Wendwilsonite, the Mg analogue of roselite, from Morocco, New Jersey, and Mexico, and new data on roselite

Pete J. Dunn

Department of Mineral Sciences, Smithsonian Institution, Washington, D.C. 20560, U.S.A.

B. Darko Sturman

Department of Mineralogy and Geology, Royal Ontario Museum, Toronto, Ontario M5S 2C6, Canada

Joseph A. Nelen

Department of Mineral Sciences, Smithsonian Institution, Washington, D.C. 20560, U.S.A.

Abstract

Wendwilsonite, ideally $Ca_2Mg(AsO_4)_2 \cdot 2H_2O$, is monoclinic, $P2_1/c$, with $a = 5.806(1)$, $b = 12.912(2)$, $c = 5.623(1)$ Å, $\beta = 107°24(1)'$, $V = 402.2(1)$ Å^3, and $Z = 2$. It is red to pink, with a perfect {010} cleavage, $D_{meas} = 3.52$, $D_{calc} = 3.57$ g/cm^3. The strongest lines in the powder-diffraction pattern are $(d, I/I_0, hkl)$ 2.994(100)121; 2.766(80)$\bar{2}$11,041; 3.226(60)040; and 3.356(40)031. Optically, it is biaxial, positive, with $2V_Z = 87(2)°$, $\alpha = 1.694(3)$, $\beta = 1.703(3)$, and $\gamma = 1.713(3)$. It occurs at the Sterling Hill mine, Ogdensburg, New Jersey; Bou-Azzer, Morocco; and Coahuila, Mexico. Wendwilsonite is the Mg analogue of roselite [$Ca_2(Co,Mg)(AsO_4)_2 \cdot 2H_2O$]. New chemical analyses show that roselite exists with as much as 89 mol% of the Co endmember, and there is solid solution to type wendwilsonite with 82 mol% of the Mg endmember.

Introduction

In early 1985, one of the authors (P.J.D.) examined a pink mineral from Sterling Hill in New Jersey. The X-ray powder pattern of this mineral was nearly identical to that of roselite, $Ca_2(Co,Mg)(AsO_4)_2 \cdot 2H_2O$. Because Mn-Mg solid solution is common at Sterling Hill and cobalt minerals are rare there, these crystals were analyzed. They were found to be Mg-dominant. Because the Sterling Hill material is exceedingly sparse and because the "roselite" from the mines near Bou-Azzer, Morocco, is known to occur with magnesium arsenates and had never been analyzed, we also studied samples from Morocco. Samples from the type locality for roselite (Schneeberg, East Germany) and Coahuila, Mexico, were also studied in search of a sample with Mg ≫ Co, which would serve as a suitable type sample. The results of this analytical investigation indicated that material from Schneeberg is true roselite, with Co > Mg in all known analyses, although all previous analyses had have Mg : Co near 1:1, including the crystal used in the structural study of Hawthorne and Ferguson (1977). However, samples from both Mexico and New Jersey, and many from Morocco, are Mg-dominant, and thus represent a new endmember, $Ca_2Mg(AsO_4)_2 \cdot 2H_2O$.

We have named this new mineral *wendwilsonite* in honor of Dr. Wendell E. Wilson, editor and publisher of the *Mineralogical Record,* in recognition of his contributions to mineralogy. The species and the name were approved by the Commission on New Minerals and Mineral Names, IMA. Type material is preserved at the Smithsonian Institution under catalogue no. NMNH 136288 and at the Royal Ontario Museum under catalogue no. M42119.

Physical and optical properties

Wendwilsonite is pink, varying from pale to intense pink, or red in color; the streak is pale pink. It has vitreous luster on cleavage and fracture surfaces, as well as on crystal faces, and occurs in transparent crystals. The hardness is approximately 3–4 (Mohs'). Cleavage is perfect on {010}, the fracture is uneven, and no parting was observed, although there are lamellar structures within the crystals, as discussed below. The density, measured using a Berman balance and employing a temperature correction, is 3.52(8) g/cm^3, compared with the calculated value of 3.57 g/cm^3. There is no discernible fluorescence in ultraviolet radiation.

