The origin of high δ^{18}O zircons: Marbles, megacrysts, and metamorphism

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Abstract

The oxygen isotope ratios ($\delta^{18}O$) of most igneous zircons range from 5 to 8‰, with 99% of published values from 1345 rocks below 10‰. Metamorphic zircons from quartzite, metapelite, metabasite, and eclogite record $\delta^{18}O$ values from 5 to 17‰, with 99% below 15‰. However, zircons with anomalously high $\delta^{18}O$, up to 23‰, have been reported in detrital suites; source rocks for these unusual zircons have not been identified. We report data for zircons from Sri Lanka and Myanmar that constrain a metamorphic petrogenesis for anomalously high $\delta^{18}O$ in zircon. A suite of 28 large detrital zircon megacrysts from Mogok (Myanmar) analyzed by laser fluorination yield $\delta^{18}O$ from 9.4 to 25.5‰. The U-Pb standard, CZ3, a large detrital zircon megacryst from Sri Lanka, yields $\delta^{18}O = 15.4 \pm 0.1‰$ (2 SE) by ion microprobe. A euhedral unzoned zircon in a thin-section of Sri Lanka granulite facies calcite marble yields $\delta^{18}O = 19.4‰$ by ion microprobe, and confirms a metamorphic petrogenesis of zircon in marble.

Small oxygen isotope fractionations between zircon and most minerals require a high $\delta^{18}O$ source for the high $\delta^{18}O$ zircons. Predicted equilibrium values of $\Delta^{18}O$(calcite-zircon) = 2-3‰ from 800-600°C show that metamorphic zircon crystallizing in a high $\delta^{18}O$ marble will have high $\delta^{18}O$. The high $\delta^{18}O$ zircons (>15‰) from both Sri Lanka and Mogok overlap values of primary marine carbonates, and marbles are known detrital gemstone sources in both localities. The high $\delta^{18}O$ zircons are thus metamorphic; the 15-25‰ zircon values are consistent with a marble origin in a rock-dominated system (i.e., low $\text{fluid}_{(\text{external})}$/rock); the lower $\delta^{18}O$ zircon values (9-15‰) are consistent with an origin in an external fluid-dominated system, such as skarn derived from marble, although many non-metasomatised marbles also fall in this range of $\delta^{18}O$. High $\delta^{18}O$

(>15‰) and absence of zoning can thus be used as a tracer to identify a marble source for high $\delta^{18}O$ detrital zircons; this recognition can aid provenance studies in complex metamorphic terranes where age determinations alone may not allow discrimination of coeval source rocks. Metamorphic zircon megacrysts have not been reported previously, and appear to be associated with high grade marble. Identification of high $\delta^{18}O$ zircons can also aid geochronology studies that seek to date high grade metamorphic events due to the ability to distinguish metamorphic from detrital zircons in marble.

Keywords: zircon, oxygen isotopes, Sri Lanka, Mogok, marble, megacryst, SIMS

1. Introduction

The widespread occurrence and durability of zircon in many geologic environments has resulted in the development of an array of different chemical and isotopic analytical methods to understand its petrogenesis. Zircon has been shown to be highly retentive of oxygen isotope ratio ($\delta^{18}O$) over a wide range of geologic conditions and time (Valley et al. 1994; Watson and Cherniak 1997; Peck et al. 2003; Page et al. 2007a; Moser et al. 2008). With accurate empirical and theoretical oxygen isotope fractionation factors for zircon and co-existing phases (Valley 2003), analysis of $\delta^{18}O$ in zircon offers unique insights into a variety of petrologic processes, including the recognition of primitive mantle-equilibrated melts (Valley et al. 1998; Page et al. 2007b; Cavosie et al. 2009; Grimes et al. 2011), evidence of the first continents and oceans (Wilde et al. 2001; Cavosie et al. 2005); evolution of the continental crust (Valley et al. 2005; Hawkesworth and Kemp 2006; Moser et al. 2008); origin of large batholiths (Lackey et al. 2005, 2008); origin of low $\delta^{18}O$ magmas (Bindeman and Valley 2001; Bindeman et al. 2008), evaluation of mineral-melt and mineral-mineral equilibria (King et al. 2001; Valley et al., 2003; Lackey et al. 2006; Trail et al. 2009), and a monitor of whole-rock alteration (King et al. 1997). Studies of $\delta^{18}O$ in metamorphic zircon also yield important information about sub-solidus processes, including the composition of crustal fluids, partial melting, and recrystallization (Peck et al. 2003; Martin et al. 2006; Page et al. 2007a; Lancaster et al. 2009; Gordon et al. 2009). In addition to 'normal' igneous and metamorphic zircon, there exist lesser-known occurrences of anomalously high $\delta^{18}O$ zircons, with $\delta^{18}O$ values higher than values reported in zircon from common igneous and pelitic/siliceous metamorphic rocks (e.g., >15‰). Determining the origin of such high $\delta^{18}O$ in zircon is the focus of this paper.

Here we present laser fluorination analyses of $\delta^{18}O$ for a population of detrital zircons from Mogok (Myanmar), and ion microprobe measurements of $\delta^{18}O$ for two zircons from Sri Lanka. One of the Sri Lanka zircons is the widely used U-Pb standard CZ3, and the other is a zircon from a granulite facies marble. In conjunction with previous work, the new $\delta^{18}O$ data allow the first robust constraints to be placed on the origin of high $\delta^{18}O$ zircons. Of significance to the question of origin is the surprising fact that all reported occurrences of high $\delta^{18}O$ zircons ($\delta^{18}O$ >15‰) are either detrital or from an unusual source where reliable determinations of protolith have not been possible. A better understanding of origin based on oxygen isotope systematics will allow the high $\delta^{18}O$ values recorded in these grains to be used as a tracer for investigating the metamorphic petrogenesis of zircon.

1.1 The $\delta^{18}O$ of igneous zircon

Nearly all $\delta^{18}O$ studies of zircon (Zrn) have focused on magmatic grains, resulting in the recognition that most igneous zircon is either in high temperature equilibrium with mantle oxygen isotope ratios ($\delta^{18}O$(Zrn) = 5.3±0.6 ‰), or slightly higher (see reviews by Valley 2003; Valley et al. 2005). The upper limit for igneous $\delta^{18}O$(Zrn) has increased from primitive mantle values of ~5-6‰ to evolved values of ~10 ‰ since the end of the Archean as a consequence of tectonics, changes in the atmosphere, evolving processes of weathering, and maturation of the crust (Valley et al. 2005). However, 99% of reported $\delta^{18}O$ values for igneous zircon of all ages are below 10‰ (Fig. 1a). One notable exception is a suite of rare high δ^{18}O granitic rocks in the Grenville Frontenac Terrane (Shieh 1985), where granitoids are interpreted to have originated from melting of buried pelitic sediments and yield zircons with δ^{18}O up to 13.5‰ (Peck et al. 2004). Given that no other granitoids of any age have been found with such high δ^{18}O(Zrn) (Valley et al. 2005), the anomalously high δ^{18}O Frontenac zircons are considered unique. Igneous zircons can thus be characterized as having δ^{18}O <10‰.

1.2 The δ^{18}O of metamorphic zircon

We use the term "metamorphic zircon" to refer to whole zircons or parts of grains (e.g., rims) whose δ^{18}O composition results from sub-solidus processes, such as recrystallization or other processes that record oxygen isotope exchange with the host rock or fluids. Most published δ^{18}O data for metamorphic zircon (99%) range from 5 to 15‰ and are from metapelites and quartzites from the Adirondack Mountains (USA) and the Kapuskasing uplift (Canada), and metapelites and metabasites from Naxos (Greece) (Fig. 1b). Ion microprobe studies have demonstrated that zircon rims from Adirondack granulites (quartzites and pelitic migmatites) yield δ^{18}O as high as 12.8 ‰ (Peck et al. 2003; Page et al. 2007a; Lancaster et al. 2009); zircon rims from Adirondack amphibolite facies rocks (pelitic migmatites) yield similar values, up to 13.2‰ (Lancaster et al. 2009). The upper value of ~13‰ for Adirondack metamorphic zircon is thus comparable to that found in igneous zircon from the Frontenac granitoids, which is higher than all other igneous zircons. Detrital zircons from granulite facies quartzites in the Kapuskasing uplift contain igneous cores surrounded by metamorphic rims that yield δ^{18}O from 8.4 to 10.4‰ (Moser et al. 2008). At Naxos, metamorphic rims on zircons from metapelitic gneiss yield $\delta^{18}O$ up to 15‰ as measured by ion microprobe, and represent the highest $\delta^{18}O$ values published for zircons from metapelitic rocks (Martin et al. 2006).

1.3. High $\delta^{18}O$ zircons

Three occurrences of zircon with high $\delta^{18}O$ values from unknown or obscure source rocks have been published. Peck et al. (2001) and Valley (2003) report a $\delta^{18}O$ value of 22.9‰ for “Mog” (USNM #R18113), a large detrital zircon from a placer deposit in an amphibolite terrane near Mogok, Myanmar. The Mogok area is known for the mining of placer deposits that yield large gemstones such as corundum, forsterite, and spinel (Yui et al. 2008). Nasdala et al. (2008) reported a $\delta^{18}O$ of 13.9‰ for M257, a zircon U-Pb standard from Sri Lanka. Zircon M257 is a large megacryst (long dimension = 20 mm) detrital zircon from a placer deposit in the Highlands Southwest Complex, a granulite terrane in Sri Lanka that is also known for the mining of gemstones from placer deposits (Nasdala et al. 2008). Like Mog, the protolith of M257 is not known. The only report of an anomalously high $\delta^{18}O$ zircon from a known source rock is from an ultra-high pressure (UHP) terrane in the Dabie-Sulu Orogen, China. Zircons separated from an eclogite facies boudin of metasedimentary rock hosted in a UHP marble yield $\delta^{18}O$ = 16.8‰ by bulk laser analysis (Wu et al. 2006a). The authors cite the high $\delta^{18}O$ as evidence that oxygen isotope equilibrium was attained between the eclogite protolith and the zircons, and was buffered by the high $\delta^{18}O$ marble. Wu et al. (2006a) reported that cathodoluminescence (CL) imaging and U-Pb spot analysis showed that many of the zircons contain inherited cores with two distinct overgrowths; thus the bulk analysis of $\delta^{18}O$=16.8‰ is an average of core and multiple rim domains.

2. Samples and Methods

2.1. Detrital zircons (Myanmar)

Twenty-eight detrital zircons from a fluvial deposit near Mogok (Myanmar) were analyzed for $\delta^{18}O$ in this study. The zircons are rounded, large (2 to 8 mm in length), and occur in a variety of colors, including dark red, orange, olive green, yellow, and clear (see color images in Online Resource 2). The Mogok zircons were analyzed for $\delta^{18}O$ in ~2 mg aliquots at the University of Wisconsin by gas source mass spectrometry using BrF_5 and a 32 W CO_2 laser. Sample analyses were corrected for accuracy with UWG-2 garnet ($\delta^{18}O$ =5.8‰ VSMOW) (Valley et al. 1995), analyzed multiple times at the beginning of the run. The reproducibility of UWG-2 for the two analytical sessions (May 5, 2008 and May 6, 2009) was 0.04‰ (2 standard deviations, sd) for each session.

2.2. U-Pb standard CZ3 (Sri Lanka)

CZ3 is a zircon U-Pb standard from a fluvial deposit in a granulite terrane from Sri Lanka (Pidgeon et al. 1994). The CZ3 crystal was a large ~1 g zircon with no observable zoning (Pidgeon et al. 1994), and was adopted as the primary U-Pb standard used at the Curtin University SHRIMP facility (Nelson 1997; de Laeter and Kennedy 1998). CZ3 has a $^{206}Pb/^{238}U$ age of 564 Ma, and U and Th concentrations of 551±10 ppm and 30±2, respectively (Pidgeon et al. 1994; Nelson 1997; Nasdala et al. 2004). Forty analyses of rare earth elements (REE) by SHRIMP-RG yield an average ΣREE abundance of 26 ppm (Mattinson et al. 2006). The Lu-Hf isotope compositions of CZ3 are ^{176}Lu/^{177}Hf = 0.000034 and ^{176}Hf/^{177}Hf = 0.281729 (Xu et al. 2004; Wu et al. 2006b), which yield $\varepsilon Hf_{(564)}$ = -25.5 (Xu et al. 2004).

Six chips of CZ3 were analyzed for δ^{18}O by ion microprobe. The chips were previously embedded in four 25 mm diameter epoxy mounts where they were utilized as U-Pb standards (Cavosie et al. 2004). Cathodoluminescence (CL) imaging of the six chips yield mostly homogeneous images showing contrast variations only around cracks. No growth zoning (magmatic or otherwise) or mineral inclusions were observed in any chips of CZ3, consistent with previous descriptions (Pidgeon et al. 1994; Nasdala et al. 2004). The mounts were re-polished to remove pits following U-Pb determinations and analyses for δ^{18}O were made using a CAMECA IMS-1280 ion microprobe at the University of Wisconsin from July 19-21, 2006.

2.3. Zircon-bearing marble CJJ4 (Sri Lanka)

A zircon identified in a thin-section of a granulite facies marble from Sri Lanka was analyzed for δ^{18}O by ion microprobe. Rock sample CJJ4 was collected by Elsenheimer (1988) from the Highlands Southwest Complex of Sri Lanka, and reported to contain 70% carbonate. Elsenheimer (1988) reported the assemblage calcite + diopside + phlogopite + pyrite + scapolite + titanite + tremolite + zircon, and a value for δ^{18}O(calcite) of 23.6‰. In an archived thin section (UW #1845-88) cut from sample CJJ4, a euhedral zircon was identified enclosed in a calcite + tremolite matrix (Fig. 2a), and is interpreted on textural considerations to be a metamorphic zircon. No discernable cathodoluminescence signal was detected from this zircon (see image in Online Resource 3). The zircon was cast in the center of a 25 mm epoxy mount and re-polished (Fig. 2b), along with a chip of zircon oxygen isotope standard KIM5 for $\delta^{18}O$ analysis by ion microprobe.

2.4. WiscSIMS Cameca 1280 ion microprobe methods

Analysis protocols for $\delta^{18}O$ in zircon closely follow those described elsewhere (Kita et al 2009; Valley and Kita 2009). A $^{133}Cs^+$ primary ion beam (20 keV total impact voltage) was focused to a diameter of 10 μm on the sample surface. Secondary O^- ions were accelerated from the sample by –10 kV and the analysis site was centered under a uniform electron field generated by a normal-incidence electron gun for charge compensation. The intensity of ^{16}O was ~2 x10^9 cps, depending on the primary intensity (ca. 1 x 10^9 cps/nA). Mass resolving power was set to ca. 2500, sufficient to separate hydride interferences on ^{18}O. Two multi-collector Faraday cups (FC) were used for simultaneous measurement of ^{16}O and ^{18}O. The base line of the FC amplifiers was calibrated at the beginning of each analytical session. Total analytical time per spot was about 4 min, including time for locating and selecting the analytical positions (1 - 2 min), pre-sputtering (10 sec), automatic retuning of the secondary beam (ca. 60 sec), and analysis (80 sec). Chips of zircon standard KIM-5 ($\delta^{18}O$ = 5.09±0.12‰, 2 sd (standard deviation) VSMOW, Valley 2003; Cavosie et al. 2005) embedded in the sample mounts were used to calibrate $\delta^{18}O$ analyses of CZ3 and CJJ4.

3. Results

Sixteen $\delta^{18}O$ analyses were made of Sri Lanka zircon CZ3 by ion microprobe and calibrated with 40 bracketing analyses of KIM-5 (Table 1). The average of all CZ3 analyses made on the six grains in four different analytical sessions over 3 days (July 19-21, 2006) is $\delta^{18}O$ = 15.43 ± 0.42‰ VSMOW (2 sd, n=16, 2 standard error = 0.10‰) (Fig. 3). Uncertainty listed for individual analyses is based on the reproducibility of KIM-5 during that session, and ranges from 0.32 to 0.39‰ (2 sd). The sd of all 16 measurements of CZ3 (±0.42‰, 2 sd) is only slightly larger than that for KIM-5 in any given session (Table 1).

Six analyses of $\delta^{18}O$ were made on zircon CJJ4 by ion microprobe and calibrated with 12 bracketing analyses of KIM-5 (Table 2). During post-$\delta^{18}O$ analysis imaging of the analytical pits, analyses #4 and #5 were found to have been made close to a ~40 µm hole in the center of the grain that may have resulted from the preferential removal of intergrown calcite during polishing (Fig. 2a). The two pits were located on rough surfaces of the zircon that were slightly lower than the polished surface, and hence not made on a polished surface (Fig. 2b). Given the irregular nature of these pits, data from these two analyses were not considered further based on published criteria for evaluation and rejection of irregular pits (Cavosie et al. 2005). The remaining four analyses yield $\delta^{18}O$ = 19.4± 0.6‰ (2 sd) VSMOW. Uncertainty listed for individual analyses is based on the reproducibility of KIM-5 during that session, and ranges from 0.34 to 0.28‰ (2 sd). The $\delta^{18}O$ values for CZ3 and CJJ4 are plotted in Figure 4a along with previously published data from Sri Lanka, including calcite from granulite facies marbles and corundum from skarns and detrital deposits. Also plotted in Figure 4a is a shaded field indicating the range of $\delta^{18}O$(zircon) in equilibrium with measured $\delta^{18}O$(calcite) at 700°C.

Analyses for $\delta^{18}O$ were made on 28 detrital zircons from Mogok by laser fluorination during analytical sessions on May 5, 2008 and May 6, 2009 (Table 3). The

$\delta^{18}O$ values range from 9.37 to 25.48‰, with an average of 18.64‰. An uncertainty of 0.04‰ (2 sd) for individual analyses of Mogok zircons is based on the reproducibility of UWG-2 during the sessions. The $\delta^{18}O$ values for the Mogok zircons are plotted in Figure 4b along with previously published data from Mogok, including calcite from amphibolite facies marbles and other minerals from marble and detrital deposits.

4. Discussion

4.1 Constraints on the source rocks of high $\delta^{18}O$ zircons

The large range in $\delta^{18}O$ for both the Sri Lanka and Mogok $\delta^{18}O$(Zrn) data sets (Fig. 4) requires multiple source rocks. The high $\delta^{18}O$ values of the Sri Lanka (13.9 to 19.4‰) and Mogok (9.4 to 25.5‰) zircons allow first-order constraints to be placed on the nature of these sources. Crustal sources are indicated, as zircons with $\delta^{18}O$ >6‰ are not known from uncontaminated mantle-derived magmas (Valley et al. 1998; Cavosie et al. 2009; Grimes et al. 2011). A metamorphic origin is also indicated for the $\delta^{18}O$(Zrn) values >13.5‰ (27 of 32 grains, 84%), as igneous zircons with $\delta^{18}O$ above 13.5‰ are not known and values above 10‰ are rare (Valley et al. 2005) (Fig. 1a). Relatively small oxygen isotope fractionations between most minerals and zircon at high temperature (Valley 2003) further require the source rocks to have higher $\delta^{18}O$ (whole-rock) values than the zircons. Sedimentary rocks, such as shale, chert, limestone, as well as metamorphosed equivalents, have high primary $\delta^{18}O$ values relative to igneous rocks (e.g., >15‰) (Valley et al. 2005) and are thus suitable candidates for potential source rocks of the high $\delta^{18}O$ zircons. Pelitic shale can have whole-rock $\delta^{18}O$ up to 24‰; a global survey of shale yields an average $\delta^{18}O$ of 17‰ (Land and Lynch 1996). While shale is a high δ^{18}O source, metamorphosed shale does not appear to be a likely protolith for the large detrital zircons analyzed in this study, as zircons reported from metapelites are not megacrystic and commonly preserve growth zoning and inherited detrital cores (Dempster et al. 2004; Rasmussen 2005). The three high δ^{18}O Sri Lankan zircons (CJJ4, CZ3, and M257) all show an absence of growth zoning in CL. The highest values of δ^{18}O for metamorphic rims on Adirondack and Naxos zircons (up to 15‰) partially overlap 9 of 32 (30%) of the lowest δ^{18}O zircons from Sri Lanka and Mogok zircon δ^{18}O (Figs. 1 and 4), however, the high δ^{18}O domains in the Adirondack and Naxos zircons occur as rims around clearly identifiable zoned cores, not as large unzoned megacrystic zircons.

