FAUSTITE, A NEW MINERAL, THE ZINC ANALOGUE OF TURQUOIS*

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ABSTRACT

The name faustite is given to a new mineral having the formula $(Zn_{.8}Cu_{.2})Al_6(PO_4)_4(OH)_8 \cdot 5H_2O$, the zinc analogue of turquois. It occurs as an apple-green vein filling in altered shales at Copper King mine, Maggie Creek district, Eureka County, Nev., intimately associated with a montmorillonitic clay. Pale greenish-white vein fillings in the same locality consist predominantly of montmorillonitic clay. Although *x*-ray powder patterns of turquois and faustite are similar, the two minerals may be distinguished by the identification of their dissociation products upon ignition. The specific gravity of faustite is 2.92; mean index of refraction is 1.613. The isomorphous relations with turquois are discussed.

INTRODUCTION

A zinc aluminum phosphate recently discovered has proved to be a new mineral, the zinc analogue of turquois. This new mineral, $(Zn_{.8}Cu_{.2})Al_6(PO_4)_4(OH)_8 \cdot 5H_2O$, is named faustite in honor of George T. Faust of the United States Geological Survey. This discovery not only adds a new member to the turquois group but suggests a new isomorphous series of turquois minerals having varying proportions of CuO and ZnO, ranging from turquois with one CuO to faustite with one ZnO. This is the second known phosphate of zinc and aluminum, the first being the mineral kehoeite, which was described by Headden in 1893.

The first specimen of this new mineral was collected by one of us (P. D. P.) at Copper King mine, Maggie Creek district, Eureka County, Nev., and was sent to the U. S. Geological Survey for mineralogic study in August 1952. *X*-ray study showed the mineral to be similar to turquois, but microchemical tests indicated the presence of considerable zinc.

GEOLOGICAL OCCURRENCE

The Copper King mine in which faustite is found is in the Maggie Creek (also known as Susie Creek or Schroeder) district which is located in the Tuscarora Mountains about 10 miles northwest of Carlin, Eureka County, Nev. The district has been mined for lead, silver, gold, antimony, and copper. Barite has also been mined in considerable quantity a few miles to the southeast. The mine is in sedimentary rocks of Paleozoic age that dip to the northwest at 45° to 50°; the rocks are thin-bedded

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cherts with interbedded shales and minor amounts of limestone. Conspicuous shears have developed along the bedding planes, probably as a result of compressional forces acting on the beds. An oxide ore body, consisting of chrysocolla, malachite, azurite, and cuprite, is localized in the limestone beds. As far as could be determined there is no primary copper mineralization visible in the mine. Directly down the rake of the main ore shoot on the 100-foot level the only sign of mineralization is a small veinlet of pale-green montmorillonite. Apparently the copper solutions, moving either from the sides or from above, encountered a favorable structural trap in the intensely sheared limestone which was also a more favorable rock for stratigraphic control than the thin-bedded cherty shales.

Faustite occurs on the main level of the mine as apple-green veinlets up to $\frac{1}{4}$-inch wide cutting through altered wall rock, which is chiefly argillized cherts and shales. It is intimately associated with montmorillonitic clay of various colors from white to dark green. Most of the faustite found in the veins is enclosed by a light- to dark-green montmorillonitic clay. It also occurs as nuggets or nodules which have roughly polygonal shape and which are enclosed by a montmorillonitic clay of an olive-green color. In both types of occurrence the interface between the green montmorillonitic clay and faustite is marked by a thin film of pure white montmorillonite. Montmorillonite is also admixed with the faustite and constitutes about 20 per cent of the sample analyzed. The altered wall rock consists chiefly of quartz and kaolinite, and in places alunite occurs in veinlets.

The origin of faustite is a matter of conjecture. The source of the zinc is not known with certainty, as no zinc minerals were noted in the mine; however, nearby lead-silver veins carry small amounts of sphalerite. The other ingredients are readily available. There is abundant apatite in the montmorillonitic clay to provide the phosphate, the source of the aluminum would appear to be in the shales, and the copper mineralization has already been mentioned.

The nearest occurrence of turquois is in the Eight mine in the Lynn district, 12 miles to the northwest.

