HIGHLY SIDEROPHILE ELEMENTS AND OSMIUM ISOTOPE SYSTEMATICS IN UREILITES: ARE THE CARBONACEOUS VEINS PRIMARY COMPONENTS?

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Ureilites are an enigmatic group of primitive carbon-bearing achondrites of ultramafic composition. The majority of the ~143 ureilite meteorites consist primarily of olivine and pyroxene (and occasionally chromite) [1]. They are coarse-grained, slowly cooled, and depleted in incompatible lithophile elements. Minor amounts of dark interstitial material consisting of carbon, metal, sulfides, and fine-grained silicates occur primarily along silicate grain boundaries, but also intrude the silicates along fractures and cleavage planes. Variable degrees of impact shock features have also been imparted on ureilites. The prevailing two origins proposed for these rocks are either as melting residues of carbonaceous chondritic material [2], [3], or alternatively, derivation as mineral cumulates from such melts [4], [5], [6]. It has recently been proposed that ureilites are the residues of a 'smelting' event, i.e. residues of a partial melting event under highly reducing conditions, where a solid Fe-bearing phase reacts with a melt and carbon to form Fe metal and carbon monoxide [7]. Rapid, localized extraction and loss of the basaltic component into space resulting from high eruption velocities could preserve unequilibrated oxygen isotopes and produce the observed olivine-pyroxene residues via 25-30% partial melting of chondritic-like precursor material.

Another unsolved problem of ureilite research, however, is the question of whether their carbon and associated metal phases are primary phases. The fine grain size of graphite in most ureilites, the presence of diamonds, the restriction of carbon to interstitial areas and veins, and its obvious reaction relationship with primary minerals, led to the idea that carbon was shock-injected into ureilites late in their history from a carbonaceous chondrite-like impactor [8], [9]. This scenario is supported by Sm-Nd isotopic data which indicate that some shocked ureilites were reset from 4.56 to ~3.79 Ga [10].

However, the major argument against the carbon injection theory is that studies of low-shock ureilites have shown that there is no correlation of either noble gas abundances or carbon contents with degree of shock. Moreover, the occurrence of large euhedral graphite crystals in apparently unshocked ureilites, which parallel the observed silicate foliation, and the occurrence of supposedly eutectic Fe_3C in metallic spherules within primary minerals show that graphite was a primary igneous phase, which had been disrupted and converted to diamond by late shock events [6], [11].

The Re-Os isotope system along with highly siderophile element (HSE) abundances of the ureilites should provide valuable insights as to whether the veins are primary ureilite components and thus were processed along with the bulk silicate phases, or alternatively represent a component which was introduced later in their history. If, for example, metallic iron was not a stable phase in the early fractionation history of the ureilites, Re should behave incompatibly and would likely be lost along with the silicate melt, similar to the process observed on Earth [e.g. 18]. This would result in subchondritic Re/Os ratios which over time evolve to subchondritic $^{187}Os/^{188}Os$ isotope ratios in minerals of the ureilite parent body. If, on the other hand, a metallic iron phase was present, siderophile element abundance patterns should be controlled by solid metal-liquid metal distribution coefficients. If the vein material, however, represents a late introduction from a chondritic impactor, we would expect chondritic HSE abundance patterns.

We analyzed 18 bulk ureilites for Os isotopes by N-TIMS (fig.1). The $^{187}Os/^{188}Os$ ratios range from 0.1213 to 0.1302 with a mean of 0.1258, similar to typical carbonaceous chondrites [12]. There are no correlations with the mineralogy, mg# or $\Delta^{17}O$, although the augite-bearing ureilite META 78008 has the most radiogenic value, and the monomineralic pigeonite ureilite MET 01085 (more smelting?) has the lowest measured value. Polymict ureilite DAG 319, which supposedly contains clasts of the missing basaltic component, has chondritic $^{187}Os/^{188}Os$ of 0.1260. Also, no correlation of $^{187}Os/^{188}Os$ with the degree of shock of ureilites is observed. It can therefore be concluded that Re was not significantly fractionated from Os and lost along with the missing basaltic ureilite component.
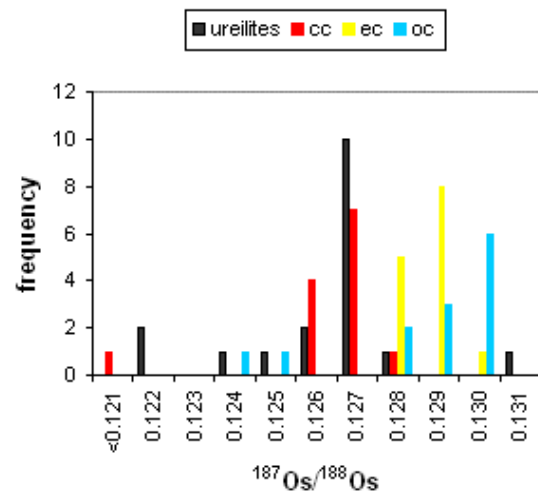

