Dating Mantle Metasomatism: U-Pb Geochronology of zircons in cratonic mantle xenoliths from Montana and Tanzania

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Mantle metasomatism is prevalent in peridotite xenoliths carried in both alkali basalts and kimberlites. Metasomatized peridotites are characterized by incompatible element enrichments (large ion lithophile element and LREE enrichments ± concomitant high field strength element enrichments) in otherwise refractory bulk compositions. These metasomatized peridotites also tend to have evolved isotopic compositions. Pinning down the timing of metasomatism is difficult due to the high temperatures at which most xenoliths equilibrated and the lower blocking temperatures of most isotopic systems. Without this age information it is difficult to interpret the isotopic compositions of metasomatized peridotites in terms of the origin of the metasomatic components.

We report here the results of U-Pb dating of zircon occurring as a metasomatic phase in harzburgites from the Highwood Mts., Montana, and from the Labait cinder cone, Tanzania. These ages pin down the timing of mantle metasomatism, which ranges from Proterozoic to Quaternary and in both cases coincides well with regional geological events.

Samples

The potassic maafic volcanics and intrusives in the Highwood Mountains represent Eocene post-subduction continental arc magmas within the Great Falls tectonic zone near the NW margin of the Archean Wyoming craton (O'Brien et al., 1995). The Great Falls tectonic zone is believed to represent a 1.8 Ga tectonic boundary between the Wyoming and Hearne provinces (Hoffman, 1989) although details of its lithology and structure are largely obscured by sedimentary and volcanic cover. A large variety of ultramafic xenoliths are found in the Highwood minettes. Spinel harzburgite and lherzolite are the dominant lithologies and contain metasomatic minerals (e.g., mica, amphibole, ilmenite and apatite). Zircon occurs in 3 of the ultramafic xenoliths: within olivine in two olivine-rich harzburgites and in glimmerite veins cutting a harzburgite (two separate veins were analyzed). In addition, zircons from a mica gabbro (cpx-plag-phlogopite-apatite-monazite-zircon) were also analyzed.

In the olivine-rich harzburgites (EN88-4, EN89-1), zircon is associated with apatite and Mg-ilmenite. Mica and amphibole also occur in the harzburgites, which have low Mg#s (e.g., Mg/(Mg+Fe) = 83) compared to residual peridotite xenoliths. Zircons (10 to 100 μm across) from the harzburgite are oval to round and in BSE and CL show patchy zoning, but no growth zoning. The glimmerites cutting harzburgite EN88-1 are surrounded by thick (several cm) orthopyroxenite reaction zones, which also contain zircon. In addition to zircon, the glimmerite veins contain mica, orthopyroxene, clinopyroxene, rutile, magnetite, chromite and calcite ± altered plagioclase (believed to be xenocrystic), monazite, apatite and thorianite. The harzburgite that they cut contains a small amount of mica and has Mg# = 88, low compared to refractory peridotites. Zircon has not been observed in the harzburgite itself. Zircons from the glimmerite (50 to 500 μm in longest dimension) are round to elongate and have a distinctive lavender color. BSE images reveal growth zoning in some of the crystals, indicative of crystallization from a melt. Zircons in the mica gabbro are relatively small (30-80 μm), muti-facted spheres, similar to zircons from granulite facies xenoliths.

Based on thermobarometry, the harzburgites described above equilibrated at rather shallow levels in the upper mantle or lower crust. Their trace element compositions are peculiar for peridotites (LREE enriched, with large Eu, Sr and Nb depletions) and are interpreted to reflect the composition of the metasomatic agent (melt or fluid), which appears to have affinities with the continental crust. They are some of the most isotopically evolved samples yet measured from the lithospheric mantle (ε_{Nd} = -9 to -39, $^{87}Sr/^{86}Sr$ = 0.705 to 0.759, $^{206}Pb/^{204}Pb$ = 17.9 to 23.2)(Carlson and Irving, 1994), indicating their incompatible trace elements are dominated by a component that experienced long term enrichment of LREE, high Rb/Sr and U/Pb.

The Labait tuff cone is an olivine melilitite that erupted on the eastern margin of the Archean Tanzanian craton where it meets Proterozoic rocks of the Usagaran belt (Dawson et al., 1997). The east African rift penetrates the edge of the craton here and Labait is part of the youngest episode of rift volcanism, dated elsewhere between 0.7 to 1.5 Ma (Bagdasaryan et al., 1973). Xenoliths are abundant at Labait and include dunitic cumulates, spinel harzburgites, chromite harzburgites, garnet harzburgite and lherzolites (Dawson et al., 1997; Lee and Rudnick, 1998). Zircon was found in a phlogopite-rutile-sulfide vein in a chromite-harzburgite. These zircons are large (100 to 500 μm), euhedral, and show growth zoning in BSE images.

