THE ANOMALOUS ENSTATITE METEORITES - PART 1: ANOMALOUS AUBRITES AND OXYGEN ISOTOPES.

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Introduction: The anomalous enstatite meteorites are a growing group of extremely reduced rock types that lie beyond the "normal" chemical, petrological, and/or isotopic boundaries of the enstatite chondrite subgroups (EH and EL) and the aubrites. They are melt-rocks that have been previously classified as anomalous, ungrouped, impact-melts, metamorphic grade 7, or grade 6 anomalous chondrites. These meteorites either 1) formed by impact melting on the surface of the EH, EL or aubrite parent asteroids, 2) formed by reprocessing (remelting, metamorphism, crystallization) a portion of the E meteorite parent asteroids at depth, or 3) represent samples from new parent bodies. Since these meteorites are controversial, we plan to examine the entire array of samples in order to determine petrological, chemical and isotopic trends, groupings, and formation histories, while comparing them to the known enstatite chondrite and aubrite groups.

We have only begun our study, and thus have not yet analyzed the entire array of anomalous E meteorites. For this abstract, we concentrate on two aspects: 1) new oxygen isotope analyses for the array, and 2) petrology and chemistry of only the previously classified anomalous aubrites, namely LAP 03719, QUE 97289 and QUE 97348, Shallowater and Mount Egerton.

Methods: Oxygen isotope analysis was performed by infrared laser-assisted fluorination [1] at Open University. All analyses were obtained on whole-rocks (0.5-2 mg), which, with the exception of two samples, were analyzed both untreated and after leaching in ethanolamine thioglycollate (EATG) to remove weathering products [2]. Analytical precision (1σ) is approximately: ±0.040‰ for $\delta^{17}O$; ±0.080‰ for $\delta^{18}O$; ±0.024‰ for $\Delta^{17}O$ [1]. $\Delta^{17}O$ values have been calculated using a linearized format [3]. Petrological and chemical analyses were performed by electron microprobe at Brown University.

Oxygen Isotopes*:* The generally high metal and sulfide content of enstatite meteorites makes them particularly susceptible to the effects of terrestrial weathering. In keeping with the general pattern for Antarctic finds, most of the untreated samples analyzed in the present study were shifted significantly to lighter values compared to their respective EATG residues. The most extreme examples of this pattern are displayed by the paired samples QUE 97289 and QUE 97348, which both show shifts of more than 4‰ in $\delta^{18}O$ between the treated and untreated aliquots.

Oxygen isotope results for EATG residues (and two untreated samples) are plotted in Fig. 1 in relation to the fields generated from the data of [4]. The anomalous E chondrites and aubrites have identical compositions and form a tight cluster compared to the previous analyses of [4]. This probably reflects the larger sample suite analyzed in this previous study [4]. The wider scatter of the EH and EL impact-melt rocks (classification as reported in the Meteoritical Bulletin), may reflect some incorporation of impactor materials (Fig. 1)

Petrology and Chemistry: *LAP 03719:* This highly equilibrated unbrecciated rock contains coarse-grained (up to 1 cm diameter) enstatite with long (up to 1 mm) rounded, diopside inclusions and numerous (~15 vol. % [5]), large (up to 3mm), round olivines ($Fo_{99.7}$) (Fig. 2). Metal, troilite, schreibersite, daubreelite, and alabandite are all present in minor abundances and many are quite weathered. No plagioclase or oldamite are found. While most anomalous aubrites contain lower than normal silicate/(metal+sulfide) modal proportions, in LAP the abundances are quite typical of aubrites, however the compositions of several phases are unusual. Enstatite has mildly low CaO (0.25 wt%); diopside contains higher than typical aubrite Cr_2O_3 (0.1 wt%) and MnO (0.3 wt%); FeNi metal contains extremely low Si (0.03-0.04 wt%), yet typical Ni (4.5-5.0 wt%); and troilite contains very low Ti (<0.1 wt). All of these characteristics point toward a less extreme reduced environment, when compared to "normal" aubrites. [5] suggested that given the high olivine volume of this rock "a protolith unlike known enstatite chondrites is required" for its formation.

QUE 97289 and QUE 97348: These two meteorites, which are definitely paired, are very different from LAP. They are unbrecciated, unequilibrated, coarse-grained rocks, containing abundant, large (many >1 mm) metal and sulfide grains. Silicates consist of large (up to 1 mm), rounded enstatite ($En_{99.5}$, 0.2 wt% CaO), and a Na-rich feldspar ($An_{14}Ab_{82}Or3$ to $An_{32}Ab_{66}Or_2$) that is interstitial to enstatite, and a K-rich glass, that occurs as inclusions in enstatite. Metal and sulfide (which include troilite, oldamite, alabandite, daubreelite, metal and schreibersite), occupy about 20 vol% of the two sections and are very weathered.

