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E.J. Thiessen[1], D. Regis[2], and H.D. Gibson[1]

[1] Department of Earth Sciences, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia
[2] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario

2017

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Overview

New mapping and sampling in southeastern Northwest Territories (NWT) in the summer of 2015 (GEM2 South Rae project) has resulted in the discovery of a ~300 km long crustal-scale shear zone, herein referred to as the Wholdaia Lake shear zone (*WLsz*). This report presents detailed SHRIMP (Sensitive High Resolution Ion Microprobe) U-Pb geochronology results on 10 samples from a segment of the WLsz to better constrain its age and its role with regard to ca. 1.9 Ga regional metamorphism and exhumation. Samples include host-rock ortho-gneisses and meta-sediments as well as six dikes that cross cut mylonitic host-rocks.

Geological Setting of the Wholdaia Lake shear zone

The Wholdaia Lake region in the southern part of the Rae craton (Figure 1) was previously mapped at reconnaissance and 1:250000 scale and covered map sheets 75A (Taylor, 1970) and 65D (Tyrrell, 1897a, 1897b; Taylor, 1963). Martel (2005) and Martel and Pierce (2006) provide an updated geological map of 65D whereas 75A has only seen isolated mapping updates near Wholdaia Lake (Hanmer et al., 1995; Hanmer, 1997). Detailed bedrock mapping of the same region in 2015 resulted in the identification of a new crustal-scale shear zone (*WLsz*) along the boundary between two previously recognized tectono-metamorphic domains (Davis et al. 2015). The ***Firedrake domain***, west of the *WLsz*, consists of 2.7–2.6 Ga granitoid gneisses and granitic rocks, ~2.6 Ga metasediments overprinted by ca. 1.83 Ga metamorphic ages (Davis et al., 2015). Voluminous magnetite-bearing granodiorite intruded the Firedrake domain at ~1.83 Ga, which dismembered the protolith gneisses producing a variety of migmatitic textures. The ***Snowbird domain***, east of the *WLsz*, in NWT is dominated by NeoArchean 2.66–2.55 Ga granodioritic to tonalitic intrusions and minor mafic rocks, 1.93–2.07 Ga sediments overprinted by a ca. 1.9 Ga high-temperature metamorphic event. The *WLsz*, at the boundary between the two described domains, consists of high-grade mafic and felsic granulites within which a 10 km wide mylonite zone was mapped along a 100 km NE-SW striking segment (Figure 2).

Total field magnetic imaging differentiates the Firedrake and Snowbird domains in both their magnetic patterns and intensities (Figure 2). Firedrake magnetics are relatively high, displaying 10's of kilometres-scale curvilinear patterns and kilometre-scale sheath folds. At the broadest scale these magnetic patterns appear to deflect into the *WLsz* with a dextral shear sense (Figure 2).

The Snowbird domain consists of distinct high and low magnetic anomalies that appear to be poly-folded into Type 2 fold interference patterns (Ramsay, 1967) at the kilometre-scale (Martel et al., 2008). The low magnetic patterns are typically composed of pelitic-psammitic to calc-silicate meta-sedimentary rocks and the high magnetic patterns typically correspond with orthogneisses (Martel et al. 2008). The magnetic fold patterns change abruptly at the margin of the *WLsz* where they become transposed into linear patterns exhibiting dextral shear sense.

Field mapping demonstrated that the *WLsz* is a composite structure with two distinct lithotectonic units both trending northeast and dipping southeast. The first unit consists of mafic and felsic granulite gneiss and mylonites that typically display cm-scale annealed gneissic banding with layers of garnet-clinopyroxene-plagioclase, garnet-clinopyroxene-plagioclase-quartz, and garnet-orthopyroxene-plagioclase-hornblende-quartz. With respect to the polydeformed bounding domains, this unit is consistently transposed, striking northeast and dipping southeast ~61°.

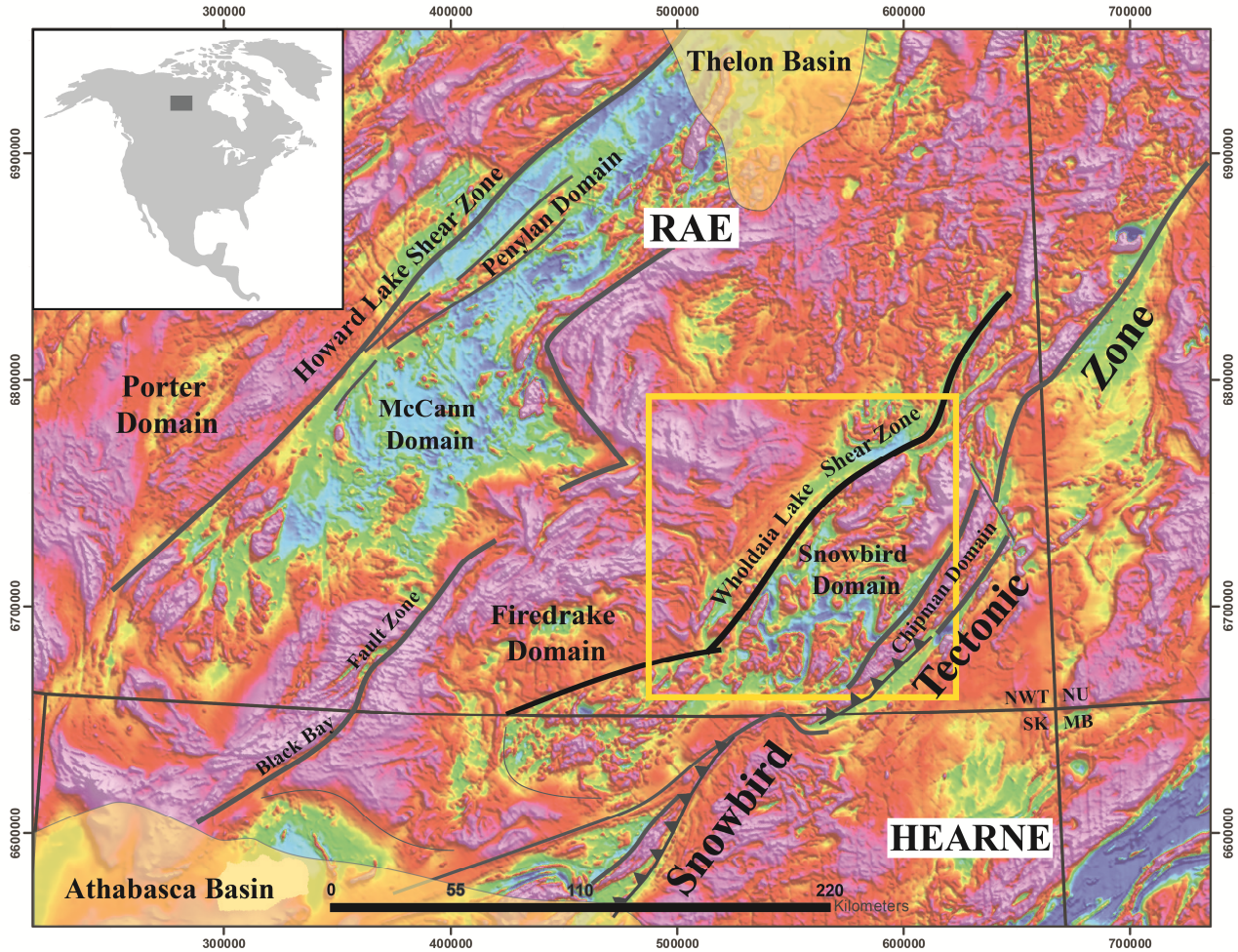

Figure 1. Total Field magnetic map of the south Rae craton illustrating major structures and lithotectonic domains from Davis et al. (2015). The yellow outline marks the location of Figure 2. Inset image is a location map within North America.

An overprinting package of penetratively transposed hornblende-biotite grade mylonites crosscut the higher-grade gneisses (Figure 2). These rocks are typically intermediate, yet mafic and felsic varieties also occur. This unit includes mm- to cm-scale rectilinear banded, highly sheared mylonites to ultramylonites striking northeast and dipping more steeply at ~85° to the southeast. Abundant dextral shear sense indicators and a low to moderate southwest-plunging stretching lineation occurs throughout this unit, which is interpreted to represent normal-oblique tops down to the southwest movement. A continuum from high-grade gneisses to low-grade mylonites is observed throughout the *WLsz*, however, the low-grade mylonite dominate the mapped extent of the shear zone. Numerous syn- to post-kinematic felsic dikes cut the low-grade mylonites. Six variably deformed dikes were sampled for geochronology to date their crystallization age and thus, minimum age of low-grade mylonitic shearing. U-Pb geochronological results presented in this report provides important timing constraints on the crustal-scale *WLsz* that is inferred to have accommodated significant exhumation in the Paleoproterozoic.

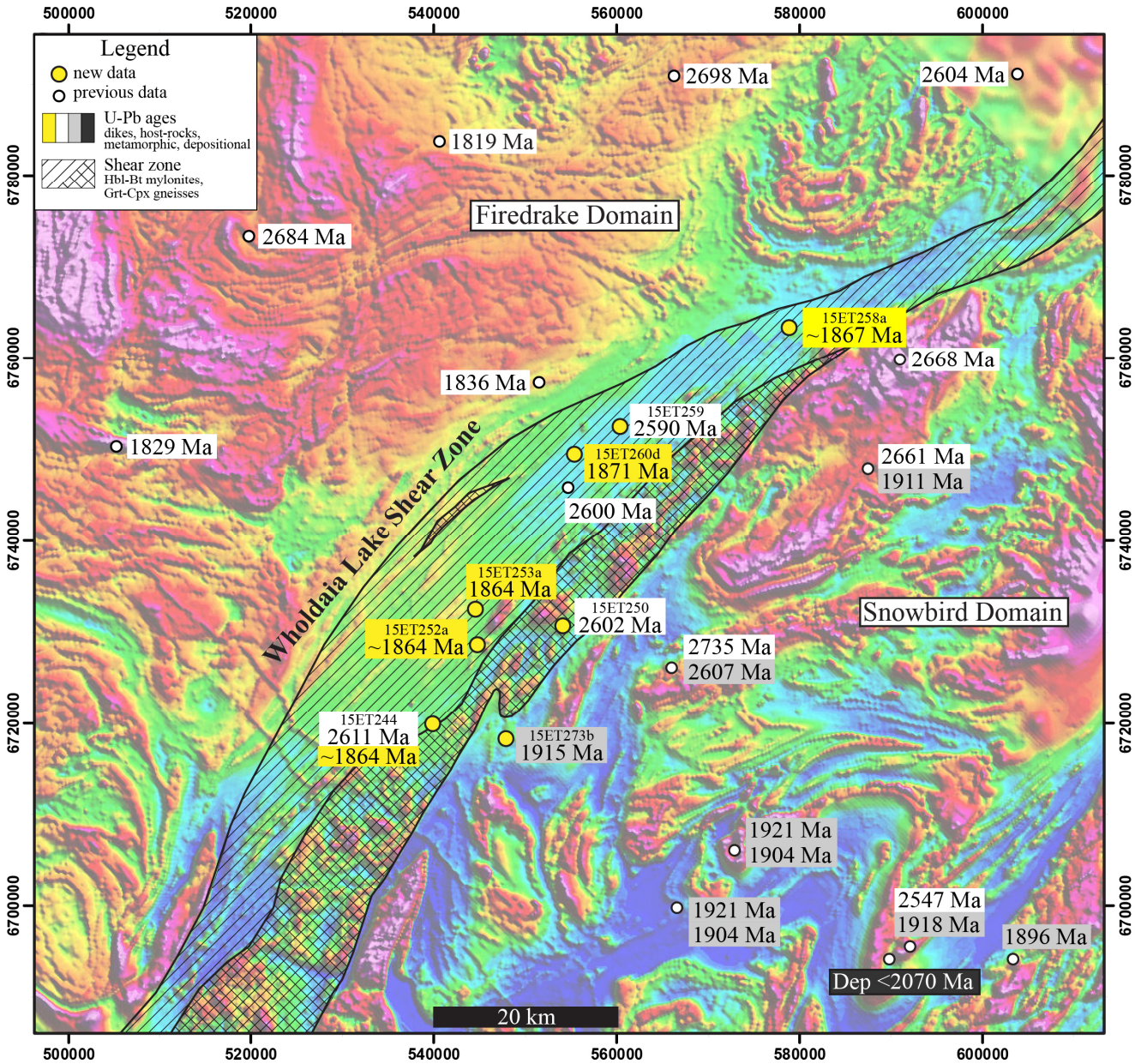

Figure 2. Total Field magnetic map of the Wholdaia Lake shear zone and bounding domains. Geochronology sample locations: yellow circles-this report; white circles Davis et al. (2015) and Martel et al. (2008).

Summary of results

Rock units selected for geochronology include 1) three variably deformed to mylonitic meta-plutonic host rocks within the *WLsz*, 2) one meta-sedimentary rock from the Snowbird domain, and 3) six weakly deformed granitic dikes that crosscut or are deformed within the northeast trending mylonites of the *WLsz*. A summary of the U-Pb results and age interpretation are in Table 1. A table containing all U-Pb analytical data is presented in an Appendix Excel data table.

