

# THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 35

JANUARY-FEBRUARY, 1950

Nos. 1 and 2

## THE LAZULITE-SCORZALITE ISOMORPHOUS SERIES<sup>1</sup>

W. T. PECORA AND J. J. FAHEY, *U. S. Geological Survey,  
Washington, D. C.*

### CONTENTS

Introduction . . . . .	2
Sample selection and separation . . . . .	2
Description of selected specimens . . . . .	2
Descriptive mineralogy . . . . .	4
Morphology . . . . .	4
Variation in chemical composition . . . . .	6
Invalidity of calcium lazulite . . . . .	8
Series nomenclature . . . . .	9
Variation in specific gravity . . . . .	9
Variation in optical properties . . . . .	9
X-ray data . . . . .	11
Occurrence . . . . .	12
General association . . . . .	12
Occurrence in quartzite . . . . .	13
Occurrence in quartz-rich veins and dikes . . . . .	13
Occurrence in granitic pegmatites . . . . .	16
Occurrence in alluvium and colluvium . . . . .	16
Gem lazulite . . . . .	16
Acknowledgments . . . . .	16
References . . . . .	17

### ABSTRACT

The lazulite-scorzalite isomorphous series—expressed by the oxide formula  $(Mg, Fe^{2+})O \cdot Al_2O_3 \cdot P_2O_5 \cdot H_2O$ —is established in this paper on the basis of chemical analyses, indices of refraction, and specific gravity of eight selected specimens. The data for six of these are new. The molecular ratio of Mg:Fe in these analyses ranges from 88:12 to 24:76, with the weight per cent of MgO ranging from 11.97 to 2.93, and the weight per cent of FeO correspondingly from 2.80 to 17.06. The progressive increase in divalent iron is correlated with a progressive increase of indices of refraction, specific gravity, and birefringence. Evidence is submitted that discredits the name calcium lazulite; for the significant percentages of CaO and of SiO<sub>2</sub>, reported in more than two dozen analyses in the literature are believed to be the result of chemical analyses of impure samples. Geological occurrences of lazulite and scorzalite are classified into four groups and world-wide geographic occurrences are noted in accordance with this classification.

<sup>1</sup> Published by permission of the Director, U. S. Geological Survey.

## INTRODUCTION

The lazulite-scorzalite isomorphous series—expressed by the oxide formula  $(\text{Mg}, \text{Fe}'')\text{O} \cdot \text{Al}_2\text{O}_3 \cdot \text{P}_2\text{O}_5 \cdot \text{H}_2\text{O}$ —is established essentially from the data obtained by the writers on 8 selected samples representative of the series. The name lazulite has been used for over a century but the name scorzalite was only recently introduced by Pecora and Fahey (1949a) for the iron analogue of lazulite.

Most of the forty or so chemical analyses of lazulite available in the literature are not acceptable for use in this series because three rigid requirements so necessary in preparing a variation diagram were not fulfilled: (1) reliable chemical analysis on samples plus-99 per cent pure; (2) specific gravity determined on a portion of the analyzed sample; and (3) precise optical data determined on a split of the analyzed sample.

*Sample selection and preparation*

In the period 1945–49, several dozen lazulite specimens obtained from museums or individuals, including a number collected in the field by Pecora, were examined optically to establish the range in their indices of refraction. From these were selected eight specimens that demonstrated a representative distribution over this range.

All the samples were prepared uniformly. Handpicked, visibly pure fragments of a single specimen, or adjacent small masses in the matrix of a single specimen, were crushed so as to pass a 100-mesh screen. The powdered sample was washed free of dust by repeated decanting with water. The air-dried 100–200 or 200–300 mesh fractions were purified by means of heavy liquids (methylene iodide and acetone) and a Frantz isodynamic separator. The sample was repeatedly inspected in immersion liquids until a plus-99 per cent purity was established.

The purified sample was divided into two parts. One portion, ranging from 5 to 25 grams, was used for the chemical analyses and for determination of specific gravity with an Adams-Johnston fused silica pycnometer. The other portion was retained for precise optical studies. The indices of refraction were determined in sodium light and an Abbé refractometer was used to check the index liquids for each measurement.

*Description of the selected specimens*

The 8 specimens selected to demonstrate the lazulite-scorzalite isomorphous series are listed in Table 1, with general information on locality, habit and occurrence, and mineral association. Two of the specimens are from Minas Gerais, Brazil, and the others are from the United States. All the samples are now deposited with the Curator of Mineralogy, U. S. National Museum, Washington, D. C.

TABLE 1. GENERAL DESCRIPTION OF 8 SELECTED SAMPLES OF THE LAZULITE-SCORZALITE SERIES

Code Name (See Table 2)	Locality	Habit and occurrence	Associated minerals	References
1. Dattus	4 Kms. north of the Diamantina-Serro road, 15 Kms. west of Dattas, Minas Gerais, Brazil.	Irregular masses in quartz vein in sericitic quartzite (tiacolumite).	Quartz, sericite, rutile.	E. R. Svoboda (personal communication)
2. Graves Mt.	Summit of Graves Mountain, Lincoln County, Ga.	Euhedral crystals in sericitic quartzite.	Quartz, kyanite, rutile, staurolite, garnet, pyrophyllite.	Shepard (1859) Watson (1912, 1921)
3. Clubbs Mt.	Southern terminus of Clubbs Mountain, Gaston County, N. C.	Irregular grains in quartz-kyanite vein in quartzite.	Same as Graves Mountain.	Hunter (1853) Smith and Brush (1853)
4. Black Eagle	Black Eagle andalusite claim, White Mountains, Mono County, Calif.	Irregular masses in quartz dike in schist.	Quartz, calcite, hematite.	Knopf (1917) C. D. Woodhouse (personal communication)
5. Breyfogle	Breyfogle Canyon, near Death Valley, Inyo County, Calif.	Irregular masses in quartz vein.	Quartz, muscovite, rutile.	Cloudman (1919) Sterrett (1911)
6. Corrego Frio	Head of Corrego Frio, near Divino, municipio of Conselheiro Pena, Minas Gerais, Brazil.	Irregular grains in border zone of granitic pegmatite.	Quartz, muscovite, albite, apatite, brazilianite, souzalite.	Pecora and Fahey (1949 a)
7. White Mt.	White Mountain andalusite mine, Mono County, Calif.	Irregular masses in quartz dike.	Quartz, andalusite, rutile, corundum, muscovite, diaspore, alunitite, pyrophyllite, augelite, woodhouseite.	Jeffrey and Woodhouse (1931) Kerr (1932) Lemmon (1937)
8. Victory	Victory mica mine, 2 miles northeast of Custer, Custer County, S. Dak.	Irregular grains in border zone of granitic pegmatite.	Quartz, muscovite, albite, tourmaline, triphyllite.	Pecora and Fahey (1949 b)

