifice of the stratovolcano.

The Boucher-Regan sequence occurs on the northern flank of the complex and comprises tholeiitic basalt and andesite lava, pillow lava and related sills that overlie and interfinger with volcaniclastic rocks and felsic domes of the Thlewycho sequence. The predominance of pillowed volcanic flows suggests that the northern flank of the volcano was submerged during deposition of the Boucher-Regan sequence.

The Keish sequence forms a broad apron on the northwestern side of the volcanic complex that is interpreted as a shallow, submarine to subaerial, clastic fan derived by degradation of the volcanic pile. It comprises epiclastic volcarenite, rhyolite to dacite block breccia (of debris flow, scree, or landslide origin) derived from lava domes, polymict breccia, and conglomerate containing andesite and dacite/rhyolite clasts, and andesitic tuff.

A nearly continuously exposed succession, including iron-formation, oolitic/stromatolitic carbonate, sulphidic volcaniclastic rocks and graphitic slate, marks the end of volcanism and beginning of turbidite sedimentation of the Beechy Lake Group.

The tightly folded and metamorphosed volcanic succession has been intruded by gabbroic dykes, one of which yields a U-Pb (zircon) igneous age 2586 $\pm$ 5 Ma (sample L1718-1). This dyke is also folded, but in a more open manner than the volcanic succession. The deformed volcanic complex is intruded in the southern part by ca. 2616 Ma intrusions of the Tarantula Quartz Diorite and in the northern part by ca. 2590 Ma granodiorite plutons. Three planar Proterozoic mafic dyke swarms represent the last igneous events: Malley diabase, Mackay diabase, and the Mackenzie dykes.

Previous publications (Lambert, 1976, 1978, 1982a,1982b, 1996, 1998; Lambert et al., 1990, 1992) provide generalized descriptions of rock units and outline preliminary stratigraphy, structure, and interpretation of the volcanic complex, at various stages of the mapping. Ages of five samples reported herein, from the volcanic sequences, Beechy Lake turbidite, a felsic sill, and a mafic dyke, bracket volcanism and deformation of the Back River volcanic complex.

METHODOLOGY

Following the separation of heavy minerals using heavy liquids, samples were passed through a Frantz LB-1J magnetic separator to purify zircon. Zircon crystals were selected for analysis based on criteria that optimized their clarity, lack of cloudiness and colour, and lack of fractures. All zircons were abraded prior to analysis to increase concordance by removing the outer portions of the grains where much of the Pb-loss and alteration take place (Krogh, 1982).

Following abrasion, photography, and final mineral selection, mineral fractions were analyzed according to methods summarized in Parrish et al. (1987). Data have been reduced and errors have been propagated using software written by J.C. Roddick; error propagation was done by numerical methods (Parrish et al., 1987; Roddick et al., 1987). Error ellipses on concordia diagrams are shown at the 2σ (95% confidence) level of uncertainty. Final errors are indicated in **Table 1**. Linear regressions on discordant arrays of data use a modified York (1969) method that takes into account the scatter of the points about the line (*see* discussion in Parrish et al. (1987)). Fraction letters shown on concordia diagrams are keyed to the fraction letters in Table 1.

SAMPLE DESCRIPTIONS AND ANALYSIS

Innerring tuff (sample L1717-ZR-1)

This sample is from a greenish-grey-weathering, massive unit of quartz- and feldspar-bearing tuff from the basal part of the dacitic to andesitic mixed lava and tuff unit (**Fig. 1**) of the Innerring sequence, about 4 km southeast of Innerring Lake.

Zircons from the sample are colourless to very pale brown, stubby multifaceted grains with minor, clear, elongate to bubble-shaped inclusions. The zircons are very clear and relatively free of fractures. Four fractions consisting of one to three heavily abraded grains give results that significantly overlap each other near and on concordia (**Fig. 2**; **Table 1**). Taking the weighted average of the $^{207}Pb/^{206}Pb$ ages of the fractions results in a crystallization age of 2708.5 ± 0.8 Ma.

