Mica Deposits in Minas Gerais Brazil

GEOLOGICAL SURVEY BULLETIN 964-C

Mica Deposits in Minas Gerais Brazil

By W. T. PECORA, M. R. KLEPPER, *and* D. M. LARRABEE, UNITED STATES GEOLOGICAL SURVEY, *and* A. L. M. BARBOSA *and* RESK FRAYHA, DIVISÃO DE FOMENTO, BRAZIL

GEOLOGIC INVESTIGATIONS IN THE AMERICAN REPUBLICS, 1949

GEOLOGICAL SURVEY BULLETIN 964-C

Prepared in cooperation with the Divisão de Fomento da Produção Mineral Departamento Nacional da Produção Mineral, Ministerio da Agricultura, Brazil, under the auspices of the Interdepartmental Committee on Scientific and Cultural Cooperation, Department of State

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1950

UNITED STATES DEPARTMENT OF THE INTERIOR

Oscar L. Chapman, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 60 cents (paper cover)

CONTENTS

ILLUSTRATIONS

TABLES

MICA DEPOSITS IN MINAS GERAIS, BRAZIL

By W. T. PECORA, M. R. KLEPPER, and D. M. LARRABEE, UNITED STATES GEOLOGICAL SURVEY, and A. L. M. BARBOSA and RESK FRAYHA, DIVISÃO DE FOMENTO, BRAZIL

ABSTRACT

Pegmatite mining is the chief mineral industry in eastern Minas Gerais, Brazil, providing the principal source of income for hundreds of fazendas and a livelihood for thousands of Brazilians. In the 10-year period 1936–45, the pegmatite mines of Minas Gerais produced some 7,200 metric tons of sheet mica, 114,000 tons of kaolin, 6.5 tons of gem-stone minerals, 530 tons of beryl, and 110 tons of tantalite and columbite. The estimated market value of this production is approximately $25,000,000, United States currency, nearly half of which is the value of the mica. More than 85 percent of the few hundred commercially significant mica-bearing pegmatites in Brazil are in the Mica Belt of eastern Minas Gerais, and about 95 percent of Brazil's output of muscovite mica has come from this area.

In the period 1900–45, about 8,500 metric tons of processed muscovite mica was exported from Brazil—about 60 percent of this amount after 1940. The total mine production since 1900 is estimated to have been about 100,000 tons of crude mica. Before 1943, almost all the mica was mined by hand. In the period 1943–45, some 30 mines employed earth-moving equipment in open-pit operations, and some 20 used air compressors for underground rock drilling. As a result of the high rate of production during the war, a number of mines have seriously depleted their indicated reserves, but others have developed even greater reserves.

The mica-bearing pegmatites may be hundreds of meters long and tens of meters thick. In form they are tabular, lenticular, irregular, and ramiform. They occur in a wide variety of igneous and metamorphic rocks that are assigned by Brazilian geologists to ages ranging from Archean to upper Algonkian. Pegmatites in quartzite, gneiss, and igneous rocks are commonly discordant, well-formed, tabular or lenticular masses, whereas those in mica schist are concordant, quasi concordant, or discordant and include many different forms.

A great number of mica-bearing pegmatites are characterized by an internal zoning based on mineral association and texture. The zoning is simple or multiple, symmetric or asymmetric. The bulk of the Brazilian mica production has come from zoned pegmatites. In general, more complex mineral assemblages occur in the pegmatites of northern Minas Gerais than in those of the southeastern part of the State.

The commercial muscovite in the pegmatites is called "ruby" mica, and in its structural and mineralogical features of primary and secondary origin it resembles ruby mica from other regions of the world. Weathering does not harm high-quality mica books significantly, but it does make low-quality mica even poorer in quality.

Exceptional concentrations of muscovite mica, related to external or internal structural features of a pegmatite, are termed mica shoots. A single pegmatite may have more than one mica shoot. In some shoots, the mine-crude mica constitutes up to 40 percent of the pegmatite rock, but it commonly ranges from

5 to 20 percent. In exceptional shoots, the quantity of mine-crude mica is as much as several thousand tons. In all mica shoots, the mine-crude mica represents more than 90 percent of the total mica in the rock.

In selectively mined parts of a pegmatite, the recovery of mine-crude mica ranges up to 20 percent of the rock mined. The processing recovery of sheet mica from mine-crude mica ranges from 5 to 20 percent and of strategic mica from 0.5 to 6 percent. Qualified sheet mica from different mines contains 20 to 80 percent strategic qualities. In 1942–45, approximately 3,250 metric tons of sheet mica was exported, its total purchase value amounting to about $9,250,000.

The value of mine-crude mica from different mines, based on the tabella price schedule of 1943–45 and excluding premium and bonus payments, ranged from $150 to $600 per ton; it averaged between $200 and $300 per ton. The tenor of the principal mica shoots, based on the tabella value, ranged from $12 to $80 per ton, and the tenor of the majority varied between $15 and $30 per ton.

In September 1945, the seven largest mines had a total measured reserve of about 2,000 metric tons of mine-crude mica and a total indicated reserve of about 5,000 metric tons. Geological relations in many other mines are favorable for an orderly exploration in depth. The indicated reserve of mine-crude mica in Minas Gerais is about 10,000 metric tons, and the inferred reserve is several times this amount. The mica industry as a whole and many mica mines in particular are more firmly established in the postwar period than they were in prewar years.

Pegmatites in the Mica Belt offer great promise for the future production of kaolin and feldspar, industrial and gem beryl, tantalite and colombite, gem stones, and lithium-bearing minerals. The inferred reserves of all these materials are greater in the northern than in the southern part of the Mica Belt, and their total is greater than the total past production from this region.

INTRODUCTION AND ACKNOWLEDGMENTS

GENERAL STATEMENT

This report is based on field investigations in eastern Minas Gerais in 1942–45 by parties composed jointly of members of the Geological Survey, United States Department of the Interior, and the Divisão de Fomento, Departamento Nacional da Produção Mineral, of Brazil. This cooperative project was requested by the Foreign Economic Administration of the United States and sponsored by the Interdepartmental Committee on Scientific and Cultural Cooperation, United States Department of State.

The personnel of the mica project comprised three members of the Geological Survey—W. T. Pecora, M. R. Klepper, and D. M. Larrabee—and two members of the Divisão de Fomento—A. L. M. Barbosa and Resk Frayha. For several months in 1942–43, Messrs. Pecora and Barbosa made a reconnaissance of several of the mica districts, but in 1944–45 they worked principally in the districts north of the Rio Doce. Messrs. Klepper, Larrabee, and Frayha worked in the Espera Feliz district in 1944, and in 1945 Messrs. Klepper and Frayha investigated the remaining mica districts south of the Rio Doce. More than 200 mica-bearing pegmatites were examined in 40 municipios in the eastern part of the State. Sixty mica mines were mapped and studied in great detail.

The functions of the field parties, as defined by arrangement among responsible officers of the Geological Survey, the Foreign Economic Administration, the American Embassy in Rio de Janeiro, and the Departamento Nacional da Produção Mineral, included, among others, detailed studies of the principal mica mines in Minas Gerais to determine the geological relationships that might have practical and immediate bearing on increased production or development for near-future production, calculation and estimation of mica reserves at individual mines and in various districts, and compilation of information on the mica-bearing pegmatites for public release.

