

# MORAESITE, A NEW HYDROUS BERYLLIUM PHOSPHATE FROM MINAS GERAIS, BRAZIL\*

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## ABSTRACT

Moraesite, a new hydrous beryllium phosphate from the Sapucaia pegmatite mine, Minas Gerais, Brazil, has the composition  $\text{Be}_2\text{PO}_4(\text{OH}) \cdot 4\text{H}_2\text{O}$ . It occurs in spherulitic masses, as distinct crystals, and as crusts with a coarse fibrous structure. Crystals are singly terminated needles, acicular [001] with forms {100} and {130} and faces (131) and ( $\bar{1}\bar{3}1$ ). Moraesite is monoclinic domatic (m, Cc), or prismatic (2/m,  $\text{C}_{2h}$ ). The specific gravity is 1.805 (measured), 1.806 (calculated). It is biaxial negative,  $2V=65^\circ$ ;  $\alpha=1.462$ ,  $\beta=1.482$ ,  $\gamma=1.490$ ;  $Z=b$ ,  $Y \wedge c=11^\circ$ . Chemical analysis gives  $\text{P}_2\text{O}_5$  34.76, BeO 25.28,  $\text{Fe}_2\text{O}_3$  0.11,  $\text{Al}_2\text{O}_3$  none,  $\text{H}_2\text{O}$  39.80, insol 0.30, total 100.25%. Possible space groups are  $\text{C}2/c$  ( $\text{C}_{2h}^2$ ) or  $\text{C}-c$  ( $\text{C}_s^2$ ). Unit cell dimensions are  $a_0=8.55$ ,  $b_0=36.90$ ,  $c_0=7.13$  Å;  $\beta=97^\circ 41'$ ; volume = 2229 Å<sup>3</sup>;  $Z=12$ . Moraesite has a superstructure, with a pseudocell in which  $b_0=12.30$  Å.

The mineral is named in honor of Dr. Luciano Jacques de Moraes, Brazilian geologist.

## INTRODUCTION

This paper presents a detailed mineralogical description of moraesite, a hydrous beryllium phosphate, the third new mineral from the Sapucaia pegmatite mine, Minas Gerais, Brazil. The first two new minerals, frondelite and faheyite, have been described in earlier papers (Lindberg, 1949; Lindberg and Murata, 1953). These published accounts are preliminary to a more complete description, now in preparation, of the structure and mineralogy of this pegmatite.

The Sapucaia pegmatite mine is in the municipio of Galilea, formerly a part of the municipio of Conselheiro Pena, in the Rio Doce valley region of eastern Minas Gerais. This mine, a substantial producer of mica and beryl, was one of a great number in the mica belt of Minas Gerais under investigation in the period 1942–45 by joint field parties of the U. S. Geological Survey and the Departamento Nacional da Produção Mineral (D.N.P.M.) of Brazil. A suite of mineral specimens from this property, collected intermittently during that period by W. T. Pecora and A. L. de M. Barbosa and examined in preliminary fashion by them in Rio de Janeiro, was turned over to M. L. Lindberg for complete identification and description. The original suite has been augmented by welcomed additions in the period 1950–53, from E. R. Swoboda, Robert Green-

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wood, Sumner Anderson, and Emerson I. Brown. The authors are particularly grateful to Mr. Greenwood for six hand specimens of excellently developed moraesite.

Moraesite is named after Dr. Luciano Jacques de Moraes, well-known Brazilian geologist, whose original geological investigations have added much to the knowledge of the geology of his beloved state of Minas Gerais. In his role of onetime Director of the D.N.P.M., he gave enthusiastic support to a program of collaboration between his bureau and the U. S. Geological Survey that has since produced a number of geological reports in Portuguese and in English.

The prototype specimens of moraesite have been deposited in the U. S. National Museum (USNM 106,577), Washington, D. C., and in the Museu Nacional, Rio de Janeiro.

#### OCCURRENCE

Phosphate minerals are most abundant in the central part of the granitic pegmatite at the Sapucaia mine, where they are associated with quartz, beryl, perthite, and muscovite. The pegmatite is oval-shaped in outcrop and internally well zoned (Pecora, *et al.*, 1950, p. 254). Large masses of triphylite and heterosite are the principal phosphate minerals, and individual masses of these minerals up to several tons in weight are not uncommon. In addition to moraesite, other phosphate minerals in-