Intrusive rhyolite (sample MLB-89-203)

This sample is from a 7 km long, 800 m wide, rhyolite body that intrudes, but is completely contained within, volcaniclastic rocks of the Thlewycho sequence northeast of Innerring Lake. It tapers out at both ends, but forms a complex interdigitating pattern at its west end, where a swarm of 1–3 m wide dykes intrude volcaniclastic rocks. The unit has sharp, irregular contacts that cut across stratigraphy at high angles, chilled margins, and, in one place, it encloses xenoliths of andesite. This body may be the root of a rhyolite dome or lava flow that effused at a higher stratigraphic level.

This white-weathering massive rhyolite unit has up to 25% feldspar and minor quartz phenocrysts up to 3 mm across in central parts, but dark greenish-grey, fine-grained, sparsely porphyritic to aphanitic chilled margins. Zircons from the sample are clear, colourless, irregular-shaped to faceted whole and broken grains with low U contents. Small, clear inclusions and potential cores are evident in some grains, although these were avoided during selection. Of seven fractions analyzed, four single-grain (A, B, C, and G) and one multi-grain (H) fractions scatter near or on concordia between 2620 Ma and 2690 Ma (**Fig. 3**). Multi-grain fractions D and E, which fall off this trend, may have suffered a secondary Pb-loss; this may also be true for fraction A. Overlapping single-grain analyses (fractions B and G) lie at ca. 2660 Ma (weighted average of the $^{207}Pb/^{206}Pb$ age of these two analyses is 2656 ± 8 Ma). Fractions C and H, which cluster near 2690 Ma, may contain inherited components (suggested by visual recognition of cores in some grains). Although the data are scattered and somewhat inconclusive, it is permissive from the intrusive nature of the unit for it to be as young as 2620 Ma (as marked by fraction A). Alternatively, the ages derived from fractions C and H are in accord with previously determined 2692 ± 2 Ma age on the late Thlewycho sequence rhyolite unit east of Jim Magrum Lake (van Breemen et al., 1987).

Felsic sill in Beechy Lake turbidite (sample EL88-6)

This sample is from a fine-grained, holocrystalline, felsic sill that intrudes the Beechy Lake turbidite near Esker Lake. The sample contains brown, euhedral to subhedral zircon crystals displaying strong internal growth zonation and some cloudiness. Minor rod- and bleb-shaped, clear inclusions and cross fractures are present, and some crystals verge on opaque. Fractions of one or two grains are all discordant (**Fig. 4**), but, except for fraction AC, form a linear array with an upper intercept at 2637 +8/-6 Ma and lower intercept at 622± 253 Ma. Fraction AC represents a dark, opaque grain with abundant fractures, possibly explaining the different Pb-loss trajectory. As such, this sample is interpreted to have an age of 2637 +8/-6 Ma and places a lower age on the time of deposition of this part of the Beechy Lake turbidite.

Greywacke in Beechy Lake turbidite (sample MLB-89-202)

This sample, from one of several felsic volcaniclastic units that are interbedded with turbidite in the northwestern corner of the map area, was originally interpreted to be a crystal tuff, but was determined to be a coarse wacke upon examination in thin section. This poorly sorted, approximately 2 m thick unit, which contains some clasts of biotite granitoid rock containing abundant zircon, along with volcanic rock fragments, quartz and feldspar, lies within thinly interbedded grey slate and siltstone.

Approximately 10 fractions of single zircon grains were analyzed, with only six having a high enough Pb content to give meaningful results. Zircon morphology ranged from subrounded to euhedral, and zircons were of variable quality. Some grains were clear, colourless, and inclusion-free, whereas others contained dark inclusions, visible growth zonation, and a dark, cloudy appearance. Some crystals maintained sharp terminations, although most appeared to have some surface rounding. Two fractions (AC, L) are concordant at ca. 2690 Ma, and two 3% discordant fractions also give similar $^{207}Pb/^{206}Pb$ ages (**Fig. 5**; **Table 1**). A single concordant analysis at 2620 ± 5 Ma suggests that this section of turbiditic sediments, although it contains components probably derived from the adjacent volcanic pile, may have affinities with post-Yellowknife Supergroup sediments recently documented in the Slave Province. Although much of the crystal and lithic material within Beechy Lake group may be derived from the volcanic complex, the very high amount of quartz in the turbidite units, coupled with the presence of granitoid fragments and detrital muscovite, suggests a granitoid component in the source terrain.

