MINERALOGY OF AN UNUSUAL CM CLAST IN THE KAIDUN METEORITE

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ABSTRACT Kaidun is breccia of disparate enstatite and carbonaceous chondrite clasts, and continues to provide real surprises. Many Kaidun clasts have been intensely altered by an aqueous fluid, as evidenced by the widespread occurrence of ferromagnesian phyllosilicates and presence of carbonate- and phyllosilicate-filled veins. In this report we describe an unusual CM lithology containing beautiful aggregates of jackstraw pyrrhotites, not previously reported from any meteorite.

The bulk of this lithology in Kaidun (sample 1.3.18a) consists of serpentine, saponite, and minor clinochlore, frequently intergrown as encountered in CI and CR chondrites and some chondritic interplanetary dust particles. Microprobe analyses of these phyllosilicates are compared to similar materials in Figure 1; the Kaidun phyllosilicates are dominated by Mg-rich serpentines; as verified by subsequent TEM work. The compositional range of Kaidun phyllosilicate is comparable with that in CI and CR chondrites. Although Kaidun phyllosilicate is distinguished from typical CMs by the presence of abundant saponite, it is instructive to note that Kaidun serpentine compositions are comparable with those from the most extensively altered CM chondrites [1]. In fact, the oxygen isotopic composition of this Kaidun lithology indicates it is CM material, being very similar to that of Murchison [3].

Floating in the phyllosilicate-dominated matrix are (1) complex aggregates (see below), (2) abundant acicular, mantled pyrrhotites, identical to those rimming the aggregates (see below), (3) framboidal magnetites, forming in some instances masses adjacent to the exposed ends of pyrrhotite crystals, (4) anhedral to euhedral pentlandites, abundant everywhere within the

Figure 1 Ternary weight % plot of phyllosilicate compositions from the Kaidun CI lithology, compared with phyllosilicates from other C chondrites (Renazzo and EET 87770 are CR, Ivuna and Orgueil are CI), including coarse-grained saponite from another Kaidun lithology [2].

lithology with the exception of the phyllosilicates lumps, and which generally lack the phyllosilicate sheaths observed about the pyrrhotites, (5) small, hollow apatites, (6) rare, anhedral diopside grains, and (7) homogeneous lumps of phyllosilicate, dotted throughout the matrix, and composed of serpentine, saponite and clinochlore of the same composition as the pyrrhotite mantles; there are no minerals in these lumps larger than 1 μm which makes them readily resolvable from the lithology matrix.

Another interesting component of this lithology are the complex aggregates (Figure 2a), which invariably are rimmed by jackstraw, acicular, pyrrhotite crystals ($Fe_{0.90-0.92}Ni_{0.02}S$) (Figure 2b). In one case these pyrrhotites extend to the center of an aggregate, although this may be a projection artifact. All of the pyrrhotites in this lithology (including those in the aggregate rims) are mantled about their long axis by a sheath of phyllosilicate (Figure 2c), in places up to 20 μm thick. Microprobe analyses of these sheaths show that K_2O and Al_2O_3 increase in abundance away from the pyrrhotite, reflecting a gradual increase in the relative amount of saponite and clinochlore, as verified by TEM observations. In many instances phyllosilicate sheets parallel the surface of the enclosed pyrrhotite crystal. In most cases the phyllosilicate sheaths are barrel shaped, as if rounded by abrasion; sheaths are never present at the ends of the acicular pyrrhotite crystals. TEM observation reveals that the sheaths contain scattered submicron-sized pentlandite grains (as for in-situ serpentinization of olivine grains [4], but no fine-grained pyrrhotite. In some instances (Figure 2c) magnetite crystals lie adjacent to embayed pyrrhotite crystals. Everything about these pyrrhotites is exceptional, including (a) their mantling of aggregates in a jackstraw fashion, for which we have not identified a precedent, (b) their acicular crystal habit; plates and laths being far more common morphologies for pyrrhotite, and (c) the phyllosilicate sheaths, which are orders of magnitude thicker than any we have previously observed on sulfide crystals. Several aggregates have discontinuous inner rims of granular andradite garnet. This andradite is very impure (average composition $Ad_{51}Al_{32}Uv_9Gr_5Py_3$), with significant Cr and Ti. The andradite is somewhat porous, with inclusions of serpentine and sulfides; all microprobe analyses yield low totals (96-99%), due to either the porosity or structural water. The interior of the complex aggregates is an assemblage of phyllosilicates and pentlandite; one aggregate also contains endiopside whose texture resembles that of a radial chondrule. The pentlandite most frequently has an irregular morphology, but a delicate skeletal form is present in one aggregate. Two aggregates contain pentlandite-filled veins; which, while cutting through the andradite inner rims, fail to cut the outer pyrrhotite rims (Figure 2d).

