STRUCTURE AND MINERALOGY OF THE GOLCONDA PEGMATITE, MINAS GERAIS, BRAZIL*

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Abstract

The granite pegmatite at the Golconda mine in Minas Gerais, Brazil, is a zoned, sheet-like mass in schist. Most of the estimated 1,000 metric tons of mine-crude muscovite mined since 1908 has been recovered from a mica shoot in the upper border zone. Detailed descriptions are given for garnet, cookeite, beryl, cassiterite, manganotantalite, and microlite—all of which minerals occur in the central zone.

Introduction and Acknowledgments

The Golconda pegmatite mine, one of the oldest mica producers in Brazil, was examined and mapped in detail in 1943–45 by Pecora and Barbosa in conjunction with a general program of the United States and Brazilian Governments aimed at increasing mica production and mica reserves in Brazil during World War II. The mineral collections made at that time were recently studied by Pecora, Switzer, and Myers in the laboratories of the U. S. Geological Survey and the U. S. National Museum.

The authors are grateful to a number of persons for aid during the field and laboratory investigations. Mr. José Nogueira, of Santos-Nogueira Company, operators of the Golconda mine, supplied production data; C. D. Foster and J. T. Cook, engineers of the U. S. Commercial Company, extended many courtesies in the field. The authors are grateful to Michael Fleischer, Earl Ingerson and K. J. Murata for critical reading of the manuscript and to S. B. Levin for calculation of the components of a garnet specimen.

Location and History

The Golconda pegmatite mine is located in the Rio Doce Valley, Brazil, 34 km by road northwest from the town of Governador Valadares (formerly Figueira)—a well-known mica center in eastern Minas Gerais that has rail, road, and airplane routes to Rio de Janeiro, Victoria, and Belo Horizonte.

Since the discovery of the Golconda pegmatite in 1908, the property has yielded muscovite mica, gem tourmaline, and gem beryl having an estimated total value of $100,000. In 1944 about 400 tons of mine-crude

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mica were recovered from open-pit operations (Fig. 1) by use of heavy, mechanical earth-moving equipment. In 1945 new underground workings were driven in the mica shoot along the hanging wall of the pegmatite.

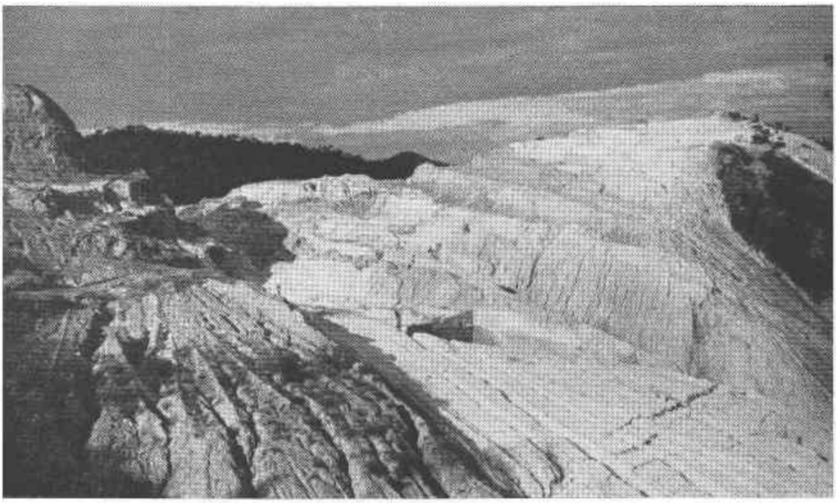

FIG. 1. View of the Golconda open pit in 1944 showing the area stripped by heavy mechanical equipment.

REGIONAL GEOLOGY

The region near Governador Valadares is underlain essentially by metamorphic rocks into which have been emplaced a great number of granitic pegmatites. The metamorphic rocks, principally schist and gneiss are considered by Brazilian geologists to be Archean in age. Although the age of the pegmatites is not known with certainty, a late pre-Cambrian or early Paleozoic age is in general accord with geologic evidence and age determinations based on analyses of radioactive minerals. The regional relations of the mica-bearing pegmatites in Minas Gerais are discussed by Pecora and others (1950).

