

ART. V.—*Crystallized Turquoise from Virginia*; by
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Introduction.

A SAMPLE of a bright blue mineral, from near Lynch Station, Campbell County, Virginia, was brought to the Geological Survey for identification by Mr. J. H. Watkins. As a few preliminary tests failed to identify the mineral with any known species, a complete study of it was undertaken. The results obtained show that the supposed new mineral is identical with turquoise. The chief interest, however, lies in the fact that this turquoise is well crystallized and it was possible to measure several of the minute crystals and determine thereby the crystallography of the mineral. I am deeply indebted to Mr. Watkins for his kindness in furnishing the material (now deposited in the United States National Museum) and in allowing this description to be published.

The matrix of the specimen consists of irregular fragments of glassy quartz of various sizes, cemented together by thin layers of turquoise crystals. On one side of the specimen the turquoise forms a drusy, botryoidal layer, cavernous in texture and including many small irregular fragments of the glassy quartz. The turquoise, with its many included quartz fragments, polishes well and makes a very handsome ornamental stone.

The spheres, bristling with minute crystals, which form the botryoidal surface, average about two or three millimeters in diameter. The individual crystals rarely are as much as a third of a millimeter long, being usually smaller and much thinner.

General description of mineral.

The turquoise is bright blue in color and vitreous in luster. Cleavage is present, possibly in two directions. The mineral is brittle and has a hardness of about 5, though the minute size and brittleness of the crystals make it difficult to determine the hardness closely. The density of the sample analyzed, determined with a pycnometer, is 2.816, which, when corrected for the 12.57 per cent insoluble material (mostly quartz) present (see analysis beyond), gives for the pure turquoise the value 2.84.

Examined under the microscope, the crystals are clear and transparent and the material is very pure. Pleochroism is distinct, from colorless to pale bluish. Extinction is inclined on all sections and, as verified by the measurements, the crystals

are triclinic. None of the sections showed a good interference figure, though such as were seen indicated biaxiality. One cleavage plate, possibly parallel to $M(1\bar{1}0)$, showed extinction of 12° against the vertical direction and 12° against the other edge ($1\bar{1}0 \wedge 0\bar{1}1$?). A different cleavage section, of a rhombic shape, showed extinction values of 5° and 34° respectively, but the orientation of this piece could not be determined. The double refraction of the mineral is high, about 0.04. The refractive indices are about 1.61 for a and 1.65 for γ . Lacroix* gives the value 1.63 for the mean index.

Crystallography.

The crystals are very minute and so closely grown together that it was almost impossible to obtain any suitable for measurement. One complete crystal was found that gave fairly good reflections and the measurements were verified by those obtained on a second, less perfect, crystal. A third incomplete one also yielded a few measurements. The size of the first two crystals measured is as follows:

Cryst. No. 1-----	{	.27 ^{mm} high (c axis)
	{	.32 ^{mm} wide (b axis)
Cryst. No. 2-----	{	.32 ^{mm} high (c axis)
	{	.40 ^{mm} wide (b axis)
	{	.12 ^{mm} thick (a axis).

The crystals are triclinic and in angles very near to those of chalcosiderite. In fact, the angular values of turquoise and chalcosiderite are so close that the crystallographical elements of chalcosiderite have been adopted for those of turquoise, as the crystals of the latter mineral are but poorly adapted for accurate measurements. Were it not for the knowledge of the crystallography of chalcosiderite (isomorphous with turquoise, see beyond under chemical composition) which we possess, it is doubtful if the orientation of the turquoise crystals could have been interpreted.

The values for turquoise are then:

$$a:b:c = 0.7910 : 1 : 0.6051; \alpha = 92^\circ 58', \beta = 93^\circ 30', \gamma = 107^\circ 41'.$$

$$\text{Forms: } b\{010\}, a\{100\}, m\{110\}, M\{1\bar{1}0\}, k\{0\bar{1}1\}.$$

The comparison of the measured angles with the calculated ones† are shown below.

* Lacroix, A., *Mineralogie de la France*, vol. iv, p. 529, 1910.

† These calculated values are, with one exception, taken from the values calculated for chalcosiderite by Maskelyne, *Journ. Chem. Soc.*, vol. xxviii, p. 586, 1875.

Comparison of measured and calculated angles, turquoise.

