

PHOSPHATE MINERALS OF THE BORBOREMA PEGMATITES:  
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## ABSTRACT

The "alto" Boqueirão is a typical zoned pegmatite of the heterogeneous type, which carries some unusual minerals besides those of the normal beryl-tantalite assemblage. Among them are minor amounts of uraninite, altered in part to uranophane and other secondary compounds; native bismuth. Lithiophilite and many secondary phosphates appear as usual in the general inner portion of the pegmatite near the quartz core. Among these phosphates appear a pink variscite (carrying minor beryllium); metastrengite as sometimes showy blue coatings of minute crystals; huréaulite and minor tavorite as coatings on fractures of lithiophilite; stewartite, massive or in rare crystals; mitridatite (a hydrous calcium iron phosphate), in deep red blades, or very fine grained masses yellowish to greenish in color. A new mineral, chavesite is described. It is a hydrous calcium manganese phosphate, occurring as thin platy crystals coating lithiophilite, and associated with huréaulite and tavorite. Triclinic,  $a_0$  5.49  $b_0$  13.07,  $c_0$  5.79;  $\alpha$   $91^\circ 18\frac{1}{2}'$ ,  $\beta$   $108^\circ 3'$ ,  $\gamma$   $99^\circ 44'$ . The powder pattern resembles that of monetite, with which it may be isostructural. The stronger powder lines have the following spacings and intensities: 3.35 Å-10, 3.023 Å-2, 2.945 Å-3, 2.74 Å-2.

## INTRODUCTION

This is the second in a projected series of reports on the phosphates and associated minerals from the complex, lithium-bearing beryl-tantalite pegmatites of Northeastern Brazil. Their general position is shown on the key map (Fig. 1). The first report was on the "alto" Patrimônio, Murdoch (1955) and the present one describes the occurrence at the "alto" Boqueirão. The general geologic setting, described in some detail by Johnston (1945) and others, is the same for both deposits: complex pegmatites intruded into a pre-Cambrian complex and exposed by erosion of the rock cover to form the Borborema "planalto"—a more or less well developed peneplane of possibly Cretaceous age, standing now at an elevation of 500 to 550 meters above sea level. In the States of Paraíba and Rio Grande do Norte, later erosion has lowered the earlier surface so that the pegmatites stand up in relief on it, hence the name "alto" given to their outcrops. Even in Ceará, where there has been no such differential erosion, the name is still applied. The Pre-Cambrian rocks are largely gneisses and mica schists (the Seridó schist), which shows no pronounced regional trend, striking sometimes northwesterly, sometimes north-easterly.

## BOQUEIRÃO

The "alto" Boqueirão lies at the northern summit of a ridge reaching an elevation of about 300 meters above the surrounding territory, some

three kilometers southeast of the town of Parelhas, in the State of Rio Grande do Norte (see index map, Fig. 2). The following description is taken largely from Johnston (1945). Exposed contacts are nearly everywhere practically vertical. The outcrop is some 240 by 25 meters, pinching out to the west, and cut off sharply by the steep slope of the ridge to the east. Johnston's zone II (coarse textured quartz-feldspar) with considerable black tourmaline, composed about half the outcrop. His zone



FIG. 1. General map of area.

III (very large crystals), has huge microclines, partially kaolinized. The quartz core is multiple, and the various patches are made up largely of milky quartz, with occasional vugs carrying euhedral quartz crystals up to 200 kilograms in weight. The occasional phosphates occur, as is normal, in the third zone, and often close to the core. The following minerals are reported: arrojadite, vivianite, spodumene, lepidolite, rhodonite (?), pitchblende and its alteration products, metallic bismuth with bismutite, and some chalcocite. These are in addition to the usual quartz-feldspar mixture, with beryl, tantalite, muscovite, etc. Of these no arrojadite, rhodonite or chalcocite were observed by the writer. The "arrojadite" is presumably represented by lithiophilite and its alteration products (sicklerite etc.); the "vivianite" is apparently metastrengite, and the rhodonite (?) is probably a pink variscite which was observed in some of the alteration products. Several other minerals were observed

by the writer, and are included in the descriptive list. The series of alteration products of lithiophilite form an interesting group, essentially the same as that described from Patrimônio.

SPODUMENE is not abundant, and is commonly altered to a fine grained mica (probably muscovite), associated with fine grained botryoidal growths of cookeite.

