

**ELECTRON BACK-SCATTER DIFFRACTION (EBSD) ANALYSIS OF TWO UNUSUAL MINERALS IN CARBONACEOUS CHONDRITES.** T. Mikouchi<sup>1</sup>, M. Zolensky<sup>2</sup>, O. Tachikawa<sup>1</sup>, M. Komatsu<sup>1</sup>, M. A. Ivanova<sup>3</sup>, L. Le<sup>4</sup> and M. Gounelle<sup>5</sup>, <sup>1</sup>Dept. of Earth and Planetary Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan (E-mail: mikouchi@eps.s.u-tokyo.ac.jp), <sup>2</sup>Mail Code KT, NASA Johnson Space Center, Houston, TX 77058, USA, <sup>3</sup>Vernadsky Inst. of Geochemistry and Analytical Chemistry, Moscow 119991, Russia, <sup>4</sup>Jacobs Sverdrup Co., Houston, TX 77058, USA, <sup>5</sup>CSNSM-Université Paris XI, Bâtiment 104, 91 405 Orsay Campus, France.

**Introduction:** Electron back-scatter diffraction (EBSD) analysis is a newly emerged analytical technique that enables us micro-area (~0.5  $\mu\text{m}$ ) crystallography on thin sections when combined with field emission gun scanning electron microscope (FEG-SEM) [e.g., 1-2]. This technique is extremely useful to identify minute minerals in extraterrestrial samples, which is thus offering valuable information on their formation conditions. In this abstract, we report EBSD analysis of two possible new minerals (Fe-Cr phosphide and Ca-Al oxide) from carbonaceous chondrites (Kaidun and NWA470) to identify their crystal structures and discuss their petrogeneses.

**Analytical:** We employed a ThermoNoran PhaseID EBSD system installed into Hitachi S-4500 FEG-SEM equipped with a Kevex EDS to analyze the samples. The accelerating voltage of the incident beam was 20 kV with the beam current of 2-3 nA. The collection semi-angle of the EBSD detector was ~37.5°. The analyzed polished sections were tilted by ~70° from the horizontal toward the phosphor screen (detector) using a specimen mount. Calculations of Kikuchi patterns and analyses of observed EBSD patterns were performed using a computer program developed by [2].

**Fe-Cr phosphide in Kaidun:** Kaidun is a unique brecciated meteorite containing an unprecedented variety of fragments, including C chondrites (CI, CM, CV), E chondrites (EH, EL), R chondrites, O chondrites, basaltic achondrites, and an equal number of new lithologies with unknown affinities [e.g., 3]. Because of wide variation of its constituent lithologies, Kaidun contains many different mineral species including some previously unknown minerals. An unknown Fe-Cr phosphide (FeCrP) was found as individuals and linear arrays grains with a maximum dimension of 8  $\mu\text{m}$  within two masses of Fe-rich serpentine from the C1 and C2 chondrite lithologies of uncertain affinities (Fig. 1). FeCrP is associated with submicrometer-sized grains of pentlandite and florenskyite (FeTiP). The average electron microprobe analyses gave the formula of  $\text{Fe}(\text{Cr}_{0.587}\text{Fe}_{0.150}\text{V}_{0.109}\text{Ti}_{0.081}\text{Ni}_{0.060}\text{Co}_{0.002})\text{P}$ .

We could successfully obtain EBSD patterns of FeCrP and analyzed its structure by testing crystal

structures of several Fe phosphide phases such as schreibersite ((Fe,Ni)<sub>3</sub>P), barringerite ((Fe,Ni)<sub>2</sub>P), allabogdanite (orthorhombic polymorph of barringerite), florenskyite, and synthetic FeCrP [4,5]. The observed patterns well match with those of allabogdanite, florenskyite, and synthetic FeCrP (Fig. 2) ( $a = 5.7\text{-}6.0$ ,  $b = 3.5\text{-}3.6$ ,  $c = 6.6\text{-}6.9$  Å, space group  $Pnma$ , and  $Z = 4$ ) [4,5].