The material from Graves Mountain occurs as well-formed crystals in quartzite; two other specimens are from granitic pegmatites and five from quartz-rich veins or dikes in metamorphic rocks.

#### DESCRIPTIVE MINERALOGY

##### *Morphology*

Well-formed crystals of lazulite occur at but a few localities. Prüfer (1847) described the crystallography of lazulite from druses in quartz veins near Werfen, Salzburg, Austria, and Shepard (1859) figured crystals recovered from quartzite at Graves Mountain, Lincoln County, Ga. About 16 forms have been reported from these localities. Only three

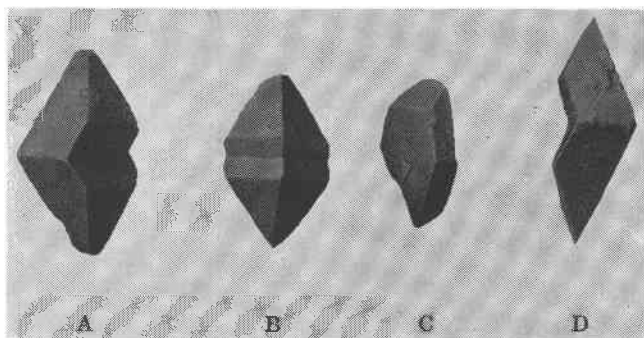


FIG. 1. Lazulite crystals from Graves Mountain, Ga. *A*, view of twinned bipyramid from the left side; *B*, twinned bipyramid from the front; *C*, tabular habit; and *D*, twinned tabular crystal from the right. (Natural size.)

forms are noted in Graves Mountain crystals— $p(111)$ ,  $e(\bar{1}11)$ , and  $l(101)$ . Dana (1892) and Hintze (1933) summarize the crystallography of lazulite from both localities. The twin laws noted are  $(223)$  and  $(100)$ . Baier (1941) reexamined lazulite specimens from several localities and reported several other twin laws as well.

Lacroix (1926) recorded crystals of lazulite from Madagascar as much as one centimeter in diameter and similar in habit to the Graves Mountain occurrence. Well-developed crystals are reported by Igelström (1855) as occurring in druses in vein quartz in Horrsjöberg, Wermland, Sweden.

In the Graves Mountain specimens available for this investigation, four crystal habits (see Fig. 1) are recognized: (1) bipyramids ( $p$  and  $e$ ), acute or stubby, symmetrical or asymmetrical, with or without a subordinate front dome ( $l$ ); (2) flat plates, representing malformed crystals with extension of one pair of pyramidal faces; (3) spindles, representing malformed crystals with extension of two pairs of pyramidal faces; and

TABLE 2. CHEMICAL ANALYSES, Mg:Fe MOLECULAR RATIOS, SPECIFIC GRAVITY, AND OPTICAL DATA FOR 8 SELECTED SAMPLES OF THE LAZULITE-SCORZALITE ISOMORPHOUS SERIES

(J. J. Fahey, analyst)

Code name in Table 1	1 Dattas, M.G.	2 Graves Mt., Ga.	3 Clubbs Mt., N.C.	4 Black Eagle, Calif.	5 Breyfogle Canyon, Calif.	6 Corrego Frio, M.G.	7 White Mt., Calif.	8 Victory, S.D.
MgO	11.97	10.38	10.02	8.42	7.98	4.23	3.38	2.93
FeO	2.80	3.95	5.22	7.96	8.94	14.74	16.27	17.06
MnO	None	None	0.03	0.01	0.14	0.11	0.07	0.10
CaO	0.08	0.06	0.06	0.08	0.13	0.02	0.08	0.03
Al <sub>2</sub> O <sub>3</sub>	32.55	32.49	32.37	32.34	31.53	30.87	30.48	30.80
Fe <sub>2</sub> O <sub>3</sub>	0.49	0.60	0.75	0.74	0.89	0.54	0.24	0.13
TiO <sub>2</sub>	0.16	0.20	0.20	0.16	0.23	0.10	0.32	0.10
P <sub>2</sub> O <sub>5</sub>	46.12	45.79	45.42	44.97	44.31	42.90	43.31	42.67
H <sub>2</sub> O+	5.90	6.48	5.83	5.72	6.27	5.86	5.46	6.10
				<del>100.34</del>		<del>ZnO</del> 0.17		
Total	100.07	99.95	99.92	100.40	100.42	99.54	99.61	99.92
Molecular ratio Mg:Fe	88:12	82:18	77:23	65:35	61:39	34:66	27:73	24:76
Specific gravity	3.118	3.122	3.160	3.190	3.190	3.268	3.272	3.327
Index of refraction (±.002)								
α	1.610	1.611	1.616	1.618	1.620	1.633	1.637	1.636
β	1.634	1.635	1.641	1.643	1.646	1.663	1.667	1.666
γ	1.644	1.645	1.652	1.654	1.656	1.673	1.677	1.676
2V (Calculated)	67°(-)	67°(-)	67°(-)	67°(-)	64°(-)	62°(-)	61°(-)	61°(-)

(4) bipyramids with a front reentrant representing crystals twinned on (100), or around the *c*-axis. In thin section the twin composition plane is an irregular, jagged surface essentially parallel to (001).