LEPIDOLITE is sparingly present as rather fine grained aggregates,

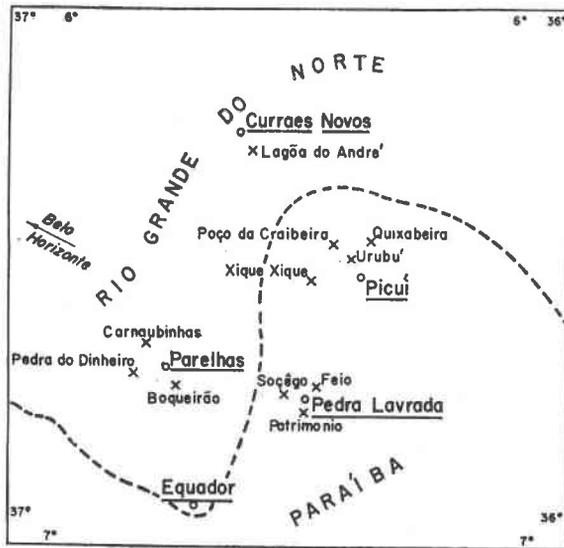


FIG. 2. Detailed map of area.

occasionally forming masses with curved surfaces, and associated with platy albite. Small prismatic grains of apatite have been seen in this association.

TANTALITE, apart from the commercially large masses, is occasionally found in the quartz-feldspar aggregate as small crystals of manganotantalite. A few tabular crystals of columbite appear in a similar matrix.

BISMUTH, as the native metal, has been found sparingly as grains or occasionally fair sized rough crystals interstitial to quartz, and associated with coatings and patches of secondary bismutite.

URANINITE. This has been reported as pitchblende, but one rough octahedral crystal was collected by the writer. This crystal is encrusted by a series of secondary minerals in thin concentric layers, and showing roughly three distinct zones. The outermost of these is uranophane, the

next an undetermined uranium mineral, or perhaps a mixture, in a number of thin, slightly varied layers, and the innermost perhaps meta-torbernite, although the powder pattern does not match too closely. In addition, a dark red mineral appears in thin veins in the uraninite, and is possibly soddyite. An analysis of the uraninite is given in Table I. Other oxidized uranium minerals, mainly meta-torbernite and meta-autunite, were found in minor amount, usually as powdery or poorly crystallized coatings on columbite.

TABLE 1. CHEMICAL ANALYSES

1		2		3	
U <sub>3</sub> O <sub>8</sub>	91.40	Fe <sub>2</sub> O <sub>3</sub>	1.00	FeO	1.97
PbO	5.92	FeO	13.23	Fe <sub>2</sub> O <sub>3</sub>	40.38
CuO	.04	MgO	1.11	Al <sub>2</sub> O <sub>3</sub>	1.20
Bi <sub>2</sub> O <sub>3</sub>	.015	CaO	.14	P <sub>2</sub> O <sub>5</sub>	39.18
FeO	.026	MnO	29.80	Mn <sub>2</sub> O <sub>3</sub>	—
Al <sub>2</sub> O <sub>3</sub>	.30	P <sub>2</sub> O <sub>5</sub>	45.00	H <sub>2</sub> O—	17.42
TiO <sub>2</sub>	.005	Li <sub>2</sub> O	8.68	H <sub>2</sub> O+	.198
CaO	.02		98.96		100.35
Na <sub>2</sub> O	.03				
SiO <sub>2</sub>	.31				
MnO	tr.				
H <sub>2</sub> O+	1.76				
H <sub>2</sub> O—	.54				
	100.37				

1. Uraninite, analysts, Johnson, Mathey & Co. Ltd. (Zn, Ni, Co, P<sub>2</sub>O<sub>5</sub>, As, Sb, Sn not detected). 2. Lithiophilite, analyst L. C. Peck. 3. Metastrengite, analyst E. L. Martin.

**VARISCITE.** One group of specimens shows a great variety of minerals apparently derived from the complete alteration of lithiophilite crystals (as shown by the outlines of the aggregates). These occur in a matrix of mixed albite, amblygonite and quartz. One of these minerals is variscite, in the form of a transparent crystalline crust, coating fracture surfaces and lining cavities. It was identified by optical properties, x-ray powder pattern, and crystal form. It varies from colorless through pale pink to raspberry red. Spectroscopic tests show the presence of a small amount of beryllium. This is in agreement with the findings on the pink variscite of the Sapucaia pegmatite (Mrose, priv. commun.)

