

THE CORREGO FRIO PEGMATITE, MINAS GERAIS:  
SCORZALITE AND SOUZALITE, TWO NEW PHOSPHATE MINERALS<sup>1</sup>

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ABSTRACT

This paper describes the structure and mineralogy of a pegmatite that has yielded three new phosphate minerals in recent years. The pegmatite is well zoned into three structural units of characteristic texture and mineral association. The minerals present include albite, muscovite, quartz, scorzalite (new mineral), souzalite (new mineral), brazilianite, apatite, zircon, tapiolite, and two unidentified phosphate minerals. Detailed descriptions, with chemical analyses, are given for scorzalite and souzalite, both of which are hydrous iron magnesium aluminum phosphates. Scorzalite is isomorphous with lazulite; the structural relationships of souzalite are not known.

INTRODUCTION AND ACKNOWLEDGMENTS

This paper contains a detailed description of the structure and mineralogy of the Corrego Frio pegmatite, Minas Gerais, Brazil, which has yielded three new phosphate minerals since its discovery in 1942. Two of these new minerals, scorzalite and souzalite, are described in this paper. Additional information on brazilianite, described in 1945, is also presented.

The authors are indebted to a number of colleagues in the Section of Geochemistry and Petrology, U. S. Geological Survey, for courteous assistance in mineral study. K. J. Murata made spectrographic analyses of scorzalite and souzalite that served as a guide for the chemical analyses by Fahey. J. M. Axelrod took x-ray powder diffraction photographs of

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the new phosphate minerals and prepared the mount reproduced in figure 3. E. S. Larsen 3d was helpful in the precise determination of the optical constants of scorzalite and souzalite. Theodore Botinelly made microchemical tests for phosphorus and other elements in two unidentified minerals in the collection. Marie L. Lindberg assisted in purifying two samples for analysis. E. S. Larsen 3d, Michael Fleischer, and Earl Ingerson, all of the Geological Survey, critically reviewed this paper and made several suggestions for its improvement.

#### LOCATION

The Corrego Frio pegmatite is in eastern Minas Gerais, Brazil (see Fig. 1) near the village of Divino and approximately 40 km. north of

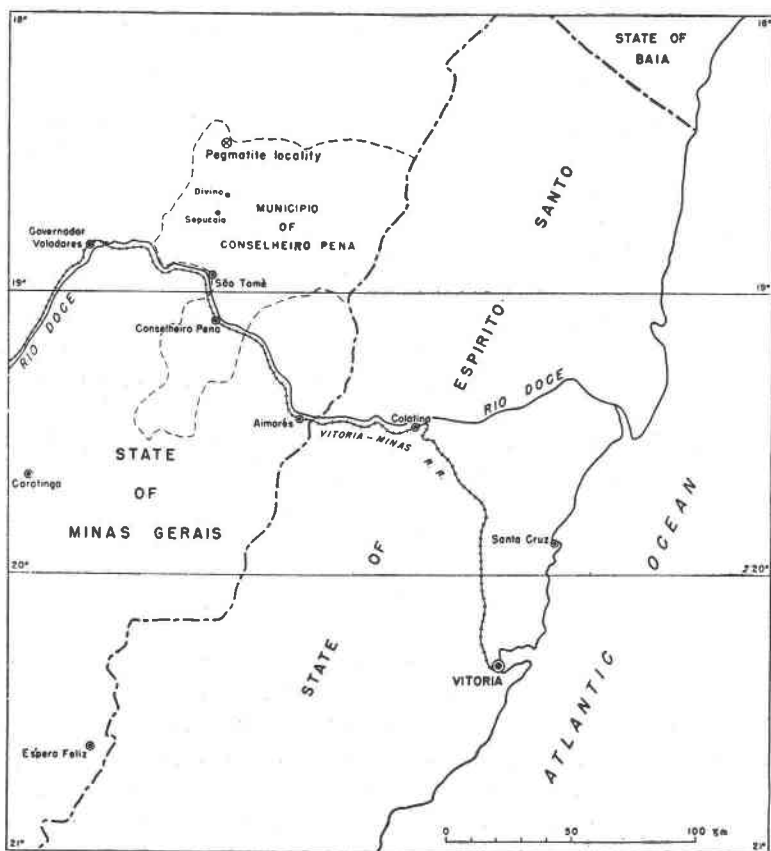


FIG. 1. Index map of a part of southeastern Brazil showing the location of the Corrego Frio pegmatite in the municipio of Conselheiro Pena, eastern Minas Gerais, Brazil.