Rock Type	Sample #	Metamorphic	Crystallization	Inherited
Amphibolite/metagabbro	15ET244b		2610.5 ± 4.0 Ma	
Metatonalite	15ET250		2601.9 ± 5.6 Ma	
Metagranite	15ET259	1.95, 1.87 Ga	2590.1 ± 9.1 Ma	
Meta-sedimentary rock	15ET273b	1915.4 ± 4.1 Ma		>1963 Ma
Granitic dike	15ET253a		1863.8 ± 2.3 Ma	~2.6 Ga
Granitic dike	15ET252a		~1.86 Ga	~2.6 Ga
Granitic dike	15ET244c		~1.86 Ga	~2.6 Ga
Granitic dike	15ET258a		~1867 Ma	~2.6 Ga
Alkali feldspar granite dike	15ET260d		1871.3 ± 5.0 Ma	~1930 Ma, ~2400 Ma
granite dike/leucosome	15ET260a			~2.4 Ga

Table 1. Summary of new U-Pb SHRIMP data from this study. Metamorphic, Igneous and Inherited refers to crystallization ages and groups of ages associated with each sample.

Zircon U-Pb isotopic data from the *WLsz* preserve a complex history of magmatism and tectonism from ca. 2700 Ma to ca. 1864 Ma. *WLsz* host rocks are characterized by Neoarchean crystallization ages (~ 2.6 Ga) with no clear evidence for magmatism or metamorphism at ca. 2550 documented more regionally (e.g. Martel et al., 2008). A cryptic event constrained at ca. 2350-2450 Ma appears to be preserved as inherited crystals in two dikes. These ages are usually restricted to the western margin of the Rae associated with Arrowsmith metamorphism (Berman et al., 2013). Host rocks and dikes record metamorphic zircon growth at ca. 1.93-1.95 Ga, and 1915 Ma in the hanging wall metasedimentary rocks.

New data presented herein provide important hard constraints on the minimum age of shearing along the *WLsz* at ~1864 Ma. Analyzed dikes have shared field relationships that crosscut mylonitic fabrics and contain weak internal deformation indicating they all post-date mylonite development. The preponderance of ~2600 Ma host rocks lead to significant zircon inheritance of this age in the younger igneous dikes. In four crosscutting dikes only inherited zircon occur, while only two dikes preserve unequivocal igneous crystallization ages of ~1860 Ma.

Our work shows the difficulty in obtaining meaningful crystallization ages from granitic dikes that may be zircon undersaturated, and highlights the importance of detailed imaging coupled with microbeam techniques (SHRIMP) in complex poly-deformed regions. Igneous zircon that allowed for accurate age determinations in dikes comprised high uranium crystals and were largely altered. The 2.6 Ga zircon that were commonly inherited as near unimodal populations were generally non-altered and have low to normal uranium values.

Analytical Methods

Samples were processed using standard crushing, grinding, Wilfley table, magnetic (Frantz™ isodynamic separator) and heavy-liquid separation techniques at Simon Fraser University. At the Geological Survey of Canada (GSC) in Ottawa, zircon crystals were hand-picked for quality and morphological variety (80-100 grains per sample) and then mounted in 2.5 cm diameter epoxy pucks with fragments of standard reference materials Z6266 (primary standard, $^{206}Pb/^{238}U$ age = 559 Ma) and Z1242 (secondary standard $^{207}Pb/^{206}Pb$ age = 2679.7 Ma). The mounts were polished to the midpoint using 9, 6 and 1 µm diamond compound to reveal internal features (zoning, alteration, cracks) using backscatter electron (BSE) images acquired using a Zeiss EVO 50 Scanning Electron Microscope (SEM). U–Pb geochronology was performed using the SHRIMP housed in the J.C. Roddick Ion Microprobe facility at the GSC, Ottawa. SHRIMP analytical procedures were followed as per Stern (1997), and Stern and Amelin (2003). The samples were analyzed on two mounts (IP796, IP800) in two separate analytical sessions. Analyses were conducted using an $^{16}O^-$ primary beam with a spot

size of ~20 µm. The data were collected in sets of six scans over 11 isotope masses of Zr, U, Pb, Th, Yb and Hf. A reference standard and secondary standard were generally analyzed every fifth analysis. Offline data processing was completed using SQUID2 (version 2.50.11.10.15, rev. 15 Oct 2011). A mass fractionation correction of 1.0029 was applied to the Pb isotopic data in samples Z11679 and Z11682. Common lead correction utilized the Pb composition of the surface blank (Stern, 1997). Specific analytical details for each sample are given in the footnotes of the Appendix data table. Isoplot v.4 (Ludwig, 2009) was used to generate concordia plots and to calculate regression ages and weighted ages. Error ellipses on the concordia plots and the weighted mean errors are reported in the text and figures at 95% confidence intervals.

Report of U-Pb Geochronology Results

Z-11693: Amphibolite/metagabbro

Sample	15ET244b
Coordinates	Zone 13 539854E 6719754N
Rock Type	Meta-plutonic
Age	2610.5 ± 4.0 Ma
Interpretation	Igneous crystallization

Geological Field relationships/ Rock Description

This sample is from within the WLsz at the boundary of a northeast trending highly linear magnetic domain to the west and a more mottled domain to the east (Figure 2). The outcrop is highly sheared and consists of metre-scale pyroxene-bearing amphibolite lozenges aligned northeast surrounded by northeast-trending anastomosing tonalite veins or leucosome (Figure 3A). The hand sample is dark green, medium grained (~1 mm) and crystalline with no apparent deformation fabrics. Non-foliated leucocratic material occurs sporadically within the mafic host. An interpretation of this unit as a mafic dike that intruded late in the strain history is precluded by field observations (large expanses of relatively homogenous outcrop with no dike margins observed) and abundance of zircon. Thin section analysis shows abundant plagioclase and hornblende after pyroxene suggesting a secondary origin for the hornblende and a possible gabbro protolith. Abundant interstitial alteration and retrogression is evident based on replacement of amphibole and pyroxene by biotite and chlorite.

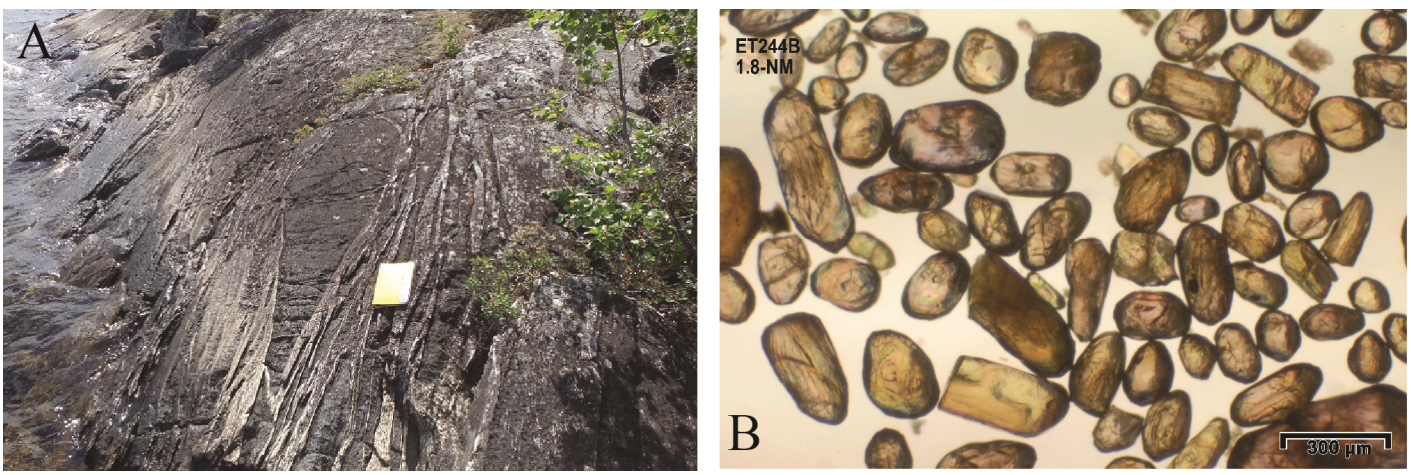

Figure 3. (A) Amphibolite lozenges enveloped by cm-scale tonalite veins (notebook = 20 cm long), (B) zircon separates.

Zircon Description

Zircon crystals are of poor to fair quality being light brown to brown and variable clarity (Figure 3B). Crystals occur as stubby and rounded grains to subhedral prismatic grains with a ~3:1 aspect ratio (a.r.). BSE imaging shows homogenous to weak, thin oscillatory zoning (Figure 4).

Results/Interpretation

Analysis of 25 homogenous to weakly oscillatory zoned zircon yield 29 mostly concordant $^{207}Pb/^{206}Pb$ dates between 2631-2450 Ma. All 29 dates were indistinguishable by zoning, morphology and chemistry. Th/U ratios are homogeneous with values between 0.1-1.0 and Hf/Yb values below 100 similar to normal igneous values. The 17 oldest analyses yield a $^{207}Pb/^{206}Pb$ age of 2610.5 ± 4.0 Ma (MSWD = 2.9, Figure 4). The excess scatter in the data indicates more geological complexity than the reported single age event at 2610.5 ± 4.0 Ma. Three replicate analyses of two young grains (#24.1 and #53.1, < 2600 Ma) yielded older ages suggesting that these

analyses underwent some degree of Pb-loss and were therefore excluded from the calculation. We suggest 2610.5 ± 4.0 as a minimum estimate of igneous crystallization of this sample.

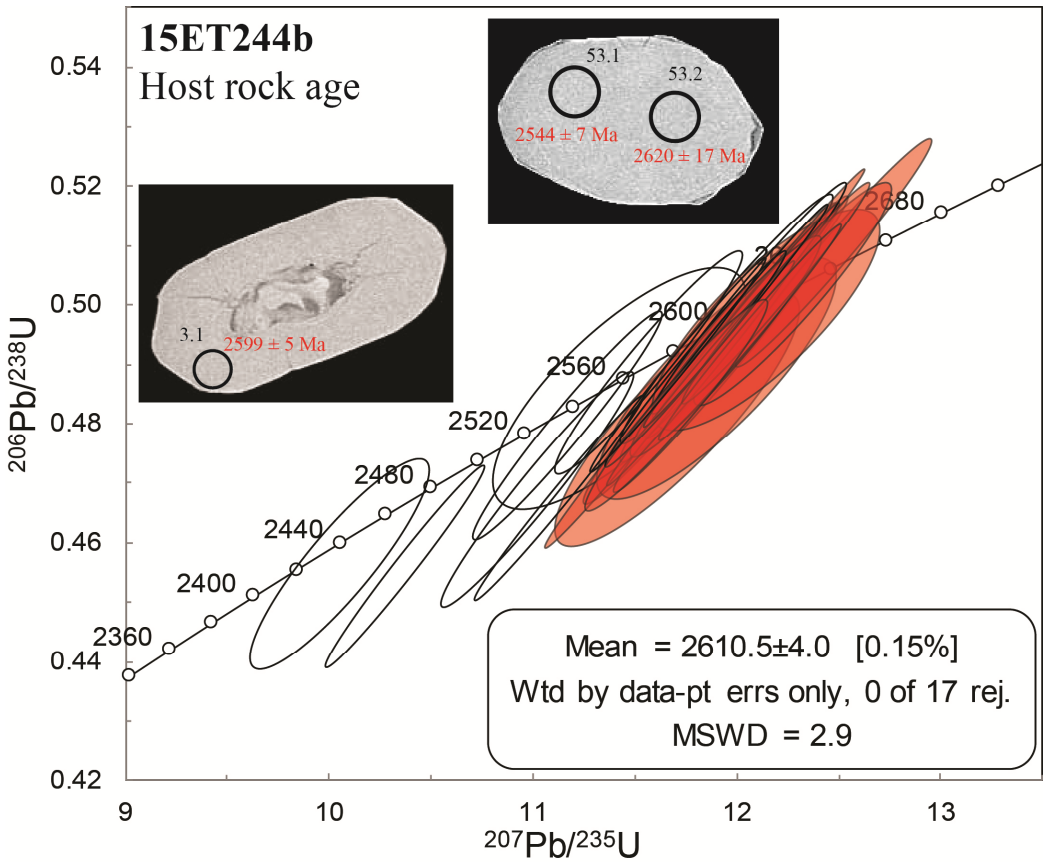

Figure 4. Concordia diagram; filled ellipses represent data used for weighted mean calculation. Inset BSE images show representative spot analyses (black circle ~20 µm diameter) and corresponding dates (1σ, red).