Fig.1: Comparison of ureilite $^{187}Os/^{188}Os$ with different chondrite classes (chondrite data from [12])

Limited refractory siderophile element data (Re, Os, W and Ir) on bulk ureilites show that they have concentrations within a factor ~0.1-2 of CI carbonaceous material [13 and refs therein, cf. fig.2].
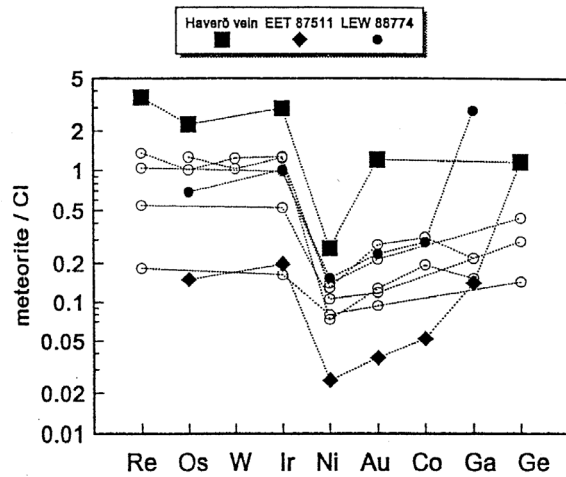

Fig.2: CI-normalized siderophile element abundances in representative ureilites (taken from [13])

Siderophile element data further suggested mixing between two components: one enriched in refractory siderophile elements, which is associated with the carbon/metal-bearing vein material [14], [15], and a depleted component associated with metal included in bulk rock crystals, probably formed by a 'smelting' process [7]. As already noted by [16], the similarity of the chondrite-normalized abundances of tungsten and the other refractory siderophiles requires that these elements were not fractionated from each other throughout the fractionation processes. A recent parameterization of solid metal/liquid metal partitioning of siderophile elements [17, cf.fig.3] suggests that for a given Fe-Ni-S-P-C composition, W and, even more pronounced, Pt, Pd and Au should be fractionated from Re and Os.
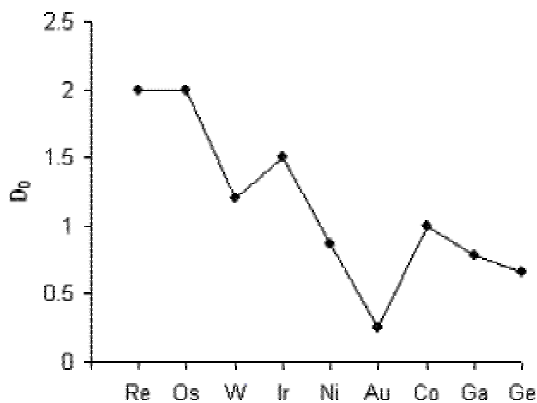

Fig.3: 'raw' distribution coefficients for solid metal-liquid metal partitioning [17]

Although the observed pattern in fig.2 is compatible with the qualitative distribution behavior in fig.3, there are discrepancies for the elements W, Ni and Co. Unfortunately, no Pt or Pd data has thus far been measured in ureilites. Quantitative modeling also requires knowledge of S, P and C contents in the metal phase.

ICP-MS concentration measurements of highly siderophile elements (HSE) are currently in progress. A comparison of HSE patterns of metal produced by the smelting process compared to vein metal will help to identify the ultimate source of the carbonaceous veins and probably help to unravel the complex history of the ureilite parent body.

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