FELDSPATHIC CLASTS IN POLYMICT UREILITES.

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Introduction: Ureilites are ultramafic meteorites composed mainly of magnesian (mg#=76-95) olivine and pyroxene, with minor carbon-bearing phases and metal. Ureilite characteristics suggest that monomict ureilites are residues of partial melting on a carbonaceous chondrite-like asteroidal parent body [1]. Basaltic meteorites complementary to the monomict ureilites are currently unknown, but would provide compositional, isotopic, and geochronologic information critical to constraining the composition and evolution of the ureilite parent body (UPB).

Polymict ureilites [2-4], regolith breccias composed mainly of monomict ureilite material, contain about 2% (vol.) feldspathic clasts. Oxygen isotopes [5] suggest these clasts are ureilitic, so they may represent ureilitic basalts. Among these feldspathic clasts, we are interested in distinguishing between primary igneous rocks and secondary products such as impact melts. This distinction is not straightforward for the UPB. Explosive volcanism on the UPB [6-8] might produce glassy and quench-textured rocks similar in texture to impact-melted rocks. Because metal separation and core formation probably did not occur on the UPB, siderophile elements are not depleted in ureilites and contamination by chondritic impactors will not be evident. Both igneous and secondary products may be strongly reduced by ubiquitous carbon in ureilites. Petrologic and chemical modeling requires knowledge of all coexisting phases and an accurate bulk composition, which may not be obtainable from single, small clasts. A survey of feldspathic clasts can identify populations of materials, whose characteristics can then be better understood and modeled.

Feldspathic Clast Populations: We used X-ray element maps to easily identify feldspathic clasts >80 μm in size within thin sections of five polymict ureilites (DaG 164, 165, 319, and 665, and EET83309). Pairing is likely between DaG 164/165 and DaG 319/665. We used SEM and EMP techniques to characterize ~150 individual clasts. Mineral compositions were obtained using 10-20 nA focused beams, glass compositions using 5 nA defocused beams, and bulk analyses using defocused beam techniques.

Texturally, 40 clasts have a distinctive intersertal texture of pyroxene in plagioclase, 12 are phosphate grains in plagioclase, 64 are single grains of feldspar and feldspathic glass, and the rest have other textures. Feldspar compositions within the clasts range over the entire plagioclase solid-solution series (Fig. 1). Two clasts of anorthoclase ($Ab_{81-83}Or_{17-19}$) were identified. Combining texture with compositions reveals at least three distinct populations: (1) anorthitic clasts, (2) albitic clasts, which we will show to be a coherent population, and (3) intermediate clasts, which may or may not be related to each other.

Anorthitic clasts occur as isolated feldspar grains. Though it has been suggested [3] that these are derived from impactors, we have not been able to identify any other minerals or rock fragments accompanying them. *Albitic clasts* consist of albitic plagioclase or feldspathic glass (Ab_{75-99}) as groundmass or in large phenocrysts (or both). These clasts commonly have a distinctive intersertal texture. The most complete phase assemblage contains pyroxene, phosphate, ilmenite, silica and glassy mesostasis rich in FeO (molar Fe/Mg 11-18) and MnO, K_2O (up to 4%), P_2O_5 (up to ~2%) and TiO_2 (up to~2.5%). A significant fraction of the plagioclase mineral clasts is probably derived from this lithology. *Intermediate clasts* have a wide range of textures and mafic mineral compositions. One of the most common groups contains euhedral, normally-zoned olivine and/or pyroxene in labradoritic plagioclase or feldspathic glass. Another common group contains radiating laths of plagioclase with interstitial

Fig. 1: Plagioclase in Feldspathic Clasts

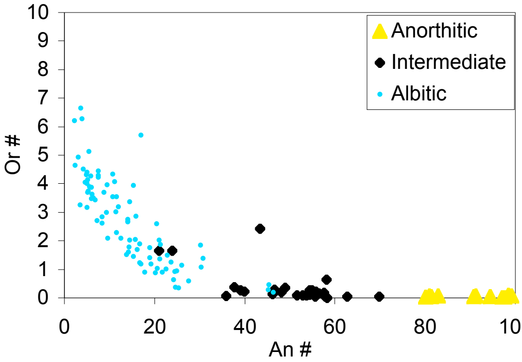
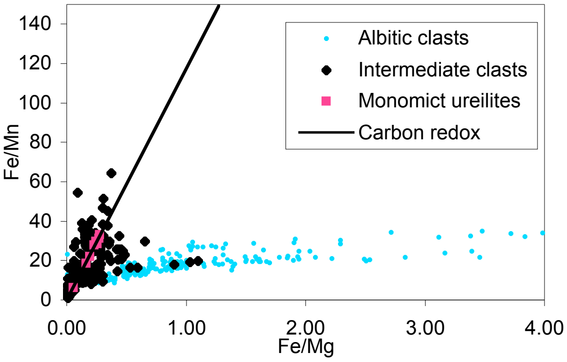


