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CHESTERMANITE, A NEW MEMBER OF THE LUDWIGITE–PINAKIOLITE GROUP FROM FRESNO COUNTY, CALIFORNIA

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ABSTRACT

Chestermanite, ideally $Mg_2(Fe^{3+},Mg,Al,Sb^{5+})BO_3O_2$, is orthorhombic, space group *Pnnm* or *Pnn*2, *a* 18.535(3), *b* 12.273(1), *c* 6.043(1) Å, *V* 1374.7(2) Å^3, *Z* = 16. Chestermanite occurs in association with magnesian calcite, ludwigite, fluoborite, wightmanite, two undescribed borate minerals, spinel, brucite, safflorite, and löllingite in a small brucite marble body in the Twin Lakes region, northern Fresno County, California, U.S.A. Microprobe analysis gave Al_2O_3 5.3, Fe_2O_3 16.0, Sb_2O_5 10.3, TiO_2 0.8, MgO 48.0, MnO 0.1, CaO 0.1, B_2O_3 (calc. for B = 1) 18.22, F 0.1, less O≡F 0.04, sum 98.88 wt. %, corresponding to $Mg_2(Fe^{3+}_{0.38}Mg_{0.28}Al_{0.20}Sb^{5+}_{0.12}Ti_{0.02})_{\Sigma1.00}BO_3(O_{1.99}F_{0.01})_{\Sigma2.00}$. Typically fibrous; rare prismatic crystals extend to 2 mm on [001] and are flattened on {010}; predominant forms are {110}, {210}, and {010}. Chestermanite is greyish green (to black in coarse crystals) with a vitreous to silky luster; *H* = 6, D_{meas} 3.72(2), D_{calc} 3.650 g/cm^3; uneven to conchoidal fracture; nonfluorescent, and nonmagnetic. Chestermanite is biaxial positive, n_a 1.753–1.759, n_b 1.763–1.767, n_c 1.791–1.797 (all ±0.002), $2V_z$ 63° (calc.). The strongest reflections in the X-ray powder-diffraction pattern [*d* in Å(*I*)(*hkl*)] are: 5.114(100)(220), 2.559(91)(440), 2.169(57)(820), 2.746(34)(530), 1.9975(32)(260), 2.475(19)(412), 1.5300(19)(10•22), 1.7071(17)(660). The new species is named to honor its discoverer, Mr. Charles W. Chesterman, retired geologist of the California Division of Mines and Geology.

Keywords: chestermanite, new mineral species, magnesium iron aluminum antimony borate, pinakiolite group, California.

SOMMAIRE

La chestermanite, de formule idéale $Mg_2(Fe^{3+},Mg,Al,Sb^{5+})BO_3O_2$, est une espèce nouvelle orthorhombique, groupe spatial *Pnnm* ou *Pnn*2, *a* 18.535(3), *b* 12.273(1), *c* 6.043(1) Å, *V* 1374.7(2) Å^3, *Z* = 16. Elle est associée à calcite magnésienne, ludwigite, fluoborite, wightmanite, deux autres espèces boratées nouvelles, spinelle, brucite, safflorite, et löllingite, dans une petite enclave de marbre brucitique dans la région de Twin Lakes, du secteur nord du comté de Fresno, en Californie (E.-U.). Les analyses à la microsonde donnent: Al_2O_3 5.3, Fe_2O_3 16.0, Sb_2O_5 10.3, TiO_2 0.8, MgO 48.0, MnO 0.1, CaO 0.1, B_2O_3 (obtenu en supposant B = 1) 18.22, F 0.1, moins O≡F 0.04, total 98.88%, en poids, ce qui correspond à $Mg_2(Fe^{3+}_{0.38}Mg_{0.28}Al_{0.20}Sb^{5+}_{0.12}Ti_{0.02})_{\Sigma1.00}BO_3(O_{1.99}F_{0.01})_{\Sigma2.00}$. Elle est fibreuse, en général. De rares cristaux prismatiques atteignent 2 mm sur [001] et sont aplatis sur {010}; les formes importantes sont {110}, {210}, et {010}. La chestermanite est vert grisâtre à noir (dans les cristaux plus grossiers), et possède un éclat vitreux à soyeux; *H* = 6, D_{mes} 3.72(2), D_{calc} 3.650; fracture inégale à conchoïdale; non-fluorescente et non-magnétique. Elle est biaxe positive, n_a 1.753–1.759, n_b 1.763–1.767, n_c 1.791–1.797 (±0.002), $2V_z$ 63° (calc.). Les huit raies les plus intenses du cliché de poudre obtenu par diffraction X [*d* en Å(*I*)(*hkl*)] sont: 5.114(100)(220), 2.559(91)(440), 2.169(57)(820), 2.746(34)(530), 1.9975(32)(260), 2.475(19)(412), 1.5300(19)(10•22), 1.7071(17)(660). Le nom honore M. Charles W. Chesterman, geologue de la division des mines et de géologie de l'état de la Californie (à la retraite) qui l'a découverte.

