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DATATION ISOTOPIQUE (U-PB) D'UN DIABASE DE L'ESSAIM DE DYKES MISTASSINI, QUEBEC - U-PB ISOTOPIC OF A DIABASE DYKE OF THE MISTASSINI SWARM, QUEBEC

Datation Isotopique (U-Pb) d'un Diabase de L'Essaim de Dykes Mistassini, Québec

U-Pb Isotopic Dating of a Diabase Dyke of the Mistassini Swarm, Québec

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INTRODUCTION

The Mistassini dyke swarm represents one of the most voluminous intrusive episodes of diabase in the Superior Province, comparable to the extensive and more dense Matachewan swarm of the central and western Superior Province (Figure 1). Although the age of the Matachewan swarm is broadly known (between 2473 +16/-9 Ma and 2446 ± 3 Ma; Heaman, 1995), an accurate and precise age for the Mistassini dykes is poorly constrained. On the basis of earlier K-Ar age determinations, Fahrig et al. (1986) estimated the age of the Mistassini dykes to be approximately 2000-2200 Ma, though some whole rock chilled margin samples yielded K-Ar ages as young as 1220 Ma, clearly indicating partial resetting due to the thermal effects of Grenville metamorphism. Heaman (1994) alluded to a U-Pb age of 2.47 Ga for a Mistassini dyke, determined on a sample from Fahrig's 1986 collection (FA65-55; see Figure 2), but the results of this analysis have not been formally published. A more recent abstract (Heaman, 2004) suggests that an age of 2510-2500 Ma has been obtained on this sample.

This report describes results of a U-Pb baddeleyite (ZrO_2) isotopic age determination on a sample of diabase from the extensive Mistassini dyke swarm, Quebec. The age of this dyke is discussed in the context of other dyke swarms of comparable age in the eastern Superior Province, as well as other possible correlative swarms occurring on different cratonic blocks that may have been adjacent to the southeastern Superior craton during the late Archean.

GEOLOGY & MINERALOGY

The Mistassini diabase dyke swarm of the eastern Superior Province fans over approximately 30-35° of arc, and extends from the Lac Mistassini area, radiating in northwesterly to north-northwesterly trends for up to approximately 400 km. Many Mistassini dykes are delineated by pronounced linear, positive magnetic anomalies. Individual dykes range from less than 1 m to over 100 m in thickness, and are locally continuous for strike lengths of approximately 150 km, cutting Archean granitoid gneisses of the Superior Province (Fahrig et al., 1986). They are hypothesized to be overlain by metasedimentary rocks of the Mistassini Group (omitted for clarity in Fig. 2), which they are not seen to intrude; therefore, a precise age for the dykes would provide a maximum depositional age for the overlying supracrustal basin.

Fahrig et al. (1986) showed that the swarm comprises a suite of tholeiitic and komatiitic (or basaltic komatiite) compositions. Most of the larger Mistassini dykes are tholeiitic in composition, and consist of a variably altered assemblage of intermediate plagioclase (An_{40-35}) and augite, with accessory interstitial quartz, microcline, apatite, skeletal oxides (including rutile). Trace baddeleyite is also present. Some dykes contain abundant, large (up to 6-8 cm) phenocrysts of plagioclase showing local internal zoning. Mistassini dykes with komatiitic to basaltic komatiite and high-Mg basalt compositions are characterized by heavily uralitized assemblages formerly dominated by ophitic to subophitic intergrowths of olivine, augite and zoned plagioclase (An_{50-26}). Unaltered grains of olivine are rare. Apatite and oxides comprise up to 5% of the rocks in this suite.

PALEOMAGNETISM

Paleomagnetic directions were determined by Fahrig et al. (1986) on over 100 oriented samples of Mistassini dykes. However, paleomagnetic results from the Mistassini dykes were complicated by the presence of multiple components (Fahrig et al., 1986; see also Buchan et al. 2007, for a discussion); these complexities render an unambiguous interpretation of the primary magnetic remanence difficult. Of the three superimposed remanences, one of the paleomagnetic directions (NE and down) matches an interpreted primary direction determined for the 2505 Ma Ptarmigan diabase dykes of the Ungava region (Buchan et al., 1998).

