

# Fontarnauite, a New Sulphate-Borate Mineral from the Emet Borate District (Turkey)

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## INTRODUCTION.

Fontarnauite is a new mineral found in core samples belonging to Doğanlar boreholes n°2 and n°188 drilled in the vicinity of the Doğanlar village, located four kilometres to the southwest of the Emet town (Western Anatolia, Turkey).

Fontarnauite is a double salt (borate-sulphate) of sodium and strontium with minor contents of potassium and calcium. So far no borates of a Sr- and Na-containing sulphate group have been reported before. Despite the mm-size, single crystals have been impossible to obtain, thus hindering the appropriate characterization required for the recognition as a new mineral by the CNMNC-IMA.

The proposed name is for deceased Dr. Ramon Fontarnau (1944-2007), Director of the Material Characterization Section the Scientific-Technical Survey of the University of Barcelona. It seems a fitting and deserving honour, given his effort to promote the development of scientific facilities focused on, among others, mineral characterization.

## GEOLOGICAL SETTING.

The western Anatolia borate deposits (Turkey) consist of five separated districts: Bigadiç, Sultançayır, Kestele, Emet and Kirka, all of them formed during the Miocene in closed lacustrine evaporite basins during periods of high volcanic and hydrothermal activity. Although the mineral association of borates varies in each district, they are generally interbedded with series of tuffaceous deposits. The principal borate mineral outcropping in several open pit mines in the Emet basin is colemanite with minor amounts of ulexite and hydroboracite (Helvacı and Ortí, 1998). The mineralogical record of Doğanlar boreholes is characterized by the

alternation of Na-Ca borate (probertite) and Na-Ca sulphate (glauberite) units including a central halite deposit. Colemanite is restricted to the base and top of the sequence.

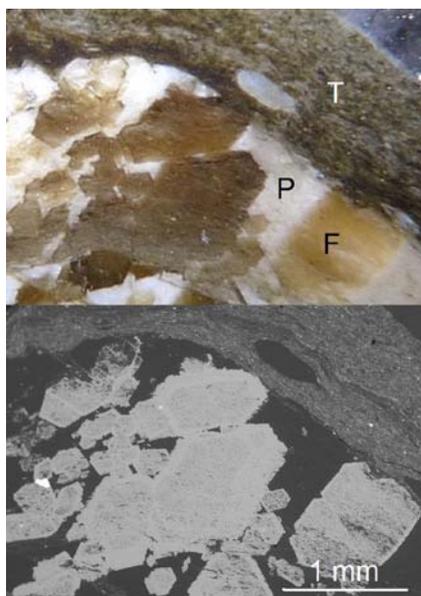


Fig. 1. Optical (upper) and BSE-SEM (lower) images of a cluster of fontarnauite crystals. (F: fontarnauite, P: probertite, T: tuff).

Sedimentary and early diagenetic processes controlled the crystal growth both subaqueously and interstitially. Moreover bacterially inducing dolomite precipitation occurred. The composition of fluid inclusions in halite samples indicates high K concentrations in SO<sub>4</sub>-rich brines. Kalistronite is abundant in the sequence indicating a significant concentration of Sr in brines. Fontarnauite appears as an early diagenetic phase, replacing both probertite and glauberite, as a consequence of a particular K-SO<sub>4</sub> composition achieved by the residual brines during evaporation in a saline lake environment with volcanoclastic contribution.

Other minor minerals found in the boreholes include: borates (aristarainite, colemanite, hydroboracite, kaliborite tunellite and ulexite), sulphates (anhydrite, celestine, gypsum, kalistronite and thenardite), and sulphides (arsenopyrite, orpiment and realgar).

## PHYSICAL AND OPTICAL PROPERTIES.

Fontarnauite occurs as colourless or slightly brown isolated crystals, or as crystal clusters (Fig. 1), with prismatic sections less than 5 mm long. More often it displays pseudo-hexagonal sections less than 1 mm in diameter. Under electron microscope it shows a perfect cleavage parallel to (010) (Fig. 2). It has a pearly, transparent to translucent lustre, a brittle tenacity and a white streak.

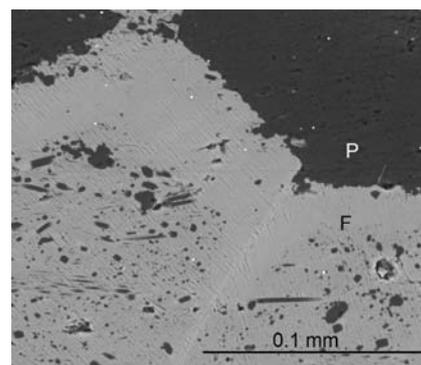


Fig. 2. BSE-SEM image of fontarnauite showing a perfect cleavage and replacing a fine-grained probertite.

Optically, it is biaxial negative and non-pleochroic. It is colourless and displays low positive relief in thin section. Interference colours in prismatic sections are first-order grey and white (Fig. 3). Centred acute bisectrix figures with numerous isochromes are obtained on sections parallel to (010). Optic axis dispersion is medium to weak ( $r > v$ ) and crossed bisectrix dispersion is distinct.

**palabras clave:** boratos, evaporitas, Mioceno.

**key words:** borates, evaporites, Miocene.

Optical orientation is  $X = b$ ,  $OAP \perp (010)$ .