Throughout the duration of the project, the writers made intensive studies of several prominent mines of particular interest to the field staff of the United States Purchasing Commission, the representative organization in Brazil of the Foreign Economic Administration. Innumerable courtesies and much assistance were extended by members of that organization, both in Rio de Janeiro and in the field, particularly in regard to the transportation of personnel and equipment. Engineers of the Purchasing Commission staff who especially facilitated the writers' field investigations include J. F. Bell, A. L. Harris, H. P. Hill, T. G. Murdock, C. B. Foster, T. L. White, Lloyd Conklin, J. C. Allen, John Canizza, E. W. Parsons, Lloyd Pratt, C. J. O'Brien, E. P. Erickson, D. F. Campbell, C. C. Hoffman, S. A. Mayer, J. T. Hicks, L. L. Pomeroy, Alford Roos, C. P. Richmond, J. H. Cook, and J. G. Kennedy. C. E. Hunter and P. P. Fox, geologists of the Commission's mica program, facilitated geologic reconnaissance in 1943, and D. D. Smythe, chief geologist of the Commission, was available for discussion on many geological problems in 1944. Sam Rodvien and Phil Lichtenberg made available general statistics on sheet-mica purchases for 1942–45.

Officials of the Departamento Nacional da Produção Mineral—particularly Antonio José Alves de Souza, Director, Avelino Ignacio de Oliveira, Anibal A. Bastos, and Alberto I. Erickson—showed a keen interest in the work and assisted the writers in many ways. They furnished office space, facilities for drafting, and many other conveniences in Rio de Janeiro that speeded a part of the work.

The widespread interest and wholehearted cooperation of a great number of Brazilian mine operators, mine foremen, mica merchants, and exporting companies enabled the writers to gather and interpret mine statistics, to make mine surveys and production analyses, and to calculate reserves. The specific recommendations or guidance given by the writers for development or exploration at some of these mines are insufficient recompense for the inestimable courtesies received.

RESULTS OF THE INVESTIGATIONS

Several detailed reports on prominent mica mines were submitted by the writers in 1944–45 for publication in Portuguese by the Departamento Nacional da Produção Mineral. Four of these reports, which appeared in 1945 as avulsos of the Divisão de Fomento, are:

Avulso 67. Bananal mica mine, by W. T. Pecora and A. L. M. Barbosa.
Avulso 68. Serra dos Lourenços mica mine, by W. T. Pecora and A. L. M. Barbosa.
Avulso 69. Pequerí mica mine, by M. R. Klepper, D. M. Larrabee, and A. L. M. Barbosa.
Avulso 72. Viuva Valerio mica mine, by D. M. Larrabee and Resk Frayha.

A number of other reports, as yet unpublished, have been submitted. These describe mica mines near Governador Valadares, Espera Feliz, and Caparaó and in the area between Caratinga and Juiz de Fora.

Four other publications on mica, of a more general nature, that were prepared by members of the United States Purchasing Commission and published by the Divisão de Fomento in 1944 are:

Avulso 53. Mica near Santa Maria do Suassuí, by T. G. Murdock and C. E. Hunter.
Avulso 54. Mica in the State of São Paulo, by T. G. Murdock.
Avulso 56. Prospecting guides for mica, by D. D. Smythe.
Boletim 60. Mica mining by "stripping," by W. J. Millard.

EXPORTS OF SHEET MICA FROM BRAZIL, 1900–1945

GENERAL STATEMENT

Muscovite mica has been mined in Brazil principally for the export trade. Knife-trimmed sheet mica more than 0.007 inch thick, called "block mica" in India, is exported as a half-trimmed, three-quarter-trimmed, or full-trimmed product. Sheets less than 0.007 inch thick, called films and scalings, are shear-trimmed and exported from Brazil unclassified as to thickness.

The technique of preparing scalings calibrated to a uniform thickness of 0.0012 inch—called "splittings"—as practiced in the mica districts of India, has not been developed in Brazil. The quantity of splittings exported from India is alone greater than the total sheet and scalings exported from Brazil. In past years, a part of the Brazilian production of rough-trimmed sheet, half-trimmed sheet, and unclassified scalings were shipped to India for processing into splittings.

Scrap mica has no market in Brazil as it has in the United States or India, where it is utilized in the preparation of wet-ground or dry-ground mica. Should the demand arise, Brazil can readily supply several thousand tons of scrap mica annually.

In the period July 1, 1942, to December 1, 1945, Brazilian mica was exported only from the port of Rio de Janeiro for the joint account of the United States and the United Kingdom after inspection and acceptance for purchase by the United States Purchasing Commission.

During this period the Brazilian mica exporters abandoned the prevailing Brazilian standard of qualification for the more widely used India standard. The following symbols, based on the India standard, will be used throughout this paper: CSS, clear and slightly stained; FS, fair stained; GS, good stained; SA, stained "A"; SB, stained "B"; and HS, heavy-stained.

Sheet mica of grade (size) 6 and larger that qualified as GS, FS, or CSS was considered "strategic" mica during the war period. In 1944–45, strategic mica commanded premium and bonus payments above the Government-prescribed table of payments. During the war years Brazil supplied a substantial amount of strategic mica and was second only to India as a source of supply.

Domestic consumption of mica has increased markedly in Brazil since 1940, especially for large, poor-quality sheets used in the electrical industry in São Paulo and Rio de Janeiro.

The demand for mica immediately before and during the recent war proved a boon to the mica industry of Brazil, which was able to improve its position in the world market, as regards both quantity and technique, in comparison to its earlier status.

GENERAL STATISTICS, 1900–1945

In the period 1900–1945, about 8,500 metric tons of partly and fully processed sheet mica and scalings was exported from Brazil. Of this amount, about 90 percent was exported in the 10-year period 1936–45. Annual exports since 1900 are shown in figure 6.

In the 6-year period 1936–41, as shown in table 1, more than 95 percent of the 3,500 metric tons exported was destined for five countries: the United States, 37 percent; Japan, 30 percent; Germany, 10 percent; Great Britain, 9 percent; and India, 8 percent. A large part of the mica sent to Japan and India was of inferior quality and only partly processed, whereas almost all of that sent to the other countries was either half-trimmed or full-trimmed.

TABLE 1.—*Destination of mica exported from Brazil, 1936–41*

[Figures from the Instituto Brasileiro de Geografia e Estatisticas]

Country	Exports of Brazilian mica, in metric tons							Percent
	1936	1937	1938	1939	1940	1941 [1]	Total, 1936–41 [1]	
United States	86.328	136.748	77.984	124.357	315.801	555	1,296	37
Great Britain	49.029	59.003	73.759	60.938	54.542	25	322	9
Japan	.859	3.744	89.336	111.398	624.499	236	1,066	30
Germany	51.531	52.475	161.292	37.096	4.389	27	334	10
France	24.698	32.907	10.019	34.034	3.598		105	3
Italy	23.415	13.744	14.323	7.203	12.371		71	2
India		29.265	92.625	60.157	102.254	8	292	8
Others	1.017	2.090	1.675			16	21	1
Total	236.877	329.976	521.013	435.183	1,117.474	867	3,507	100

[1] Figures are approximate.