X-RAY POWDER DATA

Faustite, magnified 27,000 times by electron micrographs (taken by E. J. Dwornik and C. Davis), is seen only as irregular masses. This extremely fine particle size limits crystallographic studies to an examination of the *x*-ray diffraction data. As may be seen in Table 1, the powder patterns of faustite and turquois are nearly identical, showing that the minerals are isostructural. The powder data for turquois given by Gra-

TABLE 1. *X*-RAY POWDER DATA FOR FAUSTITE AND TURQUOIS

1. Faustite. Eureka County, Nev. (Fe/Mn radiation; λ=1.9373 Å)		2. Turquois. Campbell County, Va. (Cu/Ni radiation; λ=1.5418 Å)		3. Turquois. Campbell County, Va. (Graham, 1947) (Fe/Mn radiation)			
d (meas.) Å	Intensity	*d* (meas.) Å	Intensity	*d* (meas.) kX	Intensity	*d* (graph) kX	Indices *hkl*
9.03	5	9.09	5	9.35	1	8.98	010
6.70	7	6.73	5	6.69	2	6.71	001
6.14	7	6.17	7	6.14	3	6.14 6.14	$0\bar{1}1$ $\bar{1}\bar{1}1$
5.98	4	6.00	4				
5.80	2	5.77	2				
4.81	5	4.80	6	4.78	4	4.83 4.82	011 $1\bar{1}0$
4.61	2	4.65	2				
4.48	2	4.49	1				
4.19	2	4.18	1				
4.05	4	4.06	1	4.05	2	4.09 4.05	$\bar{1}11$ 101
3.68	10	3.68	10	3.67	10	3.73 3.72 3.70	$\bar{2}\bar{1}1$ $1\bar{1}1$ 111
3.50	1	3.51	1				
3.44	6	3.44	7	3.43	3	3.46 3.41	$\bar{2}01$ $\bar{2}\bar{2}1$
3.28	6	3.28	7	3.27	2	3.32 3.31 3.30 3.30	210 $\bar{1}20$ 021 $\bar{1}\bar{3}1$
3.08	4	3.10	4	3.09	0.5		
3.03	2	3.05	2				
2.99	2	3.00	2	2.99	0.5		
2.92	6	2.91	8	2.90	9		
2.89	8	2.89	1				
2.79	1	2.84	2				
2.70	1	2.74	2				
2.60	1	2.62	1				
2.56	1	2.58	1				
2.52	4	2.52	4	2.52	2		
2.47	2	2.47	2				
2.42	2	2.44	1	2.45	1		
2.40	2	2.40	2	2.40	1		
2.35	4	2.35	4	2.34	1		
2.31	2	2.32 2.29	4 Broad	2.30	2		
2.29	4						
2.23	4	2.23	4	2.23	2		
2.18	2	2.19	2	2.14	1		
2.12	4	2.12	4	2.11	2		
2.05	7	2.07	5	2.06	2		

TABLE 1—*(continued)*

1. Faustite. Eureka County, Nev. (Fe/Mn radiation; λ=1.9373 Å)		2. Turquois. Campbell County, Va. (Cu/Ni radiation; λ=1.5418 Å)		3. Turquois. Campbell County, Va. (Graham, 1947) (Fe/Mn radiation)			
d (meas.) Å	Intensity	*d* (meas.) Å	Intensity	*d* (meas.) kX	Intensity	*d* (graph) kX	Indices *hkl*
2.02	5	2.02	6	2.01	5		
1.994	1	1.994	1				
1.970	1	1.966	1				
1.946 1.928	0.05	1.934	2				
1.900	4	1.903	4	1.90	3		
1.850	4	1.845	4	1.84	4		
1.830	4	1.824	4				
1.807	2	1.814	1	1.81	4		
1.783	2	1.784	2	1.78	2		
1.718	2	1.727	2	1.72	1		
1.682	1	1.677	2				
1.665	1	1.672	2	1.67	1		
1.645	2	1.639	4	1.64	3		
1.610	2	1.607	2	1.61	1		
1.578	2	1.582	2	1.58	1		
1.565	2	1.567	2	1.57	1		
1.550	2	1.548	2 Broad	1.54	2		
1.527	1	1.529	1				
1.517	2	1.511	2	1.51	1		
1.491	2	1.494	2	1.49	1		
1.472 1.468	1	1.471	1	1.48	1		
1.454	1	1.452	2				
1.445	2	1.438	2				
1.421	4	1.426	2				
1.397	1	1.395	1	1.39	2		
1.373	1	1.376	1				
1.353	2	1.349	2				
1.331	2	1.333	2				
1.316	1	1.320	1				
1.302	1	1.307	1				
1.283	1	1.284	1				
1.268	1	1.266	2				
1.261	3	1.258	2				
1.226	2	1.227	2 Broad				
1.221	2	1.220	2 Broad				
1.207	2	1.204	2				
1.194	2	1.193	1				
1.158	1	1.154	1				
1.152	1	1.153	2				
1.117	1	1.112	1				
1.093	1	1.093	1				

ham (1947) with the spacings in kX units and partly indexed are given for comparative purposes. The most noticeable difference between the patterns, easily detected by the unaided eye, is in the separation of the 2.05–2.02 Å spacings of faustite and of the 2.07–2.02 Å spacings of turquois. The slightly lower *d* values for faustite indicate that it has a somewhat smaller unit cell than turquois.