The optical properties for wendwilsonite given in Table 1 were determined with the spindle stage on grains previously oriented with X-ray diffraction or optical goniometric methods. Zoning was observed on all grains, as evidenced by a ±0.003 variation in the indices of refraction. The major part of the wendwilsonite crystals has monoclinic optical properties as given in Table 1. However, on crystals from all three localities we have observed very thin lamellae, discussed in the section on crystallography, which have triclinic optical properties with none of the principal vibration directions parallel to the b axis. These lamellae are far too thin to allow ac-

Table 1. Crystallographic and optical data for wendwilsonite

Formula:	$Ca_{2.03}(Mg_{0.82}Co_{0.15})_{\Sigma0.97}(AsO_4)_{2.09}\cdot1.77H_2O$				
Unit cell:	$a = 5.806(1)$ Å $\beta = 107°24(1)'$				
	$b = 12.912(2)$				
	$c = 5.623(2)$				
	Space group: $P2_1/c$				

Forms:		measured		calculated	
		phi	rho	phi	rho
	010	0°	90°	0°00'	90°00'
	110	66°	90°	66°46'	90°00'
	011	36°	28°	35°44'	28°13'
	$\bar{1}$11	−58°	39°	−58°10'	39°33'

Optical data:	$\alpha = 1.694(3)$	$Y \parallel b$
	$\beta = 1.703(3)$	$c \wedge Z = 92°$ in obtuse β
	$\gamma = 1.713(3)$	X = violet pink
	$2V_z = 87(2)°$	Y = rose pink
	$r < v$	Z = colorless
		$X \geq Y > Z$

curate determination of the orientation of the indicatrix or other optical properties.

The crystals of wendwilsonite examined all had a similar orientation of the indicatrix, with $b = Y$ and $c \wedge Z$ approximately 90°. Although the angle $c \wedge Z$ is not discernibly affected by variations in the Co/Mg ratio, indices of refraction increase with increasing Co content.

However, specimens very rich in Co, i.e., close to the roselite endmember, have a completely different orientation of the indicatrix. This was described by Peacock (1936), who noted that dark-colored crystals of roselite have the principal vibration direction X parallel to the b axis. Our observations are in general agreement with those of Peacock but differ enough in detail to be reported here. Crystals of roselite from sample B13950 are biaxial, negative, $2V_x = 85(2)°$, with $\alpha = 1.725(3)$, $\beta = 1.730(3)$, and $\gamma = 1.734(3)$; $X = b$, $Z \wedge c = 62°$ in the obtuse angle beta, and are red in color, with no observable difference in absorption for X, Y, or Z.

CHEMICAL COMPOSITION

Wendwilsonite was chemically analyzed using an ARL-SEMQ electron microprobe, utilizing an operating voltage of 15 kV and a sample current of 0.025 μA, measured on brass. A wavelength-dispersive microprobe scan indicated the absence of any elements with atomic number greater than 9, except those reported here. The data were corrected using a modified version of the MAGIC-4 program. The standards used for analysis were cobalt metal (Co), synthetic olivenite (As), manganite (Mn), synthetic ZnO (Zn), and hornblende (Ca, Mg). Water was determined for the holotype using the Penfield method. The analyses are presented in Table 2; that for the holotype is labeled no. 136288. The type material is slightly inhomogeneous, with a variation of $\pm1\%$ MgO; however, this does not affect the species designation because all parts of the crystal have Mg $\gg$ Co. Because lamellae were noted in the optical study of the type material, we also performed small-scale step-scans across these lamellae and determined that they are not compositionally different from the host crystal.

Calculation of a chemical formula for type wendwilsonite, based on 10 oxygen atoms in conformity with the structural formula of roselite (Hawthorne and Ferguson, 1977), yields $Ca_{2.03}(Mg_{0.82}Co_{0.15})_{\Sigma0.97}(AsO_4)_{2.09}\cdot1.77H_2O$, or ideally $Ca_2Mg(AsO_4)_2\cdot2H_2O$.