ANALYTICAL METHODS

From the Fahrig et al. (1986) study, approximately 1 kg of 2.54 cm diameter residual cores of diabase was available of a coarse-grained sample (FA65-56; Fig. 2) that yielded “NE, down” paleomagnetic direction, and was selected for possible dating. Roughly 150 g of this sample was processed using conventional crushing and grinding techniques (jaw crusher and ring mill). The resulting coarse powder was then spoon-fed slowly over a shaking water (Wilfley) table, left for several minutes (see Söderlund and Johansson, 2002), and a thin band of heavy minerals was pipetted directly off the table and inspected using a binocular microscope. Neither heavy liquids nor magnetic separation techniques were necessary to concentrate a modest amount of good quality baddeleyite (see below).

Following hand-picking of the best quality, fresh baddeleyites under a binocular microscope, selected grains were photographed and then analyzed using conventional isotope dilution - thermal ionization mass spectrometry (ID-TIMS) methods at the Jack Satterly Geochronology Laboratory at the University of Toronto. Weight estimates were made from a digital measurement of grain dimensions and the density of baddeleyite. Grains were washed and loaded into Teflon bombs with concentrated HF along with a mixed ^{205}Pb - ^{235}U isotopic tracer solution (Krogh, 1973). Dissolution occurred over four days at 195°C, after which fractions were dried down with phosphoric acid and loaded with silica gel directly onto outgassed rhenium filaments. The isotopic compositions of Pb and U were measured using a single Daly collector with a pulse counting detector on a solid source VG354 mass spectrometer. A detector mass discrimination of 0.053% per atomic mass unit (AMU) and a dead time of 22 nsec were employed for Daly detector measurements. A thermal source mass discrimination correction of 0.1% per atomic mass unit was applied for both Pb and U. The assigned laboratory blank for U was 0.2 pg, while that for Pb is routinely measured below 1 pg. Error estimates were calculated by propagating known sources of analytical uncertainty for each analysis including within-run ratio variability, uncertainty in the fractionation correction, and uncertainties in the isotopic composition of laboratory blank. Uncertainties for the ID-TIMS data are given at the 95% (2σ) confidence level. Initial corrections were made using an in-house data reduction program (UTILAGE). Decay constants used in age calculations are those of Jaffey et al. (1971). Graphical data presentation and quoted ages were generated using the Microsoft Excel Add-in Isoplot/Ex v. 3.00 of Ludwig (2003).

RESULTS

Baddeleyite morphologies. Baddeleyites from sample FA65-56 comprise a relatively uniform population of olive-brown to brown, flat blades and blade fragments, rarely striated (Figure 3). Grain sizes range up to approximately 60 microns in length (maximum), are frequently no greater than 15 microns wide, and 5-10 microns thick. A small proportion of grains show clouding with minor, dusty opaque oxide inclusions, and these were preferentially excluded from analysis. Likewise, although most grains appeared to be relatively fresh (with highly reflective blade surfaces), some baddeleyites had dull crystal faces suggestive of minor overgrowth by fine-grained zircon. Before analysis, it was unclear whether these coatings were late-magmatic in origin (due to increased Si activity), or are due to subtle metamorphic recrystallization effects (with excess SiO_2 available from breakdown of silicate phases (e.g. pyroxene to amphibole) – see below for a discussion.

Geochronology. Uranium-lead ID-TIMS results are presented in Table 1 and shown graphically in Figure 4. Results are presented for four fractions, each comprising between only 5-7 baddeleyite grains each. Analyzed fractions have a range of U concentrations from ca. 220-545 ppm and are variably discordant, ranging from approximately 97.4 to 98.8% concordant. All data are essentially colinear, although the three least discordant analyses are mutually overlapping at the 2σ level. Total common Pb is also low in all analyses, consistently less than 0.6 picograms (Table 1).