(Traduit par la Rédaction)

Mots-clés: chestermanite, nouvelle espèce minérale, borate de magnésium, fer, aluminium et antimoine, groupe de la pinakiolite, Californie.

INTRODUCTION

The new mineral species described herein was discovered by Mr. Charles W. Chesterman in 1980 in the course of his long-term (1938 to present) study of the geology of the Twin Lakes region, northern Fresno County, California. He furnished us with the original material and, after preliminary investigation, we recognized it to be a new species. We have named the mineral in honor of Mr. Chesterman, retired geologist of the California Division of Mines and Geology, who has had a distinguished career over many years as both a geologist and a mineralogist. The mineral name and description have been approved by the Commission on New Minerals and Mineral Names, I.M.A. After completion of studies of associated minerals, the holotype specimen (80-PP-2) and cotypic material will be preserved at the U.S. National Museum, Washington, D.C. (NMNH 165968).

OCCURRENCE

Chestermanite occurs in a contact-polymetamorphosed septum that lies between the Mt. Givens and Kaiser Peak plutons of the central Sierra Nevada. Details of the geology were given by Chesterman (1942, 1959), Hamilton (1956), Bateman *et al.* (1971), and Kerrich *et al.* (1973). The exact location of the type (and, so far, only) occurrence is 37°17′35″ N, and 119°08′0.25″ W, in the SW ¼ NE ¼, sec. 28, T.7S., R26E., MDBM, of the Kaiser Peak 7½-minute topographic quadrangle of the U.S. Geological Survey.

The new mineral occurs in a small lens of brucite marble, approximately 370 m^2 in area, encased in a magnetite–forsterite skarn that is surrounded by schists and hornfels. The metamorphosed sediments are transected by dykes and sills of granodiorite. Chestermanite is found as veinlets 2 to 20 mm thick and as sparse disseminations in the marble along at least 34 m of the marble's southwestern contact with the magnetite–forsterite skarn. The most abundant chestermanite was found at the point of original discovery at the base of a thick layer of marble in a 6-cm thick band, colored light green by the mineral, 0.6 m from the marble–skarn contact. The chestermanite fibers are concentrated along, and distorted to follow, the boundaries of the recrystallized grains of calcite. The fibers are intimately associated with an earlier-formed magnesian–aluminian ludwigite and a zincian–ferrian dodecahedral spinel that will be described in a separate report. Other associated minerals are fluoborite, wightmanite, two apparently new borate minerals (under study), brucite, an iron analog of safflorite, löllingite, and magnesian calcite.

Chestermanite fibers have been observed transecting the earlier ludwigite, but most fibers flow around or envelop both ludwigite and löllingite. The ludwigite is somewhat ragged and appears to show effects of solution in some instances, but no signs of alteration are visible. Chestermanite commonly is found as inclusions in the associated spinel, oriented parallel to [011] of the spinel. Some chestermanite has numerous, uniformly distributed and sized (about 2 µm diameter), equant, anhedral inclusions of an unidentified mineral, but most chestermanite is relatively free of included matter. No signs of its alteration could be detected.

