Mcguinnessite,
a new carbonate from California

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INTRODUCTION

A bluish green mineral that was found with vuagnatite at Red Mountain, Mendocino County, California (Pabst *et al.,* 1977), has been determined to be a new species, which we name mcguinnessite in honor of Albert L. McGuinness of San Mateo, San Mateo County, California. Mr. McGuinness has a worldwide reputation as a capable mineralogist and scrupulous mineral dealer; he has most generously donated many rare specimens from his collections for scientific studies, and he has discovered several new mineral species. Specimens of mcguinnessite have been deposited at the U.S. National Museum, Washington, D.C. (NMNH #147169), and in the Mineralogical Collection of the University P. and M. Curie, Paris. The mineral has been commercially available under this name since 1977 (*Mineralogical Record,* **8,** 435).

The name and description have been approved by the Commission on New Minerals and Mineral Names, I.M.A.

OCCURRENCE

Mcguinnessite occurs sparsely at Red Mountain as spherules (Fig. 1 and 2) on joint and vein surfaces with goethite, malachite, azurite, chrysocolla, copper sulfides, chlorite and vuagnatite in rodingitized metagabbro dikes in a serpentinized peridotite of Mesozoic age. A detailed description of the locality and geology is given by Pabst *et al.* (1977). Most commonly, mcguinnessite is found on thin crusts of hydrous iron oxides on weathered joint surfaces. However, mcguinnessite may also be found either directly on fresh host rock surfaces or on vuagnatite crystals. In a few places a thin crust of malachite covers mcguinnessite as the last-formed mineral. Mcguinnessite has also been found coated with, and possibly replaced by, chrysocolla. Mcguinnessite spherules are incomplete, being either hemispherical or flattened out into films along the joint surfaces. The spherules range in size from 0.1 to 2 mm in diameter, the average diameter being 0.5 to 0.7 mm. They are composed of extremely small radiating fibrous crystals, individuals of which are less than 2μm long. The small crystal size made measurement of the optical properties difficult and single-crystal X-ray study impossible. The spherules are concentrically color banded (Fig. 2), corresponding to compositional variation in Mg and Cu which is described below. It was impractical to separate mcguinnessite according to its color and composition, and the data presented in this paper are either for material of average composition (especially the X-ray powder data) or give the range observed (optical data, etc.).

PHYSICAL AND OPTICAL PROPERTIES

Mcguinnessite is brittle and inelastic; fracture is even, parallel to the fiber length; and the mineral has a hardness of $2\frac{1}{2}$ (Mohs). The calculated density (in g/cm^{-3}) ranges from 3.076 for Mg-rich rims of spherules, to 3.234 for Cu-rich cores, and 3.117 for material with Mg/Cu = 1.17 along the fibers. The corresponding range in measured specific gravity is between 3.02(2) and 3.22(2); for most material (fibers), the specific gravity is 3.11(2). Mcguinnessite is nonfluorescent in ultraviolet light.

The color of the fibers which constitute the main mass of the spherules is light blue-green (Munsell number 5BG 6/6), but the Cu-rich cores are a slightly darker blue, and the Mg-rich rims are very pale blue-green to nearly white (Fig. 2). Mcguinnessite is translucent; the luster varies from vitreous to silky.

Optically, mcguinnessite is biaxial negative with α = 1.602(2), β = 1.730(3), γ = 1.732(3) (Na); but the range (Mg- to Cu-rich) is from α = 1.596–1.607(2), $\beta \approx \gamma$ = 1.724–1.740(3). The optical orientation could not be determined completely; mcguinnessite has negative elongation with a maximum inclined extinction of X to c of 11° in the (010?) plane. The external morphology of crystal fragments does not permit us to know whether the extinction of X to c in the (100?) plane is parallel (indicating monoclinic symmetry) or very slightly inclined (triclinic). The mineral is weakly pleochroic with Z, Y (light bluish green) › X (very pale green).