São Tomé—a small town in the Rio Doce Valley connected by the Victoria-Minas Railroad with the cities of Victoria and Belo Horizonte. The pegmatite locality, 65 km. distant by horse trail from São Tomé, is on a steep slope south of the divide between the municipios of Conselheiro Pena and Mantena, at the head of Corrego Frio, a small tributary in the Rio Doce drainage system. Godoy (1945) has described its location in detail.

#### HISTORY

In 1942 a clear, greenish-yellow gem crystal was discovered at the Corrego Frio locality and was erroneously believed to be gem beryl or chrysoberyl. In the hope of recovering suitable material for semiprecious gems, approximately 80 cubic meters of material was excavated in 1943. The cleavability and relative softness of the crystals recovered led the miners to believe that they were recovering weathered specimens, and they later drove two short adits into unweathered pegmatite. Mining operations ceased in 1943 after it was established that the unknown mineral was by nature too soft and fragile for gem purposes. Since the discovery of the locality, crystals became distributed widely in eastern Minas Gerais. The mineral was subsequently described as brazilianite, a new sodium aluminum phosphate, by Pough and Henderson (1945).

In late 1944, E. R. Swoboda, an American mineral dealer, aware of the rarity of the crystals, obtained a lease on the locality and supervised additional excavation of the pegmatite. In 1945 and 1946 Mr. Swoboda offered brazilianite crystals for sale to mineral museums, mineral dealers, and mineral collectors in the United States.

The pegmatite locality was visited by the senior author (WTP) in June 1945 in connection with geological studies of the pegmatites of eastern Minas Gerais. To the suite of specimens collected on this visit Mr. Swoboda generously donated a number of his choice specimens for mineralogical study.

#### REGIONAL GEOLOGY

Eastern Minas Gerais is for the most part underlain by dark-colored schist and gneiss, light-colored granitoid gneiss, and sericitic quartzite. All of these rocks are assigned by Brazilian geologists to the pre-Cambrian. They contain thousands of granitic pegmatites, about 500 of which have been mined successfully for mica, beryl, tantalite and columbite, feldspar and kaolin, and gem stones. Pegmatite mining is one of the principal industries of eastern Minas Gerais. The general geology of the region and the detailed geologic features of the commercially significant pegmatites are described by Pecora and others (U. S. Geol. Survey Bulletin, in preparation).

## THE CORREGO FRIO PEGMATITE

The pegmatite exposed at the head of Corrego Frio strikes approximately east-west, dips steeply to the north, and is a tabular mass essentially in alignment with the schistosity of the biotite-garnet schist containing it. The pegmatite (Fig. 2) is exposed for about 18 meters on the surface and about 10 meters vertically. Its thickness ranges from three meters at the surface to one and one-half meters in the lower cross-cut adit shown in Fig. 2. A second pegmatite, probably similar to the one described in this paper, is partly exposed in the stream bed about 100 meters to the south.

On the basis of texture and mineral composition, the pegmatite can be subdivided into three units, named, from border to center (1) the massive border zone, (2) the crystal cavity zone, and (3) the quartz lens. Each of these units, illustrated in Fig. 2, is described below.

The massive border zone is exposed on both margins of the pegmatite where its contact with wall-rock schist is regular and well defined. At the surface (see sketch B-B') the two border units are equal in thickness, and together they make up about two thirds of the thickness of the pegmatite. In the lower adit the unit on the north side (hanging wall) is thicker, but the two units make up the same proportion of the pegmatite. In thickness the unit ranges from 30 cm. to one meter. The border zone is composed principally of massive albite and subordinately of quartz and muscovite. The cleavage faces of the albite are as much as 15 cm. wide. Thin, elongate, blue-green masses (scorzalite and souzalite), up to 25 cm. long, extend across the zone normal to the contact.

The crystal cavity zone has an irregular, poorly defined contact with the massive border zone. It ranges in thickness from a few centimeters, where it lies adjacent to the quartz lens, to one meter, where it comprises the central part of the pegmatite. This zone, in its thickest part and particularly near the edges of the quartz lens, is characterized by irregular vugs and crystal cavities bordered by stubby, terminated quartz crystals, well formed brazilianite crystals, and rhomboid masses of limonite-stained muscovite. Cleavelandite and porous and massive albite all occur in this zone, and in general, a higher proportion of quartz and muscovite occur here in the pegmatite.