The three most concordant baddeleyite analyses (fractions Bd-2, -3 and -4) yield $^{207}Pb/^{206}Pb$ ages falling within a narrow range from 2505.7-2507.5 Ma, whereas the more discordant point (Bd-1) has a slightly younger model $^{207}Pb/^{206}Pb$ age of 2499.0 Ma. Linear regression of all four data points yields a good fit (probability of fit = 75%; MSWD = 0.29) having an upper intercept age of 2515 ± 3 Ma and a lower intercept age of 916 ± 160 Ma (Figure 4). The small discordance and good colinearity of all analyses provides a high degree of confidence that 2515 ± 3 Ma represents an accurate estimate of the age of igneous emplacement and primary crystallization of the Mistassini diabase dyke at this locality. The ca. 1000 Ma lower intercept suggests that the secondary Pb loss recorded in the baddeleyite grains is likely due to the formation of fine metamorphic zircon overgrowths during Grenville orogeny.

DISCUSSION

An igneous crystallization age of 2515 ± 3 Ma for diabase sample FA65-56 confirms that the Mistassini dykes represent the oldest recognized Neoarchean swarm in the Superior Province. The age is only slightly older than the north- to northeast-trending 2505 ± 2 Ma Ptarmigan dyke swarm in the Minto block of the northeastern Superior Province (Figure 1; Buchan et al., 1998). In contrast, however, Ptarmigan dykes appear to be more sparse, having somewhat more restricted areal distribution, and are olivine-bearing two-pyroxene diabase dykes. Furthermore, Buchan et al. (1998) demonstrated that Ptarmigan dykes yield comparatively far more stable paleomagnetic directions than Mistassini dykes, suggesting that, although the dykes may have been emplaced in relatively rapid sequence, they may not be related petrologically. Available geochemical data for Ptarmigan dykes are meager, and though some trace element contents are similar between the two swarms, preliminary analysis suggests that minor but real differences may exist. Further dating of both dyke swarms may well prove a significant overlap in intrusion ages. This seems possible since the paleomagnetic directions of the few Ptarmigan dykes studied appear to coincide with one of the remanence directions represented in the Mistassini dyke study of Fahrig et al. (1986). Paleopoles interpreted to be primary from both these swarms are indistinguishable, which led Buchan et al. (2007) to suggest that there was no relative rotation of the two regions of the eastern Superior since 2500 Ma. Paleopoles for the 2473-2446 Ma Matachewan dyke swarm are complicated slightly by relative rotational effects on either side of the younger Kapuskasing structural zone, but poles from each area are nonetheless distinct, if only slightly, from the 2515 Ma Mistassini and 2505 Ma Ptarmigan pole locations (Buchan et al., 2007). As hypothesized by Ernst and Buchan (2001), the Matachewan and Mistassini radiating dyke swarms cannot have belonged to the same plume-head event (driving break-up of the southern and southeastern Superior margin) because their interpreted foci lie nearly 800-900 km apart; this is now bolstered by the recognition that the Mistassini dyke swarm significantly predates the Matachewan event.

Roughly coeval 2515-2505 Ma mafic magmatism has been found now on several Archean cratonic blocks worldwide. Heaman (1997) initially proposed a Superior-Karelia juxtaposition based on matching 2450 Ma mafic magmatic events, and though this required a difficult orientation based on paleomagnetic constraints, new data from Karelia, together with the new Mistassini dyke age, help resolve this issue. Recent U-Pb (baddeleyite) age constraints from the coarse-grained Avdeevskiy and Shalskiy gabbronorite dykes from Karelia are dated at 2508 ± 2.5 Ma and 2511 ± 1.5 Ma, respectively (Hamilton, unpublished data). This is the first recognition of a "Mistassini event" in Karelia, and helps establish that Karelia, Kola and the southeastern flank of the Superior craton were all adjacent one another within a greater Superior cratonic landmass at the end of the Archean ("Superia" of Bleeker). Moreover, matching younger magmatic events help establish that Superior and Karelia remained juxtaposed well into the Paleoproterozoic, possibly to ca. 2100 Ma or even younger. The available paleomagnetic data for Karelia (based in part on the newly–correlated Avdeevskiy & Shalskiy units) suggest that their shallow inclination poles are primary and permit a more geometrically reasonable fit for Superior and Karelia between 2515-2450 Ma.