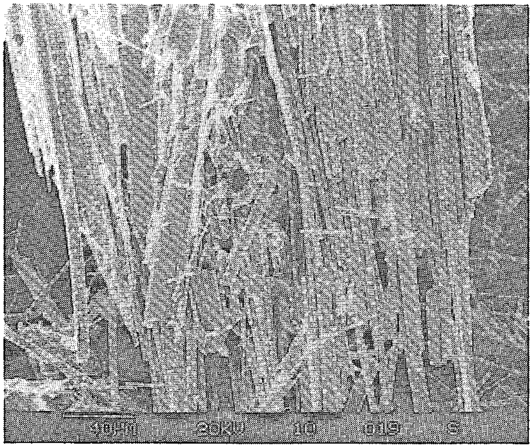

FIG. 1. SEM photograph of fibrous chestermanite.

MORPHOLOGY

Chestermanite typically is fibrous (Fig. 1) to asbestiform; the crystals attain 1.6 mm in length by 2 µm in diameter (length/width $\simeq 800$), and are commonly curved along {001}. There is a continuous gradation in size from the asbestiform crystals, through acicular, to coarse prismatic crystals as much as 2 × 0.33 × 0.06 mm in size (length/width = 6). The coarse crystals are scarce and difficult to distinguish from the associated magnesian–aluminian ludwigite. Crystals are elongate [001] and flattened on {010}. In cross-section they are approximately diamond-shaped, similar to, but more flattened than, the accompanying ludwigite, and are commonly slightly curved. Predominant forms, identified with a two-circle optical goniometer, are (in order of decreasing importance) {110}, {210}, and {010}. Forms {100}, {130}, {120}, {230}, {540}, and {320} have also been identified; no terminating forms were found. All crystals are finely striated parallel to [011].

X-RAY CRYSTALLOGRAPHY

Eight crystals of chestermanite were selected for precession studies; zero- and first-level photographs for the *a, b,* and *c* axes, and cone-axis photographs for *c,* were obtained using Zr-filtered Mo*K*α radiation. Chestermanite is orthorhombic, space group *Pnnm* (probable) or *Pnn*2 (possible), with unit-cell parameters *a* 18.535(3), *b* 12.273(1), *c* 6.043(1) Å, *V* 1374.7(2) Å^3, $Z = 16$. Chestermanite thus appears to be isostructural with orthopinakiolite (Takéuchi *et al.* 1978). However, relatively long (60 hr.) exposures are required to observe the true symmetry; *hkl* reflections with *l* odd are very weak and diffuse, indicating structural defects that are characteristic of some members of the pinakiolite group (Takéuchi *et al.* 1978, Bovin and coworkers 1980, 1981, 1981a, 1981b). In contrast, the subcell with *c*/2 of the ludwigite structure type (*Pbam* or *Pba*2) shows strong and sharp reflections. High-resolution transmission electron microscope (HRTEM) images of chestermanite (taken by Dr. Jan-Olov Bovin) show clearly the orthopinakiolite structure with a *c* repeat of 6.044 Å in the electron-diffraction pattern recorded along [010]. The HRTEM studies (electron-diffraction and crystal-structure images) by Bovin were performed on the finely fibrous crystals of chestermanite that were found in the early stages of our study, and no corresponding investigation has been made to date of the thicker acicular crystals that are now available. There is evidence (Cooper & Tilley 1985) that materials having the ludwigite structure can be directly transformed to the orthopinakiolite structure under the influence of the electron beam. However, Cooper & Tilley stated that the ludwigite fragments are stable under normal imaging conditions. Confirmation of the original orthopinakiolite structure is provided by our long-exposure X-ray-precession photographs.