Results

Zircons extracted from the Montana samples were measured on SHRIMP I and II at the Australian National University following the methods of Williams and Claesson (1987). The harzburgite zircons show a relatively simple age distribution (Fig. 1), yielding a mean age of 1784 ± 14 Ma (error quoted as 2σ of the mean). In contrast, zircons from the glimmerite vein show a significant spread in ages between ~1.7 and 1.9 Ga. These zircons also show a range of $^{238}U/^{206}Pb$ values, indicative of a small amount of modern Pb loss. There is no obvious correlation between zircon shape, structure or age. Multiple spots within single zircons generally yield the same ages; the maximum age difference within a single crystal is 50 Ma. Taking an average of all the data for glimmerite zircons yields an age of 1798 ± 18 Ma. Zircons from both samples are thus the same age, within error, and correspond well with the age of monazite from the glimmerite vein (1806 ± 1 Ma, Carlson and Irving, 1994). We interpret this age as the time when the zircons grew from a melt that was also responsible for the crystallization of mica, amphibole, apatite and ilmenite. This is also likely the time when the LREE-enriched signature was imparted to these rocks. Both samples have strongly negative ε_{Nd} at the time of metasomatism (i.e., -8 to -9, Carlson and Irving, 1994), suggesting that the metasomatic melt carried a time integrated LREE enriched signature. If one assumes an upper crustal-like Sm/Nd ratio for the source of the fluid (e.g., $^{147}Sm/^{144}Nd$ = 0.12), then the T_{DM} age of the source is ~2.7 Ga. U-Pb ages for spot analyses of centers of zircons from the mica gabbro (Fig. 2) show a spread of concordant ages between 1.8 and 2.25 Ga, providing evidence for an older component compared to the ultramafic xenoliths. This sample may have crystallized at ≥2.25 Ga and underwent high-grade metamorphism at 1.8 Ga, the timing of the metasomatism in the ultramafic xenoliths. Alternatively, the older zircons may be xenocrystic. There is no obvious morphology differences that are correlative with age.

Four zircon fractions from the Tanzanian harzburgite were analyzed by TIMS at the University of Arizona following the methods described in Gehrels (1990). These zircons are extremely young (Fig. 2), with a mean age of 400 ± 200 Ka, demonstrating that the phlogopite metasomatism displayed by this xenolith is related to the rift magmatism. The date also constrains the age of the Labait volcano to be Pleistocene or younger.

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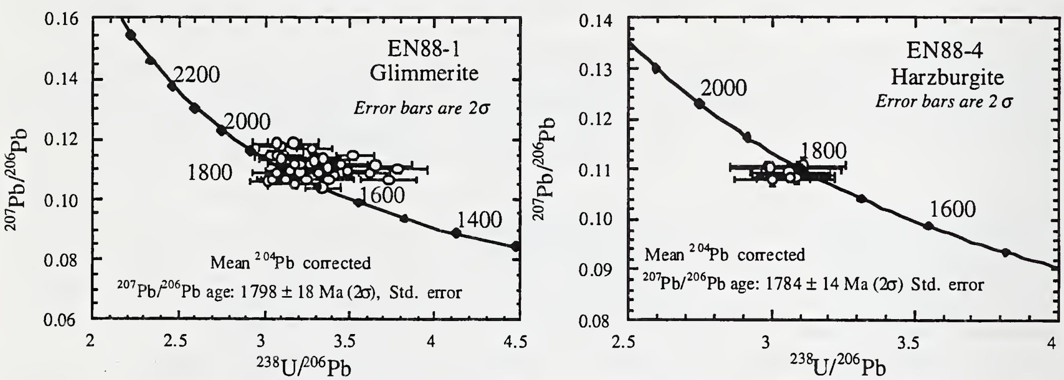

Figure 1. Tera-Wasserburg (1972) diagrams showing ages of individual spot analyses for zircons from two mantle xenoliths from the edge of the Wyoming craton, Highwood Mts., Montana. Labelled ages are in Ma.

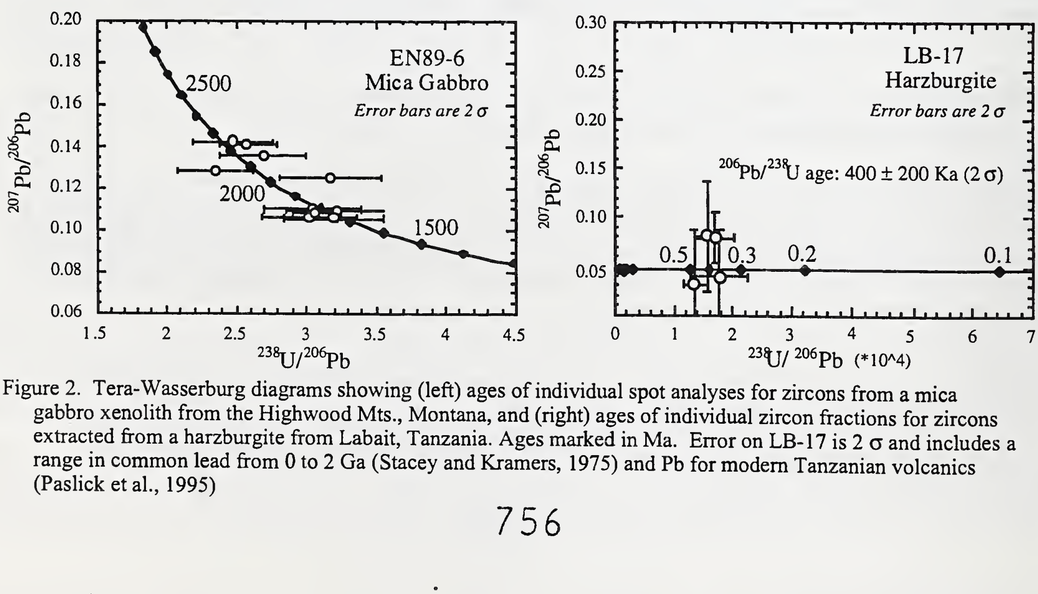

Figure 2. Tera-Wasserburg diagrams showing (left) ages of individual spot analyses for zircons from a mica gabbro xenolith from the Highwood Mts., Montana, and (right) ages of individual zircon fractions for zircons extracted from a harzburgite from Labait, Tanzania. Ages marked in Ma. Error on LB-17 is 2 σ and includes a range in common lead from 0 to 2 Ga (Stacey and Kramers, 1975) and Pb for modern Tanzanian volcanics (Paslick et al., 1995)