The quartz lens has been almost entirely removed by mining. According to the miners, it was originally exposed on the surface for about 5 meters along the strike, where it had an estimated thickness of between one-half and one meter, and gradually thinned to disappear at a depth of about 4 meters. The lower edge of the lens was irregular and had a perceptible rake to the east. The unmined portion of the quartz lens, shown in Fig. 2, is bordered by a mixture of cleavelandite and muscovite.

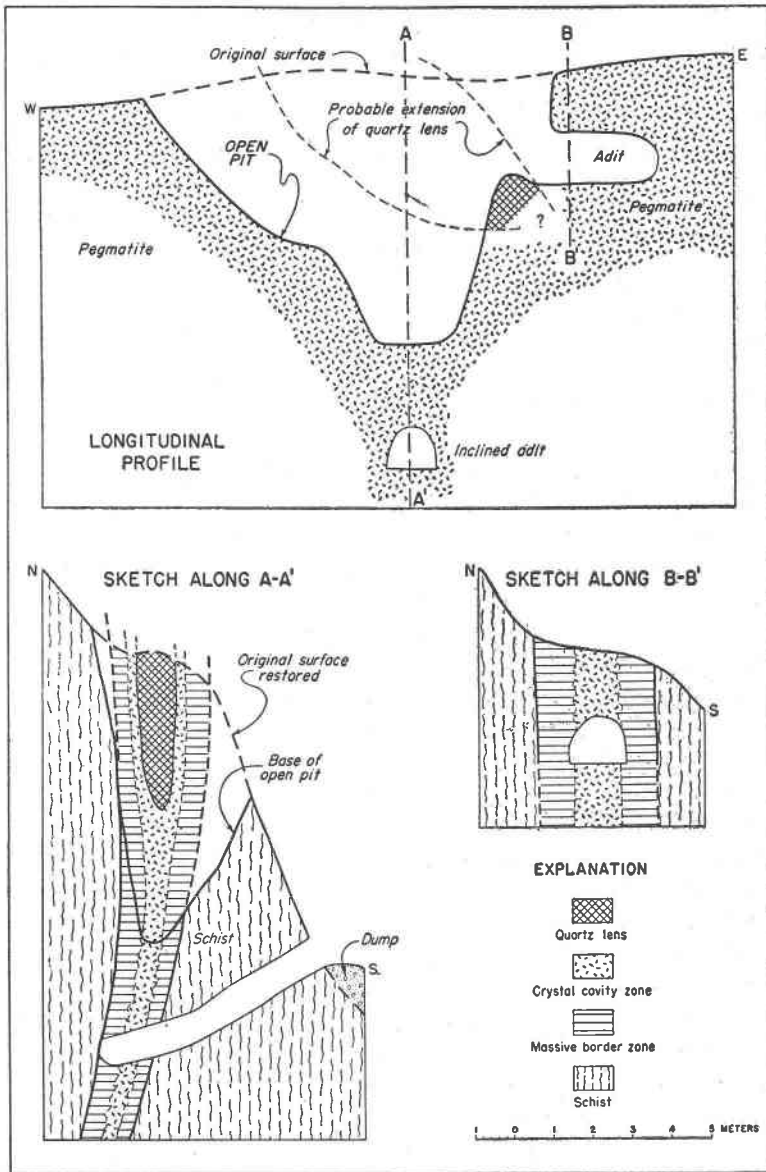


FIG. 2. Longitudinal profile and two cross-section sketches of the Corrego Frio pegmatite showing its zoning and structural relations.

## DESCRIPTIVE MINERALOGY

*Minerals in the pegmatite*

Albite, muscovite, and quartz make up more than 99 per cent of the pegmatite. Six phosphate minerals are present including scorzalite and souzalite—two new hydrous iron magnesium aluminum phosphates; brazilianite, a hydrous sodium aluminum phosphate first described in 1945; blue-green apatite; and two unidentified phosphate minerals. Tapiolite and zircon are rare accessory minerals. Beryl and tourmaline, found in the stream bed below the pegmatite, are not present in the mineral collection studied, nor were they observed in the exposed parts of the pegmatite.