The X-ray powder-diffraction data (Table 1) obtained with an X-ray diffractometer show strong preferred orientation for *hk*0 reflections. The strongest intensities for a Debye–Scherrer photograph of a randomly oriented (sphere mount) specimen (Table 1) contrast greatly with those seen in the diffractometer pattern. There are no reflections visible in either pattern, however, for *hkl* with *l* odd, even with long exposures (20 hours, using a fine-focus X-ray tube).

PHYSICAL AND OPTICAL PROPERTIES

The typical fibrous crystals of chestermanite (approximately 0.03 mm or less in diameter) are greyish green (Munsell Color No. 10 G 4/2), whereas the less common thicker crystals are black. The streak is a paler greyish green (5 G 5/2), and the luster is vitreous to silky. There is notable iridescence on the thicker black crystals, owing apparently to the finely striated surface acting as a diffraction grating. The surfaces of larger crystals of chestermanite, in fact, closely resemble the magnified surface of a phonograph record in color, luster, and iridescence.

The specific gravity of 3.72(2), determined on the thicker black crystals using heavy-liquid techniques, agrees well with the calculated density 3.650 g/cm³. Chestermanite has a Mohs hardness of 6 and is brittle. It has no observable cleavage or parting, but exhibits an uneven to conchoidal fracture. However, both chestermanite and the associated magnesian–aluminian ludwigite fracture much more easily across the crystal length than parallel to it. Relatively thin basal splinters, useful for optical study, can be produced easily from the ludwigite in this manner, but chestermanite is notably more resistant to fracture. The toughness relative to ludwigite is a diagnostic feature of chestermanite.

Chestermanite is nonmagnetic, nonfluorescent, and is either insoluble or only very slightly soluble in hot concentrated acids (HCl, HNO_3, or *aqua regia*). When heated to 1000°C, the mineral shows no change and only 0.5% loss in weight.

The optical properties of chestermanite were determined on X-ray-oriented single crystals using a Supper* spindle stage as well as on crushed grains

TABLE 1. POWDER DATA FOR CHESTERMANITE

hkℓ	d(calc)[1]	d(obs)[2]	I(rel)[3]	
110	10.233	10.23	8	
200	9.267	---	---	
210	7.396	7.375	3	
020	6.137	6.133	12	
120	5.826	5.828	14	
310	5.519	5.528	4	
220	5.117	5.114	100	(100)
400	4.634	---	---	
320	4.354	---	---	
410	4.335	---	---	
130	3.995	3.994	5	
230	3.743	3.737	9	
420	3.698	---	---	
510	3.549	3.548	3	
330	3.411	3.411	8	
040	3.068	3.067	15	
430	3.067			
002	3.022	3.022	4	
610	2.996	2.994	3	
240	2.913	2.908	6	
340	2.748	2.746	34	
530	2.747			
440	2.558	2.559	91	(75)
402	2.531	2.529	5	(80)
412	2.479	2.475	19	
150	2.433	2.433	13	
270	2.431			
540	2.364	2.365	3	
800	2.317	2.316	2	
350	2.281	2.282	4	
332	2.262	2.264	3	
450	2.169	2.169	57	(65)
820	2.168			
550	2.047	2.046	4	
060	2.046			
622	2.038	2.036	8	(70)
260	1.9974	1.9975	32	
442	1.9524	1.9510	3	
920	1.9524			
360	1.9418	1.9415	9	
632	1.9102	1.9100	3	
460	1.8713	1.8708	5	
252	1.8662	1.8659	5	
840	1.8489	1.8480	3	
750	1.8001	1.8003	3	
560	1.7909	1.7912	5	
732	1.7905			
720	1.7227	1.7229	9	
940	1.7100	1.7093	9	
660	1.7055	1.7071	17	
10·30	1.6883			
162	1.6868	1.6878	7	
370	1.6867			
262	1.6663	1.6654	3	
10·40	1.5865	1.5871	3	
950	1.5777	1.5771	6	(60)
842	1.5771			
562	1.5406	1.5405	2	
080	1.5341	1.5341	15	
10·22	1.5300	1.5300	19	(55)
280	1.5135	1.5132	5	
004	1.5108	1.5102	1	(55)
272	1.4966	1.4965	13	(55)
662	1.4852	1.4840	8	
214	1.4802	1.4802	11	

[1] All calculated hkℓ's are listed for $d_{hk\ell}$ ≥3.500 Å.