Metagabbro dyke (sample L1718-1)

This sample is from a large north-northwest-trending, metagabbroic to fine-grained diabase-textured dyke, that intrudes tightly folded mafic lava and pillow breccia of the Boucher Regan sequence, northeast of Regan Lake.

Three fractions of fine baddeleyite were separated for U-Pb isotopic analysis. Uranium concentrations ranged from 307 to 112 ppm. Analyses show little spread and are 4.1 to 6.1% discordant, with the most discordant analysis corresponding to the analysis with the highest U concentration. Regression of the three data points yields upper and lower intercepts of 2589 +110/-21 Ma and 135 +1580/-1660 Ma with a mean square of weighted deviates (MSWD) of 6.5 (**Fig. 6**). It has been noted that arrays of discordant baddeleyite generally trend towards the origin on a concordia plot (Heaman, 1997). As such, a regression forced through the origin and the three data points yields an upper intercept age of 2586 ± 5 Ma (MSWD of 3.3) and this age is interpreted as the time of emplacement and igneous crystallization of the dyke.

DISCUSSION

Samples dated herein indicate a prolonged period of magmatism in the Back River complex, albeit one consistent with time frames resolved in other volcanic centres in the Slave Province. The oldest sample, dated at 2708.5 ± 0.8 Ma is similar in age to volcanic rocks of the upper Kam Group, as determined in the Yellowknife greenstone belt (Isachsen and Bowring, 1994), as well as other volcanic centres in the western Slave Province (Villeneuve et al., 1997). Volcanic activity may have continued until ca. 2.66 Ga, as indicated by concordant zircons in the intrusive rhyolite sample (MLB-89-202). Complex isotope systematics in that sample preclude a unique interpretation and an age closer to 2.69 Ga may also be warranted. Both ages are permissive in the context of extrusive magmatism in other parts of the Slave.

The younger age is typical of the youngest volcanic rocks linked to the Yellowknife Supergroup, and 2.69 Ga felsic volcanic rocks also commonly occur (Isachsen and Bowring, 1994; Villeneuve et al., 1997). In fact, rhyolite units of this age have already been noted within the complex (van Breemen et al., 1987).

Finally, evidence for younger, onlapping turbiditic sedimentary rocks is given by the 2637 +8/-6 Ma age on a felsic sill intruding the Beechy Lake turbidite, as well as the 2620 concordant detrital zircon within the turbidite units themselves. Boulder conglomerate bodies as young as 2600 Ma have been documented in the Anialik volcanic belt of the northern Slave Province (Relf et al., 1999) and in the southern Slave Province at Jackson Lake (Isachsen and Bowring, 1994). In addition, volcanic horizons dated at ca. 2610 Ma have been noted in turbiditic sedimentary rocks at High Lake volcanic belt in the northern Slave Province (Henderson et al., 1994; Villeneuve et al., 1994) and in the Wheeler Lake area of the southern Slave Province (Isachsen and Bowring 1994). Detrital zircon geochronology on turbiditic sequences confirm that a secondary deposition of turbidite units at ca. 2620 to 2600 Ma was widespread in the Slave Province (Pehrsson and Villeneuve, 1999) (Villeneuve and van Breemen, 1994). Detrital zircons indicate turbidite sequences of similar age are present in the eastern Slave Province, although most detritus appears to be derived locally, from the Back River volcanic edifice.