**Ca-Al oxide in NWA470:** NWA470 is a CH3 chondrite containing numerous CAIs of different mineralogies as typical of this meteorite group. The most dominant CAI type in NWA470 contains abundant grossite (CaAl<sub>4</sub>O<sub>7</sub>). They are usually concentrically zoned with grossite + hibonite + perovskite + spinel cores surrounded by melilite mantles and anorthite and Al-diopside rims [6]. One of these CAIs contains a Ca-Al oxide whose composition is close to the stoichiometric CaAl<sub>2</sub>O<sub>4</sub> [6]. This Ca monoaluminate phase occurs as ~10  $\mu\text{m}$  subhedral grains intergrown with grossite, perovskite, and melilite [6]. We analyzed it by EBSD and the obtained EBSD patterns were tested by crystal structures of several Ca-Al oxide phases including synthetic CaAl<sub>2</sub>O<sub>4</sub> [7]. We found that the obtained pattern well matches with that from the high-pressure polymorph of CaAl<sub>2</sub>O<sub>4</sub> ( $a = 7.95$ ,  $b = 8.62$ ,  $c = 10.25$  Å, space group  $P2_1/c$ , and  $Z = 12$ ) rather than that from regular CaAl<sub>2</sub>O<sub>4</sub> ( $a = 8.092$ ,  $b = 8.7$ ,  $c = 15.191$  Å, space group  $P2_1/c$ , and  $Z = 8$ ) [7]. The structure of either grossite or hibonite did not match with the observed patterns.

**Discussion and Conclusions:** Phosphides are a rare mineral group and only five natural, well-defined phosphides are known today as minerals. They are schreibersite, barringerite, allabogdanite, perryite ((Ni,Fe)<sub>8</sub>(Si,P)<sub>3</sub>), and florenskyite [4,5,8]. Thus, FeCrP is the 6th phosphide to be described from nature. Because its structure is identical to those of both allabogdanite and florenskyite, it is likely that Cr replaces Fe. FeCrP occurs in masses of Fe-rich serpentine, whose composition is very similar to the observed products of aqueous alteration of Fe-Ni metal in other highly altered lithologies in Kaidun [3]. The precursor material for the serpentine in this particular Kaidun lithology plausibly included olivine, pyroxene, Fe-Ni metal enriched in P and Cr. Thus,

FeCrP could have formed as a result of cooling and crystallization of such a melted precursor. Since these phosphide-containing masses experienced aqueous alteration on the parent asteroid, which resulted in complete alteration of the metal matrix and production of the serpentine, FeCrP should have been stable during such alteration. It is also possible that the phosphides formed during aqueous alteration. However, artificial FeCrP has been synthesized only during melting experiments at low oxygen fugacity, and there is no evidence that a hydrothermal genesis is reasonable. Since florenskyite is found in a separate phyllosilicate mass [4] from this FeCrP-bearing serpentine mass, Ti and Cr of the precursor was originally heterogeneous.

The binary system of CaO-Al<sub>2</sub>O<sub>3</sub> includes two important minerals (CaAl<sub>12</sub>O<sub>19</sub>: hibonite and CaAl<sub>4</sub>O<sub>7</sub>: grossite) found in CAIs. However, other two intermediate compounds in this system (CaAl<sub>2</sub>O<sub>4</sub> and Ca<sub>3</sub>Al<sub>2</sub>O<sub>6</sub>) had not been found to occur in nature until CaAl<sub>2</sub>O<sub>4</sub> was reported in the NWA470 CH3 chondrite [6]. Thus, CaAl<sub>2</sub>O<sub>4</sub> in NWA470 is extremely unique and in fact it is proposed that its presence suggests local elevated dust/gas ratio in the

solar nebula [6]. The EBSD analysis in this study shows that CaAl<sub>2</sub>O<sub>4</sub> in NWA470 is a high-pressure polymorph. The phase boundary between regular CaAl<sub>2</sub>O<sub>4</sub> and high-pressure polymorph was experimentally determined and it lies from 700 °C, 1 GPa to 1500 °C, 2.5 GPa [7]. Thus, ~2 GPa is required to stabilize a high-pressure CaAl<sub>2</sub>O<sub>4</sub> polymorph at 1600 K at above which CaAl<sub>2</sub>O<sub>4</sub> condenses from the solar nebula [6]. Because NWA470 shows weakly developed shock features (shock stage: S1) [6], it is reasonable to consider that the high-pressure polymorph was produced during this shock metamorphism after the CAI formation.

**References:** [1] Prior D. J. et al. (1996) *Mineral. Mag.*, 60, 859-869. [2] Kogure T. (2002) *Am. Mineral.*, 87, 1678-1685. [3] Zolensky M. and Ivanov A. (2003) *Chemie de Erde*, 63, 185-246. [4] Ivanov A. V. et al. (2000) *Am. Mineral.*, 85, 1082-1086. [5] Britvin S. N. et al. (2002) *Am. Mineral.*, 87, 1245-1249. [6] Ivanova M. A. et al. (2002) *Meteoritics & Planet. Sci.*, 37, 1337-1344. [7] Ito S. et al. (1980) *Materials Res. Bull.*, 15, 925-932. [8] Buseck P. R. (1969) *Science*, 165-171.

