

FENCOOPERITE, $\text{Ba}_6\text{Fe}^{3+}_3\text{Si}_8\text{O}_{23}(\text{CO}_3)_2\text{Cl}_3\cdot\text{H}_2\text{O}$, A NEW MINERAL SPECIES FROM TRUMBULL PEAK, MARIPOSA COUNTY, CALIFORNIA

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ABSTRACT

Fencooperite, a new mineral species having the ideal formula $\text{Ba}_6\text{Fe}^{3+}_3\text{Si}_8\text{O}_{23}(\text{CO}_3)_2\text{Cl}_3\cdot\text{H}_2\text{O}$, is trigonal, $P3m1$, with unit-cell parameters refined from powder data: a 10.727(5), c 7.085(3) Å, V 706.1(5) Å³, c/a 0.6605, $Z = 1$. The strongest seven lines of the X-ray powder-diffraction pattern [d in Å (I)(hkl)] are: 3.892(100)(201), 3.148(40)(211), 2.820(90)(202), 2.685(80)(220), 2.208(40)(401), 2.136(40)(222) and 1.705(35)(421). The mineral occurs as a dominant phase within black aggregates 2 mm across in barium-silicate-rich lenses at Trumbull Peak, Mariposa County, California. It is a primary phase, formed after barite, in an aggregate assemblage that includes alforsite, barite, celsian, gillespite, quartz, pyrrhotite and sanbornite. Additional minerals found within the lenses are anandite, benitoite, bigcreekite, fresnoite, kinoshitalite, krauskopfit, macdonaldite, pellyite, titantaramellite, walstromite, witherite, biotite, diopside, fluorapatite, pentlandite, schorl, vesuvianite and three undefined species. Individual grains of fencooperite are anhedral to somewhat rounded to occasionally platy, are jet black to a dirty grey-brown (on very thin edges), do not exceed 100 µm in size, and have an uneven to subconchoidal fracture. Neither morphological forms nor twinning were observed. The streak is greyish black, tenacity is brittle, luster is vitreous to adamantine, and diaphaneity, opaque to translucent (on thin edges). There is no obvious cleavage; D (calc.) 4.338 (for the ideal formula), 4.212 g/cm³ (for the empirical formula). It is nonfluorescent in ultraviolet light; H (VHN load 10 g) 269 to 367, H (Mohs) 4.5 to 5. Fencooperite is uniaxial negative, O 1.723(4), E 1.711(2), very strongly pleochroic from blue-black (O) to light greenish grey (E); absorption $O \gg E$. Averaged results of electron-microprobe analyses yield BaO 50.51, Fe₂O₃ 12.77, MnO 0.15, SiO₂ 27.38, Al₂O₃ 1.35, P₂O₅ 0.16, Cl 3.23, CO₂ [4.81], H₂O [0.98], sum 101.34, less O = Cl -0.73, total [100.61] wt.%. The empirical formula, derived from results of the crystal-structure analysis and electron-microprobe analyses, is $\text{Ba}_{5.89}(\text{Fe}^{3+}_{2.86}\text{Mn}^{2+}_{0.04})_{\Sigma 2.90}(\text{Si}_{8.14}\text{Al}_{0.47}\text{P}_{0.04})_{\Sigma 8.65}\text{O}_{23.18}(\text{CO}_3)_{1.95}(\text{Cl}_{1.63}\text{O}_{1.37})_{\Sigma 3.00}\cdot 0.97\text{H}_2\text{O}$, on the basis of $O + \text{Cl} = 33$. The infrared-absorption spectrum shows bands for carbonate and possibly for structural H₂O. The mineral name honors Joseph Fenimore Cooper, Jr., Santa Cruz, California, in recognition of his substantive contributions to both mineralogy and mineral collecting in the western United States.

Keywords: fencooperite, new mineral species, hydrated barium-iron silicate carbonate chloride, X-ray data, electron-microprobe data, infrared spectroscopy, Trumbull Peak, Mariposa County, California.

