VAPOR DEPOSITED MINERAL ASSEMBLAGES IN VESICLES OF THE EUCRITE IBITIRA.

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Abstract. We report here the preliminary results of an SEM study of mineral assemblages within vesicles in the Ibitira eucrite. The goal of this work was to obtain better constraints on the origin and relative timing of formation of these vapor deposited minerals and thereby to learn about the role of volatiles in volcanic processes on asteroids. Our main finding was that there were essentially four compositional types of vapor deposited minerals in Ibitira vesicles, i.e., Ti-chromites, ilmenites, whitlockites and pure Fe crystals. These mineral assemblages are most similar to those found in the vugs of some highly recrystallized lunar breccias. This suggests that the vapor deposited minerals in Ibitira may also have been deposited during extensive thermal metamorphism, which was also responsible for producing the coarse exsolution lamellae in Ibitira pyroxenes.

Introduction. The unbrecciated, noncumulate eucrite Ibitira is unique in that it is the only known vesicular achondrite [1]. Vesicles in Ibitira comprise ~5-7 vol. % of the rock [2,3], and their relatively uniform sizes and spherical to ellipsoidal shapes suggest that they were formed by the exsolution of volatiles from the parent magma of Ibitira, and are not the result of shrinkage during cooling [2,3].

Previous studies have noted the presence of vapor deposited minerals (mainly ilmenite, chromite and whitlockite) in some of these vesicles [2,3,4]. It is recognized that studies of the abundances and chemical compositions of such minerals may be able to offer possible unique insights into the role of volatiles during volcanic processes on asteroids. However, there has so far not been any comprehensive effort to systematically characterize the mineral assemblages within these vesicles. We have, therefore, begun an extensive study of these mineral assemblages within vesicles in a slab of Ibitira (dimensions ~9 cm × 5 cm × 1 cm) that was recently acquired by the Field Museum of Natural History.

Experimental. In this preliminary work, we report on the initial characterization of these vapor deposited minerals by backscattered electron imaging with the University of Chicago low-vacuum scanning electron microscope (JEOL JEM-5800LV) and x-ray microanalysis and digital chemical mapping with an attached Oxford Link ISIS-300 system. The entire Ibitira slab was placed in the SEM sample chamber. The instrument was operated in the low-vacuum mode to avoid the necessity of carbon-coating the specimen. We have so far characterized a total of 102 vesicles in a portion of the Ibitira slab (area ~ 9 cm^2) by systematically scanning along uniformly spaced line profiles.

Results and discussion. The distribution of vesicles in the Ibitira slab that we analyzed is not homogenous, with a portion of the slab being almost devoid of vesicles. Additionally, the boundaries between regions with and without vesicles are quite sharp, indicating that vesicles may have been concentrated into certain regions of the magma body by processes such as flow segregation. The sizes of the vesicles are also not uniform, as previously thought [2]. In fact, macroscopic examination of the slab reveals that the largest vesicle is an ellipsoidal one that is ~1.5 cm × 0.5 cm in size, while the smallest ones approach the resolution of the naked eye (~0.01 cm across).

Ibitira vesicles in the area scanned with the SEM ranged in size from ~200 µm up to ~2 mm across, although the majority of them were ~300-500 µm in diameter. As also noted by [2], the vesicle walls are mostly lined with the terminal faces of pyroxene and plagioclase crystals. The plagioclase crystal faces lining vesicle walls appear smoothly faceted (Fig. 2), whereas the pyroxene crystal faces have a distinctly "scalloped" appearance (Figs. 1-4). The coarser low-Ca pyroxene lamellae appear to have somewhat greater relief than the relatively fine augite lamellae. These features of the vesicle walls may have been contributed, to some extent, by vapor phase transport and crystallization of plagioclase and pyroxene components.