X-RAY CRYSTALLOGRAPHY

The unit cell data for mcguinnessite (Table 1) show that it is closely related to the rosasite series of minerals. In common with other members of this series, mcguinnessite is too fine grained to permit single crystal X-ray study. The unit cell data were obtained by least-squares refinement of the X-ray diffraction data (Table 2) indexed on the basis of a monoclinic rosasite-like cell (*see* Jambor, 1976a, b). As Jambor has pointed out (1976a, p. 574), ". . . the principal unknown in these minerals is the value of c sinβ." Mcguinnessite shows strong preferred orientation for $hk0$ reflec-

tions, and only a few reflections having a *c* component appear in the diffractometer pattern. Nonetheless, the agreement of observed *hkl* reflections with those calculated for the monoclinic cell seems reasonably good. If mcguinnessite is monoclinic, the X-ray data are compatible with the diffraction aspects $P*/*$ or $P*/a$. However, given the limitations of our optical and X-ray evidence, we cannot rule out the possibility that mcguinnessite is triclinic.

Although there are many similarities between the powder patterns of mcguinnessite and those of the other members of the rosasite series, there are also easily recognizable differences that set mcguinnessite apart. These are: the (010) reflection at ~12Å is unique to mcguinnessite; the (100) reflection at ~9.4Å is present both in mcguinnessite and glaukosphaerite (previously unreported), but absent in rosasite; and most distinctive are the absences of the (200) reflection at ~4.7Å and the ($\bar{2}$01, 320) reflection at ~2.77Å in the mcguinnessite pattern. The last two reflections are present in all of the other members of this series.

Because mcguinnessite has nearly equal amounts of Mg and Cu, the suggestion of Professor J. Zemann, University of Vienna, Vienna, Austria, that these two atoms might be ordered in a malachite-*like* structure was tested. Using coordinates from Süsse (1967), we calculated powder intensities for three different models. The calculated intensities for an ordered model with Mg at the Cu(2) site of the malachite structure agree best with the observed intensities (Table 2).

CHEMISTRY

Fragments of mcguinnessite spherules from Red Mountain, Mendocino County, California, were analyzed with an ARL EMX-SM electron microprobe using an accelerating voltage of 15KV and a specimen current of 2.0×10^{-8} amperes on benitoite. The results of these analyses are shown in Table 3. Lines analyzed and the crystals used were: $CuK\alpha$ (LiF), $MgK\alpha$ (RAP), and $CaK\alpha$ (ADP). The standards used were chemically analyzed magnesite (contains 0.7 weight percent CaO) from Red Mountain, Stanislaus County, California (Bodenlos, 1950), and malachite from Bisbee, Cochise County, Arizona. Other elements sought for, but not found, were Fe, Mn, Ni, and Zn. Silica, ranging from 0 to 6 weight percent, is inhomogeneously distributed throughout the spherules and has not been included in the formulation of mcguinnessite.

The analyses listed in Table 3 represent 10-second counts for 6 to 15 sample points. Analyses 2 and 3 were tightly grouped to minimize errors due to inhomogeneities, whereas analysis 1 is the average of points along the radius of a 0.3-mm-diameter spherule whose rim was used for analysis 2. The core of this spherule was approximately 1 weight percent richer in Cu than the average. All data were reduced using a Fortran IV computer code "RABBIT" (Goff, 1977) which applies Bence-Albee corrections (Bence and Albee, 1968; Albee and Ray, 1970) to the raw analyses. The averaged values after correction for excess CO_2 and H_2O are shown in Table 3 compared with idealized compositions. The low summation of cations compared with the ideal may be due to the small quantity of silica present, to uncertainties in the Bence-Albee α-factors, or to the excess oxide routine of the "RABBIT" program.

Compositionally, mcguinnessite is defined as $(Mg,Cu)_2CO_3(OH)_2$ where Mg/Cu $\geq$ 1 (Table 3); compositions having Mg/Cu < 1 should be termed cuproan mcguinnessite. Although $Mg_2CO_3(OH)_2$ is known as a synthetic compound (*Chemical Abstracts* Registry

Figure 1. **Blue-green spherules of mcguinnessite with minor encrustations of fine green malachite crystals. The larger spherules are about 0.7 mm in diameter. (Photo by Nelly Bariand, Paris.)**

Figure 2. **Broken spherules of mcguinnessite, showing color zoning, on limonitic crust. Largest spherule visible, near the center of the photo, is 0.75 mm in diameter. (Photo by Norm Prime, U.S. Geological Survey.)**

Table 1. Unit-cell data for mcguinnessite and some related hydroxycarbonates (arranged in order of decreasing cell volume).