Fig. 2: Pyroxene in Feldspathic Clasts



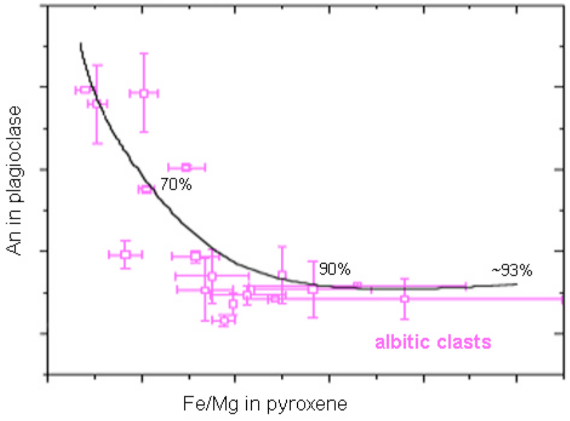
pyroxene and a Si-rich mesostasis. Still others appear to be clastic. None of these clasts contain late-stage accessory minerals such as ilmenite or phosphate.

Pyroxene and olivine compositions are shown in Fig. 2. Monomict ureilites follow a trend of constant Mg/Mn, indicating degrees of reduction (carbon redox control) due to derivation from a range of pressures/depths [9]. In contrast, suites of rocks related to a common melt in the absence of carbon follow a trend of near-constant Fe/Mn over a wide range of Fe/Mg ratios. A distinctive igneous population is evident among the albitic clasts. We consider these a complete, igneous population and discuss them as ureilitic melts. Clasts that fall on the monomict trend only show that they contain carbon, and may or may not be igneously derived; more work is being conducted on these clasts.

Ureilite basalts: The common textural and mineralogical features and mafic mineral compositional trends of the albitic clasts suggest that they represent a distinct igneous lithology related by fractionation of a common melt without carbon redox control. The albitic clast trend (Fig. 2) originates from the magnesian end of the monomict ureilite trend. The most magnesian ureilite residues originate at the shallowest depths, experienced the highest degree of reduction and therefore have the lowest carbon contents [10]. Since the high carbon (CO$_2$) contents of ureilite melts may have been responsible for explosive eruption and loss from the parent body [6,8], carbon-free (or low-carbon) melts are the most likely to have been preserved.

A correlation exists between anorthite (An) content of plagioclase and Fe/Mg ratios of pyroxenes in the albitic clasts (Fig. 3). MAGPOX and MAGFOX calculations show that this trend can be produced by crystallization of a low-degree (~5-7%) partial melt of a UPB bulk composition consistent with the most magnesian residues (mostly chondritic but Ca/Al ~3.5xCI [11]). Although all melts produce a similar trend, only the lowest degree melts produce plagioclase compositions as albitic as those observed. Higher Na contents in the starting materials result in higher degree melts that fractionate to the observed trend, but produce ol-opx rather than ol-pig residues. Lower Al contents in the starting materials have the same effect, but seem unlikely because mechanisms for producing superchondritic Ca/Al ratios involve enrichment of Ca rather than loss of Al [1]. Furthermore, the predicted crystallization sequence for these melts is consistent with the albitic clast mineralogy.

Fig. 3: Crystallization trend in albitic clasts



These results provide strong evidence that the albitic clast lithology formed by extensive fractional crystallization of the earliest melt(s) of precursor materials from which the most magnesian ureilites were produced as residues. This melting episode occurred at 4.562 Ga, as shown by ^{53}Mn-^{53}Cr age of the glass phase within a typical albitic clast [12].

Other populations: Two clasts containing euhedral olivine and skeletal pyroxene in labradoritic plagioclase appear to be unrelated to the albitic clast population, but their mafic mineral compositions show that they follow a similar igneous trend (Fig. 2). Because they are the only two examples of this population, it is not readily evident what they are.

The rest of the clasts fall on the monomict ureilite trend, indicating crystallization under carbon redox control. Several subgroups appear to be igneous products (euhedral mineral shapes, normally zoned mafic minerals, etc). Partial melts derived from deep ureilitic residues would be expected to contain abundant carbon, forcing the crystallization products to follow a constant Mn/Mg trend and perhaps explaining their paucity by explosion. Others have radiating plagioclase textures that indicate rapid cooling from multiple nucleation sites, perhaps as impact melts. An impact onto the surface of the UPB would incorporate monomict ureilite target rocks with abundant carbon. The resulting melt rocks would crystallize on the carbon redox trend. Because both impact melt rocks and deeper igneous melts would contain carbon, Fig. 2 is not able to distinguish between these scenarios. We are working on other ways to understand these smaller and more diverse populations.

References: [1] Goodrich et al. (2002) LPSC XXXIII, #1379. [2] Guan and Crozaz (2001) MAPS 36, 1039. [3] Ikeda et al. (2000) Ant. Met. Res. 13, 177. [4] Ikeda and Prinz (2001) MAPS 36, 481. [5] Kita et al. (2000) MAPS 35, A88. [6] Scott et al. (1993) GRL 20, 415. [7] Warren and Kallemeyn (1992) Icarus 100, 110. [8] Wilson and Keil (1991) EPSL 104, 505. [9] Goodrich and Jones (1987) GCA 51, 2255. [10] Singletary and Grove (2002) LPSC XXXIII, #1382. [11] Goodrich (1999) MAPS 34, 109. [12] Goodrich et al. (2002) MAPS 37, A54.