The metal contains an apparent fractionation trend. There is a continuous positive correlation between Ni

(5-17wt%) and Si (2.3-4.7 wt%), with many profiles across grains showing zoning (low Si core, high Si rims).

Both troilite and daubreelite display "shotgun" variations in many minor element-element plots apparently forming separately from different micro-reservoirs. Daubreelite has the most notably unusual composition relative to aubrites, having high Mn (1.5-2.5 wt%), measurable Cu (0.15 wt%), and extremely low Mg (0.01 wt%). Also, many individual troilite grains are heterogeneous.

The QUE 97s have been paired by [6] with both QUE 94204, as well as QUE 99059, 99122, 99157, 99158 and 99387. We have not yet analyzed the QUE 99s (these should be completed for the meeting), but based on comparisons with [7], pairing of the QUE 97s and QUE 94204 seems possible, though questions remain at the moment. QUE 94024 is an equilibrated rock containing only one feldspar, and fairly narrow sulfide and metal compositions. The silicates match QUE 94204, but the QUE 97s have fractionated metal, and more variable sulfide compsitions than what is published by [7].

Shallowater and Mt Egerton: Both of these meteorites have been extensively studied [8-10]. The important differences with aubrites are both meteorites are unbrecciated, have higher abundances of metal (Mt Eg.) or metal and sulfide (Shall.). Shallowater has orthoenstatite as the primary pyroxene, instead of the disordered enstatite seen in the brecciated normal aubrites [11], niningerite instead of alabandite, two feldspars and xenolith assemblages. Mt Egerton has no feldspar.

Conclusions: "Normal" aubrites cannot easily derive from an EH or EL starting bulk composition [9-10]. The anomalous aubrites have higher metal, sulfide, olivine, and plagioclase than the "normal" ones and also cannot derive from the ECs easily. If we assume that since the oxygen isotopic compositions of the anomalous aubrites are essentially the same as the "normal" aubrites, and they derive from the same parent body (with Shallowater being the one exception), and that their compositions represent natural variation on the aubrite parent body, than what is needed is a bulk composition that must be more chondritic than the ECs. One possible starting composition is the ordinary chondrites, assuming they are reduced and sulfidized. ECs are simply too pyroxene normative to account for the aubrites, however bulk OC might account for both the anomalous and normal aubrite variations, since the bulk is more olivine normative. The parent body must however contain lateral and/or vertical gradients in its oxidation and sulfidation fugacities to account for the range of compositions, but this would not seem unreasonable given typical planetary variations.

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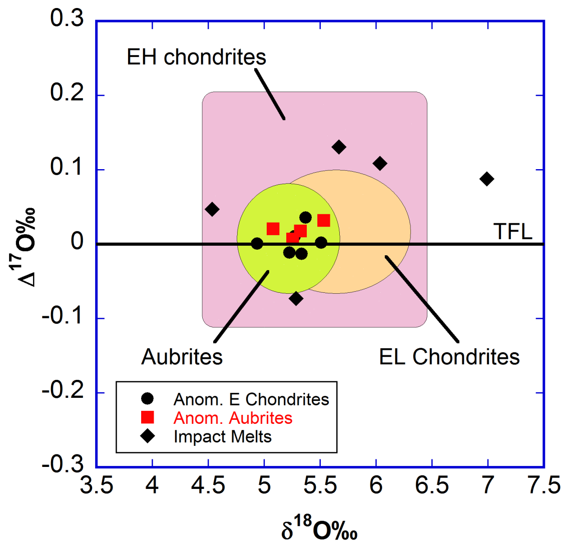

Figure 1. Oxygen isotope plot showing all of the new data for the anomalous E meteorites relative to EL, EH and aubrite fields (Fields generated from data in Newton et al., 2000). EH and EL "impact melts" meteorites (♦) are based on the previous classifications in Meteoritical Bulletin and have not been studied by us yet for petrology or chemistry.

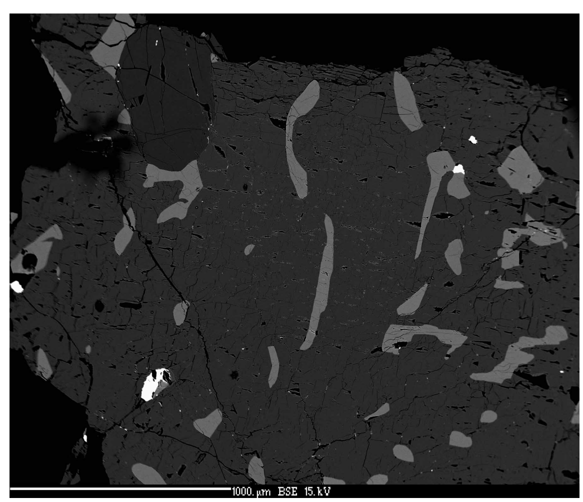

Figure 2. LAP 03719 enstatite (main phase), elongate diopside (light gray) inclusions, round olivine (gray-upper left) and sulfide grains (white).