NORTHWEST AFRICA 1500: A PLAGIOCLASE-BEARING MONOMICT UREILITE.

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Introduction: Northwest Africa (NWA) 1500 was classified as an anomalous ureilite [1]. Bartoschewitz et al. [2] described this meteorite as having similarities to typical monomict ureilites, but with significant differences – notably, the presence of plagioclase that might represent the "missing basaltic component" of the ureilite parent body (UPB). They noted, however, that its oxygen isotopic composition is not within the field of ureilites. Mittlefehldt and Hudon [3] considered it to be a unique achondrite. We report an in-depth study of NWA 1500. Petrologically, this meteorite appears to be a ureilite, and one that provides new information about the differentiation of the UPB. Although plagioclase is minor, its presence is highly significant. The oxygen isotopes of this ureilite remain unexplained.

Petrography: Three thin sections show that NWA 1500 is an unbrecciated ultramafic rock. Olivine is the most abundant phase (~95%), and shows an equilibrated texture with grain sizes of ~100-500 µm. Augite occurs as a minor phase (2-3%), with grain sizes comparable to or larger (up to ~925 µm) than those of olivine. Many augite grains have intergranular forms (convex boundaries with olivine), and partially enclose olivine grains poikilitically. The presence of augite (and absence of pigeonite) would place NWA 1500 among the small group (<10%) of augite-bearing monomict ureilites [4,5]. Chromite, previously observed only in two monomict ureilites [6-8], is present (0.6-1.6%) with grain sizes up to ~300 µm. Plagioclase (0.7-1.8%) occurs principally as large (up to ~3 mm) poikilitic grains enclosing rounded olivine and augite (Fig. 1) in veinlike areas that also have concentrations of augite and orthopyroxene (opx). It occurs elsewhere as small (~25-150 µm) interstitial grains. Other minor phases are apatite (not previously observed in a monomict ureilite), metal, sulfide and graphite.

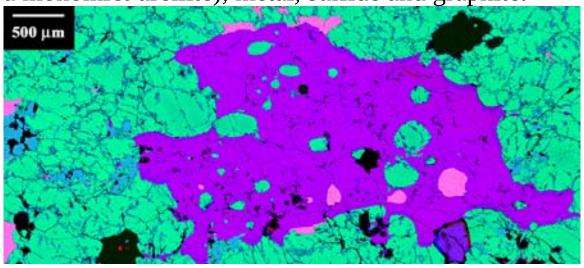

Fig. 1. Poikilitic plagioclase in veinlike area. Combined X-ray map (Red = Ca; Blue = Mg; Green = Si). Plagioclase is purple, augite is pink, olivine is green, opx is light blue. Olivine grain boundaries show reduction rims of either opx or relatively magnesian olivine (also light blue).

Olivine: All olivine grains have narrow (~10-30 µm) secondary reduction rims (compositions more magnesian than those of cores, with abundant tiny inclusions of metal), as is typical of ureilites [4]. In addition, although cores are devoid of metal inclusions, many are reversely zoned – unlike most ureilites, in which cores are homogeneous [4]. A survey of core compositions showed a range from Fo ~65-72, with a strong peak at Fo 68-69. The peak represents the dominant composition of most grains, which are weakly reverse-zoned to ~Fo 72. The largest grains, however, are strongly zoned from Fo 65 in their centers to ~Fo 72 where in contact with reduction rims. These compositions are significantly more ferroan than previously observed in monomict ureilites (Fo ≥ 75). Fe/Mg-Fe/Mn compositions of ureilite olivine (Fig. 2) have been determined to high precision, and can be used to interpret petrogenesis [9-12]. Olivine-pigeonite and olivine-opx ureilites form a trend of near-constant, chondritic Mn/Mg ratio, which indicates that they are residues and are related to one another principally by reduction [12]. In contrast, all augite-bearing ureilites are displaced to higher Mn/Mg (Fig. 2), as expected for melts related to such residues [12] and consistent with other indications that they are cumulates or paracumulates [5]. Olivine in NWA 1500 shows Fe-Mn-Mg compositions (analyses comparable to ureilite data) similar to those of augite-bearing ureilites (Fig. 2). Cr_2O_3 contents of olivine (0.04±0.01%) are much lower than in typical ureilites (0.4-0.9%), or even the chromite-bearing LEW 88774 (~0.35%). CaO contents (0.09±0.01%) are lower than in either typical ureilites (0.3-0.5%) or augite-bearing ureilites (0.2-0.3%).

Augite: Augite grains show no zonation in *mg* or Wo (*mg* 80.7±0.5; Wo 45.0±0.5), but most profiles show slight decreases in Al_2O_3 (~1.1-0.85%) and Cr_2O_3 (~0.75-0.55%) near edges.

Plagioclase: Poikilitic plagioclase grains have homogeneous compositions of An 37-38, except in ~20 µm rims in which they are normally zoned to An 26-32. Small, intergranular plagioclase grains have homogeneous compositions of ~An 33.

