ALH84001 CUMULATE ORTHOPYROXENITE: A PREVIOUSLY UNAPPRECIATED MARTIAN METEORITE

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The shergottites, nakhlites and Chassigny are igneous rocks widely thought to be samples of the martian crust [*e.g.* 1]. Discovery of new martian meteorites always generates interest in the meteoritic community. Interest is heightened if the meteorites are petrologically unusual, because increased diversity holds promise for increased understanding of martian petrologic evolution. ALH84001, originally classified as a diogenite, has recently been properly classified as a unique orthopyroxenite martian meteorite [2,3]. Here I report on petrologic and geochemical study of ALH84001.

Petrography. ALH84001 is a coarse-grained, cataclastic orthopyroxenite with much of the original magmatic or metamorphic texture preserved. Generally anhedral orthopyroxene grains up to 6 mm across exhibit patchy extinction, and contain fractures and transecting crushed zones of fine-grained anhedral orthopyroxene and chromite produced by shock. Euhedral to subhedral chromite grains up to 0.5 mm in size are enclosed in, or are interstitial to, orthopyroxene. Maskelynite, typically a few hundred µm in size, occurs interstitial to coarse orthopyroxene and in the crushed zones. Accessory phases are augite, apatite, pyrite and Mg-Ca-Mn-Fe carbonate. Augite (~10 µm) and apatite (up to ~300 µm) are interstitial phases. Pyrite (~10 µm) is associated with interstitial chromite, maskelynite and carbonate, and in the crushed zones associated with anhedral chromite. Interstitial carbonates (~100 µm), showing fine-scale compositional zoning from Ca-Mn-Fe-rich cores to Mg-rich rims, are associated with maskelynite and pyrite. Shock damage in these carbonates demonstrates that they are pre-terrestrial. Small (~10 µm), homogeneous carbonates are found in the crushed zones and in fractures, and are post-shock. The orthopyroxene and chromite grains are relatively homogeneous in composition. Average mineral compositions are; orthopyroxene - $Wo_3En_{69}Fs_{27}$, maskelynite - $An_{31}Ab_{63}Or_6$, augite - $Wo_{42}En_{45}Fs_{13}$, carbonate - $Cc_{12}Mg_{58}Sd_{29}Rd_1$.

Geochemistry. The REE pattern for a bulk interior sample of ALH84001 exhibits a depletion in LREE relative to HREE, as would be expected for a cumulate orthopyroxenite, and a negative Eu anomaly (Fig. 1). However, the depletion in LREE is not as great as expected for a cumulate from a melt with chondritic REE ratios, as shown by a mean of orthopyroxene clasts from the Johnstown diogenite [4]. The chondritic normalized La/Lu ratio of ALH84001 is 0.36, compared to ~0.007 expected for a cumulate based on opx/melt partition coefficients.

Petrogenesis of ALH84001. The original protolith had a coarse-grained, equigranular texture with common 120° triple junctures, indicating slow cooling. The uniform compositions of orthopyroxenes and chromites similarly indicate slow cooling. Because ALH84001 is nearly monomineralic, and texture and mineral compositions indicate slow cooling, it is likely that ALH84001 is a cumulate. The interstitial maskelynite suggests that a trapped melt component is present. Many of the maskelynites are not stoichiometric plagioclases. Rather, they contain excesses of SiO_2 over that required for stoichiometry. This suggests that the interstitial regions were composed of feldspar plus silica prior to shock.

The bulk sample contains about 1% maskelynite. Because the trapped melt was likely basaltic, the amounts of normative plagioclase and pyroxene in this melt were probably subequal, and therefore the amount of trapped melt likely is ~2%. The REE pattern of ALH84001 is consistent with the presence of trapped melt. The higher than expected La/Lu ratio can be explained by inclusion of ~2% of a LREE-enriched melt with a La/Lu ratio ~4 times CI, roughly half that inferred for the nakhlite parent magma [5]. This calculated parent melt also has a negative Eu anomaly, with Eu/Sm ~0.6 times CI.

It is possible that the REE pattern of ALH84001 was affected by infiltration metasomatism, a process invoked for the nakhlites [6]. The early, zoned carbonates provide petrographic evidence for fluid fluxes in ALH84001, and their compositions suggest that they were formed at ~700°C [7]. This might be taken as evidence for infiltration metasomatism. However, the early carbonates appear to be discrete grains and not metasomatic replacements of earlier phases. Regardless, an infiltrating fluid phase, rich in REE, could cause preferential enrichment in LREE in the cumulate. The parent melt REE pattern could not then be inferred from bulk REE analyses.