*Scorzalite*

Scorzalite (scor'-za-lite) is named after Dr. Evaristo Pena Scorza, chief mineralogist of the Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil. It is dark blue, massive, and occurs principally in the border zone and outer margin of the crystal cavity zone. The largest mass of scorzalite observed is about 7 cm. across, and the masses are rarely free from admixed souzalite.

The physical properties of scorzalite are given in Table 1 and its chemical analysis in Table 2. The analysis gives the formula  $(\text{Fe}'' , \text{Mg})\text{Al}_2(\text{PO}_4)_2(\text{OH})_2$ , with  $\text{Fe}:\text{Mg}=2:1$ . This formula, which may also be written  $(\text{Fe}, \text{Mg})\text{O} \cdot \text{Al}_2\text{O}_3 \cdot \text{P}_2\text{O}_5 \cdot \text{H}_2\text{O}$ , is analogous to that of lazulite. The two minerals are similar in appearance and have, as shown in Fig. 3, identical x-ray powder diffraction patterns. They form a complete isomorphous series which is now under detailed investigation by the authors. It is here proposed that the series be characterized by the two names lazulite (Mg dominant) and scorzalite (Fe dominant). Intermediate members are named by the use of adjective modifiers. Thus the scorzalite from Corrego Frio might be termed magnesian scorzalite.

Scorzalite has higher indices of refraction and higher specific gravity than lazulite, as shown in Table 1 by a comparison of lazulite (Mg:Fe = 8:1) from Chittenden, Vt. (Palache and Gonyer, 1930) with scorzalite from Corrego Frio (Mg:Fe = 1:2).

*Souzalite*

Souzalite (sōze'-a-lite) is named after Dr. Antonio José Alves de Souza, former Director of the Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil. The mineral is green and occurs in irregular, fibrous masses so intimately associated with scorzalite that it is believed

TABLE 1. PHYSICAL PROPERTIES OF SCORZALITE AND SOUZALITE FROM MINAS GERAIS, AND LAZULITE FROM CHITTENDEN, VT.

	Scorzalite	Souzalite	Lazulite
Color (hand spec.)	dark blue	dark green	dark blue
Habit	massive	coarse fibrous aggregate	massive
Specific gravity	3.268 (pycnom.)	3.087 (pycnom.)	2.96
Hardness	6	5½-6	5-6
Crystal system	Monoclinic	Monoclinic (?)	Monoclinic
Indices of Refraction			
Na } X	1.633 (colorless)	1.618 (green)	1.604 (colorless)
(±0.002) } Y	1.663 (blue)	1.642 (blue)	1.633 (blue)
} Z	1.673 (blue)	1.652 (yellow)	1.642 (blue)
2V	62° (calc.)	68° (calc.)	64° (calc.)
Optical character	(-)	(-)	(-)
Dispersion of the optic axes	$r < v$ , percept.	$r > v$ , extreme and symmetrical	$r < v$ , percept.
Twinning	multiple	polysynthetic twins, max. extinction 12°; comp. pl. parallel to good cleavage	
Cleavage	good	one good cleavage, approx. at right angle to fair cleavage	Good
Orientation	Y = <i>b</i> X near <i>c</i>	X ⊥ cleavage plates; Z = elongation (near <i>c</i> ?)	

to be a hydrothermal alteration product of scorzalite. The largest mass of souzalite observed is 10 cm. across.

The physical properties of souzalite are given in Table 1 and its chemical analysis and formula in Table 2. Souzalite, like scorzalite, is a hydrous magnesium iron aluminum phosphate but its formula is of a different type:  $(\text{Mg, Fe}^{II})_3(\text{Al, Fe}^{III})_4(\text{PO}_4)_4(\text{OH})_6 \cdot 2\text{H}_2\text{O}$ . The x-ray powder pattern of souzalite (shown in Fig. 3 and in Table 3) does not resemble any of about 25 phosphate minerals with which it has been compared.