SOMMAIRE

La fencooperite, nouvelle espèce minérale dont la composition idéale serait $\text{Ba}_6\text{Fe}^{3+}_3\text{Si}_8\text{O}_{23}(\text{CO}_3)_2\text{Cl}_3\cdot\text{H}_2\text{O}$, est trigonale, $P3m1$, avec les paramètres réticulaires suivants, affinés à partir de données sur poudre: a 10.727(5), c 7.085(3) Å, V 706.1(5) Å³, c/a 0.6605, $Z = 1$. Les sept raies les plus intenses du spectre de diffraction [méthode des poudres; d en Å (I)(hkl)] sont: 3.892(100)(201), 3.148(40)(211), 2.820(90)(202), 2.685(80)(220), 2.208(40)(401), 2.136(40)(222) et 1.705(35)(421). Elle se présente comme phase dominante dans des agrégats noirs mesurant 2 mm de taille dans des lentilles enrichies en silicates de

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barium à Trumbull Peak, comté de Mariposa, en Californie. Il s'agit d'une phase primaire, formée après la barite, dans un assemblage qui comprend alforsite, barite, celsian, gillespite, quartz, pyrrhotite et sanbornite. Lui sont associés dans ces lentilles anandite, benitoïte, bigcreekite, fresnoïte, kinoshitalite, krauskopfite, macdonaldite, pellyite, titantaramellite, walstromite, witherite, biotite, diopside, fluorapatite, pentlandite, schorl, vésuvianite et trois espèces méconnues. Les grains individuels de fencooperite sont xénomorphes à quelque peu arrondis et localement aplatis; ils sont noir à gris brunâtre sale aux bordures très minces, et ne dépassent pas 100 µm de taille. Ils ont une fracture inégale à subconchoïdale. Aucun développement de formes ou de macles n'est visible. La rayure est noir grisâtre, la ténacité est cassante, l'éclat est vitreux à adamantin, et la diaphanéité, opaque à translucide (en bordure mince). Il ne semble pas y avoir de clivage. La densité calculée est 4.338 à partir de la formule idéale, et 4.212 g/cm³ à partir de la formule empirique. La fencooperite est non fluorescente en lumière ultraviolette; sa dureté VHN avec un poids de 10 g est entre 269 et 367, et la dureté de Mohs est de 4.5 à 5. La fencooperite est uniaxe négative, O 1.723(4), E 1.711(2), très fortement pléochroïque de bleu-noir (O) à gris verdâtre pâle (E); l'absorption est $O \gg E$. Une moyenne des résultats obtenus à la microsonde électronique est: BaO 50.51, Fe₂O₃ 12.77, MnO 0.15, SiO₂ 27.38, Al₂O₃ 1.35, P₂O₅ 0.16, Cl 3.23, CO₂ [4.81], H₂O [0.98], somme 101.34, moins O = Cl -0.73, pour un total de [100.61]% en poids. La formule empirique, dérivée à partir des résultats de l'ébauche de la structure cristalline et des données provenant de la microsonde électronique, serait Ba_{5.89}(Fe³⁺_{2.86}Mn²⁺_{0.04})Σ_{2.90}(Si_{8.14}Al_{0.47}P_{0.04})Σ_{8.65}O_{23.18}(CO₃)_{1.95}(Cl_{1.63}O_{1.37})Σ_{3.00}•0.97 H₂O, sur une base de O + Cl = 33. Le spectre d'absorption infrarouge montre des bandes pour le carbonate et possiblement pour le H₂O structurellement incorporé. Le nom choisi honore Joseph Fenimore Cooper, Jr., de Santa Cruz, en Californie, et reconnaît ainsi ses contributions substantielles à la minéralogie et à la collection de minéraux dans l'ouest des États-Unis.

(Traduit par la Rédaction)

Mots-clés: fencooperite, nouvelle espèce minérale, silicate carbonate chloruré hydraté de barium et de fer, données de rayons X, données de microsonde électronique, spectroscopie infrarouge, Trumbull Peak, comté de Mariposa, Californie.

INTRODUCTION

Fencooperite, ideally Ba₆Fe³⁺₃Si₈O₂₃(CO₃)₂Cl₃•H₂O, is a newly recognized mineral species from Trumbull Peak, Mariposa County, California. It was initially noted in 1998 by one of the authors (GED) while conducting a megascopic examination of specimens collected in 1963 and 1988 from two of the three barium-silicate-rich lenses known to occur at Trumbull Peak. A number of specimens feature jet-black aggregates randomly distributed along gillespite-rich zones within sanbornite-quartz rock. Because of its unique appearance and color, the mineral warranted further study; energy-dispersion spectrometry (EDS) coupled with routine X-ray powder-diffraction analysis indicated that the phase was new to science. A full mineralogical investigation was initiated, and the resultant data are reported herein.

