Testing the limits to high spatial resolution laser analysis of noble gases in natural and experimental samples

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We have tested the limits of UV laser ablation noble gas extraction, a technique used for high spatial resolution *in situ* analyses for Ar-Ar dating, (U,Th)/He dating, and in measuring diffusion and partition experimental charges. Laser spot melting using pulsed IR lasers can cause significant argon loss outside the visible laser pit, but the shorter wavelength UV lasers cause less heating outside the pit since the higher photon energies break individual bonds, and the short high energy pulses form plasmas above the sample surface. Still the laser light penetrates further into the sample than the visible pit, and most commonly used 266, 213 and 193 nm UV lasers cause a mixture of melting and ablation at the sample surface. It seems likely therefore that there will be a zone outside the laser pit from which noble gases are released and this may prove to be a limit to spatial resolution achieveable using these lasers.

In order to test the limits of laser analysis, we have analysed He layers implanted in the natural fluorapatite durango, at depths of 0.3, 1 and 10 microns using a 193nm eximer laser. The resulting He was measured in an MAP 215-50 noble gas mass spectrometer and the topgraphy of laser pits was measured using a white light interferometer. We detected He loss at distances of around 0.2 microns beneath the visible laser pit in the 0.3 and 1 micron experiments. We detected no significant He loss in the lower resolution 10 micron experiment despite several minutes of ablation and in addition we were able to measure the radiogenic He retained quantitatively above the implanted He layer.

While this is likely to be the severest test of the laser technique (He diffuses rapidly through apatite), it may still be a maximum value for loss by heating since the pit depth did not include the thin melt and condensate layer at the base of the pit. The main constraint to the spatial resolution of laser analysis in our experiment was not heating outside the laser pit but roughness of the laser pit bottom which reached 1 micron across a 100 micron pit at depths of 10 microns.

Mantle mixing in 3D: Using strain markers to model persistence and scales of heterogeneity

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Characterizing the origins and scales of mantle heterogeneity remains a long-standing question of mantle structure and dynamics. The processes of extraction of the oceanic crust at mid-ocean ridges, followed by subduction, introduce heterogeneities into the mantle. Mantle convection stretches and disperses heterogeneities, with homogenization accomplished at the smallest scale by diffusive processes. These and other processes compete to both create and destroy heterogeneities in the mantle, leading to the distinctive spectrum observed in mantle geochemistry. To assess the rate of mixing and stirring in the mantle due to convection, we use a method that isolates the stretching and thinning of 3D strain markers. We introduce passive, infinitesimal ellipsoidal strain markers into a 3D dynamical model of mantle convection, and compute the deformation and orientation of the markers. Markers experience different rates of deformation, resulting in a distribution of cumulative stretching that characterizes the flow. This method is a more accurate representation of stretching than tracking the dispersion of non-deforming strain markers, and retains information about the orientation of the markers. At both low and high Rayleigh numbers, we find that stretching and thinning is exponential with time, with the rate of stretching increasing approximately as $Ra^{1/2}$. When heterogeneities are introduced in the models continuously, the resulting distribution of heterogeneities is consistent with that of a marble-cake distribution in the upper mantle. Because deformation is rapid, the resulting mixing is efficient; to preserve heterogeneity on the long time scales observed in the mantle requires a mechanism for isolating regions, such as deep mantle layering. The rate of stretching and thinning provides information about the rate of mixing in the mantle, while the orientations of the strain markers provide insight into possible development of fabrics in the mantle.