# ACCRETION, DIFFERENTIATION AND IMPACT PROCESSES ON THE UREILITE PARENT BODY

Hilary Downes[1,2], D W Mittlefehldt[3], J S Herrin[3], P Hudon[4] [1]School of Earth Sciences, Birkbeck, University of London, London, UK (h.downes@ucl.ac.uk); [2]Lunar and Planetary Institute, Houston Texas, USA; [3] NASA/Johnson Space Centre, Houston, Texas, USA [4]Department of Earth and Planetary Sciences, McGill University, Montreal, Canada.

**Introduction:** Ureilites are primitive ultramafic achondrites composed largely of olivine and pigeonite, with minor augite, orthopyroxene, carbon, sulphide and metal [1]. They represent very early material in the history of the Solar System and (in common with lodranites and acapulcoites) form a bridge between undifferentiated chondrites and fully differentiated asteroidal bodies. They show an intriguing mixture of chemical characteristics, some of which are considered to be nebula-derived (e.g. variations in $\Delta^{17}$O and mg# [2]) whereas others have been imposed by asteroidal differentiation (e.g. core formation, silicate partial melting, removal of basalt).

**Accretion from nebula:** Fig 1 shows bulk rock Fe/Mg ratios vs $\Delta^{17}$O for ureilites and a variety of chondritic meteorite groups. The correlation between Fe/Mg and $\Delta^{17}$O resembles that of ordinary chondrites but at lower $\Delta^{17}$O values, suggesting derivation from the solar nebula during accretion.

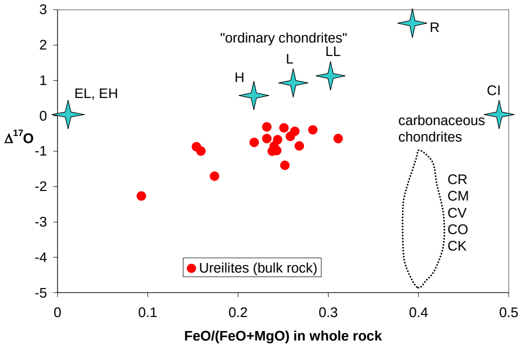

Fig. 1. Correlation between $\Delta^{17}$O values vs FeO/(FeO+MgO) in ureilites is probably derived from the solar nebula.

Our carbon isotope data show a striking negative correlation of $\delta^{13}$C values with mg# in olivine [3], and therefore this isotopic variation also may have been nebula-derived. $\delta^{13}$C also correlates with $\Delta^{17}$O (Fig 2). Thus, Fe-Mg systematics, oxygen and carbon isotope compositions for each monomict ureilite appear to have been "set in stone" before any asteroidal differentiation processes began. Olivine compositions in ureilites start suddenly at mg# = 74, a feature that must also be related to the region of the nebula where the parent body accreted. However, there are almost no correlations between other bulk-rock elemental abundances and Fe/Mg (or with its proxy, Fo content in olivine). Therefore the elemental variations in siderophile elements, REE and many other elements of petrological interest were probably not derived directly from the nebula but have been superimposed by subsequent processes.

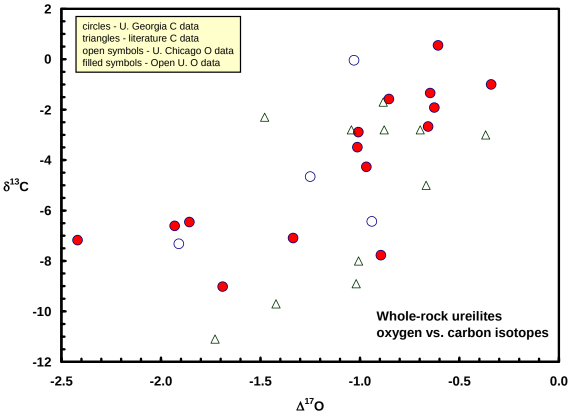

Fig. 2. Carbon and oxygen isotope compositions of ureilites show a correlation, possibly derived from the solar nebula.

**Nature of the ureilite parent body:** The parent body accreted from the nebula as a mixture of common nebula phases: olivine, orthopyroxene, diopside, plagioclase, metal, sulphide and carbon. Modal px/ (px+ol) correlates to some extent with $\Delta^{17}$O ratios, as high mg# ureilites have lower $\Delta^{17}$O values (Fig 3). Therefore some of the wide variation in px/(px+ol) ratios was probably nebula-derived, rather than the result of smelting [4]. However, ureilites with high modal px/(px+ol) tend to contain augite and this modal variation is probably due to differentiation into residual mantle and material that has interacted with basalt (e.g. Hughes 009 shows evidence for melt interaction [5]).

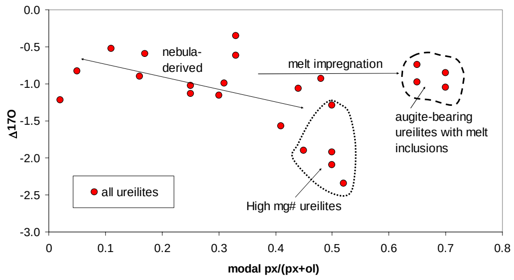

Fig. 3. Modal mineral proportions in ureilites vs $\Delta^{17}$O values in whole rocks.