Most commonly lazulite and scorzalite occur as irregular masses mixed with other minerals. The mineral breaks with good cleavage along (110) and (101). As a result most of the grains in immersion lie so oriented as to give off-centered interference figures. Twin lamellae are common in specimens from most localities.

#### *Variation in chemical composition*

Chemical analyses of the 8 selected samples of lazulite and scorzalite are listed in Table 2 in the order of their increase in divalent iron. Only two of these analyses (nos. 6 and 8) have hitherto been published. The usual methods of analysis were used, except for the determination of divalent iron. The members of the lazulite-scorzalite isomorphous series are so difficultly soluble in the dilute solution of  $H_2SO_4$  and HF used in this determination that it was necessary to grind the samples to pass a 300-mesh sieve and, further, to collect the undecomposed portion found in the beaker after titration with permanganate and carry it again through the procedure. This was repeated as many as three times for the magnesium-rich members of the series.

For the samples in Table 2, FeO ranges from 2.80 to 17.06 per cent, and MgO correspondingly ranges from 11.97 to 2.93 per cent. Inasmuch as MgO+FeO makes up more than 99 per cent of the total RO, the use of the MgO:FeO molecular ratio is a reliable basis of reference on which the variation diagram of the series is established. The theoretically pure end members of the series have a composition as shown below:

Oxides	Lazulite $MgAl_2(PO_4)_2(OH)_2$	Scorzalite $Fe''Al_2(PO_4)_2(OH)_2$
MgO	13.34	00.00
FeO	00.00	21.57
$Al_2O_3$	33.74	30.54
$P_2O_5$	46.96	42.50
$H_2O$	5.96	5.39
Total	100.00	100.00

The specimens selected for special study therefore cover a wide enough range to establish reasonably the isomorphous series.

In Table 3 are listed 13 additional chemical analyses of lazulite—all obtained from published sources. These selected analyses include all that are judged to have been made from reasonably pure samples as well

TABLE 3. THIRTEEN SELECTED CHEMICAL ANALYSES OF LAZULITE SHOWING WIDE DIVERGENCE OF CHEMICAL COMPOSITION AND INADEQUATE DATA ON PHYSICAL PROPERTIES

Locality	9	10	11	12	13	14	15	16	17	18	19	20	21
Stubachstollen, Austria	Meixner	Paragatchai, Armenia	Mt. Sura-Iz, USSR	Keewatin, Canada	Chittenden, Vt.	Mt. Bity, Madagascar	Graves Mt., Ga.	Fischbach, Austria	Westana, Sweden	Gaston County, N. C.	Horsjöberg, Sweden	Stoddard, N. H.	Zeremat, Switz.
Analyst	Meixner	Shumilo	Beliakov	Hoffman	Gonyer	Pisani	Watson	Meixner	Blomstrand	Brush	Iglestrom	Gonyer	Gamper
MgO	11.83	12.10	12.54	13.84	12.38	9.19	9.08	9.87	9.05	10.04	8.58	6.45	8.64
FeO	0.69	1.30	2.08	2.09	2.59	3.95	3.99	4.58	7.82	8.17	10.55	11.58	11.91
MnO	0.01	0.03	—	—	—	—	—	0.08	0.18	—	trace	—	—
CaO	3.77	None	—	2.83	—	—	3.12	0.14	0.84	—	trace	—	—
Al <sub>2</sub> O <sub>3</sub>	31.36	32.58	32.99	29.14	33.11	35.22	33.92	33.75	32.82	31.70	32.86	31.83	28.06
SiO <sub>2</sub>	4.05	—	—	—	—	—	6.05	—	—	1.07	—	—	3.04
P <sub>2</sub> O <sub>5</sub>	42.16	46.66	46.38	46.39	46.17	45.30	38.25	45.88	43.83	43.76	42.52	45.10	42.97
H <sub>2</sub> O+	6.30	6.25	6.05	6.47	6.24	5.80	5.83	6.03	5.72	5.59	5.32	5.19	5.61
Total	100.15	99.97	100.31	100.76	100.49	99.46	100.24	100.39	100.36	100.32	99.81	100.15	100.23
Mol. ratio Mg:Fe	97:3	94:6	91:9	93:7	90:10	81:19	80:20	78:22	67:33	69:31	59:41	50:50	56:44
Specific gravity	—	—	3.04	3.044	3.08	3.12	2.96	3.081	—	3.122	2.78	—	—
Index of refraction	—	1.621	1.616	—	1.612	—	1.604	—	—	—	—	1.634	—
$\alpha$	—	1.625	—	—	1.634	—	1.633	—	—	—	—	1.659	—
$\beta$	—	1.634	1.634	—	1.643	—	1.642	—	—	—	—	1.668	—
$\gamma$	—	—	—	—	—	—	—	—	—	—	—	—	—
2V	—	70°(-)	67°(-)	—	—	—	—	—	—	—	—	63°(-)	—

Notes on analyses:

No. 10. FeO = 0.53; TiO<sub>2</sub> = 0.40; indices of refraction published as approximate values.

No. 11. Low birefringence indicates indices of refraction are approximate.