Chert is a high δ^{18}O source rock, and zircon in oxygen isotope equilibrium with high δ^{18}O chert (SiO_2) is predicted to have similarly high δ^{18}O (Valley et al. 2003). Zircon occurrences in chert appear to be rare, and may reflect the paucity of Zr. The only δ^{18}O reported for zircon in metamorphosed chert is by Page et al. (2009), who reported metamorphic rims with δ^{18}O from 17 to 24‰ around zircons with oscillatory zoned inherited igneous cores (δ^{18}O = 4.7 to 9.1‰) in amphibolite facies chert on Santa Catalina Island (USA). The high δ^{18}O rims from the Santa Catalina meta-chert zircons overlap with the highest δ^{18}O zircons from both Sri Lanka and Mogok. However, similar to the metapelite zircons, the high δ^{18}O components of the Santa Catalina zircons occur as rims around igneous cores, rather than as large megacrystic zircon, and no inherited cores or other growth zoning has been observed in the Sri Lanka zircons.

Marine carbonates, or marbles, commonly have δ^{18}O(calcite) >17‰ (Valley 1986); values up to 28‰ have been reported for many greenschist to granulite facies marbles (Fig. 5). For this discussion, we use "marble" to describe calcite- or dolomiterich rocks produced from the recrystallization of a marine carbonate protolith regardless of the extent of fluid-rock interaction, whereas "skarn" is used to describe a rock that is largely the result of metasomatic replacement of a carbonate protolith by a high fluid-rock interaction. Note that in marbles that have experienced high-grade metamorphism, the role of fluids can be controversial and this distinction may be unclear (Valley et al. 1990).

Zircons have been reported in marbles from several areas (Elsenheimer 1988; Ferry 1996; Tang et al. 2006; Liu et al. 2006); marble is thus known to contain zircon and has an appropriate range of δ^{18}O(whole-rock) to be a suitable source for the high δ^{18}O zircons. The hypothesis that marble is a source for high δ^{18}O zircons can be further evaluated based on oxygen isotope exchange considerations. The equilibrium fractionation factor for calcite-zircon calculated from published values for zircon-quartz and quartz-calcite yields $1000 \ln\alpha_{(\text{calcite-zircon})} = 2.26*10^6/T^2$ (T in K, Valley 2003). This fractionation factor yields Δ^{18}O(calcite-zircon) = 2.0 to 3.8‰ from 800 to 500 °C (Fig. 6). In the following sections δ^{18}O values of calcite from rocks in Mogok and Sri Lanka are compared with the zircon data to evaluate further marble as a potential source for the high δ^{18}O zircons.

4.2 Origin of Mogok high δ^{18}O zircons

The source of large zircons in the Mogok placer deposits has not been determined, however the area is well known for the occurrence of gemstone deposits (corundum, spinel, forsterite) in amphibolite facies marbles of Tertiary age, as well as placer deposits of these minerals (Garnier et al. 2008). Mogok marbles yield δ^{18}O(calcite) = 19.9 to

27.8‰ (Garnier et al. 2008; Yui et al. 2008), values typical for marine carbonate (Fig. 4b). Gemstones from Mogok marbles are also characterized by high $\delta^{18}O$, including rubies ($\delta^{18}O$ = 20.1 to 25.7‰), spinel ($\delta^{18}O$= 19.7 to 22.2‰), and forsterite ($\delta^{18}O$ = 19.2 to 22.0‰); corundum from placer deposits, desilicated pegmatites, and gemstones from unknown source rocks ranges to lower values ($\delta^{18}O$ = 10.3 to 21.4‰) (Giuliani et al. 2005; Garnier et al. 2008; Yui et al. 2008) (Fig. 4b). The $\delta^{18}O$ values of the zircons measured in this study overlap with the gemstones, particularly for the higher zircon values (Table 3). Not all of the Mogok detrital zircons are from high $\delta^{18}O$ rocks; there appear to be several source rocks represented in the zircon population based on the range in $\delta^{18}O$(Zrn) from 9.4 to 25.5‰ (a single source would be required to preserve >15‰ in $\delta^{18}O$(whole-rock) variability and is viewed as unlikely). A weak correlation exists between $\delta^{18}O$(Zrn) and color; dark red-to-orange zircons (n=8) are restricted to a narrower range from 12.6 to 15.8‰, whereas light yellow-to-green zircons span the entire range (see color images in Online Resource 2). Roughly half (16 of 29) of the Mogok detrital zircons have $\delta^{18}O$ >18‰, and are in oxygen isotope equilibrium with measured calcite at 700°C (Fig. 4b). Marble is thus interpreted as the source for the Mogok detrital zircons with $\delta^{18}O$ >18.0‰, whereas zircons with lower but still high $\delta^{18}O$ (9.4-17‰) could have originated in marble, skarn or other lower $\delta^{18}O$ rocks.

4.3 Origin of Sri Lanka high $\delta^{18}O$ zircons

4.3.1 Zircon CJJ4

The $\delta^{18}O$ value of 19.4‰ makes CJJ4 the highest $\delta^{18}O$ zircon identified from Sri Lanka. CJJ4 is also the only high $\delta^{18}O$ zircon in this study with a known source rock-granulite facies marble. Previously reported δ^{18}O(calcite) values from granulite facies marbles from the Highland Southwest Complex (HSWC) of Sri Lanka yield δ^{18}O(calcite) = 15.9 to 24.4‰ (Elsenheimer 1988; Hoffbauer and Spiering 1994), values typical of high grade marble (Fig. 5). The δ^{18}O(calcite) value of 23.6‰ measured by Elsenheimer (1988) for a bulk sample of calcite from the same hand sample as CJJ4 yields Δ^{18}O(calcite-zircon) = 4.2‰, corresponding to a temperature of 480°C if in equilibrium (Fig. 6). Zircon CJJ4 is euhedral and in textural equilibrium with calcite and tremolite (Fig. 2a), however it is not in isotopic equilibrium with calcite at granulite facies temperatures. The non-equilibrium fractionation may indicate that the calcite is zoned at the cm-scale; that is, the bulk calcite aliquot that yielded δ^{18}O = 23.6‰ may have contained calcite zoned with high and low δ^{18}O domains. Alternatively, the δ^{18}O value of this calcite may have been partially reset during granulite facies metamorphism or subsequent retrograde metamorphism. Taken together, the high δ^{18}O and absence of growth zoning are consistent with the petrographic occurrence of zircon CJJ4 as a metamorphic grain, and provides 'ground truth' that high δ^{18}O zircons can crystallize in marble.

4.3.2 Detrital zircon CZ3

Both CZ3 and M257 have U-Pb ages that coincide with the timing of Neoproterozoic granulite facies metamorphism at ca. 570-560 Ma in the HSWC (Kröner and Williams 1993; Hölzl et al. 1994). The compositions of CZ3 and M257 have previously been well characterized due to their use as standards in U-Pb geochronology, and thus additional geochemical data are available for evaluating marble as a source for these zircons based on the $\delta^{18}O$ values.

For CZ3, trace element abundances and ratios support a crustal origin, including high U (551 ppm) and low Th/U (0.05) (Pidgeon et al. 1994; Nelson 1997; Belousova et al. 1998; Valley et al. 1998; Konzett et al. 2000; Belousova et al. 2002; Nasdala et al. 2004). The low average ΣREE abundance of 26 ppm for CZ3 (Mattinson et al. 2006) is not typical of igneous zircon from the crust; such low abundances have only been previously reported for zircons from kimberlite (Belousova et al. 1998; Spetsius et al. 2002; Page et al. 2007b) and carbonatite (Hoskin and Schaltegger 2003). The CART classification scheme for zircon provenance based on trace element composition (Belousova et al. 2002) suggests an origin for CZ3 in kimberlite, however, the high U, low εHf (Griffin et al. 2000), low Th/U, and high $\delta^{18}O$ of CZ3 clearly preclude an origin in the mantle. Separately, each trace element data set for CZ3 shows characteristics typical for igneous zircon from both the crust (U, εHf, $\delta^{18}O$) and the mantle (ΣREE), and also for metamorphic zircon (Th/U). However, the combined trace element data for CZ3 are unlike any known igneous zircon (Hoskin and Ireland 2000; Belousova et al. 2002; Hoskin and Schaltegger 2003), and taken together with the high $\delta^{18}O$ and lack of growth zoning in CZ3, are consistent with a metamorphic petrogenesis in marble, or skarn derived from marble. With a $\delta^{18}O$ value of 15.4‰, CZ3 is in equilibrium with measured $\delta^{18}O$ values of Sri Lanka calcite at temperatures from 700-800°C (Fig. 4a).

4.3.3 Detrital zircon M257

Zircon standard M257 has a $\delta^{18}O$ value of 13.9‰ (Nasdala et al. 2008), slightly lower than CZ3. M257 has a $^{206}Pb/^{238}U$ age of 561 Ma, U abundance of 840 ppm, a Th/U ratio of 0.27, and it is unzoned (Nasdala et al. 2008). It contains ~1 ppm Li, and has a $\delta^{7}Li$ value of 2.1±1.0 (Li et al. 2010). No other trace element data have thus far been reported for M257. With a $\delta^{18}O$ of 13.9‰, M257 is marginally in equilibrium with the lowest measured $\delta^{18}O$ values of Sri Lanka calcite at temperatures of 700-800°C (Fig. 4a). The similarity of M257 to CZ3 in age, lack of growth zoning, and lower, but still high, $\delta^{18}O$, indicate that M257 also originated as a metamorphic zircon, in marble or marble-derived skarn.

4.4 Petrogenesis of high $\delta^{18}O$ zircons

Zircon was identified as a trace mineral in 5 of 33 granulite facies marbles from Sri Lanka by Elsenheimer (1988). In this paper it is further demonstrated by in situ analysis that Sri Lanka granulite facies marble (sample CJJ4) contains high $\delta^{18}O$ zircon, here interpreted to have crystallized during high grade metamorphism. We propose that metamorphosed marble is a suitable source rock for the high $\delta^{18}O$ detrital zircons from Sri Lanka and Mogok analyzed in this study, based on the oxygen isotope systematics between zircon and calcite, and also from the results of other studies that have demonstrated the occurrence of zircon in marble. Tang et al. (2006) reported zircons in 'impure marble' from the Sulu orogen (China) and interpreted their origin as detrital igneous grains, based on euhedral forms and the presence of oscillatory zoning. If detrital zircons provide the Zr for metamorphic zircon growth in high grade marbles, a process of dissolution and reprecipitation is indicated; this is consistent with the absence of inherited zoning in the high $\delta^{18}O$ zircons reported here. Dissolution and reprecipitation may explain other occurrences and/or disappearances of zircon in marble. In the Ballachulish contact aureole (Scotland), zircon occurs as a trace phase in siliceous quartz-free dolomites, persisting until the baddeleyite isograd is encountered (Ferry 1996):

zircon + 2 dolomite = baddeleyite + forsterite + 2 calcite + 2 CO_2

$$ZrSiO_4 + 2\ CaMg(CO_3)_2 = ZrO_2 + Mg_2SiO_4 + 2\ CaCO_3 + 2\ CO_2$$

Phase equilibria constraints demonstrate that zircon in the Ballachulish aureole is stable with dolomite at 3 kbar and at temperatures up to ~710 °C (Ferry 1996; Ferry et al. 2002). The upper stability of zircon will reach higher temperature and pressure values in quartz-saturated calcitic marbles in the absence of dolomite. A 'zircon-in' reaction was not identified for the Ballachulish marbles; it is thus unclear if these zircons are detrital or metamorphic, as their zoning characteristics were not described. Zircon was also reported as an abundant accessory phase in high $\delta^{18}O$ marble dikes cross-cutting granulite facies rocks in the eastern Himalaya that were interpreted to be remobilized from metasedimentary carbonates (Liu et al. 2006); zircon zoning characteristics were not reported, so both detrital and metamorphic origins are possible.

The reports of zircon in marble described above include grains that range from 10s to <200 µm in length; thus the processes active during their formation may be applicable to the petrogenesis of high $\delta^{18}O$ zircon CJJ4 (Fig. 2), which at ~150 µm can be considered a 'typical' size zircon. The above examples do not, however, describe the occurrence of megacrystic zircon in marble; the formation and/or (re)crystallization mechanisms may be very different for the large high δ^{18}O zircons from Mogok and Sri Lanka, some of which are > 8 mm (Online Resource 2). Zircon megacrysts have been reported from numerous rock types, including kimberlites (Kresten et al 1975; Valley et al. 1998; Page et al. 2007b), carbonatites, syenites, and alkali basalts (Hinton and Upton 1991; Sutherland 1996), and to a lesser extent, granitic pegmatites. In all cases, the zircons have been interpreted as igneous grains that originated in mantle-derived melts based on the presence of oscillatory growth zoning (Page et al. 2007b; Ashwal et al. 2007; Siebel et al. 2009) and mantle-equilibrated oxygen isotope ratios (Valley et al. 1998; Upton et al. 1999; Valley, 2003; Page et al. 2007b; Siebel et al. 2009).

The large detrital zircons from Sri Lanka and Myanmar described here are clearly distinguishable from previous reports of igneous zircon megacrysts based on their high δ^{18}O values and absence of growth zoning, and may represent the first report of megacrystic zircon from metamorphic rocks (even though we emphasize the fact that their host rocks have not been identified). It is therefore likely that different crystallization processes were active during the solid-state formation of the high δ^{18}O metamorphic megacrysts compared to the igneous megacrysts. Several studies have addressed processes governing the growth, recrystallization, and coarsening of zircon in quartzite and metapelitic rocks, including Ostwald ripening and the role of anatectic melt enhanced Zr transfer (Nemchin et al. 2001; Ayers et al. 2003; Peck et al. 2010). Without knowledge of certain characteristics of the host rocks for the high δ^{18}O megacrysts (e.g., bulk composition, Zr content, zircon crystal size distribution), it is not possible to evaluate the influence of Ostwald ripening or the presence of partial melts during the formation of the megacrysts. However, we note that in the above three studies the amount of coarsening reported, whether by Ostwald ripening (Ayers et al. 2003) or in conjunction with melt transfer (Nemchin et al. 2001; Peck et al. 2010) did not produce zircons larger than 250 µm (most are <100 µm), even when the overgrowth constituted 70% by volume of the grain. Moreover, in all cases, the newly precipitated overgrowths preserve readily identifiable growth zoning in CL images. It appears that both Ostwald ripening and/or partial melting in quartzite and metapelitic rocks, where documented, produce metamorphic zircons with markedly different internal zoning characteristics and grain sizes when compared to the high δ^{18}O zircon megacrysts from Sri Lanka and Mogok. A detailed investigation of the growth mechanisms for the high δ^{18}O megacrysts is beyond the scope of this paper, and would require identification of the source rocks.

4.5. Conclusions

The δ^{18}O of zircon from high δ^{18}O marble is a readily identifiable isotopic fingerprint of the source. The δ^{18}O of 19.4‰ for zircon CJJ4 from this study confirms a metamorphic petrogenesis of zircon in marble. High δ^{18}O can be combined with other geochemical data for determining provenance of detrital metamorphic zircon derived from carbonate rocks. Detrital zircons with δ^{18}O of 15‰ or higher are most likely to have originated in high δ^{18}O marble or skarn derived from marble. Meta-chert and metapelite can also be high δ^{18}O source rocks, however high δ^{18}O zircons reported from these lithologies occur as rims around inherited igneous cores and are thus readily distinguishable from the large and unzoned grains described here. Targeting high δ^{18}O metamorphic zircon in marble for U-Pb analysis may provide more accurate determination of the timing of high grade marble formation.

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FIGURE CAPTIONS

Fig. 1 Compilation of oxygen isotope ratios for zircon from igneous and metamorphic rocks. The shaded vertical bar indicates range of mantle-equilibrated zircon, 5.3±0.6‰ (2 sd, Valley et al. 2005). **a** Oxygen isotope data for zircons separated from 1345 igneous rocks. Note that 99% of all igneous data are lower than 10‰ (dashed vertical line). **b** Oxygen isotope data for metamorphic zircons and rims from quartzites, metapelites, and metabasites. Note that 99% of all metamorphic data are lower than 15‰ (dashed vertical line). Data in **a** are from Valley et al. 2005 (n=1117) and 15 additional studies published from 2006-2010 (n=228); references in Online Resource 1)

Fig. 2 Zircon CJJ4 from Sri Lanka granulite facies marble. **a** Back-scattered electron image of zircon CJJ4 in thin-section, prior to removal for casting in epoxy. **b** Secondary electron image of zircon CJJ4 after casting in epoxy and re-polishing. The lower-left tip of the zircon correlates to the tip on the left side of the zircon in **a**. White circles indicate location of δ^{18}O analysis pits by ion microprobe, including analysis number (Table 2). Zrn = zircon; Tr = tremolite; Cal = calcite

Fig. 3 Histogram of oxygen isotope analyses of zircon U-Pb standard CZ3 by ion microprobe

Fig. 4 Compilation of oxygen isotope ratios for zircon and other minerals from Sri Lanka and Mogok (Myanmar). **a** Sri Lanka data include δ^{18}O values of calcite from granulite facies marbles (Elsenheimer 1988; Hoffbauer and Spiering 1994); detrital zircon megacrysts CZ3 (this study) and M257 (Nasdala et al. 2008); zircon from granulite facies marble (CJJ4, this study); and corundum from various sources (Giuliani et al. 2005). **b** Mogok data include δ^{18}O values of calcite from amphibolite facies marbles (Garnier et al. 2008; Yui et al. 2008); detrital zircons (this study: n=28; Valley 2003: n=1); and corundum, spinel, and forsterite (Garnier et al. 2008; Giuliani et al. 2005; Yui et al. 2008). The star indicates the interpreted primary calcite δ^{18}O value of 27.5‰ by Yui et al. (2008). The vertical dashed line in both zircon histograms at 10‰ is the igneous '99% limit' indicated in Figure 1a. The shaded area in both zircon histograms indicates the range of δ^{18}O values calculated for zircon in equilibrium with the measured range of δ^{18}O values for **a** Sri Lanka calcite at 800 °C and **b** Mogok calcite at 700 °C. Note that choosing lower metamorphic temperatures would shift the shaded ranges in both histograms to the left. See text for discussion

Fig. 5 Compilation of 605 oxygen isotope analyses of dolomite, calcite, and WR from amphibolite and granulite facies marbles and skarns. The data represent 20 different high grade metamorphic terranes. Mrbl = marble; WR = whole rock. Data sources are listed in Online Resource 1

Fig. 6 Oxygen isotope equilibrium for calcite-zircon. The calcite-zircon fractionation factor is from Valley (2003)

Table 1. Cameca 1280 oxygen isotope analyses of zircon U-Pb standard CZ3.