**MITRIDATITE.** This rare mineral occurs in these same specimens in clear, red bladed grains: also probably fine-grained, massive, yellowish brown; and also perhaps in compact, almost earthy form, khaki colored. (This is somewhat doubtful, but the powder pattern is at least in moderate agreement with that of mitridatite.)

**METASTRENGITE** occurs as crusts, finely crystalline, and ranging in color from nearly white through pink to pale blue in this series of specimens. It also occurs in considerable amount, deep purplish blue, and often quite spectacular, as a late product of alteration of lithiophilite in other specimens. See Table I for analysis of this mineral.

**BERAUNITE**. An orange colored mineral occurring as blade-like grains in the variscite specimens, may perhaps be assigned to this species on the basis of a closely matching powder pattern.

**ROCKBRIDGEITE**. This mineral was found in small amount in dark green patches associated with alteration products of lithiophilite, and also in the variscite specimens as olive green, minute spherical clusters (probably partly altered).

**MANGANITE** and **CRYPTOMELANE**. The end-product of weathering besides some limonitic powders, is manganese oxide, which is sometimes crystalline, with powder pattern matching manganite, or in compact, steely masses which seem to be cryptomelane.

**HURÉAULITE**. This mineral is rather abundant as colorless or reddish brown crystalline crusts on fracture surfaces and in open spaces, in lithiophilite. It not infrequently has small, rather well developed crystals.

**TAVORITE**. Associated with some of the huréaulite, and approximately contemporaneous with it, tavorite occurs in yellowish green films or clusters of minute radiating crystals. This occurrence is identical with that at Patrimonio (Murdoch 1955).

**STEWARTITE**. Stewartite is rare, occurring in the outer zone of alteration of the lithiophilite. Rather poorly developed single crystals enabled the writer to make determinations of cell-size and symmetry which agree closely with those of this mineral from the Palermo Mine, New Hampshire, which is in process of study by Miss Mary Mrose. Powder patterns of stewartite made by the writer of material from Pala (the original locality), Palermo, Boqueirão and (quoted from Tennyson, 1956) from Hagedorf, are in good agreement with each other (see Table 2), and confirm the identity of the mineral from all four localities.

**LITHIOPHILITE**. This is the principal primary phosphate of the deposit (see Table 1 for analysis), and occurs as very coarse-grained aggregates, usually more or less altered to a considerable variety of secondary minerals, in general under oxidizing and hydrating conditions. Occasional small grains of green gahnite are associated with it, and rarely a little pyrite. Surrounding unaltered cores of lithiophilite are successive zones of sicklerite and purpurite, derived from the successive oxidation of the original mineral, accompanied by hydration and loss of lithium. This occurrence shows again the typical sequence which has been observed at Varuträsk, at Patrimonio, Pala and other localities. It is prob-