This Kaidun lithology completely lacks olivine, glass or objects which can unambiguously be called chondrules, and contains only rare, minuscule clinopyroxene grains. These observations and the abundance of phyllosilicates indicates a classification of CI. Andradite can easily form at temperatures below 400°C, in oxidizing, low CO_2 fluids (as in a skarn), and has even been formed by fumarolitic activity [5]. However, andradite is also stable relative to olivine or clinopyroxene during
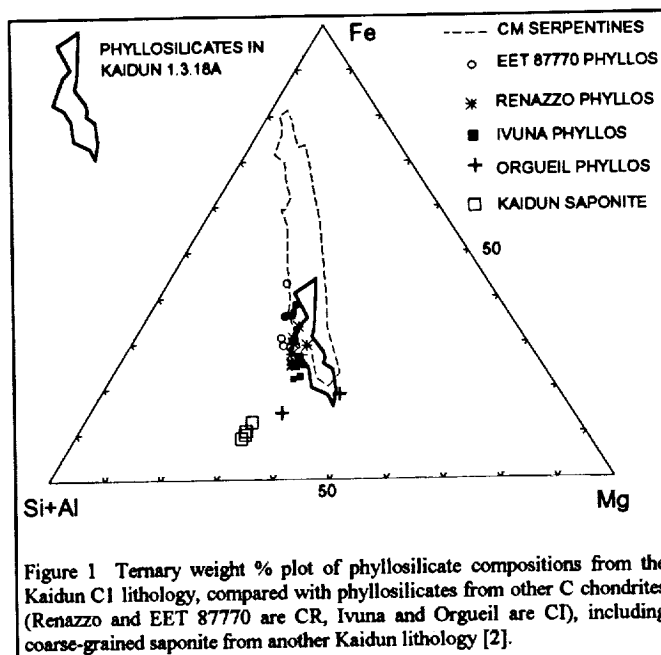
low-temperature aqueous alteration, so could also be a residual primary phase. Pentlandite veins, of probable parent body origin, crosscut the andradite, and must be later; hydrothermal pentlandite may indicate temperatures on the order of 450°C.[6] These same veins fail to cut the outer pyrrhotite rims, possibly indicating a later origin for the latter. However, the phyllosilicate mantles may replace a pre-existing silicate mantle, probably olivine (we have observed olivine mantles about *pentlandite* crystals in the Santa Cruz CM chondrite), which could require a condensation origin for the pyrrhotites. Thus, the pyrrhotites themselves could be pre- or post-accretional in origin. The framboidal magnetites, in close association with the exposed ends of pyrrhotite crystals, probably formed through the oxidation of the latter. The phyllosilicate lumps could have formed from the abrasion of pyrrhotite mantles, or simply through the alteration of the same precursor phase as the mantles.

This Kaidun lithology is, in general characteristics, much like the dark, wet clasts frequently observed in CR chondrites, and a large portion of Kaidun is in fact CR. This material has clearly been subjected to an extreme period (or periods) of aqueous alteration, at temperatures sufficiently high (~450°C) for pentlandite veins to form, sufficiently oxidizing (i.e. wet) for magnetite to replace pyrrhotite (log fO_2 = -60 to -65 [4]), and sufficiently long to permit formation of the well-crystalline, thick phyllosilicate mantles. These conditions would also permit andradite to form in-situ from clinopyroxene. This episode of parent-body alteration occurred on a CM parent body, prior to final consolidation of Kaidun.