Grain-spot	^{18}O/^{16}O (meas, x10^{3})[a]	2 SE[b]	δ^{18}O (meas)	2 SE	δ^{18}O (VSMOW)	2 SD[c]
Mount 01JH-13b (chip 1) July 19 2006						
KIM5-44	2.01837	0.000412	6.57	0.20		
KIM5-45	2.01742	0.00043	6.09	0.21		
KIM5-46	2.01766	0.000617	6.21	0.31		
KIM5-47	2.01806	0.000455	6.42	0.23		
KIM5-48	2.01770	0.000555	6.23	0.28		
KIM5-49	2.01796	0.00040	6.36	0.20		
CZ3-1.1	2.03817	0.000506	16.44	0.25	15.21	0.32
CZ3-1.2	2.03924	0.000429	16.97	0.21	15.74	0.32
CZ3-1.3	2.03880	0.000587	16.76	0.29	15.52	0.32
KIM5-50	2.01732	0.000616	6.04	0.31		
KIM5-51	2.01787	0.000471	6.32	0.23		
KIM5-52	2.01823	0.000548	6.50	0.27		
KIM5-53	2.01822	0.000538	6.49	0.27		
KIM5-54	2.01784	0.000542	6.31	0.27		
KIM5-55	2.01799	0.000581	6.38	0.29		
KIM-5 (n=12)						0.32
Mount 01JH-36 (chip 2) July 20 2006						
KIM5-1	2.01774	0.000608	6.26	0.30		
KIM5-2	2.01865	0.000567	6.71	0.28		
KIM5-3	2.01856	0.000505	6.67	0.25		
KIM5-4	2.01844	0.000537	6.60	0.27		
KIM5-5	2.01899	0.000433	6.88	0.22		
KIM5-6	2.01834	0.000457	6.55	0.23		
CZ3-2.1	2.03876	0.000369	16.74	0.18	15.25	0.32
KIM5-7	2.01838	0.00047	6.57	0.23		
KIM5-8	2.01819	0.000539	6.48	0.27		
KIM5-9	2.01836	0.00050	6.57	0.25		
KIM5-10	2.01826	0.000566	6.52	0.28		
KIM-5 (n=10)						0.32
Mount 01JH-54b (chip 3) July 21 2006						
KIM5-11	2.01867	0.000547	6.72	0.27		
KIM5-12	2.01886	0.00052	6.81	0.26		
KIM5-13	2.01912	0.000422	6.94	0.21		
KIM5-14	2.01838	0.000561	6.57	0.28		
CZ3-3.1	2.03977	0.000525	17.24	0.26	15.55	0.33
CZ3-3.2	2.03938	0.000475	17.04	0.23	15.35	0.33
CZ3-3.3	2.04011	0.000313	17.41	0.15	15.72	0.33

Table 1. Cameca 1280 oxygen isotope analyses of zircon U-Pb standard CZ3.

KIM5-15	2.01932	0.000488	7.04	0.24		
KIM5-16	2.01879	0.000453	6.78	0.22		
KIM5-17	2.01912	0.000423	6.94	0.21		
KIM5-18	2.01844	0.00050	6.60	0.25		
KIM5-19	2.01850	0.000464	6.63	0.23		
KIM-5 (n=9)						0.33
Mount W74/4 (chip 4, 5, 6) July 21 2006						
KIM5-1	2.01747	0.00050	6.12	0.25		
KIM5-2	2.01805	0.000416	6.41	0.21		
KIM5-3	2.01775	0.000573	6.26	0.28		
KIM5-4	2.01792	0.000355	6.34	0.18		
CZ3-4.1	2.03880	0.000424	16.76	0.21	15.47	0.39
CZ3-5.1	2.03808	0.000327	16.40	0.16	15.12	0.39
CZ3-6.1	2.03899	0.000539	16.85	0.26	15.57	0.39
CZ3-4.2	2.03810	0.000518	16.41	0.25	15.12	0.39
CZ3-5.2	2.03814	0.00040	16.43	0.20	15.15	0.39
CZ3-6.2	2.03867	0.000466	16.69	0.23	15.41	0.39
CZ3-4.3	2.03870	0.00040	16.71	0.20	15.42	0.39
CZ3-5.3	2.03902	0.000452	16.87	0.22	15.58	0.39
CZ3-6.3	2.03921	0.000562	16.96	0.28	15.68	0.39
KIM5-5	2.01833	0.000438	6.55	0.22		
KIM5-6	2.01803	0.000486	6.40	0.24		
KIM5-7	2.01877	0.000379	6.77	0.19		
KIM5-8	2.01764	0.000377	6.20	0.19		
KIM5-9	2.01785	0.00050	6.31	0.25		
KIM-5 (n=9)						0.39
CZ3 (average, n=16)				**0.11**	**15.43**	**0.42**

Analyses are listed in chronological order, within each session

Sample analyses are bracketed by the zircon standard KIM-5

[a]Meas = measured; [b]SE = standard error; [c]SD = standard deviation

Table 2. Cameca 1280 oxygen isotope analyses of Sri Lanka zircon CJJ4.

Grain-spot	$^{18}O/^{16}O$ (meas, x10^3)[a]	2 SE[b]	$\delta^{18}O$ (meas)	2 SE	$\delta^{18}O$ (VSMOW)	2 SD[c]
Mount CJJ4: August 10, 2009						
KIM5-1	2.01717	0.00037	5.97	0.18	-	
KIM5-2	2.01764	0.00044	6.20	0.22	-	
KIM5-3	2.01740	0.00044	6.08	0.22	-	
KIM5-4	2.01716	0.00054	5.96	0.27	-	
CJJ4-1	2.04679	0.00038	20.74	0.19	19.66	0.34
KIM5-5	2.01748	0.00071	6.12	0.35	-	
KIM5-6	2.01821	0.00040	6.49	0.20	-	
KIM5-7	2.01781	0.00044	6.29	0.22	-	
KIM5-8	2.01760	0.00050	6.18	0.25	-	
CJJ4-2	2.04554	0.00043	20.12	0.21	18.94	0.28
CJJ4-3	2.04661	0.00035	20.65	0.17	19.47	0.28
CJJ4-4	2.02765	0.00037	11.20	0.18	~~10.02~~*	0.28
CJJ4-5	2.02950	0.00030	12.12	0.15	~~10.94~~*	0.28
CJJ4-6	2.04684	0.00045	20.77	0.22	19.58	0.28
KIM5-9	2.01791	0.00034	6.34	0.17	-	
KIM5-10	2.01739	0.00032	6.08	0.16	-	
KIM5-11	2.01760	0.00045	6.19	0.22	-	
KIM5-12	2.01798	0.00041	6.37	0.21	-	
CJJ4 (average, n=4)					**19.4**	**0.6**

Analyses are listed in chronological order, within each session
Sample analyses are bracketed by the zircon standard KIM-5
[a] meas = measured; [b] SE = standard error; [c] SD = standard deviation
*Irregular analysis spot- data rejected. See text for discussion.

Table 3. Laser fluorination oxygen isotope analyses of detrital zircons from Mogok, Myanmar.

Sample #	aliquot (mg)	Color	δ^{18}O	2 SD[a]
Session 1: May 5, 2008 (n=10)				
MOGOK 2o	2.12	clear/ lt. yellow[b]	24.33	0.04
MOGOK 2g	1.96	clear/ lt. green	23.44	0.04
MOGOK 1A	2.06	clear/ lt. yellow	23.10	0.04
MOGOK 2i	1.89	lt. yellow/ olive green	21.89	0.04
MOGOK 1k	2.16	dark green	19.21	0.04
MOGOK 1H	2.68	lt. orange/ honey yellow	17.96	0.04
MOGOK 2a	1.96	lt. orange	15.65	0.04
MOGOK 2j	2.15	lt. yellow	12.08	0.04
MOGOK 2b	2.80	lt. orange	10.72	0.04
MOGOK 2h	2.31	lt. olive green	9.37	0.04
UWG-2	1.66		5.53	-
UWG-2	1.59		5.56	-
UWG-2	1.49		5.52	-
UWG-2, average (n=3)			5.54	0.04
Session 2: May 6, 2009 (n=18)				
Mogok 2L	2.88	clear/ lt. olive green	25.48	0.04
Mogok 2M	2.95	clear/ lt. yellow	25.37	0.04
Mogok 1G	2.32	clear/ lt. yellow	25.09	0.04
Mogok 1D	2.49	lt. yellow/ olive green	24.78	0.04
Mogok 1E	2.92	clear/ lt. green	22.38	0.04
Mogok 2D	2.40	clear/ lt. yellow	22.15	0.04
Mogok 2E	2.48	clear/ lt. yellow	21.77	0.04
Mogok 1i	2.56	lt. yellow/ olive green	20.83	0.04
Mogok 1J	3.02	lt. yellow/ olive green	18.90	0.04
Mogok 2N	2.53	clear/ lt. yellow	16.97	0.04
Mogok 1C	2.81	dark yellow/ olive green	16.68	0.04
Mogok 4H	2.65	orange-red	15.85	0.04
Mogok 4F	2.92	orange	15.83	0.04
Mogok 4D	2.66	dark orange-red	14.27	0.04
Mogok 3D	3.15	dark orange-red	14.21	0.04
Mogok 4C	2.64	dark red	13.96	0.04
Mogok 3B	2.57	two-tone: dark red to clear	12.82	0.04
Mogok 4E	2.85	dark red	12.58	0.04
UWG-2	2.06		5.80	-
UWG-2	2.23		5.76	-
UWG-2	1.67		5.76	-
UWG-2	1.51		5.78	-
UWG-2, average (n=4)			5.78	0.04

[a] SD = standard deviation; [b] lt. = light

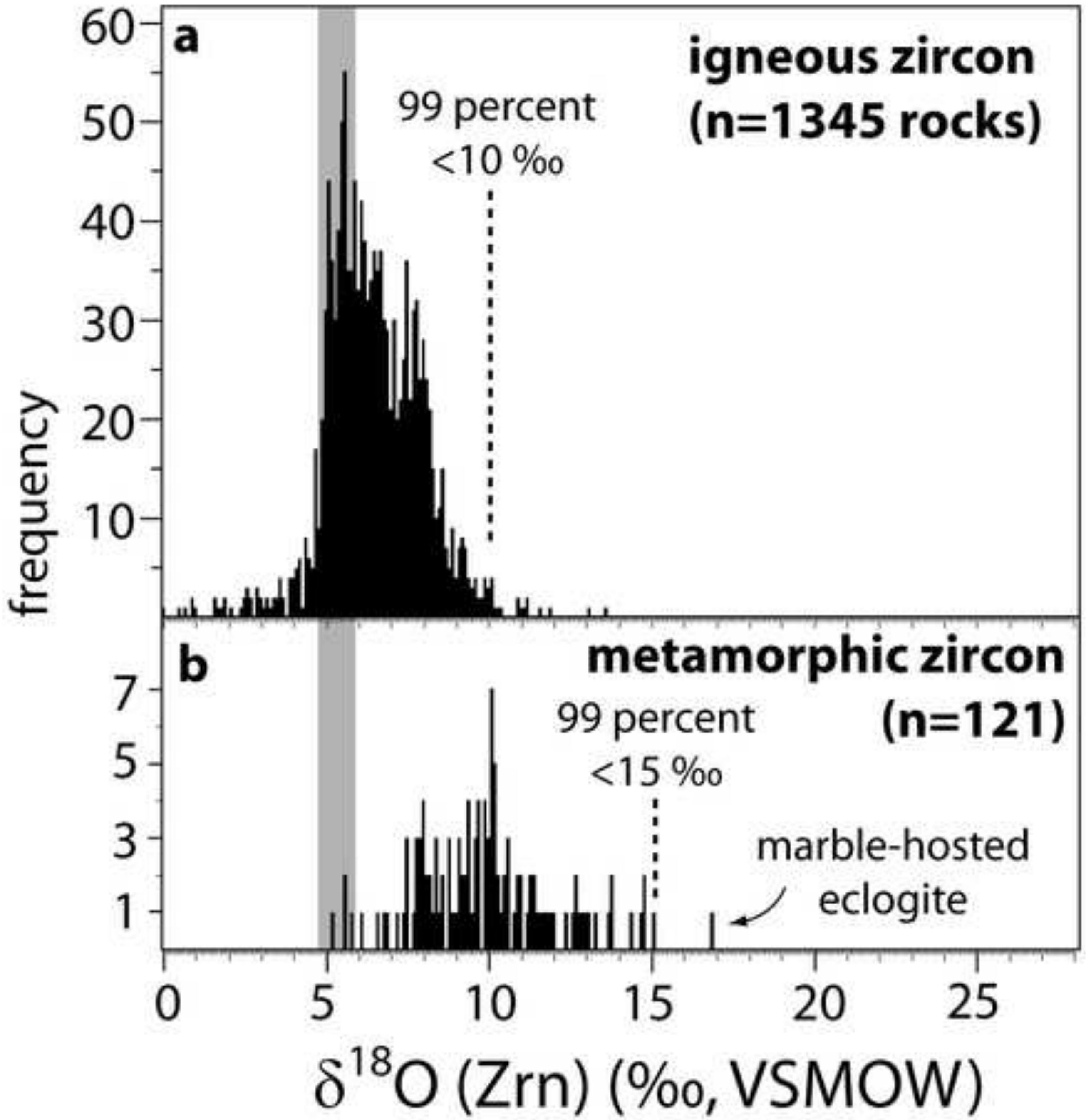
60
50
40
30
20
10
frequency
a
igneous zircon
(n=1345 rocks)
99 percent
<10 ‰
b
metamorphic zircon
(n=121)
7
5
3
1
99 percent
<15 ‰
marble-hosted
eclogite
0
5
10
15
20
25
δ18O (Zrn) (‰, VSMOW)

Fig. 1

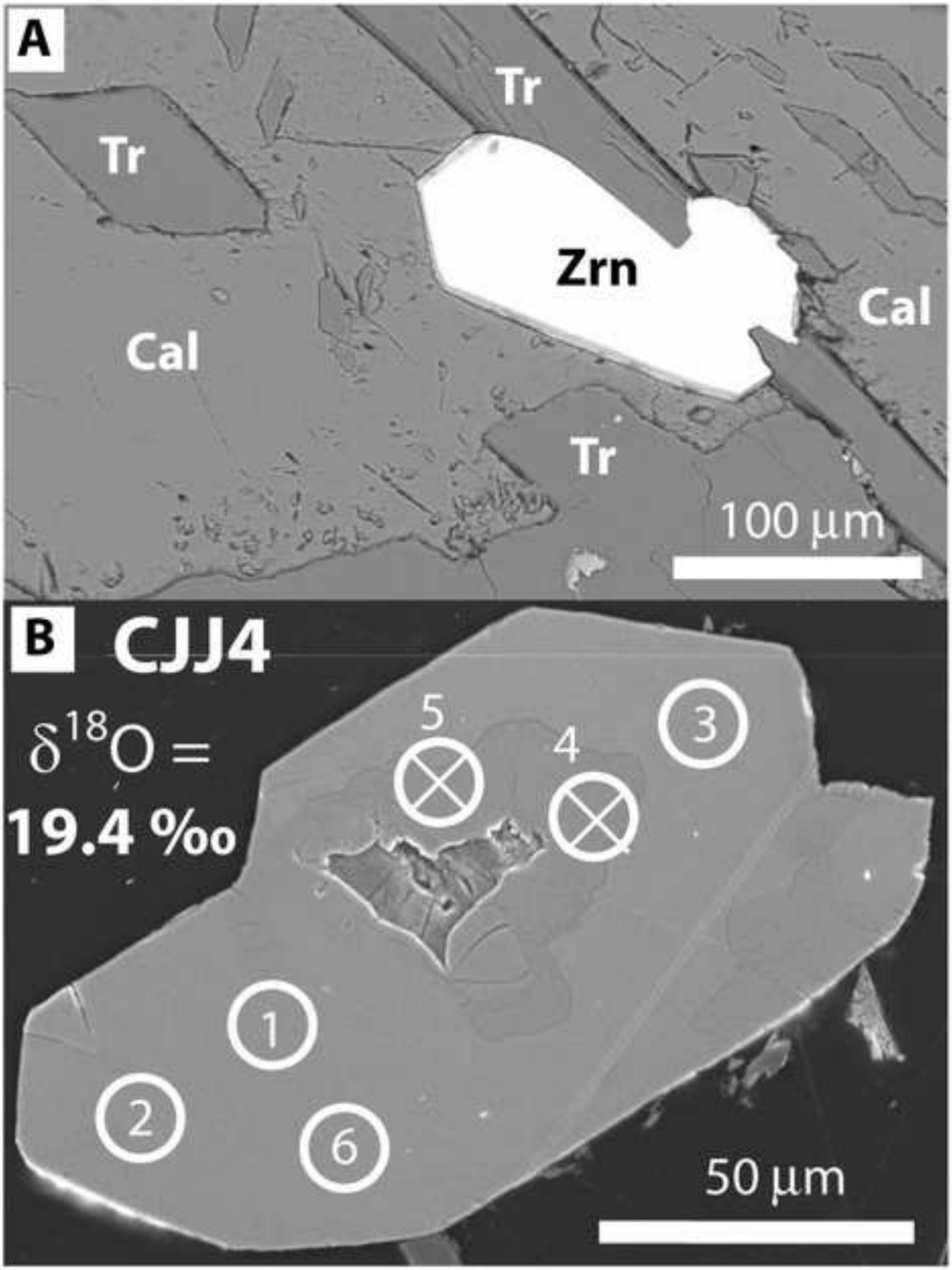

Figure 2

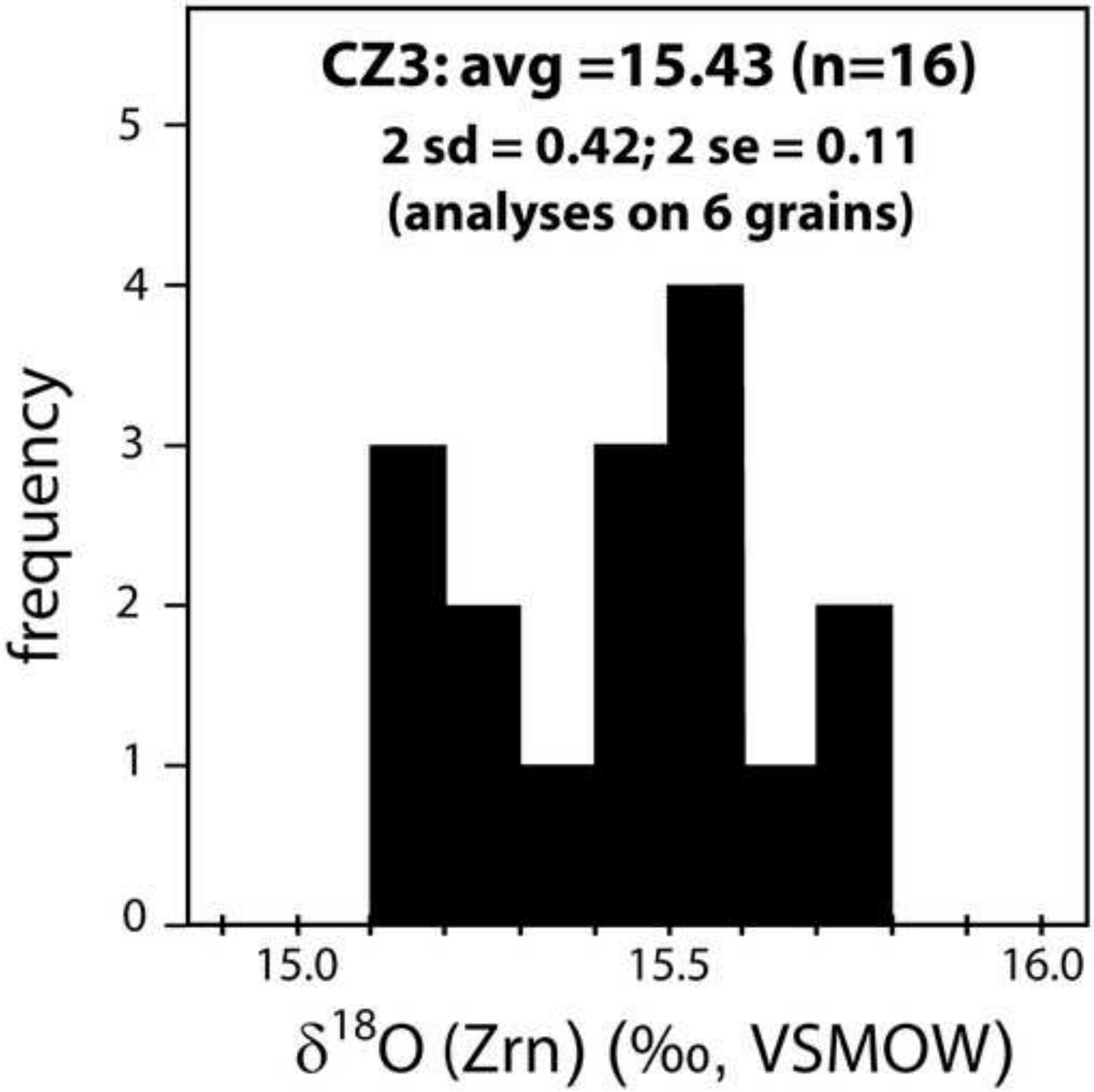
CZ3: avg =15.43 (n=16)
2 sd = 0.42; 2 se = 0.11
(analyses on 6 grains)
frequency
0
1
2
3
4
5
15.0
15.5
16.0
δ18O (Zrn) (‰, VSMOW)