Z-11694: Metatonalite

Sample	15ET250b
Coordinates	Zone 13 554082E 6730673N
Rock Type	Meta-plutonic
Age 1	2601.9 ± 5.6 Ma
Interpretation	Igneous crystallization

Geological Field relationships/Rock Description

This metatonalite occurs within weakly linear and mottled magnetic patterns at the eastern margin of the *WLsz*. Hand sample is buff coloured with elongate quartz ribbons (4:1 a.r.) and minor scattered mm-scale garnet porphyroblasts retrogressed largely to chlorite and minor biotite. Quartz and plagioclase define compositional banding in the rock and have a coarse texture with serrated margins and subgrain formation at interstices. Overall the deformation within this sample has not been completely overprinted by shear zone transposition fabrics.

Zircon Description

Zircon crystals are poor to fair quality ranging from clear to dark brown (Figure 5). Generally the darker brown zircon appear stubby to round and are ~0.1 mm in diameter. Clearer zircon crystals are more prismatic

with 3:1 a.r. crystals and some euhedral prism faces. BSE image shows homogeneous to faint oscillatory zoning (Figure 6 inset). A small population of zircon grains shows distinct core-rim relationships with oscillatory zoned cores. Some zircon display alteration parallel to crystal faces highlighting otherwise unobserved crystal zoning.

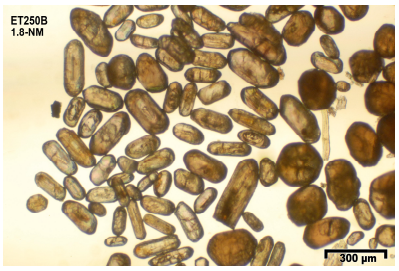

Figure 5. Image of zircon crystals prior to mounting.

Results/Interpretation

Analyses of 30 homogeneous to weakly oscillatory zoned zircon crystals and oscillatory zoned cores yielded 34 concordant ages between 2774-2423 Ma. The chemistries of all analyses are similar with the exception of the oldest 5 analyses corresponding to the cores, that have variable and low Hf/Yb values below 100. A population of 16 homogenous and oscillatory zoned zircon yield a weighted mean $^{207}Pb/^{206}Pb$ age of 2601.9 ± 5.6 Ma (MSWD = 4.5, Figure 6). The oldest 5 analyses were excluded due to their differing chemistry and older ages. The excess scatter in the age calculation and the younger analyses are interpreted to reflect variable Pb-loss at Paleoproterozoic times from igneous zircon crystallization based on the irreproducibility of younger grains (e.g. #94). Therefore 2601.9 ± 5.6 Ma is interpreted as a minimum age for igneous crystallization of the metatonalite.

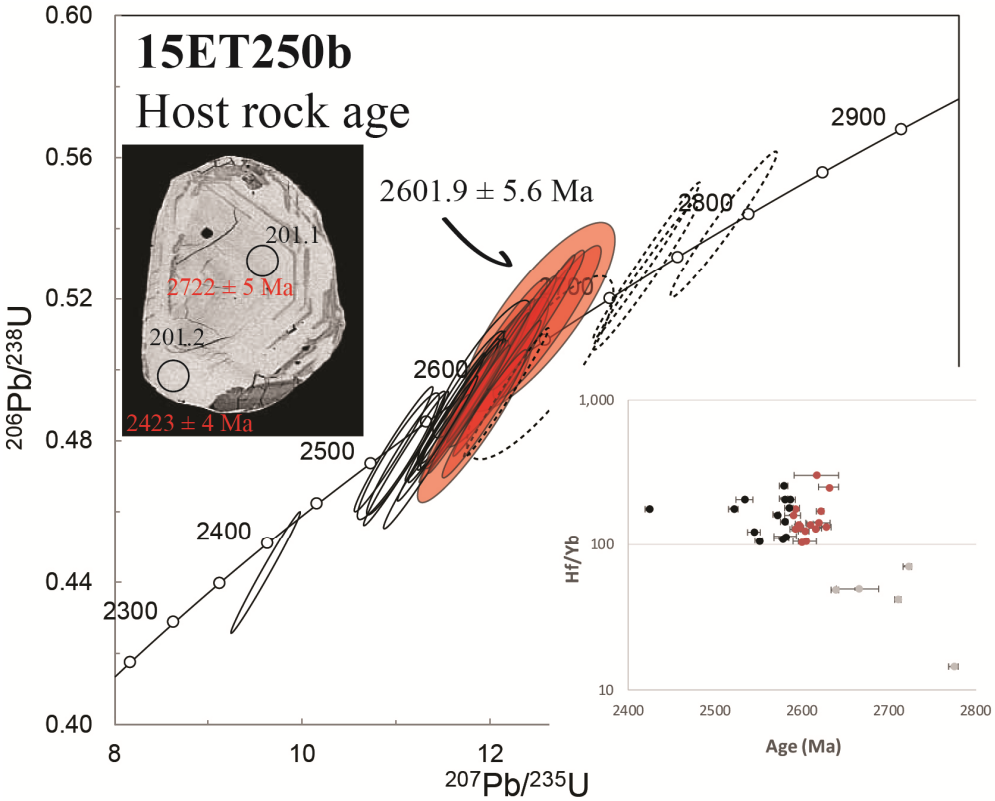

Figure 6. Concordia diagram; filled ellipses represent data used for weighted mean calculation and dashed ellipses are inherited grains. Inset BSE image shows representative spot analyses (black circle ~20 µm diameter) on core and rim domains and corresponding dates (1σ, red). Inset graph shows Hf/Yb differences between the inherited zircon (grey points) and zircon used for weighted mean calculation (red points); black points were excluded form the weighted mean.

Z-11681: Metagranite

Sample	15ET259
Coordinates	Zone 13 560407E 6752500N
Rock Type	Meta-plutonic
Age 1	2590.1 ± 9.1 Ma
Interpretation	Igneous crystallization
Age 2	1.95 Ga
Interpretation	Metamorphic

Geological Field relationships/Rock Description

Sample 15ET259 occurs at the northern reaches of Wholdaia Lake, outcropping as a topographic high. This unit resides within a linear and streaky low magnetic domain along strike and in between mylonite localities 15ET258a and 15ET253a (discussed below, Figure 2); it is interpreted to occur within a more retrogressed portion of the shear zone. A compositionally banded shear fabric contains a foliation parallel with the rest of the *WLsz*. This sample has a medium grained granitic composition with prominent quartz ribbons (3:1 a.r.) and a well banded foliation. Strain is heterogeneously partitioned at the outcrop scale where certain portions have ductile intrafolial folds (Figure 7A) and streaky quartz ribbons, and other portions are weakly foliated to isotropic with the same composition. Thin section analyses reveal weak compositional bands consisting of coarse plagioclase-K-feldspar and quartz ribbons with minor biotite and chloritized garnets.

Zircon Description

The zircon crystals are generally poor quality, large, subhedral to prismatic with 4:1 a.r. and brown to light brown (Figure 7B). BSE imaging reveals whole zircon or cores with thin faint oscillatory zoning and homogenous rim domains (Figure 7C-D).

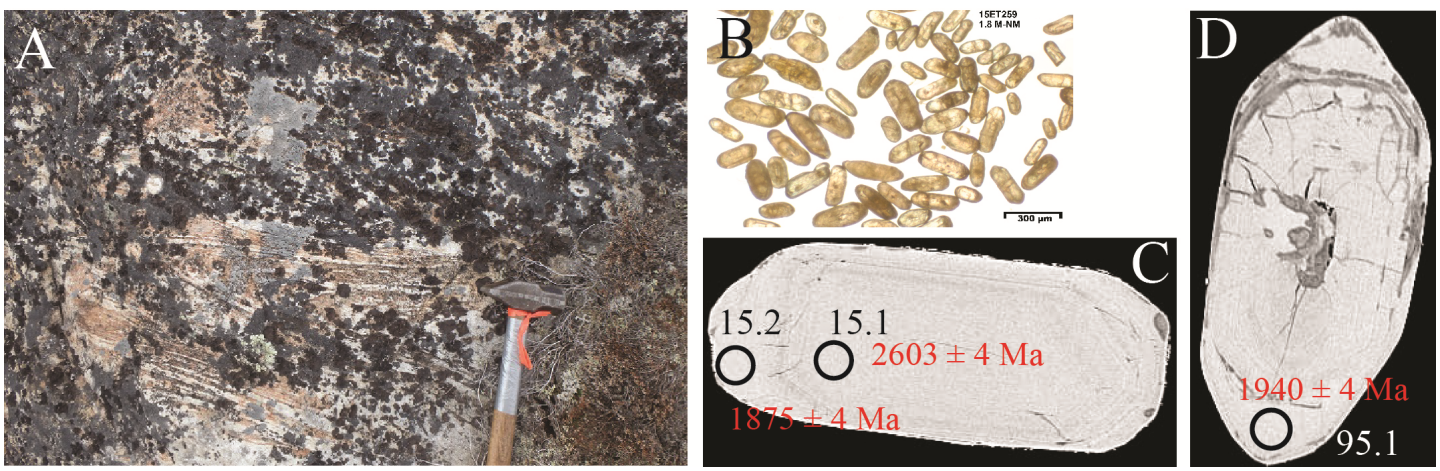

Figure 7. (A) Folded granitic gneiss nearby where sample 15ET259 was taken, (B) zircon separates, (C-D) representative spot analyses (black ~20 µm diameter) and corresponding dates (1σ, red).

Results/Interpretation

Analysis of 29 oscillatory zoned to homogenous zircon cores and rims yielded 33 mostly concordant dates between 2603-1875 Ma (Figure 8). The oldest 25 analyses are from faint oscillatory zoned zircon and homogenous zircon cores that have Th/U values between 0.1-1.0 (except for one analysis lower than 0.1) and Hf/Yb values less than 100 typical of igneous zircon. The ten oldest analyses (red ellipses of Figure 8) of oscillatory and homogenous zircon cores yield a $^{207}Pb/^{206}Pb$ weighted mean age of 2590.1 ± 9.1 Ma (MSWD = 3.8). The 15 younger analyses are interpreted to reflect partial lead-loss during metamorphic recrystallization (as suggested by replicates on younger grains, e.g. #47) and thus, were excluded from the mean.

The youngest 8 analyses are from homogenous rim domains that have Th/U values below ~0.1 and Hf/Yb values above ~100. These comprise two young age groupings that are mostly concordant dates between 1924-1875 Ma. The 4 oldest analyses (of the youngest 8) yield a $^{207}Pb/^{206}Pb$ weighted mean age of 1950 ± 11 Ma (MSWD = 3.8, green ellipses Figure 8), interpreted as the age of metamorphism of the sample. This age was not reproduced by a replicate analysis on one of these zircon grains (#18), which yielded a younger result (1921±5 Ma, 1σ) suggesting some degree of Pb-loss. This younger analysis (18.1) was excluded from the mean age. A second small cluster consists of 3 analyses (blue ellipses of Figure 8) homogenous rim domains with Th/U below 0.1 and Hf/Yb above 100, similar to the older group. A $^{207}Pb/^{206}Pb$ weighted mean age of 1876 ± 5.7 Ma (MSWD = 0.38) for these three analyses are within error of dike emplacement locally (see sample 15ET253a, 15ET260d). This youngest age group may reflect Pb-loss from the 1950 Ma population or be a discrete metamorphic or metasomatic event related to the emplacement of dikes at ca. 1.87 Ga.