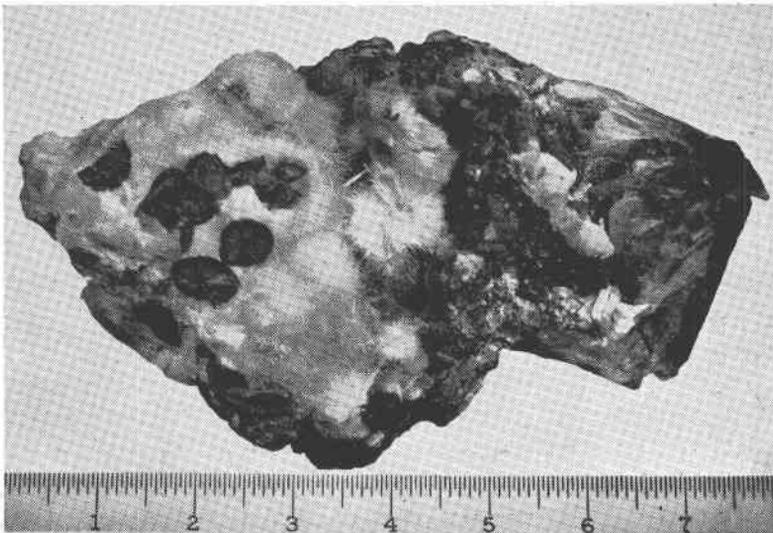


FIG. 1. Moraesite (white needles in crusts and radiating fibers) enclose spherulites of brown frondelite (on left) and are associated with books of muscovite (on right).

clude frondelite, faheyite, hureaulite, childrenite, apatite, roscherite, vivianite, and variscite.

Moraesite occurs in tufted or radial aggregates, in fibrous coatings, or in spherulitic masses on the walls of vugs that have developed in or adjacent to beryl, and on surfaces of albite, quartz, and muscovite (Fig. 1). Growths of moraesite frequently occur on the botryoidal surfaces of frondelite and contain unaltered fragments of beryl. On free surfaces, individual crystals form a fragile and delicate assortment of needles that grade into crusts with a coarse fibrous structure.

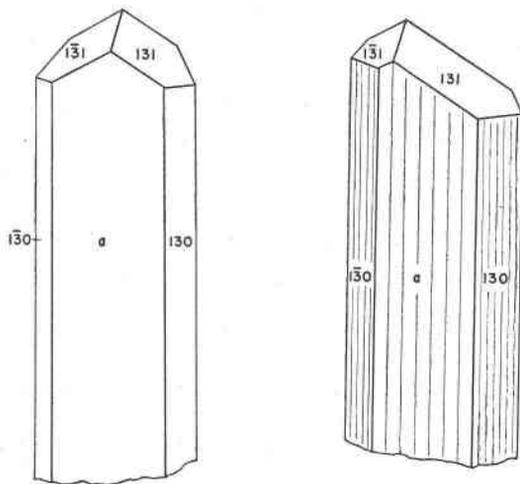


FIG. 2. Moraesite, idealized (left) and natural (right) habit of typical crystals of moraesite.

#### CRYSTALLOGRAPHY

Crystals are minute singly terminated needle-like laths, acicular parallel to the  $c$ -axis  $[001]$ , and tabular parallel to the orthopinacoid  $\{100\}$ . The pyramid face  $(131)^1$  is usually better developed than  $(\bar{1}31)$  and in some crystals gives the general appearance of a basal plane of a triclinic mineral. The faces  $(130)$  and  $(\bar{1}30)$  are better developed than  $(\bar{1}30)$  and  $(130)$ . The orthopinacoid and prism faces of the forms  $\{100\}$  and  $\{130\}$  are striated parallel to the  $c$ -axis. Figure 2 shows the idealized and natural habits of crystals. The dimensions of a typical crystal measured parallel to the crystal axes are  $(\parallel \text{ to } c) = 1.0 \text{ mm.}$ ,  $(\parallel \text{ to } a) = .05 \text{ mm.}$ ,  $(\parallel \text{ to } b) = .02 \text{ mm.}$

<sup>1</sup> The  $\{131\}$  and  $\{130\}$  forms are so indexed on the basis of  $x$ -ray data which gives the length of the  $b$ -axis as  $36.9 \text{ \AA}$  in the true cell. Moraesite has a superstructure, with a smaller pseudocell in which  $b = 12.3 \text{ \AA}$ . In this pseudocell the pyramid and prism become  $\{111\}$  and  $\{110\}$ .