No. 13. Indices of refraction redetermined on analyzed sample:  $\alpha = 1.608$ ,  $\beta = 1.631$ ,  $\gamma = 1.642$ .No. 20. Indices of refraction redetermined on type specimen:  $\alpha = 1.628$ ,  $\beta = 1.654$ ,  $\gamma = 1.663$ ; Specific gravity = 3.24.

as a number of the less reliable analyses. More than two dozen analyses of lazulite in the literature are of no value in this study because of the significant amounts of SiO<sub>2</sub> or CaO reported.

K. J. Murata made a spectrographic study of 5 of the samples shown in Table 2. His determination of minor elements present in these samples is given below:

	Graves Mt.	Clubbs Mt.	Breyfogle Canyon	Corrego Frio	White Mt.
.X%	Ti	Ti	Ti	Zn, Mn	Ti
.0X%	Ni, Ca, Si, V	Mn, Ca, Si, V, Ba	Mn, Ca, Ba, Sr, Si, V	Ti, Ca, Si	Cu, Mn, Ni, Ca, Si, V
.00X%	Mn, Zr, Sr, Cr	Ni, Mo, Zr, Ga, Sr	Ni, Cr	Ni, Co, Ga	Sr, Cr
.000X%	Cu, Ba	Cu, Cr	Cu	Cr	Co, Ba

Not found in any: B, Be, La, Y, Sn, Pb, Ag, Bi, Cd, Ge, In, Tl, Re, Th, U, W, Cb.

#### *Invalidity of calcium lazulite*

Watson (1921), on the basis of 3.12 per cent CaO reported in lazulite from Graves Mountain, Ga. (Table 3, no. 15), and 2.83 per cent CaO in lazulite from Kewatin, Canada (Table 3, no. 12), suggested the name *calcium lazulite* to distinguish this variety from calcium-free lazulite. Meixner (1937), who analyzed several lazulite specimens from Austrian localities, and Lemmon (1937), who studied lazulite from White Mountain, Calif., both accepted the name of calcium lazulite as valid. In 38 chemical analyses of lazulite published prior to 1948, 23 show more than 0.40 per cent CaO and the highest value is 8.20 per cent. The present writers offer the explanation that the chemical analyses showing a significant percentage of CaO were probably made on impure samples.

It is noteworthy that CaO is an insignificant constituent in all of the samples studied by the authors. The new Graves Mountain analysis (Table 2, no. 2) shows 0.02 per cent CaO; whereas the original analysis by Watson (Table 3, no. 15) shows 3.12 per cent. The White Mountain analysis (Table 2, no. 7), which shows only 0.02 per cent CaO, likewise does not support the acceptance of the name calcium lazulite used by Lemmon (1937, p. 943) for material from the same locality.

In the impure fractions recovered by purification of the samples analyzed for this paper, such calcium-bearing minerals as calcite, apatite, and garnet are included in the great number of mineral impurities identified. It is likely, therefore, that either or both mineral impurity and



analytical technique may account for those chemical analyses containing significant amounts of CaO.

#### *Series nomenclature*

The name scorzalite applies only to those members of the isomorphous series whose Fe:Mg molecular ratio exceeds 50:50. Accordingly, the only three known scorzalite localities are represented by analyses nos. 6, 7, and 8 in Table 2. In theoretical considerations, lazulite and scorzalite might be used as names for the pure end members of the series. Following the usage suggested by Schaller (1930), ferroan lazulite and magnesian scorzalite are acceptable as names covering the range for the series. Thus as examples, lazulite from Graves Mountain (Table 2, no. 2) is properly identified as ferroan lazulite ( $Mg_{82}:Fe_{18}$ ) and scorzalite from White Mountain (Table 2, no. 7) as magnesian scorzalite ( $Mg_{27}:Fe_{73}$ ).

#### *Variation in specific gravity*

The specific gravity of the 8 selected samples ranges from 3.118 to 3.327. The progressive increase in specific gravity for the series, shown in Fig. 2, also is correlated with a progressive increase in ferrous iron. The specific gravity of the Chittenden sample is plotted as published and that for the Stoddard sample was determined on type material furnished by T. R. Meyers.

#### *Variation in optical properties*

The indices of refraction of the 8 members of the lazulite-scorzalite isomorphous series listed in Table 2 are plotted in Fig. 2. The progressive increase in  $\alpha$ ,  $\beta$ , and  $\gamma$  is correlated with the progressive increase in divalent iron. Birefringence likewise increases from 0.034 for lazulite to 0.040 for scorzalite. As shown in Fig. 2, the value of  $(\gamma - \beta)$  remains constant for the series, whereas  $(\beta - \alpha)$  is larger for scorzalite. The value of  $2V$  is somewhat smaller for scorzalite.

Data for only two other samples are plotted in Fig. 2. For one of these—Chittenden, Vt., (Table 3, no. 13)—the indices of refraction were re-determined on a duplicate of the analyzed sample; and for the other—Stoddard, N. H., (Table 3, no. 20)—only a type specimen could be provided for reexamination. Both the published and redetermined values are listed in Table 3 (and footnote), but the latter only are plotted on Fig. 2. It is unfortunate that precise optical data are not given with the many other published analyses.