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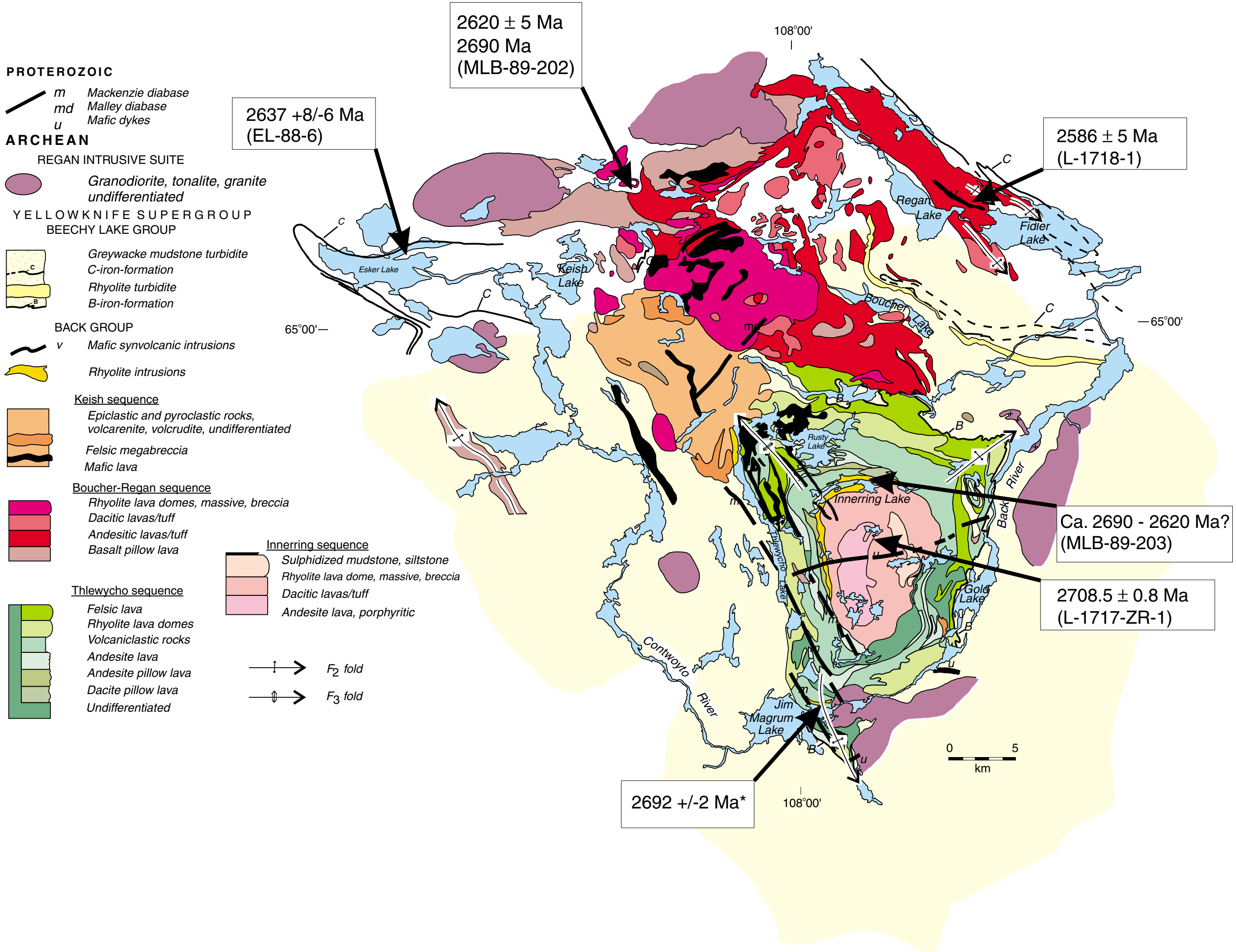

Figure 1. Sketch map of Back River volcanic complex with sample locations marked. Data is from van Breemen et al. (1987).

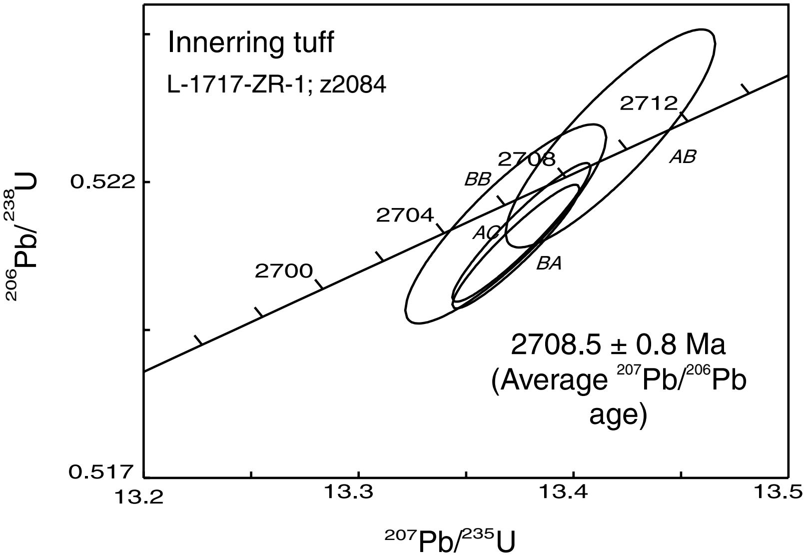

Figure 2. U/Pb concordia plot for sample L-1717-ZR-1 (Innerring tuff). Error ellipses are 2σ.