[2] Specimen 80-PP-2. X-ray diffractometer Chart No. X4637; CuKα_1 radiation (λ=1.540598 Å); Si internal standard; scanned at 1/8° 2θ per minute from 5 to 128° 2θ.

[3] Relative intensities in parentheses are strongest reflections measured in a microdensitometer trace of a Debye-Scherrer film (No. 1052); sphere mount of crushed single crystal from specimen 80-PP-2; CuKα radiation (λ=1.5419 Å); camera diameter=114.6 mm.

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*Use of trade names in this report is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

TABLE 2. CHEMICAL COMPOSITION OF CHESTERMANITE*

	Weight %	No. of Cations
Al_2O_3	5.3	0.20
Fe_2O_3	16.0	0.38
Sb_2O_5	10.3	0.12
TiO_2	0.8	0.02
MgO	48.0	2.28
MnO	0.1	---
CaO	0.1	---
B_2O_3**	18.22	1.00
F	0.1	0.01
Total	98.92	
O≡F	0.04	
Σ	98.88	

* Electron-microprobe data; average of eight analyses; E. E. Foord, analyst.

** Calculated for B=1.

in immersion media and in thin section. The mineral is biaxial positive, with indices of refraction for the holotype specimen: n_a 1.753, n_b 1.763, n_c 1.791 [all ±0.002; Na light; note that we follow Bloss (1985) in labeling the indices of refraction]. Most of the chestermanite examined has indices near these values, but there is some variability, with the range extending to n_a 1.759, n_b 1.767, and n_c 1.797. Even at the high end of the range, the indices of refraction are notably lower than those of any heretofore reported member of the pinakiolite–ludwigite group and are important diagnostic criteria.

Also diagnostic for chestermanite are the pleochroism and absorption scheme: *X* dark greenish blue, *Y* green, and *Z* pale yellowish brown; X (0.04) $>>$ Y (0.09) $>$ Z (0.11). The values in parentheses represent the approximate crystal thickness (in mm) at which the optical direction becomes sensibly opaque for white light. These values were determined on the X-ray-oriented crystals on the spindle stage. The opacity of *X* along the acute bisectrix (*Z*) precludes determination of the axial angle or of the dispersion. The $2V_z$ calculated for the holotype specimen is 63°.

The indices of refraction, low birefringence, and absorption scheme of chestermanite are closest to those of warwickite (and somewhat less close to those of azoproite) of the pinakiolite–ludwigite group, but chestermanite differs from these minerals in its optical orientation and pleochroism. The absorption scheme is the easiest means of distinguishing chestermanite from the closely associated magnesian–aluminian ludwigite, which has X (0.04) $>$ Z (0.06) $>>$ Y (0.17).

Calculation of the compatibility of the optical, chemical, and specific gravity data using the Gladstone–Dale relationship (Mandarino 1981) yields a K_P of 0.211 and a K_C of 0.218, and a compatibility index of +0.32. This value indicates excellent agreement between the physical and chemical data.

CHEMICAL COMPOSITION

Standard 3.8-cm-diameter bakelite polished sections were prepared of chestermanite-bearing marble (specimen 80–PP–2) and of acid-insoluble (HCl) residues. An ARL–SEMQ microprobe with six automated wavelength-dispersive spectrometers was used for the determination of the composition of chestermanite. Operating conditions were: 15 kV accelerating potential, 10 nA sample current on brass, 40-second count times on peak positions and 4-second count times on background positions for standards and samples. Lines used were Fe$K\alpha$, Ca$K\alpha$, Mn$K\alpha$, Ti$K\alpha$, Al$K\alpha$, Si$K\alpha$, Cl$K\alpha$, F$K\alpha$, Mg$K\alpha$, and Sb$L\alpha$. The following standards were used: natural titanite (Ca), synthetic NBS glass B65D (Fe,Mn,Si), synthetic Pb–Cu–Sb–S (Sb), synthetic TiO_2 (Ti), synthetic $MgAl_2O_4$ (Al), synthetic KCl (Cl), synthetic MgF_2 (F), and synthetic MgO (Mg). Data were reduced using a modified version of the MAGIC IV program of Colby (1968).