	Un-named[1]	Rosasite[2]	Mcguin-nessite[3]	Glauko-sphaerite[4]	Malachite[5]
a(Å)	9..338	9.344	9.398(2)	9.343(1)	9.502
b	12.076	12.069	12.011(2)	11.954(1)	11.974
c	3.396	3.392	3.379(2)	4.307(1)	3.240
β	90.78°	90.48°	93.28(5)°	91.70(12)°	98.75°
Vol. (Å³)	382.9	382.5	380.8(2)	380.4(2)	364.3
a/b	0.773	0.774	0.782	0.782	0.794
D(calc.; g/cm⁻³)	3.781	3.865	3.117	3.827	4.031
D(obs.; g/cm⁻³)	——	3.88(2)	3.11(2)	3.96(2)	4.05(2)

[1]Cobaltoan malachite (Specimen M6; 18.46 weight percent Co) from Zaire (Deliens *et al.*, 1973), but with rosasite-like unit cell (Jambor, 1976b). D(calc.) assuming Co/Cu = 0.52.

[2]Rosasite (Jambor, 1976b) from Durango, Mexico (Zn/Cu = 0.68. D(obs.) by Y. Shimazaki (*in* Jambor, 1976b) for rosasite with Zn/Cu = 0.49 from Durango.

[3]Mcguinnessite (this study) from Red Mountain, Mendocino County, California (Mg/Cu = 1.17). D(obs.) by suspension in methylene iodide-acetone mixture checked with a Westphal balance.

[4]Glaukosphaerite (this study) from Carr Boyd Rocks mine, Glory Hole No. 2, Carr Boyd Rocks, Western Australia (Ni/Cu = 0.25; analysis and D(obs.) by Pryce and Just, 1974).

[5]Data by Swanson *et al.* (1960) for synthetic malachite. D(obs.) by M. E. Mrose (1947, *in* Palache *et al.*, 1951).

Table 3. Electron-microprobe analyses of mcguinnessite.

Analysis 1*	*Expressed as oxide*	*Idealized composition*	
Mg 14.3	MgO 23.7	24.35	$(Mg_{0.54}Cu_{0.46})_2CO_3(OH)_2$
Cu 31.6	CuO 39.6	40.95	
Ca 0.05	CaO 0.07	——	(Average composition along fiber)
	CO₂ 24.73**	24.62	
	H₂ 10.13**	10.08	
	98.23	100.00	

Analysis 2*			
Mg 15.2	MgO 25.2	26.05	$(Mg_{0.57}Cu_{0.43})_2CO_3(OH)_2$
Cu 30.2	CuO 37.8	38.78	
Ca 0.04	CaO 0.06	——	(Mg-rich rim of spherule)
	CO₂ ——	24.95	
	H₂ ——	10.22	
		100.00	

Analysis 3*			
Mg 11.7	MgO 19.4	19.78	$(Mg_{0.46}Cu_{0.54})_2CO_3(OH)_2$
Cu 36.5	CuO 45.7	46.76	
Ca 0.06	CaO 0.08	——	(Cu-rich core of spherule)
	CO₂ ——	23.74	
	H₂ ——	9.72	
		100.00	

*Analyst: Fraser E. Goff. Data in weight percent.

**From 34.86 weight percent loss during TGA; Fabien P. Cesbron, analyst.

Table 2. X-ray powder diffraction data for mcguinnessite.