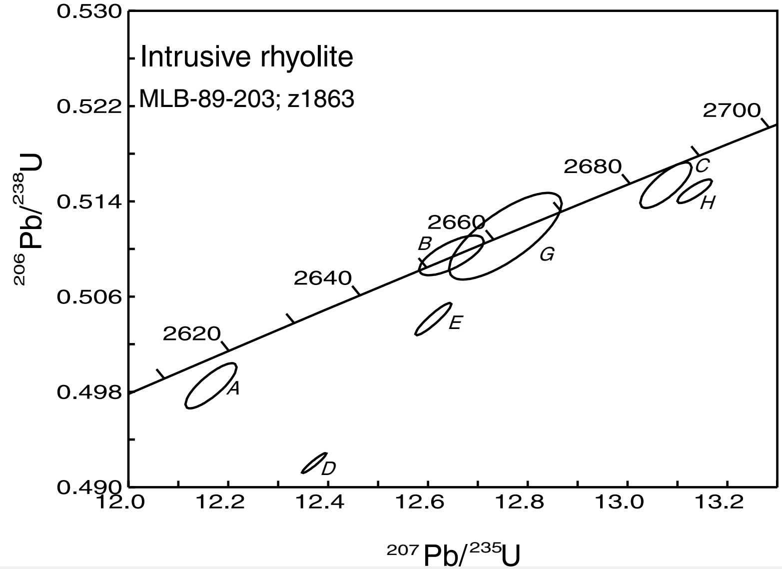

Figure 3. U/Pb concordia plot for sample MLB-89-203 (intrusive rhyolite). Error ellipses are 2σ.

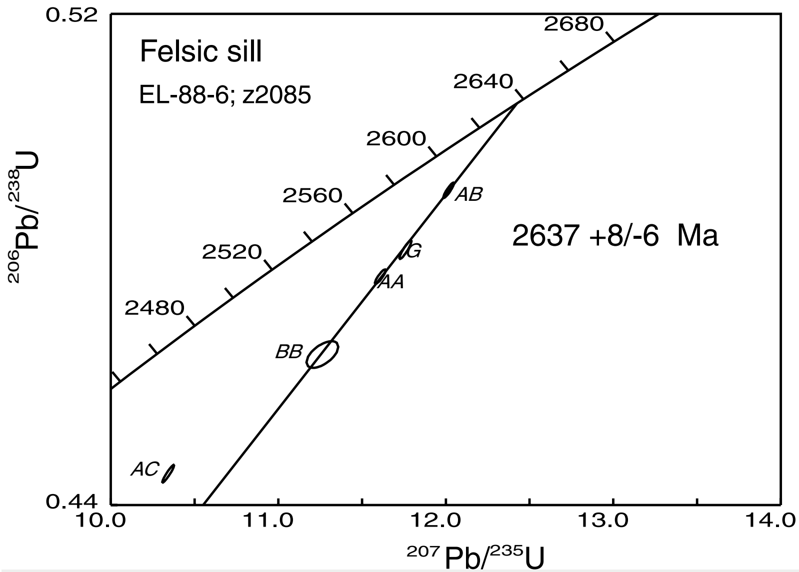

Figure 4. U/Pb concordia plot for sample EL-88-6 (felsic sill in Beechy turbidite). Error ellipses are 2σ.