Examination of the analytical data presented in Table 2 indicates that there is extensive solid solution between roselite (up to 89 mol% of the Co endmember) and wendwilsonite (up to 82 mol% of the Mg endmember). All previous analyses of roselite in the literature were of Schneeberg material and had Co > Mg ratios near 1:1 but, as pointed out by Hawthorne and Ferguson (1977), the (Co,Mg) site occupies a single equipoint. Although all our analyses show Ca in excess of the amount required, we interpret this as analytical error, rather than substi-

Table 2. Chemical analytical data for wendwilsonite-roselite

Sample	Weight percent								Cations per formula unit†						Species	Locality
	ZnO	MnO	MgO	CaO	CoO	As_2O_5	H_2O	Total	Zn	Mn	Mg	Ca	Co	As		
136288	0.0	0.0	7.7	26.4	2.6	55.8	7.4*	99.9	0.00	0.00	0.82	2.03	0.15	2.09	Wendwilsonite	Morocco
C6675	0.0	0.0	6.8	27.2	4.3	53.7	8.0**	100.0	0.00	0.00	0.71	2.05	0.24	1.97	Wendwilsonite	Morocco
136287	0.0	0.0	5.8	26.6	6.7	54.1	6.8**	100.0	0.00	0.00	0.61	2.01	0.38	2.00	Wendwilsonite	Morocco
154170	0.0	0.0	5.7	26.6	6.1	54.8	6.8**	100.0	0.00	0.00	0.61	2.04	0.35	2.05	Wendwilsonite	Mexico
112885	0.0	0.0	5.7	27.4	6.7	54.1	6.1**	100.0	0.00	0.00	0.59	2.04	0.37	1.96	Wendwilsonite	Morocco
E.G.	1.1	0.2	5.6	26.6	5.4	51.5	9.4**	100.0	0.06	0.01	0.59	2.03	0.31	1.92	Wendwilsonite	New Jersey
140815	0.0	0.0	4.0	25.5	8.9	53.8	7.8**	100.0	0.00	0.00	0.44	2.03	0.53	2.09	Roselite	Morocco
155678	0.0	0.0	3.2	26.7	9.9	52.6	7.6**	100.0	0.00	0.00	0.35	2.08	0.57	2.00	Roselite	Morocco
140816	0.0	0.0	3.0	26.7	11.1	54.5	4.7**	100.0	0.00	0.00	0.32	2.04	0.64	2.04	Roselite	Germany
B10607	0.0	0.0	2.7	26.5	10.8	53.2	6.8**	100.0	0.00	0.00	0.30	2.07	0.63	2.03	Roselite	Morocco
B13978	0.0	0.0	1.7	26.1	12.9	51.0	8.3**	100.0	0.00	0.00	0.19	2.05	0.76	1.96	Roselite	Germany
B13951	0.0	0.0	1.5	25.8	13.3	50.5	8.9**	100.0	0.00	0.00	0.16	2.05	0.79	1.95	Roselite	Germany
C4240-2	0.0	0.0	0.4	26.3	15.1	51.3	6.9**	100.0	0.00	0.00	0.04	2.07	0.89	1.97	Roselite	Germany
B13950	0.0	0.9	0.3	25.5	14.6	53.1	5.6**	100.0	0.00	0.06	0.03	2.04	0.87	2.07	Roselite	Germany
Theory				24.8	16.5	50.7	8.0	100.0				2.00	1.00	2.00	Roselite	

Note: Accuracy of data: 4% of the amount present for major elements.
* Water determined by the Penfield method.
** Water calculated by difference.
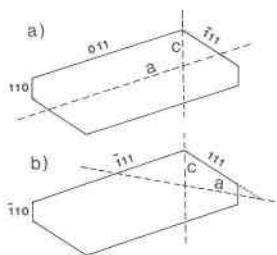† Atoms calculated on the basis of ΣR^{2+} cations = 2.

Fig. 1. A section parallel to (010) of a wendwilsonite crystal, showing the orientation of the unit cell of (a) Hawthorne and Ferguson (1977), and (b) Peacock (1936).