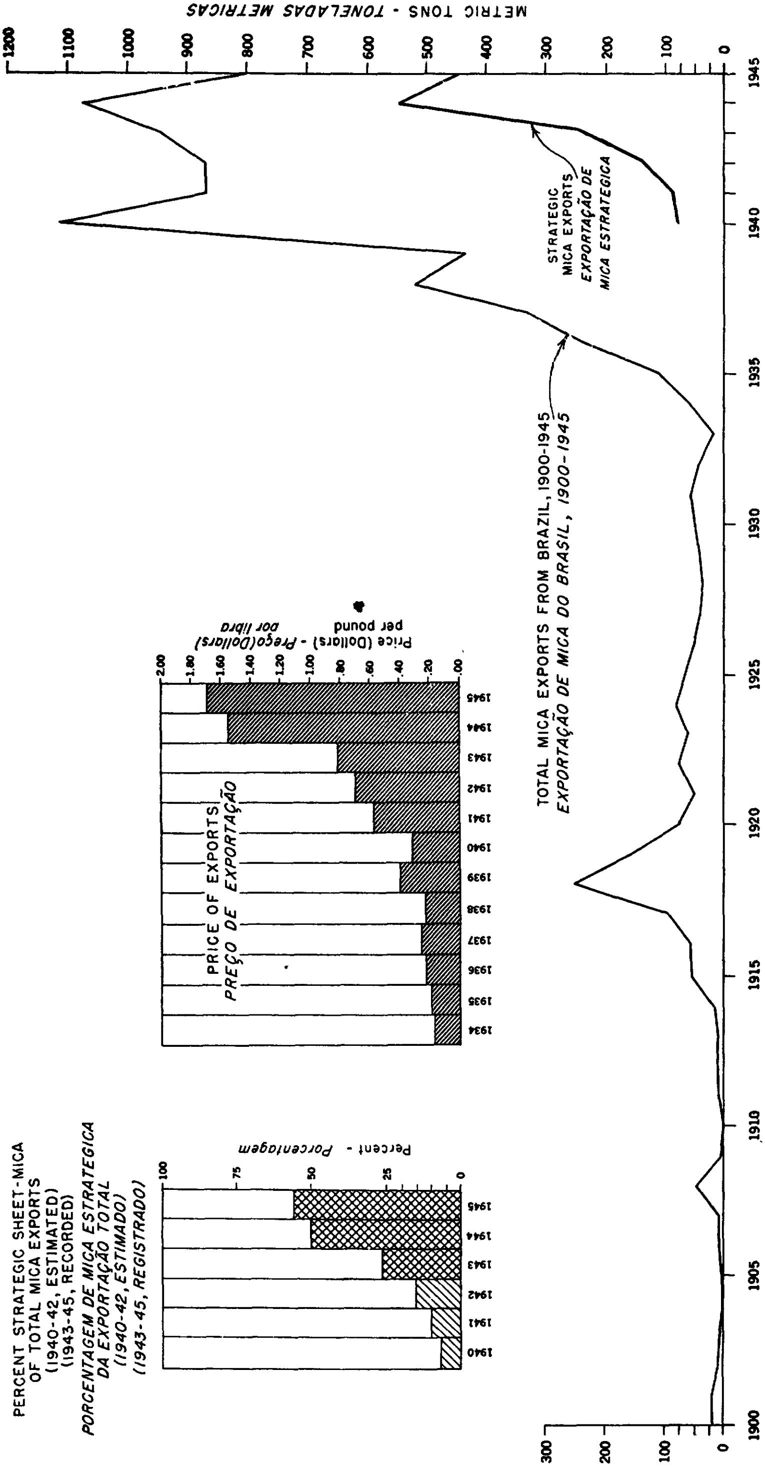


FIGURE 6.—Sheet-mica exports from Brazil and strategic-mica exports, 1940–1945.

In the 41-month period between July 1, 1942, and December 1, 1945, approximately 3,250 metric tons of sheet mica was purchased in Rio de Janeiro by the United States Purchasing Commission, of which about 82 percent was for the United States and the balance for the United Kingdom. As shown in the following comparison of these purchases, full-trimmed sheet mica accounts for more than 80 percent of all the mica bought in 1943–45—a much higher proportion than in earlier years. Also evident from the same data, supplied by the Mica Division of the United States Purchasing Commission, is the remarkable increase in the production of scalings in 1945.

	Mica purchased, in kilograms		
	1943	*1944*	*1945*
Full-trimmed (qualificada)	794, 277	936, 735	632, 617
Scalings (folha fina)		22, 085	147, 921
Half-trimmed (passada)	147, 420	120, 372	12, 703
Total	941, 697	1, 079, 192	793, 341

The percentages of different sizes of this mica may be summarized as follows:

	Percent		
Grade (size)	*1943*	*1944*	*1945*
7	4. 7	None	None
6	46. 0	46. 5	47. 0
5	12. 3	12. 5	8. 5
5½	21. 0	23. 5	25. 0
4 and larger	16. 0	17. 5	19. 5

STRATEGIC MICA, 1940–1945

The production of sheet mica that qualified GS and better in quality, referred to in the period 1942–45 as "strategic" mica, increased markedly in Brazil from 1940 to 1945, as shown below:

	Strategic mica exports, in metric tons	*Percent of total exports*
1940	[1] 80	7
1941	[1] 90	12
1942	[1] 140	15
1943	250	26. 6
1944	545	50. 5
1945	450	56. 5

[1] Approximate.

In 1944, emergency purchases of strategic mica included about 20 percent that was actually nonstrategic. It will be noted that although the total mica exports for the first three years of this period are about the same as for the last three years, the exports of strategic mica are about four times greater in the latter period. This notable achievement is a result of several factors related to war measures and economic subsidies. Principal among these factors were:

1. Payment of premiums and bonuses to exporters in addition to increased prices for high-quality mica.

2. More complete processing of sheet mica as a consequence of requirements and additional payments by the United States Purchasing Commission.

3. Continual instruction in the India standards of trimming and qualification that replaced the Brazilian standards in mid-1942.

4. General increase in mica production in the mica districts as a result of general price increase and technical aid supplied by both the Brazilian and United States Governments.

Observations by the writers and men in the mica trade indicate that about 20 percent of the strategic mica purchased in 1944 would have qualified as nonstrategic according to inspection standards existing in 1943 or 1945. The greater tolerance in inspection by the United States Purchasing Commission in 1944 was intended as an added subsidy.

VALUE OF EXPORTS, 1934–45

The recorded value in cruzeiros of mica exports from Brazil for the period 1934–42 and in dollars for the period 1943–45 is listed in table 2. Prior to July 1, 1942, prices were based on negotiations

TABLE 2.—*Exports and export value of processed mica, Brazilian ports, 1934–45*

[Figures for 1934-42 based on records of the Instituto de Geografia e Estatisticas, Rio de Janeiro; those for 1943-45, including premium and bonus payments in 1944-45, on records of the United States Purchasing Commission]

Year	Exports, in kilograms	Export value at Brazilian ports		Approximate value per kilogram	
		In cruzeiros [1]	In U. S. dollars	In cruzeiros	In dollars
1934	59, 383	439, 045		7. 39	
1935	109, 678	889, 248		8. 11	
1936	236, 877	2, 322, 076		9. 80	
1937	329, 976	3, 476, 591		10. 53	
1938	521, 013	5, 140, 665		9. 87	
1939	435, 183	7, 890, 719		18. 13	
1940	1, 117, 474	15, 755, 722		14. 10	
1941	867, 000	23, 845, 000		27. 50	
1942	866, 000	26, 211, 000		30. 27	
1943	941, 697		1, 735, 292		1. 84
1944	1, 079, 193		3, 921, 620		3. 62
1945	793, 241		2, 930, 277		3. 70

[1] The value of the cruzeiro, based on bulletins of the Federal Reserve Board, ranged from 5 to 6 cents, free market, 1934–45.

between exporter and consignee, but during the period in which the United States Purchasing Commission operated as sole exporting agency, prices were fixed by the official price table or tabella, here shown as table 3, which was in effect from July 1, 1943, to December 1, 1945. These prices were exclusive of the premiums and bonuses paid to the Brazilian exporting companies in 1944 and 1945.