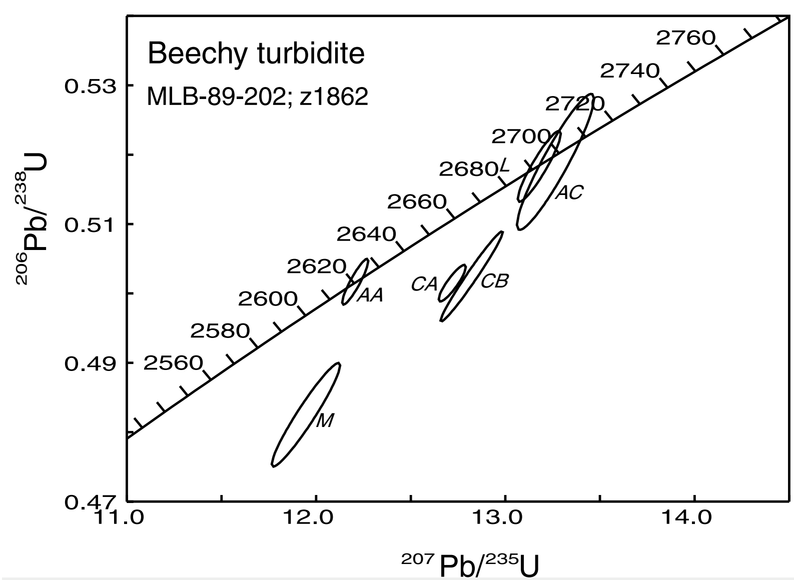

Figure 5. U/Pb concordia plot for sample MLB-89-202 (Beechy turbidite). Error ellipses are 2σ.

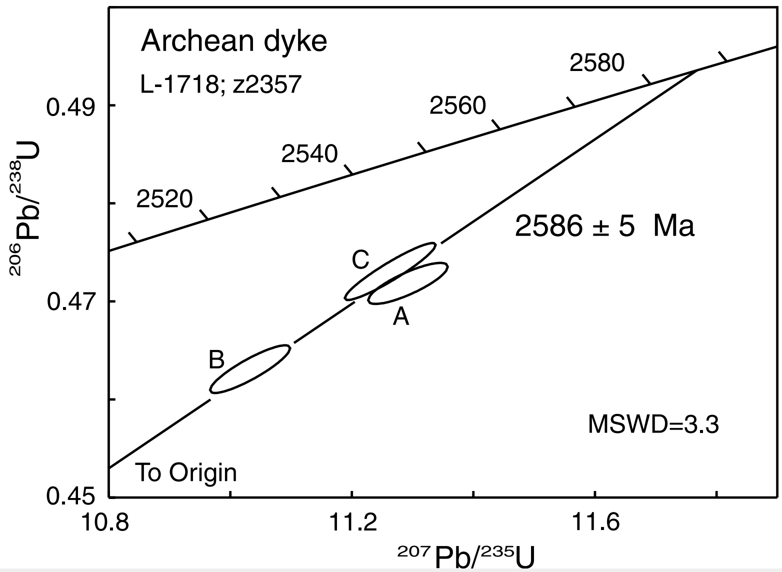

Figure 6. U/Pb concordia plot for sample L-1718-1 (metagabbro dyke). Error ellipses are 2σ.

Table 1. Table of U/Pb data.