Of the 102 vesicles observed with the SEM, only 43 appeared to contain wholly vapor deposited crystals. Further, we noted that the majority of these 43 vesicles contained a single euhedral crystal of one of the following: (i) titanian chromite (Fig. 1), (ii) ilmenite (Fig. 2), (iii) whitlockite (Fig. 3), and (iv) pure Fe^0 (Fig. 4). Titanian chromite and ilmenite are by far the most commonly occurring crystals, with chromite occurring in 20, and ilmenite in 14, of the 43 vesicles. Whitlockite was found to occur in 9 of the observed vesicles, while native iron grains are relatively rare (only 3 were observed; we note that this is the first reported occurrence of vapor deposited Fe crystals in Ibitira vesicles). Although only one compositional type occurs in most vesicles that were found to contain vapor deposited minerals, a few contained either chromite *and* ilmenite or ilmenite *and* whitlockite.

X-ray mapping of an ilmenite grain revealed the presence of a tiny zircon crystal growing on the ilmenite (indicated by arrow in Fig. 2), as well as tiny whitlockite and chromite crystals. Only a few vesicles have been x-ray mapped, so other minerals may occur.

The mineral assemblages in Ibitira appear to be most analogous to vapor deposited minerals in some lunar samples (e.g., [5,6]). In particular, we note that vapor deposited Fe crystals having similar crystal habits to those observed here have been found in recrystallized Apollo 14, 15 and 16 breccias [6]. This lends credence to previous suggestions that these mineral assemblages in Ibitira vesicles may have been deposited during recystallization and thermal metamorphism [4]. Additionally, textural features such as those evident in Fig. 3 (i.e., the base of the Fe crystal appears to follow the "scalloped" outline of the vesicle wall comprised of the exsolved pyroxene crystal), indicate that the vapor phase deposition in Ibitira vesicles occurred subsequent to pyroxene exsolution, which most likely took place during subsolidus metamorphic equilibration at ~950 °C [4]. This episode of thermal metamorphism most likely followed an initial period of rapid cooling from magmatic temperatures (required by the presence of vesicles and the relatively fine grain size of <0.2 mm in Ibitira [2,4]), and may have been the event that was also responsible for remobilizing components such as Fe, Cr, Ti, Ca and P from the Ibitira bulk rock into a vapor phase, which subsequently redeposited them within the pre-existing vesicles. This is consistent with the fact that the compositions of titanian chromite and ilmenite in the Ibitira matrix are the same as those reported in the vesicles [2,4]. Finally, we note that the question of the composition of the dominant "carrier" vapor phase (i.e., which was responsible for transporting the various elements noted above) is still largely unresolved. It has been suggested that this vapor phase may be CO gas [2], but no strict constraints are as yet available. We hope to explore this issue further by analyzing minor and trace element abundances in selected vapor deposited crystals that are large enough to be picked from the vesicles.

References: [1] Wänke H. et al. (1972) *PLPSC 3rd*, 1251–1268. [2] Wilkening L. L. and Anders E. (1974) *GCA* **39**, 1205–1210. [3] Gomes C. B. and Keil K. (1980) in *Brazilian stone meteorites*, UNM Press, pp. 65–74. [4] Steele I. M. and Smith J. V. (1976) *EPSL* **33**, 67–78. [5] McKay D. S. et al. (1972) *PLSC 3rd*, 739–752. [6] Clanton U. S. et al. (1973) *PLSC 4th*, 925–931.

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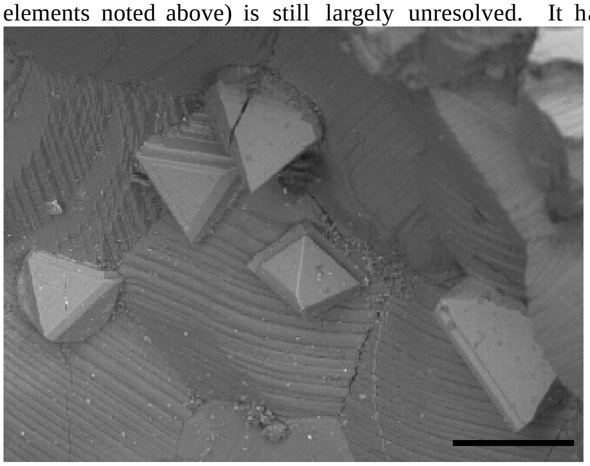

Figure 1. BSE image of a nest of Ti-chromite crystals within a vesicle. Note the euhedral shapes and growth lines which are evident on the crystal faces of some of the chromites. The vesicle walls in this region are composed mainly of exsolved pyroxenes, which have a distinctive "scalloped" appearance. The scale bar (lower right) is 50 µm.

