

GSA Data Repository item 2014324, containing sample descriptions, field relationships and analytical methods for the paper:

Neoproterozoic to early Paleozoic extensional and compressional history of East Laurentian margin sequences: the Moine Supergroup, Scottish Caledonides

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SAMPLE DESCRIPTIONS AND FIELD RELATIONSHIPS

Metasedimentary units

Samples of metasandstone and metapelite were obtained from the Moine rocks on the Ross of Mull (Figs. 2, 3) that have been correlated with the Morar and Glenfinnan groups (Holdsworth et al., 1987). Whereas on the mainland, the two groups are everywhere thought to be separated by the Sgurr Beag Thrust (Tanner, 1970), on the Ross of Mull they are interpreted to be linked by sedimentary transition (Holdsworth et al., 1987). In order to evaluate further the nature of the contact between the two groups at this locality, four samples were collected, in stratigraphic order (Fig. 3): Lower Shiaba Psammite (MG01, sampled at NM 44554 18971¹), Upper Shiaba Psammite (MG04, sampled at NM 42829 18367), Scoor Pelitic Gneiss (RS01–10, sampled at NM 4201 1882), and the Ardalanish Striped and Banded unit (MG03, sampled at NM 39627 18699). The Lower and Upper Shiaba Psammite units are thought to correlate, respectively, with the Lower and Upper Psammite units of the Morar Group on the mainland, and the Scoor Pelitic Gneiss and the Ardalanish Striped and Banded units have been assigned to the Glenfinnan Group (Holdsworth et al., 1987; Holdsworth et al., 1994). The three samples of metasandstone (MG01, MG04, MG03) are fine- to medium-grained, characterized by granoblastic texture, and dominated by quartz (~50%), with approximately sub-equal proportions of plagioclase and K-feldspar (~20%–25% each), and minor accessory biotite, zircon and opaque minerals (<5% total). The metapelite is medium-grained, dominated by intergrown layers of aligned biotite and muscovite (~50%) that fringe mm-scale layers and augen of quartz and feldspar (latter is mainly plagioclase) with accessory zircon and opaque oxide minerals. There is no petrographic indication of segregation or migmatization within this amphibolite facies pelite.

In addition, a sample of the Morar Group (KD07–02) was obtained from the Knoydart Peninsula at NM 79698 96119 (Fig. 2). The unit sampled is the regionally extensive Ladhar Bheinn Pelite (Ramsay and Spring, 1962), thought to be the northern continuation of the Morar Pelite (Holdsworth et al., 1994), and to lie stratigraphically between Lower and Upper Shiaba Psammite samples MG01 and MG04. The sample analyzed is a medium- to coarse-grained pelitic gneiss composed of biotite-muscovite-garnet-quartz-plagioclase, with accessory zircon and opaque oxide minerals. Stromatic migmatitic leucosomes rimmed by thin selvages of aligned biotite grains lie parallel to the gneissosity.

Meta-igneous intrusions: West Highland Granitic Gneiss

Ardgour granitic gneiss (Sgurr Dhomhnuill facies; sample 'SD Gneiss'). The West Highland Granitic Gneiss comprises a series of highly deformed and metamorphosed granitic intrusions that mainly occur close to the boundary between the Glenfinnan and Loch Eil groups, but also outcrop further east adjacent to the Great Glen Fault (Fig. 2; Johnstone, 1975). Barr et al. (1985) concluded that the granitic gneisses represent S-type, anatectic granites derived by partial melting of Moine metasedimentary rocks during regional high-grade metamorphism. In contrast, Dalziel and Soper (2001) and Ryan and Soper (2001) argued that the igneous protoliths were pre-tectonic and intruded during extensional rifting. Friend et al. (1997) carried out U-Pb SIMS and TIMS analyses of zircons from the southernmost of the granitic gneiss bodies, the Ardgour granitic gneiss (Fig. 2). These zircons were analytically complex, reflecting the combined effects of inheritance and multiple metamorphic events that included migmatization of the igneous protolith. A TIMS zircon age of 873 ± 7 Ma obtained from a segregation pegmatite was considered to be the best estimate of the age of crystallization of the Ardgour granitic gneiss (Friend et al., 1997). A U-Pb zircon (SIMS) age of 870 ± 30 Ma obtained from the Fort Augustus granitic gneiss (Fig. 2; Rogers et al., 2001) is consistent with this body being part of the same intrusive suite as the Ardgour body, although precision is poor.

In order to more accurately ascertain the age of the igneous protolith of the Ardgour granitic gneiss, a sample of non-migmatitic granitic gneiss was obtained from NM 84677 66189 (Fig. 2). In this southern part of the body the granitic gneiss commonly contains numerous 2–3 cm K-feldspar augen, the 'Sgurr Dhomhnuill' facies of Harry (1953). The augen are thought to have resulted from the deformation and recrystallization of megacrysts within the igneous protolith (Dalziel and Soper, 2001). The augen are aligned parallel to, and wrapped by, a well-developed composite S_1/S_2 gneissic fabric defined by a medium-grained assemblage of aligned biotite and stromatic layers of quartz, K-feldspar and oligoclase in approximately equal amounts. Sub-concordant gneissic quartzo-feldspathic layers with biotite-rich selvages are common within the granitic gneiss. Myrmekite is locally common in thin section, developed along K-feldspar-plagioclase boundaries. Minor accessory constituents include apatite, titanite, zircon, garnet, and opaque oxide minerals.