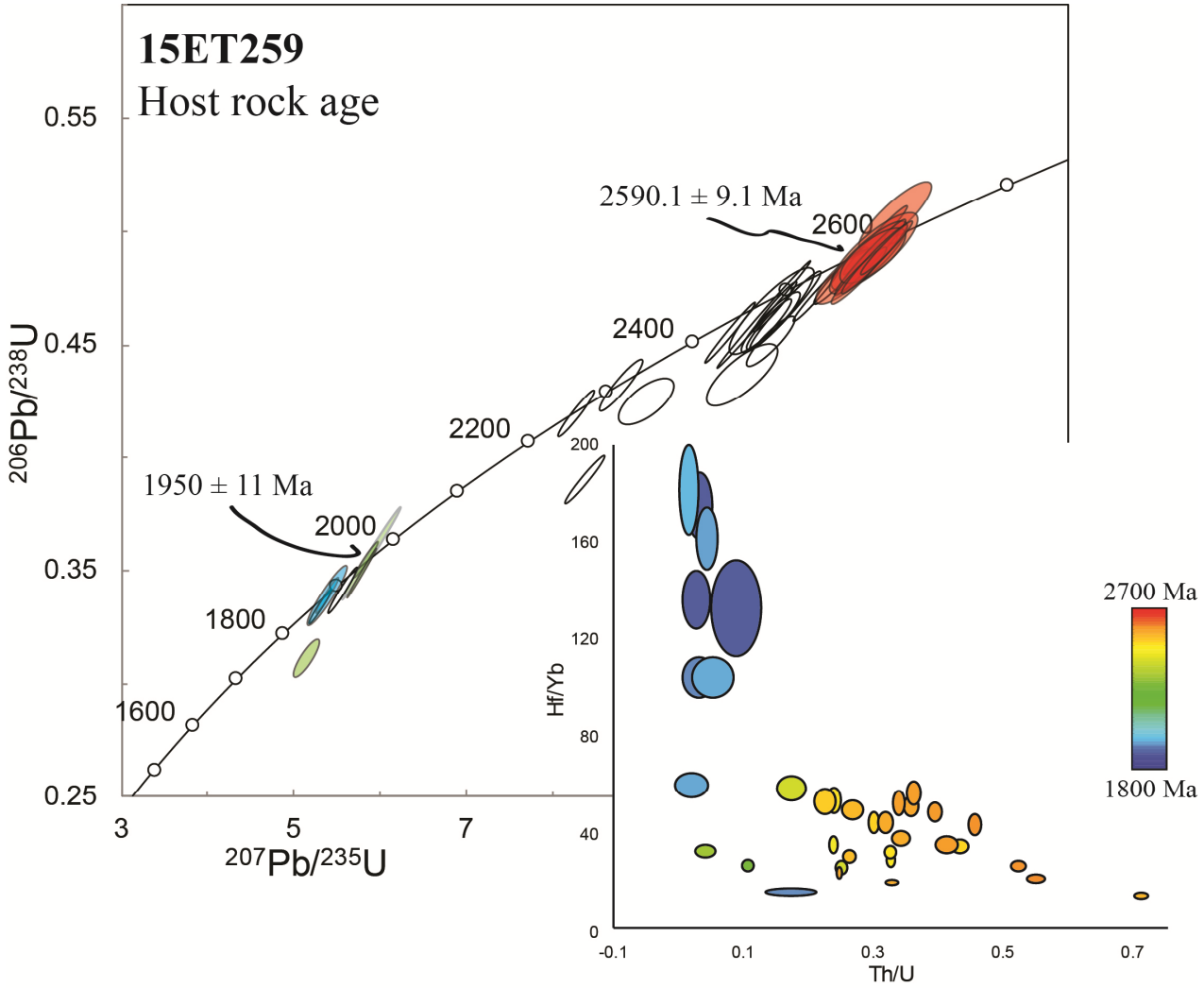

Figure 8. Concordia diagram; filled ellipses represent data populations used for weighted mean calculations. Inset plot shows Hf/Yb vs Th/U with colour coded ages per analysis. Inset ellipses display the Th/U relative error and the Hf/Yb absolute error.

Z-11696: Diatexite (metasedimentary)

Sample	15ET273b
Coordinates	Zone 13 547895E 6718125N
Rock Type	Metasedimentary
Age 1	1915.4 ± 4.1 Ma
Interpretation	Metamorphic
Age 2	>1963 Ma
Interpretation	Detrital

Geological Field relationships/Rock Description

This sample occurs east of the *WLsz* on the western margin of the Snowbird domain within a magnetic low characterized by regional Type 2 fold interference patterns (Figure 2). Eastward within the Snowbird domain this curvilinear magnetic low corresponds with other metasedimentary packages (Martel et al., 2008). The diatexite contains sillimanite-garnet-quartz-K-feldspar-biotite-rutile. Garnet comprises 40-50% of the sample with abundant sillimanite and quartz defining the dominant foliation. The rock is fairly homogenous at the outcrop scale (Figure 9A) with the exception of cm-scale elongate leucocratic pods.

Zircon Description

The zircon crystals are largely equant and rounded and vary from brown to almost clear (Figure 9B). BSE imaging shows mostly homogeneous rounded zircon (Figure 9C-D) with rare oscillatory zoned resorbed cores (Figure 9C). The dominant population of zircon include rounded, homogenous single zircon grains and homogenous overgrowths.

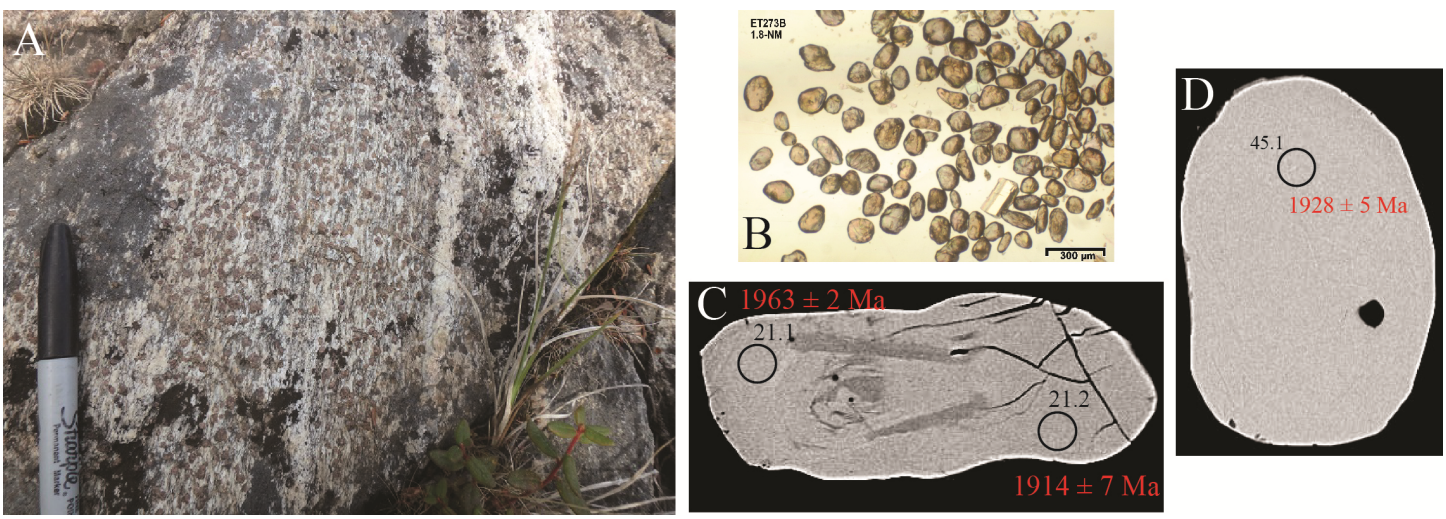

Figure 9. (A) Sample 15ET273b outcrop exposure with pen for scale, (B) zircon separates, (C-D) representative spot analyses (black circles ~20 µm diameter) and corresponding dates (1σ, red).

Results/Interpretation

Analyses of 26 zircon grains, comprising both homogenous and oscillatory zoned material and both cores and rims yield 30 dates between 2304-1888 Ma. Analyses were focused on unzoned grains and overgrowths inferred to be metamorphic since constraining the maximum depositional age of the metasedimentary rock was not a priority for this study. The five oldest analyses span 2304-1963 Ma and consist of faintly oscillatory zoned zircon cores with variable Th/U values > 0.2 and low Hf/Yb values ranging between ~30–90.

Homogenous spherical grains and homogenous overgrowths on oscillatory zoned cores yielded 25 analyses ranging between 1937-1888 Ma. This younger population has Th/U values below 0.1 (with homogenous U at

400-650 ppm) and Hf/Yb above 100 and comprise a tightly clustered mostly concordant group. Twenty-three of the twenty-five analyses, have overlapping concordant dates with a weighted mean $^{207}Pb/^{206}Pb$ age of 1915.4 ± 4.1 Ma (MSWD = 2.7, Figure 10). The oldest and youngest dates were excluded because these analyses have anomalously high U values >1000 ppm and lower Yb contents compared to the 23 analyses used to calculate the mean age.

The low Th/U and high Hf/Yb values are indicative of metamorphic crystallization in a Yb depleted environment. The abundance of garnet in the sample (a strong HREE sink) suggests the 1915 Ma zircon age may reflect post-garnet crystallization of zircon. The oldest 5 oscillatory zoned zircon cores are interpreted to be detrital in origin.

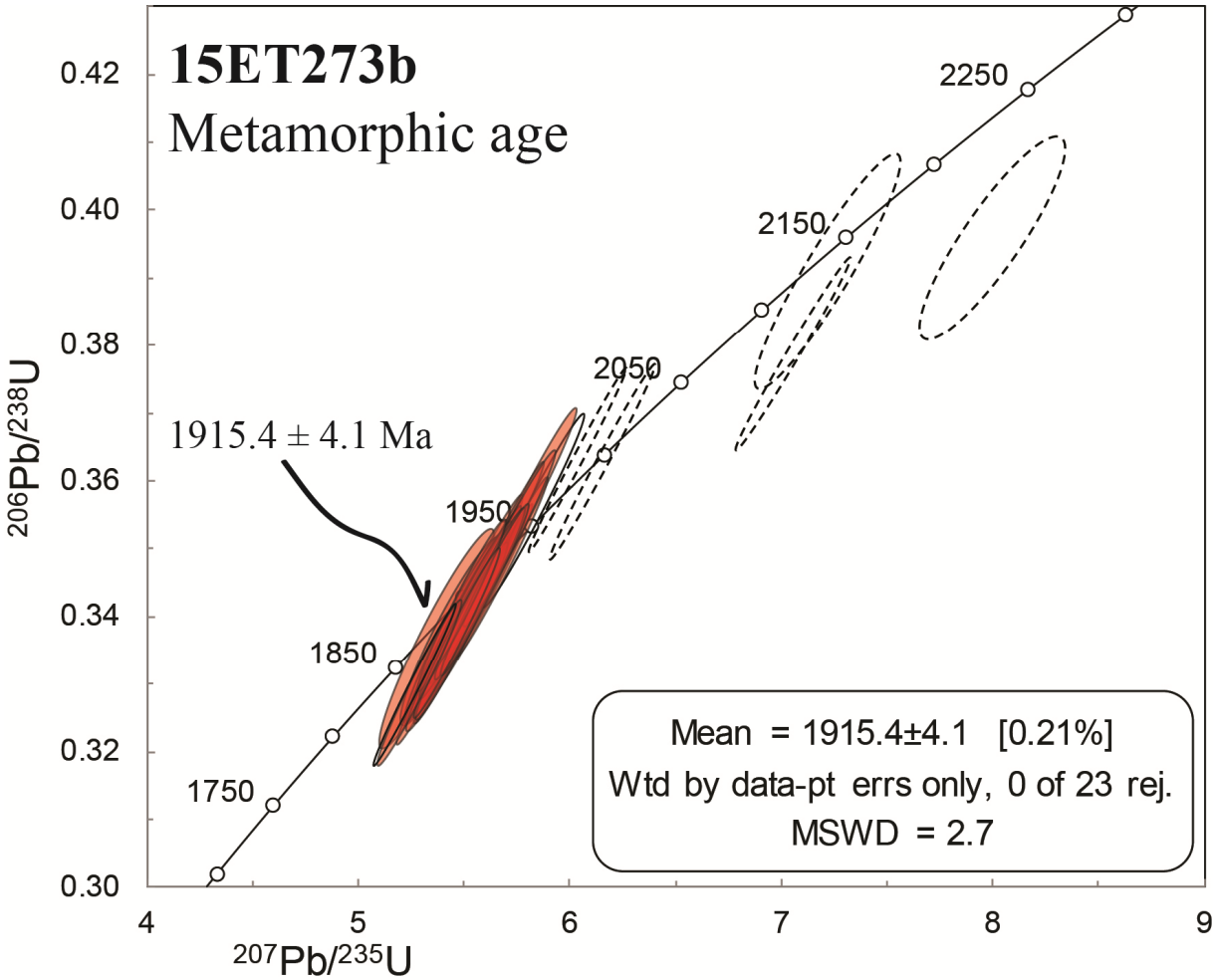

Figure 10. Concordia diagram; filled ellipses represent data used for weighted mean calculation, dashed ellipses are detrital analyses.

Z-11679: Granitic dike

Sample	15ET253a
Coordinates	Zone 13 544510E 6732621N
Rock Type	Igneous
Age 1	1863.8 ± 2.3 Ma
Interpretation	Igneous crystallization
Age 2	~2.6 Ga
Interpretation	Inherited

Geological Field relationships/Rock Description

Sample 15ET253a is a 50 cm wide leucocratic dike that crosscuts the mylonitic fabric in the central *WLsz* (Figure 11A, B). This unit occurs in the lower-grade (biotite-hornblende) portion of the *WLsz* where a low, streaky northeast trending magnetic signature occurs (Figure 2). The dikes are variably deformed, locally folded with attenuated limbs. The dike sample is granitic to granodioritic in composition and has a weak foliation manifested as elongated feldspar and quartz aggregates. Feldspar crystals have well developed albite, carlsbad and tartan twins with serrated margins indicating minimal deformation of igneous crystals compared to the mylonitic host rock. Quartz crystals have well developed chessboard extinction and minor garnet occurs throughout suggesting intrusion at high temperatures in the garnet stability field.

Zircon Description

Zircon crystals from this sample are typically poor in quality, irregular to subhedral and brown (Figure 11C). Only 64 zircon crystals were recovered from a large sample (~5 Kg) indicating low zircon fertility for this particular melt phase. BSE imaging reveals mostly altered, yet prismatic and oscillatory zoned crystals, as well as larger less altered homogenous blocky subhedral crystals (Figure 12).