The mineral is named *fencooperite* in honor of Mr. Joseph Fenimore ("Fen") Cooper, Jr. (b. 1937), of Santa Cruz, California, who helped collect the samples in which the new phase was identified. Mr. Cooper, a now-retired building and road specifications engineer with Santa Cruz County, has been an avid collector of rare minerals since 1957 and has coauthored more than twenty papers dealing with minerals and mineral occurrences in the western United States. The mineral and mineral name have been approved by the Commission on New Minerals and Mineral Names, IMA (2000–023). Four polished sections and six fencooperite-bearing rock chips (none exceeding 2 cm in longest dimension) are housed in the Systematic Reference Series of the National Mineral Collection of Canada at the Geological Survey of Canada, Ottawa, Ontario, under catalogue number NMCC 68089.

About forty specimens containing the new mineral are known; they range from less than 1 cm up to about 4 cm in size. Each specimen generally contains one or more fencooperite-bearing aggregates. At Trumbull Peak, the mineral should be considered rare. Fencooperite has also been identified as a rare constituent of quartz–sanbornite rock at the Esquire #7 claim, Fresno County, California.

OCCURRENCE AND ASSOCIATED MINERALS

Trumbull Peak is located on the western slope of the Sierra Nevada Range in NE S. 9, T3S, R19E, Mount Diablo Meridian (lat. 37°40'58"N, long. 119°47'08"W), about 67 km northeast of Merced and 8 km west of El Portal, Mariposa County, California. The barium-silicate-rich lenses are located about 200 m down the steep northwest slope of the peak from the sharp bend in Forest Service Road 1S20. These lenses are less than a meter wide by one to two meters long, have a strike near 80°, and show a fine-grained texture similar to that found in the surrounding quartzite. The lenses are found within Paleozoic metasedimentary rocks that have undergone low-grade metamorphism and have also been isoclinally folded. A detailed paper (and references therein) describing the location, history, geology and mineralogy of the Trumbull Peak occurrence has recently been published by Dunning & Cooper (1999).

A typical hand-specimen of lens material consists of a predominant mixture of sanbornite and gillespite in a quartz matrix. Sections of titantaramellite crystals occur scattered throughout the sample, as do isolated flakes of anandite and kinoshitalite. Black fencooperite-bearing aggregates typically occur along zones containing gillespite (Fig. 1) and are usually surrounded by



FIG. 1. Black fencooperite-bearing aggregates associated with red gillespite and surrounded by quartz. Field of view is 1.5 cm across photograph. G.E. Dunning specimen, T.A. Hadley photograph.

sanbornite, though it is not unusual for these aggregates also to be found completely enclosed within gillespite (Fig. 2). In polished section, these black aggregates, megascopically monomineralic, are, in fact, composed of a mixture of fencooperite, celsian, alforsite, barite, sanbornite, quartz, pyrrhotite and diopside, the proportions of which vary from aggregate to aggregate. Other minerals identified from Trumbull Peak, but not found within these aggregates, include benitoite, bigcreekite (Basciano *et al.* 2001a), fresnoite, krauskopfite, macdonaldite, pellyite, walstromite, witherite, biotite, fluorapatite, cobaltian pentlandite, schorl, vesuvianite and three undefined species currently under investigation.

Textural relationships, as observed in scanning electron microscopy using energy-dispersion spectra and back-scattered electron imaging (Fig. 3), suggest the following paragenetic sequence: (1) barite formed first, followed by simultaneous crystallization of (2) fencooperite, diopside, celsian, and alforsite, followed by (3) pyrrhotite, then (4) gillespite, and finally (5) sanbornite. Titanataramellite, although not observed within the aggregates, appears to have formed within the same time-frame as fencooperite. Of note was the discovery of a single grain of fencooperite in direct contact with cobaltian pentlandite, both totally enclosed within pyrrhotite. Thin fractures in the hand specimens



FIG. 2. Black fencooperite-bearing veins enclosed in orange-red gillespite. Fencooperite-gillespite aggregate is approximately 3 mm across. G.E. Dunning specimen, T.A. Hadley photograph.

contain middle- to late-stage bigcreekite. Last to form in the assemblage were macdonaldite, secondary witherite and one of the undefined phases (a hydrous form of silica).