Opx: 1) Some reduction rims on olivine consist of magnesian opx (Wo ≤1) with undetectable Al_2O_3 – consistent with formation by reduction of olivine as is common in ureilites [4]. 2) In the veinlike areas (and to a lesser extent elsewhere), opx occurs as isolated grains (100-150 µm), and as overgrowths on augite and olivine (containing "islands" of olivine, suggesting an oliv→opx reaction). Its composition (*mg* 71.4±0.3, Wo 2.1±0.1, Al_2O_3=0.33) is distinct from that of reduction rims, and it appears to be a late, primary phase.

Other Phases: Chromites have homogeneous compositions of ~73% molar chromite, 24% spinel, and 3% ulvöspinel. Apatite was observed as one 150 µm-sized grain, and in patches of smaller grains. It contains

4-5% Cl and 0.7-1.4% F, with 0.4-3.4% FeO and 0.2-0.4% Na_2O. Metal (with 0.9-1.6% Ni) is abundant as an interstitial phase, and shows a low degree of terrestrial weathering. Its Cr, P and Si concentrations are very low (near or below detection limits), in contrast to metal in most ureilites [4]. Carbon (which is common in most ureilites) occurs as euhedral graphite crystals, indicating that shock effects are mild.

Bulk Composition: INAA data were obtained for one sample of NWA 1500. They show low Ca, Na and Cr, suggesting that the sample was olivine-rich and contained little plagioclase or chromite. REE were also very low, and only upper limits were obtained for all but Sm (0.035 × CI) and Yb (0.17 × CI), which are within the range of olivine-rich ureilites [4].

Discussion: Petrologically, NWA 1500 shows many similarities to known augite-bearing ureilites, and its differences support a model for the differentiation history of the UPB [5]. As summarized by [5], all augite-bearing ureilites appear to be cumulates or paracumulates. Textural features of NWA 1500, and the Fe-Mn-Mg composition of its olivine, suggest that it likewise contains a large melt component. Melts crystallizing early augite on the UPB could only be derived from depths greater than those at which the most ferroan olivine-pigeonite ureilites formed (Fig. 3), and would be initially less reduced due to pressure-dependent carbon redox control [5]. The ferroan silicate compositions of NWA 1500 suggest that it is a cumulate from such a melt, and the primary reverse zoning of its olivine may record reduction during ascent. The presence of chromite (and the low Cr in olivine and metal) and apatite (and the low P in metal) also indicate higher oxidation state than in most ureilites (in which Cr occurs largely as Cr^{2+} in olivine and P occurs in metal). The dominance of olivine of Fo 68-71 suggests that it reached final equilibration at a depth slightly greater than that at which the most ferroan olivine-pigeonite ureilites formed.

The crystallization sequence of the NWA 1500 parent melt (inferred from textural relationships) was olivine → augite → plagioclase → opx, which is consistent with that predicted for a melt derived from deep on the UPB and experiencing slight reduction during ascent (Fig. 3). Most of the late basaltic component continued to ascend and is not present. Either the parent melt of NWA 1500 was less refractory than melts from which other augite-bearing ureilites formed, or a larger proportion of it was trapped in the rock, or both. The low Cr and Ca contents of the olivine suggest the possibility that augite and chromite cumulates also formed. The concentration of late-crystallizing phases in veinlike areas suggests the possibility of multiple intrusions.

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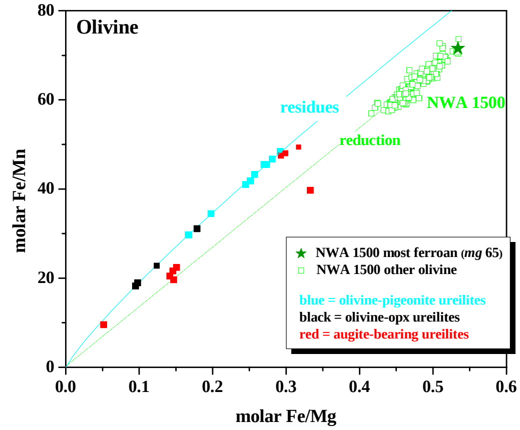

Fig. 2. Molar Fe/Mg vs. Fe/Mn for ureilite olivine. All data are of high precision and internally consistent [9-11].

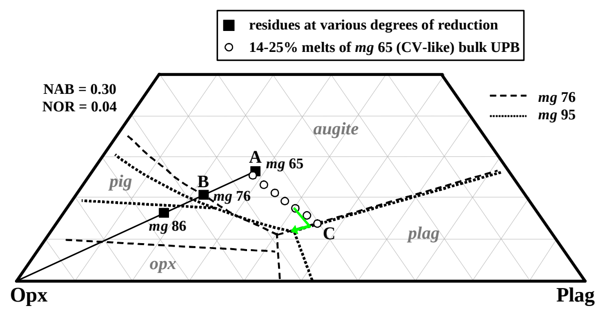

Fig. 3. Opx-Plag-Wo system, projected from olivine. Augite-bearing ureilites may have crystallized from magmas derived from less-reduced source regions (between A and B), located at greater depths, than olivine-pigeonite ureilites. Melts (14-25%) derived from *mg* 65 source region (inferred bulk UPB) shown by circles. Possible crystallization path of NWA 1500 parent magma shown by green arrow.