# KURATITE (IMA 2013-109): THE "UNKNOWN" Fe-Al-Ti SILICATE FROM THE ANGRITE D´ORBINGY


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**45th LPSC (2014)**


**Introduction:** Angrites are a fascinating group of achondritic meteorites, the petrogenesis of which has been, and still is, a matter of ongoing debates. The chemical composition of angrites is peculiar with high abundances of refractory lithophile elements and low abundances of siderophile and volatile elements. Its unusual composition is reflected in their odd mineralogy. Here we report a detail mineralogical study of one such rare mineral: the Fe-Al-Ti-Si phase from the angrite D´Orbigny that has been recently approved as a new mineral (kuratite) by the CNMNC [1].

**Sample and Results:** The PTS used for this study was kindly loaned by the Naturhistorisches Museum Wien, Austria (inventory number: Section D´Orbigny C-N1172-NH Wien).

The studied Kuratite crystals typically are euhedral to anhedral in shape, < 20 µm in size, and occur, along with whitlockite and submicrometer-sized Fe sulfide droplets, within a rim of olivine with Ca-rich fayalite composition (Ca ~20 mol%) + kirschsteinite (Ca ~40 mol%) intergrowths at the contact between Fe sulfide spherules and the space-filling hedenbergite (Fig. 1A-B, 2).

For the purpose of microstructure analysis, two TEM samples of dimensions 5 µm x 5 µm x 100 nm were prepared by FIB from two kuratite grains (inserts in Figure 1 B).

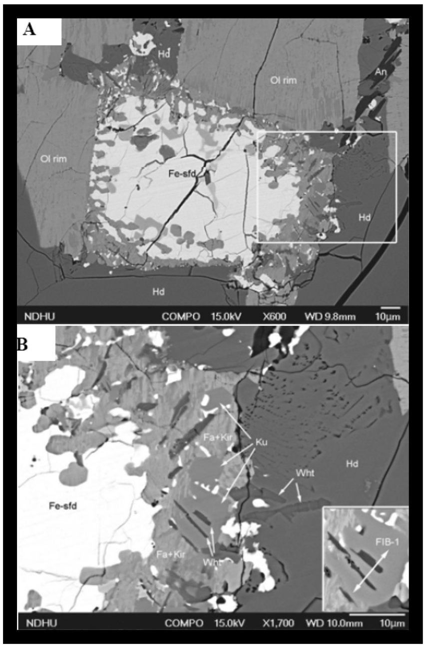



*Figure 1: A-B) SEM-BSE micrographs showing kuratite (Ku) and whitlockite (Wht) crystals surrounded by Fe/Ca-olivine intergrowth at the periphery of Fe sulfide spherules. The inset in B) indicate the site for an FIB thin section for electron diffraction study.*

Chemical analyses (8 analyses from 4 different grains) were carried out using a JEOL JXA8500-F FE-electron microprobe (WDS mode, 12 kV, 5 nA, 2 µm beam diameter). Analytical data are given in Table 1.

| | B5-a-3 | B5-a-4 | B5-a-5 | B5-a-6 | B5-a-7 | B5-a-8 | B5-a-9 | B5-a-10 | Average |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 25.37 | 25.16 | 25.95 | 25.06 | 26.39 | 25.21 | 25.50 | 25.80 | 25.55 |
| $TiO_2$ | 8.43 | 9.17 | 8.52 | 8.51 | 9.78 | 8.68 | 8.33 | 8.15 | 8.70 |
| $Al_2O_3$ | 10.32 | 10.18 | 9.53 | 9.35 | 8.86 | 10.29 | 10.01 | 9.90 | 9.80 |
| $Cr_2O_3$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.00 | 0.01 |
| $Y_2O_3$ | 0.08 | 0.00 | 0.05 | 0.04 | 0.03 | 0.00 | 0.00 | 0.00 | 0.03 |
| $La_2O_3$ | 0.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.07 | 0.04 |
| $Pr_2O_3$ | 0.15 | 0.00 | 0.22 | 0.00 | 0.18 | 0.12 | 0.06 | 0.00 | 0.09 |
| $Nd_2O_3$ | 0.18 | 0.01 | 0.00 | 0.00 | 0.13 | 0.21 | 0.00 | 0.00 | 0.07 |
| FeO Total | 42.01 | 41.09 | 40.98 | 41.76 | 41.95 | 41.86 | 41.60 | 41.57 | 41.60 |
| MnO | 0.20 | 0.02 | 0.04 | 0.13 | 0.06 | 0.03 | 0.24 | 0.15 | 0.11 |
| NiO | 0.01 | 0.00 | 0.15 | 0.00 | 0.00 | 0.19 | 0.00 | 0.18 | 0.07 |
| SrO | 0.06 | 0.08 | 0.04 | 0.04 | 0.05 | 0.03 | 0.00 | 0.06 | 0.05 |
| ZnO | 0.00 | 0.00 | 0.00 | 0.00 | 0.22 | 0.00 | 0.03 | 0.10 | 0.04 |
| MgO | 0.00 | 0.02 | 0.00 | 0.06 | 0.00 | 0.02 | 0.00 | 0.01 | 0.01 |
| CaO | 11.92 | 11.86 | 11.84 | 11.78 | 11.56 | 12.10 | 11.96 | 11.82 | 11.86 |
| $Na_2O$ | 0.00 | 0.02 | 0.13 | 0.03 | 0.01 | 0.00 | 0.07 | 0.04 | 0.04 |
| $K_2O$ | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 |
| $P_2O_5$ | 0.27 | 0.16 | 0.20 | 0.23 | 0.08 | 0.17 | 0.19 | 0.27 | 0.20 |
| F | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.03 | 0.00 | 0.01 |
| Cl | 0.03 | 0.00 | 0.02 | 0.04 | 0.03 | 0.04 | 0.00 | 0.01 | 0.02 |
| $SO_3$ | 0.09 | 0.07 | 0.06 | 0.13 | 0.08 | 0.05 | 0.09 | 0.05 | 0.08 |
| Total | 99.36 | 97.82 | 97.72 | 97.16 | 99.42 | 99.01 | 98.23 | 98.19 | 98.36 |