**Asteroidal differentiation:** Heated principally by decay of short-lived radioactive isotopes, the asteroid started to melt. Metal and sulphide would have melted first, forming a Fe-S eutectic liquid, which removed chalcophile elements and incompatible siderophile elements, possibly to a core [6]. Heating also formed basaltic melts, starting at the most ferroan bulk-rock compositions which have the lowest melting point and moving progressively to more magnesian ones. Thus, mg#s in olivine or whole rocks do not correlate with either the degree of melting or the extent of smelting. The silicate melts were removed efficiently from the asteroid, possibly by highly explosive volcanic activity, and were retained only as rare basaltic clasts in polymict ureilites [7]. Elements such as Al, Ca and LREE were removed at this point.

**Parent-body break-up:** Several elements show different abundances and/or correlations with Fo content in olivine, e.g. carbon (Fig 4) shows a positive correlation until approximately Fo86, and a weak or even negative correlation in more magnesian compositions.

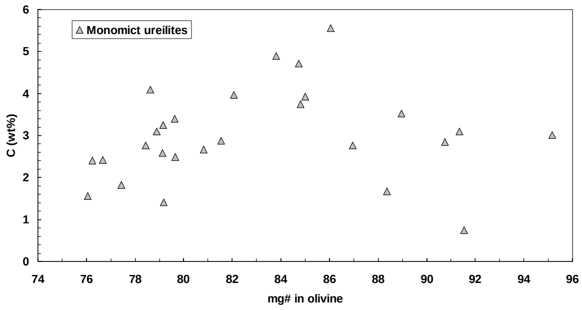

Fig. 4 Carbon abundance vs mg# in olivines for ureilites, showing two groups of ureilites.

Refractory siderophile elements such as Os and Ir also show different distributions, i.e. ureilites with Fo contents <82 have very scattered Os and Ir concentrations, which reach high values, whereas ureilites with Fo > 82 tend to have much less scattered and overall lower Os and Ir abundances (Fig. 5). A similar change in elemental behaviour is shown by the Fe-Mn relations in olivine from monomict ureilites: those with Fo contents < 85 show a good negative correlation, whereas those with Fo > 85 show much greater scatter (Fig 6). This suggests that a major change must have affected the parent body at a time when melting had reached a relatively magnesian bulk composition. We consider that this event may have been a “hit and run” collision in which the ureilite parent body collided with a larger object [8].

During the collision, the ureilite mantle broke up catastrophically but re-accreted in a jumbled state around the still-intact core. Mg-rich basaltic melts that were in the process of being formed at the time of break-up were retained in part as melt clasts that re-accreted to the regolith and are found in polymict ureilites.

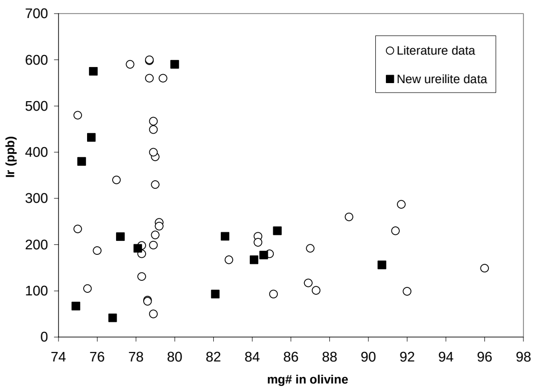

Fig 5. Ir abundances in whole rock ureilites vs mg# in constituent olivines. Two groups of ureilites are apparent: those with low mg#s and variable Ir contents, and those with high mg#s and much lower and less variable Ir contents. Os shows the same distribution pattern.

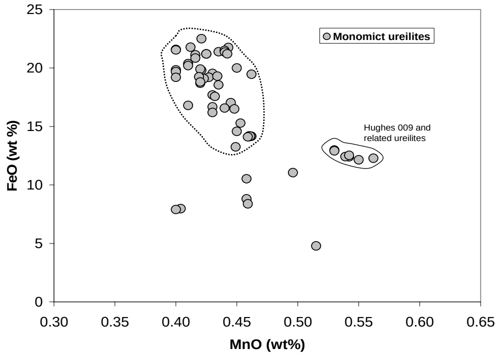

Fig. 6. FeO vs MnO contents of olivines in monomict ureilites. Those with mg# < 85 show a coherent trend derived from the nebula, whereas those with mg# > 85 are much more scattered. Data for ureilitic olivine clasts in polymict ureilites show separation into the same two groups.

**References:** [1] Mittlefehldt D W et al (1998) *Rev in Mineral* 36, 4-1-4-195. [2] Clayton R N and Mayeda T K (1988). *GCA* 52, 1313-1318. [3] Hudon P et al (2004) 35th LPSC Abst. 2075. [4] Singletary S J and Grove T L (2003). *MAPS* 38, 95-108. [5] Goodrich C et al (2001) *GCA* 65, 621-652. [6] Warrren P H et al (2006) *GCA* 70, 2104-2126 [7] Cohen B et al (2004) *GCA*, 68, 4249-4266. [8] Asphaug et al (2006) *Nature* 439, 155-160.