The small number of crystal faces observed makes determination of the crystal class uncertain. X-ray data indicate a choice of classes: monoclinic, prismatic or domatic. Crystallographic data confirm a plane of symmetry, as indicated by the presence of pairs of faces (131) ( $\bar{1}\bar{3}\bar{1}$ ), (130) ( $\bar{1}\bar{3}\bar{0}$ ), and ( $\bar{1}\bar{3}\bar{0}$ ) ( $\bar{1}\bar{3}\bar{0}$ ). A two-fold axis would give as possible crystal faces the pairs (131) ( $\bar{1}\bar{3}\bar{1}$ ), ( $\bar{1}\bar{3}\bar{1}$ ) ( $\bar{1}\bar{3}\bar{1}$ ), (130) ( $\bar{1}\bar{3}\bar{0}$ ), and ( $\bar{1}\bar{3}\bar{0}$ ) ( $\bar{1}\bar{3}\bar{0}$ ). Crystals of moraesite are singly terminated, and the pyramid faces ( $\bar{1}\bar{3}\bar{1}$ ) and ( $\bar{1}\bar{3}\bar{1}$ ) have not been observed. However, all four faces of the form {130} are present, although not equally well developed. The ( $\bar{1}\bar{3}\bar{0}$ ) and ( $\bar{1}\bar{3}\bar{0}$ ) faces may be related to the (130) and ( $\bar{1}\bar{3}\bar{0}$ ) faces by a twofold axis (prismatic class), or they may be independently developed (domatic class).

The morphological data determined from measuring 20 crystals on the goniometer are summarized in Table 1. Owing to the small number of forms observed, and the poor quality of the reflections from the striated faces of the prism zone, it became necessary to make use of x-ray data to identify the crystal forms observed and to calculate the morphological

TABLE 1. MORPHOLOGICAL DATA

Form	No. of Times Observed	Quality	$\phi$		$\rho$	
			Range	Average	Range	Average
100	25	Poor	88°38'–90°45'	89°38'	89°28'–90°16'	89°51'
160	2	Poor	36°14'–36°28'	36°21'	89°55'–90°04'	90°00'
130	40	Fair	54°47'–56°09'	55°34'	89°41'–90°14'	89°57'
133	1	Fair		65°30'		25°00'
131	30	Fair-Good	59°00'–60°17'	59°22'	48°05'–49°20'	48°35'

TABLE 2. CRYSTALLOGRAPHIC ELEMENTS AND ANGLE TABLE  
(Calculated from x-ray data)

Monoclinic; prismatic $-2/m$ ( $C_{2h}$ ) or domatic $m$ ( $C_s$ )						
a:b:c=0.2317:1:0.1932; $\beta=97^\circ41'$						
$p_0:q_0:r_0=0.8339:0.1915:1$						
$r_2:p_2:q_2=5.222:4.355:1$ ; $\mu=82^\circ19'$						
$p_0'=0.8415$ ; $q_0'=0.1932$ ; $x_0'=0.1349$						
Forms:	$\phi$	$\rho$	$\phi_2$	$\rho_2=B$	C	A
100	90°00'	90°00'	0°00'	90°00'	82°19'	0°00'
160	35 58	90 00	0 00	35 58	85 30	54 02
130	55 26	90 00	0 00	55 26	83 40	34 34
133	65 04	24 37	67 27	79 53	26 31	67 48
131	59 18	48 38	45 41	67 28	42 10	49 49

elements and angle table given in Table 2. Measured values for  $\phi$  and  $\rho$  (Table 1) agree closely with the values calculated from  $x$ -ray data (Table 2).

#### PHYSICAL PROPERTIES

Moraesite is white. Some samples have a light-brown coating of iron oxide. Moraesite has two excellent cleavages, the traces of which on {100} are parallel to the  $b$ - and  $c$ -axes. The specific gravity, as measured on the sample used for analysis by means of an Adams-Johnston pycnometer of fused silica, is 1.805. That calculated from  $x$ -ray data is 1.806. The streak is white. The small size and perfect cleavage of the fibers made determination of the hardness impracticable.

Moraesite is biaxial negative, with  $2V = 65^\circ$ . Indices of refraction are:  $\alpha = 1.462$ ,  $\beta = 1.482$  and  $\gamma = 1.490$ . The optical orientation is:  $Z = b$ ,  $Y \wedge c = 11^\circ$ .

#### CHEMICAL PROPERTIES

Moraesite is a hydrous beryllium phosphate with formula  $\text{Be}_2(\text{PO}_4)(\text{OH}) \cdot 4\text{H}_2\text{O}$ . The analysis is given in Table 3. The presence of 0.11 per cent  $\text{Fe}_2\text{O}_3$  is probably due to the small amount of iron staining and is excluded in calculating the ratios.  $\text{Al}_2\text{O}_3$  was not found even though it was tested for by the fluorometric method (Weissler and White, 1946) which would have detected 0.01 per cent  $\text{Al}_2\text{O}_3$ .