The empirical formula (based on 20 O *apfu*) (ignoring S, P, F, Cl as impurities) is:
$(Ca_{1.95}Na_{0.01}REE^{3+}_{0.01}Mn_{0.01}Ni_{0.01}Zn_{0.01})_{\Sigma 2.00}(Fe_{5.35}Ti_{0.72})_{\Sigma 6.07}(Si_{3.93}Al_{1.78}Ti_{0.29})_{\Sigma 6.00}O_{20}$ .

**The simplified formula is $Ca_2(Fe^{2+}_5Ti)(Si_4Al_2)O_{20}$**

Comparision of unit-cell parameters between kuratite and other Aenigmatite-rhönite group minerals.

| | *a*(Å) | *b*(Å) | *c*(Å) | *α*(°) | *β*(°) | *γ*(°) | sample type |
|---|---|---|---|---|---|---|---|
| Kuratite | 10.5 | 10.9 | 9.0 | 106.0 | 96.0 | 124.8 | D'Orbigny angrite |
| $Ca_{1.954}(Fe^{+2}_{4.871}Fe^{+3}_{0.481}Ti_{0.648})(Si_{3.931}Al_{1.777}Ti_{0.358})O_{20}$ | | | | | | | |
| $Ca_2(Fe^{+2}_{4.9}Fe^{+3}_{0.5}Ti^{+4}_{0.6})(Si_{3.9}Al_{1.8}Ti_{0.3})O_{20}$ | | | | | | | |
| Rhönite[1] | 10.4 | 10.8 | 8.9 | 105.9 | 96.1 | 124.8 | volcanic breccias |
| $Ca_{1.9}Na_{0.1}(Mg_{3.3}Fe^{+2}_{0.6}Fe^{+3}_{1.1}Ti)(Si_3Al_3)O_{20}$ | | | | | | | |
| $Ca_2(Mg_4Fe^{+3}_1Ti)(Si_3Al_3)O_{20}$ | | | | | | | |
| Rhönite[1] | 10.4 | 10.8 | 8.9 | 106.0 | 96.0 | 124.7 | Allende angrite |
| $Ca_2(Mg_{2.9}Fe^{+2}_{0.3}Fe^{+3}_{1.2}Al_{0.5}V_{0.3}Ti_{1.2})(Si_2Al_4)O_{20}$ | | | | | | | |
| $Ca_2(Mg_4Fe^{+3}_1Ti)(Si_3Al_3)O_{20}$ | | | | | | | |
| Makarochkinite[2] | 10.4 | 10.8 | 8.9 | 105.7 | 96.2 | 124.9 | granitic pegmatite |
| $(Ca_{1.64}Na_{0.25}Mn_{0.11})(Fe^{+2}_{3.5}Fe^{+3}_{1.4}Ti_{0.61}Mg_{0.25}Mn_{0.02}Nb_{0.038}Ta_{0.007})(Si_{4.48}Be_{0.91}Al_{0.54}Fe_{0.07})O_{20}$ | | | | | | | |
| $Ca_2(Fe_4^{2+}Fe^{3+}Ti)(Si_4BeAl)O_{20}$ | | | | | | | |

[3]. Bonaccorsi et al. (1990), [4]. Grew et al. (2005).

The name Kuratite was given in honor of Professor Dr. Gero Kurat (1938 - 2009). Former Head of the Mineralogical-Petrographical Department and Curator of the Meteorite Collection at the Natural History Museum in Vienna, Austria.