References: [1] Browning et al. (1993) *Meteoritics 28*, 331; [2] Zolensky et al. (1991) *LPSC XXII*, 1565-1566; [3] Clayton et al., *LPSC XXV*, this volume; [4] Eckstrand (1975) *Economic Geology 70*, 183-201; [5] Varet (1970) *Contr. Mineral. Petrol. 27*, 321-332; [6] Godlevskiy et al. (1971) *Doklady Akad. Nauk. SSSR 196*, 146-149.
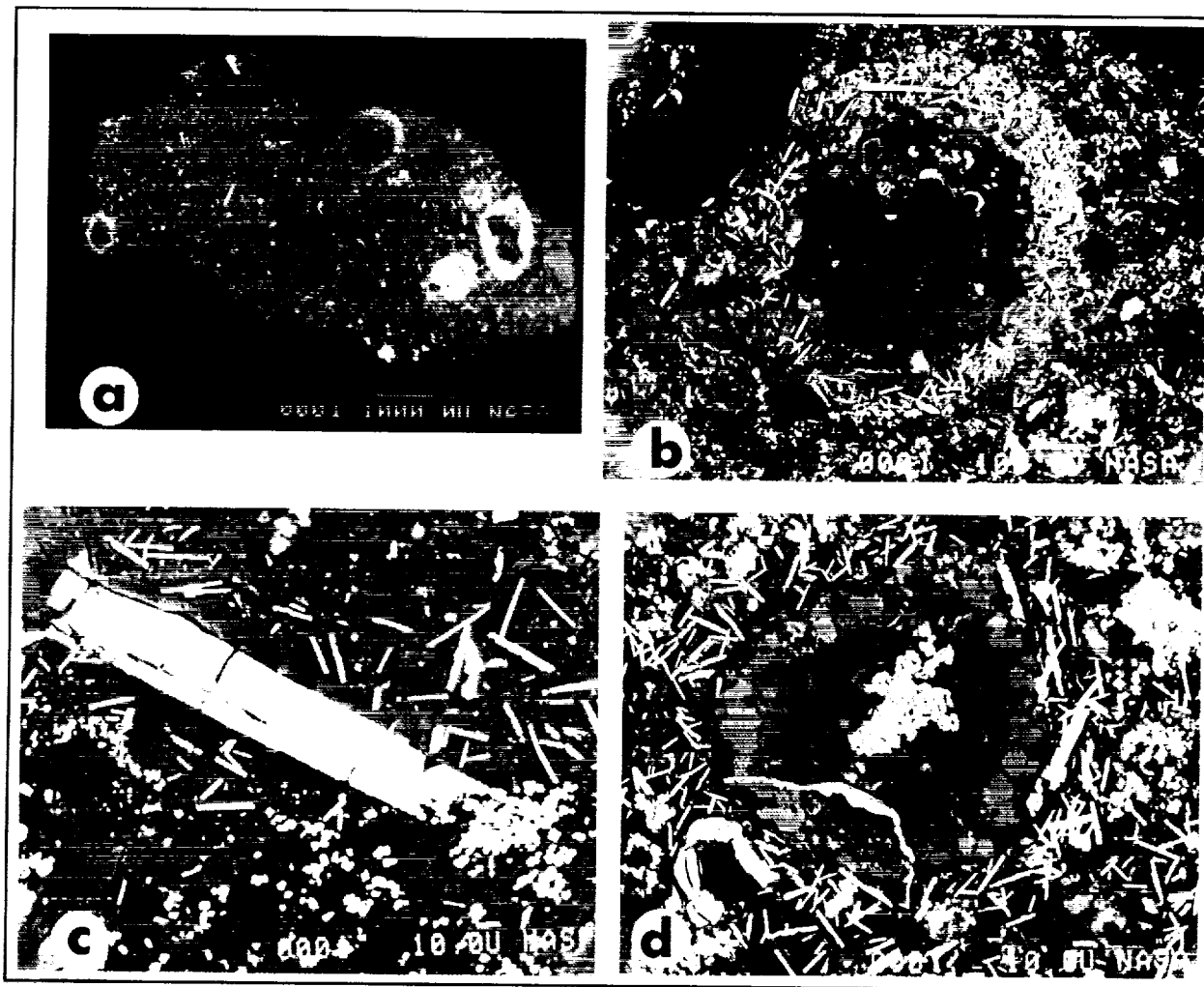

Figure 2 (a) Backscattered electron (BSE) image of a section of the Kaidun lithology, with pyrrhotite-rimmed aggregates plainly visible, (b) BSE image of one complex aggregate, view measures 1200 µm, (c) BSE image of one large acicular pyrrhotite crystal in matrix, with sheath of phyllosilicate and adjacent cluster of magnetite framboids at lower right end of the crystal, crystal measures 200 µm in length, (d) BSE image of a complex aggregate with a core and crosscutting vein of pentlandite (white), inner rim of andradite (gray) and outer rim of acicular pyrrhotites. Cluster of framboidal magnetites are visible at the margins of the image, which measures 500 µm across.