Glen Doe Granitic Gneiss and Metagabbro. The Glen Doe granitic gneiss is the northernmost body of the West Highland Granitic Gneiss (Fig. 2) and occurs in association with metagabbros and metadolerites (Barr et al., 1985; Millar, 1990; Millar, 1999; Peacock, 1977). Field relationships indicate that the igneous protoliths of the granitic gneisses and the metagabbros were intruded more or less contemporaneously and are pre-tectonic relative to regional deformation and metamorphism of the host Moine rocks (Dalziel and Soper, 2001; Millar, 1990; Millar, 1999). A U-Pb zircon age of 873 ± 6 Ma obtained from a metagabbro, in combination with the MORB affinities of spatially associated metadolerites, are key lines of

evidence indicating that the ca. 870 Ma event was dominated by extensional rifting and bimodal magmatism (Dalziel and Soper, 2001; Millar, 1999).

In order to test the hypothesis that igneous protoliths of the granitic gneisses and the metagabbros were of approximately the same age, four samples were obtained from the River Doe section (Fig. 2). Two of these were collected from the main body of the granitic gneiss: samples SH-02–18B (NH 21643 12642) and D24 (NH 21162 12661). A third granitic gneiss sample (D48) was a xenolith within metagabbro (NH 21864 12583). The fourth sample (D93) was a foliated metagabbro collected at NH 21848 12598. Granitic gneiss samples SH-02–18B and D24 are texturally and mineralogically very similar. The dominant lithology is relatively homogenous, medium-grained, quartz-K-feldspar-plagioclase-biotite gneiss that lacks the distinctive augen and gneissic layering observed in the Ardgour body (see above). Mafic sheets here have preserved chilled margins. Accessory phases include garnet, zircon and opaque oxide minerals. The penetrative gneissic fabric is interpreted as a composite S_1/S_2 foliation (Barr et al., 1985; Millar, 1990; Millar, 1999; Peacock, 1977). Sample D48 was collected from a granitic xenolith within the central part of a large metagabbro body at Glen Doe. This gabbro is very weakly deformed, and preserves primary igneous textures and field relationships (chilled margins, xenoliths, igneous banding). The granitic xenoliths appear to have undergone extensive partial melting during incorporation into the basic magma. They consist of quartz-plagioclase-K-feldspar-biotite micro-pegmatite and in thin section commonly display a myrmekitic texture, surrounding partially resorbed crystals of quartz and feldspar. The partially resorbed crystals reach almost 1 cm in length, significantly coarser than the grain size of the local granitic gneiss. No tectonic fabrics are present in the granitic xenoliths, and they are thought to represent partially melted blocks of undeformed granite, equivalent to the protolith of the West Highland Granitic Gneiss, to which they are chemically and isotopically identical (Millar, 1999). The foliated metagabbro (D93) was sampled from a sheet ca. 2 m in width. It displays an augen texture, with garnet-quartz-plagioclase augen wrapped by a coarse hornblende-plagioclase-quartz schist. The foliated metagabbros are chemically similar to the undeformed metagabbros described above, and are thought to be higher-strain equivalents (Millar, 1999). The penetrative fabric which they carry is the same composite S_1/S_2 foliation seen in the granitic gneiss.

Felsic melts

Knoydart pegmatite (KD07–04). The Knoydart pegmatite was sampled at NM 79707 96103 where it occurs within the Ladhar Bheinn Pelite of the Morar Group (Fig. 2). The first indication that the Moine Supergroup had been affected by Precambrian metamorphism was provided by Rb-Sr muscovite ages of ca. 740 Ma obtained from the pegmatite by Giletti et al. (1961). However, there has been no subsequent attempt to ascertain the age of the pegmatite using modern isotopic techniques. The Knoydart ‘pegmatite’ comprises a series of concordant sheets and veins of pegmatite within migmatitic pelitic gneiss (Hyslop, 2009b). A considerable volume of pegmatite was removed by quarrying in 1943–44 as it was an excellent source of sheet mica (Kennedy et al., 1943). The remaining pegmatites are up to ca. 2–3 m in length and ca. 0.5 m thick, and composed of medium- to coarse-grained assemblages of quartz, plagioclase feldspar, muscovite and garnet with accessory beryl and zircon. Muscovite books several centimeters thick are locally common. A coarsely-developed foliation defined by quartz-feldspar aggregates is parallel to the margins of the pegmatites and a composite $S_0/S_1/S_2$ foliation in host pelitic gneisses. The presence of the pegmatites within particularly biotite-rich host gneisses, with common mafic selvages at the margins of the pegmatites, are features consistent with formation more or less in situ by recrystallization and segregation during high-grade

