EARLY SOLAR SYSTEM PROCESSES REVEALED BY AN INTEGRATED STUDY OF UREILITE METEORITES

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Introduction: Far from being "bizarre" and "perplexing", ureilite meteorites provide us with a wealth of information about processes in the early Solar System which have important implications for the formation of the Earth and other terrestrial planets. The ureilite parent body (UPB) was formed by **accretion** from a chondritic precursor (as seen in the distribution of oxygen isotope values), which was rich in carbon (ureilites contain up to 6 wt% C, which exceeds typical values in carbonaceous chondrites). The UPB then underwent **differentiation**, forming an Fe-rich core and ultramafic silicate mantle, but did not achieve the magma ocean stage experienced by many other planets and asteroids (i.e. its mantle did not homogenize in terms of mg# and $\delta^{18}O$) [1]. Thus it provides a window into **pre-magma ocean** processes not available from any other source. Partial melting of the mantle of the UPB (heated by short-lived radioactive isotopes) produced **magmatic activity**, as revealed by basalt melt droplets, melt inclusions, LREE-depletion in the silicate mantle phases, and some regions of pyroxene-rich mantle. Extensive magmatic differentiation may also have resulted in small volumes of evolved magmas that formed granitioid-like material [2].

Impact and reaccretion: Ureilites also yield information about **impact processes** in the early Solar System, as many of them are polymict regolith breccias [3]. The original UPB was disrupted by a major impact while it was undergoing partial melting [1]. This produced extensive **reduction** of silicates to metal in the presence of graphite [4], and also caused the formation of Fe-Ni silicides [5]. If incorporated into larger accreting bodies, such silicides may have contributed to strongly reduced cores in early-formed terrestrial planets. Graphite was converted to diamonds by this shock event [6]; thus not all of the carbon accreted to terrestrial planets and asteroids was in the form of the low-temperature organic component found in carbonaceous chondrites. Following the disruptive impact, a daughter planetesimal rapidly reformed by **reaccretion**, producing a **rubble-pile asteroid** which is the body sampled by present-day ureilite meteorites. On the surface regolith of this asteroid, **impact gardening** occurred, with accretion of late veneers of chondritic and other material, including many unusual "orphan" clasts that have no equivalent in our meteorite collections [1]. These clasts are more variable than those found in regolith breccias from the HED parent body. A late addition of water formed opal (hydrated silica) in some areas of the regolith of the ureilite asteroid [7].

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