TABLE 2. X-RAY POWDER PATTERNS OF STEWARTITE  
Fe RADIATION, Mn FILTER.  $\lambda = 1.9373 \text{ \AA}$

Pala		Boqueirão		Hagendorf		Palermo	
<i>d</i>	I	<i>d</i>	I	<i>d</i>	I	<i>d</i>	I
10.04	10	10.10	10	9.926	10	10.08	10
8.39	$\frac{1}{2}$	—	—	—	—	8.35	$\frac{1}{2}$
—	—	7.44	$\frac{1}{2}$	—	—	7.47	$\frac{1}{2}$
6.73	7	6.75	4	6.751	6	6.75	5
5.88	3	5.93	2	5.869	3	5.91	2
5.035	5	5.03	2	—	—	5.02	3
4.877	2	4.85	$\frac{1}{2}$	4.817	4b	4.84	2
4.75	3	4.75	$\frac{1}{2}$	—	—	—	—
4.65	1	4.64	$\frac{1}{2}$	—	—	4.63	2
4.345	$\frac{1}{2}$	—	—	—	—	—	—
3.925	5	3.94	3	3.935	4	3.96	4
3.83	$\frac{1}{2}$	—	—	—	—	3.84	$\frac{1}{2}$
—	—	—	—	—	—	3.77	$\frac{1}{2}$
3.59	1	3.59	$\frac{1}{2}$	3.602	1	3.618	$\frac{1}{2}$
3.48	$\frac{1}{2}$	—	—	—	—	3.453	$\frac{1}{2}$
3.384	2	3.40	1	3.351	2	3.392	2
3.318	3	3.315	1	—	—	3.313	3
3.246	$\frac{1}{2}$	3.238	$\frac{1}{2}$	—	—	3.247	$\frac{1}{2}$
—	—	3.156	1	—	—	—	—
3.115	3	3.117	1	3.118	2	3.128	3
3.03	4	3.045	2	3.021	3	3.045	5
2.96	2	2.963	1	2.945	2	2.966	3
—	—	2.913	$\frac{1}{2}$	—	—	2.916	$\frac{1}{2}$
2.87	3	2.866	1	2.860	2	2.870	3
—	—	2.812	$\frac{1}{2}$	—	—	2.813	$\frac{1}{2}$
2.80	$\frac{1}{2}$	—	—	—	—	—	—
—	—	2.775	$\frac{1}{2}$	—	—	—	—
2.743	1	2.737	$\frac{1}{2}$	2.734	2	2.740	$\frac{1}{2}$
2.60	4	2.595	2	2.586	3	2.593	4
2.556	$\frac{1}{2}$	—	—	—	—	—	—
2.489	4	2.491	2	2.484	2	2.492	4
2.44	$\frac{1}{2}$	2.443	$\frac{1}{2}$	2.420	2	—	—
—	—	—	—	—	—	2.398	$\frac{1}{2}$
2.365	1	2.374	$\frac{1}{2}$	1.363	2	2.380	$\frac{1}{2}$
—	—	2.342	$\frac{1}{2}$	—	—	2.337	$\frac{1}{2}$
2.26	1	2.254	1	2.250	2	2.262	1
—	—	2.222	$\frac{1}{2}$	—	—	2.227	$\frac{1}{2}$
—	—	2.182	$\frac{1}{2}$	—	—	2.194	$\frac{1}{2}$
2.148	$\frac{1}{2}$	2.148	$\frac{1}{2}$	2.137	2	2.155	$\frac{1}{2}$
2.103	$\frac{1}{2}$	2.113	$\frac{1}{2}$	—	—	—	—
2.075	$\frac{1}{2}$	2.080	$\frac{1}{2}$	2.077	2	2.086	$\frac{1}{2}$
2.039	$\frac{1}{2}$	2.039	$\frac{1}{2}$	—	—	2.052	$\frac{1}{2}$
2.003	2	2.005	1	—	—	2.008	1
1.984	2	1.989	1	1.986	3	1.982	1
1.956	$\frac{1}{2}$	1.934	$\frac{1}{2}$	1.923	1	1.933	$\frac{1}{2}$
1.904	$\frac{1}{2}$	1.892	$\frac{1}{2}$	1.881	1	1.886	$\frac{1}{2}$
1.841	2	1.844	$\frac{1}{2}$	1.838	1	1.844	$\frac{1}{2}$
1.826	$\frac{1}{2}$	1.828	$\frac{1}{2}$	—	—	1.824	$\frac{1}{2}$
1.812	$\frac{1}{2}$	1.804	$\frac{1}{2}$	—	—	—	—
1.785	$\frac{1}{2}$	1.776	$\frac{1}{2}$	—	—	1.774	$\frac{1}{2}$

able that this sequence precedes the formation of huréaulite, since the latter is not uncommonly found intimately associated with the alteration products of sicklerite and purpurite as well as in cracks in the relatively fresh lithiophilite.

**CHAVESITE.** One specimen of lithiophilite shows, on fracture surfaces with huréaulite and tavorite, an intermittent thin colorless crystalline coating which sometimes shows poorly formed individual crystals. This appears to be a new mineral, tentatively named "chavesite" (pronounced shav-ez-ite), after Dr. Onofre Chaves, an engineer of the Brazilian Departamento Nacional da Produção Mineral. It is a hydrated calcium manganese phosphate, but not enough material is available for a chemical analysis. Hardness is near 3, cleavages, two good, in the prism zone, and nearly perpendicular to each other. Optically, biaxial positive, with 2V large, and indices  $\alpha$ 1.60,  $\beta$ 1.62,  $\gamma$ 1.65. Multiple twinning, with twin plane parallel to elongation of crystals. Extinction about  $30^\circ$  to the twin plane. A cleavage sliver which proved to be a single individual was used to determine the symmetry and cell-dimensions. Rotation, and Weissenberg equator, first and second layer lines about  $c$  show it to be triclinic with the following values:

$$\begin{array}{llll}
 a_0=5.49 & b_0=13.07 & c_0=5.79 & \\
 \alpha 91^\circ 18\frac{1}{2}' & \beta 108^\circ 3' & \gamma 99^\circ 44' & \\
 \lambda 84^\circ 58' & \mu 71^\circ 20' & \nu 78^\circ 00' & x_0'=0.325 \quad y_0'=0.093 \\
 a:b:c=1.4200:1:0.4438 & & & 
 \end{array}$$