DESCRIPTION OF THE PEGMATITE

Form, Size, and Structure

The Golconda pegmatite, one of several sheetlike pegmatites in the Rio Doce Valley, ranges in thickness from 3 to 11 meters and is nearly horizontal (Fig. 2). In the western part, the pegmatite has a well-defined arch or "roll"—a characteristic feature of many sheetlike pegmatites in this region. The crest of the roll pitches about 10°N. and has been exposed by mining for about 100 meters. In an east-west direction the pegmatite is exposed for about 300 meters.

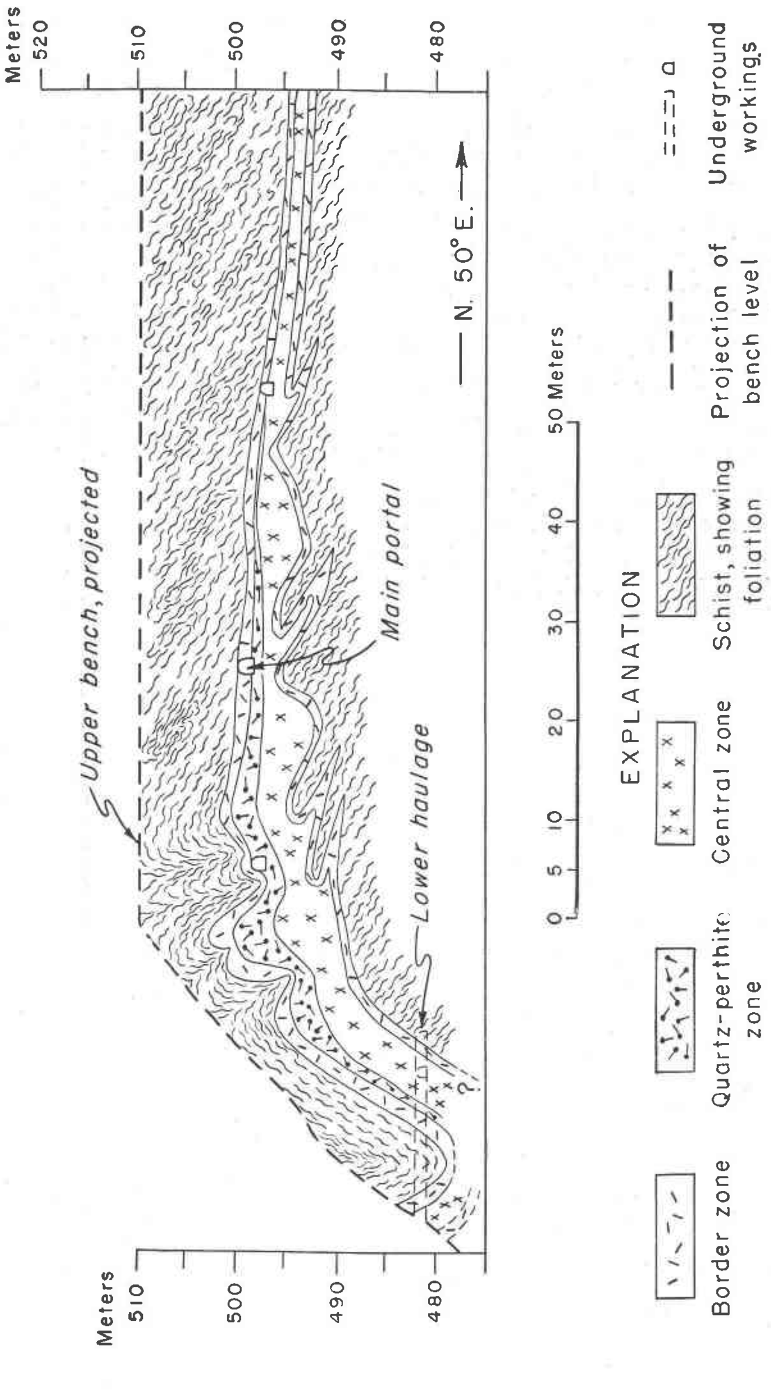

FIG. 2. Generalized cross section of the Golconda pegmatite, in part projected and reconstructed, showing internal zoning and the structural relation to schist.