Table 3. X-ray powder-diffraction data for wendwilsonite

I/I_0	d_{obs}	d_{calc}	hkl
15	6.42	6.456	020
50	5.085	5.091	110
25	4.941	4.955	011
20	4.330	4.336	$\bar{1}11$
5	4.183	4.204	120
20	3.743	3.748	$\bar{1}21$
30	3.397	3.399	130
40	3.356	3.357	031
15	3.262	3.271	111
60	3.226	3.228	040
25	3.140	3.144	$\bar{1}31$
100	2.994	2.996	121
5	2.783	2.789	140
80	2.766	2.765	$\bar{2}11$
		2.766	041
10	2.701	2.699	$\bar{1}12$
10	2.681	2.683	002
15	2.626	2.627	012
40	2.592	2.592	$\bar{2}21$
5	2.545	2.545	220
1	2.478	2.477	022
1	2.339	2.341	150
10	2.328	2.329	230
1	2.266	2.266	$\bar{2}12$

I/I_0	d_{obs}	I/I_0	d_{obs}
15	2.252	20	1.816
5	2.173	5	1.801
1	2.128	1	1.777
30	2.101	1	1.764
1	2.087	1	1.751
5	2.060	25	1.726
1	2.006	5	1.721
2	1.940	10	1.714
2	1.909	15	1.698
1	1.888	5	1.691
5	1.875	1	1.678
2	1.860	1	1.654
5	1.853	1	1.634
1	1.847	5	1.614
10	1.828	5	1.603

Note: Data obtained using CuKα radiation; Guinier camera; intensities estimated visually; indexed with the unit cell given in Table 1.

tution of Ca for (Mg,Co). The data in Table 2 allow some statements concerning assignment of species name by locality. All Schneeberg crystals examined are true roselite. Many of the samples from Morocco that we studied are wendwilsonite. The occurrences at Coahuila, Mexico, and Sterling Hill, New Jersey, although represented by only one analysis each, are likewise wendwilsonite.

The fact that previously examined roselite samples had Mg : Co near 1:1 might suggest that these elements are ordered for some composition near 1:1 in the roselite-wendwilsonite series. This would reduce the symmetry, but lower symmetry was not observed by Hawthorne and Ferguson (1977), for such material.

CRYSTALLOGRAPHY

Several unit cells have been proposed for roselite-group minerals. Peacock (1936) reviewed the previous work based on morphological studies; he noted some evidence for the triclinic cell proposed in early studies but concluded that the majority of his observations were consistent with a monoclinic cell. Peacock's monoclinic cell (except for the halving of the *a* axis) was confirmed by Wolfe (1940) in a study of a twinned crystal using the Weissenberg method. Hawthorne and Ferguson (1977), in the course of a crystal structure determination, noted that Wolfe's cell is *B*-centered. The cell they use had **b** and **c** in conformity with those of Wolfe, but **a** was oriented differently, as shown in Figure 1, on which we have drawn traces of the most commonly developed forms. The axes of Peacock's morphological cell, are related to those of the structure cell of Hawthorne and Ferguson (1977) by the transformation (Peacock to Hawthorne and Ferguson): (101 / 020 / 002).

In our studies of minerals of the wendwilsonite-roselite series, we have found evidence for both monoclinic and triclinic symmetry. Eleven crystals from four localities with a wide range of Mg : Co (see Table 2) were studied by X-ray diffraction (the precession and Weissenberg methods) and by optical goniometrical and spindle-stage optical methods. Many oriented thin sections were prepared, and parts of them were studied separately. We have given the unit cell for wendwilsonite in the setting used by Hawthorne and Ferguson because the majority of our single-crystal studies and powder data are in agree-

ment with this cell. We have, however, observed a doubling of spots on many films obtained from morphologically single crystals. We have tried, unsuccessfully, to find a pattern in the doubling of spots, by comparing their geometrical positions and intensities, and relating this to multiple reflections observed on crystal faces using the optical goniometer.

Optical examination showed a very fine scale lamellar structure parallel to {011}, {111}, and {010}. The optical properties of these fine lamellae could not be determined because of overlapping during rotation, but it was possible to see that none of the principal vibration directions of the lamellae at the edge of the crystals is parallel to the **b** axis. A possible explanation is that the lamellae are of a triclinic phase included in the monoclinic roselites or
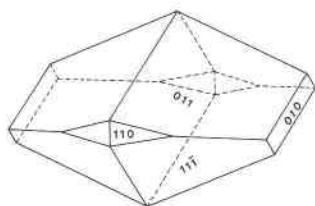
Fig. 2. Crystal drawing of wendwilsonite from Bou-Azzer, Morocco.

wendwilsonites. The facts that powder photographs of seven such crystals did not reveal any reflections other than those of roselite and wendwilsonite and that all lines in these seven patterns have exactly the same relative intensities argue against this hypothesis. However, in view of the low sensitivity of the powder method to trace components in mixtures, the presence of a separate triclinic phase cannot be ruled out. Such a phase, if it exists, may, in the case of wendwilsonite, be talmessite, a triclinic dimorph of that mineral, since no compositional differences between the lamellae and host were observed. Talmessite reflections were not observed in the powder patterns of wendwilsonite, however.