metamorphism (Hyslop, 1992; Kennedy et al., 1943). The pegmatites occur as boudins on the limbs of isoclinal F_2 folds and are locally rodded parallel to east-southeast plunging F_2 axes and an L_2 mineral lineation (Hyslop, 2009b). There has been debate as to whether the pegmatites formed prior to or during F_2 folding (James, 1977; Kennedy et al., 1943). Although the field evidence is not clear-cut, the view adopted here is that the pegmatites formed during the development of the S_1 migmatitic banding within the host pelitic gneisses. The composite $S_0/S_1/S_2$ foliation in host pelitic gneisses is deformed by upright, open F_3 folds that trend approximately N-S.

Carn Gorm pegmatite (SH-03–04A). The Carn Gorm pegmatite (Fig. 2) was sampled at NH 4388 6289 where it occurs within pelitic gneisses assigned to the Glenfinnan Group (Wilson, 1975). Long and Lambert (1963) reported muscovite Rb-Sr ages from the pegmatite of ca. 747, 721 and 662 Ma. The Precambrian age of the pegmatite was confirmed by van Breeman et al. (1974) who obtained Rb-Sr muscovite ages of between 755 Ma and 727 Ma. However, there has been no subsequent attempt to ascertain the age of the pegmatite using modern isotopic techniques. The following description of the pegmatite is derived in part from Hyslop (2009a). The pegmatite is exposed over an area of ca. 200 m²; its exact thickness is uncertain as its upper boundary has been removed by erosion, but it is likely to be at least 2–3 m thick. The pegmatite is composed of a coarse-grained, assemblage of quartz, muscovite, K-feldspar and plagioclase, with accessory biotite, garnet, beryl and tourmaline. Muscovite books up to 20 cm across and 3 cm thick have been recorded. A coarsely developed foliation defined by quartz and muscovite encloses lenticular, cm-scale aggregates of feldspar and quartz. This foliation is parallel to the margins of the pegmatite and to the S_0/S_1 gneissic fabric in the host rocks (Wilson, 1975). Adjacent to the pegmatite, the host pelitic gneisses contain abundant muscovite, quartz veins and lenticular quartzofeldspathic segregations (see also Kennedy et al., 1943). The field evidence suggests that the pegmatite formed as a result of in situ recrystallization and segregation during high-grade metamorphism of the host Moine rocks (Hyslop, 1992; Long and Lambert, 1963; van Breeman et al., 1974). The contacts between the pegmatite and adjacent Moine rocks are mainly concordant and gradational, though slightly discordant at some exposures, suggesting that some migration of melt occurred locally.

Cruachan Coille a'Chait pegmatite (MS07–01). The Cruachan Coille a'Chait pegmatite (Fig. 2) was sampled at NH 11532 11103. It is the largest of a suite of cross-cutting, foliated pegmatites intruding interbanded cross-bedded psammities and semi-pelites assigned to Loch Eil Group (Millar, 1990). The pegmatite is a sub-vertical sheet, up to 2 m in thickness, that cuts obliquely across the sub-vertical composite S_0/S_1 gneissic banding within host Moine lithologies (Fig. 4A). The S_0/S_1 fabric contains intrafolial isoclinal folds, but these do not deform the contact between the pegmatite and its host rocks. The pegmatite is composed of a medium-grained assemblage of muscovite, quartz and plagioclase feldspar, in approximately equal proportions, with accessory garnet, zircon and opaque minerals. Coarse muscovite books up to 3 cm in diameter are found in less deformed parts of the pegmatite. A penetrative S_2 schistosity is defined within the pegmatite by aligned muscovite grains that wrap quartz-feldspar aggregates; this fabric is oblique to S_0/S_1 and sub-parallel to the contact between the pegmatite and host rocks. The field evidence therefore suggests that the pegmatite was intruded between the D_1 and D_2 deformation events identified in this area.

Loch Cluanie Pegmatite (C51). The Loch Cluanie pegmatite was sampled at NH10151 11456, where it occurs within pelitic gneisses of the Glenfinnan Group. The pegmatite is a sheet less than 1 m in width, tightly folded by N-S trending upright F_3 folds (Fig. 4B). At this locality,

pelitic gneisses of the topmost Glenfinnan Group are strongly reworked during the D₃ event. However, on the flat limbs of F₃ folds, earlier isoclinal fold structures are preserved in boudinaged psammite horizons, and rare cross-bedding indicates younging upwards, and to the east. The pegmatite cuts a composite S₀/S₁ fabric, but its relationship to the pre-F₃ isoclinal fold structures is not seen. The pegmatite appears to carry a much weaker axial planar S₃ schistosity than the surrounding pelitic gneiss. The pegmatite contains quartz, K-feldspar, plagioclase, muscovite and apatite, together with sparse garnet and zircon. Coarse muscovite crystals up to 4 cm in diameter lie roughly parallel to the S₃ fabric in the country rocks, and show undulose extinction and kink bands. The field evidence suggests that the pegmatite was intruded before the D₃ event, but its relationships to earlier structures are somewhat ambiguous.