Angle	Measured			Calculated
	Cryst. No. 1	Cryst. No. 2	Cryst. No. 3	
$1\bar{1}0 \wedge 100$	$45^{\circ} 12'$	-----	-----	$44^{\circ} 50'$
$100 \wedge 110$	31 14	$31^{\circ} 28'$	-----	31 10
$110 \wedge \bar{1}10$	104 14	-- --	104 03	104 00
$110 \wedge 010^*$	37 28	38 39	-----	40 54
$0\bar{1}1 \wedge \bar{1}10$	107 42	105 15	-----	105 36
$0\bar{1}1 \wedge 100$	-----	95 33	-----	95 45
$0\bar{1}1 \wedge 110$	-----	110 00	-----	109 36
$0\bar{1}1 \wedge 010^*$	-----	117 26	-----	119 19

* The faces of $\{010\}$ gave very poor reflections.

FIG. 1.

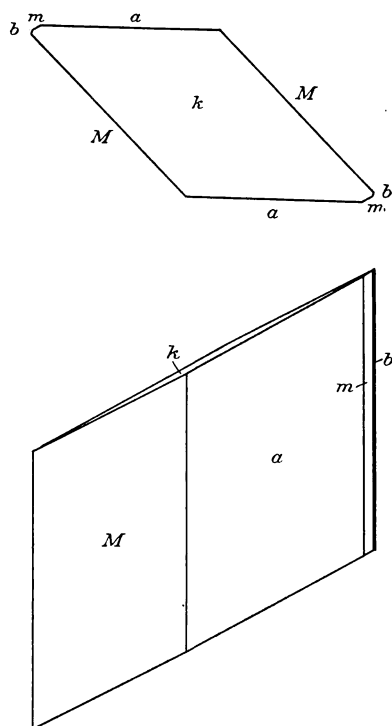


FIG. 1. Turquoise crystal.

$b\{010\}$, $a\{100\}$, $m\{110\}$, $M\{1\bar{1}0\}$, $k\{0\bar{1}1\}$.

The forms $a\{100\}$ and $M\{1\bar{1}0\}$ are large and striated vertically, a generally more striated than M . The prism $m\{110\}$ is narrow and striated parallel to the edge $(110) : (0\bar{1}1)$. Between m and $k\{0\bar{1}1\}$ lies an undetermined small face very

much striated. The clinopinacoid $b\{010\}$ is very small and uneven and gives a very poor reflection. The dome $k\{0\bar{1}1\}$ is the only terminal face definitely determined and is strongly striated on crystal No. 1, while perfectly smooth and yielding an excellent reflection on crystal No. 2. It may be that the face of k on crystal No. 2 is a cleavage face, as an easy cleavage parallel to this dome was noted by Maskelyne on chalcosiderite.

The habit of the crystals is shown in figure 1.

The pointed appearance of the minute crystals is due to the sharpness of the corners where the intersections of $k\{0\bar{1}1\}$ with the faces of the prism zone yield acute points.

Chemical Composition.

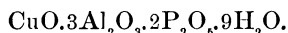
Abundant material was on hand for the analysis, which was made on carefully selected pieces free from all impurities except for the quartz. It was found that the mineral is insoluble in boiling hydrochloric acid, but after gentle ignition (when it has turned brown) it is readily soluble in acids. The mineral does not lose any water below 200° and retains its blue color at this temperature. Between 200° and 650° all the water is given off* and the mineral becomes greenish in color. On higher heating the greenish color changes to a brown. The mineral is infusible before the blowpipe but becomes brown.

The average analysis is shown in the table below in the first column, while in the second column is given the same analysis with the insoluble matter (quartz) deducted. The ratios derived herefrom are also given.

Analysis and ratios of turquoise.

	Analysis	Same with insol. matter deducted	Ratios	
P_2O_5 -----	29.84	34.13	.240	2.07 or 2
Al_2O_3 -----	31.91	36.50	.357	3.09 " 3
Fe_2O_3 -----	.18	.21	.001	
CuO -----	7.87	9.00	.113	.97 " 1
H_2O -----	17.59	20.12	1.118	9.64 " 9
Insol. -----	12.57	----		
	<hr/> 99.96	<hr/> 99.96		

The formula derived from the ratios of the analysis is as follows:



* Nearly all of the water is expelled below 400° .

Following Penfield's* suggestion as to the relation of the hydroxyl groups, this formula can be interpreted as:



I believe that this formula expresses the definite composition of turquoise, and a comparison with other analyses shows that this formula is doubtless the correct one.

Among the best analyses of turquoise is the one by Penfield† on material from Lincoln County, Nevada. This turquoise was "of exceptionally fine quality . . . very fine-grained, of a beautiful robin's-egg blue color, and broke with a smooth fracture. . . . when examined under the microscope, the turquoise seemed to be perfectly uniform, showing no evidence of being made up of two substances . . . it acted somewhat on polarized light." Density given as 2.791.