TABLE 3.—*Official tabella of sheet-mica prices in Brazil, 1943–45, in United States dollars per kilogram*

Grade (size)	Quality					
	CSS	FS	GS	SA	SB	HS
6	2.10	1.58	1.20	0.92	0.54	0.33
5½	3.95	3.15	2.15	1.75	.87	.46
5	9.25	5.00	3.85	2.65	1.70	1.20
4	10.90	8.50	6.05	4.55	2.60	2.20
3	13.30	9.70	7.30	5.25	3.08	2.86
2	17.00	10.90	8.50	6.60	4.00	3.30
1	21.80	13.30	10.90	7.90	6.00	4.40
A-1	25.70	15.75	13.30	9.25	6.80	6.60
S	28.60	20.90	14.30	11.50	9.30	7.70
XS	30.80	26.40	17.60	13.20	11.00	8.80
XXS	35.20	30.80	22.00	17.60	13.20	11.00

In the period 1942–45, the Brazilian exporting companies sold to the United States Purchasing Commission in Rio de Janeiro about 3,247 metric tons of sheet mica for approximately $9,250,000, United States currency, an average of about $2.80 per kilogram. The sums paid in 1944–45 were greater than in 1942–43 because of the additional premiums and bonuses. The increasing average payment per kilogram of commercial sheet mica from 1942 to 1945 is shown by a comparison of the following figures:

	Average payment per kilogram, in dollars
1942	1.56
1943	1.84
1944	2.62 [1] 3.62
1945	[1] 3.70

[1] With premium and bonus.

It will be noted from the above figures that approximately 40 percent of the price paid for Brazilian mica in 1944–45 was actually a subsidy above the price established by the official tabella. A significant factor contributing to the increased average price per kilogram in 1942–44 was the more advanced processing technique, which made possible the production of full-trimmed and higher-quality sheet mica.

MICA-MINING INDUSTRY IN MINAS GERAIS

GENERAL STATEMENT

In the absence of complete production records, estimates of the total production of Brazil or of the State of Minas Gerais are necessarily based on available statistics of quantity and type of mica exports, municipio tax records, and estimated recovery ratios of processed mica from mine-crude mica. Rifting of mine-crude mica commonly takes place at the mine; part of the knife trimming is done there and part in several stages at different shops within the State and in Rio de Janeiro.

Until 1943, when some qualifying shops became established in the mica districts, the partly knife-trimmed sheet mica was transported to Rio de Janeiro and Vitória for export or further trimming. Under such conditions, particularly in view of changes brought about by the war, only a general estimate of mica production for districts, for the State of Minas Gerais, or for Brazil as a whole is possible.

The estimated total past production of mine-crude mica in Brazil is 100,000 metric tons. This figure includes only that crude mica recovered from underground workings, from open pits, and from salvage operations on old dumps and used in the preparation of partly or fully knife-trimmed sheet mica and scalings. About 95 percent of the total output of Brazil has come from eastern Minas Gerais and the balance from the States of Rio de Janeiro, São Paulo, Baía, Goiaz, Matto Grosso, Rio Grande do Norte, Pernambuco, and Paraíba.

In the 3-year period 1943–45 the estimated mine-crude mica production of Minas Gerais was about 30,000 metric tons. In 1944, the most active year in the history of Brazilian mica mining, between 12,000 and 14,000 metric tons of mine-crude mica was recovered from the mines of the State.

MICA-PRODUCING MUNICIPIOS IN MINAS GERAIS

Although the mica mines and prospects are distributed among some 50 municipios in eastern Minas Gerais, 27 of these account for 95 percent of the State's production and 90 percent of Brazil's total. Five of these municipios—Governador Valadares, Peçanha, Santa Maria do Suassuí, Conselheiro Pena, and Espera Feliz—have supplied about 70 percent of Brazil's total mica production. Recorded shipments from eight principal municipios in eastern Minas Gerais in 1942–44 were as follows:

	Mica shipments, in metric tons		
	1942	*1943*	*1944*
Governador Valadares	310	480	560
Espera Feliz	204	196	240
Bicas	32	24	38
Juiz de Fora	26	31	(?)
Muriaé	12	14	(?)
Glória	8	5	(?)
Cataguazes	11	14	(?)
Raul Soares	(?)	(?)	40

Records of mica shipments from municipios are based on fiscal reports, however, and are not properly indicative of production in the municipio. For example, the municipio of Juiz de Fora contains very few mica mines; most of the mica shipped from this municipio and and a significant part of that shipped from Governador Valadares, Muriaé, and Raul Soares originate in neighboring municipios. The larger cities, with their trucking, railroad, and warehouse facilities, merely tend to become the principal sales and shipping centers of the mica-producing region.

OUTSTANDING MICA MINES

Of the many hundreds of pegmatites in southeastern Brazil, only a few hundred have yielded any significant quantities of commercial muscovite mica. Some 50 mica mines—all in Minas Gerais—have each yielded more than 200 metric tons of mine-crude mica, but only six of these have yielded more than 1,000 tons. The principal mica producers during 1942–45 are listed in the table facing figure 7. Their combined production during these years is estimated to be between 60 and 70 percent of the total Brazilian production for the same period. Some of these mines were insignificant producers prior to 1942 but attained prominence during the war period through the application of modern mining techniques or by the fortuitous discovery of rich mica deposits. Others have been prominent for many years.

The estimated and recorded production statistics for 38 outstanding mica mines have been assembled in table 4. The two most productive mines have been the Cruzeiro and the Borges. Three mines—the Serra dos Lourenços, Bananal, and Pequerí—are noted for their high production as well as for the high quality of the sheet mica trimmed from the mine-crude mica. Other mines, including the Carrapato, Rochedo, Serra Negra, Santa Therezinha, União, Paraiso da Barra, and Palmital, though less productive, also are noted for the fine quality of the sheet mica obtained. The Cruzeiro mine, Brazil's most productive mica mine, is noted for the large size, but only average quality, of its sheet mica.

