Symplectic assemblages in howardites: First results. Andrea Patzer* and Harry Y. McSween, Department of Earth & Planetary Sciences, University of Tennessee, 1412 Circle Dr., Knoxville, TN 37996 (* apatzer@utk.edu).

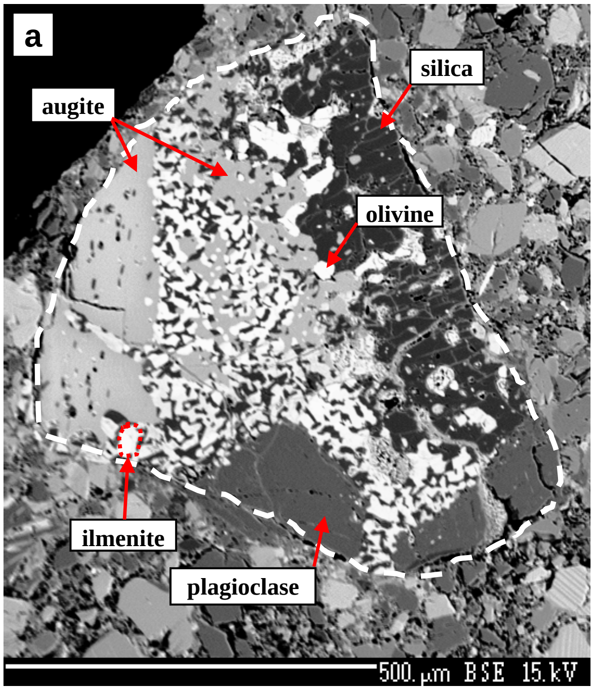
Introduction: Symplectic mineral assemblages are fine- to very fine-grained intergrowths of two or more distinct phases. They often display vermicular or viscous textures and have been reported from terrestrial and extraterrestrial samples. Reports from extraterrestrial materials so far have been limited to lunar and Martian rocks. Typically, these lunar or Martian symplectites include ferroan clinopyroxene, fayalitic olivine, and a SiO_2-rich phase. Most of them have been interpreted to be the breakdown product of metastable pyroxferroite upon cooling under low pressure [e.g., 1]. In some instances, direct late-stage crystallization from an Fe-rich melt has been considered [2].

Here, we report the first identification of symplectic assemblages from two new Antarctic howardites. Both meteorites are part of an ongoing study investigating the spectrum of lithologies found in howardites. Howardites, in all likelihood, constitute a major crustal lithology of 4Vesta, the sole surviving large asteroid that differentiated within a few million years of accretion ca. 4.565 Ga ago [3].

Samples: *MIL 05085.* Miller Range (MIL) 05085 is a highly diversified breccia. Observed clasts include basalts with various textures, diogenite fragments, secondary breccias (breccia-in-breccia), impact produced rocks, glass spherules, and symplectic clasts. All clasts are set in a poorly sorted matrix of comminuted pyroxene and plagioclase. Opaque phases are comparatively sparse and include ilmenite, chromite, Fe-Ni metal, and troilite. Among the opaque minerals, fine-grained ilmenite is most abundant, followed by fine-grained chromite. Metal and sulfide phases are very fine-grained and rare. The meteorite's polymict and relatively loose texture in conjunction with the observed lithological diversity suggest a regolith origin.

LAP 04838. The second sample, LaPaz Ice Field (LAP) 04838, consists of two distinct lithologies: cumulate eucrite and howardite. The cumulate area is composed of large plagioclase laths, coarse-grained pyroxene, and small amounts of olivine. The area is highly fractured and displays numerous pockets of incipient melting. The feldspar often is full of tiny inclusions. Pyroxene compositions vary from orthopyroxene to augite. Distinct grains are commonly homogeneous; obvious zoning occurs only sporadically. Olivine solely appears as a fine-grained interstitial phase. Its distribution is heterogeneous, ranging from 0 to about 10 area% in a given 1 x 1 mm frame. The howardite fraction of the sample shows a lithological variety similar to MIL 05085, with the same general categories of clasts. Individual types, however, are somewhat different. Among others, we found several mm-sized subophitic basalt fragments, an astonishing spectrum of symplectic and symplectite-bearing clasts, some impactites, and occasional secondary breccias.

Results: Miller Range 05085 contains two larger symplectic clasts – ca. 600 and 250 µm, respectively – as well as a few (unstudied) smaller fragments with grain sizes below the given analytical limit. The two larger clasts are compositionally similar: main constituents are ferroan augite, fayalitic olivine, and silica. However, textural aspects vary. The 600 µm-fragment features a fine-grained symplectic wedge bordered by several large, inclusion-rich grains (pyroxene, plagioclase, and silica; Fig. 1a). The large pyroxene grain is zoned ferroan augite; it grows more Mg- and Ca-rich toward the symplectic center of the clast (from $En_7Fs_{57}Wo_{36}$ to $En_{13}Fs_{46}Wo_{41}$). Other large grains include anorthitic plagioclase (An_{92-93}) and silica (~99 wt% SiO_2, up to 1.2 wt% FeO). Within the symplectic wedge, augite and olivine compositions yield little variation ($En_{15-16}Fs_{42-43}Wo_{41-42}$ and Fa_{90}, respectively). In terms of proportions, the mafic minerals predominate (ca. 70 area%). Augite appears more clustered (patch sizes up to 75 µm) while olivine and silica exhibit a more vermicular intergrowth (patch sizes up to 50 µm). A single 45 µm-grain of ilmenite and two <10 µm-grains of plagioclase are present as well.