TABLE 3. CHEMICAL COMPOSITION OF MORAESITE

	Analysis	Recalcd. to 100% after deducting insol. and $\text{Fe}_2\text{O}_3$	Ratios	Equivalents	Atoms per* unit cell
Insol.	0.30				
$\text{P}_2\text{O}_5$	34.76	34.82	0.2453	Be 1.0124	24.5
BeO	25.28	25.32	1.0124	P 0.4906	11.9
$\text{Fe}_2\text{O}_3$	0.11			O 4.4509	107.9
$\text{Al}_2\text{O}_3$	none			H 4.4240	107.2
$\text{H}_2\text{O}$	39.80	39.86	2.2120		
	100.25	100.00			

USNM 106,577

M. L. Lindberg, analyst.

Formula  $\text{Be}_2\text{PO}_4(\text{OH}) \cdot 4\text{H}_2\text{O}$ ,  $Z = 12$ .

\* Obtained by multiplying equivalents by  $.01 \times 2423$ , the weight of unit cell on a chemical scale in which  $\text{O} = 16$ .

Moraesite is soluble in dilute HCl, HNO<sub>3</sub>, and H<sub>2</sub>SO<sub>4</sub>. When heated, it decrepitates, giving off water, but does not fuse into a globular mass.

#### X-RAY CRYSTALLOGRAPHY

Moraesite has no apparent structural relationship to any known phosphate mineral. X-ray rotation and Weissenberg pictures for the 0-, 1-, and 2-levels were taken, with [100] and [001] as rotation axes; also rotation and 0-level pictures were taken about [010]. The plane net patterns and reflections observed<sup>2</sup> indicate a centered monoclinic lattice with choice of space groups C2/c(C<sub>2h</sub><sup>6</sup>) or C-c(C<sub>s</sub><sup>4</sup>).

Examination of the Weissenberg pictures taken about the c-axis shows that strong, medium, and weak spots occupy positions indicating a large diamond-shaped reciprocal pseudocell; additional weak spots occupy positions indicating a smaller true reciprocal cell, also diamond shaped, in which the length of the a\*-axis remains unchanged, and the length of the b\*-axis is one-third that of the larger reciprocal pseudocell. The same relations (thirthing of the b\*-axis) are observed in pictures taken about the a-axis, except that the plane net pattern is rectangular. The rotation picture about the b-axis gives strong 0, 3, 6, 9, 12, and 15 layers, with scattered spots on the in-between levels barely visible.

In Table 4 are given the cell dimensions determined from single crystal data and the powder-diffraction data including calculated spacings for the various planes observed in the Weissenberg photograph. Calculations were made only for planes observed, i.e., planes for which either h or l = < 2 or k = 0 although other planes may have contributed to the intensity of some reflections. Similarly, calculations were made only for hkl planes in which the k index was 0 or divisible by 3, since the intensity of reflections from other planes is too weak to consider that they form a major contribution to the d-spacings measured on the powder photograph. A rotation picture of a needle [001] was taken in the powder camera, and the hk0 reflections were scaled off on the powder photograph as an additional aid to indexing.

#### PARAGENESIS

Moraesite formed late in the mineral sequence at the Sapucaia granitic pegmatite mine. Early minerals to form include quartz, albite, perthite, beryl, muscovite, and triphylite. Hydrothermal fluids generated within the pegmatite produced a large variety of secondary minerals, which have been deposited as spherulitic masses, fibers, needles, and equant crystals in cavities, in or adjacent to quartz, beryl, muscovite, triphylite, and other minerals.

<sup>2</sup> Reflections observed on hkl:h+k even, l even or odd; on hol:h even and l even; on okl:k even, l even or odd; on oko:k divisible by 6 only.