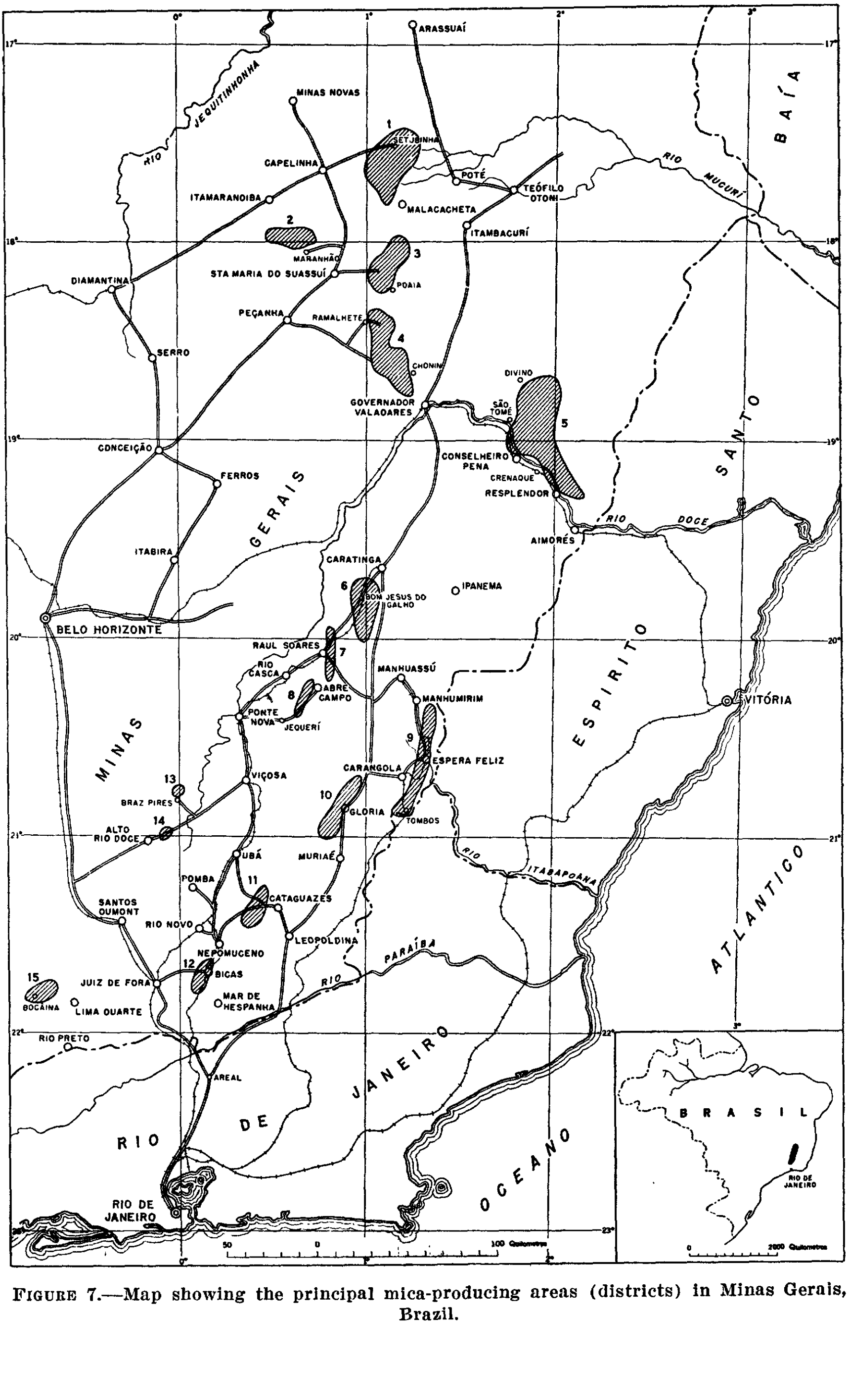


FIGURE 7.—Map showing the principal mica-producing areas (districts) in Minas Gerais, Brazil.

Principal mines and producing areas shown on figure 7

Area No. indicated on map	Name of area, with municipios included	Percent of total Minas Gerais production	Number of producing properties	Principal mines
1	Setubinha (Capelinha, Malacacheta)	1	16	Rancho do Meio. Colosso.
2	Maranhão (Itamarandiba, Santa Maria do Suassuí).	1	12	Coqueiro. Serra Negra. Socorro.
3	Santa Maria do Suassuí (Santa Maria do Suassuí, Capelinha).	12	18	Cruzeiro. Jacutinga. Safirão. Xiá. Perdido.
4	Governador Valadares (Governador Valadares, Peçanha).	30	62	Pedro Espirito. Golconda. Serra dos Lourenços. Bananal. Pontal. Carrapato. Ipê. Mical. Pedra Redonda. Ferrugem. Fortaleza. Boca Junta. Evangelista.
5	Conselheiro Pena (Conselheiro Pena, Resplendor, Mantena).	12	66	Palmital. Rochedo. Sapucaia. Mariano. Bôa Vista Mansur. Bôa Vista Alves. Laranjeiras. Baixio.
6	Galho (Caratinga, Bom Jesus do Galho, Raul Soares).	2	33	Cobiça. Chapeu Duro.
7	Raul Soares (Raul Soares, Abre Campo)	3	18	Velocindo. Alferes. Corrego da Mata.
8	Abre Campo (Abre Campo, Jequerí, Rio Casca).	1	17	Bôa Vista Floresta. Casa Nova.
9	Espera Feliz (Espera Feliz, Manhumirim, Carangola, Tombos).	20	125	Bôrges. Urubú. Chalet Verde. Chico Dentista. Zacarias. Capoeirão. Fazendinha. Viuva Valerio. Taquara Preta.
10	Glória (Glória, Muriaê)	3	40	União. Cebola. Onça.
11	Cataguazes (Cataguazes, Astolfo Dutra)	3	20	Santa Therezinha. Paraiso da Barra.
12	Bicas (Bicas, São Joao de Nepomuceno)	4	28	Pequerí. Santa Clara. Saracura.
13	Braz Pires (Senador Firmino)	1	7	São Miguel. São Jose.
14	Alto Rio Doce (Alto Rio Doce)	1	4	Onça.
15	Bocâina (Lima Duarte)	1	11	Porteira de Chave.
	Miscellaneous	5		
Total		100	477	

TABLE 4.—*Estimated production of outstanding mica mines in Minas Gerais, Brazil*

Mine	Area indicated on map (fig. 7)	Total past mine-crude mica production, in metric tons	Mine-crude mica production, 1943–45, in metric tons	Percentage of strategic sheet mica recovered from mine-crude mica, 1943–45	Number of producing pegmatites in mine
Rancho do Meio	1	200	150	1.0	1
Serra Negra	2	250	150	6.0	1
Cruzeiro	3	9,000	4,500	1.5	5
Perdido	3	400	300	2.5	1
Serra dos Lourenços	4	900	550	6.0	4
Bananal	4	1,000	850	5.0	2
Pedro Espirito	4	850	750	2.5	1
Golconda	4	900	550	3.0	1
Mical	4	650	500	2.5	2
Pedra Redonda	4	250	175	3.0	3
Pontal	4	200	150	2.5	1
Evangelista	4	200	100	3.0	1
Ipê	4	200	150	4.0	1
Carrapato	4	200	75	6.0	1
Palmital	5	350	225	4.5	1
Sapucaia	5	600	300	2.0	1
Bôa Vista Alves	5	400	280	2.5	3
Bôa Vista Mansur	5	200	125	2.5	1
Mariano	5	350	200	2.0	1
Rochedo	5	200	150	5.0	3
Cobiça-Chapeu Duro	6	200	125	.5	2
Velocindo	7	300	275	1.0	1
Alferes	7	300	275	1.5	1
Borges	9	3,500	1,200	2.0	1
Urubú	9	1,200	500	2.0	1
Chalet Verde	9	1,000	500	1.0	3
Zacarias	9	500	225	3.0	1
Capoeirão	9	400	125	1.5	2
Chico Dentista	9	350	175	3.0	1
Fazendinha	9	200	125	3.0	1
Viuva Valerio	9	200	100	2.5	2
União	10	200	200	5.0	1
Santa Therezinha	11	450	225	6.0	1
Paraiso da Barra	11	250	175	2.0	1
Pequerí	12	2,500	750	3.0	1
Santa Clara	12	300	150	3.5	1
Saracura	12	250	150	3.5	1
Porteira de Chave	15	600	300	3.5	1

GEOGRAPHY OF THE MICA BELT OF MINAS GERAIS

LOCATION

Of the 725 mica concessions (pesquizas) registered with the Departamento Nacional da Produção Mineral prior to 1944, about 90 percent are in the State of Minas Gerais. The majority of the mica mines and prospects in Minas Gerais are scattered through the eastern part of the State in a belt as much as 200 kilometers wide and more than 600 kilometers long. About 95 percent of the State's mica production is obtained from 15 separate areas within the belt as shown in figure 7. These areas include 28 municipios and contain about 450 mines and prospects. A greater number of prospects and a few mines are distributed in some 30 other municipios, but their combined production is insignificant.