The absorption and pleochroism of lazulite and scorzalite are among the most striking found in minerals. With one exception, blue is the dominating color for Y and Z, and X is colorless. Lazulite from Stoddard is green but blue lazulite is admixed with the green material. The ab-

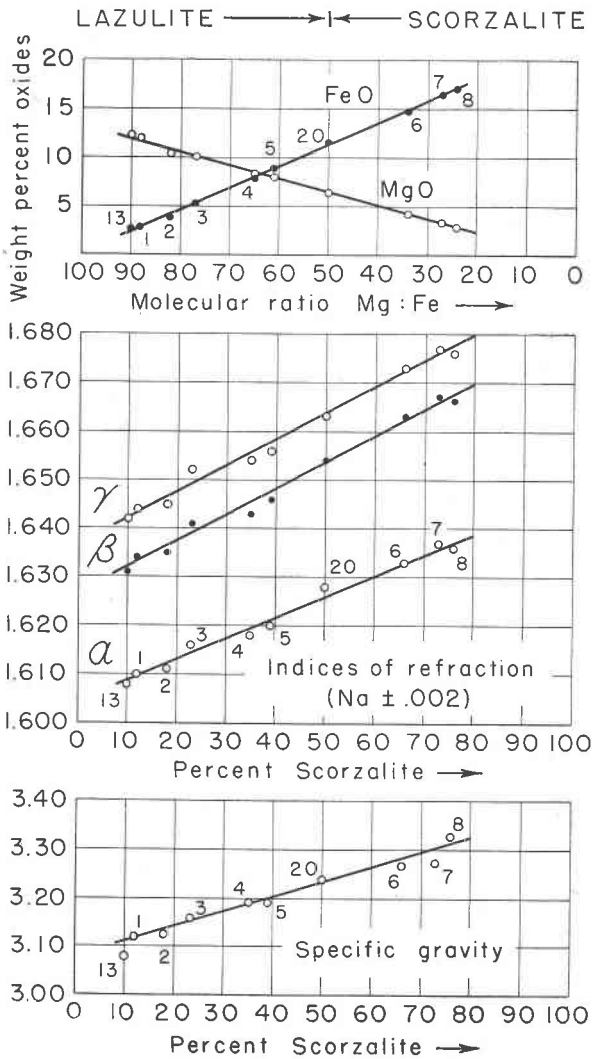


FIG. 2. Variation diagram of the lazulite-scorzalite isomorphous series. Sample numbers are identified in Tables 2 and 3.

sorption formula is the same for all specimens— $Z > Y \gg X$ , but the depth of color for Z and Y varies in specimens from different localities. Lazulite from Graves Mountain, Dattas, and Clubbs Mountain is light blue, for example, and the lazulite and scorzalite specimens from California are dark blue. There appears to be no definite correlation of color with composition, although it is noteworthy that the specimens obtained from quartz veins and dikes are darker blue than those in quartzite.

The dispersion of the optic axes is  $r < v$ , perceptible. The orientation, established on oriented thin sections, is: Monoclinic,  $Y=b$ ;  $X$  near  $c$ . Cleavage is good, (110) and (101).

### *X-ray data*

X-ray powder diffraction patterns of the eight samples in Table 2 are similar, and each is identified readily as a member of the isomorphous series. Detailed measurements by J. M. Axelrod of the  $d$ -spacings (filtered Cu radiation) of two samples are given below:

Lazulite (Graves Mt.)		Scorzalite (Corrego Frio)	
$d$	Intensity	$d$	Intensity
6.16	w	6.17	m
4.72	m	4.72	m
3.60	vwv	3.60	w
3.23 (broad)	s	3.24	vs
		3.20	vs
3.14	m	3.14	s
3.07	m	3.08	m
2.55	m	2.55	m
2.34	vw	2.34	vw
2.26	w	2.26	m
2.22	w	2.22	mw
2.05	vw	2.05	vw
2.01	w	2.01	m
1.977 (broad)	mw	1.989	mw
		1.973	m
		1.828	vw
1.807	w	1.811	mw
1.787	vw	1.787	w
1.684	vw	1.682	vw
1.618	w	1.622	mw
1.600	w	1.601	w
1.568 (broad)	m	1.574 (a group)	m
1.538	w	1.541	mw
1.407	w	1.412	w
1.389	vw	1.390	vw
1.274	m	1.277	m
1.185	vw	1.186	vw
1.113	vwv	1.115	vw
.8315 ( $\alpha_1$ )	vwv	.8318 ( $\alpha_1$ )	vw
.8270 ( $\alpha_1$ )	vw	.8294 ( $\alpha_1$ )	vw
.7836 ( $\alpha_1$ )	vw	.7849 ( $\alpha_1$ )	vw
.7739 ( $\alpha_1$ )	vw	.7746 ( $\alpha_1$ )	vw

Note:  $\lambda = 1.5418$  ( $\alpha_{av.}$ ) and  $1.5405$  ( $\alpha_1$ ).

The 0.78 Å line in the patterns of all the samples shows a small variation of spacing with divalent iron content, as shown below:

Sample	Per cent FeO	$d(\text{Å})$
Graves Mt.	3.95	0.7836
Breyfogle	8.94	.7844
Stoddard	11.58	.7846
Corrego Frio	14.74	.7849
White Mt.	16.27	.7856
Victory	17.06	.7853

The total variation is 0.0020. Interplanar spacings could be used, therefore, to place a member of the series approximately. Spacing alone would not give a reliable placement.

Berry (1948) calculated the unit cell for lazulite and scorzalite from cleavage pieces as follows:

Locality	Unit cell, in Å			
	a	b	c	$\beta$
1. Werfen, Salzburg	7.12	7.24	7.10	118°55'
2. Graves Mt., Ga.	7.14	7.27	7.16	119°18'
3. Churchill River, Canada	7.16	7.25	7.14	118°47'
4. Corrego Frio, Minas Gerais	7.15	7.32	7.14	119°00'

On the basis of his studies, Berry calculated the theoretical specific gravity of pure lazulite to be 3.14 and pure scorzalite to be 3.39. In comparison with the data plotted in Fig. 2, both of his values are higher than those obtained by extrapolation of the measured values.

#### OCCURRENCE

##### *General association*

Lazulite and scorzalite occur in many regions throughout the world where metamorphic rocks are intruded by granitic rocks. The age of these petrogenetic provinces ranges from pre-Cambrian to Cenozoic. The metamorphic rocks commonly exhibit a high-grade facies of metamorphism and contain veins, dikes, and replacement masses genetically related to the granitic rocks of the province.