Analysis of acid-treated chestermanite in specimen 80–PP–2 gave results indistinguishable from those obtained on untreated material. Results of eight analyses were averaged to give the data shown in Table 2. Total Fe is expressed as Fe_2O_3 on the basis of the Mössbauer spectrum, which shows only ferric iron to be present in chestermanite (R.G. Burns, pers. comm. 1986). This is in agreement with the Mössbauer spectrum for orthopinakiolite, which shows that Fe is mostly in the ferric state (Takéuchi *et al.* 1978). Boron could not be directly determined because of the difficulty in obtaining sufficiently pure material. A semiquantitative six-step spectrographic analysis (Nancy M. Conklin, U.S.G.S., analyst) shows the boron concentration to be >10 wt.%.

The analysis, with the number of cations calculated on the basis of one boron atom, yields the formula:

$Mg_2(Fe^{3+}_{0.38}Mg_{0.28}Al_{0.20}Sb^{5+}_{0.12}Ti_{0.02})_{\Sigma 1.00}BO_3(O_{1.99}F_{0.01})_{\Sigma 2.00}$ or, ideally, $Mg_2(Fe^{3+},Mg,Al,Sb^{5+})BO_3O_2$.

DISCUSSION

Chestermanite shows both strong similarities with, and distinct differences from, the other members of the ludwigite–pinakiolite group of minerals (hereafter abbreviated as "L–P"; see summary by Dunn *et al.* 1983) in its chemical, crystallographic, and optical properties. A brief discussion of these properties seems worthwhile at this point, although final resolution of some questions must await determination of the crystal structure of the mineral.

Chemically, chestermanite is distinguished by having the highest content of Mg of any of the L–P group; only azoproite (Konev 1978) approaches chestermanite in this respect. Chestermanite has nearly the same content of Sb as an unnamed member of the L–P group from Nordmark, Sweden (Dunn *et al.* 1983), but is easily distinguished from this mineral by its X-ray powder-diffraction pattern. The chemical composition of this unnamed mineral suggests that it may be identical to a second unnamed member of the L–P group recently described by Bovin *et al.* (1986) from Mossgruvan, Nordmark, Sweden. The Mossgruvan mineral is described as orthorhombic (space group *Pnnm* or *Pnn*2), *a* 37.40 (roughly 2*a* of chestermanite), *b* 12.54, and *c* 6.23 Å.

Crystallographically, chestermanite is isostructural with orthopinakiolite, which it resembles in having a subcell closely related to ludwigite and in having ferric rather than ferrous iron (Takéuchi *et al.* 1978). Optically, chestermanite is distinguished by having the lowest indices of refraction of any member of the L–P group. Only warwickite has indices of refraction that approach those of the new mineral and has a further similarity in its absorption scheme; however, the pleochroic colors are distinctly different. The pleochroic colors of blue and greenish blue reported for the *X* and *Y* directions of aluminum-rich ludwigite (Pertsev & Aleksandrov 1964) are the closest match to those of chestermanite of any member of the L–P group. However, other specimens of aluminum-rich ludwigite do not show these tints of blue in their pleochroism (Schaller & Vlisidis 1961). Furthermore, Pertsev & Aleksandrov gave the optical orientation $a = Y$ and $b = X$, which differs from that reported for other specimens of ludwigite (Leonard *et al.* 1962). Chestermanite is also the most transparent member of the group, and the asbestiform or fibrous crystals show only moderate pleochroism and absorption.

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