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VESUVIANITE FROM GEORGETOWN, CALIFORNIA

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INTRODUCTION

Within the last year or so crystals of vesuvianite from near Georgetown, El Dorado County, California, have been sold by several mineral dealers. The writer has made two visits to the locality from which these crystals have come and has examined all of the more important veins in which they occur. A grant from the Board of Research of the University of California in support of this work is gratefully acknowledged.

GEOLOGICAL OCCURRENCE

All of the veins lie in a serpentine belt along Traverse Creek about two and a half miles south southeast of Georgetown in the Placerville Quadrangle,[1] California. The veins are near the southern extremity of this serpentine belt where the Bear Creek Road crosses Traverse Creek. The serpentine here is about half a mile wide and is bounded on both sides by amphibolite with minor bodies of schist.

The serpentine is for the most part highly sheared. The shear surfaces, though irregular, tend to follow the regional strike, N-NW. Magnetite and chromite are scattered through the serpentine. A few chromite segregations have yielded small quantities of ore. There are some bands of chlorite.

Several dikes cut the serpentine. Near the eastern contact there is a fresh massive diorite dike several yards thick that may be traced for a few hundred yards. Near the center of the serpentine belt there are a few small aplitic dikes that have been greatly sheared. These are only a foot or two thick and can be traced for only a few yards. One small vein or dike consists of angular fragments of albite up to half an inch long crowded with high index inclusions, possibly epidote, and cemented by clear glassy quartz. None of these dikes come in contact with the vesuvianite veins.

VESUVIANITE VEINS

The veins containing the vesuvianite and associated minerals are

[1] See Folio 3 of the Geologic Atlas of the United States.

scattered over an area of several hundred acres. Most of them are near the center of the serpentine belt on a small hill west of Traverse Creek which will be referred to as West Hill, but a few small veins also occur on the other side of the creek. The distance between the veins most remote from each other is a little over half a mile.

Ten claims have been staked on these deposits by Mr. W. L. Stifle, who lives on the property, and the veins are exposed in numerous pits and prospect holes. Two short tunnels have also been driven in the serpentine near the veins but as yet they have not exposed any material comparable to that in the pits. It is impossible to say how many of these veins occur in the serpentine since those that have not been prospected easily escape notice, but several score may be seen in the pits and holes and doubtless many more exist. They range in dimensions from mere lenses and kidneys a few inches across to the size of the vein in the main "gem" pit on West Hill. This vein is three feet or more thick and has been worked to a depth of 15 feet and for 50 feet on the strike. Most of the veins are extended parallel to the shear surfaces of the enclosing rock but it may be that some cut across these structures. A few small massive veins show a little slickensiding but most of the veins show no disturbance at all.

Vesuvianite is by far the most important mineral in these veins. Other minerals, in order of importance, are garnet (grossularite and hessonite) diopside, clinochlorite, prehnite, tremolite and opal. In no single vein were all of these minerals found together. Many of the veins are nearly monomineralic. The vein in the main "gem" pit consists almost wholly of vesuvianite with only a little grossularite or clinochlorite in a few patches and many of the smaller veins consist wholly of vesuvianite.

There are many varieties of vesuvianite represented in these deposits. Most commonly it is yellow green and granular to massive. Some is nearly white or colorless and at least one large vein at "Gem Point" beside the road a quarter of a mile northwest of the ford over Traverse Creek, consists wholly of this variety in long acicular crystals. The darker varieties are found only in patches, often lining vugs. Violet or purple crystals, some conspicuously zoned, are rare and were seen only in the southern end of the main "gem" pit and in another nearby pit. The violet crystals occur in juxtaposition with very pale to green crystals.

Dense vesuvianite resembling the variety californite in structure, but rather pale and mottled, forms several small veins on the left bank of Traverse Creek.