Glenelg pegmatite (SH-03-01C). The Glenelg pegmatite was sampled at Rudha Camas na Caillin (NG 8504 0795) south of Arnisdale (Fig. 2) where Lewisianoid basement has been interfolded isoclinally with Moine psammities of the Morar Group (Ramsay, 2010). This episode of deformation is the earliest to affect the Moine rocks and has therefore been designated 'D₁' (Ramsay, 1957, 2010). Subsequent 'D₂' deformation affected both Lewisianoid basement and its Moine cover, and resulted in widespread tight folding on all scales, development of a pervasive 'S₂' schistosity, and formation of granitic segregations (Ramsay, 1957). A prominent SE-plunging 'L₂' mineral lineation is parallel to D₂ fold axes. Granitic segregations are deformed by D₂ folds, but more commonly appear to have been intruded during the final stages of D₂. These syn- to late D₂ segregations are typically no more than 10–15 cm thick at maximum, often slightly boudinaged, but are generally un-deformed internally and thus do not carry either S₂ or L₂. The sample was obtained from a ~15 cm thick pegmatitic segregation that occurs as a concordant sheet within Lewisianoid orthogneisses. It is composed of a medium- to coarse-grained, equigranular assemblage of quartz, plagioclase and orthoclase in approximately equal proportions, with accessory biotite and zircon.

A detailed outline of analytical methods is given below with a complete listing of results in Supplementary Data Tables DR1–7.

ANALYTICAL METHODS

Detrital zircons from the metasedimentary units were analyzed in situ using the high-resolution ion microprobe at Curtin University. Zircons from the Ardgour and Glen Doe granite gneisses, the Glen Doe metagabbros, and the Knoydart and Cruachan Coille a'Chait pegmatites were analyzed in situ using a high-resolution ion microprobes at Curtin University and NORDSIM. The ID-TIMS (Isotopic Dilution-Thermal Ionisation Mass Spectrometry) technique was also used to investigate zircon from the Ardgour and Glen Doe granitic gneisses, the Glenelg pegmatite, and the Carn Gorm pegmatites (the TIMS data set for the latter also including monazite analyses). Monazite was also analyzed from the paragneiss hosting the Carn Gorm pegmatite. These TIMS analyses were carried out at University of Texas at Austin. TIMS and ICP-MS analyses were undertaken on zircon from a pegmatite at Loch Cluanie at the NERC Isotope Geosciences Laboratory. In order to further constrain the timing of metamorphic events, muscovite from the Knoydart Pelite and the Cruachan Coille a'Chait pegmatite was investigated using the ⁴⁰Ar/³⁹Ar dating technique at the Western Australian Argon Isotope Facility at Curtin University.

Cathodoluminescence (CL) imaging

Zircons grains were imaged by cathodoluminescence (CL) prior to analysis. For those grains analyzed by the SHRIMP at Curtin University they were imaged using a JEOL 5800 scanning electron microscope with an accelerating voltage of 15 KV at the CMCA at the

University of Western Australia. At University of Texas at Austin grains were imaged on a Philips XL30 ESEM equipped with a Gatan PANA CL system housed in Jackson School of Geosciences. Grains were typically imaged using 15 KV accelerating voltage, 0.5 Torr chamber pressure and 500–600 V high voltage on the CL unit. Grains analyzed at NIGL were imaged using the British Geological Survey FEI Quanta 600 ESEM.

SIMS U-Pb dating
Curtin University

For each sample, 1–5 kg of rocks were crushed and the zircons were extracted using LST heavy liquid and Frantz magnetic separator. From the non-magnetic, heavy fraction of each sample, zircons were mounted in an epoxy resin, which was then polished to expose the interior of the zircons.

The U-Pb zircon analyses were performed with a high-resolution ion microprobe (SHRIMP II instrument). The analytical conditions were identical to those described by Compston et al. (1984), Nelson (1997) and Williams (1998). The samples were analyzed over several sessions during which the intensity of the O^{2-} primary beam was set between 0.5 nA and 2 nA to allow analyze of U-rich grains (see results). Pb/U and Pb/Th calibration was performed relative to the 556 Ma-old CZ3 zircon standard (Pidgeon et al., 1994) which was analyzed after every five unknowns throughout the analytical session. The raw data were reduced using the Squid macro (Ludwig, 2003) and the Concordia plots made with Isoplot (Ludwig, 2003). Common Pb was corrected for by using ^{204}Pb using the present-day terrestrial ratios from Stacey and Kramers (1975). Although less precise than corrections based on ^{207}Pb or ^{208}Pb for young zircons, this correction can be applied to both old and young grains and hence results in consistency of data treatment. The errors were calculated by propagating analytical uncertainties and are shown as 1-sigma level on the Concordia diagrams. Errors were calculated by propagating analytical uncertainties and are shown at the 2-sigma level on the Concordia diagrams. Errors of individual Concordia ages are also given at the 2-sigma level.