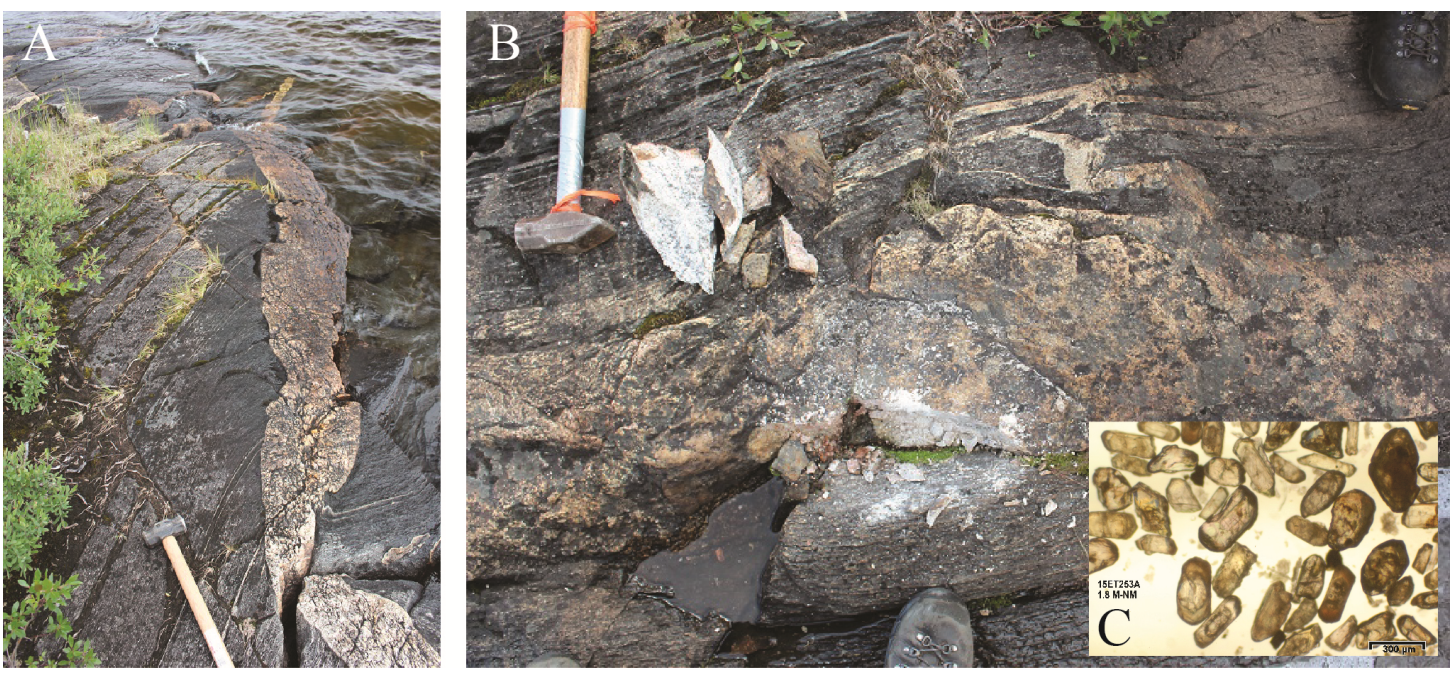

Figure 11. (A) Dike crosscuts mylonitic host rocks, hammer is 1.3 m long, (B) sampled portion dike with boot for scale, (C) zircon separates.

Results/Interpretation

Twenty-two analyses were conducted on 20 separate zircon grains. The results fall into two age clusters, one at ~2.60 Ga and one at ~1.86 Ga. The older zircon cluster consists of blocky to prismatic homogenous to

weakly oscillatory zoned zircon. This group yields dates between 2628-2595 Ma and is characterized by homogeneous Th/U values between 0.1-1.0 and Hf/Yb values between 34-128. The younger population consists of prismatic zircon with wide oscillatory zoning and has Th/U values between 0.01-0.1 and Hf/Yb values between 10-100 and U values of 819-4228 ppm. A weighted mean of all 13 old analyses yields a $^{207}Pb/^{206}Pb$ age of 2610.9 ± 5.0 Ma (MSWD = 4.2). The younger, mostly concordant population of 9 prismatic oscillatory zoned zircon yield a weighted mean $^{207}Pb/^{206}Pb$ age of 1863.8 ± 2.3 Ma (MSWD = 0.40, Figure 12). The two age populations allow two different data interpretation: either an Archean crystallization age and a later Paleoproterozoic reworking or an old inherited component in a 1.86 Ga granitic intrusion. The low Th/U values associated with the young population is likely due to anomalously high U concentrations, which is not typical of metamorphic zircon (Hoskin and Schaltegger, 2003). Additionally these young zircon have well defined oscillatory zones within prismatic crystals indicative of magmatic crystallization. Together, we interpret the 1863 Ma population to record the igneous crystallization age of the dike and the 2.6 Ga zircon to represent an inherited population. The age of 1863 Ma provides a minimum age on shearing within the *WLsz*.

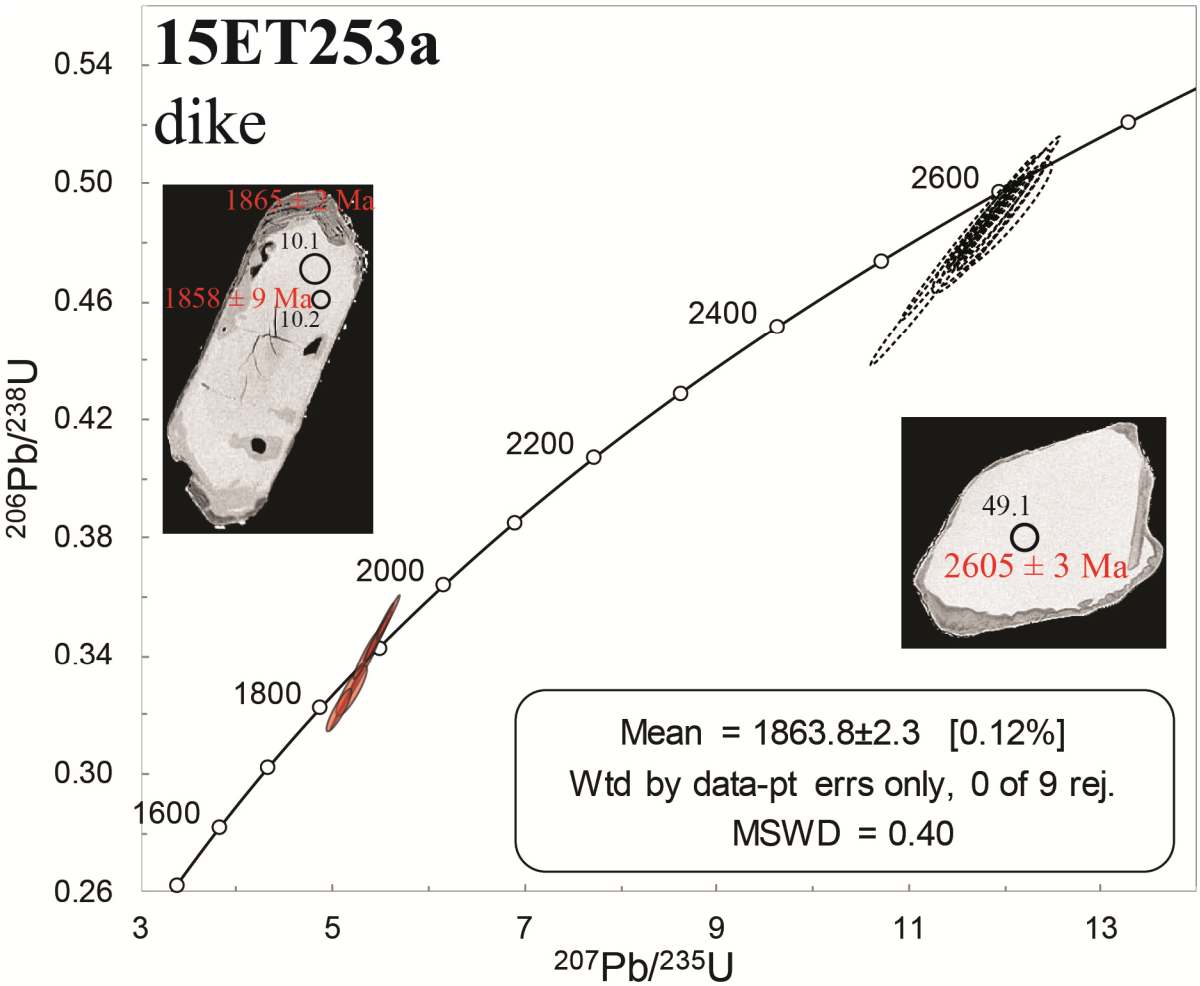

Figure 12. Concordia diagram; filled ellipses represent data population used for weighted mean calculation, dashed ellipses are inherited grains. BSE zircon insets show representative spot analyses (black circles ~20 µm diameter, spot 10.2=10 µm) and corresponding dates (1σ, red).

Z-11678: Granitic dike

Sample	15ET252a
Coordinates	Zone 13 544767E 6728679N
Rock Type	Igneous
Age 1	~1.86 Ga
Interpretation	Igneous crystallization
Age 2	~2.6 Ga
Interpretation	Inherited

Geological Field relationships/Rock Description

Sample 15ET252a occurs ~5km to the east of 15ET253a (Figure 2), yet it has the same field relations. The sample is from an attenuated limb of a folded granitic dike ~20 cm wide that crosscuts penetratively mylonitized intermediate host rocks (Figure 13A) in the central portion of the WLsz. The sample is a coarse-grained to pegmatitic K-feldspar granite (Figure 13B) with large weakly deformed megacrysts of K-feldspar, plagioclase and quartz with serrated margins and weak subgrain formation.

Zircon Description

Zircon crystals are of poor quality and elongate to blocky, broken and brown to light-brown in colour. BSE imaging shows that the zircon are mostly homogeneous with some faint oscillatory zoning (Figure 14). Minor thin homogenous rims are also observed, but most were too small to analyze with the 20 µm spot.

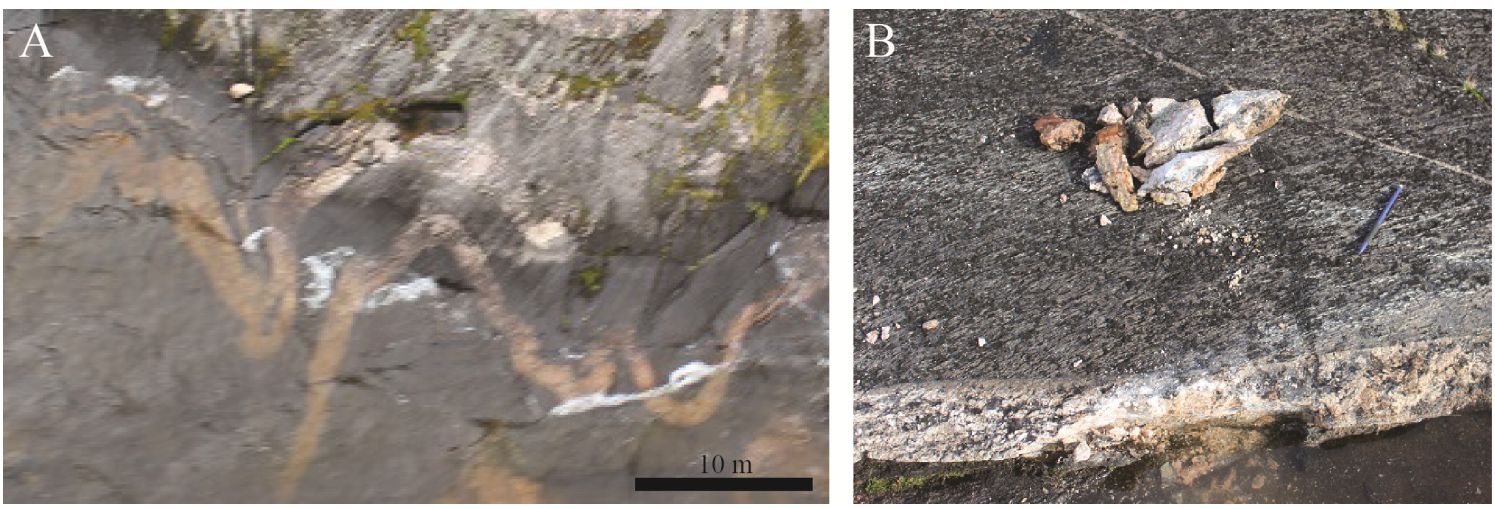

Figure 13. (A) Sample 15ET252a outcrop from air, (B) sampled dike with north pointing pencil for scale.

Results/Interpretation

Seventeen analysis were conducted on 16 homogenous to weakly oscillatory zoned zircon that were elongate to blocky in morphology. Dates range from 2628-2142 Ma with a general trend of increasing discordance with younger analyses. With exception of the youngest analysis, the data comprise homogenous Th/U values between 0.1-1.0 and Hf/Yb values below 100. The oldest 4 analyses of homogenous zircon grains define a concordant cluster that yield a weighted mean $^{207}Pb/^{206}Pb$ age of 2619.5 ± 9.9 Ma (MSWD = 1.4). The younger data lie along a discordia line. A linear regression of the data (excluding the youngest analysis) defines an upper intercept at 2662 ± 46 Ma (MSWD = 1.5, Figure 14) and a poorly defined lower intercept in the Paleoproterozoic (1946 ± 180 Ma). The youngest analysis was excluded from the linear regression due to its anomalously low Yb value of 78 ppm compared to the 16 older analyses that have 134-363 ppm Yb.