The Mica Belt trends north-northeastward and is divided by the Rio Doce into a northern region that is difficult of access and a southern region that is more accessible and more populous. About 60 percent of the State's production comes from the northern region. Kaolin is recovered with mica at several mines in the southern part of the mica belt, whereas the bulk of the State's output of industrial beryl, pegmatite gem stones, tantalite, and columbite has come from mines in the northern part of the belt.

ACCESSIBILITY

Development of the mica districts in eastern Minas Gerais has been retarded for many years by lack of adequate transportation facilities. As recently as 1943, most mines could be reached only by long mule trips from the nearest railroad or highway. The Leopoldina railroad system in southeastern Minas Gerais and the Vitória-Minas railroad in east-central Minas Gerais have for many years transported most of the partly processed mica to the ports of Rio de Janeiro and Vitória. Since 1943, however, much of the processed mica has been hauled by truck on the Federal Rio-Baía highway, which connects Rio de Janeiro with such large cities in the Mica Belt as Muriaé, Caratinga, Governador Valadares, and Teófilo Otoni. Contemporaneous construction and maintenance of several municipal and mine-access roads have facilitated the haulage of crude mica from mines to processing shops and of processed mica to Rio de Janeiro.

Much of the region north of Conselheiro Pena and Governador Valadares is geologically favorable for the discovery and development of deposits of mica and associated pegmatite minerals; in addition, the region is becoming more accessible through road construction.

PHYSIOGRAPHY

The mica deposits of eastern Minas Gerais are in a mountainous terrain that is part of the upland of central and southeastern Brazil known as the Planalto Brasileiro. Several river systems have dissected this major orographic unit and modified it into a number of smaller mountain units. For so widespread an upland, the Planalto Brasileiro does not attain impressive heights; less than a dozen mountain groups are known whose highest peaks exceed 1,500 meters in altitude, and no peak exceeds 2,900 meters. Most of the principal streams are within a few hundred meters of sea level, and the topography is rugged and characterized by steep slopes.

The mountains of the southern part of the Mica Belt are part of the Serra da Mantiqueira, which extends across southern Minas

Gerais into Espirito Santo. The Serra da Mantiqueira is separated from the Serra do Mar of São Paulo and Rio de Janeiro by the valley of the Rio Paraíba. Two mountain groups dominate the topography of southeastern Minas Gerais and form part of the watershed between the drainage systems of the Rio Doce and Rio Paraíba: (1) the Serra do Caparaó (fig. 8), along the State boundary east and north of the

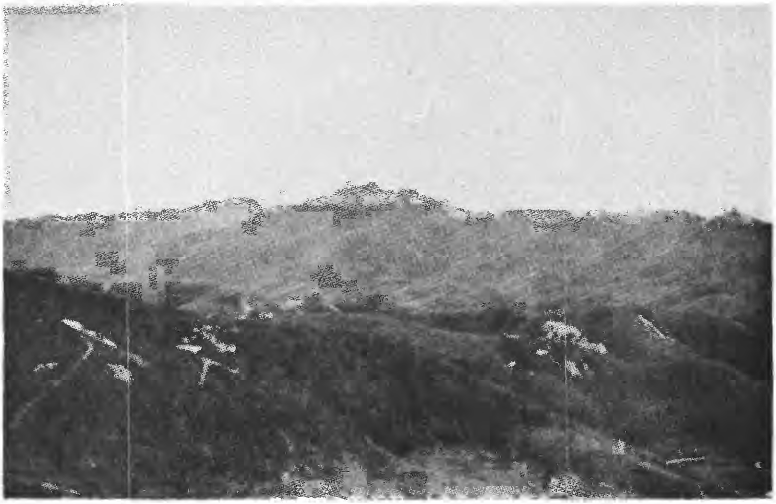


FIGURE 8.—Serra do Caparaó, Minas Gerais, Brazil, viewed from the hills on the west.

Espera Feliz mica district, and (2) the Serra do Brigadeiro, between the Glória and Jequerí mica districts. Pico da Bandeira (2,284 meters), in the Serra do Caparaó, is the highest peak in Brazil. Neighboring peaks in the same range are Pico do Cruzeiro (2,861 meters) and Pico do Crystal (2,789 meters). Pico do Soares, the highest point in the Serra do Brigadeiro, has an altitude of 1,850 meters.

The mica districts near Governador Valadares are in a mountainous area called the Serra das Escadinhas, whose highest summits rise to altitudes of 1,100 to 1,250 meters. These mountains are a continuation of the Serra da Mantiqueira north of the valley of the Rio Doce.

In the northernmost part of the Mica Belt, north of Santa Maria do Suassuí, the mica districts are in a high tableland called the Chapada Diamantina and in rugged mountains that are part of a chain called the Serra do Espinhaço. Continuing the trend of the Serra da Mantiqueira in central Minas Gerais, the Serra do Espinhaço forms the watershed separating the drainage basins of the Rio São Francisco, Rio Jequitinhonha, Rio Mucurý, and Rio Doce and dominates the topography in northeastern Minas Gerais and western Baía. Derby (1895 and 1906), Freyberg (1934), and Fróes Abreu (1945) support the separation of the Serra da Mantiqueira and Serra do Espinhaço on an orogenic rather than an orographic basis. According to these authorities, the Serra do Espinhaço is underlain mainly by quartzites of post-Archean age and the Serra da Mantiqueira by gneiss, schist, and granular intrusive rocks assigned for the most part to the Archeozoic era.

The Planalto Brasileiro (fig. 9), as exposed in the Mica Belt, is probably an ancient erosion surface of low relief that was formed at a much lower altitude but has since been rejuvenated by interrupted regional uplifts. Four lines of evidence indicating this history are:

1. Several widespread erosion surfaces are suggested by the several levels of accordance of the mountain summits.

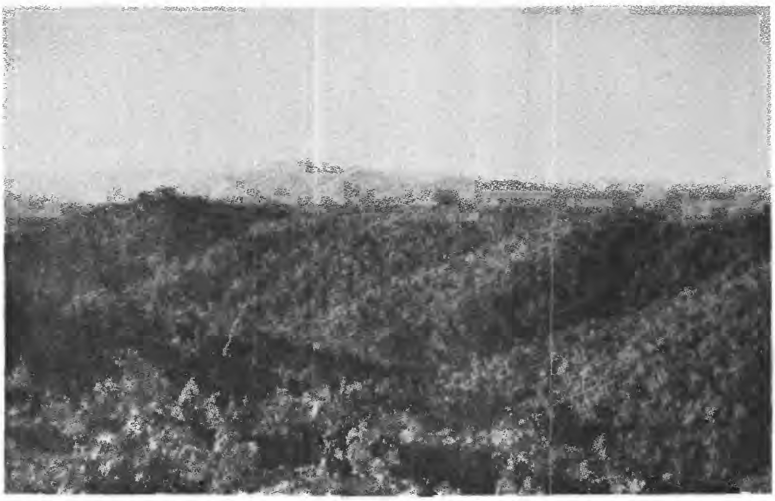


FIGURE 9.—Planalto Brasileiro, looking north from the Serra dos Lourenços, Minas Gerais, Brazil.