The number of scans of each mass for a single analysis of detrital zircon grains was reduced from seven to four in order to investigate ~60–80 grains in each session. The number of analyzed grains provides a 95% probability of finding any population that makes up 5% of the total (Dodson et al., 1988). The cores of these grains were preferentially investigated in order to focus on their provenance, although some metamorphic overgrowths were also analyzed. For all other samples, the number of scans was set to seven in order to investigate ~20–30 grains during each session.

NORDSIM

U-Pb zircon geochronology was carried out using the NORDSIM Cameca 1270 ion-microprobe at the Swedish Museum of Natural History, Stockholm. The analytical procedure closely followed that outlined by Whitehouse and Kamber (2005). Zircon separates were handpicked and mounted in epoxy along with a few grains the 1065.4 ± 0.3 Ma 91500 Geostandards 91500 zircon standard (Wiedenbeck et al., 1995) which has reported U and Pb concentrations of 80 ppm and 15 ppm, respectively, and polished to expose the centers of the grains. The polished mount was then introduced into an SEM for optical and cathodoluminescence (CL) imaging, which were used to guide the location of the spot analyses. The mount was then cleaned, gold-coated and introduced into the ion-microprobe. Pb/U ratios were calibrated against the zircon standard using the measured UO_2/U ratios. The measured ^{204}Pb signal assessed the proportion of common Pb present, and where appropriate (Table 1), was corrected for assuming surface contamination and a composition of present day terrestrial Pb

estimate of Stacey and Kramers (1975). Errors reported in Table 2 are 1σ and include propagated errors of the standard measurements. Individual ages quoted in the text and on figures are given with 2σ uncertainties. Ages have been calculated using ISOPLOT version 3.1 (Ludwig, 2003). Decay constants follow Steiger and Jäger (1977).

TIMS U-Pb dating – University of Texas

U/Pb TIMS geochronology was completed in the Jackson School of Geosciences at The University of Texas at Austin. Samples were crushed and milled and zircons were separated by standard separation techniques using a Rogers or Wilfley Table, heavy liquids and a Frantz Isodynamic Magnetic Separator (Krogh, 1982b). Minerals were handpicked to segregate distinct morphologies and select the best grains. Representative zircons were imaged by cathodoluminescence (CL) to determine internal morphologies (Connelly, 2000). Similar grains were chosen or partial grains were removed from CL mounts for analysis. All grains were abraded, cleaned and spiked with a $^{205}\text{Pb}/^{235}\text{U}$ mixed spike prior to dissolution in HF and HNO_3 in Teflon dissolution bombs at 210 jC (Krogh, 1973, 1982a, b; Krogh and Davis, 1975; Parrish and Krogh, 1987). U and Pb were isolated from dissolved zircon by anion exchange techniques. Both U and Pb were loaded onto zone-refined Re filaments with a mixture of silica gel and phosphoric acid and analyzed with a Finnigan Mat 261 thermal ionization mass spectrometer with seven Faraday cups and a single ioncounting channel. Due to complex zircon populations, most zircon fractions were analyzed in peak jumping mode using only the ion counter, but a few initial zircon fractions were analyzed in static faraday-ion counter mode with ^{204}Pb measured by the ion counter. Repeated analyses of the NBS981 Pb standard and U500 U standard in peak jumping mode determined Pb and U fractionation to be 0.1% and 0.07% per amu, respectively. Blanks were typically less than 2 pg Pb and 0.2 pg U. Initial common Pb was calculated using Pb isotopic compositions of (Stacey and Kramers, 1975). Ages and errors were generated using an in-house program that incorporates an unpublished error propagation program (L. M. Heaman) and a linear regression calculation program (Davis, 1982). The 2 sigma error is represented by the size and orientation of the ellipse. These uncertainties are reported after the ratios and refer to the final digits. The regressions represent a 95% confidence of fit.

TIMS U-Pb dating – NIGL

Single zircon crystals were hand-picked and analyzed at NIGL, BGS, Nottingham, using chemical abrasion isotope-dilution thermal ionisation mass spectrometry (ID-TIMS). Prior to ID-TIMS analyses zircons were subject to a modified version of the chemical abrasion technique (Mattinson, 2005). The reader is referred to Sláma et al. (2008) for details of anion exchange chemistry and mass spectrometry. U-Pb dates and uncertainties were calculated using the algorithms of Schmitz and Schoene (2007) and a $^{235}\text{U}/^{205}\text{Pb}$ ratio for ET535 of $100.18 \pm 0.1\%$. All common Pb in the analyses was attributed to the blank and subtracted based on the isotopic composition and associated uncertainties analyzed over time. All analytical uncertainties are calculated at the 95% confidence interval.