Figure 3

line figure

Click here to download high resolution image

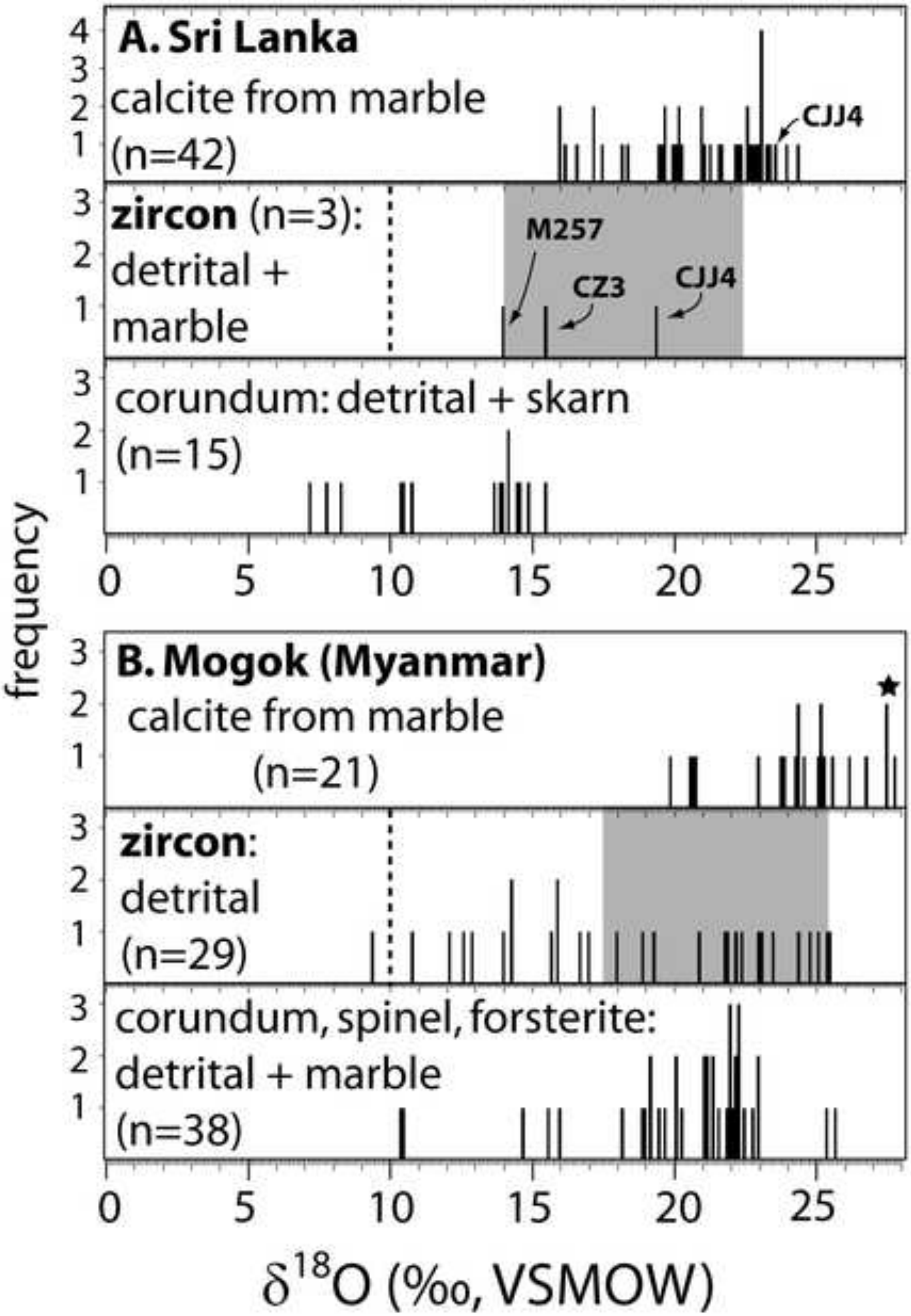

Figure 4

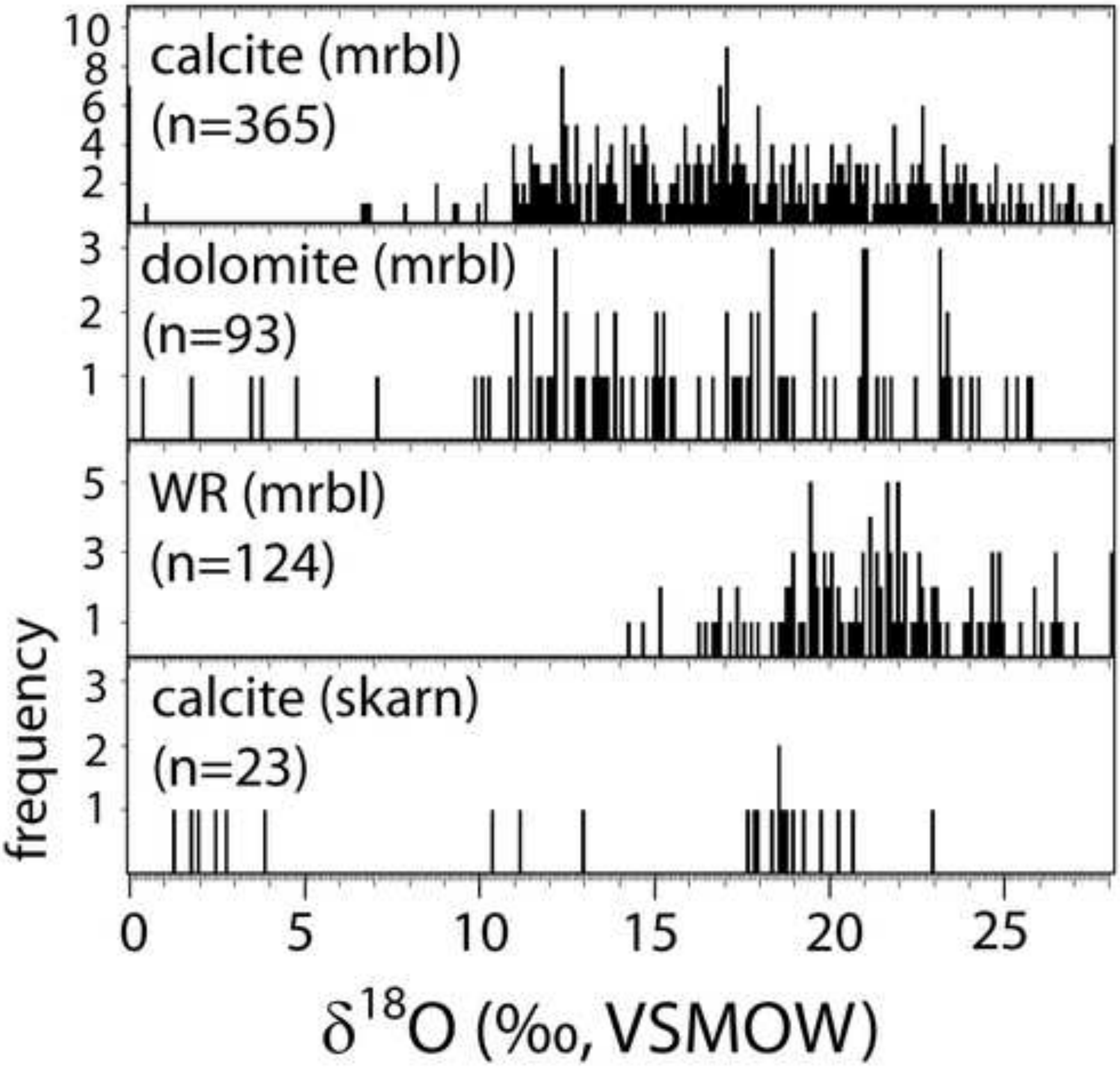
calcite (mrbl)
(n=365)
dolomite (mrbl)
(n=93)
WR (mrbl)
(n=124)
calcite (skarn)
(n=23)
frequency
10
8
6
4
2
3
2
1
5
3
1
3
2
1
0
5
10
15
20
25
$\delta^{18}O$ (‰, VSMOW)

Figure 5

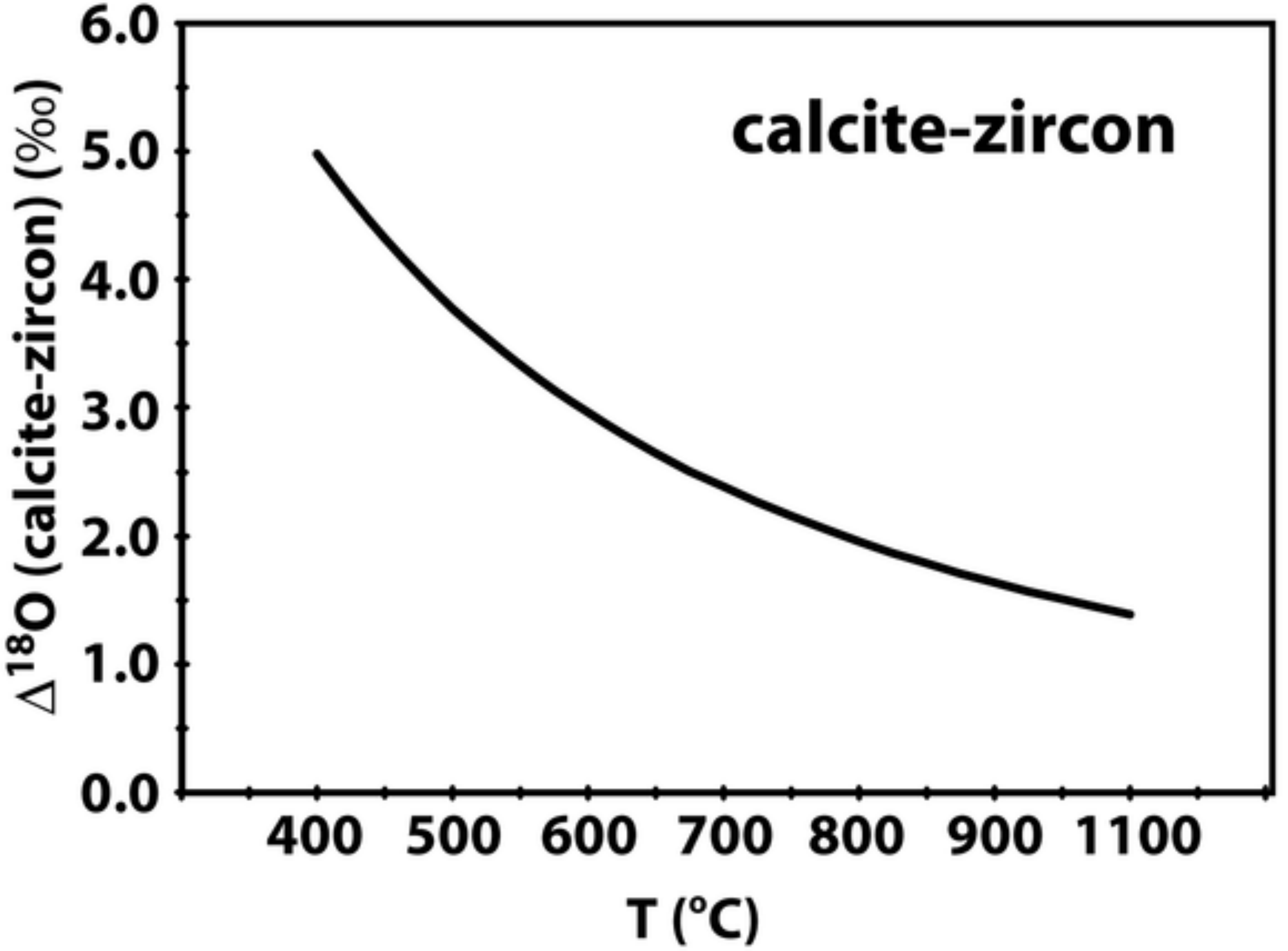
calcite-zircon
6.0
5.0
4.0
3.0
2.0
1.0
0.0
$\Delta^{18}O$ (calcite-zircon) (‰)
400
500
600
700
800
900
1100
T (°C)

Figure 6

Online Resource 1

Article title: Origin of high δ^{18}O zircons: Marbles, megacrysts, and metamorphism
Journal: Contributions to Mineralogy and Petrology
Authors: Aaron J. Cavosie, John W. Valley, Noriko T. Kita, Mike Spicuzza, Takayuki Ushikubo, Simon Wilde
Corresponding author: Aaron J. Cavosie, Univ. of Puerto Rico. Email: aaron.cavosie@upr.edu

Oxygen isotope ratios for igneous zircon published from 2006-2010 used in Fig. 1a

Sample #	δ^{18}O	Unit	lithology/rock	Reference
Australia				
TKB5	6.70	Cobargo dioritic enclave	I-type granite	Kemp et al. 2007
TKB1	6.51	Cobargo tonalite	I-type granite	Kemp et al. 2007
TKB11	6.51	Cobargo granite	I-type granite	Kemp et al. 2007
TKB100	8.10	Why Worry tonalite	I-type granite	Kemp et al. 2007
TKB17	8.15	Pretty Point tonalite	I-type granite	Kemp et al. 2007
TKB15	6.82	doleritic enclave	I-type granite	Kemp et al. 2007
B4-28	6.69	Blind gabbro	I-type granite	Kemp et al. 2007
KK2	7.74	Round Flat tonalite	I-type granite	Kemp et al. 2007
KK4	6.87	Round Flat tonalite	I-type granite	Kemp et al. 2007
97-159	6.47	Wando tonalite	I-type granite	Kemp et al. 2009
97-WA1	7.28	Warradale tonalite	I-type granite	Kemp et al. 2009
COH-8	5.21	quartz diorite	granitoid	Kemp et al. 2009
HV-1	9.14	Hawkins dacite	S-type granite	Kemp et al. 2009
BB1	8.36	Coontralantra grano.	S-type granite	Kemp et al. 2009
BB3	9.47	Arable granodiorite	S-type granite	Kemp et al. 2009
BB6	8.37	Arable granodiorite	S-type granite	Kemp et al. 2009
Kdd-1	7.24	Kadoona dacite	I-type granite	Kemp et al. 2009
TKG-1	6.87	Glenbog granodiorite	I-type granite	Kemp et al. 2009
178	4.80	Narraburra granite	A-type granite	Kemp et al. 2009
Brazil				
Loure 2	6.52	Lourenco pluton	granitoid	Ferreira et al. 2010
Loure 3	6.52	Lourenco pluton	granitoid	Ferreira et al. 2010
Loure 40	6.88	Lourenco pluton	granitoid	Ferreira et al. 2010
Ccima 2	8.40	Curral de Cima pluton	granitoid	Ferreira et al. 2010
Ccima 8	8.10	Curral de Cima pluton	granitoid	Ferreira et al. 2010
Greenland				
G01136	5.10	Itsaq Gneiss Complex	Meta-tonalite	Heiss et al. 2009
G01113	4.90	Itsaq Gneiss Complex	Meta-tonalite	Heiss et al. 2009
G97118	5.00	Itsaq Gneiss Complex	Meta-tonalite	Heiss et al. 2009
248228	4.90	Itsaq Gneiss Complex	Meta-tonalite	Heiss et al. 2009
248202	5.00	Itsaq Gneiss Complex	felsic meta-volc.	Heiss et al. 2009
248203	4.90	Itsaq Gneiss Complex	felsic meta-volc.	Heiss et al. 2009
248251	4.20	Itsaq Gneiss Complex	granitoid gneiss	Heiss et al. 2010
248212	4.60	Itsaq Gneiss Complex	granitoid gneiss	Heiss et al. 2010
G97/111	5.80	augen gneiss	meta-granite	Heiss et al. 2010
VM9701	4.00	Ikkattoq gneiss	granitoid gneiss	Heiss et al. 2010
195392	5.00	Qorqut granite complex	migmatite	Heiss et al. 2010
195376	4.20	Qorqut granite complex	granite	Heiss et al. 2010