2. Rocks of different lithology make up the accordant mountain summits of any one level.

3. The accordance of the mountain summits is independent of the structure of the mountains.

4. The lower courses of the principal streams have an old-age pattern that is not in adjustment with either the structural alinement of the region or the present physiographic stage of the regional erosion cycle.

The highest accordant level of mountain summits, at an altitude of approximately 1,500 meters, is less conspicuous than two lower levels of 1,150 meters and 750 meters, respectively. A great number of spurs and low hills have crests at altitudes of 450 to 500 meters, and along the main course of the Rio Paraíba and Rio Doce is a well-defined terrace about 100 meters above the valley floor.

Harder and Chamberlin (1915) advanced the idea that the summit surface of the Serra do Espinhaço, in central Minas Gerais, is a peneplain surface. Pecora and Barbosa (1944) noted several erosion-surface levels in central Goiaz that they attributed to rejuvenation. In the future a detailed correlation of field observations with topographic maps will undoubtedly disclose more complete evidence on the geomorphic history of the Planalto Brasileiro.

RELATION OF MICA DEPOSITS TO SLOPES

The mica mines of Minas Gerais are at altitudes ranging from 150 to 1,150 meters. A few, such as those on the Serra do Cruzeiro and Serra Negra near Santa Maria do Suassuí, are on the summits of mountains; a few others, including those along the Rio Doce near Conselheiro Pena, are on valley floors cleared of alluvium; but the bulk of the mines are located on steep mountain slopes (fig. 10). This is not

FIGURE 10.—General view of the topography near the Fazenda Chico Dentista, Espera Feliz, Minas Gerais, Brazil.

surprising when it is considered that the region is in the early mature stage of erosion—that period in the erosion cycle characterized by an abundance of water courses, by narrow divides and narrow valley floors, and by a high percentage of slope area. Freise (1933) and Martonne (1940) have ably discussed the formation of slope profiles in eastern Brazil.

Rarely, as at the Ipê mine near Governador Valadares or at the Palmital mine near Conselheiro Pena, mica deposits are exposed on cliff faces free of overburden. Most of the known deposits were concealed under a mantle of colluvium composed largely of quartz fragments, mica flakes, and earthy material rich in hydrated iron oxide.

Locally this colluvium also contains abraded fragments or crystals of beryl, tourmaline, tantalite, columbite, clear quartz, topaz, and other resistant minerals. The thickness and widespread distribution of colluvium and alluvium at lower elevations in the region have made it impractical to prospect for new mica deposits except on slopes or spurs.

DISCOVERY OF MICA DEPOSITS

With few exceptions the mica mines and prospects are on large farms (fazendas) that support small communities by cattle raising, dairying, and farming. At a great number of the smaller mines, mica mining is interrupted during the planting and harvesting seasons and is incidental to the general work of the fazenda.

Clearing of forested land and agricultural development over more than two centuries have largely been responsible for the discovery of concentrations of residual mica in the soil. These led in turn to the discovery of mica deposits concealed nearby. Rapid erosion, or "gully gravure," caused by surface runoff in the deforested areas (fig. 11)

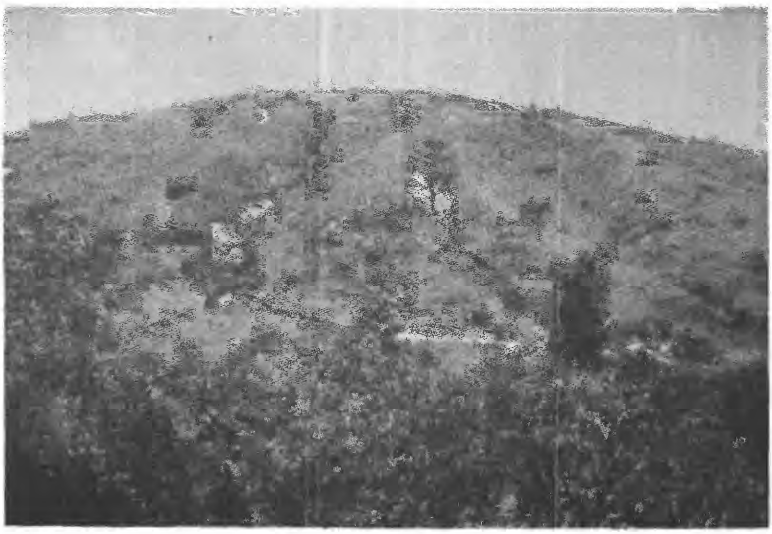


FIGURE 11.—"Gulley gravure," or rapid-erosion gulleys, in deeply weathered mantle in a deforested area near Governador Valadares, Minas Gerais, Brazil.

has also been responsible in part for bringing to light residual mica concentrations. Residual fragments of gem-stone minerals associated with mica are still a great incentive for prospecting in some areas north of the Rio Doce. Smythe (1944) has written an excellent guide for the prospecting of mica deposits. The southern part of the Mica Belt is culturally developed to a greater extent than the northern part and therefore offers less opportunity for the discovery of new mica prospects.

GEOLOGY OF THE MICA BELT

GENERAL STATEMENT

Rocks assigned to the Archeozoic era underlie most of Minas Gerais, and rocks assigned to the Proterozoic and Paleozoic eras underlie the remainder of the region. The stratigraphic relations of the formations in this part of Brazil, as presented in standard Brazilian publications, are listed below, from the youngest to the oldest:

Silurian: Bambuí series.
Unconformity.
Lower Paleozoic or upper Proterozoic: Lavras series.
Unconformity.
Proterozoic (?) : Itacolomí series.
Proterozoic (?) : Minas series.
Unconformity.
Archeozoic (?) : Complexo Fundamental (basement complex).

The Complexo Fundamental is prominent in the Serra da Mantiqueira and the Serra do Mar; the Minas and Itacolomí series make up the rugged mountains of the Serra do Espinhaço in central and northern Minas Gerais; the Lavras series underlies much of the tableland country extending from northern Minas Gerais into Baía; and the Bambuí series is prominent along the São Francisco Valley west of the Mica Belt. Small areas of the Minas, Itacolomí, and Lavras series are evident in terrain generally underlain by the Complexo Fundamental because of complex faulting. Fossil evidence for age exists only for the Bambuí series.

The mica-bearing pegmatites are found principally in areas underlain by the Complexo Fundamental and are absent in those areas underlain by the Lavras and Bambuí series. Some rocks tentatively assigned to the Minas and Itacolomí series contain mica-bearing pegmatites. The age of the pegmatites is probably pre-Lavras, and there may have been more than one period of pegmatite formation.