In the following table are given the analysis of the turquoise from Virginia, Penfield's analysis of turquoise from Lincoln Co., Nevada, and in the third column the composition calculated for the formula proposed:

Analyses of turquoise.

	Virginia	Nevada	Calculated for $\text{CuO}.3\text{Al}_2\text{O}_3.2\text{P}_2\text{O}_5.9\text{H}_2\text{O}$
P_2O_5 -----	34.13	34.18	34.12
Al_2O_3 -----	36.50	35.03	36.84
Fe_2O_3 -----	.21	1.44	----
CuO -----	9.00	8.57	9.57
H_2O -----	20.12	19.38	19.47
Insol.-----	----	0.93	----
	<hr/> 99.96	<hr/> 99.53	<hr/> 100.00

The agreement of the three analyses is very close, so that the formula $\text{CuO}.3\text{Al}_2\text{O}_3.2\text{P}_2\text{O}_5.9\text{H}_2\text{O}$ expresses definitely the composition of this mineral.

Of the other analyses in which the purity of material is not so definitely known as in the two analyses just cited, there are quoted only those given by Penfield.‡

The high alumina may be partly accounted for by the admixture of a little aluminous rock. By considering some of the iron present as ferrous oxide, FeO , isomorphously replacing the CuO , the analyses agree very well with the values calculated for the composition.

The idea of Penfield's that the composition of the mineral should be expressed as $[\text{Al}(\text{OH})_2, \text{Fe}(\text{OH})_2, \text{CuOH}, \text{H}]\text{PO}_4$ can be more definitely fixed now, as the analysis of crystals of tur-

* Penfield, S. L., On the Chemical Composition of Turquoise. This Journal (4), vol. x, p. 346, 1900.

† Loc. cit.

‡ Loc. cit.

Analyses of turquoise.

	Calculated	Persia. Church	Russia. Nicolajew	California. Moore	New Mexico, Clarke		
P ₂ O ₅ ..	34.12	32.86	34.42	33.21	31.96	32.86	28.63
Al ₂ O ₃ ..	36.84	40.19	[35.79]	35.98	39.53†	36.88	37.88
Fe ₂ O ₃ ..	----	2.45*	3.52	2.99	----	2.40	4.07
CuO...	9.57	5.27	7.67	7.80	6.30	7.51	6.56
H ₂ O...	19.47	19.34	18.60	19.98	19.80	19.60	18.49
X.....	----	0.36‡	----	----	1.28§	.54	4.20¶
	100.00	100.47	100.00	99.96	98.87	99.79	99.83
D.....		2.75	2.89	2.86		2.80	

* Given as FeO. The figures would be in better agreement with values calculated from formula if the iron were considered in the ferrous condition.

† MnO.

‡ Includes some Fe₂O₃.

§ Insoluble, 1.15; CaO, 0.13.

|| Insoluble, 0.16; CaO, 0.38.

¶ Insoluble.

quoise shows that the Al(OH)₃, CuOH, and H are present in fixed amounts, namely in the ratio of 6 : 1 : 5. Penfield's own analysis agrees very closely with these figures.*

The crystallographical measurements have shown the apparent isomorphism of turquoise and chalcosiderite. The formula given for chalcosiderite is CuO.3Fe₂O₃.2P₂O₅.8H₂O, which differs in form from that proposed for turquoise by one molecule less of water. From Maskelyne's† description of the material used for the analysis of chalcosiderite it seems probable that the sample was contaminated by a little andrewsite, limonite and dufrenite. These all contain less water‡ than chalcosiderite, so that the value obtained is probably a little low and the true amount of water for pure chalcosiderite is higher than that given. The correct formula for chalcosiderite is then more probably to be written with 9H₂O instead of 8H₂O. The isomorphous character of this mineral with turquoise is then clearly brought out.

Turquoise, CuO.3Al₂O₃.2P₂O₅.9H₂O. triclinic.
Chalcosiderite, CuO.3Fe₂O₃.2P₂O₅.9H₂O. triclinic.

Summary.

In closing, the three main points developed in this paper may be briefly restated:

- (1). Turquoise is triclinic with the crystal form as determined.
- (2). Turquoise has the definite composition CuO.3Al₂O₃.2P₂O₅.9H₂O.
- (3). Turquoise and chalcosiderite are isomorphous.

* Penfield deduced the ratios 7 : 1 : 6 from his analysis, but 6 : 1 : 5 is still closer.

† Maskelyne, N. S., On Andrews site and Chalkosiderite. Journ. Chem. Soc., vol. xxviii, p. 586, 1875.

‡ Andrews site has 8.8 per cent, limonite 14.5 per cent, and dufrenite 10.5 per cent water, while chalcosiderite has 15.00 per cent.