Ca. 2505-2510 Ma dyke swarms have also recently been recognized from the southern Slave craton (Hamilton and Bleeker, in prep.), the North Atlantic craton, the Zimbabwe craton, and the North China craton. Relating the position of these blocks relative to the Superior craton, however, will require demonstrably primary paleopoles from each of these blocks. A baked contact test for the newly dated 2515 ± 3 Ma Mistassini dykes would be highly advantageous; however, as Buchan et. al (2007) have shown, even Mistassini dykes lying at great distances from the Grenville Front remain complicated by multiple remanence directions, and so the likelihood of establishing a robust, primary Mistassini paleomagnetic pole remains a challenge.

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Table 1. U-Pb isotopic data for baddeleyite from the Paleoproterozoic Mistassini diabase dyke swarm, Quebec

Analysis No.	Fraction	Weight (μg)	U (ppm)	Th/U	Pb_{com} (pg)	$^{206}Pb/^{204}Pb$ measured	$^{206}Pb/$ ^{238}U	2σ	$^{207}Pb/$ ^{235}U	2σ	$^{207}Pb/$ ^{206}Pb	2σ	$^{206}Pb/^{238}U$ Age (Ma)	2σ	$^{207}Pb/^{235}U$ Age (Ma)	2σ	$^{207}Pb/^{206}Pb$ Age (Ma)	2σ	% Disc	Rho
FA65-56	***Mistassini diabase dike***																			
MAH8043	Bd-1; 6 fr, br, euh bl	0.5	265	0.049	0.4	6409	0.461235	0.000891	10.44000	0.02523	0.164163	0.000154	2445.0	3.9	2474.6	2.2	2499.0	1.6	2.6	0.931
MAH8114	Bd-2; 7 fr, br, bl & frags	0.6	545	0.064	0.3	19191	0.469291	0.000929	10.67606	0.02538	0.164994	0.000135	2480.5	4.1	2495.3	2.2	2507.5	1.4	1.3	0.946
MAH8133	Bd-3; 5 fr, br, bl & frags	0.4	220	0.073	0.5	9587	0.467712	0.000980	10.62890	0.02664	0.164819	0.000143	2473.5	4.3	2491.2	2.3	2505.7	1.5	1.5	0.944
MAH8134	Bd-4; 6 fr, br, bl frags	0.5	257	0.046	0.6	3367	0.469379	0.000918	10.67282	0.02799	0.164913	0.000207	2480.8	4.0	2495.1	2.4	2506.7	2.1	1.2	0.890

Notes: fr = fresh; br = brown; euh = euhedral; bl = blade(s); frags = fragments

Pbcom - common Pb assuming the isotopic composition of laboratory blank: 206/204 - 18.221; 207/204 - 15.612; 208/204 - 39.360 (errors of 2%).

Th/U calculated from radiogenic 208Pb/206Pb ratio and 207Pb/206Pb age assuming concordance.

Disc - per cent discordance for the given 207Pb/206Pb age. **Rho** - Error correlation coefficient.

Uranium decay constants are from Jaffey et al. (1971).