The ~2620 Ma date is consistent with ages of host-rock crystallization documented in samples 15ET244b, 15ET250, 15ET259 and in Martel et al. (2008) and Davis et al. (2015). The field relations of this sample

(15ET252a) is identical to 15ET253a, which is interpreted to have crystallized at ~1863 Ma with a 2.6 Ga inherited population. Therefore, we interpret the 2.6 Ga zircon population to represent inherited zircon and that the true igneous crystallization age is not represented by any analyzed zircon but is likely 1.86 Ga. Perhaps this samples composition was too zircon undersaturated to precipitate new zircon at the time of crystallization (Boehnke et al., 2013), or we failed to hand-pick and/or analyze igneous zircon. The lower intercept of the discordia is not well constrained, but may coincide with the Paleoproterozoic post-igneous intrusion of the dikes.

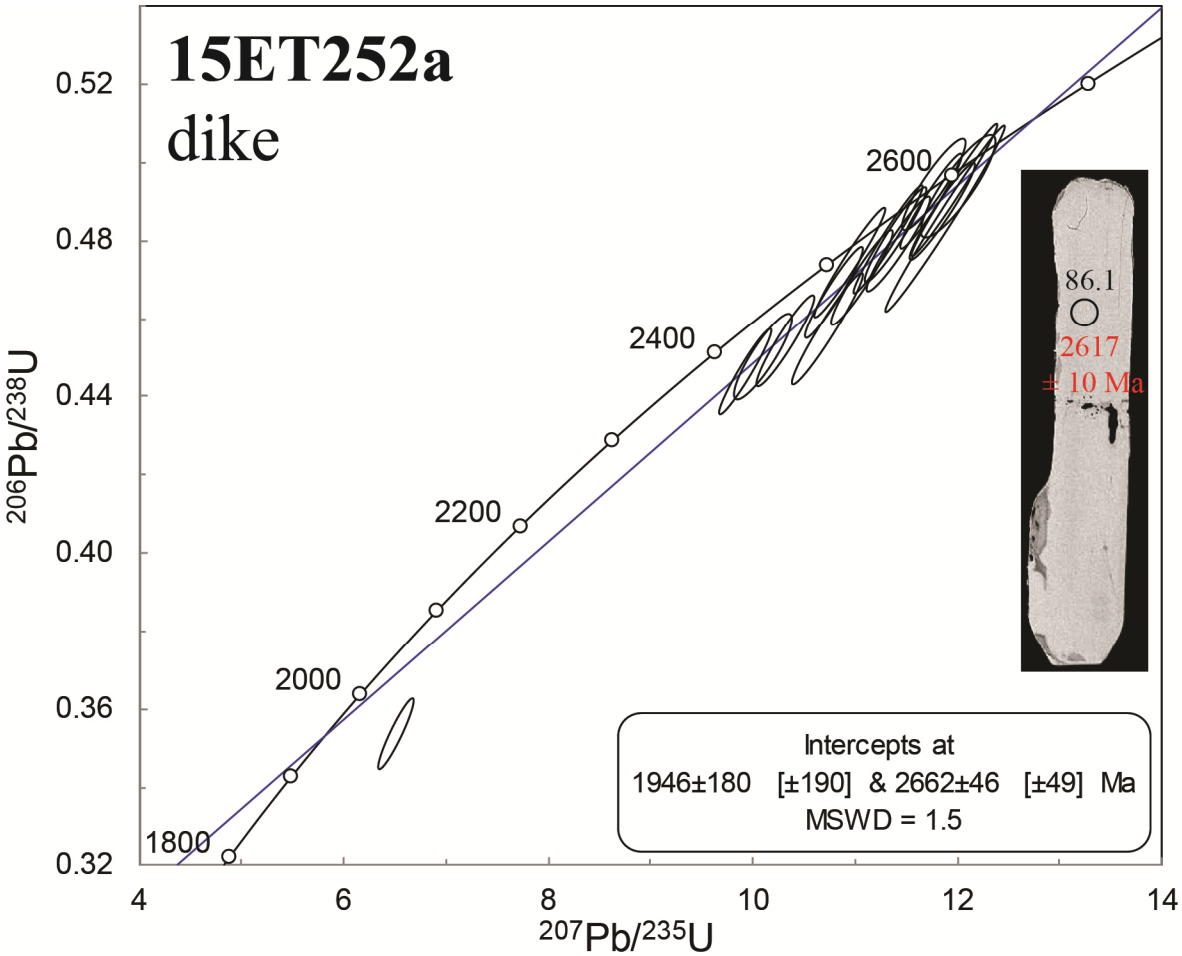

Figure 14. Concordia diagram showing linear regression through all but youngest analysis. BSE zircon inset shows a representative analysis (black circle ~20 µm diameter) and corresponding date in red (1σ).

Z-11677: Granitic dike

Sample	15ET244c
Coordinates	Zone 13 539838E 6719682N
Rock Type	Igneous
Age 1	~1.86 Ga
Interpretation	Igneous crystallization
Age 2	~2.6 Ga
Interpretation	Inherited

Geological Field relationships/Rock Description

This sample comes from the boundary of a northeast trending highly linear magnetic domain to the west and a more mottled domain (Figure 2). This 15 cm dike cuts ~2610 Ma sheared host rocks described and analyzed from sample 15ET244b. A compositional banding foliation is oriented 028°/77° and has a shallow SW-plunging stretching lineation (14°-212°) at the contact between the leucocratic veins and host amphibolite.

Zircon Description

Zircon crystals are brown to light brown and vary from blocky to subhedral prisms (4:1 a.r.). Generally they are of poor to fair quality (Figure 15). BSE imaging shows largely homogenous to weakly oscillatory zoned crystals with subordinate homogenous rims (Figure 16). Many crystals have highly altered core domains that were not amenable for analysis.

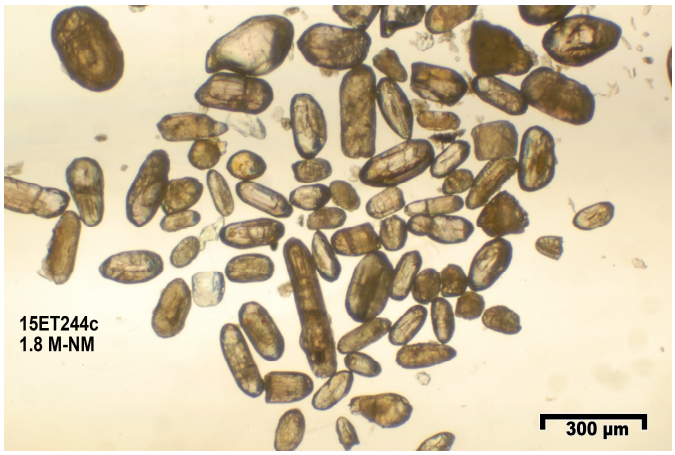

Figure 15. Zircon crystals prior to mounting.

Results/Interpretation

Twenty-two analyses of 22 zircon crystals yielded concordant and discordant dates (Figure 16) between 2650-2386 Ma. All analyses are from homogenous to weakly oscillatory zoned zircon with Th/U between 0.1-1.0 and Hf/Yb below 100. A free linear regression of the data yield an upper intercept age of 2582 ± 33 and a poorly constrained lower intercept at 1643 ± 270 Ma (MSWD = 4.5). The roughly linear discordia array suggests these analyses have been affected by Pb-loss, therefore the ~2600-2580 Ma age is interpreted as a minimum age for this population.

Similar to sample 15ET252a, simple interpretation of igneous crystallization at 2582 Ma is precluded by the similarity in field relationships as sample 15ET253a (1863 Ma) and the abundance of 2.6 Ga host rocks locally. We interpret that the zircon analyzed in this sample are inherited. The true age of igneous crystallization for this dike is unknown, but we suggest it is probably ca. 1.86 Ga.

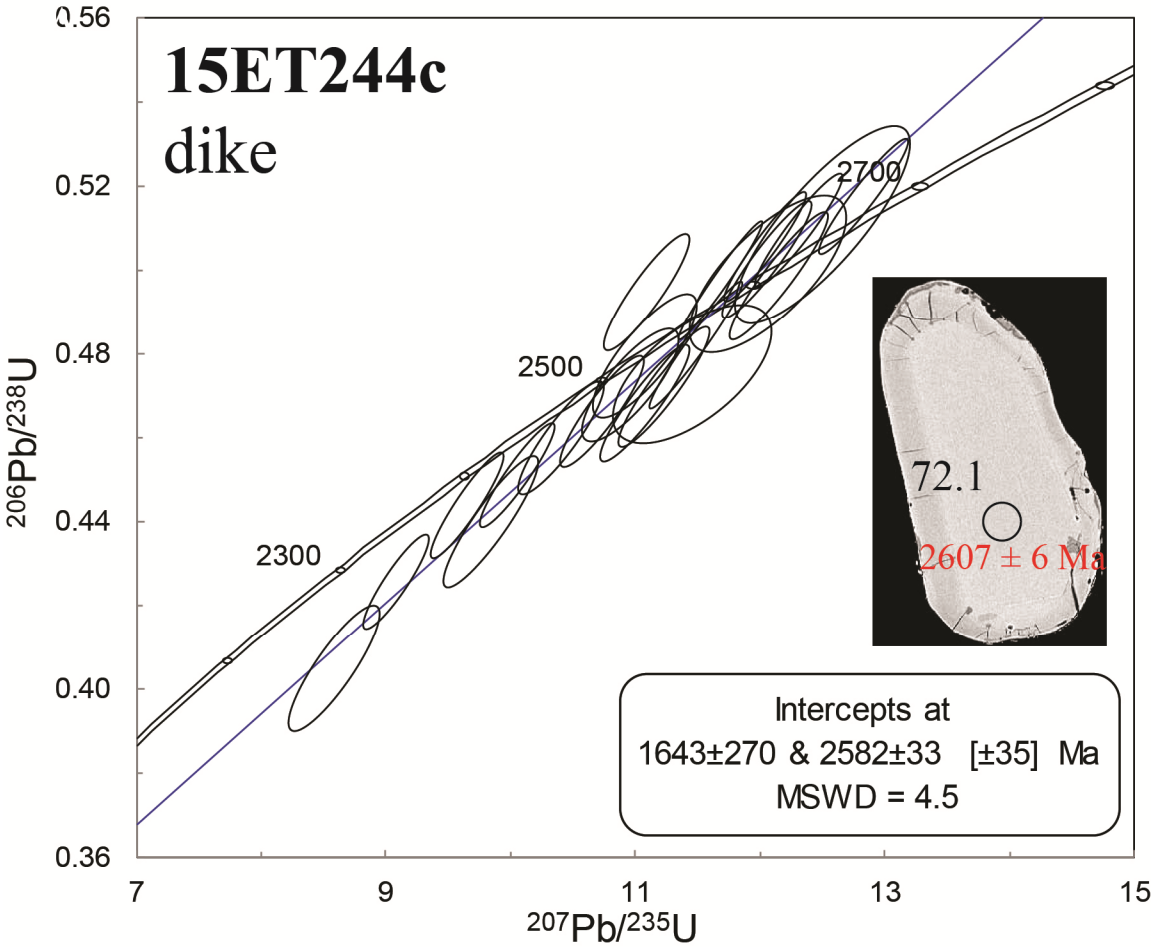

Figure 16. Concordia diagram showing linear regression through the data. Inset displays BSE image of representative zoning of zircon in this sample (black circle ~20 µm diameter) and corresponding date of analysis (1σ, red).

Z-11680: Granitic dike

Sample	15ET258a
Coordinates	Zone 13 578788E 6763444N
Rock Type	Igneous
Age 1	~1867 Ma
Interpretation	Igneous crystallization
Age 2	~2.6 Ga
Interpretation	Inherited

Geological Field relationships/Rock Description

This sample occurs within a region that comprises a low magnetic signature with a dominant northeast trending linear pattern which coincides with mylonitic rocks along strike. The 1 m wide dike crosscuts northeast striking mylonitic foliations at a low angle (Figure 17). This sample is a fine- to medium-grained granitic dike with minor euhedral pink garnet crystals. The dextral shear-sense in the mylonitic host is also present in the dike which exhibits a protomylonitic dextral shear fabric.

Zircon Description

Zircon crystals in this sample are typically brown and elongate (3:1 a.r.) and of poor to fair quality. Overall, very few zircon crystals were collected from this sample. BSE imaging revealed prismatic/elongate and blocky

oscillatory zoned and homogenous zircon of fair quality (Figure 18) and homogenous to oscillatory zoned overgrowths. Many of these zircon crystals are highly altered and were not amenable for analysis.