*Gero Kurat showing the back side of the angrite D´Orbigny*

He identified the unusual D'Orbigny meteorite as an angrite. Kuratite belongs to the aenigmatite-rhönite mineral group.
The presence of dominant $Fe^{2+}$ in octahedral sites warrants its status as a new mineral [2].

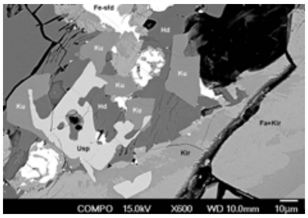



*Figure 2: SEM-BSE micrographs showing kuratite (Ku)*

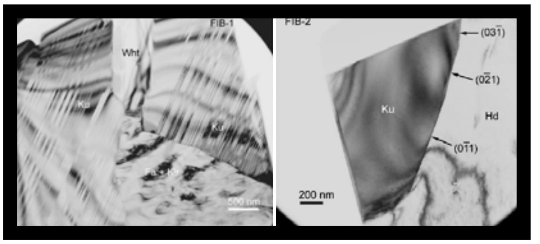
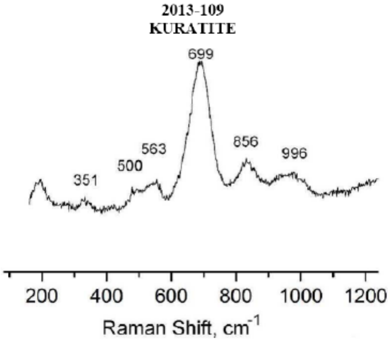



*Figure 3: A-B) TEM bright field images showing (A) kuratite (Ku) crystals in thin section FIB-1 with abundant polysynthetic (011) nano-twins, associated with whitlockite inclusions and Fe/Ca-olivine intergrowth matrix, and (B) the twin-free kuratite crystal with (01̄1), (02̄1) and (03̄1) facets in thin section FIB-2, with the associated euhedral whitlockite crystals*




The Raman spectrum of kuratite shows four main scattering peaks near 563-571, 697-699 (strongest), 852-856 and 986-996 cm-1 resembling that of lunar rhönite [5]) but with higher frequencies due to different chemical composition

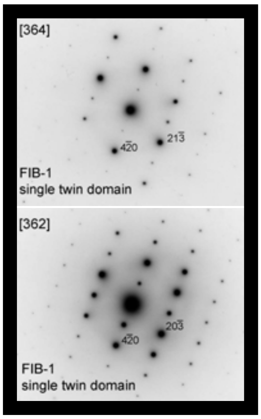



*Figure 4: High-order zone-axis diffraction patterns from a single twin domain of kuratite in section FIB-1 showing (top) the strong 42̄0 and 21̄3 reflections in the [364], zone axis and (bottom) the strong 42̄0 and 20̄3 reflections in the [362] zone axis.*

The first description of this rare phase was done by [6] reporting the discovery of an unknown Fe-Al-Ti-silicate, characterized by a cation/Si ratio of ~2.65. Kurat et al [7] found the unknown Fe-Al-Ti silicate in multi-phase inclusions in anorthite, forming euhedral crystals of up to 20 µm in diameter. This unknown phase is also enclosed by augite and associated with magnetite, troilite and kirschsteinite. Its major chemical composition is homogeneous [2-3] and is characterized by high and unfractionated REE (~100 x CI) contents [8]. More recently this mineral was found in the angrite NWA 4590 and identified as rhönite [9]. Comparisons of D'Orbigny and SAH 99555 rhönites with that from the angrite NWA 4590 indicates a slightly different chemistry, in particular the absence of $Fe^{3+}$ and $Cr^{3+}$ and the Si, Al deficiency in the tetrahedral site [1099].


**References:** [1] Hwang et al., (2014) CNMNC Newsletter 19, Mineralogical Magazine, 78, 165-170; [2] Nickel E.H. and Grice J.D. (1998) Canadian Mineralogist **36**, 913-926; [3] Bonaccorsi et al., (1990) European Journal of Mineralogy **2**, 203-218; [4] Grew et al., (2005), American Mineralogist **90,** 1402-1412; [5] Treiman A.H. (2008) American Mineralogist **93**, 488-491; [6] Mittlefehldt et al. (2002) Meteoritics and Planetary Science **37**, 345–369; [7] Kurat et al., (2004) Geochimica et Cosmochimica Acta **68**, 1901–1921; [8] Varela et al., (2005) Meteoritics and Planetary Science **40**, 409–430; [9] Kuehner S M. and Irving, A J. (2007) Eos Trans. AGU 88, Abst P41A-0219; [10] Jambon A. and Boudouma O. (2011) Meteoritics and Planetary Science Suppl. # 5167.]