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Processes in early planetesimals: evidence from ureilite meteorites

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Ureilites are primitive ultramafic achondrites composed largely of olivine and pigeonite, with minor augite, carbon, sulphide and metal. They represent very early material in the history of the Solar System and form a bridge between undifferentiated chondrites and fully differentiated asteroids. They show a mixture of chemical characteristics, some of which are considered to be nebula-derived (e.g. a negative correlation between Mg/Fe and $\Delta^{17}O$ that resembles that of the ordinary chondrites but at lower $\Delta^{17}O$ values) whereas others have been imposed by asteroidal differentiation. Carbon isotope data show a striking negative correlation of $\delta^{13}C$ values with mg# in olivine. $\delta^{13}C$ also correlates positively with $\Delta^{17}O$, and therefore this isotopic variation was probably also nebula-derived. Thus, oxygen and carbon isotope compositions and Fe-Mg systematics of each monomict ureilite were established before differentiation processes began.

Heated by decay of short-lived radioactive isotopes, the ureilite 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, and basaltic melts that removed Al, Ca and the LREE. Several elements show different abundances and/or correlations with Fo content in olivine, e.g. carbon shows a positive correlation in ferroan ureilites, and a weak or even negative correlation in more magnesian compositions. HSE such as Os and Ir also show different distributions, i.e. ureilites with Fo $<$ 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. A similar change in elemental behaviour is shown by the Fe-Mn relations in ureilitic olivines: those with Fo contents $<$ 85 show a good negative correlation, whereas those with Fo $>$ 85 show much greater scatter.

This suggests that a major change affected the parent body at a time when melting had reached relatively magnesian bulk compositions. We consider that this event may have been a "hit and run" collision in which the ureilite parent body collided with a larger object. 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.