PHYSICAL PROPERTIES

Fencooperite occurs as a dominant phase within black aggregates. These typically do not exceed 2 mm in size and may also contain alforsite, barite, celsian, gillespite, quartz, pyrrhotite and sanbornite. Individual grains of fencooperite are anhedral to somewhat roundish to occasionally platy and usually do not exceed 100 μm in size. There is no direct evidence of any identifiable morphology, and twinning was not observed megascopically nor in single-crystal X-ray studies. The color of the mineral varies from jet black to a dirty grey-brown (on very thin edges), and the streak is greyish black. The luster varies from vitreous to adamantine, and grains are opaque to translucent on thin edges. Fencooperite is brittle, with an uneven to subconchoidal fracture, no obvious cleavage, and is nonfluorescent under both long- and short-wave ultraviolet light. Thirteen Vickers microhardness indentations gave a mean VHN_{10} of 321 kg/mm^2 (range 269 to 367 kg/mm^2), equivalent to a Mohs hardness 4.5 to 5. The density could not be measured because of the small size of the available grains and the dearth of clean material.

OPTICAL PROPERTIES

The two crystals previously used for the single-crystal precession study were subsequently used to determine the optical properties. Spindle-stage mounts observed in Na gel-filtered light (λ 589.9 nm) show that

fencooperite is uniaxial negative, O 1.723(4), E 1.711(2). The mineral is very strongly pleochroic, with O blue black and E light greenish grey; the absorption is $O \gg E$. These optical properties are very distinctive and set it apart from the other Ba-bearing phases found in the Trumbull Peak mineral assemblage; optical identification of fencooperite in either thin section or polished thin section should be fairly straightforward given its distinctive pleochroism.

X-RAY CRYSTALLOGRAPHY

Single-crystal precession studies of two anhedral fragments, employing Zr-filtered Mo radiation, show that fencooperite is hexagonal, with measured unit-cell parameters a 10.65 and c 7.097 \AA . One crystal was mounted such that a^* is parallel to the dial axis, and the other crystal was mounted such that c^* is parallel to the dial axis. The following levels were photographed: $hk0 \rightarrow hk2$, $h0l \rightarrow h2l$ and $110^* \wedge c^*$. The diffraction symmetry observed on both zero- and upper-level hkn films is $6/mmm$; however, the correct diffraction-symmetry is trigonal $\bar{3}m$, as deduced from crystal-structure analysis (Grice 2001). The unique space-group determined from the successful refinement is $P3m1$ (156). The subtle variations in nodal intensity that would alter the diffraction symmetry from hexagonal $6/mmm$ to trigonal $\bar{3}m$ are not obvious on any of the precession single-crystal films. The X-ray powder-diffraction data are presented in Table 1. The refined unit-cell parameters, a 10.727(5), c 7.085(3) \AA , V 706.1(5) \AA^3 , c/a 0.6605, are based on 19 X-ray powder lines between 3.892 and 1.408 \AA for which unambiguous indexing was possible. All indexed reflections were checked on precession single-crystal films and confirmed using the calculated intensities

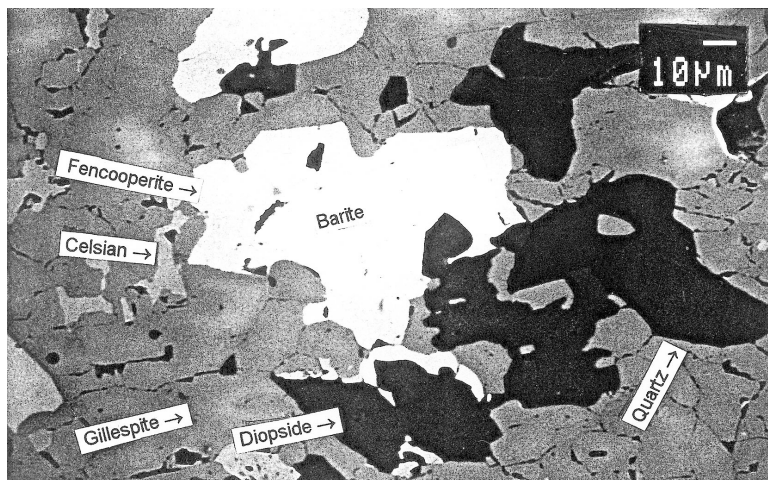


Fig. 3. SEM backscattered electron photomicrograph of a polished section showing a typical fencooperite-bearing mineral assemblage. Scale bar: 10 μm .