The country rock containing the pegmatite is mica schist. In the western part of the open pit the schist is rich in hornblende, and in the eastern part it is essentially a quartz-biotite-garnet schist. The hanging-wall contact of the pegmatite locally conforms to the schistosity of the roof rock, but the footwall contact is clearly discordant to the schistosity of the floor rock. The schist above the pegmatite is intimately folded into a series of asymmetrical drag folds whose axial planes strike about N. 25°W. and dips northeast. The roof block of schist, now evident as a small anticlinorium overturned to the west, was probably sheared from the floor block, by deformational stresses, thus providing a locus for implacement of the granitic fluid. The roll of the pegmatite is believed to be an original implacement form and not one caused by later deformation. The shearing of the country rock and the subsequent introduction of granitic fluid were probably related to the same general diastrophism.

Zoning

The grain size of the minerals in the pegmatite increases inward from both its upper and its lower contact and is coarsest where the pegmatite is thickest. On the basis of differences in texture and mineral composition this pegmatite can be divided into several internal units.

In the eastern, thinner, part of the pegmatite sheet and in the larger appendages extending into the floor rock a central zone separates an upper and lower border zone. The central zone is composed essentially of quartz and weathered potash feldspar with accessory white mica, green tourmaline, and blue-green beryl. The border zone contains quartz, potash feldspar, and "ruby" mica as essential minerals with accessory black tourmaline, garnet, and biotite.

In the western part of the pegmatite the central zone is separated from the upper border zone by a lens of quartz-perthite rock that is locally graphic in texture. At this place the central zone is thickest and is composed of a great assortment of complex minerals.

The maximum thickness and the mineral composition of the pegmatite units are shown in Table 1, and the structural relations of the different units are illustrated in Fig. 2. The occurrence of a quartz-perthite unit, locally graphic textured, separating a hanging-wall mica-rich zone and inner complex mineral zones, has also been reported for several granitic pegmatites in the United States (Cameron and others, 1949).

The hanging-wall border zone where best developed is about 1.5 meters thick. In its upper part, against the schist, mica books composed of "ruby" muscovite and intercrystallized biotite are arranged edgewise to the contact. In the lower part of the zone is a concentration of nests of randomly oriented "ruby" muscovite books and quartz, free of biotite, imbedded in potash feldspar. Quartz, tourmaline, and garnet are much more abundant in the upper part of the zone. The mica-rich part of the zone is called a "mica shoot."

The quartz-perthite unit has a maximum thickness of 4 meters. Perthitic feldspar makes up about 80 per cent of the rock and quartz and white muscovite the rest. Locally, particularly near the apex of the roll, or minor arches, the rock is graphic in texture. The largest individual cleavage surfaces in the feldspar are 1.5 meters across.

Irregular cavities are numerous in the central zone, particularly in the western, thicker part of the pegmatite. In addition to quartz and microcline, the mineral assemblage includes albite, tourmaline, beryl, cassiterite, tantalite, microlite, spodumene, cookeite, garnet, and muscovite. Altered spodumene "logs" up to 80 cm. long and albite "logs" up to 25 cm. long occur in the zone, and both minerals show effects of deuteric alteration and intense weathering.

The footwall border zone has the same essential mineral composition as the hanging-wall zone but differs in being thinner, in having less muscovite and black tourmaline, in lacking the conspicuous edgewise growth pattern of mica books at the contact, and in being relatively free of biotite.

The Mica Shoot

The mica shoot in the hanging-wall zone provides the principal source of commercial muscovite in the pegmatite. In the western part of the pegmatite, east of the "roll" (Fig. 3), the concentration of mica in the shoot approaches an average of 20 to 25 per cent by volume not all of which is commercial. The average thickness of the mica shoot in 1945 was 0.5 meter, and the calculated recovery of the commercial mica in the mica shoot was about 400 kilograms per cubic meter, or approximately 12 per cent by weight. Elsewhere in the hanging-wall zone the recovery of mine-crude mica ranges from 50 to 100 kilograms per cubic meter. The sheet mica trimmed from the Golconda mine-crude mica averages between 10 and 15 per cent by weight. Based on prices paid for sheet mica in 1943–45, the mine-crude mica at the Golconda mine was evaluated at approximately $180 per metric ton and the mica shoot itself between $20 and $30 per ton. This mica shoot thus has a higher value per ton of rock than the ore of most gold mines in Brazil, although its reserves, unfortunately, are much less. The economic features of the mica mines in Minas Gerais have been fully discussed (Pecora and others, 1950).