Sample #	$\delta^{18}O$	Unit	lithology/rock	Reference
Kimberlites				
	5.32	Kaalvallei Mine	kimberlite	Page et al. 2007
	5.45	Balmoral Mine	kimberlite	Page et al. 2007
	5.18	Kamfersdam Mine	kimberlite	Page et al. 2007
	5.30	Leicester Mine	kimberlite	Page et al. 2007
	5.35	Kimberley Pool	kimberlite	Page et al. 2007
	4.69	Jwaneng DK2, Precambrian	kimberlite	Page et al. 2007
	5.73	Jwaneng DK2, Permian	kimberlite	Page et al. 2007
	5.55	Orapa rutile-bearing suite	kimberlite	Page et al. 2007
	4.98	Orto-Yarga, Anomaly 12/853	kimberlite	Page et al. 2007
	4.73	Chomurdakh, Khaiyrgastakh	kimberlite	Page et al. 2007
	5.07	Chomurdakh, Anomaly 180/78	kimberlite	Page et al. 2007
	7.09	Ukukit West, Leningrad	kimberlite	Page et al. 2007
	5.26	Ukukit West, Anomaly 134	kimberlite	Page et al. 2007
	5.02	Ukukit West, Anomaly 152	kimberlite	Page et al. 2007
	5.53	Mir	kimberlite	Page et al. 2007
	5.20	Ponte Funda	kimberlite	Page et al. 2007
	5.33	Sa˜o Joa˜o da Glo´ ria	kimberlite	Page et al. 2007
	4.87	Fazen da Inac¸ao	kimberlite	Page et al. 2007
	5.28	Botafogo	kimberlite	Page et al. 2007
	5.49	Vargem 4B	kimberlite	Page et al. 2007
	5.05	Buriti	kimberlite	Page et al. 2007
	5.28	Tata˜o	kimberlite	Page et al. 2007
	5.12	Morro do Lobo	kimberlite	Page et al. 2007
	8.25	Cedro	kimberlite	Page et al. 2007
	5.17	Japecanga	kimberlite	Page et al. 2007
	5.55	Capa˜o da Erva	kimberlite	Page et al. 2007
	5.08	Almas	kimberlite	Page et al. 2007
	5.08	Canas AN32	kimberlite	Page et al. 2007
	5.48	Canastrel	kimberlite	Page et al. 2007
	5.51	Descida para Vargem	kimberlite	Page et al. 2007
	5.25	Galeria	kimberlite	Page et al. 2007
	5.28	Morunga	kimberlite	Page et al. 2007
	5.82	Poc¸o Verde	kimberlite	Page et al. 2007
	5.60	Tamborete	kimberlite	Page et al. 2007
	5.31	Vargem 1, Poc¸o 9	kimberlite	Page et al. 2007
	7.53	Velosa	kimberlite	Page et al. 2007
	7.31	Represinha	kimberlite	Page et al. 2007
	5.02	Acuri	kimberlite	Page et al. 2007
	4.80	Mutum	kimberlite	Page et al. 2007
	4.92	Duas Barras	kimberlite	Page et al. 2007
	5.09	Six-Pak, Kenosha, Wisconsin	kimberlite	Page et al. 2007
	5.47	Site 73, Hermansville, Mich.	kimberlite	Page et al. 2007
Mid-Atlantic Ridge				
153-922B-2R-2	5.30	20-23 cm	gabbro	Cavosie et al. 2009
153-920B-2R-1	5.00	44-50 cm	vein in serpentinite	Cavosie et al. 2009

Sample #	$\delta^{18}O$	Unit	lithology/rock	Reference
153-920B-5R-1	5.50	59-64 cm	vein in serpentinite	Cavosie et al. 2009
Mid-Atlantic Ridge/ SW Indian Ridge				
209-1270D-3R-1	5.50	47 cm	vein in serpentinite	Grimes et al. 2011
209-1270D-4R-1	5.20	133 cm	vein in serpentinite	Grimes et al. 2011
209-1275D-2R-2	5.30	96cm	plagiogranite	Grimes et al. 2011
209-1275D-29R-2	5.40	89 cm	plagiogranite	Grimes et al. 2011
209-1275D-31R-2	5.30	68 cm	plagiogranite	Grimes et al. 2011
209-1275D-36R-1	5.10	81 cm	plagiogranite	Grimes et al. 2011
209-1275D-39R-2	5.50	0 cm	plagiogranite	Grimes et al. 2011
209-1275D-43R-1	5.50	34 cm	plagiogranite	Grimes et al. 2011
MARVEL2000	5.10	Alvin 3652-1333	fault schist	Grimes et al. 2011
MARVEL2000	5.20	Alvin 3646-1205	fault schist	Grimes et al. 2011
MARVEL2000	5.40	D3-21 (dredge)	fault schist	Grimes et al. 2011
MARVEL2000	5.50	Alvin 3647-1359	fault schist	Grimes et al. 2011
MARVEL2000	5.60	Alvin 3652-1002	breccia	Grimes et al. 2011
304-U1309B-7R-1	4.90	77 cm	plagiogranite	Grimes et al. 2011
304-U1309B-13R-2	5.20	26 cm	plagiogranite	Grimes et al. 2011
304-U1309D-5R-3	5.10	136 cm	plagiogranite	Grimes et al. 2011
304-U1309D-9R-2	5.20	97 cm	plagiogranite	Grimes et al. 2011
304-U1309D-40R-1	5.30	21 cm	plagiogranite	Grimes et al. 2011
305-U1309D-93R-1	5.30	27 cm	plagiogranite	Grimes et al. 2011
305-U1309D-115R-2	5.20	59 cm	plagiogranite	Grimes et al. 2011
305-U1309D-178R-1	5.20	97 cm	plagiogranite	Grimes et al. 2011
305-U1309D-216R-1	5.00	54 cm	plagiogranite	Grimes et al. 2011
305-U1309D-295R-3	5.10	100 cm	plagiogranite	Grimes et al. 2011
304-U1309D-47R-2	5.30	102 cm	oxide gabbro	Grimes et al. 2011
304-U1309D-54R-1	5.10	52 cm	oxide gabbro	Grimes et al. 2011
304-U1309D-69R-2	4.90	52 cm	oxide gabbro	Grimes et al. 2011
304-U1309D-75R-3	5.00	99 cm	oxide gabbro	Grimes et al. 2011
305-U1309D-114R-1	5.30	62 cm	oxide gabbro	Grimes et al. 2011
305-U1309D-126R-2	5.00	27 cm	oxide gabbro	Grimes et al. 2011
305-U1309D-131R-2	5.30	0 cm	oxide gabbro	Grimes et al. 2011
305-U1309D-168R-2	5.20	0 cm	oxide gabbro	Grimes et al. 2011
305-U1309D-189R-4	5.10	41 cm	oxide gabbro	Grimes et al. 2011
305-U1309D-244R-2	5.00	100 cm	oxide gabbro	Grimes et al. 2011
305-U1309D-259R-1	5.00	22 cm	oxide gabbro	Grimes et al. 2011
305-U1309D-276R-1	5.40	34 cm	oxide gabbro	Grimes et al. 2011
304-U1309D-5R-3	4.80	136 cm	plagiogranite	Grimes et al. 2011
305-U1309D-295R-3	4.70	100 cm	plagiogranite	Grimes et al. 2011
179-1105A-8R-4	5.60	21 cm	plagiogranite	Grimes et al. 2011
118-735B-7D-1	5.10	10 cm	plagiogranite	Grimes et al. 2011
176-735B-90R-1	5.40	45 cm	plagiogranite	Grimes et al. 2011
176-735B-110R-4	5.20	8 cm	plagiogranite	Grimes et al. 2011
176-735B-137R-2	5.40	71 cm	plagiogranite	Grimes et al. 2011
176-735B-202R-7	5.00	85 cm	plagiogranite	Grimes et al. 2011
118-735B-28R-1	5.30	56 cm	gabbro	Grimes et al. 2011

Sample #	$\delta^{18}O$	Unit	lithology/rock	Reference
New Zealand				
RNZ20	5.54	Separation Point Bath.	monzogranite	Bolhar et al. 2008
RNZ49	5.31	Separation Point Bath.	granite	Bolhar et al. 2008
RNZ83	5.05	Pearse pluton	granodiorite	Bolhar et al. 2008
RNZ87	5.61	Rocky pluton	granodiorite	Bolhar et al. 2008
NF3	4.37	North Fiord pluton	granite	Bolhar et al. 2008
SF2a	3.61	Takahe pluton	granodiorite	Bolhar et al. 2008
TT6	3.18	Titiroa pluton	granite	Bolhar et al. 2008
WFO1	5.47	Western Fiordland pluton	orthogneiss	Bolhar et al. 2008
Nubian Shield				
2	8.09	Taba orthogneiss	Elat IAC	Be-eri et al. 2009
3	8.18	Roded orthogneiss	Elat IAC	Be-eri et al. 2009
4	6.92	Elat granitic orthogneiss	Elat IAC	Be-eri et al. 2009
5	5.57	Aliat paragneis	Elat IAC	Be-eri et al. 2009
6	7.32	SMGD def. pluton	Feiran IAC	Be-eri et al. 2009
7	7.93	SGG def. pluton	calc-alkaline suite1	Be-eri et al. 2009
8	6.57	Jantil def. pluton	calc-alkaline suite1	Be-eri et al. 2009
9	4.99	Rurabi def. pluton	calc-alkaline suite1	Be-eri et al. 2009
10	7.06	Elat-Shlomo pluton	calc-alkaline suite1	Be-eri et al. 2009
11	6.36	Elat-Rehavam pluton	calc-alkaline suite2	Be-eri et al. 2009
12	6.61	RQD pluton	calc-alkaline suite2	Be-eri et al. 2009
13	6.17	TPG pluton	calc-alkaline suite2	Be-eri et al. 2009
14	5.43	Shahira pluton	calc-alkaline suite2	Be-eri et al. 2009
15	5.32	Zreir pluton	calc-alkaline suite2	Be-eri et al. 2009
16	5.45	Hibran-Miar pluton	calc-alkaline suite2	Be-eri et al. 2009
17	5.69	Rahba pluton	calc-alkaline suite2	Be-eri et al. 2009
18	6.50	Ahdar pluton	calc-alkaline suite2	Be-eri et al. 2009
19	5.14	Sama pluton	calc-alkaline suite2	Be-eri et al. 2009
20	5.05	Lathi pluton	calc-alkaline suite2	Be-eri et al. 2009
21	6.77	Malaha pluton	calc-alkaline suite2	Be-eri et al. 2009
22	5.30	Girgar pluton	calc-alkaline suite2	Be-eri et al. 2009
23	5.16	Gashi pluton	calc-alkaline suite2	Be-eri et al. 2009
24	5.28	Mandar pluton	calc-alkaline suite2	Be-eri et al. 2009
25	6.14	Sulaf pluton	calc-alkaline suite2	Be-eri et al. 2009
26	5.25	Abu-K'sheib pluton	calc-alkaline suite2	Be-eri et al. 2009
27	6.50	Tubeina pluton	calc-alkaline suite2	Be-eri et al. 2009
28	5.89	Nasrin pluton	alkaline suite	Be-eri et al. 2009
29	5.50	TAG pluton	alkaline suite	Be-eri et al. 2009
30	5.78	TMN pluton	alkaline suite	Be-eri et al. 2009
31	5.79	Timna syenite pluton	alkaline suite	Be-eri et al. 2009
32	6.60	Yehoshafat pluton	alkaline suite	Be-eri et al. 2009
33	6.49	Elat subvolcanics	alkaline suite	Be-eri et al. 2009
34	6.84	Elat composite dike	alkaline suite	Be-eri et al. 2009
35	6.36	Elat rhyolite dike1	alkaline suite	Be-eri et al. 2009
36	6.35	Elat rhyolite dike2	alkaline suite	Be-eri et al. 2009
37	6.23	Elat rhyolite dike3	alkaline suite	Be-eri et al. 2009

Sample #	**$\delta^{18}O$**	**Unit**	**lithology/rock**	**Reference**
38	5.14	Sahara pluton	alkaline suite	Be-eri et al. 2009
39	4.79	Sharm pluton	alkaline suite	Be-eri et al. 2009
40	4.49	Yahmed pluton	alkaline suite	Be-eri et al. 2009
41	5.13	Umm-Shomer pluton	alkaline suite	Be-eri et al. 2009
42	5.20	Dahab pluton	alkaline suite	Be-eri et al. 2009
43	6.70	Serbal pluton	alkaline suite	Be-eri et al. 2009
44	5.49	Umm-I-Fai pluton	alkaline suite	Be-eri et al. 2009
45	5.65	Iqna-Kid pluton	alkaline suite	Be-eri et al. 2009
46	8.04	Umm-Bugma pluton	alkaline suite	Be-eri et al. 2009
47	5.53	Katharina ring dikes	alkaline suite	Be-eri et al. 2009
48	5.82	Katharina pluton	alkaline suite	Be-eri et al. 2009
49	6.68	Iqna subvolcanics	alkaline suite	Be-eri et al. 2009
50	7.07	Iqna pluton	alkaline suite	Be-eri et al. 2009
YE-9	7.09	Elat granitic gneiss	granitoid	Katzir et al. 2007
YE-16	6.68	Elat granitic gneiss	granitoid	Katzir et al. 2007
YE-24	7.23	Elat granitic gneiss	granitoid	Katzir et al. 2007
YE-11	7.15	Elat granite	monzogranite	Katzir et al. 2007
YE-33	6.97	Elat granite	monzogranite	Katzir et al. 2007
YE-34	6.36	Elat granite	monzogranite	Katzir et al. 2007
YE-36	6.76	Yehoshafat granite	syenogranite	Katzir et al. 2007
YE-35	6.52	Yehoshafat granite	syenogranite	Katzir et al. 2007
AG-81	6.60	Yehoshafat granite	syenogranite	Katzir et al. 2007
AG-40	5.75	Timna Complex	quartz syenite	Katzir et al. 2007
AG-62	5.82	Timna Complex	quartz syenite	Katzir et al. 2007
AG-63	5.50	Timna Complex	alkali feld granite	Katzir et al. 2007
AG-63a	5.55	Timna Complex	alkali feld granite	Katzir et al. 2007
AG-67	5.48	Timna Complex	alkali feld granite	Katzir et al. 2007
IL-8	5.48	Katharine ring complex	perthite qtz syenite	Katzir et al. 2007
IL-84	5.66	porphyry, ring dike	granitoid	Katzir et al. 2007
IL-147	5.49	porphyry, ring dike	granitoid	Katzir et al. 2007
IL-9	5.50	porphyry, ring dike	granitoid	Katzir et al. 2007
69	6.27	Timna granite	A-type granite	Steinitz et al. 2009
70	6.11	Timna granite	A-type granite	Steinitz et al. 2009
71	6.10	Timna granite	A-type granite	Steinitz et al. 2009
44	5.93	Timna monzodiorite	A-type granite	Steinitz et al. 2009
64	5.68	Timna monzodiorite	A-type granite	Steinitz et al. 2009
66	5.60	Timna monzodiorite	A-type granite	Steinitz et al. 2009
77	5.89	Timna monzodiorite	A-type granite	Steinitz et al. 2009
Scotland (Caledonides)				
Kemnay	9.00	Kemnay granite	S-type granite	Appleby et al. 2010
Cove	9.80	Cove granite	S-type granite	Appleby et al. 2010
Nigg Bay	6.80	Nigg Bay granite	S-type granite	Appleby et al. 2010
USA (St. Francois Mnts, Missouri)				
Knob Lick	6.05	Knob Lick	granite	King et al. 2008
Hawn Park	7.52	Hawn State Park	granite	King et al. 2008
Pickle Creek	5.78	Hawn State Park	granite	King et al. 2008

Sample #	**δ^{18}O**	**Unit**	**lithology/rock**	**Reference**
Munger	8.17	Munger granite	granite	King et al. 2008
MOSH-100	7.90	Shannon county drill core	granite	King et al. 2008
Troy	5.88	Troy Granite	granite	King et al. 2008
USA (Arbuckle Mountains, Oklahoma)				
ARB 36	6.14	Tishomingo granite	granite	King et al. 2008
BRG	6.09	Blue River gneiss	gneiss	King et al. 2008
BRG	6.12	Blue River gneiss	gneiss	King et al. 2008
Gd	6.13	granodiorite	granodiorite	King et al. 2008
TISH	6.14	Tishomingo granite	granite	King et al. 2008
TSH	6.28	Tishomingo granite	granite	King et al. 2008
USA (Salton Trough, CA)				
SB0402	5.15	Obsidian Butte rhyolite	volcanic	Schmitt and Vazquez 2006
SB0402-i1	2.60	Obsidian Butte granophyre xeno	volcanic	Schmitt and Vazquez 2006
SB0403-1	3.84	Obsidian Butte basaltic xeno	volcanic	Schmitt and Vazquez 2006
SB0403-i2	5.05	Obsidian Butte basaltic xeno	volcanic	Schmitt and Vazquez 2006
SB0403-i2	4.97	Obsidian Butte basaltic xeno	volcanic	Schmitt and Vazquez 2006
SB0401-i1	4.80	Red Island "felsite" xeno	volcanic	Schmitt and Vazquez 2006

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Online Resource 1 (cont.)

Article title: Origin of high δ^{18}O zircons: Marbles, megacrysts, and metamorphism
Journal: Contributions to Mineralogy and Petrology
Authors: Aaron Cavosie, John Valley, Noriko Kita, Mike Spicuzza, Takayuki Ushikubo, Simon Wilde
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Oxygen isotope ratios for metamorphic zircon used in figure 1b

Location/ Sample	**δ^{18}O**	**MM facies**	**lithology**	**Reference**
Canada, British Columbia, Valhalla Complex				
EL-20	9.50		migmatite- paragneiss	Gordon et al. 2009
UP-20	10.30		deformed metapelite	Gordon et al. 2009
Canada, Super Province, Kapuskasing uplift (n=26)				
KAP05-32 G2	8.7	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G3	9	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G4	8.74	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G5	9.41	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G6m	8.8	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G6o	9.6	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G7	8.38	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G8	8.57	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G9	9.39	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G10	10.02	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G15	10.11	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G27	10.04	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G34	9.27	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G35	8.7	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G37	10.13	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G39	9.14	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G42	9.86	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G43	9.32	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G46	9.97	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G50	8.54	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G53	9.61	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G56	9.98	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G57	10	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G59	10.18	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05032 G61	9.38	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
KAP05-32 G63	9.93	granulite	metamorphic rim on detrital zircon	Moser et al. 2008
China, Dabie Shan orogen				
Xindian	16.85	eclogite	UHP eclogite boudin	Wu et al. 2006
Greece, Naxos (n=31)				
80b6	7.40	amphibolite	zircon rim, metabasite NA0180b	Martin et al. 2006
80b9	5.50	amphibolite	zircon rim, metabasite NA0180b	Martin et al. 2006
80b3-r1	7.10	amphibolite	zircon rim, metabasite NA0180b	Martin et al. 2006
80b47-r1	5.10	amphibolite	zircon rim, metabasite NA0180b	Martin et al. 2006
80b16-r1 (Rim A)	7.40	amphibolite	zircon rim, metabasite NA0180b	Martin et al. 2006
80b16-r2 (Rim B)	6.70	amphibolite	zircon rim, metabasite NA0180b	Martin et al. 2006