ICP-MS - NIGL

Zircons were separated using Zircon was analyzed using a Nu Instruments AttoM single-collector inductively coupled plasma mass spectrometer (SC-ICP-MS). Laser ablation was performed with either a New Wave Research UP193SS laser ablation system with a two-volume New Wave Research large format cell; this cell had a washout to less than 1% of the peak signal in less than one second. Ablation parameters were optimized to suit the Pb and U contents of the material, and in all cases, bracketing reference materials were analyzed using the same

parameters; these were 5Hz, with a fluence of 1.5–3.0 J/cm², a 30 second ablation time, and a 25–35 μm spot size.

Instrumental tuning was adopted that gave ThO and UO of <0.4%. Data processing for all analyses used the time-resolved function on the Nu Instruments' software, an in-house Excel spreadsheet for data reduction and error propagation, and Isoplot 4.15 for data presentation (Ludwig, 2003). Uncertainties were propagated in the manner advocated by Horstwood (2008) and include a contribution from the external reproducibility of a reference material analyzed within each session.

The Nu Attom SC-ICP-MS is used in peak-jumping mode with measurement on a MassCom secondary electron multiplier. The following masses are measured in each sweep: ²⁰²Hg, ²⁰⁴Pb+Hg, ²⁰⁶Pb, ²⁰⁷Pb, and ²³⁵U. Each data integration records 100 sweeps of the measured masses, which roughly equates to 0.22 seconds. Dwell times on each mass are 400μs on ²⁰⁷Pb and ²³⁵U, and 200μs on all other masses; the switching between masses takes 40μs. ²³⁸U is calculated using $^{238}\text{U}/^{235}\text{U} = 137.818$.

Three zircon reference materials (91500, GJ-1 and Plesovice) were analyzed at regular intervals; the average bias of the ²⁰⁷Pb/²⁰⁶Pb and ²⁰⁶Pb/²³⁸U ratios from preferred values derived by TIMS analysis are used for normalization. Accepted ages are: 91500 - 1062 Ma ((²⁰⁶Pb/²³⁸U age, Wiedenbeck et al., 1995); GJ-1 - accepted ²⁰⁷Pb/²⁰⁶Pb age 609 Ma, but its ²⁰⁶Pb/²³⁸U age is accepted as ~602–604 Ma due to its slight normal discordance (Jackson et al., 2004); Plesovice - 337.13 Ma (Sláma et al., 2008). ²⁰⁶Pb/²³⁸U and ²⁰⁷Pb/²⁰⁶Pb uncertainties were propagated in a similar way utilizing the measurement uncertainty and the reproducibility of the ablation reference material used.

⁴⁰Ar-³⁹Ar dating

Unaltered, 50 μm-size muscovite grains were separated using a Frantz magnetic separator, hand-picked under a binocular microscope, and thoroughly rinsed with distilled water in an ultrasonic cleaner. Samples were loaded into two large wells of one 1.9 cm diameter and 0.3 cm depth aluminum disc. These wells were bracketed by small wells that included GA1550 biotite used as a neutron fluence monitor for which an age of 98.79 ± 0.55 Ma was adopted and in-between grain reproducibility has been demonstrated (Renne et al., 1998). The discs were Cd-shielded (to minimize undesirable nuclear interference reactions) and irradiated for 25 h in the Hamilton McMaster University nuclear reactor (Canada) in position 5C. The mean J-value computed from standard grains within the small pits range yielded 0.0096090 ± 0.0000183 determined as the average and standard deviation of J-values of the small wells for the irradiation disc. Mass discrimination was monitored using an automated air pipette and provided a mean value of 1.0013 ± 0.0047 (2σ) per dalton (atomic mass unit). The correction factors for interfering isotopes were (³⁹Ar/³⁷Ar)_{Ca} = 7.30x10⁻⁴ (±11%), (³⁶Ar/³⁷Ar)_{Ca} = 2.82x10⁻⁴ (±1%) and (⁴⁰Ar/³⁹Ar)_K = 6.76x10⁻⁴ (±32%).

The samples were step-heated using a 110 W Spectron Laser Systems, with a continuous Nd-YAG (IR; 1064 nm) laser rastered over the sample during 1mn to ensure a homogeneously distributed temperature. The gas was purified in a stainless steel extraction line using a GP50 and two AP10 SAES getters and a liquid nitrogen condensation trap. Ar isotopes were measured in static mode using a MAP 215–50 mass spectrometer (resolution of ~600; sensitivity of 2x10⁻¹⁴ mol/V) with a Balzers SEV 217 electron multiplier mostly using 9–10 cycles of peak-hopping. The data acquisition was performed with the Argus program written by M.O. McWilliams and ran under a LabView environment. The raw data were processed using the ArArCALC software (Koppers, 2002) and the ages have been calculated using the decay constants recommended by

