Geophysical Research Abstracts,
Vol. 11, EGU2009-10508, 2009
EGU General Assembly 2009

Carbon in ureilite meteorites

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Ureilites are ultramafic meteorites and the second most common class of achondrite. They are believed to represent mantle residues from a single planetary body known as the ureilite parent body (UPB). Composed primarily of olivine and pyroxenes, with minor metals and suphides, they are also the most carbon rich of meteorites groups – up to 7 wt%. The carbon is interstitial to the silicate minerals and exists either as amorphous carbon or in multiple coexisting phases including: graphite, organic carbon, carbides, cohenite, diamond and lonsdaleite. This gives ureilitic carbon a superficial similarity to carbonado polycrystalline diamond on Earth. The presence of diamond in ureilites has been correlated with the degree of shock texture seen in the silicate minerals. Ureilites are significant amongst meteorites as they show primitive characteristics inherited from the solar nebula (such as their oxygen isotope signatures) as well as properties which have been imposed by planetary differentiation processes (such as igneous textures and depletions in light rare earth elements).

The origin of the carbon, and in particular the diamonds, in ureilites is still a highly contentious subject. The carbon could be primary to the UPB (meaning that it formed in the same region of the solar nebula as the silicates) or secondary (implying that it was shock injected by a carbon-rich impactor). The diamonds may have formed by impact shock during the hypothesised catastrophic destruction of the UPB (or previous impacts). An alternative is that the diamonds formed by chemical vapour deposition (CVD) in the nebula. These theories are not mutually exclusive, however, as there may be multiple generations of diamond.

Bulk analyses of ureilitic graphite yield a modest range in δ^{13}C $\approx$ –10‰ to 0‰ which is similar to those of enstatite chondrites and winonaites. However, analyses of some ureilite samples with very low carbon contents (less than 0.5%) give δ^{13}C $\sim$ –22‰This indicates a bimodality of both carbon isotope values and carbon content. For samples with between 1 and 7% carbon it appears that the smaller the carbon content, the heavier the carbon. There may also be a weak negative correlation between the Mg# of olivine cores and δ^{13}C. Carbon isotope results from ureilites contrast with Martian and HED meteorites, both of which have a range of δ^{13}C $\approx$ –30‰ to –20‰ but are of significant interest when compared with the bimodality of terrestrial mantle carbon isotope signatures (with δ^{13}C peaks at –5‰ to –25%¸).

$\sim 10-15\mu$m diamonds in the graphite in a sample of HAJMAH (A) were investigated using cathode luminescence and displayed unusual red to purple colours quite unlike either impact or terrestrial diamonds (which are typically blue). The red colour can possibly be explained by radiation damage to the diamonds.

Analyses of the polymict (representing the regolith of the UPB) ureilite sample DAG 1000 using MicroRaman shows a negative peak displacement and broadening of the band. Such negative peak shifts for the 1332 first order diamond band can be explained by admixture with a lonsdaleite component. These analyses are very similar compared with spectra from terrestrial diamonds subjected to hypervelocity impact experiments.

To the first order ureilite carbon consists of graphite with or without diamond. When examined in detail, it is complex in nature and its origin greatly debated. Studying the evolution of the UPB may give us a better understanding of the formation of the proto-Earth, and in particular its carbon signature.