Location/ Sample	**$\delta^{18}O$**	**MM facies**	**lithology**	**Reference**
80b23-2	5.50	amphibolite	zircon rim, metabasite NA0180b	Martin et al. 2006
80b17-r2	8.30	amphibolite	zircon rim, metabasite NA0180b	Martin et al. 2006
80b38-1	8.00	amphibolite	zircon rim, metabasite NA0180b	Martin et al. 2006
62b15 (n=2)	14.70	amphibolite	zircon rim, metapelite NA0262b	Martin et al. 2006
62b7-1	13.70	amphibolite	zircon rim, metapelite NA0262b	Martin et al. 2006
62b6-1	14.70	amphibolite	zircon rim, metapelite NA0262b	Martin et al. 2006
62b14-1	15.00	amphibolite	zircon rim, metapelite NA0262b	Martin et al. 2006
62b6-3	13.60	amphibolite	zircon rim, metapelite NA0262b	Martin et al. 2006
62b10	14.60	amphibolite	zircon rim, metapelite NA0262b	Martin et al. 2006
62b12	14.30	amphibolite	zircon rim, metapelite NA0262b	Martin et al. 2006
113b22-1	10.40	amphibolite	zircon rim, calcic gneiss NA01113b	Martin et al. 2006
113b5-1	13.00	amphibolite	zircon rim, calcic gneiss NA01113b	Martin et al. 2006
113b6-2	9.50	amphibolite	zircon rim, calcic gneiss NA01113b	Martin et al. 2006
113b16-r	13.70	amphibolite	zircon rim, calcic gneiss NA01113b	Martin et al. 2006
113b15-r	12.90	amphibolite	zircon rim, calcic gneiss NA01113b	Martin et al. 2006
113b26 (n=2)	11.95	amphibolite	zircon rim, calcic gneiss NA01113b	Martin et al. 2006
granite 01-14	7.90		anatectic granite with recrystalized zrc	Martin et al. 2008
granite 01-3	6.50		anatectic granite with recrystalized zrc	Martin et al. 2008
granite 01-4	8.10		anatectic granite with recrystalized zrc	Martin et al. 2008
granite 01-16	7.90		anatectic granite with recrystalized zrc	Martin et al. 2008
granite 01-16	6.80		anatectic granite with recrystalized zrc	Martin et al. 2008
granite 01-32	5.70		anatectic granite with recrystalized zrc	Martin et al. 2008
granite 01-7	7.60		anatectic granite with recrystalized zrc	Martin et al. 2008
granite 01-7	7.40		anatectic granite with recrystalized zrc	Martin et al. 2008
USA, Adirondack Mountains (n=61)				
Adirondack Lowlands				
MH-02-19	13.20	amphibolite	MM overgrowth- Devils Elbow	Lancaster et al. 2009
MH-02-15a	10.20	amphibolite	MM overgrowth- Foolish Dog L	Lancaster et al. 2009
MH-02-16b	10.00	amphibolite	MM overgrowth- Foolish Dog M	Lancaster et al. 2009
MH-02-09	9.00		Rt. 812 L	Lancaster et al. 2009
MH-02-10	7.80		Rt. 812 M	Lancaster et al. 2009
Adirondack Highlands				
BM-04-01b (M)	12.50	granulite	MM overgrowth- Daniels Rd. M	Lancaster et al. 2009
BM-04-01a (L)	12.30	granulite	MM overgrowth- Daniels Rd. L	Lancaster et al. 2009
BMH-01-14	11.60	granulite	MM overgrowth- Treadway Mt. #1L	Lancaster et al. 2009
BM-04-06a	7.30		Treadway Mt. #2L	Lancaster et al. 2009
MH-02-06	11.50	granulite	MM overgrowth- Pleasant Lake M	Lancaster et al. 2009
BMH-01-20	9.50		Pumpkin Hollow	Lancaster et al. 2009
BMH-01-12	11.20	granulite	MM overgrowth- Pleasant Lake L	Lancaster et al. 2009
BM-04-02b (M)	11.20	granulite	MM overgrowth- Comstock M	Lancaster et al. 2009
BMH-01-16	10.90	granulite	MM overgrowth- Conklingtonville Dam	Lancaster et al. 2009
06-ADK-34D	10.80	granulite	MM overgrowth- Treadway Mt. #2M	Lancaster et al. 2009
BMH-04-06B1	10.40	granulite	MM overgrowth- Treadway Mt. #2M	Lancaster et al. 2009
06-ADK-35AZrc1.4/	8.10		meta- avg. of 2 analyses	Lancaster et al. 2009
06-ADK-34DZrc2.2	10.80		meta	Lancaster et al. 2009

Location/ Sample	$\delta^{18}O$	MM facies	lithology	Reference
06-ADK-50EZrc1.1	7.70		meta	Lancaster et al. 2009
BM-04-02a (L)	10.20	granulite	MM overgrowth- Comstock L	Lancaster et al. 2009
BM-04-01a, 35	12.63	granulite	MM overgrowth- Daniels Rd. L	Page et al. 2007
92ADK7	10.14		quartzite	Peck et al. 2003
97ADK2	9.62		quartzite	Peck et al. 2003
97ADK2-1	12.60	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-10	10.90	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-11	9.80	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-12	11.30	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-15	12.70	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-17	10.50	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-18	11.10	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-3	11.30	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-6	12.80	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-7	11.40	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-8	9.30	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK2-9	11.80	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK-3	7.83		quartzite	Peck et al. 2003
97ADK-4	9.05		quartzite	Peck et al. 2003
97ADK4-1	10.70	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK4-11	11.70	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK4-2	10.00	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK4-3	9.80	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK4-5	10.10	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK4-6	10.50	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK4-7	10.00	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK4-8	10.00	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97ADK4-9	10.50	granulite	MM overgrowth- Irving Pond Fm.	Peck et al. 2003
97WE10	8.98		quartzite	Peck et al. 2003
97BM2	9.28		quartzite	Peck et al. 2003
SL2	7.76		quartzite	Peck et al. 2003
Adirondacks				
AC85-7	8.36		AMCG, metamorphic/disturbed zircons	Valley et al. 1994
AC85-9	8.45		AMCG, metamorphic	Valley et al. 1994
CGAB	6.04		AMCG, metamorphic/disturbed zircons	Valley et al. 1994
Rt. 81	9.15		quartzite	Valley et al. 1994
CT-1	9.60		quartzite	Valley et al. 1994
CT-2	9.82		quartzite	Valley et al. 1994
SL-1	7.91		quartzite	Valley et al. 1994
SL-2	7.90		quartzite	Valley et al. 1994
AC85-11	7.71	granulite	jotunitic gneiss; meta zircons	Valley et al. 2003
AM87-9	7.80	granulite	charnockitic gneiss; meta zircons	Valley et al. 2003
AM87-10	8.04	granulite	charnockite; meta zircons	Valley et al. 2003
TOE	8.29	granulite	metagranite; meta zircons	Valley et al. 2003

All references above are listed in the main article.

Online Resource 1 (cont.)

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Oxygen isotope ratios for high-grade marbles used in Fig. 5

Location/ Sample	δ^{18}O	MM facies	material	Reference
Antarctica				
CO#18,Sr#18	-4.92	amph-gran	calcite	Satish-Kumar et al. 2010
CO#11,Sr#11	-4.37	amph-gran	calcite	Satish-Kumar et al. 2010
CO#17	-4.07	amph-gran	calcite	Satish-Kumar et al. 2010
CO#12	-3.9	amph-gran	calcite	Satish-Kumar et al. 2010
CO#3,Sr#1	-3.76	amph-gran	calcite	Satish-Kumar et al. 2010
CO#5	-1.47	amph-gran	calcite	Satish-Kumar et al. 2010
CO#15	0.47	amph-gran	calcite	Satish-Kumar et al. 2010
CC2	12.33	amph-gran	calcite	Satish-Kumar et al. 2010
CC3	12.33	amph-gran	calcite	Satish-Kumar et al. 2010
CC1	12.57	amph-gran	calcite	Satish-Kumar et al. 2010
CC4	14.36	amph-gran	calcite	Satish-Kumar et al. 2010
CC5	14.36	amph-gran	calcite	Satish-Kumar et al. 2010
CC1	14.92	amph-gran	calcite	Satish-Kumar et al. 2010
CC2	14.93	amph-gran	calcite	Satish-Kumar et al. 2010
CC2	15.66	amph-gran	calcite	Satish-Kumar et al. 2010
CC3	17	amph-gran	calcite	Satish-Kumar et al. 2010
CC1	17.39	amph-gran	calcite	Satish-Kumar et al. 2010
Antarctica				
602b-c1	16.3	granulite	calcite	Satish-Kumar and Wada 2000
602b-c2	16.02	granulite	calcite	Satish-Kumar and Wada 2000
602b-c3	15.81	granulite	calcite	Satish-Kumar and Wada 2000
602b-c4	16.13	granulite	calcite	Satish-Kumar and Wada 2000
602c-C1	16.44	granulite	calcite	Satish-Kumar and Wada 2000
602c-C2	16.35	granulite	calcite	Satish-Kumar and Wada 2000
602c-C3	16.84	granulite	calcite	Satish-Kumar and Wada 2000
602c-C4	16.28	granulite	calcite	Satish-Kumar and Wada 2000
602c-C5	16.56	granulite	calcite	Satish-Kumar and Wada 2000
602d-c1	16.91	granulite	calcite	Satish-Kumar and Wada 2000
602d-c2	17.04	granulite	calcite	Satish-Kumar and Wada 2000
602d-c3	17.02	granulite	calcite	Satish-Kumar and Wada 2000
602e-c1	15.8	granulite	calcite	Satish-Kumar and Wada 2000
602e-c2	15.53	granulite	calcite	Satish-Kumar and Wada 2000
602e-c3	15.89	granulite	calcite	Satish-Kumar and Wada 2000
602e-c4	15.64	granulite	calcite	Satish-Kumar and Wada 2000
602e-c5	16.69	granulite	calcite	Satish-Kumar and Wada 2000
602e2-c21	17.41	granulite	calcite	Satish-Kumar and Wada 2000
602e2-c22	16.2	granulite	calcite	Satish-Kumar and Wada 2000
602e2-c3	16.27	granulite	calcite	Satish-Kumar and Wada 2000
China, Sulu Orogen				
02SD06	12.86	amphibolite	calcite	Tang et al. 2006

Location/ Sample	**δ^{18}O**	**MM facies**	**material**	**Reference**
02SD07	18.92	amphibolite	calcite	Tang et al. 2006
02SD08	13.13	amphibolite	calcite	Tang et al. 2006
04SD07	19.32	amphibolite	calcite	Tang et al. 2006
04SD11	17.24	amphibolite	calcite	Tang et al. 2006
02SD16	20.03	amphibolite	calcite	Tang et al. 2006
02SSD17	23.82	amphibolite	calcite	Tang et al. 2006
China, Sulu and Dabie Shan Orogen				
95-QL-3B	**-2.95**	amph-gran	calcite	Rumble et al. 2000
SL91-8	**24.74**	amph-gran	calcite	Rumble et al. 2000
SL91-8A	**23.68**	amph-gran	calcite	Rumble et al. 2000
SL91-8B	**22.66**	amph-gran	calcite	Rumble et al. 2000
SL91-8I	**23.58**	amph-gran	calcite	Rumble et al. 2000
SL91-9E	**24.54**	amph-gran	calcite	Rumble et al. 2000
SL92-9A	**23.81**	amph-gran	calcite	Rumble et al. 2000
SL92-9D	**21.07**	amph-gran	calcite	Rumble et al. 2000
SL92-9J	**20.56**	amph-gran	calcite	Rumble et al. 2000
SL95-9B	**22.79**	amph-gran	calcite	Rumble et al. 2000
94-7A	**15.09**	amph-gran	calcite	Rumble et al. 2000
94-7B	**22.26**	amph-gran	calcite	Rumble et al. 2000
94-DB-08E	**19.06**	amph-gran	calcite	Rumble et al. 2000
95-16B	**20.39**	amph-gran	calcite	Rumble et al. 2000
95-16C	**18.09**	amph-gran	calcite	Rumble et al. 2000
CP-7	**19**	amph-gran	calcite	Rumble et al. 2000
MHM-17	**7.84**	amph-gran	calcite	Rumble et al. 2000
MHM-19	**8.73**	amph-gran	calcite	Rumble et al. 2000
94-DB-57A	**11.35**	amph-gran	calcite	Rumble et al. 2000
94-DB-57C	**9.24**	amph-gran	calcite	Rumble et al. 2000
SH-05	**11.49**	amph-gran	calcite	Rumble et al. 2000
SH06	**11.4**	amph-gran	calcite	Rumble et al. 2000
SH07	**12.5**	amph-gran	calcite	Rumble et al. 2000
SH08	**11.42**	amph-gran	calcite	Rumble et al. 2000
92H17	**17.04**	amph-gran	calcite	Rumble et al. 2000
92HW20	**12.41**	amph-gran	calcite	Rumble et al. 2000
94-DB-	**12.03**	amph-gran	calcite	Rumble et al. 2000
95-015	**12.78**	amph-gran	calcite	Rumble et al. 2000
96201	**18.27**	amph-gran	calcite	Rumble et al. 2000
96202	**17.95**	amph-gran	calcite	Rumble et al. 2000
96204	**14.47**	amph-gran	calcite	Rumble et al. 2000
96205	**15.48**	amph-gran	calcite	Rumble et al. 2000
96301	**13.58**	amph-gran	calcite	Rumble et al. 2000
96302	**15.07**	amph-gran	calcite	Rumble et al. 2000
96303	**16.94**	amph-gran	calcite	Rumble et al. 2000
96304	**12.47**	amph-gran	calcite	Rumble et al. 2000
96305	**16.54**	amph-gran	calcite	Rumble et al. 2000
96307	**11.61**	amph-gran	calcite	Rumble et al. 2000
96308	**13.33**	amph-gran	calcite	Rumble et al. 2000
96309	**14.44**	amph-gran	calcite	Rumble et al. 2000
96401	**14.6**	amph-gran	calcite	Rumble et al. 2000

Location/ Sample	$\delta^{18}O$	MM facies	material	Reference
96402	**14.98**	amph-gran	calcite	Rumble et al. 2000
96403	**14.56**	amph-gran	calcite	Rumble et al. 2000
96404	**16.82**	amph-gran	calcite	Rumble et al. 2000
96405	**17.3**	amph-gran	calcite	Rumble et al. 2000
96406	**12.03**	amph-gran	calcite	Rumble et al. 2000
96502	**11.47**	amph-gran	calcite	Rumble et al. 2000
96504	**12.16**	amph-gran	calcite	Rumble et al. 2000
96509A	**12.74**	amph-gran	calcite	Rumble et al. 2000
96509B	**12.64**	amph-gran	calcite	Rumble et al. 2000
96509C	**12.78**	amph-gran	calcite	Rumble et al. 2000
96509D	**12.71**	amph-gran	calcite	Rumble et al. 2000
96510A	**11.59**	amph-gran	calcite	Rumble et al. 2000
96510B	**11.89**	amph-gran	calcite	Rumble et al. 2000
96510C	**11.67**	amph-gran	calcite	Rumble et al. 2000
96510D	**11.67**	amph-gran	calcite	Rumble et al. 2000
96510F	**11.74**	amph-gran	calcite	Rumble et al. 2000
96510G	**11.81**	amph-gran	calcite	Rumble et al. 2000
96601	**12.33**	amph-gran	calcite	Rumble et al. 2000
96602	**18.36**	amph-gran	calcite	Rumble et al. 2000
96701	**14.15**	amph-gran	calcite	Rumble et al. 2000
96702	**14.09**	amph-gran	calcite	Rumble et al. 2000
96705	**12.76**	amph-gran	calcite	Rumble et al. 2000
96706	**13.86**	amph-gran	calcite	Rumble et al. 2000
96708	**13.46**	amph-gran	calcite	Rumble et al. 2000
96710	**16.31**	amph-gran	calcite	Rumble et al. 2000
96711	**17.51**	amph-gran	calcite	Rumble et al. 2000
96712	**20.08**	amph-gran	calcite	Rumble et al. 2000
96713	**17.14**	amph-gran	calcite	Rumble et al. 2000
93-46B	**8.78**	amph-gran	calcite	Rumble et al. 2000
94-DB-	**14.68**	amph-gran	calcite	Rumble et al. 2000
92-8D	**6.61**	amph-gran	calcite	Rumble et al. 2000
92-D2	**22.86**	amph-gran	calcite	Rumble et al. 2000
XH05	**11.13**	amph-gran	calcite	Rumble et al. 2000
XH09	**9.31**	amph-gran	calcite	Rumble et al. 2000
94-18B	**11.27**	amph-gran	calcite	Rumble et al. 2000
94-18C	**11.5**	amph-gran	calcite	Rumble et al. 2000
94-18D	**10.99**	amph-gran	calcite	Rumble et al. 2000
94-52A	**20.53**	amph-gran	calcite	Rumble et al. 2000
94-52B	**22.81**	amph-gran	calcite	Rumble et al. 2000
94-52E	**19.4**	amph-gran	calcite	Rumble et al. 2000
94-DB-53B	**15.95**	amph-gran	calcite	Rumble et al. 2000
94-53C	**15.1**	amph-gran	calcite	Rumble et al. 2000
MW-45	**17.93**	amph-gran	calcite	Rumble et al. 2000
92-W-50	**13.34**	amph-gran	calcite	Rumble et al. 2000
Greece- Naxos				
111	18.48	amphibolite	calcite	Bickle and Baker 1990
112	18.66	amphibolite	calcite	Bickle and Baker 1990
114	18.62	amphibolite	calcite	Bickle and Baker 1990

Location/ Sample	$\delta^{18}O$	MM facies	material	Reference
115	18.75	amphibolite	calcite	Bickle and Baker 1990
13	20.08	amphibolite	calcite	Bickle and Baker 1990
3	20.74	amphibolite	calcite	Bickle and Baker 1990
4	22.42	amphibolite	calcite	Bickle and Baker 1990
5	23.36	amphibolite	calcite	Bickle and Baker 1990
6	23.05	amphibolite	calcite	Bickle and Baker 1990
7	23.85	amphibolite	calcite	Bickle and Baker 1990
12	24.59	amphibolite	calcite	Bickle and Baker 1990
8	24.99	amphibolite	calcite	Bickle and Baker 1990
9	24.39	amphibolite	calcite	Bickle and Baker 1990
10	24.06	amphibolite	calcite	Bickle and Baker 1990
14	24.02	amphibolite	calcite	Bickle and Baker 1990
1	17.03	amphibolite	calcite	Bickle and Baker 1990
62	16.29	amphibolite	calcite	Bickle and Baker 1990
62	16.1	amphibolite	calcite	Bickle and Baker 1990
2	17.5	amphibolite	calcite	Bickle and Baker 1990
4	19.13	amphibolite	calcite	Bickle and Baker 1990
5	20.11	amphibolite	calcite	Bickle and Baker 1990
6	20.72	amphibolite	calcite	Bickle and Baker 1990
7	24.18	amphibolite	calcite	Bickle and Baker 1990
8	26.59	amphibolite	calcite	Bickle and Baker 1990
63	26.74	amphibolite	calcite	Bickle and Baker 1990
9	26.88	amphibolite	calcite	Bickle and Baker 1990
India, Kerala Khondalite bel				
SK1-27C	12.4	granulite	calcite	Satish-Kumar et al. 2001
SKI-27B	11.9	granulite	calcite	Satish-Kumar et al. 2001
SK1-27a	12.2	granulite	calcite	Satish-Kumar et al. 2001
SK1-10a	12	granulite	calcite	Satish-Kumar et al. 2001
SK1-10Ba	12.1	granulite	calcite	Satish-Kumar et al. 2001
SK1-10Bb	12.3	granulite	calcite	Satish-Kumar et al. 2001
N/CS/a	11	granulite	calcite	Satish-Kumar et al. 2001
N/CS/b	10.9	granulite	calcite	Satish-Kumar et al. 2001
N/CS/c	10.9	granulite	calcite	Satish-Kumar et al. 2001
N/C32F/a	11.5	granulite	calcite	Satish-Kumar et al. 2001
N/32F3b	10.9	granulite	calcite	Satish-Kumar et al. 2001
SK 3-1a1	13	granulite	calcite	Satish-Kumar et al. 2001
SK 3-1a2	13.1	granulite	calcite	Satish-Kumar et al. 2001
SK 3-1a3	13.4	granulite	calcite	Satish-Kumar et al. 2001
SK 3-1a4	14.1	granulite	calcite	Satish-Kumar et al. 2001
SK 3-1a5	13.3	granulite	calcite	Satish-Kumar et al. 2001
KOR/CS/a	14.7	granulite	calcite	Satish-Kumar et al. 2001
KOR/CS/b	14.1	granulite	calcite	Satish-Kumar et al. 2001
KOR/CS/c	13.6	granulite	calcite	Satish-Kumar et al. 2001
SK20-3b1	22	granulite	calcite	Satish-Kumar et al. 2001
SK20-3b2	21.9	granulite	calcite	Satish-Kumar et al. 2001
SK7-6C	20.9	granulite	calcite	Satish-Kumar et al. 2001
SK7-6D	20.7	granulite	calcite	Satish-Kumar et al. 2001
SK21-2aC	20.4	granulite	calcite	Satish-Kumar et al. 2001