The phosphate minerals intimately associated with lazulite or scorzalite in these regions include apatite, triphylite, wagnerite, berlinite, svanbergite, tetragophosphate, attakolite, kirrolite, trolleite, augelite, brazilianite, souzalite, and other unidentified phosphates. Admixed aluminum-rich minerals include kyanite, andalusite, sillimanite, corundum, pyrophyllite, spinel, dumortierite, and garnet. Other associated minerals are

quartz, albite, microcline, muscovite, beryl, tourmaline, rutile, ilmenite, hematite, magnetite, pyrite, chalcopyrite, calcite, and aragonite.

Lazulite or scorzalite is a common accessory mineral in several commercially significant nonmetallic mineral deposits. Among these are: (1) mica deposits in the United States, Brazil, and eastern Siberia; (2) andalusite deposits in California and Armenia; (3) diamond and gold placers in Brazil; (4) sapphire placers in the Himalaya Mountains; and (5) quartz crystal deposits in the Ural Mountains.

On the basis of information in the geological literature and field observations of Pecora, lazulite-scorzalite occurrences can be conveniently classified into four geological classes:

Class 1. Euhedra and subhedra in quartzite and associated metamorphic rocks.

Class 2. Anhedra in quartz-rich veins, dikes, and related replacement deposits in metamorphic rocks. Euhedra in druses are rare.

Class 3. Anhedra in granite pegmatites.

Class 4. Abraded fragments in alluvium or colluvium.

These occurrences are described below with representative localities for each group listed in Table 4.

#### *Occurrence in quartzite* (See Table 4, column 1)

The largest quantity of lazulite occurs in quartzite and quartzitic schist as individual or bunched grains scattered throughout the rock or aligned along quartzitic horizons in a sequence of foliated rocks. Aluminum-rich silicates and titanium-rich oxides are common mineral associates in this environment. The quartzite formations in many regions contain hematite-rich beds. In Madagascar, the lazulite-bearing quartzite beds are interlayered with dumortierite-rich schist.

#### *Occurrence in quartz-rich veins and dikes* (See Table 4, column 2)

Quartz-rich veins and dikes containing lazulite or scorzalite occur in the same metamorphic rocks described in Class 1, above, as well as in schist and gneiss of other regions. One dike, in Breyfogle Canyon, Calif., is reported to be several miles long, and another, at the White Mountain andalusite mine, is reported to be 300 feet thick. Most veins and dikes are much smaller. The lazulite or scorzalite occurs as irregular masses in the quartz or, rarely, as faceted crystals in druses. The quartz is of the massive or comb variety and clear or milky. Andalusite, rutile, kyanite, muscovite, and pyrophyllite are common mineral associates. Many rare phosphate minerals occur in the veins and dikes, particularly in Austria, Sweden, and California. The druses in the veins in Werfen, Austria, have provided many fine crystals of lazulite.

TABLE 4. GEOLOGIC AND GEOGRAPHIC OCCURRENCES OF LAZULITE AND SCORZALITE

	Class 1 Quartzite and quartzitic schist	Class 2 Quartz veins and dikes	Class 3 Granitic pegmatites	Class 4 Alluvium and Colluvium
United States	<ol style="list-style-type: none"> <li>Graves Mountain, Lincoln County, Ga. (Shepard, 1859; Watson, 1912 and 1921).</li> <li>Crowders Mountain and Clubbs Mountain, Gaston County, N. C. (Hunter, 1853; Smith and Brush, 1853; Genth, 1873).</li> </ol>	<ol style="list-style-type: none"> <li>Near Chittenden, Vt. (Palache and Gonyer, 1930).</li> <li>Near Stoddard, N. H. (Meyers, 1948)</li> <li>White Mountains, Mono County, Calif. (Knopf, 1917; Kerr, 1932; Lemmon, 1937; Jeffrey and Woodhouse, 1931).</li> <li>Breyfogle Canyon, near Death Valley, Inyo County, Calif. (Eakle, 1914; Sterrett, 1911).</li> <li>Several localities in California in Madeira, Alpine, and Kern Counties.</li> <li>In fault zone, Secs. 15 and 22, T. 37 S., R. 3 W., Grants Pass Quadrangle, southwestern Oregon. (F. G. Wells, pers. communication).</li> </ol>	<ol style="list-style-type: none"> <li>Numerous pegmatites in western N. H.</li> <li>Victory pegmatite, near Custer, S. Dak. (Pecora and Fahey, 1949b).</li> </ol>	Boulder in bed of stream near Chittenden, Vt. (Palache and Gonyer, 1930).
Austria		In Salzburg, near Werfen, Stubach, Huttau, and Tauernoo; and in Steiermark near Krieglach and Krumbach (Cornelius, 1931, 1936; Gamper, 1878; Hegemann, 1927; Prüfer, 1845; Rammelsberg, 1845; Sigmund, 1909).		
Belgian Congo				With kyanite in diamond-bearing river gravels in Moko district, Haut Vele. (Buttenbach, 1929).
Brazil	In sericitic quartzite near Diamantina and Dattas, Minas Gerais.	In quartzite near Diamantina and Dattas, Minas Gerais.	Corrego Frio, near Divino, município of Conselheiro Pena, Minas Gerais (Pecora and Fahey, 1948c).	In diamond placers of the Parauna River near Dattas, Minas Gerais (Ferraz, 1929) and of the Paraguassú River, Bahia (Hussak, 1899).