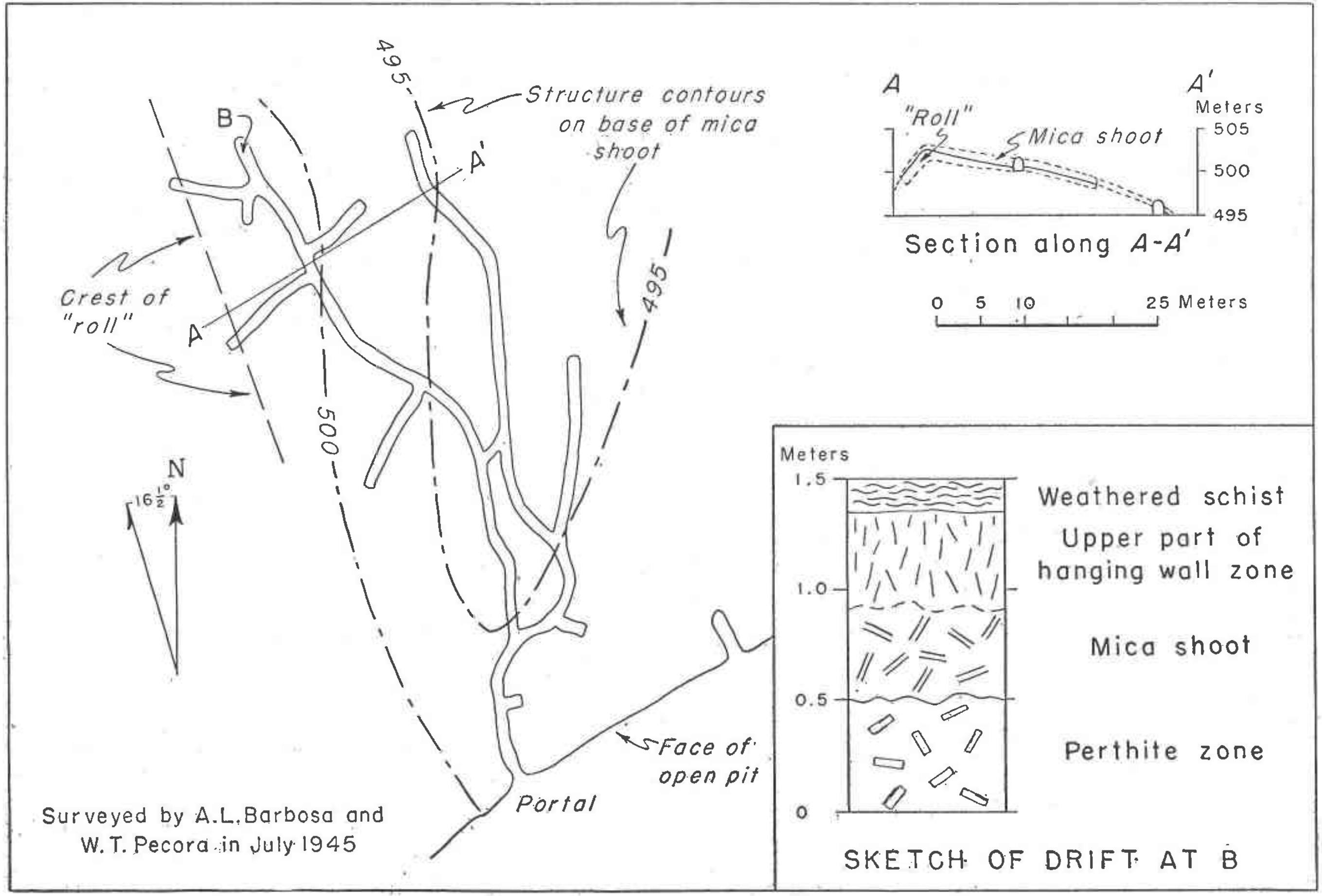

FIG. 3. Underground workings and sketch showing structural relation of the mica shoot of the Golconda pegmatite.