Associated Minerals

The colorless grossularite forms many small veins alone or with some chlorite and diopside. It is granular to massive and contains only small

vugs lined with clear perfect crystals. It also occurs in patches in some of the large vesuvianite veins. Hessonite (used to designate a honey colored garnet higher in density and refractive index than the grossularite and probably containing more ferric iron) occurs in several small veins alone or with chlorite, diopside or vesuvianite but not with grossularite. One such garnet, occurring with clinochlorite in a vein on West Hill has a density of 3.65 and an index greater than 1.79, probably indicating a content of 30 per cent or more of the andradite molecule.

Dense white diopside forms veins enclosing small aggregates of green vesuvianite or occurs on the selvages of vesuvianite veins. Lath-like crystals of pale diopside up to 7 mm. long occur in small veinlets with prehnite on West Hill and in vugs in vesuvianite. Large poikilitic crystals of clear diopside enclose purple and colorless vesuvianite in one vein and a few clear glassy crystals of diopside occur in openings in a veinlet of hessonite.

Very pale, in part silvery, chlorite occurs both in the enclosing serpentine and in many of the veins. It may form selvages, fill in irregular spaces or occur as implanted crystals in vugs in vesuvianite or as minute rosettes on grossularite. The chlorite in most cases is optically positive, with small optic angle and has an index, β, near 1.58 and may so be classified as clinochlorite. Only adjoining the diopside-prehnite vein on West Hill mentioned above was some chlorite collected the optical properties of which show it to be diabantite.

Prehnite was not found with the vesuvianite. It was identified only in the veinlet with diopside just referred to and with garnet remote from the main group of veins.

Tremolite was only identified at one place where it forms a dense white band together with some clinochlorite adjoining a small vein of vesuvianite.

Although only 7 or 8 minerals have been identified in these deposits more than double that number of combinations were observed. In several places it is apparent that diopside or clinochlorite crystallized after vesuvianite or grossularite, opal occurs as a coating on prehnite and it may be that garnet encrusts vesuvianite in a few spots in the larger veins, but it does not seem possible to set up any simple sequence for the formation of all the minerals.

Vesuvianite

Good clear crystals in a variety of colors are found in the vugs of the vesuvianite veins. At the time of the writer's visits no large vugs were exposed but they are said to have reached a diameter of about one foot. Most of the good crystals have come from the main "gem" pit in which scores of large crystal-lined pockets were found.

TABLE 1. SUMMARY OF PRINCIPAL FORMS FOUND ON VESUVIANITE FROM GEORGETOWN

Group of Crystals	Number of Crystals	Color	Ridgway Number	(001)	(110)	(100)	(120)	(111)	(331)	(221)	(112)	(011)	(021)	(031)	(045)	(131)	(132)	(263)	(151)
1	1	Pink, very pale	paler than 5."OO-R.f	1.00	1.00	1.00	0.37	1.00	0.25							0.75	0.62		
2	3	Very pale, dull green yellow	paler than 27.'G-Y.f	0.66	1.00	1.00	0.46	1.00	0.67							0.96	0.54	0.33	
3	11	Small light dull green yellow	27.'G-Y.d	1.00	1.00	1.00	0.31	1.00	0.59	0.20		0.25	0.09	0.09		0.94	0.45	0.23	0.04
4	4	Large clear dull green yellow	27.'G-Y.b	1.00	1.00	1.00	0.69	1.00			0.50	0.62				0.56	0.34	0.12	0.09
5	5	Small "Rivage" green	31.'Y-G.b	1.00	1.00	1.00	0.25	1.00	0.80	0.10		0.55		0.15	0.15	0.92	0.60		0.05
6	2	Large "Oriental" green	31.'GY-G	1.00	1.00	1.00	0.87	1.00				0.62				1.00			
7	5 (one doubly terminated)	Small "Turtle" green	31."Y-G.b	1.00	1.00	1.00	0.70	1.00			0.10	0.67		0.08		0.79	0.40	0.02	
8	4	Light grayish blue-violet	51."BV-B.d	1.00	1.00	1.00	0.22	1.00	0.31	0.06				0.94	0.50				
9	3 (one doubly terminated)	"Rivage" green	31.'Y-G.b	0.25	1.00	1.00		1.00	1.00	0.56						1.00	1.00		0.72
All Crystals				0.90	1.00	1.00	0.36	1.00	0.47	0.13	0.06	0.33	0.03	0.06	0.03	0.85	0.50	0.10	0.10