TABLE 4—(continued)

	Class 1 Quartzite and quartzitic schist	Class 2 Quartz veins and dikes	Class 3 Granitic pegmatites	Class 4 Alluvium and Colluvium
Canada		1. In Silurian (?) quartzite near mouth of Churchill River, Keewatin. (Bell, 1878-9; and Hoffman 1878-9). 2. Mistassini, Quebec. (Hoffmann, 1890-4).		
French Equatorial Africa	In sericitic quartzite with kyanite, in Chari. (Chevalier, 1907, p. 689).			
India				In sapphire placers, Himalayan Mts. (Latouche, 1890).
Madagascar	1. Near Ankofa, Western High Plateau, with dumortierite schist. (Lacroix, 1926). 2. Near Inalamaza, southeast of Betafo (Lacroix, 1912).	In Yakonankaratra, Mount Bity district. (Lacroix, 1902, 1908, and 1912).		In surface float, Mount Bity district (Lacroix, 1908).
Portugal		In quartzite and schist of the Serra do Roberedo, northern Portugal, (Schreiber, 1929).		
Sweden	In iron-bearing quartzites of Westanaå (Blomstrand, 1868).	1. Near Horrsjöberg, Ekdahls district, Wermland (Igelstrom, 1855). 2. In Westanaå (Blomstrand, 1868).		
Switzerland		Near Zermatt, (Gamper, 1875; and Kennigott, 1866).		
U.S.S.R.	With andalusite in sericitic quartzite near Kazakhstan (Beliakov, 1945).	1. In the Paragachai andalusite deposit, near Kapudzick, Kongur-Alanghez Range, Armenia. (Movsesyan, 1939, 1941). 2. In quartz vein in schist, Mount Surala, Near-Polar Urals. (Beliakov, 1945).	Mica-bearing pegmatites in eastern Siberia. (Beliakov, 1945).	

*Occurrence in granitic pegmatites* (See Table 4, column 3)

Lazulite or scorzalite in granitic pegmatites selectively occurs in the border zone rather than in the central zone. This spatial relationship has been already described by Pecora and Fahey (1948 *a* and 1948 *b*). A number of other phosphate minerals, extremely sodic plagioclase, quartz, muscovite, tourmaline, and beryl are the common mineral associates in this environment. Within regions containing pegmatites, lazulite or scorzalite is found only in those districts where other phosphate minerals are abundant. A number of specimens collected from several New Hampshire pegmatites are ferroan lazulite in composition.

*Occurrence in alluvium and colluvium* (See Table 4, column 4)

Fragments composed of quartz and lazulite have been recovered in the diamond-bearing colluvium near Diamantina, Minas Gerais, and the gem tourmaline district of Mount Bity, Madagascar. Grains of lazulite have been identified as one of the heavy mineral associates in diamond and gold placers in Bahia, Brazil, and Belgian Congo, and in the sapphire placers in northern India.

#### GEM LAZULITE

The lazulite recovered in many localities, particularly in association with clear quartz, is of such clarity that it has been cut into gem stones. Kerr (1926) assigned the name *berkeyite* to gem lazulite, and this variety name can apply to gem scorzalite as well.

#### ACKNOWLEDGMENTS

The authors are indebted to many individuals and institutions for their courtesy in supplying specimens for examination and for information concerning localities or specimens. Among the institutions are the U. S. National Museum, the Philadelphia Academy of Arts and Sciences, Harvard University, Yale University, University of South Carolina, Stanford University, California State Bureau of Mines, and the American Museum of Natural History.

Individuals who supplied specimens for examination include E. R. Swoboda, B. F. Buie, C. E. Hunter, and C. D. Woodhouse. G. E. Switzer of the Smithsonian Institution courteously aided the writers in assembling specimens from many localities.

The writers are indebted to a number of their colleagues in the Geochemistry and Petrology Branch of the U. S. Geological Survey for their interest and advice in the course of these investigations. They include Michael Fleischer, E. S. Larsen, 3d, Earl Ingerson, and W. T. Schaller for critical suggestions; J. M. Axelrod for  $x$ -ray work; K. J. Murata for spectrochemical work; and M. L. Lindberg for heavy liquid separations.