TABLE 1. GENERAL DESCRIPTION OF THE INTERNAL UNITS OF THE GOLCONDA PEGMATITE, GOVERNADOR VALADARES, MINAS GERAIS, BRAZIL

Unit	Maximum thickness (meters)	Essential minerals	Accessory minerals	General comments
Hanging-wall border zone	1.5	Potash feldspar, quartz, and "ruby" muscovite	Biotite, garnet, and black tourmaline in upper part of zone	Muscovite books, with inter-crystallized biotite, are arranged edgewise to contact in upper part of zone. Commercial sheet mica obtained only from lower part of zone
Quartz-perthite zone	4	Perthite and quartz	White muscovite	Quartz and microperthite are locally graphic, especially near the crest of rolls
Central zone	5	Potash feldspar, albite, and quartz	Beryl (morganite and aquamarine), tourmaline (green and blue), garnet (spessartite), cassiterite, tantalite, microlite, spodumene, cookeite, and muscovite	Cavities lined with accessory minerals are most common in the western part of the pegmatite
Footwall border zone	1	Potash feldspar, quartz, and "ruby" muscovite	Black tourmaline, garnet	Muscovite books too small sized to be commercial

DESCRIPTIVE MINERALOGY

Essential Minerals

Quartz and feldspar make up more than 95 per cent of the bulk of the pegmatite. Microcline perthite is the principal feldspar in the border zone and in the quartz-perthite zone. Because of the advanced state of weathering, the relative abundance of the different feldspars in the separate zones cannot be established with any assurance. In the central zone, nevertheless, albite is common and the microcline lacks any visible perthitic texture. The quartz-perthite rock is locally graphic and in the thickest part of the zone cleavage faces of the perthite measure up to 1.5 meters across.

Quartz is scattered throughout the border zone, but is much less abundant in the mica shoot and quartz-perthite zone than in either the border or central zones. Quartz lenses, ramiform quartz masses inter-grown with microcline, and cavities lined with clear or smoky quartz crystals are scattered throughout the central zone and are best developed in the thicker, western part of the pegmatite. The crystals range in size from a few centimeters to one-half meter, are commonly in parallel growths, and show steplike development of the prism and rhombohedron faces.

The term "ruby muscovite" is widely used in the mica industry for commercial muscovite that is yellow-brown or red-brown in color. In the Golconda pegmatite, ruby mica is distributed only in the border zone, whereas the white, green, and yellow varieties are scattered in the inner part of the pegmatite. Only the ruby muscovite occurs in large enough size and of quality to be of commercial value. Books of commer-mercial ruby muscovite are imperfect and rarely exceed 30 centimeters in breadth and 5 centimeters in thickness. Size and quality of the knife-trimmed sheet mica produced from the crude books is reported according to the India Standard, and a breakdown of about 25 tons of sheet mica recovered in 1944 from the mine is given below:

Size	*Area (sq. in.)*	*Kilograms*
6	1	12,282
$5\frac{1}{2}$	$2\frac{1}{2}$	3,311
5	3	5,533
4	6	2,504
3 and larger	10+	1,483
	Total	25,113

Quality		*Kilograms*
Good-Stained and better		12,986
Stained-A and worse		12,127
	Total	25,113

In the thick western part of the central zone, rounded masses of concentrically grown brown muscovite are embedded in the weathered feldspar. The curved planar surfaces are marked by bumps so that the Brazilian name of "mica de tatu" (armadillo mica) is not inappropriate.

Biotite is locally intergrown with the ruby muscovite in the upper border zone, but it is rare or absent in the commercially significant mica shoot.

Accessory Minerals

Garnet (spessartite)

Red-brown garnet is abundant as crystals less than 1 centimeter in size in the outer part of the border zone and in the schist of the country rock. In the central zone, however, irregular masses of dark brown garnet up to 15 centimeters across are embedded in weathered feldspar. Owing to the extent of alteration, the garnet masses now consist of clear brown fragments up to 5 millimeters in diameter in a matrix of black fine-grained oxide of manganese. The dark brown garnet was determined to be spessartite on the basis of the following properties: index of refraction $= 1.808 \pm 0.005$; specific gravity $= 4.18 \pm 0.05$; unit cell size $(a) = 11.57 \pm 0.01$A; $MnO = 14.16\%$.