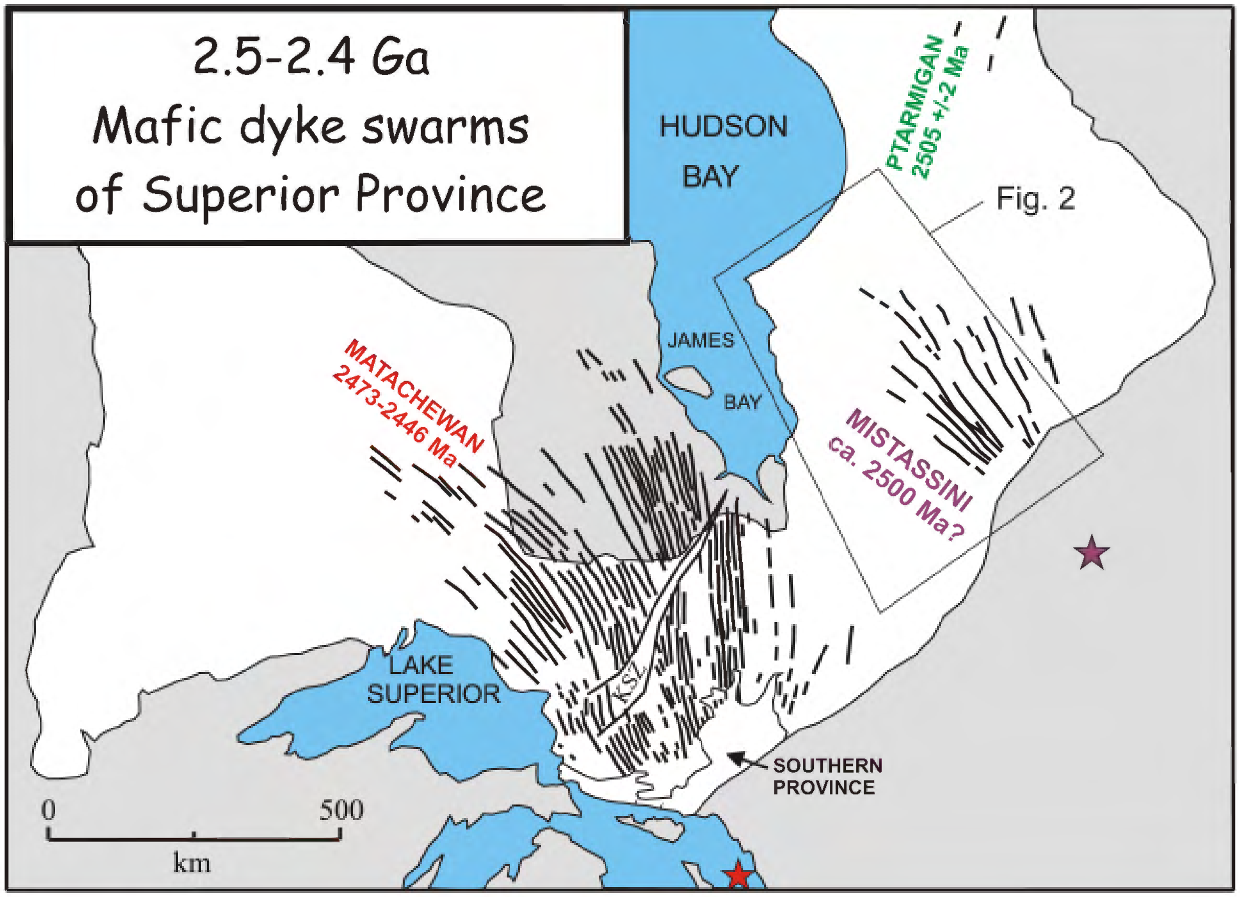

Figure 1. Location of major ca. 2.5-2.4 Ga diabase dyke swarms in the Superior Province. Fanning pattern for the Matachewan and Mistassini swarms led Ernst and Buchan (1997) to hypothesize two distinct loci (approximate positions of red, purple stars), from which magmatism radiated, possibly driven by mantle plume upwelling that drove continental breakup along the southeast margin of the Superior craton.

