GEOCHEMISTRY OF UNIQUE ACHONDRITE MAC88177: COMPARISON WITH POLYMICT UREILITE EET87720 AND "NORMAL" UREILITES

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The 35-g MAC88177 meteorite is a medium-grained, equigranular aggregate of anhedral to subhedral olivine and pyroxene, with minor troilite, FeNi-metal, and chromite, but no plagioclase [1]. Score and Mason [1] classified MAC88177 as a ureilite, but also noted that it lacks the carbonaceous material characteristic of all previously investigated ureilites, and its olivine "contains less than 0.1% Ca and Cr." Olivines of previously investigated ureilites have >0.21 wt% Ca [2,3]. The uniqueness of this meteorite is underscored by the O-isotopic results of Prinz et al. [4], who find that unlike any previously investigated ureilite, MAC88177 has a combination of low $\delta^{18}O$ and moderate $\delta^{17}O$, causing it to plot far to the low-$\delta^{18}O$ side of the Allende ^{16}O-mixing line. Our studies have thus far consisted mainly of INAA for a 293-mg chip. We have also studied eight other ureilites mainly by INAA, including EET87720, which appears to be polymict.

We chose to study EET87720 because Schwarz and Mason [5] found a wide range (Fo_{79-87}) for its olivine *mg*, and a grain of plagioclase (An_{24}), features that led us to suspect that it might be polymict. We have studied thin section EET87720,12. Most of its 60-mm^2 area consists of apparently typical, "monomict" ureilite. However, in one corner of the thin section there is a 5-mm clast of a far more coarse-grained lithology, reminiscent of the coarse-grained clast in polymict ureilite EET83309 [6]. Just beyond the perimeter of this clast is a grain of albite ($Ab_{90}Or_3$, 110 x 90 μm), sandwiched between a silica phase (2-3 mm across) and a grain of forsterite (Fo_{98}, 8 x 6 μm). At an undocumented location, we also found nearly pure enstatite (En_{98}). Similarly exotic mineral assemblages have been found previously in polymict ureilites, including EET83309 [7], which might be paired with EET87720.

INAA results indicate that MAC88177 is unique, but in many respects similar to previously investigated ureilites. Considered as a ureilite, the MAC88177 bulk composition is fairly typical for most elements determined, including Na, Mg, Al, Si, K, Sc, Mn, Fe, Co, Ga, As, Br, Sb and Au. For many of these elements, ureilites show remarkably wide compositional ranges, and thus the overlap with MAC88177 has little genetic significance. However, the range for Sc is relatively narrow among ureilites, 6-12 μg/g [8], and MAC88177 has 9.6 μg/g. Ureilites also have a relatively narrow range for Mn, and their olivine and pigeonite Mn contents are strongly correlated with their olivine and pigeonite *mg* ratios [3]. Analyses of ureilites thus show a correlation between bulk-rock Mn/Fe and olivine-core *mg* (Fig. 1). The MAC88177 composition plots along this correlation, or very close to it (olivine *mg* from Score and Mason [1] and Prinz et al. [4]). The Ca content of MAC88177 (19 mg/g) is high by ureilite standards, but not without precedent. One of our two analyses of the augite-rich ureilite META78008 shows 19 mg/g Ca (the other shows only 9.3 mg/g, however). Literature analyses [8] show that ureilites are commonly heterogeneous in their Ca contents, and include several individual results in the 17-18 mg/g range.

The CI-chondrite-normalized REE patterns of ureilites tend to be V-shaped, but the light REE are generally not nearly so enriched relative to Sm as the heavy REE [6]. Among the few exceptions are the two previously-investigated polymict ureilites: Nilpena [9], which has high REE overall, and La 3 x higher than middle and heavy REE; and EET83309 [6], the REE pattern of which is relatively flat at 0.4-0.8 x CI (and nevertheless LREE-enriched compared to most ureilites). The REE pattern we find for a 213-mg sample of EET87720 appears more "normal" than these, with La as well as Yb at only 0.2 x CI. However, EET87720 is apparently heterogeneous. A sample from a different portion of the meteorite might show a closer resemblance to Nilpena and EET83309. The REE patterns of Ca-rich (i.e., augite-rich) ureilites, such as our samples META78008 and ALH84136, tend to have uncommonly high heavy-REE concentrations. The REE pattern of MAC88177 features uncommonly high LREE (La = 0.6 x CI) and exceptionally high HREE (Yb and Lu both = 1.0 x CI). However, in view of the extremely high Ca content of MAC88177 (by ureilite standards), a pattern of HREE enrichment is just as expected.

