Introduction: Ureilites are primitive ultramafic acondrites 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. 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.

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]).
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.

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