Figure 17. Granitic dike 15ET258a crosscutting mylonitic host rocks at a low angle.

Results/Interpretation

Twenty-seven analyses were conducted on 24 zircon crystals with variably concordant analyses ranging between 2683 and 1867 Ma (Figure 18). The spread in ages and errors in the $^{207}Pb/^{206}Pb$ dates precludes a simple age interpretation. The youngest analysis at 1867 Ma is a homogenous overgrowth that is partially intergrown with the zircon core (see Figure 18 inset). The oldest 23 analyses are from oscillatory zoned to homogenous zircon crystals with dates that span from 2651-2070 Ma. These older analyses have Th/U values above 0.1 and Hf/Yb values mostly below 100 (younger analyses have higher and variable Hf/Yb, Figure 18). Duplicate analyses on grains 10 and 71 were unable to reproduce ages suggesting Pb-loss affected these crystals. High errors on many single analyses is attributed to Pb-variability within individual analyses. The 14 oldest analyses yielded a weighted mean $^{207}Pb/^{206}Pb$ date of 2577 ± 11 Ma (MSWD = 3.6). Younger analyses were excluded from the weighted mean due to non-reproducibility of ages and variable Hf/Yb values. Since Pb-loss likely affected this population the 2577 Ma age is considered a minimum estimate.

The concordant 1867 Ma single analysis of an embayed zircon rim may be metamorphic in origin (low Th/U, high Hf/Yb). Although this analysis was not reproduced, its age overlaps the age of igneous crystallization of dike 15ET253a on Wholdaia Lake. Sample 15ET258a also shares the same field relationships as that dike, crosscuts Hbl-Bt grade northeast trending mylonites. Also, the abundance of 2.6 Ga host-rocks locally lead us to interpret the crystallization age of this dike is Paleoproterozoic and probably ca. 1867 Ma. The older ~2.6-2.0 Ga zircon are interpreted to be inherited.

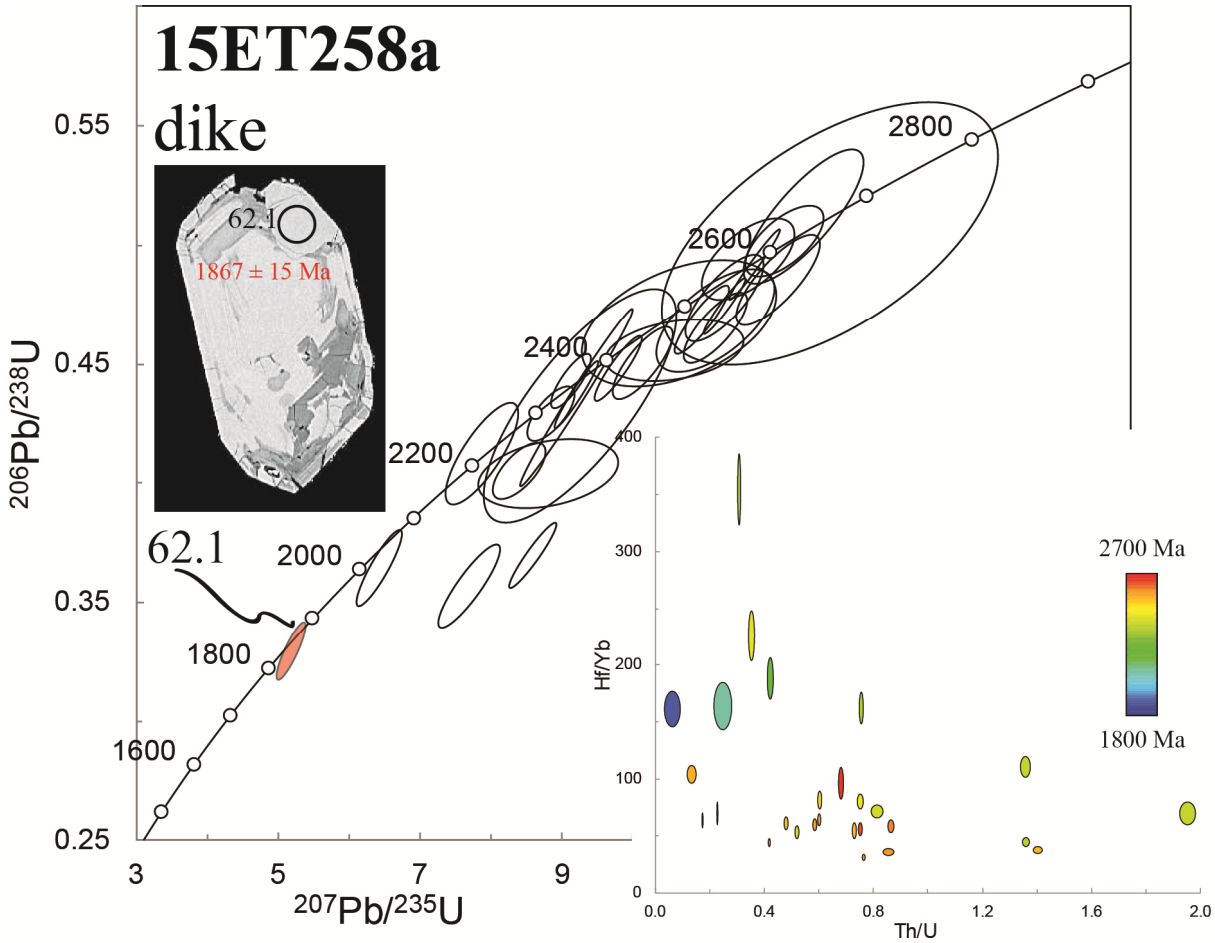

Figure 18. Concordia diagram highlighting spot 62.1. BSE image of spot 62.1 (black circle ~20 µm diameter) and corresponding date (1σ, red) is also displayed. Inset graph shows Hf/Yb (absolute error) vs Th/U (relative error), the youngest analysis (#62.1) is in blue.

Z-11695: Alkali feldspar granite dike

Sample	15ET260d
Coordinates	Zone 13 555365E 6749451N
Rock Type	Igneous
Age 1	1871.3 ± 5.0 Ma
nterpretation	Igneous crystallization
Age 2	~1.93 Ga
Interpretation	Inherited (Metamorphic)
Age 3	~2.4 Ga
Interpretation	Inherited (Igneous)

Geological Field relationships/Rock Description

This 30 cm wide dike intruded parallel to mylonitic host rocks and exhibits a lesser degree of strain. Dike margins display pinching and swelling and the mylonitic foliation of the host rock wraps into these boudinaged embayments (Figure 19A). The sample is a light pink alkali feldspar granite and is fine-grained. Porphyroclasts of quartz and feldspar are enveloped by fine grained recrystallized subgrains that are parallel to the mylonitic foliation. Quartz porphyroclasts are equant to weakly elongate and consist of aggregates of polygonal subgrains.

Zircon Description

Zircon crystals from this dike have spherical and prismatic and mostly brown in colour (Figure 19B). BSE imaging shows prismatic zircon are usually altered and display faint oscillatory zoning (Figure 19C-D). Most zircon are homogenous to faintly oscillatory zoned spherical grains with rare cores and often display very thin homogenous to oscillatory zoned rims (Figure 19C-D).

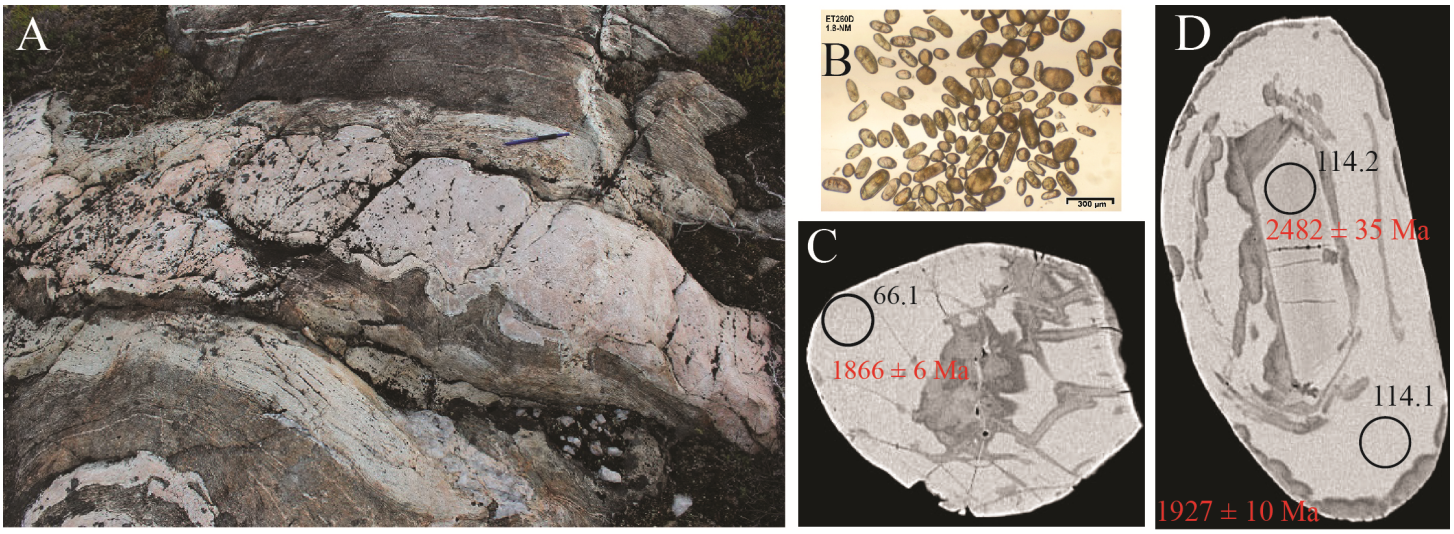

Figure 19. (A) 15ET260d sampled dike parallel to mylonite, north pointing pen for scale, (B) zircon separates, (C-D) representative spot locations (black circles ~20 µm diameter) and corresponding dates (1σ, red).

Results/Interpretation

Thirty-one analyses on 23 individual zircon grains yield dates between 2482-1862 Ma. The results fall into three age clusters at 2.4 Ga, 1.93 Ga and 1.87 Ga (Figure 20). The oldest age cluster is between 2482-2350 Ma and consists of 10 mostly concordant analyses with large errors ~20 My (1σ). These zircon crystals are oscillatory zoned or homogenous whole grains. This group has Th/U values that range from 0.05-0.21 that decrease in value with decreasing age. The Hf/Yb values for this group are mostly above 100 with some analyses of ~30, yet no systematic trends occur with age. The oldest 3 analyses have distinctly lower U (258-528 ppm) compared to the rest of the group (1095-2544 ppm). Two analyses on grain 22 have reproducible ages at 1σ levels (22.1 = 2269 ± 16 Ma, 22.2 = 2310 ± 26 Ma).

The age cluster at 1.93 Ga consists of 8 analyses of homogenous zircon, homogenous rims and one oscillatory zoned zircon. These analyses range from 1994-1919 Ma and have Th/U below 0.1 (except one above 0.1) and consistent Hf/Yb values above 100.

The youngest age cluster at 1.87 Ga consists of 9 mostly concordant analyses of homogenous to oscillatory zoned zircon and overgrowths and ranges from 1883-1862 Ma. The Th/U values are above 0.1 (one analyses of 0.09) and the Hf/Yb values cluster consistently above 100. These 9 youngest analyses yield a weighted mean $^{207}Pb/^{206}Pb$ age of 1871.3 ± 5.0 Ma (MSWD=1.9, Figure 20).

The oscillatory nature of the 1871 Ma population coupled with normal igneous chemistry leads us to interpret 1871 Ma as the igneous crystallization age of the dike. This mean age is not within error (0.2 My apart) of the 1863 Ma mean age of igneous dike sample 15ET253a.

All older results from this sample are considered inherited. However, the 1.93 Ga population exhibits morphologies and chemistry akin to metamorphic crystallization and is similar in age to metamorphic zircon in sample 15ET259. Interestingly, no 2.6 Ga zircon were analyzed despite the 2.6 Ga nature of local host rocks. Rather, the oldest grouping of analyses in this sample consist of inherited ~2.4 Ga zircon that were likely derived from magmatic sources.