These data were furnished to S. B. Levin of the Squier Signal Corps Laboratory, Fort Monmouth, N. J., and using the method he devised (Levin, 1949) he calculated the following components of the Golconda spessartite:

Components	*Per cent*
Almandite	54
Spessartite	32
Pyrope	8
Grossularite	6
Andradite	0

Cookeite

Pure masses of cookeite are intergrown with other rare minerals or have formed on surfaces of crystals in the cavities. Some logs of spodumene up to 40 centimeters long are completely replaced by very fine grained cookeite. Individual aggregates in other associations are up to 2 millimeters in size. The colors of the mineral include rose, lavender, and pale lilac, and the material is composed of hexagonal plates and sections.

A mass of pale lavender dense material was purified for special study. The optical properties of the mineral are:

$$\left.\begin{array}{l}\alpha = 1.578\\ \beta = 1.581\\ \gamma = 1.598\end{array}\right\} \pm 0.002 \qquad \begin{array}{l}\text{Biaxial } (+)\\ 2V = 45°\text{, calculated}\end{array}$$

A partial spectrochemical analysis of this material by A. T. Myers gave the following results: $Li_2O = 2.7\%$; $K_2O = 0.0X$; $Na_2O = 0.0X$; and $Cs_2O = 0.0X$. Semiquantitative chemical analyses indicate that some Golconda cookeite may have up to 4 per cent Li_2O.

In habit, optical properties, and x-ray powder pattern the Golconda material resembles cookeite examined by the authors from other mineral localities, and its chemical composition is like that of cookeite reported by Brammall and others (1937). Quensel (1937) has described cookeite that has formed by replacement of spodumene in a pegmatite from Sweden.

Beryl (Morganite and Aquamarine)

Pale pink beryl (morganite) was found associated with quartz, albite, and cookeite in the central zone. A number of specimens up to 20 centimeters in diameter were recovered. The beryl occurs in irregular crystalline aggregates of many deeply etched parallel and sub-parallel individual crystals. Many crystal faces are represented, but no complete individual crystals were found and the crystals are highly malformed. Individual crystals are up to about 5 centimeters in size. Much of the beryl is free from flaws and inclusions, but it is too pale in color to be classed as good gem material.

The pink beryl has the following properties:

Uniaxial (−) $\left.\begin{matrix}\omega=1.591\\ \epsilon=1.584\end{matrix}\right\}\pm 0.002$

Sp. gr. $=2.78\pm 0.01$

These values indicate a beryl very high in alkalies, according to unpublished data of W. T. Schaller.

The pink beryl crystals have an unusual crystal habit in that they are tabular parallel to $\{10\bar{1}1\}$.

Bluish-green beryl (aquamarine), in part of gem quality, was also found as a rare constituent of the central zone.

Cassiterite

Coarsely crystalline masses of cassiterite were encountered in the central zone, associated with other rare minerals. The well developed crystals are as much as 4 centimeters in diameter. They are usually subhedral but a few rough euhedral crystals were found showing only faces of the unit dipyramid.

The color of the cassiterite in some zoned crystals ranges from black to greenish yellow. Spectrochemcial analyses by A. T. Myers of each of these zones in a single crystal are given in the table below.

The presence of columbium and tantalum in Golconda cassiterite is

	Black Cassiterite	Greenish yellow Cassiterite
MnO	0.65%	0.14%
Fe_2O_3 (total)	0.29	0.06
SnO_2	×0.0	×0.0
Cb_2O_5	0.46	0.18
Ta_2O_5	1.0	0.1
Si	0.X	0.X
Al	0.0X	0.00X
Mg	0.0X	0.00X
Ca	0.00X	0.000X
Cu	0.000X	0.0000X
Ti	0.000X	0.00X

Not found: Ag, Au, Be, Bi, Co, Cr, Ga, Ge, In, La, Li, Mo, Na, Pb, Sb, Th, Tl, V, Y, Zn, Zr.

noteworthy. Edwards (1940) likewise reports solid solution of columbium and tantalum in cassiterite from Australia, and other localities showing similar relationship are listed in Dana's *System of Mineralogy* (7th ed., p. 576). Borovick and Gotman (1939) demonstrate from a compilation of spectrochemical data of numerous cassiterite samples that cassiterite from pegmatites generally contains more columbium than cassiterite from veins.