The MAC88177 Zn content is 50 µg/g. Most ureilites have Zn in the 150-300 µg/g range. However, Goalpara has ~60 µg/g, and one literature analysis of Goalpara indicates only 35 µg/g [10]. Goalpara, or at least the ~200-mg portion of it analyzed by Grady et al. [11], also has a remarkably low C content: 2 mg/g (most ureilites have 20-30 mg/g). The Cr content of MAC88177 is 2600 µg/g. Nearly all ureilites have Cr in the 4500-6000 µg/g range. The closest reliable precedent among ureilites is one of our new results for the augite-rich META78008: 3300 µg/g (our other analysis indicates 3800 µg/g). We also find a relatively low Cr content for the augite-rich ALH84136, 3900-4200 µg/g. The Ni content of MAC88177 is 3200 µg/g. Nearly all ureilites have Ni in the 700-2000 µg/g range, but one analysis of Dingo Pup Donga [12] indicates 3300 µg/g. The high Ni content of MAC88177 is not so easily rationalized, however, because it also features moderate Co (128 µg/g) and uncommonly *low* Ir (23 ng/g), by ureilite standards. Ureilites are remarkable for their lack of correlation between Ni and Ir [6], but the Ni/Ir ratio of MAC88177 appears to be at least five times higher than that of any previously investigated ureilite. Another distinctive feature of our MAC88177 sample is its high Se content, 6.0 µg/g. Binz et al. [10] reported 3.0 µg/g for the weathered ureilite Dingo Pup Donga (MAC88177 is of weathering class B/C), but most ureilites have Se contents of <1 µg/g. They also have far lower modal FeS than MAC88177. Possibly MAC88177 is enriched in FeS (and depleted in C?) due to a vagary of cumulus deposition.

Whether this low-C, low-$\delta^{18}O$ meteorite should still be classified as a ureilite is moot. However, we find that in many respects its trace-element composition overlaps the range for ureilites; and in some cases where overlap is not observed, the MAC88177 composition is close to that expected based on modest extrapolation from chemical trends observed among the ureilites. O-isotopes had already shown [13] that ureilites did not all form on a single, isotopically-equilibrated parent body. Goalpara [11] shows that ureilites are remarkably diverse in their C contents. Indeed, we have argued that ureilites may have formed by a two-stage process, entailing first, igneous crystallization of olivine-pigeonite cumulate-like materials, and second, mechanical admixture (by large-scale impact) of C-rich material [6]. Provided that many separate parent bodies went through these two processes (as suggested by the O-isotopes [13] and noble gases [14]), such a model predicts that the degree of C admixture in the second stage will be highly variable. Thus, MAC88177 might in a sense be not a ureilite, but a fossil protoureilite. This model also predicts the low Ca contents of the olivines, as results of normal cumulate-like (slow) cooling; whereas for "main group" ureilites it predicts rapid, unshielded cooling after the disruptive C-mixing impacts [6]. Alternatively, MAC88177 might have formed by Takeda's [15] model for ureilite genesis (compaction, fractional melting, and recrystallization within carbonaceous-chondritic parent bodies), except in this case within a more C-poor parent body. The origin of this unique meteorite should be clarified by further studies to constrain its noble gas concentrations and overall isotope geochemistry.

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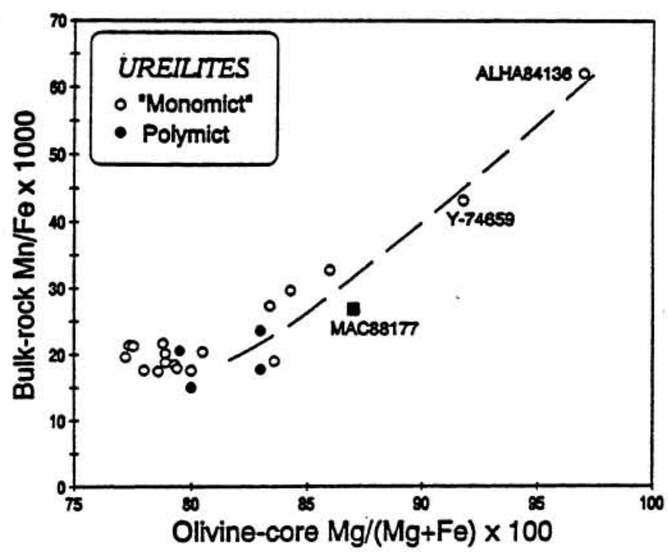

Fig. 1