PHYSICAL PROPERTIES

Faustite occurs as hard compact masses with a smooth feel and with a slightly conchoidal to smooth fracture. The mineral is brittle; the hardness is $5\frac{1}{2}$. A slight correction in the determined hardness, and in some of the other measured physical and optical properties of faustite, might be necessary owing to the 20 per cent of montmorillonite present. The specific gravity, as determined with a Berman microbalance, is 2.76. As determined using an Adams-Johnston pycnometer of fused silica, the specific gravity is 2.791 at 4° C., measured on a 1.162 g sample. If the admixed montmorillonite is assumed to have a specific gravity of 2.25, the recalculated value for faustite would be 2.92. This compares with the calculated value of 2.91 for turquois. The agreement is what would be expected, as zinc and copper have nearly identical atomic weights and constitute only a small part of the structure. The substitution of zinc for copper increases the formula weight by 0.2 per cent.

OPTICAL PROPERTIES

The material on which the chemical analysis was made is apple green in color, with a waxy to somewhat dull luster. Associated material, which contains a greater percentage of copper and may be intermediate between faustite and turquois, has a distinctly bluish cast. Faustite compared with various specimens of "green" turquois was seen to have more yellow in its color; presumably the pure zinc end member, free of copper and iron, would be white or colorless. In transmitted light the color is brown with a slight greenish cast. The powdered mineral is yellow green and the streak is white to pale yellow green. Faustite is opaque except on thin edges. It is not fluorescent.

In thin section the mineral is extremely fine grained, and no crystal outlines could be found. The surfaces of the aggregate grains are marked by shatter cracks, similar to those of opal or halloysite, which probably represent a slight contraction of the material in drying. A complete determination of the optical properties of faustite could not be made owing to the small particle size. The mean index of refraction, determined using sodium light and standard immersion media, is 1.613; the birefringence is medium and appears to be about the same or slightly less than that of fine-grained turquois with which it was compared.

CHEMICAL PROPERTIES

Pyrognostics

In a closed tube faustite decrepitates rather strongly, loses water, and turns a light clove brown. The mineral does not fuse before the blowpipe and leaves the flame uncolored; the residue is colored clove brown. As insufficient material was available for study by differential thermal analysis, small (2 to 5 mg.) grains of faustite were heated on an electric hot plate at various temperatures and for varying lengths of time in order to study the products of dehydration. Faustite dried at 110° C. for 60 hours faded slightly in color; heated at 210° C. for 30 hours, it faded to a light brownish gray. The structure is not destroyed, however, as shown by x-ray diffraction patterns, until a temperature of 400° C. is reached. These data agree with the findings of Schaller (1912) for turquois. Faustite held at 400° C. for 60 hours turned dark clove brown in color and gave an x-ray pattern with two broad and diffuse bands at 4.5 Å and 12 Å. A few spotty lines of the pattern of berlinite ($AlPO_4$, quartz type) are also present, but the material is chiefly amorphous and has an index of refraction of 1.568. When faustite was strongly heated (above 900° C.) in a crucible or before the blowpipe, the residue was found to consist of gahnite and aluminum phosphate ($AlPO_4$, cristobalite type). In samples insufficiently heated, the tridymite-like polymorph of $AlPO_4$ is also present (Manly, 1950).

The residue of turquois, ignited for comparison, was found to consist of oxides of copper and, again depending upon the degree of heating, of either or both of the high temperature polymorphs of $AlPO_4$. As faustite yields a spinel on extreme heating, x-ray study of the ignition products (Foster, 1952) provides an easy method of distinguishing faustite from turquois.

Ground faustite is very slowly soluble in cold concentrated acids but is much more soluble after ignition to about 400° C. The solubility is not increased by heating beyond this point, which presumably marks the destruction of the crystal structure. Faustite is readily soluble without heating in warm $1N$ orthophosphoric acid. The color is unaffected by ammonia, in which the mineral is no more than slightly soluble.

Chemical analysis and composition

X-ray examination showed that faustite was intimately associated with a clay of the montmorillonite type. In order to allocate properly the common constituents Al_2O_3, Fe_2O_3, and H_2O between faustite and the clay present, it was necessary to know the composition of the clay. *X*-ray examination showed that a pale greenish-white vein filling in the same locality was predominantly a montmorillonitic clay. As the greenish-white material and the green material containing, and admixed with, faustite occurred under similar conditions, it seemed probable that the montmorillonitic clay, which was the dominant mineral in the greenish-white material, would have approximately the same composition as the montmorillonitic clay in the green material. An analysis of the greenish-white material is given in Table 2. As *x*-ray examination showed the greenish-white vein material to contain some apatite, we are justified in removing CaO (except for exchangeable CaO in the clay), and P_2O_5 from the analysis of the greenish-white material in order to arrive at the composition of the clay. And as treatment with 0.5*N* NaOH (Foster, 1953) showed the material to contain 1.27 per cent free Al_2O_3, this also may be subtracted from the Al_2O_3 found to obtain the Al_2O_3 content of the clay. The 1.3 per cent CuO found, together with the 0.23 per cent CO_2, may indicate the presence of a small amount of malachite, an amount, however, too small to be detected in the *x*-ray diffraction pattern. The ZnO found is, on the other hand, considered to be in the clay, as zinc is known

