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Report

Galileiite: A new meteoritic phosphate mineral

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Abstract–A new mineral named galileiite, $NaFe_4(PO_4)_3$, has been found within troilite nodules in iron meteorites of the IIIA and IIIB groups. The mineral is optically positive ($\omega = 1.72$, $\epsilon = 1.75$), colorless in transmitted light and pale amber in reflected light. Grains of galileiite are very small, generally 10 μm or less; rarely, grains are up to 30 μm. It is associated with Ca-free graftonite (or Ca-free sarcopside), chromite and, occasionally, schreibersite. Johnsomervilleite may occur within troilite nodules in the same meteorite as galileiite, but they have never been observed together in the same troilite nodule. Because of the small sample size, single crystal x-ray work was not successful; however, Gandolfi diffraction measurements were made. The three strongest diffraction peaks are 2.71 Å, 3.01 Å and 4.13 Å. On the basis of its composition and similar diffraction pattern, it is considered to be related to johnsomervilleite, fillowite and chladniite, all of which are rhombohedral and isostructural. Galileiite may also be rhombohedral, but that is yet to be demonstrated.

OCCURRENCE

Galileiite occurs as minute inclusions within troilite nodules in IIIAB iron meteorites. Specifically, it has been found in the Grant IIIB (Field Museum, Me2165), El Sampal IIIA (Field Museum, Me2860), Mount Edith IIIB (Field Museum, Me1959), Chupaderos IIIB (Field Museum, Me1046) and Bella Roca IIIB (Field Museum, Me1903) meteorite samples. Crystals of galileiite are usually ~10 μm in their largest dimensions but occasionally are 20 to 30 μm. Galileiite is commonly associated with Ca-free graftonite or its polymorph, Ca-free sarcopside ($[Fe,Mn]_3[PO4]_2$) sometimes together with clusters of chromite grains; which polymorph is present can only be determined by x-ray diffraction. X-ray work was done in one case only, El Sampal, and sarcopside was the polymorph present. Schreibersite is present in some occurrences. Johnsomervilleite may occur in other troilite nodules within the same meteorite but has not been observed in contact with galileiite within the same nodule. Many IIIAB iron meteorites contain phosphate minerals, most commonly Ca-free graftonite (or Ca-free sarcopside). It is very likely that careful searches of any graftonite or sarcopside-bearing IIIAB iron meteorite will yield additional occurrences of galileiite.

Because of the small grain size, it was not possible to characterize galileiite satisfactorily until a 30 μm grain in Grant (IIIB) was found favorably situated for collection. This grain was removed from the surface of a polished section after it had been analyzed by electron microprobe. During subsequent handling to obtain optical measurements, it became disjointed into several pieces that have adhered together in the medium (Apiezon vacuum grease) used for a Gandolfi x-ray mount. All of the measurements and characterization of galileiite were obtained from this sample from Grant IIIB.

OPTICAL AND PHYSICAL PROPERTIES

Optical measurements were extremely difficult and limited. The grain appears to be uniaxial (+), $\omega = 1.72(3)$, $\epsilon = 1.75(5)$ (white light) and not pleochroic. In transmitted light, it is transparent and essentially colorless; however in incident light, it appears to have a very pale amber color. It was not possible to measure a Moh's hardness; but during removal from the section, it was noted to be sectile and fairly soft, possibly ≤4. No cleavage or parting was observed. It was impractical to measure the density for fear of losing the grain.

In terms of optical properties, it would be extremely difficult for anyone to distinguish galileiite from graftonite, sarcopside or johnsomervilleite; their optical indices are in a similar range. In practical terms (because of its size), galileiite is going to be observed only by electron microprobe or scanning electron microscope. The best way to recognize galileiite would be by a so-called energy dispersive spectrum (EDS): strong peaks of Fe, P, Na and no Ca. The only confusion with this method would be with maricite, $NaFePO_4$, which has been found in one IIIA iron, Cape York. We have searched many Cape York sections and have not found galileiite in that meteorite. Were maricite and galileiite to be found in the same section, a quantitative microprobe analysis would have to be used to settle the identification.

COMPOSITION

Three analyses were made with a Cameca SX-50 electron probe microanalyzer, operating at 15 kV, 25 nA, 2 μm focused beam using analyzed mineral and synthetic standards: albite (Na), microcline (K, Al), manganese-hortonolite (Fe, Mn, Mg), calcium pyrophosphate (P, Ca) and chromium sesquioxide (Cr). In addition to the elements reported below, Al, Mg and Ca were sought but were below detection (<0.01%). The average analytical result (wt%) is: Na_2O, 5.87; K_2O, 0.04; Cr_2O_3, 0.07; MnO, 3.98; FeO, 49.0; P_2O_5, 40.2; Sum, 99.16.

The empirical formula (based on 24 oxygens, namely, $6(PO_4)$ groups, which is customary for phosphate minerals that appear to be related to the fillow-group, *cf.* below) is $Na_{2.02}\ K_{0.01}\ Cr_{0.01}\ Fe_{7.26}\ Mn_{0.60}\ P_{6.04}\ O_{24}$. The ideal (24 oxygen) formula is $(Na,K)_2\ (Fe,Mn,Cr)_8\ (PO_4)_6$. Because all the subscripts in this 24-oxygen formula are all divisible by 2, the idealized empirical formula must be reduced to a 12-oxygen basis, $NaFe_4(PO_4)_3$. The ideal composition requires Na_2O, 5.83; FeO, 54.09; P_2O_5, 40.08; Sum, 100.00.