hkl	d(calc.)* (Å)	d(obs.)** (Å)	I
10#	12.001	11.98	6
100#	9.383	9.39	4
110	7.394	7.40	11
020	6.005	6.015	100
120	5.058	5.054	16
200	4.691	——	——
210	4.370	——	——
030#	4.004	——	——
220	3.697	3.694	67
310	3.027	3.024	10
040	3.003	3.002	12
021	2.941	2.942	9
140	2.860	2.857	9
320	2.774	——	——
211	2.604	2.605	12†
240	2.529	2.530	25
1̄31	2.516	2.493	9
330	2.464	2.465	9
150	2.327	2.326	15
410	2.302	2.300	6
231	2.220	2.212	4
420	2.185	2.185	9
250	2.138	2.139	23
060	2.002	1.999	7
160	1.958 ⎫	1.956	4
051	1.957 ⎭		
350	1.905	1.906	8
500#	1.876 ⎫	1.876	4
401	1.876 ⎭		
520	1.791 ⎫	1.791	3
421	1.791 ⎭		
170	1.688 ⎫	1.688	7
002	1.687 ⎭		
360	1.686		
4̄41	1.653	1.653	4
370	1.504 ⎫	1.504	5
171	1.503 ⎭		
180	1.482	1.482	5
550	1.479 ⎫	1.477	5
451	1.479 ⎭		
280	1.430	1.430	4
6̄21	1.410 ⎫	1.411	4
322	1.410 ⎭		

*All calculated *hkl*'s listed for d_{hkl} » 3.500Å. Indices and d(calc.) from least-squares refinement of X-ray powder data using the digital computer program of Appleman and Evans (1973).

**Data for material from Red Mountain, Mendocino County, California. X-ray diffractometer conditions are: Chart No. X3911; Cu/Ni radiation, λCuK α_1 = 1.540598Å; Si used as internal standard; scanned at ¼° per minute from 5-72° 2$\ominus$.

#Not permitted with the malachite space group ($P2_1/a$).

†Intensity equals approximately 80 on the powder photographs.

No. [23303-17-5]; we could find no crystallographic or optical data for this compound), material of this composition has not yet been reported as a mineral. Artinite, which is the trihydrate of this composition, probably forms instead of mcguinnessite in most geochemical environments. The combinations of major cations in the rosasite-like minerals now known are Cu + Zn (rosasite), Cu + Co (kolwézite), Cu + Ni (glaukosphaerite), and Mg + Cu (mcguinnessite). Combinations of Cu with major Fe, Mn, or Pb appear to be possible, but are yet to be discovered. The only naturally occurring end-members known so far are malachite (Cu) and nullaginite (Ni) (Nickel *et al.*, 1979).

Mcguinnessite is slowly but completely soluble with effervescence in cold dilute mineral acids.

THERMAL BEHAVIOR

The thermal behavior of mcguinnessite is shown in Figure 3 by the thermogravimetric (TGA) and differential thermogravimetric (DTG) curves. The only feature shown by these curves is that accompanying a rapid loss of CO_2 and H_2O peaking at 457°C on the DTG curve. Losses of 34.86 and 34.95 weight percent were recorded for duplicate runs of 5.482 and 5.436 mg samples respectively. The residual mass consists of periclase, tenorite, and poorly crystallized Cu_2MgO_3.

The differential thermo-analysis (DTA) curve for mcguinnessite is shown in Figure 4 compared with the DTA curves of malachite (Ural Mts., U.S.S.R.) and rosasite (Mapimi, Durango, Mexico), all obtained using a heating rate of 300° per hour. The DTA curve of mcguinnessite first shows a small, broad, endothermic trough near 100°C accompanying the initial loss of some of the H_2O. This is followed by a large endothermic peak at 498°C (loss of CO_2 and balance of H_2O); a very small exothermic peak at 810°C; and, finally, two endothermic peaks: a very small one at 1053°C and a large one at 1080°C. Cuprite, periclase, and well crystallized Cu_2MgO_3 appear after the second endothermic peak at 1080°C.

Heated in a closed tube, mcguinnessite gives off H_2O and CO_2 and turns dark reddish brown.
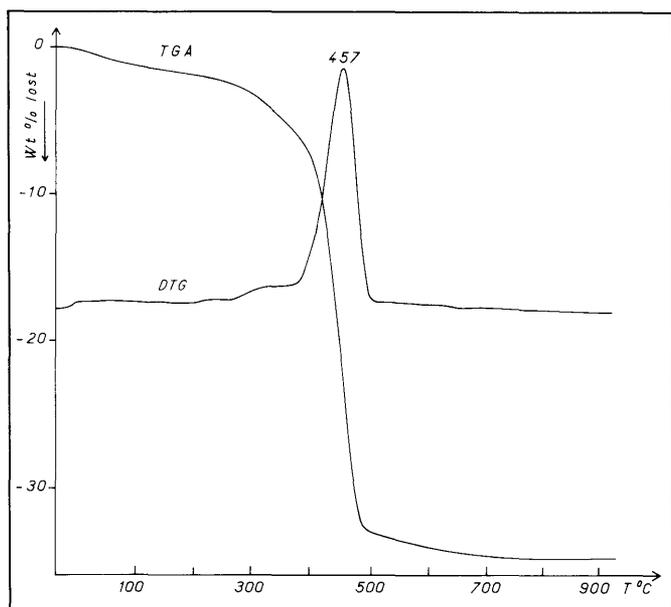
Figure 3. Thermogravimetric (TGA) and differential thermogravimetric (DTG) curves for mcguinnessite.