Steiger and Jäger (1977). Blanks were monitored every 3–4 steps and typical ^{40}Ar blanks range from 1×10^{-16} to 2×10^{-16} mol. Ar isotopic data corrected for blank, mass discrimination and radioactive decay are given in electronic material. Individual errors are given at the 1σ level. Our criteria for the determination of plateau are as follows: plateaus must include at least 70% of ^{39}Ar . The plateau should be distributed over a minimum of 3 consecutive steps agreeing at 95% confidence level and satisfying a probability of fit (P) of at least 0.05. Plateau ages are given at the 2σ level and are calculated using the mean of all plateau steps, each weighted by the inverse variance of their individual analytical error. Mini-plateaus are defined similarly except that they include between 50% and 70% of ^{39}Ar . Integrated ages (2σ) are calculated using the total gas released for each Ar isotope. Inverse isochrons include the maximum number of steps with a probability of fit ≥ 0.05 . The uncertainties on the $^{40}\text{Ar}^*/^{39}\text{Ar}$ ratios of the monitors are included in the calculation of the integrated and plateau age uncertainties, but not the errors on the age of the monitor and on the decay constant (internal errors only, see discussion in Min et al., 2000).

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- The location of each sample is linked to a UK National Grid Reference.

TABLES

[Table 1. SHRIMP-Dataset](#)

[Table 2. UT TIMS data](#)

[Table 3. Moine Gabbros NORDSIM data](#)

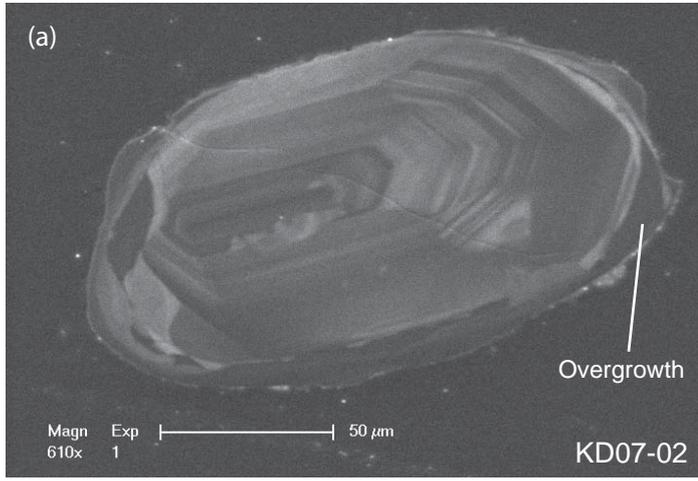
[Table 4. Cluanie Pegmatite TIMS data](#)

[Table 5. Cluanie Pegmatite LA-ICPMS data](#)

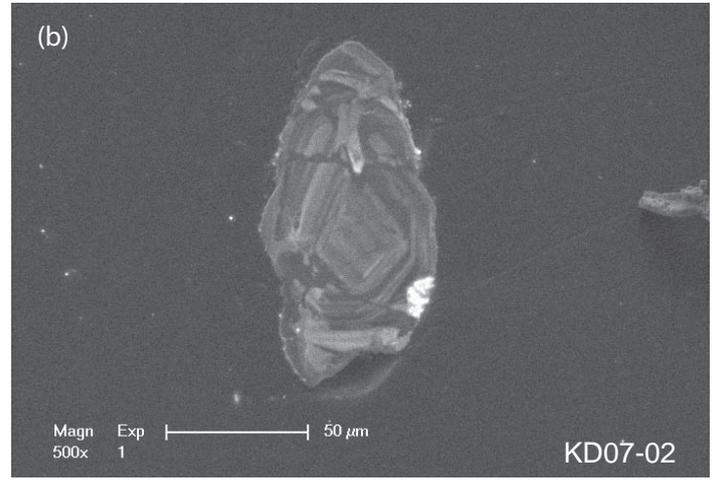
[Table 6. Argon supplementary material](#)