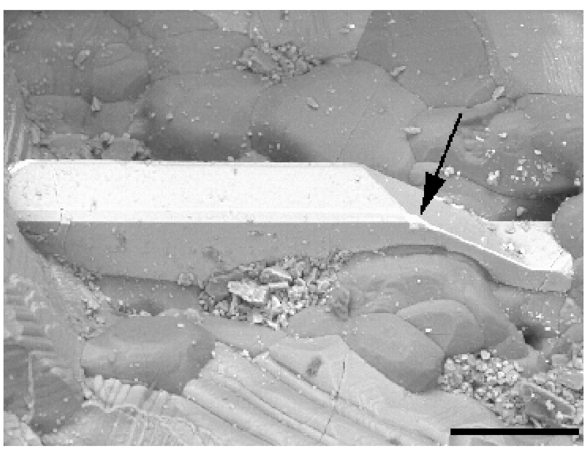

Figure 2. BSE image of an ilmenite crystal within a vesicle. The arrow indicates a small bright patch composed of zircon. The vesicle walls in this region are composed of smoothly faceted plagioclase (dark gray in this image) and exsolved pyroxenes. The scale bar (lower right) is 50 µm.

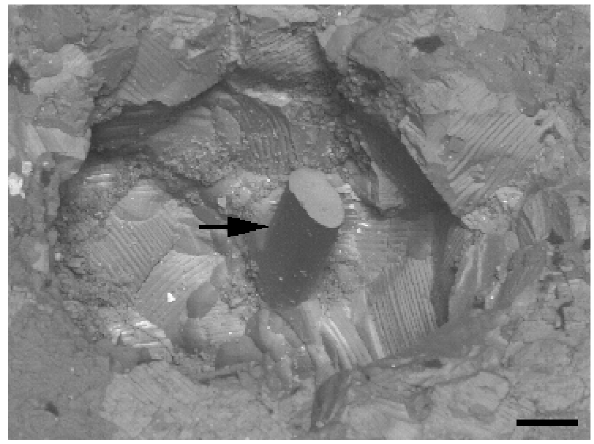

Figure 3. BSE image of a whitlockite grain (indicated by arrow) in a vesicle. The vesicle walls are lined with smoothly faceted plagioclase (darker gray) and exsolved pyroxenes (lighter gray). The scale bar (lower right) is 50 µm.

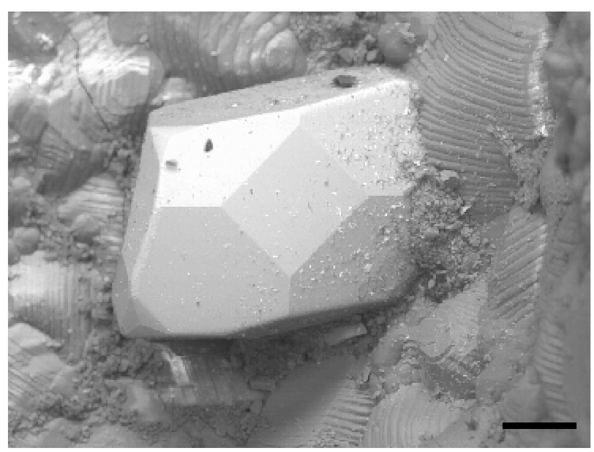

Figure 4. BSE image of a pure Fe crystal in a vesicle. Note that the base of the crystal (at the right-hand end in the image) follows the "scalloped" outline of the exsolved pyroxene which constitutes a portion of the vesicle wall. The scale bar (lower right) is 50 µm.