HABIT. Thirty eight vesuvianite crystals, two of which were doubly terminated, were measured on the two-circle goniometer. It was found possible to arrange these crystals in nine groups based on color, habit and size. A summary of the results is given in table 1. In this table the persistence of each of the certainly identifiable forms is given for crystals in each group and for all of the crystals measured. The persistence of a form may be defined as the ratio of the number of times its faces were recorded in a certain group of measurements to the number of times they would have been recorded if the form were fully developed on all of the crystals in the group.[2]

The crystals of groups 1 to 8 are all from the main "gem" pit and it will be seen that some of them show nearly the same habit. All of the crystals show the forms (100), (110) and (111) completely developed and are prismatic in habit. The basal plane is present on nearly all crystals but is more conspicuous in groups 4, 6 and 7. In group 7 it is the dominant terminal face. The table shows that the occurrence of (011) is limited largely to these groups.

The crystals of groups 1, 2, 3 and 5 vary in thickness from 1 to 2.5 mm. and in length from 2 to 7 mm. The crystals of 4 and 6 are 3 to 6 mm. thick. The blue-violet crystals of group 8 are not over 1.3×4 mm.

The crystals of group 9 are from "Gem Point." Their color is quite similar to that of some of the others, but most of the less well crystallized material at this point is practically colorless. These crystals are thin and acicular, being a millimeter or less in thickness and having a ratio of length to breadth of 6 or more. They are notable for the perfection of the forms (331), (131) and (132) of which not a single face is missing in four terminations, the prominence of (151), and the almost complete suppression of the basal plane.

The habits of three of these groups are shown in figure 1, which gives a fair idea of the variation that may be found. All of the crystals are shown enlarged about twenty times.

MORPHOLOGICAL ACCESSORIES.—The table gives statistics only for the occurrence of the more persistent forms. Besides those listed, 17 other forms, including 12 not given in Goldschmidt's Atlas, which gave persistence values of 0.04 or less, were found.

Among the forms listed (045) is not given in Goldschmidt's Atlas. Included in the table under the indices (263) are narrow vicinal strips in the zone [$3\bar{1}0$] between (131) and (132).

The form entered as (112) in group 4 occurs fully developed on two of

[2] Parker R. L., Die Kristallmorphologie im Lichte neuerer analytischer Untersuchungen: *Fortschritte der Min.* etc., vol. **14,** pp. 75–142, 1930.