Relationship to Other Martian Meteorites. ALH84001 has several mineralogic and petrographic features in common with the nakhlites and Chassigny. The latter are cumulates with minor interstitial melt [8,9], as is ALH84001. The nakhlites and Chassigny contain generally homogeneous pyroxenes

[9,10], indicating slow cooling, as inferred for ALH84001. The maskelynite compositions of ALH84001 are within the range of feldspar compositions in nakhlites and Chassigny [8,9], but more sodic than those in the shergottites [11-13]. However, many maskelynites in ALH84001 are similar to some of the mesostasis compositions of Shergotty and Zagami [12], but with less SiO_2. The parent melt inferred above for ALH84001 (assuming no infiltration metasomatism) is LREE-enriched, as were those for the nakhlites and Chassigny [5]. Pyrite is present in ALH84001, nakhlites and Chassigny, but not in the shergottites. However, petrogenetic models for the nakhlites and Chassigny are not compatible with the petrology of ALH84001. Estimated parent melts for nakhlites and Chassigny are saturated in olivine and augite, not orthopyroxene [e.g. 14], and therefore it does not seem likely that ALH84001 is directly related to the nakhlites or Chassigny.

Although shergottites contain strongly zoned minerals and textures indicative of rapid crystallization, ALH84001 does show several petrologic affinities to the shergottites. Orthopyroxenes and chromites in ALH84001 are similar in composition to those of the megacrysts from EETA79001 lithology A [11,15] (Fig. 2). Hence, a parent melt with major element composition like that which formed the megacrysts might be a suitable parent for ALH84001. The ALH84001 orthopyroxene compositions suggest its parent was slightly more ferroan (Fig. 2). The EETA79001 megacrysts contain olivine [11], which is absent in ALH84001. Olivine is in reaction relation with a megacryst parent melt composition [16], and therefore, fractional crystallization processes could form an olivine-free orthopyroxenite from this parent melt. Plagioclase compositions are a severe problem as the most calcic maskelynite in ALH84001 (An_{39}) is much more sodic than those in shergottites [11-13] or than experimental plagioclases [16]. Finally, the calculated shergottite parent melts are LREE-depleted [5], which is incompatible with the trace element composition of ALH84001, unless infiltration metasomatism affected the REE pattern of the protolith.

Thus, ALH84001 exhibits petrologic affinities to both the nakhlites-Chassigny on one hand, and the shergottites on the other, as well as differences. The parent melt of ALH84001 likely was compositionally distinct from those of the other martian meteorites.

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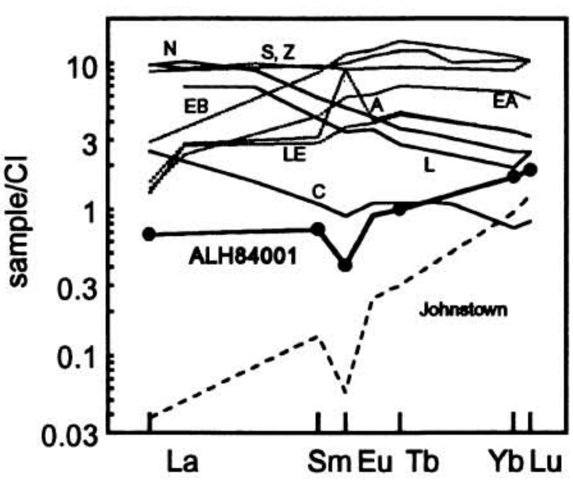

Figure 1. Rare earth element diagram for ALH84001 compared to other martian meteorites and to mean Johnstown diogenite orthopyroxene clasts [4]. REE data are from [1] - Chassigny (C), Lafayette (L), Nakhla (N), Shergotty (S); from [12] - Zagami (Z); and from [13] - ALHA77005 (A), EETA79001 lithologies A (EA) and B (EB) and LEW88516 (LE).

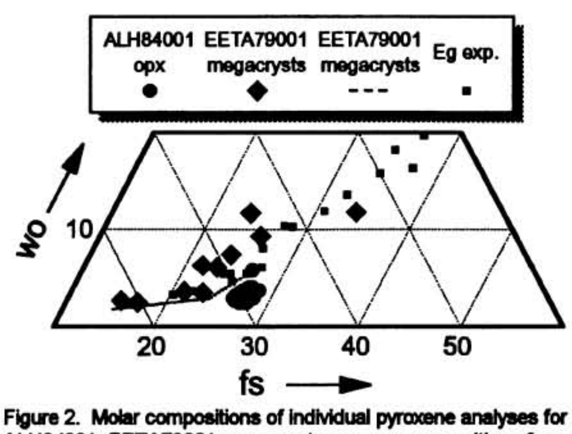

Figure 2. Molar compositions of individual pyroxene analyses for ALH84001. EETA79001 megacryst pyroxene compositions from [15] (diamonds) and [11] (line); Eg exp. - experimental pyroxenes from synthetic EETA79001 groundmass melt composition from [16].