TABLE 1. X-RAY POWDER-DIFFRACTION DATA FOR FENCOOPERITE

$I_{\text{est.}}$	$d\text{\AA}_{(\text{meas.})}$	$d\text{\AA}_{(\text{calc.})}$	hkl	$I_{\text{est.}}$	$d\text{\AA}_{(\text{meas.})}$	$d\text{\AA}_{(\text{calc.})}$	hkl
10	9.189	9.290	100	3	1.936	1.942	402
10	7.081	7.085	001	5	1.880	1.878	303
5	5.618	5.634	101	* 20	1.827	1.826	322
20	5.372	5.364	110	* 10	1.800	1.797	501
20	4.646	4.645	200	* 15	1.773	1.771	004
* 100	3.892	3.885	201				
* 20	3.541	3.542	002	3	1.755	1.759	412
* 20	3.320	3.310	102	5	1.739	1.741	313
* 40	3.148	3.146	211	* 35	1.705	1.704	421
5	3.097	3.097	300	3	1.684	1.682	114
* 15	2.957	2.956	112	3	1.673	1.669	510
* 90	2.820	2.817	202				
* 80	2.685	2.682	220	10	1.654	1.656	403
5	2.582	2.577	310	5	1.622	1.624	511
10	2.498	2.508	221	* 25	1.573	1.573	422
		2.494	212	5	1.548	1.548	600
* 10	2.420	2.421	311	3	1.538	1.538	304
		2.331	302	3	1.523	1.527	430
30	2.329	2.323	400	3	1.510	1.513	601
3	2.288	2.289	103	3	1.489	1.488	520
* 40	2.208	2.207	401	* 20	1.478	1.478	224
3	2.171	2.161	113				
* 40	2.136	2.138	222	10	1.459	1.456	521
* 30	2.106	2.105	203				
3	2.084	2.084	312	5	1.419	1.419	602
5	2.024	2.027	410	* 15	1.408	1.417	610
* 10	1.958	1.960	213				

114.6 mm Debye-Scherrer powder camera employing Ni filtered Cu radiation (λ , CuK α = 1.54178 Å). Intensities estimated visually. Not corrected for shrinkage and no internal standard used; * = lines used for unit-cell refinement. Indexed on a 10.727(5), c 7.085(3) Å.

derived from the crystal structure. The powder data are unique and bear no resemblance to any other inorganic phase listed in the Powder Diffraction File. Fencooperite is the second confirmed barium silicate carbonate chloride mineral found in nature, the first being kampfite (Basciano *et al.* 2001b).

The unit-cell parameters derived from the crystal structure (Grice 2001) are: a 10.740(2), c 7.0950(14) Å, V 708.7(2) Å³, c/a 0.6606. Using these cell parameters and $Z = 1$, the calculated density based on the ideal formula is 4.338 g/cm³, and the calculated density based on the empirical formula is 4.212 g/cm³.

CHEMICAL COMPOSITION

Grains of fencooperite in a polished section were chemically analyzed with a Cameca SX-50 electron microprobe utilizing an operating voltage of 20 kV, a beam current of 10 nA, a beam 1 μ m in diameter and a 10 s count time. The following standards were employed: sanbornite (Ba), synthetic Fe metal (Fe), synthetic Mn metal (Mn), quartz (Si), corundum (Al), synthetic GaP (P) and halite (Cl). An energy-dispersion spectrum indicated the absence of elements with atomic number greater than 9 other than those reported here; F, Na, K, Mg, Ca, Ti, Cr, Ni, Rb, Sr, Zn and V were specifically sought, but not found. Data were corrected using the ZAF procedure (Armstrong 1988). The valence state of iron (Fe³⁺) and the number of oxygen atoms (30) were determined by bond-valence calculations based on

TABLE 2. CHEMICAL DATA FOR FENCOOPERITE

	wt. %	Range
BaO	50.51	48.70 - 52.37
Fe ₂ O ₃ †	12.77	12.49 - 13.07
MnO	0.15	0.00 - 0.43
SiO ₂	27.38	25.07 - 28.55
Al ₂ O ₃	1.35	1.18 - 1.52
P ₂ O ₅	0.16	0.00 - 0.49
Cl	3.23	3.03 - 3.37
CO ₂	[4.81]*	
H ₂ O	[0.98]*	
sum	101.34	
-O = Cl	-0.73	
total	[100.61]	

†Valence determined by crystal-structure analysis (Grice 2001).