Because the type souzalite from the Corrego Frio pegmatite occurs as

TABLE 2. CHEMICAL ANALYSES AND MOLECULAR RATIOS OF SCORZALITE AND SOUZALITE FROM MINAS GERAIS, BRAZIL  
(J. J. Fahey, *analyst*)

Scorzalite					Souzalite			
Per cent		Ratio			Per cent		Ratio	
Al <sub>2</sub> O <sub>3</sub>	30.87	.3028	.3073		0.98	26.07	.2557	.2732
Fe <sub>2</sub> O <sub>3</sub>	.54	.0034						
TiO <sub>2</sub>	.10	.0011						
FeO	14.74	.2051	.3140	1.01	11.49	.1599	.4036	3.00
MgO	4.23	.1049						
MnO	.11	.0015						
ZnO	.17	.0021						
SnO	none	—						
CaO	.02	.0004						
P <sub>2</sub> O <sub>5</sub>	42.90	.3022	.3022	0.97	37.70	.2656	.2656	1.98
H <sub>2</sub> O—	none				none			
H <sub>2</sub> O+	5.86	.3252	.3252	1.04	12.04	.6681	.6681	4.98
Total	99.54				100.01			
Formula R <sub>2</sub> O <sub>3</sub> · RO · P <sub>2</sub> O <sub>5</sub> · H <sub>2</sub> O					2R <sub>2</sub> O <sub>3</sub> · 3RO · 2P <sub>2</sub> O <sub>5</sub> · 5H <sub>2</sub> O			
Mol. ratio MgO:FeO=1:2					Mol. ratio MgO:FeO=3:2			

Note: In the blowpipe flame, both minerals are infusible and disintegrate. Both minerals are soluble with difficulty in HCl.

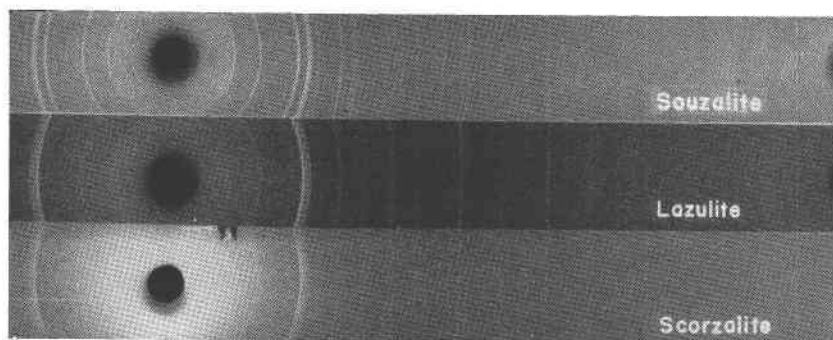


FIG. 3. X-ray powder diffraction photographs of scorzalite and souzalite from the Corrego Frio pegmatite, Minas Gerais, and of lazulite from Graves Mt., Georgia.



coarse, fibrous, twinned aggregates, the optical constants given in Table 1 are less reliable than those determined for scorzalite. The powdered mineral in immersion shows positive elongation, one very good cleavage normal to the  $Bx_a$  and a diagnostic dispersion of the optic axes.

TABLE 3. MEASURED  $d$  SPACINGS OF X-RAY POWDER PATTERN PHOTOGRAPH OF SOUZALITE FROM THE CORREGO FRIO PEGMATITE

(Filtered Cu radiation,  $\lambda = 1.5418 \text{ \AA}$ )

Legend: VS=very strong; S=strong; M=medium; MW=medium weak; W=weak; F=faint; B=broad.

(measurements by E. A. Cisney)

$\text{\AA}$	Intensity	$\text{\AA}$	Intensity
(3) 5.35	S	1.665	F
(2) 3.79	S	1.629	MW
3.57	F	1.574	W
3.25	W	1.530	MW
2.852	W	1.511	W
(1) 2.690	VS	1.448	MW
2.505	S	1.418	F
2.472		1.376	F
2.436		1.348	W
2.324	M	1.320	MW
2.246	F	1.228	MW
2.027	S	1.218	W
1.920	F	1.183	F
1.894	W	1.169	F
1.868	W	1.015	MB
1.794	F	.898	WB

### *Brazilianite*

The mineralogy of brazilianite from this locality has been described by Pough and Henderson (1945), Tavora (1945), and Hurlbut and Weichel (1946). A second occurrence of brazilianite in the Palermo pegmatite, North Groton, N. H., has been described by Frondel and Lindberg (1948).