Location/ Sample	$\delta^{18}O$	MM facies	material	Reference
SK21-2aD	20.3	granulite	calcite	Satish-Kumar et al. 2001
SK20-3bA	21	granulite	calcite	Satish-Kumar et al. 2001
SK20-3bD	22	granulite	calcite	Satish-Kumar et al. 2001
SK20-1aA	21.4	granulite	calcite	Satish-Kumar et al. 2001
SK20-1aB	21.7	granulite	calcite	Satish-Kumar et al. 2001
SK20-5C1	20.9	granulite	calcite	Satish-Kumar et al. 2001
SK20-5C2	21.1	granulite	calcite	Satish-Kumar et al. 2001
SK7-6J	21	granulite	calcite	Satish-Kumar et al. 2001
SK7-6K	20	granulite	calcite	Satish-Kumar et al. 2001
Norway- Lofoten-Vesteralen				
A-1	21.7	granulite	calcite	Baker and Fallick 1988
A-2	11.2	granulite	calcite	Baker and Fallick 1988
A-3	17.4	granulite	calcite	Baker and Fallick 1988
A-4	20.6	granulite	calcite	Baker and Fallick 1988
A-5	23.5	granulite	calcite	Baker and Fallick 1988
A-6	23.3	granulite	calcite	Baker and Fallick 1988
A-7	20.5	granulite	calcite	Baker and Fallick 1988
A-8	24.2	granulite	calcite	Baker and Fallick 1988
B,C-1	10.1	granulite	calcite	Baker and Fallick 1988
B,C-2	12.3	granulite	calcite	Baker and Fallick 1988
B,C-3	12.3	granulite	calcite	Baker and Fallick 1988
D-1	13.7	granulite	calcite	Baker and Fallick 1988
D-2	14.3	granulite	calcite	Baker and Fallick 1988
D-3	13.1	granulite	calcite	Baker and Fallick 1988
D-4	13.7	granulite	calcite	Baker and Fallick 1988
D-5	15.8	granulite	calcite	Baker and Fallick 1988
D-6	11.9	granulite	calcite	Baker and Fallick 1988
D-7	15.3	granulite	calcite	Baker and Fallick 1988
E1	13.7	granulite	calcite	Baker and Fallick 1988
E2	15.6	granulite	calcite	Baker and Fallick 1988
F1	16.7	granulite	calcite	Baker and Fallick 1988
F2	14.8	granulite	calcite	Baker and Fallick 1988
G-1	16.7	granulite	calcite	Baker and Fallick 1988
G-2	17	granulite	calcite	Baker and Fallick 1988
G-3	17.2	granulite	calcite	Baker and Fallick 1988
H-1	23.4	granulite	calcite	Baker and Fallick 1988
H-2	21.3	granulite	calcite	Baker and Fallick 1988
H-3	19.2	granulite	calcite	Baker and Fallick 1988
H-4	19.7	granulite	calcite	Baker and Fallick 1988
H-5	11.7	granulite	calcite	Baker and Fallick 1988
H-6	14.6	granulite	calcite	Baker and Fallick 1988
H-7	18.9	granulite	calcite	Baker and Fallick 1988
H-8	17.9	granulite	calcite	Baker and Fallick 1988
I-1	14.1	granulite	calcite	Baker and Fallick 1988
I-2	12.4	granulite	calcite	Baker and Fallick 1988
I-3	12.1	granulite	calcite	Baker and Fallick 1988
J-1	15.9	granulite	calcite	Baker and Fallick 1988
J-2	17.6	granulite	calcite	Baker and Fallick 1988

Location/ Sample	$\delta^{18}O$	MM facies	material	Reference
J-3	20	granulite	calcite	Baker and Fallick 1988
J-4	16.1	granulite	calcite	Baker and Fallick 1988
J-5	20.1	granulite	calcite	Baker and Fallick 1988
J-6	19.4	granulite	calcite	Baker and Fallick 1988
K-1	15.9	granulite	calcite	Baker and Fallick 1988
K-2	17.6	granulite	calcite	Baker and Fallick 1988
K-3	15.8	granulite	calcite	Baker and Fallick 1988
K-4	17.8	granulite	calcite	Baker and Fallick 1988
L-1	17.5	granulite	calcite	Baker and Fallick 1988
L-2	17	granulite	calcite	Baker and Fallick 1988
L-3	16.9	granulite	calcite	Baker and Fallick 1988
L-4	14.1	granulite	calcite	Baker and Fallick 1988
L-5	22.1	granulite	calcite	Baker and Fallick 1988
L-6	17.4	granulite	calcite	Baker and Fallick 1988
M-1	14.6	granulite	calcite	Baker and Fallick 1988
M-2	14.7	granulite	calcite	Baker and Fallick 1988
M-3	14.5	granulite	calcite	Baker and Fallick 1988
M-4	16.5	granulite	calcite	Baker and Fallick 1988
M-5	14.5	granulite	calcite	Baker and Fallick 1988
M-6	15.5	granulite	calcite	Baker and Fallick 1988
M-7	15.4	granulite	calcite	Baker and Fallick 1988
M-8	15.7	granulite	calcite	Baker and Fallick 1988
M-9	12.4	granulite	calcite	Baker and Fallick 1988
M-10	13.6	granulite	calcite	Baker and Fallick 1988
M-11	14.7	granulite	calcite	Baker and Fallick 1988
M-12	9.9	granulite	calcite	Baker and Fallick 1988
M-13	14.7	granulite	calcite	Baker and Fallick 1988
M-14	14.4	granulite	calcite	Baker and Fallick 1988
M-15	17.9	granulite	calcite	Baker and Fallick 1988
M-16	13	granulite	calcite	Baker and Fallick 1988
Norway- W. Gneiss Region				
E11m	17.9	amphibolite	calcite	Agrinier et al. 1985
C300m	6.7	amphibolite	calcite	Agrinier et al. 1985
C300c	6.8	amphibolite	calcite	Agrinier et al. 1985
USA- ADIRONDACKS				
AUS77-1	13.3	granulite	calcite	Valley and O'Neil 1984
AUS78-5	13.7	granulite	calcite	Valley and O'Neil 1984
AUS78-10	22.6	granulite	calcite	Valley and O'Neil 1984
BL2-2	21.9	granulite	calcite	Valley and O'Neil 1984
FH2-2	23.8	granulite	calcite	Valley and O'Neil 1984
FH4-1	16.9	granulite	calcite	Valley and O'Neil 1984
FH5-2	18.6	granulite	calcite	Valley and O'Neil 1984
FH6-2	17.2	granulite	calcite	Valley and O'Neil 1984
GOV24-4	26.4	granulite	calcite	Valley and O'Neil 1984
GOV34	25.6	granulite	calcite	Valley and O'Neil 1984
GOV39	20.8	granulite	calcite	Valley and O'Neil 1984
GOV50-2	21.6	granulite	calcite	Valley and O'Neil 1984
GOV53	26.1	granulite	calcite	Valley and O'Neil 1984

Location/ Sample	$\delta^{18}O$	MM facies	material	Reference
GOV67	24.7	granulite	calcite	Valley and O'Neil 1984
GOV77-300-3	25.5	granulite	calcite	Valley and O'Neil 1984
GOV77-307-7	20.4	granulite	calcite	Valley and O'Neil 1984
GOV77-307-9	18.8	granulite	calcite	Valley and O'Neil 1984
GOV377-311-5	19	granulite	calcite	Valley and O'Neil 1984
GOV78-10	23.3	granulite	calcite	Valley and O'Neil 1984
GOV78-17	27.2	granulite	calcite	Valley and O'Neil 1984
GOV78-22	27	granulite	calcite	Valley and O'Neil 1984
GOV78-23	17.3	granulite	calcite	Valley and O'Neil 1984
GOV100	19.9	granulite	calcite	Valley and O'Neil 1984
GOV104	22.5	granulite	calcite	Valley and O'Neil 1984
IL2-1	13.6	granulite	calcite	Valley and O'Neil 1984
IL2-6	13.5	granulite	calcite	Valley and O'Neil 1984
IL2-7	13.8	granulite	calcite	Valley and O'Neil 1984
IL10-1	20.2	granulite	calcite	Valley and O'Neil 1984
IL11	17	granulite	calcite	Valley and O'Neil 1984
IL13	16.8	granulite	calcite	Valley and O'Neil 1984
IL14	17.3	granulite	calcite	Valley and O'Neil 1984
IL20	12.8	granulite	calcite	Valley and O'Neil 1984
IL25	20.9	granulite	calcite	Valley and O'Neil 1984
IL27	22.7	granulite	calcite	Valley and O'Neil 1984
LP1-1	14.6	granulite	calcite	Valley and O'Neil 1984
LP8-2	18.3	granulite	calcite	Valley and O'Neil 1984
LP77-201	26.1	granulite	calcite	Valley and O'Neil 1984
LP77-210-11	22.4	granulite	calcite	Valley and O'Neil 1984
LP77-210-12	22.3	granulite	calcite	Valley and O'Neil 1984
LP77-210-13	21.5	granulite	calcite	Valley and O'Neil 1984
LP77-210-15	25.5	granulite	calcite	Valley and O'Neil 1984
LP77-216-1	19.8	granulite	calcite	Valley and O'Neil 1984
LP200	23.3	granulite	calcite	Valley and O'Neil 1984
LP204-1	18.9	granulite	calcite	Valley and O'Neil 1984
NC7-76	22.7	granulite	calcite	Valley and O'Neil 1984
NC10	17.9	granulite	calcite	Valley and O'Neil 1984
NC12	22.7	granulite	calcite	Valley and O'Neil 1984
NC13-76	21.1	granulite	calcite	Valley and O'Neil 1984
NC78-3	21.8	granulite	calcite	Valley and O'Neil 1984
NC78-5	23.3	granulite	calcite	Valley and O'Neil 1984
NC78-6	22.2	granulite	calcite	Valley and O'Neil 1984
OF3-1	13.3	granulite	calcite	Valley and O'Neil 1984
OF202	12.3	granulite	calcite	Valley and O'Neil 1984
OF203-1	13.9	granulite	calcite	Valley and O'Neil 1984
SL9-1	17.8	granulite	calcite	Valley and O'Neil 1984
SP2-2	16.8	granulite	calcite	Valley and O'Neil 1984
SP2-3	16.8	granulite	calcite	Valley and O'Neil 1984
SP200	22.8	granulite	calcite	Valley and O'Neil 1984
TP9-5	22.4	granulite	calcite	Valley and O'Neil 1984
TP10-1	24.3	granulite	calcite	Valley and O'Neil 1984
TP13-1	12.3	granulite	calcite	Valley and O'Neil 1984

Location/ Sample	**δ^{18}O**	**MM facies**	**material**	**Reference**
TP16	14.3	granulite	calcite	Valley and O'Neil 1984
TP20-1	19.4	granulite	calcite	Valley and O'Neil 1984
V-3-11-355	17.1	granulite	calcite	Valley and O'Neil 1984
V-3-11-434	16.8	granulite	calcite	Valley and O'Neil 1984
V-3-11-461	20.3	granulite	calcite	Valley and O'Neil 1984
V-3-11-514	18.1	granulite	calcite	Valley and O'Neil 1984
W2-3b	21.9	granulite	calcite	Valley and O'Neil 1984
W3-1	18.2	granulite	calcite	Valley and O'Neil 1984
W78-3	23.7	granulite	calcite	Valley and O'Neil 1984
USA- ADIRONDACKS				
C87GV12	16.9	amphibolite	calcite	Cartwright and Valley 1991
C87GV13	18.4	amphibolite	calcite	Cartwright and Valley 1991
C87GV17	17	amphibolite	calcite	Cartwright and Valley 1991
C87GV18	19.7	amphibolite	calcite	Cartwright and Valley 1991
C87GV19	22.7	amphibolite	calcite	Cartwright and Valley 1991
C87GV20	23	amphibolite	calcite	Cartwright and Valley 1991
C87GV23	22.6	amphibolite	calcite	Cartwright and Valley 1991
C87HA71	18.3	granulite	calcite	Cartwright and Valley 1991
C87HA72	16.6	granulite	calcite	Cartwright and Valley 1991
C87HA73	20.5	granulite	calcite	Cartwright and Valley 1991
C87HA74	21.9	granulite	calcite	Cartwright and Valley 1991
C87HA76	20.6	granulite	calcite	Cartwright and Valley 1991
C87HA78	19	granulite	calcite	Cartwright and Valley 1991
C87HA80	21.9	granulite	calcite	Cartwright and Valley 1991
C87HA81	21.4	granulite	calcite	Cartwright and Valley 1991
C87HA83	23.7	granulite	calcite	Cartwright and Valley 1991
C87HA85	22.7	granulite	calcite	Cartwright and Valley 1991
Ontario- GRENVILLE				
145-3	27.8	amphibolite	calcite	Shieh et al. 1976
198-4	26.9	amphibolite	calcite	Shieh et al. 1976
198-5	26.4	amphibolite	calcite	Shieh et al. 1976
110-3	25.2	amphibolite	calcite	Shieh et al. 1976
86	22.6	amphibolite	calcite	Shieh et al. 1976
130	19.6	amphibolite	calcite	Shieh et al. 1976
199	19.3	amphibolite	calcite	Shieh et al. 1976
233	23.8	amphibolite	calcite	Shieh et al. 1976
USA and Canada- Grenvill				
FN2	22.4	granulite	calcite	Valley and O'Neil 1981
HBU79-1-1	16.8	granulite	calcite	Valley and O'Neil 1981
HBU79-1-2	16.6	granulite	calcite	Valley and O'Neil 1981
MR7	24.8	amphibolite	calcite	Valley and O'Neil 1981
PS79-1-1	16.6	amphibolite	calcite	Valley and O'Neil 1981
Q100	23.6	amphibolite	calcite	Valley and O'Neil 1981
Q120	20.3	amphibolite	calcite	Valley and O'Neil 1981
USA- ADIRONDACKS				
LL-1	25.8	amph/gran	calcite	Whelan et al. 1984
UL-4	27	amph/gran	calcite	Whelan et al. 1984
UL-13	24.8	amph/gran	calcite	Whelan et al. 1984

Location/ Sample	**$\delta^{18}O$**	**MM facies**	**material**	**Reference**
HT-6	25.2	amph/gran	calcite	Whelan et al. 1984
HT-10	25.4	amph/gran	calcite	Whelan et al. 1984
USA, Scotland, Italy				
KP3E	19.57	595 C	calcite	Ferry et al. 2010
R3L	18.37	595 C	calcite	Ferry et al. 2010
B4Q	10.12	700 C	calcite	Ferry et al. 2010
KPIL	11.01	595 C	calcite	Ferry et al. 2010
B4L	21.4	680 C	calcite	Ferry et al. 2010
Turkey				
OB-1	28.76	amph.	calcite	Orhan et al. 2010
OB-4a	29.83	amph.	calcite	Orhan et al. 2010
OA-2-10	28.61	amph.	calcite	Orhan et al. 2010
KA-16	27.66	amph.	calcite	Orhan et al. 2010
NB-9	28.53	amph.	calcite	Orhan et al. 2010
Mozambique				
Mvm040	17.9	amphibolite	WR	Melezhik et al. 2008
Mvm041	18.9	amphibolite	WR	Melezhik et al. 2008
Mvm042	20.3	amphibolite	WR	Melezhik et al. 2008
Mvm043	16.8	amphibolite	WR	Melezhik et al. 2008
Mvm044	14.6	amphibolite	WR	Melezhik et al. 2008
Mvm045	15.1	amphibolite	WR	Melezhik et al. 2008
BB037	16.6	amphibolite	WR	Melezhik et al. 2008
Mvm052	19.3	amphibolite	WR	Melezhik et al. 2008
mvm051	22.7	amphibolite	WR	Melezhik et al. 2008
mvm050	21.7	amphibolite	WR	Melezhik et al. 2008
mvm053	22.4	amphibolite	WR	Melezhik et al. 2008
mvm054	22	amphibolite	WR	Melezhik et al. 2008
mvm056	22.7	amphibolite	WR	Melezhik et al. 2008
BB031	22	amphibolite	WR	Melezhik et al. 2008
Mvm65	22.2	amphibolite	WR	Melezhik et al. 2008
Mvm66	22.6	amphibolite	WR	Melezhik et al. 2008
Mvm75	21.4	amphibolite	WR	Melezhik et al. 2008
Mvm061	19.5	amphibolite	WR	Melezhik et al. 2008
Mvm064	22.6	amphibolite	WR	Melezhik et al. 2008
Mvm067	22	amphibolite	WR	Melezhik et al. 2008
Mvm070	22.2	amphibolite	WR	Melezhik et al. 2008
Mvm071	21.8	amphibolite	WR	Melezhik et al. 2008
Mvm072	21.2	amphibolite	WR	Melezhik et al. 2008
Mvm081	21.7	amphibolite	WR	Melezhik et al. 2008
BB022	16.7	amphibolite	WR	Melezhik et al. 2008
TBM143A	24.7	amphibolite	WR	Melezhik et al. 2008
IH04.027	15.1	amphibolite	WR	Melezhik et al. 2008
JS285	22	amphibolite	WR	Melezhik et al. 2008
JS299	19	amphibolite	WR	Melezhik et al. 2008
TBM-126	19	amphibolite	WR	Melezhik et al. 2008
JS200	26.1	amphibolite	WR	Melezhik et al. 2008
JS303	28.4	amphibolite	WR	Melezhik et al. 2008
JS330	23.1	amphibolite	WR	Melezhik et al. 2008