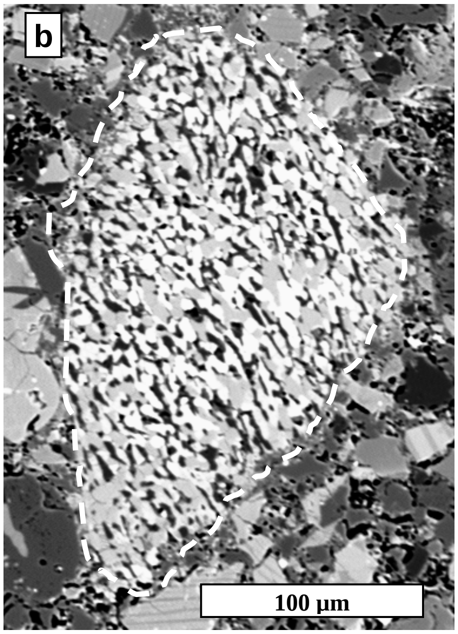


Fig. 1. Symplectic clasts of MIL 05085: a) ca. 600 µm-fragment featuring several large grains of ferroan augite, anorthitic plagioclase, and silica bordering a symplectic wedge of vermicular fayalitic olivine+silica and clustered anhedral ferroan augite. The large grains of silica and augite contain numerous inclusions. A smaller number of inclusions are present in the plagioclase grains. b) ca. 250 µm-fragment showing a vermicular texture of ferroan augite (light gray), fayalitic olivine (white), and silica (dark). All three phases are approximately equally abundant.

The other, smaller symplectic clast in MIL 05085 is very fine-grained (grain sizes ≤10 µm) with roughly equal proportions of vermicular ferroan augite, fayalitic olivine, and silica (Fig. 1b). Elemental abundances for both, augite and olivine appear very homogeneous ($En_{10}Fs_{48}Wo_{41-42}$ and Fa_{94}, respectively). Compared to the 600 µm-fragment, they are slightly more Fe-rich.

In LAP 04838, the spectrum of symplectic lithologies is markedly broader. Textures vary from vermicular or viscous intergrowths to oriented stubby (exsolution) lamellae. Involved minerals include not only ferroan augite, fayalitic olivine, silica, and ilmenite but – in some instances – also troilite, kamacite, and hedenbergite (Wo_{45-50}). While most of the smaller symplectic clasts show little of their original geological setting, some of the larger (>200 µm) fragments exhibit symplectic assemblages in primary contact to large grains of pyroxene, silica, and/or plagioclase (Fig. 2).

Preliminary conclusions: Symplectic mineral assemblages, previously only known from terrestrial, lunar, and Martian rocks, have now been found to also occur in howardites. Seemingly, they are a minor but not uncommon feature of highly fractionated igneous rocks on differentiated Solar System bodies.

In addition, howardites MIL 05085 and LAP 04838 not only harbor the first symplectic clasts reported for howardites but also reveal (some of) the geological context necessary to understand the evolution of these symplectic assemblages. Based on our findings, the observed symplectites are associated with cumulate eucrite material that is relatively rich in silica and ilmenite, i.e., late stage minerals. On the other hand, LAP 04838 also contains cumulate areas that exhibit interstitial olivine. According to the present state of knowledge, cumulate eucrites are not “supposed” to bear ultramafic minerals. Instead, olivine has been shown to be the major component of certain diogenites [4]. Thus, the olivine-bearing cumulate eucrite fraction of LAP 04838 is to be placed on the least fractionated end of cumulate eucrite formation, opposite to the cumulate eucrite units containing Fe-rich late-stage symplectic assemblages.

In essence – but pending further investigation –, our findings suggest a range of cumulate eucrite lithologies broader than previously assumed. We support the general view that the howardite-eucrite-diogenite classification scheme is gradational and propose that olivine-bearing cumulate eucrites constitute a genetic link between eucrites and diogenites.

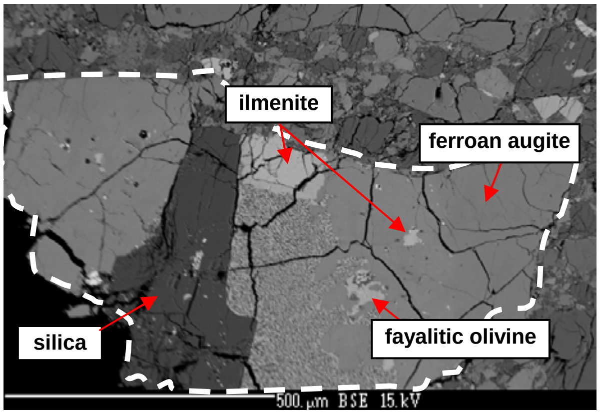


Fig. 2. Millimeter-sized clast in LAP 04838 showing a symplectic mineral assemblage including its geological setting in coarse-grained pyroxene, silica, and ilmenite. The symplectic center of the clast consists of ferroan augite, fayalitic olivine, and silica in a very fine-grained vermicular intergrowth.

References: [1] Rost D. et al. (2009) *Meteoritics & Planet. Sci., 44,* 1225-1237. [2] Fagan T. J. et al. (2003) *Meteoritics & Planet. Sci., 38,* 529-554. [3] Lugmair G. W. & Shukolyukov A. (1998) GCA 62, 2863-2886. [4] Beck A. W. et al. (2010) *Meteoritics & Planet. Sci., 45,* 850-872.