*Calculated from ideal formula derived from crystal-structure analysis (Grice 2001).

bond lengths derived from the crystal-structure analysis (Grice 2001) prior to the final interpretation of the electron-microprobe results. It proved impossible to separate enough pure material for classical chemical analysis for H₂O and CO₂; all "monomineralic" grains and aggregates are composites of several different phases. However, the presence of H as H₂O was confirmed by structure analysis, and the presence of C as CO₃ was confirmed by both crystal-structure analysis and a powder infrared-absorption study (see below). The average of twelve electron-microprobe determinations and ranges are given in Table 2. With O + Cl = 33, the empirical formula is Ba_{5.89}(Fe³⁺_{2.86}Mn²⁺_{0.04}) Σ 2.90(Si_{8.14}Al_{0.47}P_{0.04}) Σ 8.65O_{23.18}(CO₃)_{1.95}(Cl_{1.63}O_{1.37}) Σ 3.00•0.97 H₂O. The simplified formula, Ba₆Fe₃³⁺Si₈O₂₃(CO₃)₂Cl₃•H₂O, requires BaO 50.31, Fe₂O₃ 13.10, SiO₂ 26.29, Cl 5.82, CO₂ 4.81, H₂O 0.98, sum 101.31, less O = Cl = 1.31, total 100.00 wt. %.

Calculations using the Gladstone-Dale relationship indicate a compatibility index $1 - (K_P / K_C)$ of +0.054 [considered to be good by Mandarino (1981)] if one uses the calculated density from the empirical formula, K_C derived from the empirical formula and unit-cell parameters calculated from the crystal structure. However, if one chooses the calculated density and K_C derived from the simplified structural formula, the compatibility between K_P and K_C is considered to be poor. The reason for this poor compatibility is unknown at this time. It may be due to significant differences between indices of refraction of the crystal used for structure determination and that used for optical characterization, though it is possible that the constants (k) given by Mandarino (1981) for some of the oxides listed above may need to be revised for this particular type of silicate structure.

INFRARED SPECTROSCOPY

The procedures for acquiring the infrared-absorption spectrum are identical to those used to obtain the spectrum of mcalpineite (Roberts *et al.* 1994) and are not

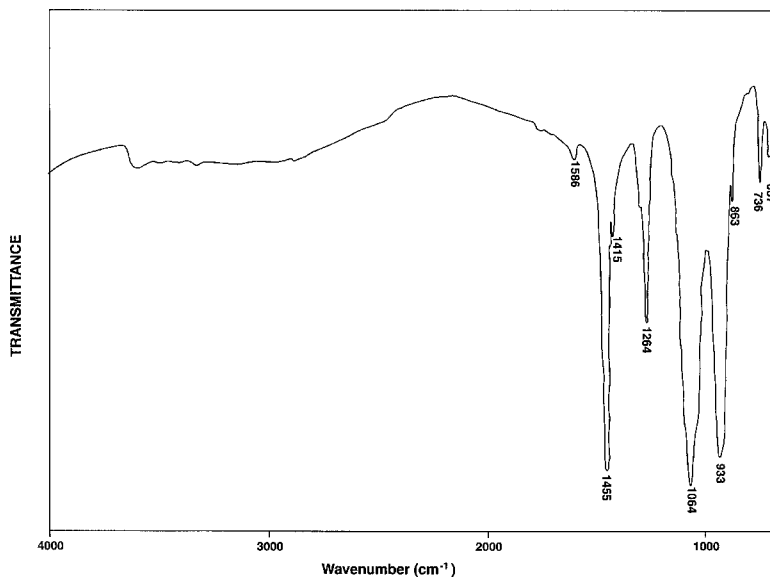


FIG. 4. Infrared-absorption spectrum of fencooperite.

repeated here. The sample was analyzed using a Bomem Michelson MB-100 Fourier-transform infrared spectrometer equipped with a wide-band mercury-cadmium telluride detector. The transmittance spectrum (Fig. 4) confirms the presence of carbonate: ν_1 (very strong) 1064, ν_2 (medium) 863, ν_3 (very strong) 1455, ν_4 (medium) 736 cm^{-1} bands, which are all very sharp and pronounced. In contrast, bands diagnostic of H_2O are not obvious. A small peak centered at 1586 cm^{-1} could possibly be due to H-O-H bending, and an extremely broad, extremely shallow band, which ranges from approximately 2700 to 3700 cm^{-1} with no obvious peak, might be indicative of O-H stretching in the H_2O molecules.

ACKNOWLEDGEMENTS

The authors thank E. Moffatt (Canadian Conservation Institute) for the infrared spectrum of fencooperite, T.A. Hadley for the photographs reproduced in Figures 1 and 2, M. Clarke (GSC) for redrafting Figure 4, K. Mooney (GSC) for typing the manuscript, and Drs. L.A. Groat, M. Raudsepp and R.F. Martin for their thoughtful reviews of the manuscript.

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Received October 9, 2000, revised manuscript accepted April 4, 2001.