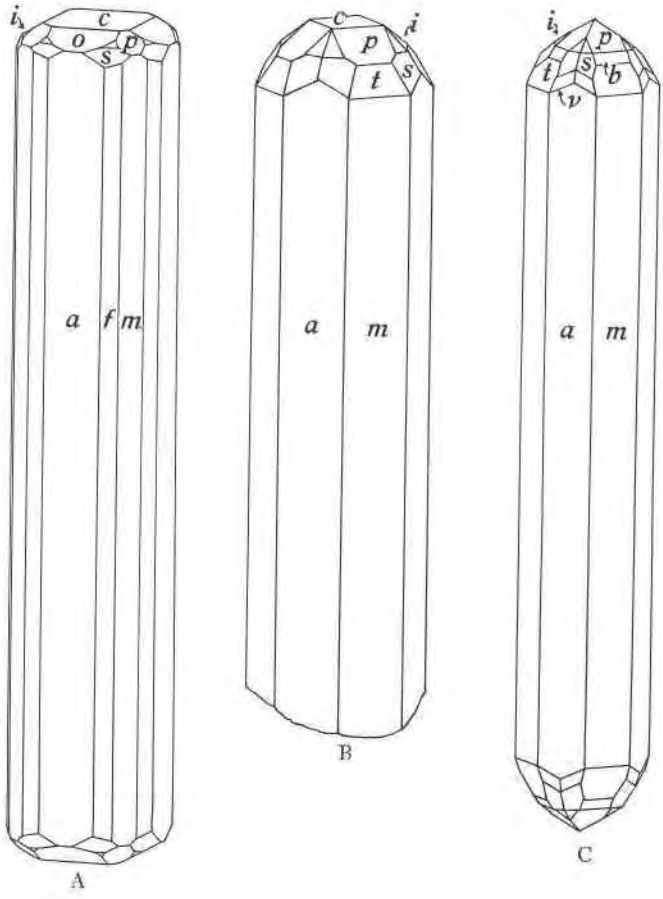

FIG. 1

c (001),	*o* (101),	*s* (131),
a (100),	*p* (111),	*i* (132),
m (110),	*t* (331),	*v* (151).
f (120),	*b* (221),	

A, Green vesuvianite, type 7,
B, Blue-violet vesuvianite, type 8,
C, Green vesuvianite, type 9.

the four crystals of this group. The faces are large but dull with only a bright fringe. The mean value of ρ for these faces is 19°6′, which is much closer to 18°40′, the value for (449), another new form, than to 20°49′, the value for (112).

Many of the crystals having prominent basal pinacoids show a rectangular pattern of striations on these faces. They are mainly in the

direction [010], but [110] striations or both were also seen on a few crystals.

Crystals in all the groups show a few light striations in the directions [011] and [$0\bar{1}1$] on the faces of the second order prism.

The first order prism shows vertical striations on most crystals and in group 7 is replaced by a series of vicinal faces. In contrast to this the blue-violet crystals of group 8 show no vicinal faces at all in the prism zone and pronounced horizontal striations on the first order prism. The table shows that this group has the greatest development of *hhl* forms and wholly lacks *h*0*l* forms.

Axial Ratio.—Three groups of crystals showing the most conspicuous color differences were selected for the determination of the axial ratios. The results are shown in table 2. The differences are entirely within the limits of error and the value obtained is the same as that given in Goldschmidt's Winkeltabellen.

Table 2

Group of Crystals	Number of Observations	(111∧001)	Range	Axial Ratio
2	10	37°14¾′ (111∧$\bar{1}\bar{1}$1)	37°13′ —37°17′	0.5376
8	4	74°30¼′	74°27′ —74°36′	0.5377
9	4	74°29¼′	74°28½′—74°30½′	0.5375

Color.—The wide color variations of the vesuvianite, even among crystals grown in juxtaposition lends some interest to the determination of the cause of these differences. Dr. T. G. Kennard of Claremont, California, made spectroscopic tests of a number of vesuvianites four of which are reported in table 3.

Table 3

Sample 1	Sample 2	Sample 3	Sample 4
Large:	Large:	Large:	Large:
Ca	Ca	Ca	Ca
Al	Al	Al	Al
Si	Si	Si	Si
Medium:	Medium:	Medium:	Medium:
Fe	Fe	Fe	Fe
Mg	Mg	Mg	Mg
	Small:		
	Cr		
Trace:	Trace:	Trace:	Trace:
Mn*	Mn	Mn	Mn
Ti	Ti	Ti	Ti
	Ni		

* The Mn content in sample 1 is considerably larger than in the other three samples.

Minute Trace:	Minute Trace:	Minute Trace:	Minute Trace:
Na	Na	Na	Na
B	B	B	B
V	V	V	V

Sample 1, Blue-violet crystals of group 8,
Sample 2, Turtle green crystals of group 7.
Sample 3, Pale green-yellow crystals of group 2.
Sample 4, Very pale crystals from "Gem Point" not included in table 1.

The results obtained are, of course, only qualitative but Dr. Kennard states that "trace" indicates the presence of hundredths of a per cent. The first three samples are all from the main "gem" pit. The last is from another pit several hundred yards north thereof and was chosen because the crystals were especially pale colored.

It will be seen that the minor constituents are nearly the same in all of the crystals and include several elements not found in the quantitative analysis (table 4). The blue-violet color of the crystals of group 8 appears to be caused by a slightly higher manganese content and the green color of crystals in group 7 seems to be due to chromium.

COMPOSITION AND FORMULA.—After preliminary spectroscopic tests by Dr. T. G. Kennard analyses of two specimens of vesuvianite were made by W. H. Herdsman with the results shown in Table 4.