The powder pattern (see Table 3) closely resembles that of monetite, and it has been suggested (Mrose, priv. commun.) that chavesite and monetite may be isostructural. The  $x$ -ray powder pattern can be adequately indexed using the above values for the elements.

**MINERAL A.** One of the variscite specimens shows an unidentified mineral, chestnut brown in color, occurring in radiating blades, and with one good cleavage. Qualitative tests show it to be an anhydrous (?) iron phosphate, with index well over 1.74; extinction parallel to elongation; biaxial negative, with 2V large; pleochroic pale to amber brown. The powder pattern gives the following spacings and intensities for the stronger lines: 3.145-10, 2.405-6, 3.57-5, 3.36-5, 4.74-4.

**MINERAL B.** Associated with tavorite are small, spherulitic aggregates, greenish white in color, of a calcium manganese phosphate with very high index of refraction. It is too fine-grained to make further optical determinations. The powder pattern does not appear to match that of any published mineral. Spacings and intensities of the stronger lines are as follows: 4.67-10, 3.42-5, 3.01-5, 2.52-2.

TABLE 3. X-RAY POWDER PATTERN OF CHAVESITE

Fe Radiation, Mn Filter,  $\lambda = 1.9373 \text{ \AA}$ 

Chavesite			Monetite <sup>1</sup>	
<i>d</i>	I	<i>hkl</i>	<i>d</i>	I
6.33	1	0,20		
5.03	$\frac{1}{2}$	100, 0 $\bar{1}$ 1		
4.56	$\frac{1}{2}$	$\bar{1}$ 11, 1 $\bar{2}$ 0		
4.35	$\frac{1}{2}$	030		
3.89	$\frac{1}{2}$	$\bar{1}$ 21		
3.69	1	130	3.72	1
3.54	$\frac{1}{2}$	120	—	
3.48	$\frac{1}{2}$	1 $\bar{2}$ 1	3.47	1
3.35	10	0 $\bar{3}$ 1, 1 $\bar{3}$ 1	3.38	10
3.24	$\frac{1}{2}$	1 $\bar{1}$ 1	—	
3.18	$\frac{1}{2}$	040	—	
3.13	$\frac{1}{2}$	121	3.13	3
3.076?	$\frac{1}{2}$	—	—	
3.023	2	111	2.99	9
2.945	3	130	—	
2.87	$\frac{1}{2}$	1 $\bar{3}$ 1	—	
2.81	$\frac{1}{2}$	131	—	
2.74	2	002, 0 $\bar{4}$ 1	2.76	8
2.72	2	121	—	
2.66	$\frac{1}{2}$	201, 0 $\bar{1}$ 2	—	
2.63	$\frac{1}{2}$	2 $\bar{1}$ 0, 012	—	
2.56	$\frac{1}{2}$	2 $\bar{2}$ 0, 050	—	
2.489	1	140, 1 $\bar{4}$ 1	2.50	5
2.305	1	051, 2 $\bar{2}$ 1	2.32	1
2.23	3	2 $\bar{4}$ 0, 141	2.26	6
2.198	1	220	2.21	2
2.155	$\frac{1}{2}$	151, 1 $\bar{6}$ 0	2.16	2
2.124	$\frac{1}{2}$	060, 150	—	
2.087	1	201, 221	2.10	2
2.034	1 b	250	2.04	1
1.978	1	230, 0 $\bar{6}$ 1	2.00	2
1.918	2	241	1.93	4
1.85	2	151, 003	1.86	6
1.79	2	301, 240	1.80	2
1.75	$\frac{1}{2}$	071	—	
1.725	3	310, 3 $\bar{1}$ 1	1.73	7
1.685	1	3 $\bar{3}$ 0	1.69	3
1.657	$\frac{1}{2}$	340, 161	1.65	2

<sup>1</sup> Comparative list of spacings for monetite from Prien & Frondel (1947), p. 949.

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