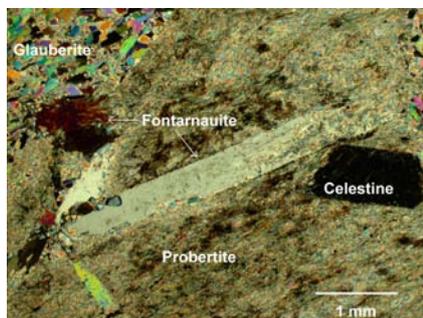


Fig 3. Prismatic fontarnauite crystals in thin section with crossed polars.

### CHEMICAL COMPOSITION.

Chemical analysis (Table 1) has been obtained by Electron Microprobe using a Mo/B<sub>4</sub>C-layered synthetic crystal (McGee et al. 1991). Moderate energy (15 kV), low intensity current (6 nA), large beam diameter (10 μm) and a short counting time (10 s) were applied to avoid mobilization of boron and sodium. Accuracy > 95% for boron analysis in fontarnauite was obtained analyzing the contents in probertite and kaliborite crystals present in the same samples. Water content (including OH) was estimated by difference. Divalent cations (Sr and Ca) show significant variations (Fig. 4) According to chemical data, the empirical formula (based on 15 O atoms) is:

$(Na_{1.84}K_{0.16})_{\Sigma 2}(Sr_{0.83}Ca_{0.18})_{\Sigma 1.01}B_{3.91}S_{1.01}H_{8.21}O_{15}$ , or  $(NaK)_2(SrCa)B_4SH_8O_{15}$ .

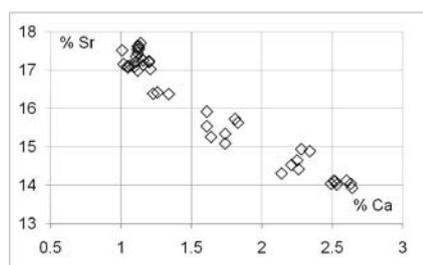


Fig 4. Sr versus Ca contents.

FTIR spectrum at environmental conditions shows a broad band with four overlapping peaks between 3587 and 3208  $cm^{-1}$  assigned to OH stretching frequencies. B-O frequencies are consistent with the presence of the hydrated tetraborate  $[B_4O_5(OH)_4]^{2-}$  containing both trigonal planar ( $BO_3$ ) and tetrahedral ( $BO_4$ ) fragments (Jun et al., 1995). A Raman spectrum (Fig. 4) shows the fundamental symmetric stretching vibration of the sulphate group. As occurs in kernite the symmetric vibration of tetraborate anion

expected at 540-590  $cm^{-1}$  is missing (Jun et al. 1995) suggesting the elimination of one water molecule from the poliborate anion to give the one-dimensional chain of composition  $[B_4O_6(OH)_2]^{2-}$ .

According to stoichiometry and molecular spectroscopy, and pending the determination of the crystal structure, fontarnauite could be classified as tetraborate with a proposed ideal formula:

$(Na,K)_2(Sr,Ca)SO_4[B_4O_6(OH)_2] \cdot 3H_2O$ . Considering the Sr and Na predominance, the hypothetical end-member formula should be  $Na_2SrSO_4[B_4O_6(OH)_2] \cdot 3H_2O$  which requires Na<sub>2</sub>O: 13.56, SrO: 22.68, SO<sub>3</sub>: 17.52, B<sub>2</sub>O<sub>3</sub>: 30.47 and H<sub>2</sub>O + OH: 15.76.

	wt %	range
B <sub>2</sub> O <sub>3</sub>	30.22	29.72 - 31.94
Na <sub>2</sub> O	16.65	12.23 - 13.24
SO <sub>3</sub>	17.77	17.00 - 18.60
K <sub>2</sub> O	1.69	0.87 - 2.20
CaO	2.25	1.41 - 3.69
SrO	19.01	16.58 - 20.81
H <sub>2</sub> O*	16.41	
Total	100.00	

Table 1. Analytical data (EPMA) for fontarnauite. (\*water content, including hydroxyl, by difference).

### KRYSTALLOGRAPHY.

Single-crystal study could not be carried out because of the unavailability of suitable crystals. Although the powder diffraction analysis shows the presence of probertite as a minor phase, most of the peaks observed in the diagram do not match any reported phase.

Indexation using DICVOL04 (Loüer and Boulitf, 2006) took into account all observed peaks except those assigned to probertite. A monoclinic cell was found and the space group  $P2_1/c$  determined from the systematic absences. To check the cell parameters and space group, a profile pattern matching fitting procedure was carried out using the Le Bail method (Le Bail et al., 1988) and by means of the FullProf program (Rodríguez-Carvajal, 1990). The calculated powder X-ray diffraction diagram of probertite was considered in the fitting procedure. The reported cell parameters ( $a$ : 8.456,  $b$ : 22.3004,  $c$ : 8.5615,  $\beta$ : 103.095 Å°, and  $V$ : 1200.11 Å<sup>3</sup>,  $Z$ : 4, density: 2.39 g/cm<sup>3</sup>) has been

reported after Le Bail fitting. Main X-ray powder diffraction data (in Å for  $CuK\alpha_1$ ) are given in Table 2.

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$(l/l_0)1000$	$d$ (Å)	$hkl$
1000	11.1498	0 2 0
199	3.3389	0 4 2
100	3.0458	0 5 2
78	3.3948	0 6 1
75	2.3999	2 6 0
71	3.0250	2 2 0
71	2.2300	0 10 0
66	3.1990	-1 4 2
65	7.8104	0 1 1
64	6.2859	1 0 0
62	3.9061	-1 0 2
58	2.9760	0 7 1
55	3.1429	2 0 0

Table 2. Principal intensities of X-ray powder data for fontarnauite.

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