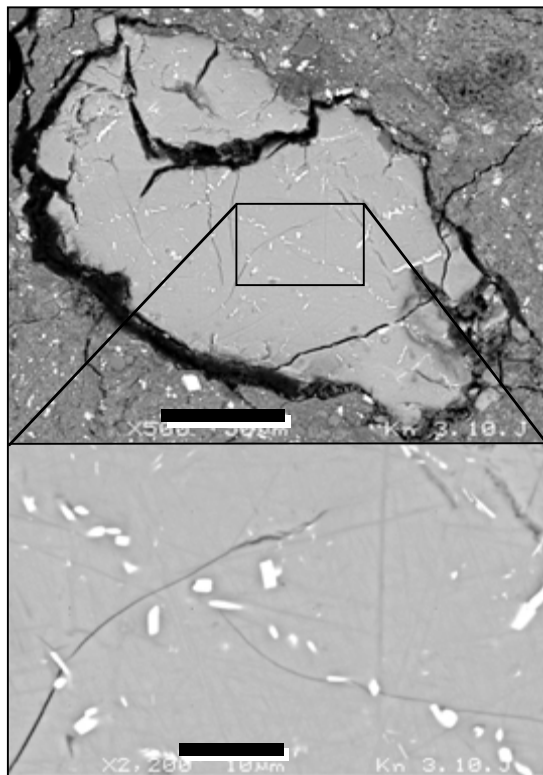


Fig. 1. Back-scattered electron images of the FeCrP-bearing serpentine mass in Kaidun. FeCrP (bright phases) is present as individuals and linear arrays grains. Scale bars are 50 µm (above) and 10 µm (below), respectively.

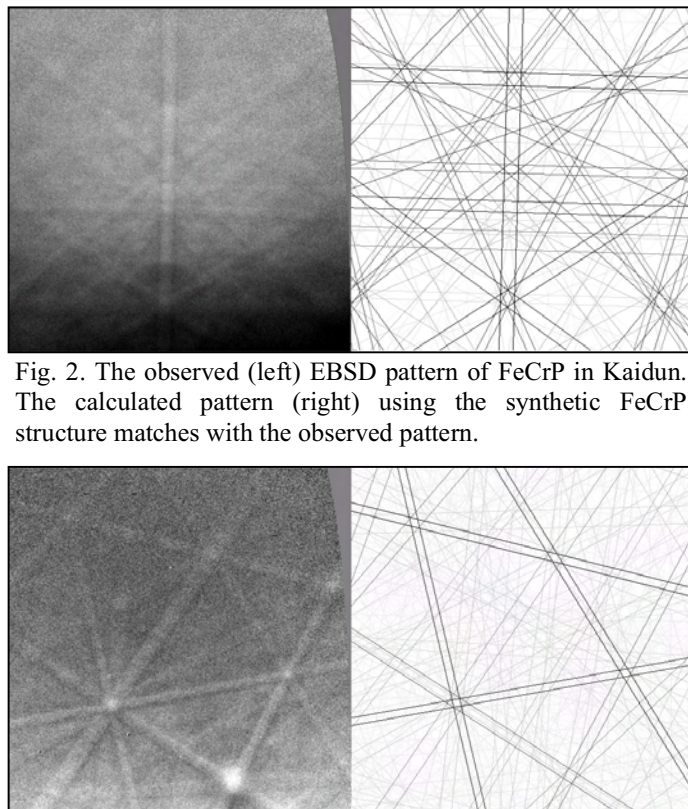


Fig. 2. The observed (left) EBSD pattern of FeCrP in Kaidun. The calculated pattern (right) using the synthetic FeCrP structure matches with the observed pattern.

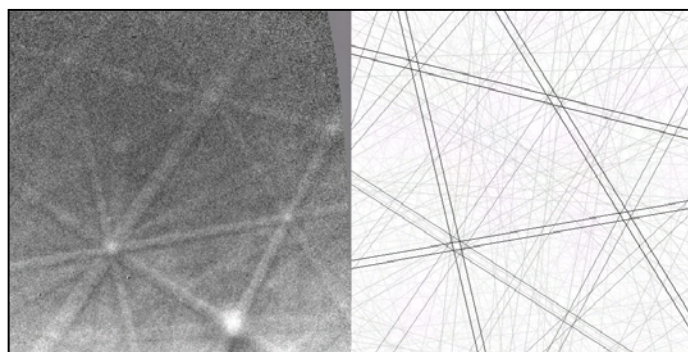


Fig. 3. The observed (left) EBSD pattern of CaAl<sub>2</sub>O<sub>4</sub> in NWA470. The calculated pattern (right) using the structure of high-pressure polymorph of synthetic CaAl<sub>2</sub>O<sub>4</sub> matches with the observed pattern.