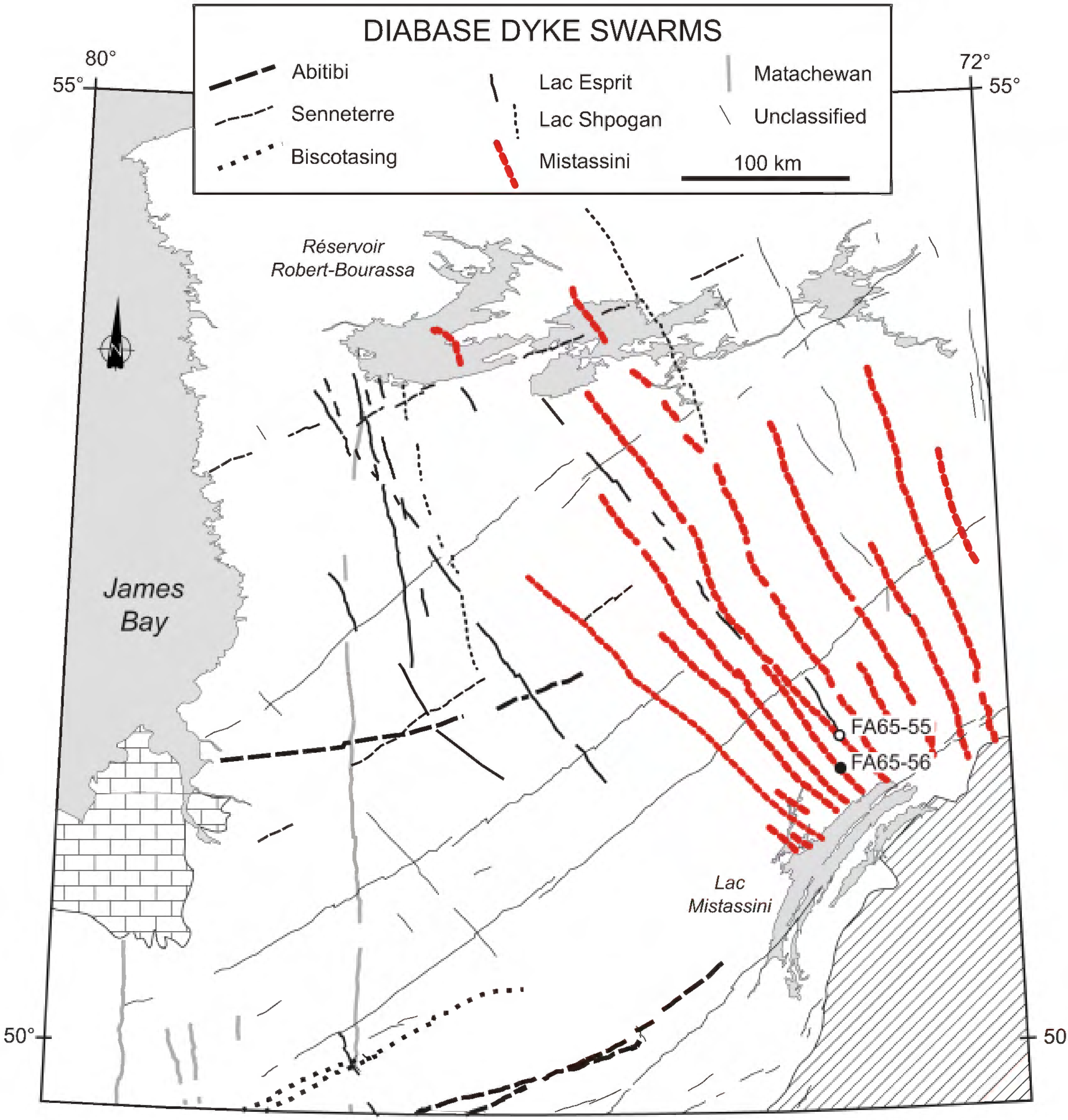

Figure 2. Paleoproterozoic dyke swarms east of James Bay, Quebec (modified after Buchan et al., 2007). NW- to NNW-trending fan of radiating Mistassini dykes are shown highlighted in red. Sample locations from the original study of Fahrig et al. (1986) show the dyke sites dated by Heaman (open circle; FA65-55) and this study (filled circle; FA65-56) north of Lac Mistassini. Note the near coincidence in trend of some 2069 Ma Lac Esprit dykes with the Mistassini swarm. Paleoproterozoic sedimentary basins not shown, for clarity.