RELATED MINERALS

In order to compare galileiite with members of the fillowite-group (all of which carry one Ca atom), we double the basic empirical formula to a 24-oxygen basis, $Na_2Fe_8(PO_4)_6$. Expressed this way, galileiite may be related to the formula for johnsomervilleite, $Na_2CaFe_7(PO_4)_6$, in which the single Ca atom is replaced by an additional Fe atom. Johnsomervilleite (Livingstone, 1980), fillowite ($Na_2CaMn_7(PO_4)_6$) (Araki and Moore, 1981) and chladniite ($Na_2CaMg_7(PO_4)_6$) (McCoy *et al.*, 1994; Steele, 1994) are all rhombohedral; the latter two are known to be isostructural.

An occurrence of the potassium analog of galileiite, $KFe_4(PO_4)_3$ has been located in another IIIA iron meteorite. It is much smaller than the sample studied here and will present difficulties in its characterization. If successful, it will be submitted for approval as a new mineral.

X-RAY

After initial handling to obtain optical measurements, it was thought that the grain had remained a single piece, and a single crystal x-ray diffraction pattern was attempted. But it was obvious from the film that the original crystal had become disjointed into several adhering fragments. Rather than attempt to isolate a single fragment, with the possibility of losing it, it was decided to obtain only powder diffraction data. A Gandolfi x-ray pattern was made with Mn-filtered Fe-radiation in a 57.3 mm camera for several periods from 24 h to 120 h. The films permitted measurement of 26 diffraction peaks (Table 1).

Because galileiite appears to be related to johnsomervilleite, fillowite and chladniite, all of which are rhombohedral, it is possible that galileiite is also rhombohedral. The powder diffraction pattern was indexed on a rhombohedral cell: a = 14.98 Å, c = 41.66 Å, Z = 36. However, the results are not entirely satisfactory. In Table 1, the observed and calculated d-spacings agree fairly well except for the (024) reflection, for which the agreement is unacceptable. When time permits, we shall undertake single crystal studies by attempting to isolate a single grain from the sample we have. Location of another large crystal is problematical because the grain that was excavated for this work was the largest and most accessible one yet encountered. Considering the small size of any of the fragments from the existing sample, it will be necessary to attempt to obtain Laue crystallographic structural information using a synchrotron x-ray source, which is a method that has been successful for the phosphate mineral stanfieldite (Pluth *et al.*, 1996).

TABLE 1. Galileiite powder diffraction pattern from the occurrence in the Grant IIB meteorite.

I	hkl	Galileiite	Calc.
20	110	7.50	7.49
40	024	5.83	5.51
40	116	5.09	5.09
20	122	4.75	4.77
10	214	4.42	4.44
80	303	4.13	4.13
10	306	3.68	3.67
50	00<u>12</u>	3.47	3.47
20	226	3.30	3.30
50	042	3.21	3.20
90	321	3.01	2.97
50	229	2.93	2.91
50	407	2.85	2.85
100	30<u>12</u>	2.71	2.71
50	502	2.57	2.57
30	244	2.40	2.39
20	063	2.14	2.14
10	520	2.08	2.08
10	50<u>14</u>	1.96	1.96
10	1121	1.93	1.92
20	443	1.86	1.86
20	44<u>12</u>	1.65	1.65
40	179	1.61	1.61
10	07<u>14</u>	1.57	1.57
10	00<u>27</u>	1.52	1.54
10	461	1.48	1.49

Relative visual intensities: a = 14.98 Å, c = 41.66 Å, Z = 36, V = 8085.2 $Å^3$, Trigonal R $\bar{3}$.

TYPE MATERIAL

The specimen from Grant will be the holotype material. It is in the possession of the authors, who wish to retain it for single crystal structure work. When that work is completed, either successfully or unsuccessfully, it will be deposited in the mineral collection of the Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, D.C., USA. Obtaining access to a synchrotron source, and associated data reduction of the Laue measurements, will require the interest and cooperation of individuals from other institutions. We are currently exploring this avenue. If we are unable to obtain such cooperation within a year, the sample will be offered to the above institution for deposit.

NAME

Galileiite is named for the Italian astronomer and physicist, Galileo Galilei (1564–1642), son of Vincenzo Galilei, the musician and composer. It is appropriate, and long overdue, that a mineral discovered in extraterrestrial objects be named for this great man. The mineral and its name have been approved by the Commission on New Minerals and Mineral Names of the International Mineralogical Association (submission # 96-028).

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REFERENCES

ARAKI T. AND MOORE P. B. (1981) Fillowite, $Na_2Ca(Mn,Fe)_7(PO_4)_6$: Its crystal structure. *Am. Mineral.* **66**, 827–842.

LIVINGSTONE A. (1980) Johnsomervilleite, a new transition-metal phosphate mineral from the Loch Quoich area, Scotland. *Mineral. Mag.* **43**, 833–836.

MCCOY T. J., STEELE I. M., KEIL K., LEONARD B. F. AND ENDRESS M. (1994) Chladniite, $Na_2CaMg_7(PO_4)_6$: A new mineral from the Carlton (IIICD) iron meteorite. *Am. Mineral.* **79**, 375–380.

PLUTH J. J., STEELE I. M., LEGRANDE A. AND REN Z. (1996) Laue data refinement of the crystal structure of stanfieldite, data collected at CHESS using undulator radiation with image plates in a cylindrical film cassette (abstract). *International Union of Crystallography, 17th Congress*, C14.

STEELE I. M. (1994) Crystal structure of chladniite, $Na_2CaMg_7(PO_4)_6$, from the Carlton (IIICD) iron meteorite (abstract). *Lunar Planet. Sci.* **25**, 1337–1338.