TABLE 2. ANALYSIS OF GREENISH-WHITE VEIN FILLING[1]

	Greenish-white material	Apatite	Malachite	Free Al_2O_3	Clay	Clay Calculated to 100%
SiO_2	39.67	—	—	—	39.67	47.48
Al_2O_3	19.27	—	—	1.27	18.00	21.54
Fe_2O_3	0.66	—	—	—	0.66	0.79
CuO	1.30	—	1.30	—	—	—
ZnO	0.30	—	—	—	0.30	0.36
CaO	8.87[2]	7.27	—	—	1.60	1.92
MgO	2.72[3]	—	—	—	2.72	3.26
P_2O_5	5.91	5.91	—	—	—	—
H_2O^-	8.40	—	—	—	8.40	10.05
H_2O^+	12.20	—	—	—	12.20	14.60
CO_2	0.23	—	0.23	—	—	—
Total	99.53					100.00

Cation exchange—milliequivalents 0.78.

[1] Margaret D. Foster, analyst.

[2] Exchangeable CaO, 1.60 per cent.

[3] Exchangeable MgO, 0.42 per cent.

to enter the montmorillonite structure (Ross, 1946). With these adjustments, and calculating the remaining constituents to 100 per cent, the composition of the clay is that of a typical montmorillonite (Table 2). Assuming the clay in the green vein filling (admixed with faustite) to be of similar composition and taking the silica found in the green material as indicating the amount of clay in the material, the composition of faustite, calculated to 100 per cent, is shown in Table 3. Thus faustite may be considered the zinc analogue of turquois and near the zinc end member of a possible isomorphous series of which turquois is the copper end member.

TABLE 3. ANALYSIS OF GREEN VEIN FILLING AND COMPOSITION OF FAUSTITE[1]

	Green vein filling	Clay	Faustite	Calculated to 100%	Ratios		
SiO_2	8.63	8.63	—	—	—		
Al_2O_3	33.10	3.39	29.19	35.31	0.3463	0.3571	1.01×3
Fe_2O_3	1.57	0.14	1.43	1.73	0.0108		
CuO	1.33	—	1.33	1.61	0.0202	0.1153	0.98×1
ZnO	6.40	—	6.40	7.74	0.0951		
CaO	0.40	0.40	—	—	—		
MgO	0.56	0.56	—	—	—		
P_2O_5	28.79	—	28.79	34.83		0.2453	1.04×2
H_2O^-	0.70	0.70	—	—	—		
H_2O^+	18.17	2.65	15.52	18.78		1.0422	0.98×9
Total	99.65			100.00			

Sp. Gr. 2.791

Formula of faustite $(Zn_{.8}Cu_{.2})O \cdot 3Al_2O_3 \cdot 2P_2O_5 \cdot 9H_2O$ or, in more condensed form, $(Zn_{.8}Cu_{.2})Al_6(PO_4)_4(OH)_8 \cdot 5H_2O$.

A spectrographic analysis by Janet D. Fletcher, U. S. Geological Survey, gives the following results for faustite, in per cent:

X0.0	Al, P
X.0	Zn, Cu, Fe, Si
0.X	Ca, Mg, Ba, V
0.0X	Cr, Ti
0.00X	Co, Ni, Sc, Zr, Sr
0.000X	Mn, Be

Elements looked for but not found were: Ag, Au, Pb, Bi, Pt, Mo, W, Ge, Sn, As, Sb, Cd, Tl, Ga, Y, Yb, La, Tb, Nb, Ta, U, and B.

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[1] Margaret D. Foster, analyst.

The turquois-faustite series

The discovery of a zinc member of the turquois group raises the question as to whether other samples of turquois, in which the amount of CuO present is considerably less than the theoretical amount, may not contain some zinc. In the analysis of turquois, zinc is not ordinarily determined and may, therefore, have been missed. Re-examination of samples of turquois may show some to be intermediate between turquois and faustite. To pursue this point, qualitative microchemical tests were made on 15 samples of turquois from England, France, Chile, and Cuba and from Arizona, California, Nevada, and New Mexico. Weak to moderate (less than 1 per cent) tests for zinc were obtained on all but 3 of the samples; however, all the samples are close to the turquois end member and give a strong test for copper. These tests were also applied to some minute grains of faustite that had a bluer color than the analyzed apple-green material, and these contained slightly more copper than type faustite. These tests indicate that intermediate members of the series may be present.

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