TABLE 4. ANALYSES OF VESUVIANITE

	Green crystals	White vein material	$Ca_{10}Al_4(Mg, Fe)_2(OH)_4Si_9O_{34}$	
SiO_2	36.60	37.70	36.96	37.89
Al_2O_3	19.75	19.30	13.94	14.29
Fe_2O_3	0.80	0.85		
TiO_2	trace	trace		
FeO	1.64	0.37	0.73	0.75
MgO	2.58	2.45	5.10	5.23
MnO	nil	nil		
CaO	37.80	38.30	38.34	39.31
H_2O-	0.20	0.10		
H_2O+	0.40	0.70	4.93	2.53
F	nil	nil		
CO_2	nil	nil		
Ni	nil	nil		
Cr_2O_3	0.18	nil		
	99.95	99.77		
S.G. $\frac{25°}{4°}$	3.326	3.322		

In the last column of the table is given the composition of an ideal vesuvianite having the formula of Warren and Modell and an Fe''/Mg

ratio of 0.08, about the same as that of the white vesuvianite. Both of the analyses show a very high Al_2O_3 content, higher than in any modern analyses of fluorine free vesuvianite quoted by Doelter. The sum of Fe'' and Mg is too low. This might be adjusted by assuming that a part of the Al is in positions equivalent to Mg and Fe'', but no amount of juggling will raise the water content to correspond to that required by the formula.

Optical Properties.—The indices of refraction of vesuvianite crystals belonging to three different color groups were determined for three wave lengths by the least deviation method on natural 45° prisms. A small Leitz monochromator, calibrated with Li, Na and Tl flames, was used.

Table 5. Refractive Indices of Vesuvianite

	λ	.589μ	.535μ	.480μ
Group 2	ε	1.707	1.711	1.717
Very pale	ω	1.710	1.714	1.720
Group 8	ε	1.708	1.712	1.718
Blue-violet	ω	1.710	1.714	1.720
Group 9	ε	1.7103	1.7140	1.7208
Green	ω	1.7129	1.7163	1.7224

The absorption of all varieties of the vesuvianite is so slight that no pleochroism is observable in thin sections or crushed grains, but by examining whole crystals in polarized light differential absorption can be seen in all but the palest. In groups 3 and 4 the absorption of the extraordinary ray is greater. In all the other groups the ordinary ray is more absorbed.

Grossularite

Habit.—Five colorless grossularite crystals from the main "gem" pit were chosen for measurement. All showed the forms (110), (211), (321) and (332). Three also showed very small cube faces. The habit of these and the other white garnets may be trapezohedral or dodecahedral and both types may occur in the same vein.

These garnets do not, in general, exceed 2 or 3 millimeters in maximum dimension. Only in one vein, consisting of garnet with minute rosettes of chlorite, were there found trapezohedrons of grossularite reaching 5 millimeters or more in diameter.

No measurements were made on other types of garnet.

Composition.—A chemical analysis of the grossularite made by Mr. Herdsman, following spectroscopic tests by Dr. Kennard, yielded the results in table 6.

TABLE 6. ANALYSIS OF GROSSULARITE

	Wt. %	mol. prop.	
SiO_2	39.30	0.6544	0.6544
TiO_2	nil		
Al_2O_3	21.93	0.2151	
Fe_2O_3	0.80	0.0050	0.2210
Cr_2O_3	0.13	0.0009	
FeO	0.23	0.0039	
MnO	nil		0.6655
MgO	traces		
CaO	37.10	0.6616	
H_2O_-	nil		
H_2O_+	0.30		
CO_2	nil		
Ni	nil		
	99.84		
S.G. $\frac{25°}{4°}$	3.5062	$RO:R_2O_3:SiO_2 = 3.051:1.013:3.000$	

OPTICAL PROPERTIES.—The refractive indices of the grossularite were determined by the least deviation method using natural 60° prisms and a small Leitz monochromator. The results given below are the mean of six determinations.

λ	.589μ	.535μ	.460μ
n	1.737	1.741	1.748