TABLE 4. X-RAY DIFFRACTION DATA FOR MORAESITE  
 IRON RADIATION, MANGANESE FILTER

Single Crystal Data											
$a_0 = 8.55 \pm .04 \text{ \AA}$ ; $b_0 = 36.90 \pm .18$ (true cell), $12.30 \pm .06 \text{ \AA}$ (pseudocell); $c_0 = 7.13 \pm .04 \text{ \AA}$ ; $\beta = 97^\circ 41' \pm 15'$ ; volume = 2229 $\text{\AA}^3$ ; cell contents 12 $\text{Be}_2\text{PO}_4(\text{OH}) \cdot 4\text{H}_2\text{O}$ ; cell weight = 2433											
Powder Diffraction Data											
I	d meas. $\text{\AA}$	Index	d calc. $\text{\AA}$	I	d meas. $\text{\AA}$	Index	d calc. $\text{\AA}$	I	d meas. $\text{\AA}$	Index	d calc. $\text{\AA}$
10	7.00	130	6.98	1	2.116	400	2.118	$\frac{1}{2}$	1.512	264	1.511
4	6.15	060	6.15			$\bar{2}$ .12.2	2.115	1	1.492	3.21.0	1.492
3	5.28	$\bar{1}$ 31	5.26	4	2.050	0.18.0	2.050	$\frac{1}{2}$	1.472	4.18.0	1.473
6	4.24	200	4.24			$\bar{2}$ 63	2.056			$\bar{4}$ .18.1	1.470
$\frac{1}{2}$	3.69	190	3.70			$\bar{3}$ 92	2.049	2	1.440	2.24.0	1.445
1	3.54	002	3.54	3	1.998	460	2.002			$\bar{1}$ .15.4	1.441
1	3.49	260	3.49			$\bar{1}$ .15.2	1.999			532	1.440
$\frac{1}{2}$	3.34	$\bar{1}$ 91	3.35	2	1.964	0.18.1	1.969			3.21.1	1.439
9	3.278	$\bar{2}$ 61	3.273			2.12.2	1.963	1	1.409	600	1.411
3	3.198	191	3.195	2	1.937	193	1.936			$\bar{3}$ .21.2	1.411
3	3.071	0.12.0	3.075			$\bar{4}$ 02	1.934			0.24.2	1.410
		062	3.066	1	1.870	0.12.3	1.870			$\bar{1}$ .21.3	1.408
6	3.023	132	3.022	$\frac{1}{2}$	1.843	$\bar{4}$ 62	1.845	1	1.396	5.15.0	1.395
$\frac{1}{2}$	2.910	202	2.913			2.18.0	1.845	1	1.378	065	1.378
6	2.819	0.12.1	2.819	$\frac{1}{2}$	1.813	$\bar{2}$ .18.1	1.811	$\frac{1}{2}$	1.359	$\bar{2}$ .24.2	1.360
3	2.753	330	2.753	3	1.757	3.15.1	1.756	$\frac{1}{2}$	1.341	5.15.1	1.341
$\frac{1}{2}$	2.685	$\bar{3}$ 31	2.678			$\bar{1}$ 34	1.760			3.21.2	1.341
1	2.631	$\bar{2}$ 62	2.632	$\frac{1}{2}$	1.738	4.12.0	1.744			$\bar{6}$ 62	1.340
		$\bar{1}$ 92	2.630			$\bar{4}$ .12.1	1.736			0.18.4	1.339
1	2.479	192	2.482	$\frac{1}{2}$	1.720	1.21.0	1.721	$\frac{1}{2}$	1.333	*	
		2.12.0	2.488	$\frac{1}{2}$	1.677	$\bar{5}$ 31	1.684	$\frac{1}{2}$	1.316		
1	2.459	331	2.458			$\bar{1}$ .21.1	1.682	$\frac{1}{2}$	1.307		
1	2.405	2.12.1	2.407			$\bar{2}$ .18.2	1.676	$\frac{1}{2}$	1.289		
2	2.354	1.15.0	2.362	1	1.651	462	1.655	$\frac{1}{2}$	1.274		
		262	2.357			4.12.1	1.652	$\frac{1}{2}$	1.262		
4	2.325	390	2.326	2	1.639	1.15.3	1.638	$\frac{1}{2}$	1.251		
		$\bar{3}$ 32	2.323			$\bar{4}$ .12.2	1.637	1	1.245		
		0.12.2	2.320	$\frac{1}{2}$	1.586	531	1.586	$\frac{1}{2}$	1.229		
$\frac{1}{2}$	2.288	2.12.1	2.291	$\frac{1}{2}$	1.571	591	1.570	2	1.220		
		$\bar{3}$ 91	2.285			590	1.566	$\frac{1}{2}$	1.190		
2	2.141	391	2.141			1.21.2	1.564	1	1.183		
				$\frac{1}{2}$	1.560	204	1.559				

Accuracy of reading: lines with intensity  $\frac{1}{2} \pm .2$  mm; lines with intensity  $> 1 \pm .1$  mm

\* These lines have not been indexed because the large number of choices made results meaningless.

Conditions of formation of moraesite were such as to effect a simple separation of this hydrous beryllium phosphate from other constituents present in the hydrothermal solutions attacking beryl and other pegmatite minerals. Additional elements in the hydrothermal solutions, principally iron, manganese, and aluminum, were combined to form other secondary minerals of complex composition. It is noteworthy that such a distinct and pure mineral of as simple a composition as moraesite could be formed under these conditions.

#### ACKNOWLEDGMENTS

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