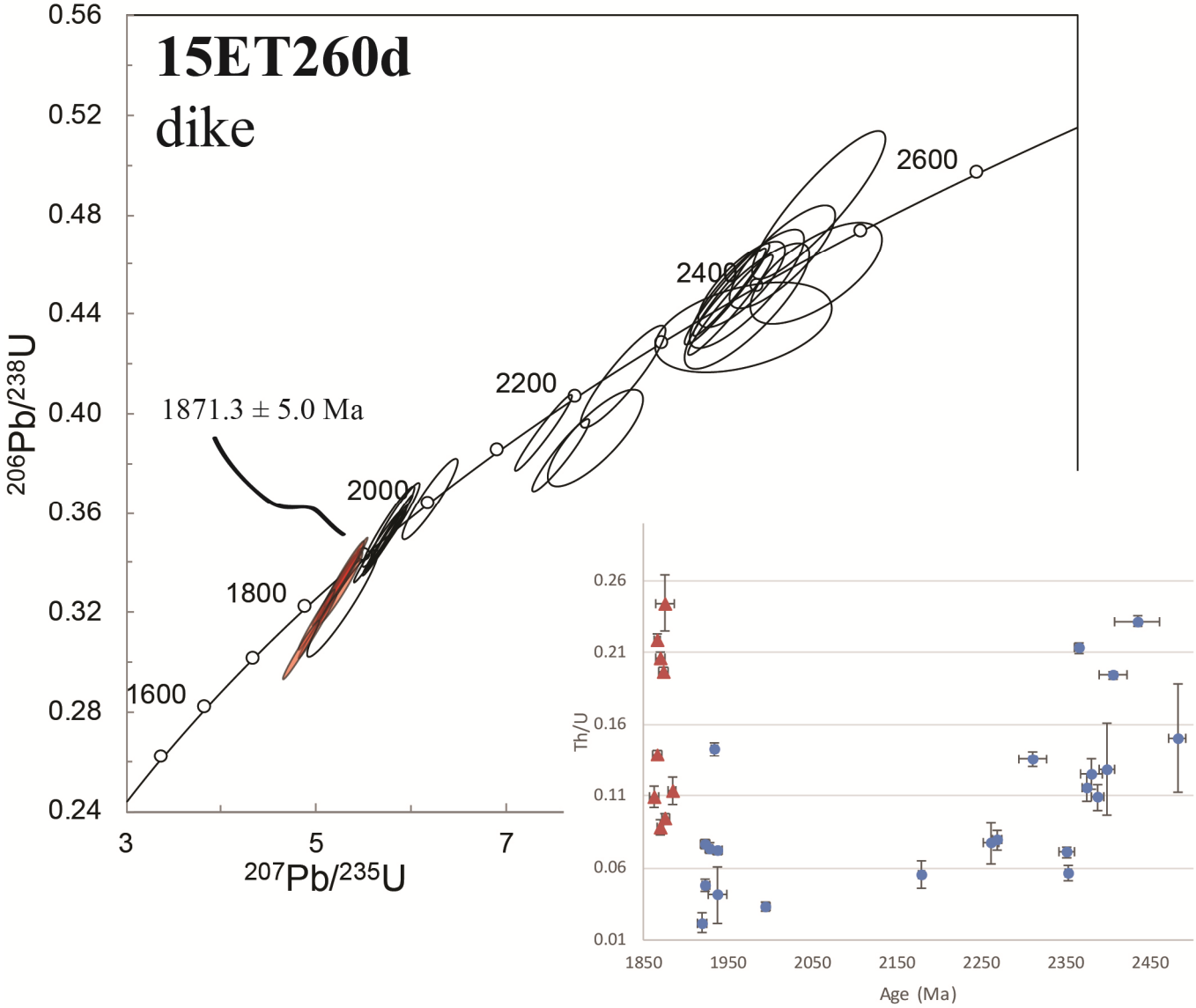

Figure 20. Concordia diagram where filled ellipses represent the data population used for the weighted mean calculation. Inset graph displays Th/U vs age for all data (red triangles are data used for weighted mean age of dike). Error bars on graph are relative errors (Th/U) and 1σ (age).

Z-11682: granite dike/leucosome

Sample	15ET260a
Coordinates	Zone 13 555303E 6749575N
Rock Type	Igneous
Age	~2.4 Ga
Interpretation	Inherited or Igneous

Geological Field relationships/Rock Description

The region containing sample 15ET260a consists of a linear low magnetic signature trending northeast. Host-rock annealed mylonites contain variably strained dikes such as low-strain concordant dikes (sample 15ET260d) and highly sheared dikes (15ET260a). Sample 15ET260a contains a strong deformation fabric (northeast trending) roughly parallel to the host mylonite fabric. This sample is an alkali feldspar granite (Figure 21A) with a foliation consisting of quartz-K-feldspar layers and layers of biotite-ilmenite. The quartz-K-feldspar phenocrysts are strongly deformed showing subgrain formation, bulging and up to 3:1 a.r. Qz-ribbons. However, the quartz often occurs in sub-equidimensional domains with multiple granoblastic subgrains. Biotite crystals also occur perpendicular to the foliation suggesting post-tectonic mineral growth and annealing. Overall these textures suggest strong degree of deformation pre- to syn-kinematic relative to host mylonites. It is unclear whether this sample is from a pre-strain dike or ambiguous leucocratic material. Regardless, the higher degree of strain within this sample suggests it has an older crystallization age that 15ET260d (1.87 Ga).

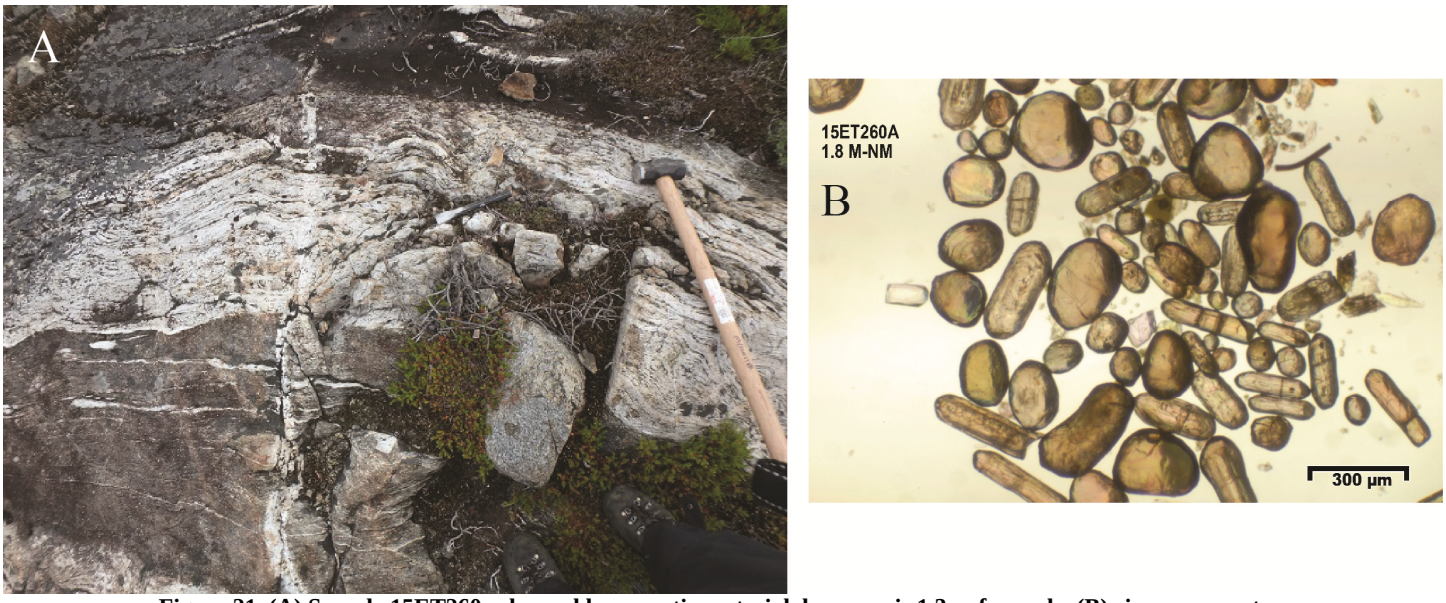

Figure 21. (A) Sample 15ET260a sheared leucocratic material, hammer is 1.3 m for scale, (B) zircon separates.

Zircon Description

Zircon crystals were generally of poor to fair quality and varied from spherical to subhedral prisms with up to 4:1 a.r. and a light to moderate brown colour (Figure 21B). Two dominant populations of round and prismatic zircon occur with homogenous and weak oscillatory zoning, respectively (Figure 22). Oscillatory zoning is rarely observed. More commonly, homogenous zoned zircon occur as single crystals, as rim domains, and as recrystallized domains that overprinted the prismatic oscillatory zoned crystals.

Results/Interpretation

Twenty-three analyses on 23 zircon grains yield a spread in dates between 2678-2173 Ma (Figure 22). These results have Th/U values between 0.1 and 1.0 and Hf/Yb values between 10-1000. The oldest 3 analyses (2678-

2540 Ma) are distinct in that they have oscillatory zoning and elongate morphologies (and lower U contents <550 ppm) whereas the younger 20 analyses are all spherical homogenous whole crystals or overgrowths. The spread of ages in this group of 2504-2173 Ma and large errors makes it unlikely that it represents a single geological population. Except for the three oldest analyses (interpreted to be inherited) and the youngest grain (most probably recording lead-loss) all the analyses extend along the Concordia with no evident distinct population.

The field relations and U-Pb data hinder equivocal interpretation of these results. The cluster of ages around ~2.4 Ga is similar to inherited zircon in sample 15ET260d yet it is not clear whether this group represents a cryptic crystallization age for the dike/leucosome or an inherited population. Due to the highly sheared nature of this sample with respect to the mylonitic host, the poorly constrained 2.4 Ga age may represent igneous crystallization of the leucocratic material prior to significant shearing. Conversely, the 2.4 ages may represent inherited zircon during 1.87 Ga dike intrusion followed by late localized strain.

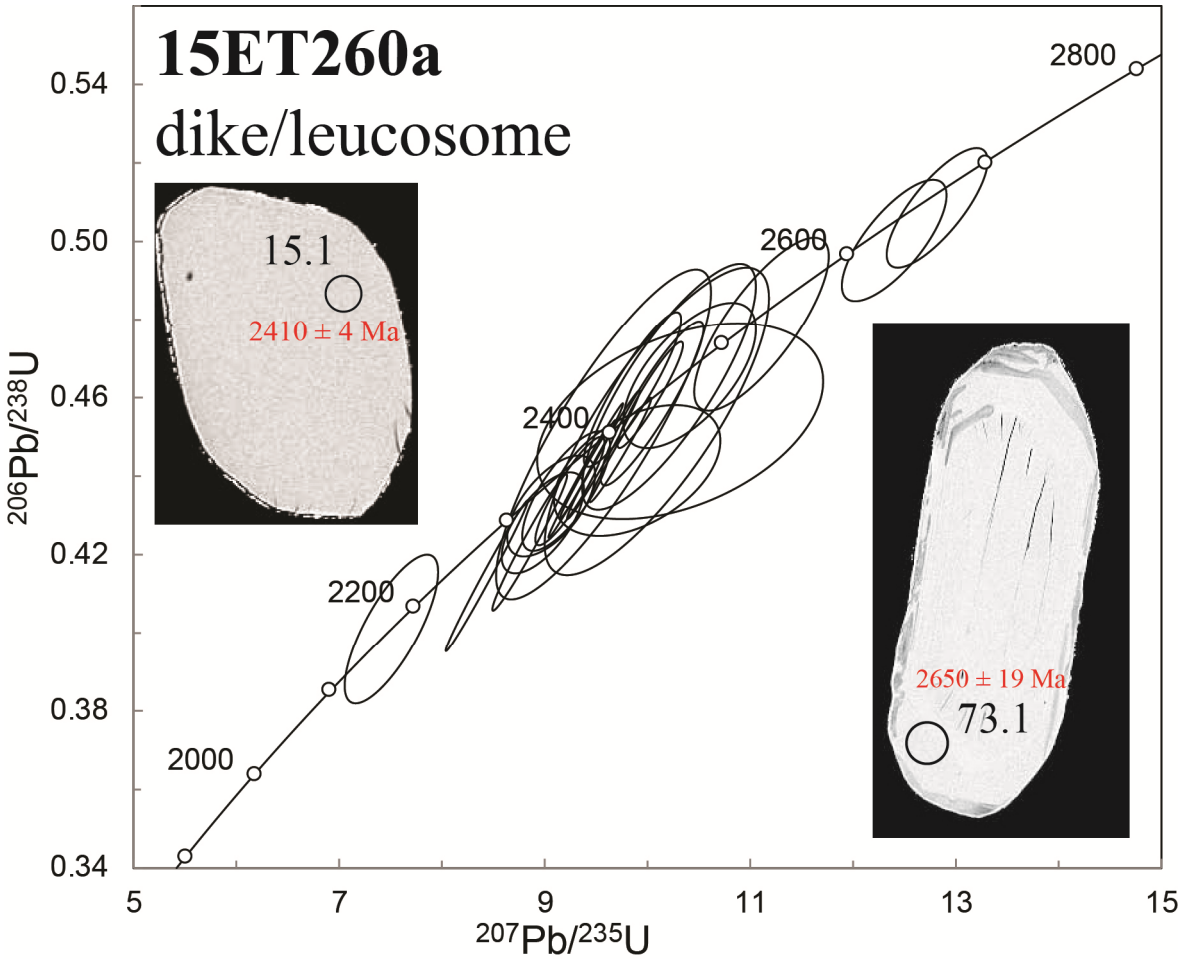

Figure 22. Concordia diagram and representative zircon morphologies and spot locations (black circles ~20 µm diameter), dates are in red (1σ).

Acknowledgements

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