Mistassini diabase dyke

Baddeleyite mineral concentrates

FA65-56

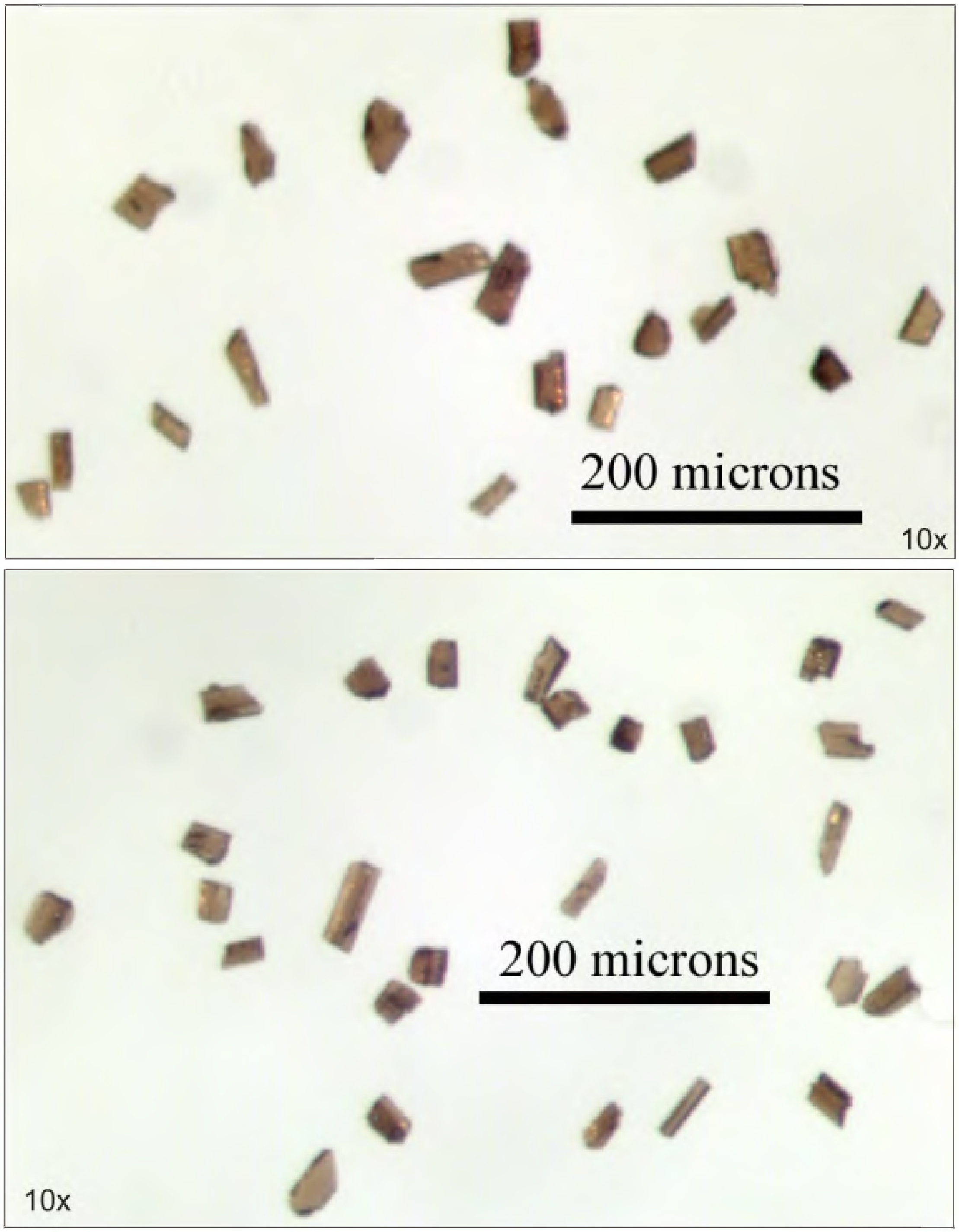

Figure 3. Representative populations of baddeleyite grains recovered from sample FA65-56. Best quality grains were selected for dissolution and isotopic analysis.