The refined unit-cell parameters of type wendwilsonite are given in Table 1. The extinctions observed by single-crystal study are consistent with the space group $P2_1/c$. The intensities and d values of the powder pattern of type wendwilsonite (Table 3) are consistent with such data for roselite (Hawthorne and Ferguson, 1977).

The crystal habit and forms developed on crystals from the type specimen of wendwilsonite are given in Table 1 and are shown on Figure 2. The measured values of phi and rho are rounded off to the nearest degree because all faces gave multiple or poor signals on the optical goniometer, with a variation of over 1° in values for a single face. Peacock (1936) observed this same phenomenon, which he explained as a "slight distortion due to an increasing misfit between successive zones that differ in optics and therefore in chemical composition and crystallographic form." However, we have calculated phi and rho for forms for both type wendwilsonite and the roselite used by Hawthorne and Ferguson (1977) and have found that they vary by only several minutes, even though their Mg/Co ratios are very different.

Crystals from the type wendwilsonite specimen (Fig. 2) are stout, prismatic, elongate on [100] with large {011} and {111} faces, and very narrow {110} and {010} faces. Crystals of wendwilsonite from other localities have similar crystal habit and forms. Crystals of roselite with high Co content (no. B13950, Table 2) have a slightly different habit because of larger (110) faces, but otherwise the same forms are developed. Twinning by reflection on {100} with {100} as the composition plane was observed on several crystals. The previously described lamellar growths parallel to {011}, {111}, and {010} may also represent twinning. A representative SEM photomicrograph of wendwilsonite is shown in Figure 3.
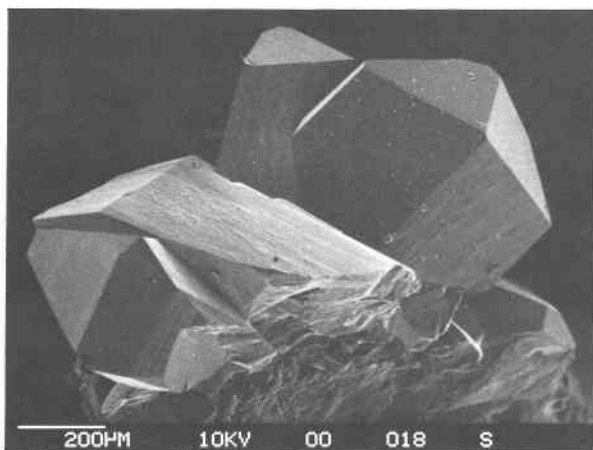

Fig. 3. SEM photomicrograph of wendwilsonite from Morocco.

Occurrence

Wendwilsonite has been found at three localities: Coahuila, Mexico, the Sterling Hill mine in Ogdensburg, Sussex County, New Jersey, and at a number of localities near Bou-Azzer, in Morocco.

Our samples from Morocco consist of pink glassy crystals, up to 6 mm in size, associated with talmessite and erythrite on altered ore and calcite gangue. One sample is labeled as coming from the Arhbar mine; the others are simply labeled with the name of the mining district, Bou-Azzer. A review of the geology and mineralogy of Bou-Azzer was published by Pallix (1978). The common paragenesis, where a sequence is visible, consists of erythrite, followed by wendwilsonite or roselite, followed by talmessite, and possibly a second generation of erythrite. Wendwilsonite is likely moderately common in modern systematic collections. During the course of this study, we also examined some samples labeled *erythrite* from Morocco, to ascertain if they were samples with Co > Mg; the studied samples are all Co-dominant and thus erythrite.

At Sterling Hill, wendwilsonite forms 0.5-mm crystals with calcite crystals on a serpentine, which encrusts manganoan calcite with very sparse franklinite and willemite. Only a few specimens are known, and the mineral is thus rare at this locality.

The one sample from Coahuila, Mexico, consists of dark pink crystals on calcite. We know nothing of its geologic occurrence.

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