## REFERENCES

- BAIER, ERNST (1941), Zur Kristallographie des Lazuliths: *Central. Min., Abt. A*, 145-154.
- BELIAKOV, M. F. (1945), Lazulite from a quartz vein in the region of Mt. Sura-Iz in the near-Polar Urals: *Compt. Rend. (Doklady), Acad. Sci. URSS*, **47**, 124-126.
- BELL, R. (1878), Report, Geol. Survey of Canada, 196.
- BERRY, L. G. (1948), Structural crystallography of lazulite, scorzalite, and vezelyite (Abstract): *Am. Mineral.*, **33**, 750.
- BLOMSTRAND, C. W. (1868), Om Westaná Mineralier: *Ofv. K. Vet. Akad. Förh.*, **25**, 197-212.
- BRADLEY, W. W. (1939), Thirty-fifth annual report of the State Mineralogist: *California Div. Mines, Rept.*, **35**, 28.
- BUTTGEBACH, H. (1929), Diamants, lazulite, et atacamite do Congo Belge: *Publ. Rel. au Congo Belge, Ann. Soc. Geol. de Belgique*, **52**, Fasc. 3, C 66.
- CHEVALIER, AUGUSTE (1907), L'Afrique Central Francaise: 776 pp., Paris.
- CLOUDMAN, H. C., MERRILL, F. J. H., AND HUGUEMIN, E. (1919), *California Min. Bur., Rept.* **15**, 864.
- CORNELIUS, H. P. (1931), Neue Lazulithfunde in Mürztal: *Verh. Geol. Bund. Wien*, **52**, 93-94.
- (1936), Ein Vorkommen von Lazulith am Graulahnkopf: *Verh. Geol. Bund. Wien*, 115-116.
- DANA, E. S. (1892), System of Mineralogy, Sixth Edition, 798-799.
- EAKLE, A. S. (1914), *California Min. Bur., Bull.* **67**, 162.
- FERRAZ, L. C. (1929), Compendio dos Mineraes do Brasil, 645 pp., Rio de Janeiro, Brazil.
- GENTH, F. A. (1854), *Am. Jour. Sci.*, **18**, 410.
- (1873), *Proc. Am. Philos. Soc. Philadelphia*, **13**, 405.
- GAMPER, J. (1875), Alpine Phosphate: *Jahr. K. K. Geol. R. A.*, **28**, 611-618.
- (1878), Lazulith von Krieglach: *Verh. Geol. R. A.*, 118-121.
- HEGEMANN, F., AND STEINMETZ, H. (1927), Die Mineralgänge von Werfen in Salzkammergut: *Central. Min. Abt. A.*, 45-56.
- HINTZE, CARL (1933), Handbuch der Mineralogie: Bd. 1, Abt. 4, Pt. 2, (Lazulith), 1126-1134.
- HOFFMAN, C. (1879), *Report (Laboratory) Canada Geol. Survey*, p. 2H.
- (1891), Same, p. 66R.
- HUNTER, C. L. (1853), Minerals in North Carolina: *Am. Jour. Sci.*, **15**, 376-377.
- HUSSAK, E. (1899), *Min. Pet. Mitt.*, **18**, 353.
- IGELSTROM, J. (1855), Neue Schwedische Mineralien: *Jour. prakt. Chem.*, **64**, 252-254.
- JEFFREY, J. A., AND WOODHOUSE, C. D. (1931), A note on a deposit of andalusite in Mono County, California: *California Bur. Mines Rept.* **27**, 459-464.
- KENNGOTT, A. (1866), Die Mineralien der Schweiz.
- KERR, P. F. (1932), Andalusite and related minerals at White Mountain, California: *Econ. Geol.*, **27**, 629-643.
- (1926), A new gem, *Jewelers' Circular*, New York, **92**, No. 18, 67.
- KNOPF, ADOLPH (1917), An andalusite mass in the pre-Cambrian of the Inyo Range, California: *Wash. Jour. Acad. Sci.*, **7**, 549-552.
- LACROIX, A. (1902), Sur la Klaprothine de Madagascar: *Bull. Soc. Franc. Mineral.*, **25**, 115-116.
- (1908), Les mineraux des filons de pegmatite à tourmaline lithique de Madagascar: Same, **31**, 218-247.
- (1912), Les gisement de lazulithe du Vakonankaratra: Same, **35**, 95-97.
- (1913), Mineralogie de France, **5**, 40.

- (1926), Les schistes cristalline à dumortierte et lazulithe de Madagascar: *Compt. Rend.*, **183**, 405-408.
- LATOCHE, T. D. (1890), The sapphire mines of Kashmir: *Rec. Geol. Survey India*, **23**, 65-69.
- LEMMON, D. L. (1937), Woodhouseite, a new mineral of the Beudantite group: *Am. Mineral.*, **22**, 943.
- MEIXNER, HEINZ (1937), Das Mineral Lazulith und sein Lagerstättentypus: *Berg. Hutt. Jahrb. Montan. Hoch. Leoben*, **85**, 1-22 and 33-49.
- MEYERS, T. R. (1948), Green lazulite from Stoddard, N. H.: *Am. Mineral.*, **33**, 366-368.
- MOVSESYAN, S. A. (1939), The Paraga-Tchai deposit of andalusite: *Bull. Acad. Sci. URSS, Ser. Geol.*, 170-171.
- (1941), Lazulite in the andalusite-sericite-quartz rocks of the Kongur-Alanghaz Range, Armenia: *Compt. Rend. (Doklady) Acad. Sci. URSS*, **31**, No. 1, 31-32.
- PALACHE, CHARLES, AND GONYER, F. A. (1930), Lazulite from Chittenden, Vermont: *Am. Mineral.*, **15**, 338-339.
- PECORA, W. T., AND FAHEY, J. J. (1948a), The Corrego Frio pegmatite, Minas Gerais: Scorzalite and Souzalite, two new phosphate minerals: *Am. Mineral.*, **34**, 83-93.
- (1948b), Scorzalite from South Dakota, a new occurrence: *Am. Mineral.*, **34**, 685-687.
- PRUFER, KARL (1845), Ueber die Krystallform des Lazuliths: *Naturw. Abh. Wien*, Quarto 1, table 6 and pp. 169-170.
- RAMMELSBURG, C. F. (1945), Untersuchung einiger natürlicher und kunstlicher Verbindung der Phosphorsäure: *Ann. Phys. Chem., Poggendorff*, **64**, 251-271.
- ROGERS, A. F. (1912), Notes on rare minerals from California: *Columbia Univ. Sch. of Mines Quart.*, **33**, 375.
- SCHALLER, W. T. (1930), Adjectival ending of chemical elements used as modifiers to mineral names: *Am. Mineral.*, **15**, 566-574.
- SCHREITER, R. (1929), Ueber ein neue Lazulithvorkommen in Portugal: *Central. Min., Abt. A*, 111.
- SHEPARD, C. U. (1859), On lazulite, pyrophyllite, and tetradymite in Georgia: *Am. Jour. Sci.*, **27**, 36-39.
- SIGMUND, A. (1909), Die Minerale Niederösterreichs: Wien.
- SMITH, J. L., AND BRUSH, G. J. (1853), Reexamination of American minerals: *Am. Jour. Sci.*, **16**, 370.
- STERRETT, D. B. (1911), *U. S. Geological Survey, Mineral Resources for 1911*, Pt. 2, 1060.
- WATSON, T. L., AND WATSON, J. W. (1912), A contribution to the geology of Graves Mountain, Ga.: *Virginia Univ. Publ., Sci. Sect.*, **1**, 201-221.
- WATSON, T. L. (1921), Lazulite from Graves Mt., Ga.: *Wash. Jour. Acad. Sci.*, **11**, 386-390.