Manganotantalite

Manganotantalite occurs as small, well formed, prismatic crystals associated with microlite in cavities of cassiterite. The crystals are as much as 1 centimeter in length by 2 millimeters in diameter. In color they range from black to reddish brown.

Unit cell dimensions[4] determined on one brown crystals by the Weissenberg method are as follows:

$$\left.\begin{array}{l} a=\ \ 5.14\text{ A} \\ b=14.44\text{ A} \\ c=\ \ 5.78\text{ A} \end{array}\right\} \pm 0.01$$

The specific gravity as determined by the average of several crystals measured on the Berman balance is 7.34 ± 0.05.

The Golconda manganotantalite crystals are elongated parallel to [001] and are prismatic to acicular in habit (Fig. 4). The prism zone is usually striated, and the terminations are simple, usually consisting only of a basal pinacoid. Termination of some crystals by a single face of the

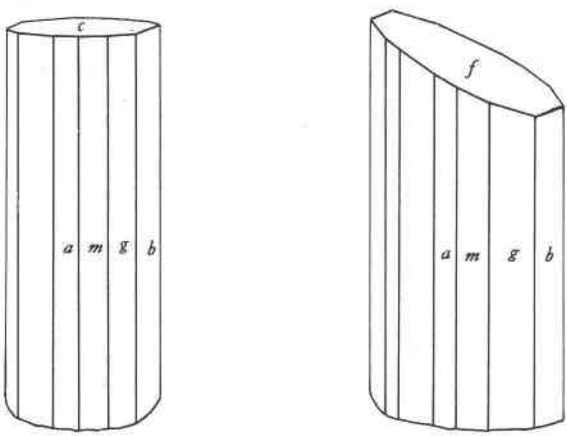

Fig. 4. Crystal drawings of manganotantalite from the Golconda pegmatite.

[4] Unit cell dimensions are given here in the same orientation used in Dana's *System of Mineralogy*, 7th ed., rather than in the conventional form $c<a<b$. The same orientation is followed in the following section on morphology.

dome *f*{032} causes them at first glance to appear monoclinic. The forms observed by measurement of several crystals were: {001}, {010}, {160}, {130}, {110}, {032}, and {131}.

A spectrochemical analysis of the Golconda manganotantalite by A. T. Myers gave the following results:

MnO	14.0 %
FeO (total)	0.52
SnO_2	0.96
Cb_2O_5	14.0
Ta_2O_5	71.0

Ti 0.X; Si, Mg 0.0X; Ca 0.00X; Al, Cu 0.000X.
Not found: Ag, As, Au, Be, Ge, La, Li, Th, Tl, U, Zn, Y.

In Dana's *System of Mineralogy* (7th ed., pp. 782–785) the usage of manganoan and ferroan as adjectival modifiers for tantalite and columbite is not completely in accord with the original suggestions of Schaller (1930). The term manganoan tantalite should be used for a tantalite in which the iron content is in excess of the manganese and not, as used in the Dana volume, for a manganese-rich tantalite. The iron end member is implied in the single name of tantalite or columbite, whereas the manganese end member is implied in the name manganotantalite or manganocolumbite.

Microlite

Microlite was found in small amounts as honey-yellow crystals associated with cassiterite and manganotantalite in the complex mineral zone. The crystals show rough octahedral form, and their maximum size is about 3 millimeters.

Some of the physical properties of the microlite are as follows: index of refraction $= 2.055 \pm 0.005$ (selenium melts); specific gravity $= 6.12 \pm 0.05$; unit cell $(a) = 10.422$ A ± 0.001.

The Golconda microlite is very near the pure tantalum end member of the microlite-pyrochlore series as indicated by its index of refraction, specific gravity, and the spectrochemical analysis (by A. T. Myers) given below:

MnO	0.42%
FeO (total)	0.22
SnO	1.9
Cb_2O_5	1.9
Ta_2O_5	X0.0
CaO	X.0

Na, Si, Ti 0.X; Mg 0.0X; Al, Bi, Pb 0.00X; Ag trace.
Not found: As, Au, Be, Co, Cr, Ge, Ga, La, Li, Mo, Th, Tl, U, V, Y, and Zn.

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