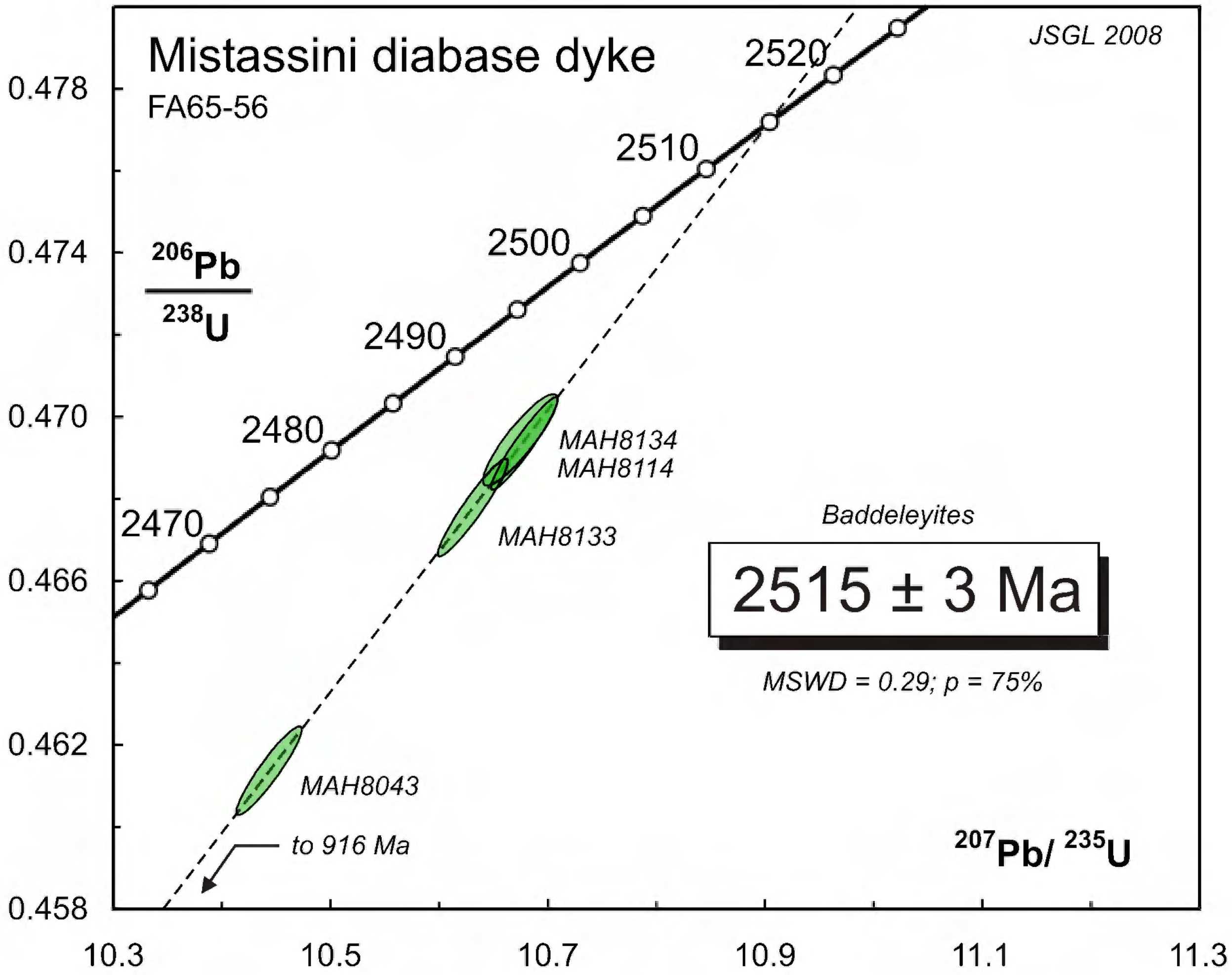

Figure 4. Concordia diagram showing the U-Pb isotope dilution results for four fractions of baddeleyite from Mistassini diabase dyke sample FA65-56. Error ellipses are shown at the 2σ level of uncertainty.