OTHER OCCURRENCES

Mcguinnessite has been reported to occur at Gabbs, Nevada (Oswald and Crook, 1979); the mineral partially described by Smith (1978) as "magnesian rosasite" from southwestern Lancaster County, Pennsylvania, is probably mcguinnessite; and a third oc-
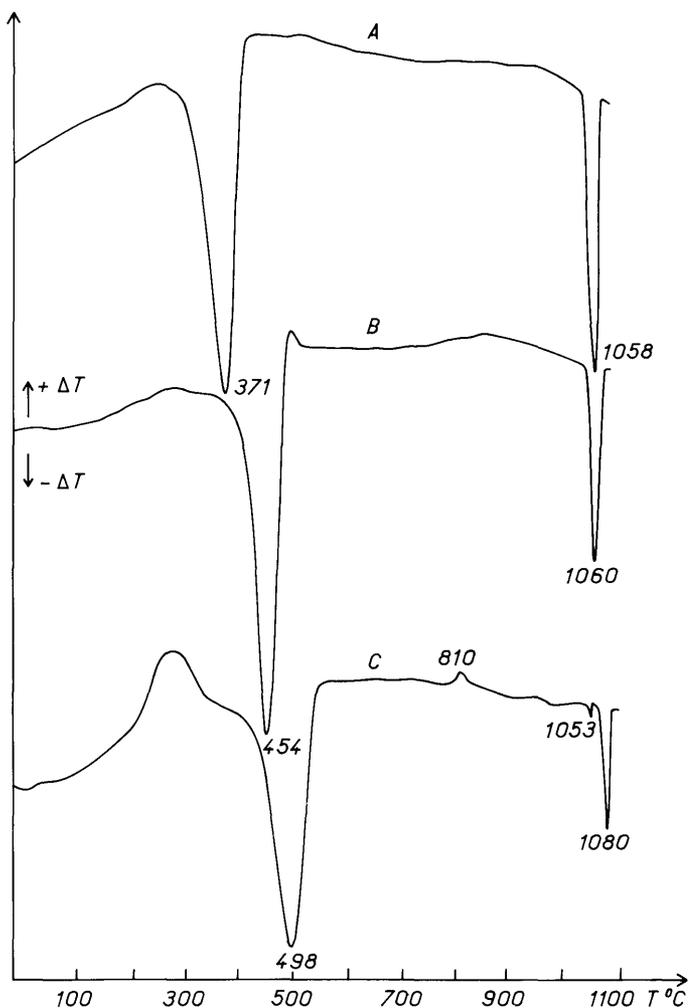
Figure 4. Differential thermo-analysis (DTA) curves for (A) malachite from the Ural Mts., U.S.S.R., (B) rosasite from Mapimi, Durango, Mexico, and (C) mcguinnessite from Red Mountain, Mendocino County, California.

currence in Austria has been brought to our attention by Walter Postl (written communication, 1978).

DIAGNOSTIC TESTS

Mcguinnessite closely resembles the other members of the rosasite series in many of its properties. The following tests should be useful in identifying the mineral to the mineral collector who commonly does not have X-ray facilities available to him. First, mcguinnessite is distinctly bluer than rosasite or glaukosphaerite; second, its indices of refraction are well below those of the other members; and third, only mcguinnessite will float in pure methylene iodide.

ACKNOWLEDGMENTS

Note added in proof:

The (Cu,Co) analog has now been named kolwézite and all members of the series proposed to be triclinic by Michel Deliens and Paul Piret ((1980) Bull. Soc. Franç. Min. Crist., **103**, 179–184).

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