Fraction[a]	Wt[b] µg	U ppm	Pb[c] ppm	$^{206}Pb/^{204}Pb$ [d]	Pb[e] pg	$^{208}Pb/^{206}Pb$ [f]	Radiogenic ratios (±1σ, %)[f] $^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$	Age (Ma)[g] $^{207}Pb/^{206}Pb$	Discord.[h] %
L1717-ZR-1 (Z2084) 64°51' 15" N, 107°53' 30" W											
AB (Z)	5	54	33	653	12	0.160	13.417 ± 0.18	0.5227 ± 0.18	0.18616 ± 0.09	2709 ± 3	-0.1
AC (Z)	10	54	33	2212	2	0.160	13.376 ± 0.12	0.5212 ± 0.11	0.18615 ± 0.04	2708 ± 1	0.2
BA (Z)	14	45	28	2164	6	0.190	13.373 ± 0.11	0.5209 ± 0.10	0.18620 ± 0.04	2709 ± 1	0.3
BB (Z)	6	41	25	607	14	0.210	13.368 ± 0.18	0.5213 ± 0.16	0.18599 ± 0.09	2707 ± 3	0.1
MLB-89-203 (Z1863) 64°53' 30" N, 107°53' 07" W											
A (Z)	21	10	6	464	14	0.160	12.165 ± 0.21	0.4985 ± 0.19	0.17699 ± 0.12	2625 ± 4	0.8
B (Z)	15	36	20	340	52	0.100	12.647 ± 0.26	0.5095 ± 0.16	0.18004 ± 0.18	2653 ± 6	-0.1
C (Z)	10	45	26	1614	5	0.150	13.075 ± 0.20	0.5153 ± 0.19	0.18404 ± 0.13	2690 ± 4	0.5
D (Z)	17	93	52	3657	13	0.130	12.372 ± 0.10	0.4920 ± 0.09	0.18237 ± 0.03	2675 ± 1	4.3
E (Z)	17	28	16	1188	12	0.120	12.611 ± 0.14	0.5041 ± 0.13	0.18143 ± 0.05	2666 ± 2	1.6
G (Z)	9	29	17	482	2	0.160	12.755 ± 0.44	0.5111 ± 0.36	0.18101 ± 0.29	2662 ± 10	0.0
H (Z)	13	51	31	1558	14	0.180	13.134 ± 0.13	0.5149 ± 0.10	0.18502 ± 0.07	2698 ± 2	1.0
EL-88-6 (Z2085) 65°02' 30" N, 108°43' W											
AA (Z)	6	155	79	1008	25	0.070	11.609 ± 0.14	0.4772 ± 0.12	0.17643 ± 0.07	2620 ± 2	4.8
AB (Z)	3	103	55	1947	5	0.080	12.018 ± 0.13	0.4913 ± 0.13	0.17740 ± 0.05	2629 ± 2	2.4
AC (Z)	4	228	104	2266	1	0.030	10.343 ± 0.17	0.4451 ± 0.16	0.16853 ± 0.06	2543 ± 2	8.0
BB (Z)	4	45	23	455	13	0.090	11.263 ± 0.42	0.4645 ± 0.23	0.17586 ± 0.34	2614 ± 11	7.1
G (Z)	1	255	133	1150	8	0.080	11.761 ± 0.15	0.4817 ± 0.16	0.17708 ± 0.06	2626 ± 2	4.2
MLB-89-202 (Z1862) 65°05' 27" N, 108°14' 25" W											
AA (Z)	23	27	14	504	42	0.010	12.207 ± 0.28	0.5017 ± 0.33	0.17647 ± 0.14	2620 ± 5	0.0
AC (Z)	8	68	41	205	51	0.170	13.265 ± 0.77	0.5190 ± 0.94	0.18538 ± 0.37	2702 ± 12	0.3
CA (Z)	4	94	58	987	11	0.230	12.719 ± 0.28	0.5015 ± 0.26	0.18395 ± 0.13	2689 ± 4	3.1
CB (Z)	3	30	17	582	6	0.150	12.822 ± 0.64	0.5025 ± 0.65	0.18508 ± 0.13	2699 ± 4	3.4
L (Z)	3	67	40	336	22	0.150	13.180 ± 0.43	0.5183 ± 0.49	0.18441 ± 0.20	2693 ± 6	0.0
M (Z)	1	245	127	437	1	0.070	11.946 ± 0.76	0.4825 ± 0.78	0.17957 ± 0.24	2649 ± 8	5.1
L-1718 (z2357) 65°04' 48" N, 107°43' 56' W											
A (B)	3	112	56	366	29	0.07	0.4718 ± 0.22	11.292 ± 0.29	0.17358 ± 0.17	2593 ± 6	4.
B (B)	1	307	151	461	19	0.06	0.4631 ± 0.26	11.032 ± 0.30	0.17278 ± 0.14	2585 ± 5	6.1
C (B)	2	138	70	522	16	0.07	0.4730 ± 0.31	11.263 ± 0.33	0.17269 ± 0.12	2584 ± 4	4.1

[a]All zircon fractions are abraded; (Z)=Zircon, (B)= Baddelyite. [b]Error on weight = ± 0.001 mg. [c]Radiogenic Pb. [d]Measured ratio corrected for spike and Pb fractionation of 0.09 ± 0.03%/AMU. [e]Total common Pb on analysis corrected for fractionation and spike of blank model Pb composition. [f]Corrected for blank and spike Pb and U and common Pb (Stacey-Kramers model Pb equal to the $^{207}Pb/^{206}Pb$ age). [g]Age error is ± 2σ in Ma. [h]Discordance along a discordia to origin.