Location/ Sample	$\delta^{18}O$	MM facies	material	Reference
TBM-097	19.6	amphibolite	WR	Melezhik et al. 2008
TBM-098	19.9	amphibolite	WR	Melezhik et al. 2008
TBM-099	18.6	amphibolite	WR	Melezhik et al. 2008
TBM-105	20.8	amphibolite	WR	Melezhik et al. 2008
AS04-26	20.1	amphibolite	WR	Melezhik et al. 2008
Norwegian Coledonides				
Fr13	18.3	amphibolite	WR	Melezhik et al. 2005
Fr15a	24.9	amphibolite	WR	Melezhik et al. 2005
Fr35a	22	amphibolite	WR	Melezhik et al. 2005
Fr40	21	amphibolite	WR	Melezhik et al. 2005
Fr42	20.8	amphibolite	WR	Melezhik et al. 2005
Fr16a	26.5	amphibolite	WR	Melezhik et al. 2005
Fr33a	21.9	amphibolite	WR	Melezhik et al. 2005
Fr34a	24.9	amphibolite	WR	Melezhik et al. 2005
Fr36a	17.3	amphibolite	WR	Melezhik et al. 2005
Fr37a	24.9	amphibolite	WR	Melezhik et al. 2005
Fr38	19	amphibolite	WR	Melezhik et al. 2005
Fr39	24.1	amphibolite	WR	Melezhik et al. 2005
Fr28	14.2	amphibolite	WR	Melezhik et al. 2005
Fr17	27.1	amphibolite	WR	Melezhik et al. 2005
Fr18	26.5	amphibolite	WR	Melezhik et al. 2005
Fr19	30.2	amphibolite	WR	Melezhik et al. 2005
Fr20	28.5	amphibolite	WR	Melezhik et al. 2005
Fr21	26.4	amphibolite	WR	Melezhik et al. 2005
Fr22	25	amphibolite	WR	Melezhik et al. 2005
Fr25	26.5	amphibolite	WR	Melezhik et al. 2005
Fr26	24	amphibolite	WR	Melezhik et al. 2005
Fr27	26.6	amphibolite	WR	Melezhik et al. 2005
Fr1	21.4	amphibolite	WR	Melezhik et al. 2005
Fr10	21.7	amphibolite	WR	Melezhik et al. 2005
Fr11	23.9	amphibolite	WR	Melezhik et al. 2005
Fr12a	22.6	amphibolite	WR	Melezhik et al. 2005
Fr24	24.7	amphibolite	WR	Melezhik et al. 2005
Fr29a	21	amphibolite	WR	Melezhik et al. 2005
Fr56a	21.2	amphibolite	WR	Melezhik et al. 2005
Hef-8	21.5	amphibolite	WR	Melezhik et al. 2005
MP-114a	19.5	amphibolite	WR	Melezhik et al. 2005
a246	19.5	amphibolite	WR	Melezhik et al. 2005
a267	20.1	amphibolite	WR	Melezhik et al. 2005
a348	18.7	amphibolite	WR	Melezhik et al. 2005
a356	20	amphibolite	WR	Melezhik et al. 2005
a357	20.3	amphibolite	WR	Melezhik et al. 2005
Fr74	21.2	amphibolite	WR	Melezhik et al. 2005
a281	22.1	amphibolite	WR	Melezhik et al. 2005
a284	21.7	amphibolite	WR	Melezhik et al. 2005
a290	24.7	amphibolite	WR	Melezhik et al. 2005
a306	23.2	amphibolite	WR	Melezhik et al. 2005
a307	24.8	amphibolite	WR	Melezhik et al. 2005

Location/ Sample	**$\delta^{18}O$**	**MM facies**	**material**	**Reference**
a385	23	amphibolite	WR	Melezhik et al. 2005
a386	23.4	amphibolite	WR	Melezhik et al. 2005
a285	21.8	amphibolite	WR	Melezhik et al. 2005
a289	24.6	amphibolite	WR	Melezhik et al. 2005
a293	24.4	amphibolite	WR	Melezhik et al. 2005
a255	25.9	amphibolite	WR	Melezhik et al. 2005
Fr1	21.4	amphibolite	WR	Melezhik et al. 2005
Fr2	22.2	amphibolite	WR	Melezhik et al. 2005
Fr3	20.9	amphibolite	WR	Melezhik et al. 2005
Fr4	20.4	amphibolite	WR	Melezhik et al. 2005
Fr5	19.9	amphibolite	WR	Melezhik et al. 2005
Fr7	17.3	amphibolite	WR	Melezhik et al. 2005
Fr8a	18.5	amphibolite	WR	Melezhik et al. 2005
Fr9a	19.9	amphibolite	WR	Melezhik et al. 2005
Fr10	21.7	amphibolite	WR	Melezhik et al. 2005
Fr55	26.7	amphibolite	WR	Melezhik et al. 2005
Fr54	24.1	amphibolite	WR	Melezhik et al. 2005
Fr53	24.3	amphibolite	WR	Melezhik et al. 2005
Fr59	23.1	amphibolite	WR	Melezhik et al. 2005
Fr52	21.8	amphibolite	WR	Melezhik et al. 2005
Fr58	20	amphibolite	WR	Melezhik et al. 2005
Fr60	22.8	amphibolite	WR	Melezhik et al. 2005
Fr50	20.6	amphibolite	WR	Melezhik et al. 2005
Fr57	19.5	amphibolite	WR	Melezhik et al. 2005
Fr49a	17.5	amphibolite	WR	Melezhik et al. 2005
Fr56	21.2	amphibolite	WR	Melezhik et al. 2005
Fr23	21	amphibolite	WR	Melezhik et al. 2005
Fr41	20.1	amphibolite	WR	Melezhik et al. 2005
Fr44	23	amphibolite	WR	Melezhik et al. 2005
Fr45	17.7	amphibolite	WR	Melezhik et al. 2005
Fr47	16.4	amphibolite	WR	Melezhik et al. 2005
Fr48a	19.2	amphibolite	WR	Melezhik et al. 2005
Fr14	25.5	amphibolite	WR	Melezhik et al. 2005
a246	19.5	amphibolite	WR	Melezhik et al. 2005
Fr43a	22.5	amphibolite	WR	Melezhik et al. 2005
Fr69	17.1	amphibolite	WR	Melezhik et al. 2005
Fr70	18.7	amphibolite	WR	Melezhik et al. 2005
a336	18.8	amphibolite	WR	Melezhik et al. 2005
Fr67	16.8	amphibolite	WR	Melezhik et al. 2005
Fr68	16.2	amphibolite	WR	Melezhik et al. 2005
Fr76	19.7	amphibolite	WR	Melezhik et al. 2005
Fr64	19.6	amphibolite	WR	Melezhik et al. 2005
Fr46	19.6	amphibolite	WR	Melezhik et al. 2005
Fr75	19.7	amphibolite	WR	Melezhik et al. 2005
Fr77	20.7	amphibolite	WR	Melezhik et al. 2005
Fr78	21.5	amphibolite	WR	Melezhik et al. 2005
Fr79	25.9	amphibolite	WR	Melezhik et al. 2005

China- Sulu

Location/ Sample	**δ^{18}O**	**MM facies**	**material**	**Reference**
02SD06	14.31	amphibolite	dolomite	Tang et al. 2006
02SD07	20.2	amphibolite	dolomite	Tang et al. 2006
02SD16	18.6	amphibolite	dolomite	Tang et al. 2006
02SSD17	23.44	amphibolite	dolomite	Tang et al. 2006
USA, Adirondacks				
GOV57	21.4	granulite	dolomite	Valley and O'Neil 1984
GOV60	22.5	granulite	dolomite	Valley and O'Neil 1984
GOV63	23.2	granulite	dolomite	Valley and O'Neil 1984
GOV74	21.8	granulite	dolomite	Valley and O'Neil 1984
GOV77-300	23.8	granulite	dolomite	Valley and O'Neil 1984
GOV78-18	21	granulite	dolomite	Valley and O'Neil 1984
GOV78-20	23.4	granulite	dolomite	Valley and O'Neil 1984
GOV80	21.1	granulite	dolomite	Valley and O'Neil 1984
GOV83	21.1	granulite	dolomite	Valley and O'Neil 1984
USA, Adirondacks				
LL-1	25.4	amph/gran	dolomite	Whelan et al. 1984
LL-2	25.1	amph/gran	dolomite	Whelan et al. 1984
UC-4	25.8	amph/gran	dolomite	Whelan et al. 1984
UC-5	25.7	amph/gran	dolomite	Whelan et al. 1984
USA, Scotland, Italy				
B43A	17.37	655 C	dolomite	Ferry et al. 2010
B1W	18.7	690 C	dolomite	Ferry et al. 2010
B4L	20.99	680 C	dolomite	Ferry et al. 2010
P2A	23.19	710 C	dolomite	Ferry et al. 2010
China, Sulu and Dabie Shan Orogen				
SL91-8B	**23.11**	amph-gran	dolomite	Rumble et al. 2000
SL91-8I	**24.03**	amph-gran	dolomite	Rumble et al. 2000
SL92-9A	**24.26**	amph-gran	dolomite	Rumble et al. 2000
SL92-9D	**21.52**	amph-gran	dolomite	Rumble et al. 2000
SL92-9J	**21.02**	amph-gran	dolomite	Rumble et al. 2000
94-8A	**18.95**	amph-gran	dolomite	Rumble et al. 2000
94-DB-08E	**19.52**	amph-gran	dolomite	Rumble et al. 2000
95-16B	**20.84**	amph-gran	dolomite	Rumble et al. 2000
95-16C	**18.55**	amph-gran	dolomite	Rumble et al. 2000
CP-7	**19.51**	amph-gran	dolomite	Rumble et al. 2000
92-72B	**18.35**	amph-gran	dolomite	Rumble et al. 2000
96101	**17.92**	amph-gran	dolomite	Rumble et al. 2000
96102	**18.3**	amph-gran	dolomite	Rumble et al. 2000
96103	**17.98**	amph-gran	dolomite	Rumble et al. 2000
96104	**17.68**	amph-gran	dolomite	Rumble et al. 2000
96105	**9.89**	amph-gran	dolomite	Rumble et al. 2000
96206	**12.18**	amph-gran	dolomite	Rumble et al. 2000
96301	**14.05**	amph-gran	dolomite	Rumble et al. 2000
96302	**15.53**	amph-gran	dolomite	Rumble et al. 2000
96303	**17.4**	amph-gran	dolomite	Rumble et al. 2000
96304	**12.93**	amph-gran	dolomite	Rumble et al. 2000
96305	**17**	amph-gran	dolomite	Rumble et al. 2000
96307	**12.08**	amph-gran	dolomite	Rumble et al. 2000

Location/ Sample	**$\delta^{18}O$**	**MM facies**	**material**	**Reference**
96308	**13.8**	amph-gran	dolomite	Rumble et al. 2000
96309	**14.9**	amph-gran	dolomite	Rumble et al. 2000
96401	**15.07**	amph-gran	dolomite	Rumble et al. 2000
96402	**15.44**	amph-gran	dolomite	Rumble et al. 2000
96403	**15.03**	amph-gran	dolomite	Rumble et al. 2000
96404	**17.28**	amph-gran	dolomite	Rumble et al. 2000
96405	**17.76**	amph-gran	dolomite	Rumble et al. 2000
96406	**12.45**	amph-gran	dolomite	Rumble et al. 2000
96705	**13.22**	amph-gran	dolomite	Rumble et al. 2000
96707	**16.26**	amph-gran	dolomite	Rumble et al. 2000
94-DB-	**15.14**	amph-gran	dolomite	Rumble et al. 2000
92-8D	**7.08**	amph-gran	dolomite	Rumble et al. 2000
92-D2	**23.32**	amph-gran	dolomite	Rumble et al. 2000
94-18B	**11.73**	amph-gran	dolomite	Rumble et al. 2000
94-18C	**11.97**	amph-gran	dolomite	Rumble et al. 2000
94-18D	**11.46**	amph-gran	dolomite	Rumble et al. 2000
94-52A	**20.99**	amph-gran	dolomite	Rumble et al. 2000
94-52B	**23.26**	amph-gran	dolomite	Rumble et al. 2000
94-52E	**19.85**	amph-gran	dolomite	Rumble et al. 2000
W-44	**17.76**	amph-gran	dolomite	Rumble et al. 2000
MW-45	**18.39**	amph-gran	dolomite	Rumble et al. 2000
92-W-50	**13.8**	amph-gran	dolomite	Rumble et al. 2000
Antarctica				
CO#10,Sr#10	0.38	amph-gran	dol + calcite	Satish-Kumar et al. 2010
CO#1,Sr#1	1.77	amph-gran	dol + calcite	Satish-Kumar et al. 2010
CO#7,Sr#7	3.41	amph-gran	dol + calcite	Satish-Kumar et al. 2010
CO#4	4.7	amph-gran	dol + calcite	Satish-Kumar et al. 2010
CO#8,Sr#8	3.73	amph-gran	dolomite	Satish-Kumar et al. 2010
CC3	10.04	amph-gran	dolomite	Satish-Kumar et al. 2010
CO#6,Sr#6	10.22	amph-gran	dolomite	Satish-Kumar et al. 2010
CC2	10.89	amph-gran	dolomite	Satish-Kumar et al. 2010
CO#13	11	amph-gran	dolomite	Satish-Kumar et al. 2010
CC1	11.06	amph-gran	dolomite	Satish-Kumar et al. 2010
CC2	11.45	amph-gran	dolomite	Satish-Kumar et al. 2010
CC1	11.64	amph-gran	dolomite	Satish-Kumar et al. 2010
CO#14,Sr#14	12.14	amph-gran	dolomite	Satish-Kumar et al. 2010
CO#2,Sr#1	12.19	amph-gran	dolomite	Satish-Kumar et al. 2010
CO#9,Sr#9	12.48	amph-gran	dolomite	Satish-Kumar et al. 2010
CO#16	12.77	amph-gran	dolomite	Satish-Kumar et al. 2010
CC3	12.88	amph-gran	dolomite	Satish-Kumar et al. 2010
CC3	13.35	amph-gran	dolomite	Satish-Kumar et al. 2010
CC1	13.38	amph-gran	dolomite	Satish-Kumar et al. 2010
CC2	13.44	amph-gran	dolomite	Satish-Kumar et al. 2010
CC1	13.59	amph-gran	dolomite	Satish-Kumar et al. 2010
CC2	13.65	amph-gran	dolomite	Satish-Kumar et al. 2010
CO#19	14.7	amph-gran	dolomite	Satish-Kumar et al. 2010
CC1	15.22	amph-gran	dolomite	Satish-Kumar et al. 2010
CC2	15.27	amph-gran	dolomite	Satish-Kumar et al. 2010

Location/ Sample	$\delta^{18}O$	MM facies	material	Reference
Y69-0602e*	16.69	amph-gran	dolomite	Satish-Kumar et al. 2010
Y69-0602d*	17.02	amph-gran	dolomite	Satish-Kumar et al. 2010
SKARN DATA				
Turkey				
TMK 29	18.51	low amph	calcite	Oyman 2010
TEK 22	18.36	low amph	calcite	Oyman 2010
Turkey				
NB-7a	10.33	amph.	calcite	Orhan et al. 2010
NA-10b	11.1	amph.	calcite	Orhan et al. 2010
NA-15	17.96	amph.	calcite	Orhan et al. 2010
NB-8	17.86	amph.	calcite	Orhan et al. 2010
OB-7	12.97	amph.	calcite	Orhan et al. 2010
NA-12b	1.96	amph.	calcite	Orhan et al. 2010
NA-9	2.77	amph.	calcite	Orhan et al. 2010
NC-4	1.21	amph.	calcite	Orhan et al. 2010
OA-3-2	3.83	amph.	calcite	Orhan et al. 2010
KA-12	1.79	amph.	calcite	Orhan et al. 2010
KA-13	2.49	amph.	calcite	Orhan et al. 2010
OB-5	20.62	amph.	calcite	Orhan et al. 2010
OB-6	18.78	amph.	calcite	Orhan et al. 2010
South Korea				
L1-C	20.3	amph	calcite	Shin and Lee 2002
L2-C	23	amph	calcite	Shin and Lee 2002
USA, Adirondacks				
GOV78-14	19.8	granulite	calcite	Valley and O'Neil 1984
LP77-210-2	18.5	granulite	calcite	Valley and O'Neil 1984
LP77-210-3	18.6	granulite	calcite	Valley and O'Neil 1984
LP77-210-4	19.3	granulite	calcite	Valley and O'Neil 1984
LP77-210-5	19	granulite	calcite	Valley and O'Neil 1984
LP77-210-6	17.6	granulite	calcite	Valley and O'Neil 1984

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Location/ Sample	**$\delta^{18}O$**	**MM facies**	**material**	**Reference**

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Online Resource 2
Article title: The origin of high $\delta^{18}O$ zircons: Marbles, megacrysts, and metamorphism
Journal: Contributions to Mineralogy and Petrology
Authors: Aaron J. Cavosie, John W. Valley, Noriko T. Kita, Mike Spicuzza, Takayushi Ushikubo, Simon A. Wilde
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The following page contains a photo-mosaic of 28 detrital zircons from Mogok (Myanmar) analyzed for $\delta^{18}O$ by laser fluorination in this study. The number on the upper left of each image is the grain number. The number on the lower left of each image is the $\delta^{18}O$ value in ‰ (see Table 3 for additional details). The grains have been arranged from lowest $\delta^{18}O$ in the upper left (9.37‰), and increase in each row from left to right, to the highest $\delta^{18}O$ (25.48‰) in the lower right. A group containing dark red grains has been outlined in black. Each increment of the scale bar is 1 (one) mm.


2H
9.37
2B
10.72
2J
12.08
4E
12.58
3B
12.82
4C
13.96
3D
14.21
4D
14.27
2A
15.65
4F
15.83
4H
15.85
1C
16.68
2N
16.97
1H
17.96
1J
18.90
1K
19.21
1I
20.83
2E
21.77
2I
21.89
2D
22.15
1E
22.38
1A
23.10
2G
23.44
2O
24.33
1D
24.78
1G
25.09
2M
25.37
2L
25.48

Online Resource 3

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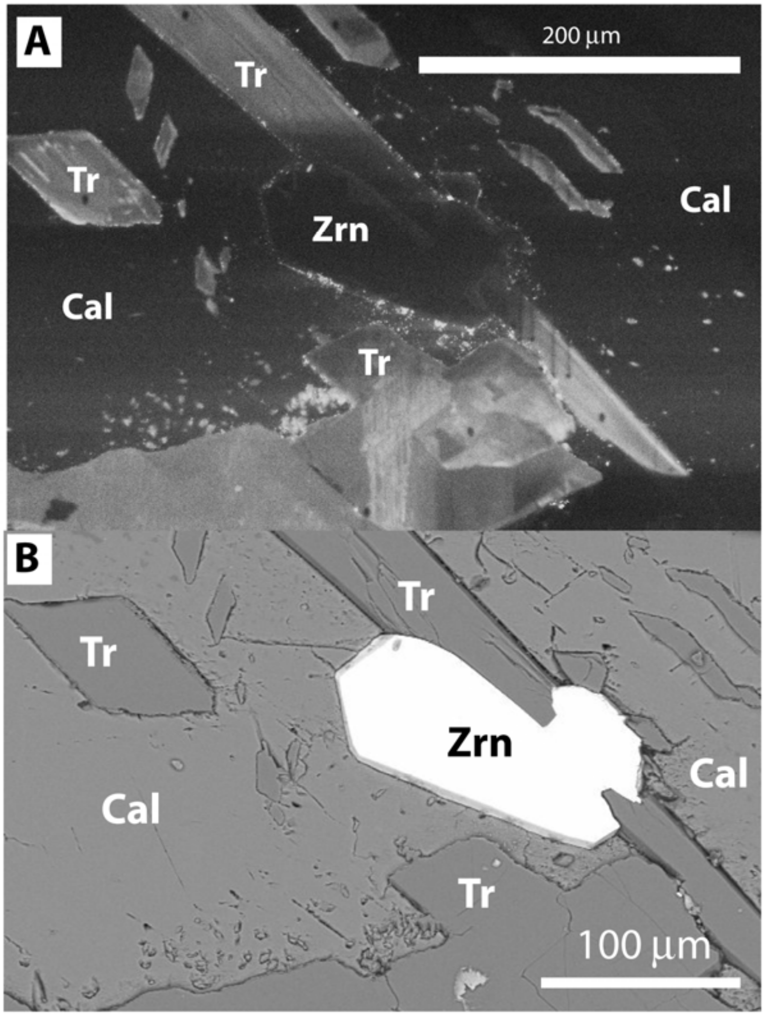

a Cathodoluminescence (CL) image of zircon CJJ4, taken at the University of Wisconsin, Madison using a Hitachi 3400 SEM. Zircon CJJ4 is located directly in the center of the image (compare with location of zircon in **b**). No visible CL was observed for this grain.
b Back scattered electron image of the same general area in **a**. Zrn = zircon; Tr = tremolite; Cal = calcite (see also Fig. 2a in article).