Morar metasediments: rounded morphology dominant

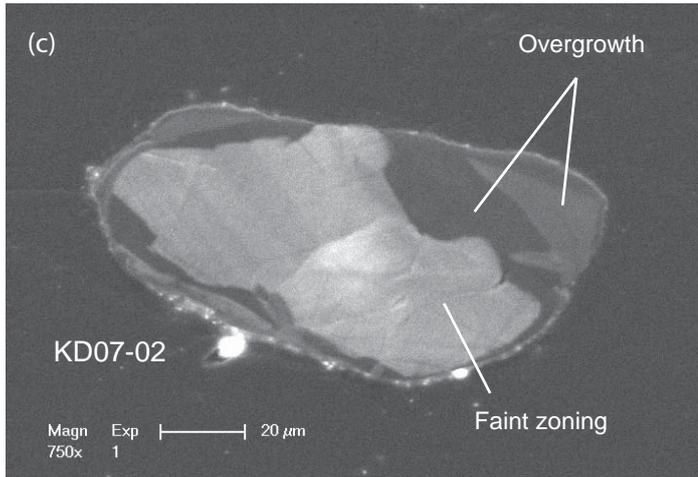
Complex oscillatory zoning



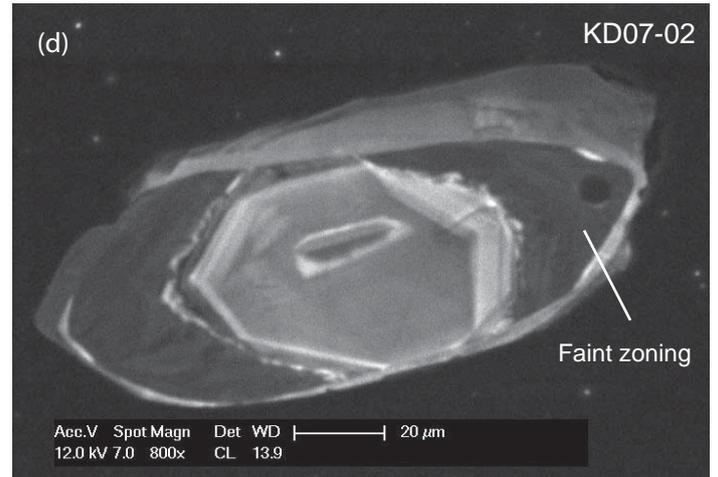
Multi-stage growth and resorption



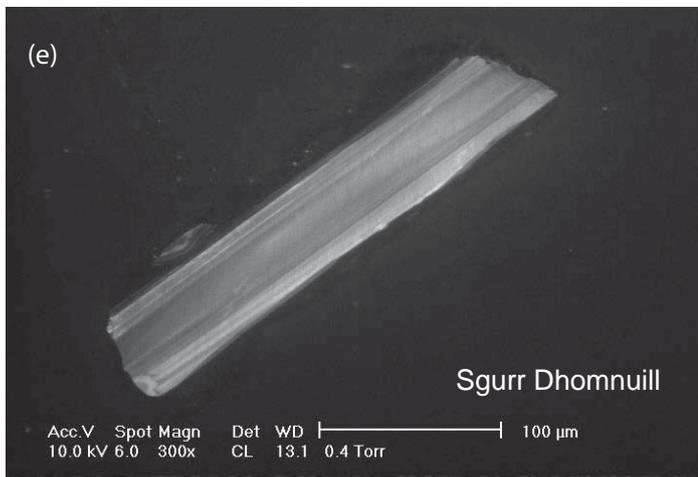
Faint zoning and overgrowth



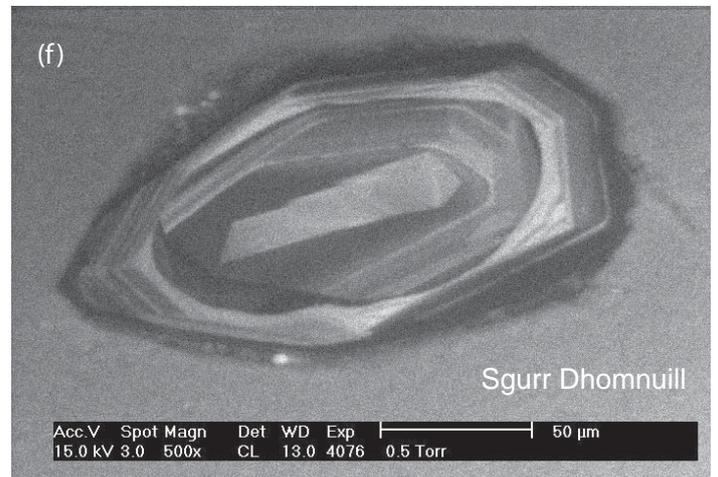
Inherited core



Magmatic acicular morphology

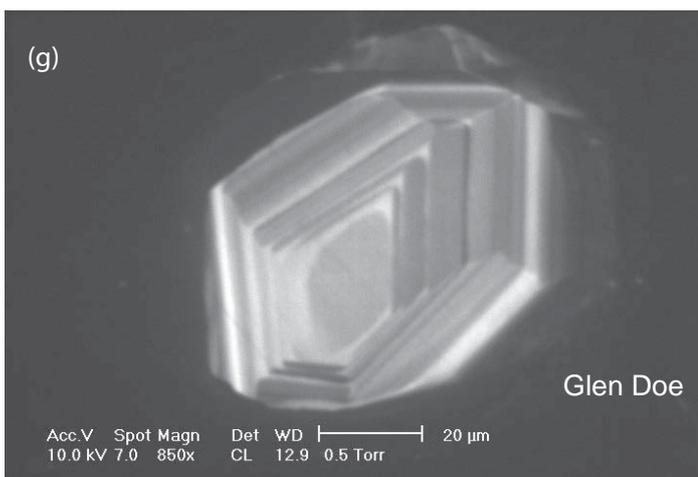


Magmatic euhedral morphology



Meta-igneous rocks: prismatic morphology dominant

Oscillatory zoning



Inherited cores