George Switzer of the U. S. National Museum, Washington, D. C., examined thirty-seven new crystals from the Pecora-Swoboda collection. The crystals are all splendid, range in size from one-half to four centimeters across, and range in weight from less than one up to thirty-two grams. The most completely developed crystals are doubly terminated and have 20 to 30 faces. Switzer (personal communication) states: "The crystals have two habits, as described by Pough and Henderson (1945). The dominant habit is one with a narrow prism zone and considerable elongation parallel to [100]. This habit is similar to that recently de-

scribed for brazilianite from New Hampshire by Frondel and Lindberg (1948). In the less common of the two habits the prism zone is slightly elongated. No new forms were noted in the Brazilian crystals."

According to available sources of information, about 30 kg. of gem crystals and about 200 kg. of specimen "pound material" were recovered in the period 1943-46. Many of the gem crystals were destroyed in preparation for or during lapidation. According to two miners, one large many-faced crystal recovered in 1943 weighed about two kilograms and was broken up in an attempt to acquire gem-clear pieces. The largest crystal known to exist weighs approximately one kilogram and is on display in the U. S. National Museum in Washington. About a dozen other crystals are known whose weights range from 100 to 1,000 grams. Most of the crystals are less than an inch across and weigh less than 10 grams.

The indices of refraction for brazilianite, as determined from a number of specimens, are higher by 0.003 than those published by Pough and Henderson (1945), as shown below:

	Earlier data (published)	New data ( $\pm 0.001$ , Na)
$n_X$	1.598	1.601
$n_Y$	1.605	1.608
$n_Z$	1.617	1.620

#### *Other minerals*

Apatite occurs as dark-green, hexagonal crystals up to 3 cm. across, commonly clear or gemmy in quality. As indicated by its indices of refraction ( $\omega = 1.633$  and  $\epsilon = 1.630$ ), the mineral is probably a nearly pure fluorapatite.

Two unidentified phosphate minerals were noted in a few specimens. One, a light-brown mineral, occurs as an irregular intergrowth with altered scorzalite and its optical constants are: biaxial (+),  $2V = 50^\circ$  (estimated);  $r < v$ , strong;  $n_X = 1.607$ ,  $n_Y = 1.619$ ,  $n_Z = 1.632$ ; color in immersion is yellow. The second unidentified phosphate mineral occurs as dark-brown prismatic crystals in tiny alteration cavities in the light-brown phosphate mineral or in scorzalite. Its optical constants are: biaxial (+),  $2V = 20^\circ$  (estimated);  $n_X$  = (yellow-brown) = 1.705,  $n_Y$  = (dark-yellow) = 1.709,  $n_Z$  = (yellow) = 1.735; orientation,  $X$  = elongation; orthorhombic (?).

Tiny bipyramidal crystals of colorless zircon with the prism form subordinatedly developed are imbedded in a quartz-albite mixture and surrounded by the unidentified light-brown phosphate mineral.

Black, splendent, striated, tabular crystals of tapiolite are imbedded in albite in a few specimens. The crystals range up to one centimeter in

length. Its optical constants are: Uniaxial (+); birefringence, very high;  $\omega$  (brownish-red) and  $\epsilon$  (greenish) both higher than 2.0 (selenium melt); Absorption  $E > O$ , strong.

#### GENESIS

The well defined contact with schist and the texture of the border facies support the hypothesis of intrusion of a magmatic fluid which consolidated from border to center after emplacement. Similar relations exist for hundreds of other pegmatites in the region in many different kinds of host rock. Accessory phosphate minerals are common in many pegmatites near the Corrego Frio locality, but are rare in pegmatites of other districts in Minas Gerais. Within the granitic petrogenetic province of eastern Minas Gerais, with a locus in Conselheiro Pena, is a subprovince characterized by a relatively significant concentration of  $P_2O_5$ . With respect to other pegmatites in this subprovince, the Corrego Frio pegmatite is especially characterized by the presence of the rare phosphate minerals brazilianite, scorzalite, and souzalite, and by the conspicuous absence of potash feldspar.

The sequence of mineral formation in the pegmatite has not been established with certainty. The massive albite is characteristic of the early stage of pegmatite consolidation, whereas cleavelandite has formed in the late stage. Scorzalite, souzalite, and apatite are intermixed with massive albite in the border zone and are included by crystals of brazilianite and quartz in the crystal cavity zone. Shell-like intergrowths of apatite and massive albite in the outer margin of the crystal cavity zone indicate that apatite began to form near the end of massive albite formation. The field relations support the hypothesis of continuous crystallization from a magmatic to an autohydrothermal stage.

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