Quartz-crystal deposits are associated with pegmatites in the Complexo Fundamental and in the Minas and Lavras series. Quartz-crystal deposits, however, in the Lavras and Bambí series are believed by the present writers to be related to a younger diastrophism than that responsible for the pegmatites of the Mica Belt.

Correlation of igneous and metamorphic rocks in southeastern Brazil has been attempted in the past largely by means of lithographic comparison. Some igneous rocks, assumed to be Archean, may well be post-Archean in age. Differences in degree of metamorphism, unconformities, complex structural relations, deep weathering profiles, and a dearth of topographic maps have all been factors retarding the construction of a satisfactory geologic map of eastern Minas Gerais. Some of the general observations made by the writers during the course of their work in 1942–45 and here presented may perhaps prove of value to future workers in this region.

COMPLEXO FUNDAMENTAL (BASEMENT COMPLEX)

GENERAL DESCRIPTION

The southern and central part of the Mica Belt is underlain largely by dark schist, granitoid gneiss, and diverse gneissoid igneous rocks that are all grouped by Brazilian geologists (Oliveira and Leonardos, 1943) in a unit called the Complexo Fundamental, or Complexo Brasileiro, or Complexo Archeano. In eastern Brazil, this basement complex is exposed irregularly in a strip up to 600 kilometers in width and parallel to the Atlantic coast.

A great variety of the rocks assigned to the Complexo Fundamental is exposed in the mica districts of eastern Minas Gerais. Biotite schist and interlayered amphibolite schist and quartzite characterize the area between Governador Valadares and Santa Maria do Suassuí. Numerous stocks of granodioritic rock are exposed in the area east as well as north of Conselheiro Pena, where they are surrounded by granitoid gneiss and biotite-garnet schist. Between Bicas and Glória are a great variety of banded and gneissoid basic igneous rocks composed essentially of pyroxene, plagioclase, and garnet. The mica district of Espera Feliz, which lies on the western flank of the Serra do Caparaó, is characterized by dark schist, granitoid gneiss, and granulite derived by alteration of the schist.

The Complexo Fundamental is too complex in lithology to be considered as a single stratigraphic unit, and the Archean age for all the rocks is not well substantiated. In the future, detailed geologic mapping may provide an adequate basis for subdivision of the complex into several different geologic units based on relative age, metamorphism, and deformation.

DARK SCHIST AND RELATED GRANITOID GNEISS

In the mica districts between Tombos and Santa Maria do Suassuí, schistose rocks predominate. Biotite schist, composed essentially of quartz, biotite, and oligoclase or andesine, is the principal variety; graphitic, chloritic, and amphibolitic varieties are subordinate. Eastward, toward the coast, schist is less abundant than granitoid gneiss.

Albuquerque (1926) has suggested that the schistose rocks of this part of Minas Gerais represent a stratigraphic section younger than the coarse-grained feldspathic gneiss so prominent along the coast in the Serra do Mar. Dutra (1926), however, reports that the Serra do Caparaó near Espera Feliz is composed largely of granitoid gneiss

FIGURE 12.—Fault scarp on the south side of the Serra dos Lourenços, Minas Gerais, Brazil, exposing quartzite members of the Complexo Fundamental.

that is intimately mixed with dark mica schist. Near Manhumirim, Governador Valadares, and Aimorés and at several other places, the writers observed mica schist that had been locally altered to porphyroblastic granitoid gneiss through granitic lit-par-lit injection or through combined silicification and feldspathization. Guimarães (1938) also has called attention to this geologic process in reference to the origin of some granitoid gneiss in Minas Gerais, and Lamego (1938) and Fróes Abreu (1945) both note the metamorphic effects of granitic intrusions in the Serra do Mar. It appears likely, therefore, that some of the granitoid gneiss in the Mica Belt is equivalent to the schistose rock that has been further metamorphosed by the addition of potash and silica originating from a granitic source.

Amphibolite and chlorite schist are in many places complexly interfolded with quartz-biotite schist in the Complexo Fundamental. These three varieties of schist are especially well exposed in the surface cuts at the Golconda and Evangelista mines near Governador Valadares, and they perhaps represent metamorphic products of rocks originally different in composition.

The quartz-biotite-oligoclase schist is considered to have undergone a lesser degree of metamorphism than the schist that contains abundant garnet and hornblende and is associated with granitoid gneiss. The increase in the degree of metamorphism is probably a result of the same agencies that effected the transformation of the original rock.

QUARTZITE INTERLAYERED WITH DARK SCHIST

Beds or members of quartzite interlayered with biotite or amphibolite schist are exposed in many places in the Mica Belt, particularly in the region north of the Rio Doce bordered by Governador Valadares, Peçanha, and Itambacurí. The quartzite layers are undoubtedly part of the complex and have suffered the same deformational history as the schist. In the Serra dos Lourenços, east of Ramalhete, several hundred meters of the complex is well exposed. One quartzite member about 50 meters thick, overlain by biotitic schist and underlain by amphibolitic and biotitic schist, forms steep escarpments where it is exposed in fault blocks (fig. 12). Thin beds and layers of quartzite ranging up to 10 meters in thickness and interlayered with schist are also exposed in road cuts along the Rio-Baía highway between Governador Valadares and Itambacurí, in road cuts between Governador Valadares and Peçanha, in railroad cuts near Resplendor, in a quarry north of Muriaé, and near Manhumirim.

GNEISSOID AND BANDED MAFIC IGNEOUS ROCKS

In the region between Bicas and Carangola a wide variety of partly metamorphosed igneous rocks, including anorthosite, gabbro and norite, and diorite, are associated with dark schist. These basic igneous rocks are exposed in a belt about 150 kilometers long and 30 kilometers wide that is bordered on the east and west by schistose rock. Gabbroic rocks with inclusions of pyroxenite predominate in the eastern part of this belt near Leopoldina, Muriaé, Glória, and Carangola, whereas in the western part, near Bicas and Nepomucena, anorthositic varieties are predominant. The regional trend of this belt of basic rocks is reflected in detail by an interlayering of rocks rich in plagioclase with rocks rich in pyroxene. In addition to these primary structures, metamorphism has induced a gneissic character and a secondary quartz mineralization.

The plagioclase in these igneous rocks varies in composition between andesine and bytownite, with the less calcic varieties dominant in the anorthositic types. In thin section, the traces of the twin planes are curved and warped. The pyroxene is predominantly hypersthene, which, in the more mafic rock types, has exsolution lamellae of augite that also are curved and warped. Euhedral crystals of rose-pink garnet are abundant in the gneissoid anorthosite and less abundant in the noritic rocks. Granular aggregates of quartz occur as veinlets in all the rocks, and in many specimens quartz forms embayments in the plagioclase and rare myrmekitic intergrowths. In some specimens the pyroxene is completely altered to hornblende. Biotite is a common, though not abundant, mineral in these rocks. Epidote is rare, and microcline is absent.

These rocks probably represent a complex series of injections of a mafic magma that further differentiated during emplacement. Regional metamorphism and thermal and chemical effects of a subsequent series of granitic injections are responsible for the present character of these rocks.

GRANODIORITIC ROCKS

North of Conselheiro Pena and east of the Rio Suassuí Grande, a number of prominent rounded summits are underlain by stocks of granodiorite, the largest of which is several kilometers in diameter. The rocks in the stocks are composed essentially of quartz, microcline, and oligoclase or andesine. Most of these masses are perceptibly foliated because of an alinement of biotite. Near the borders of the stocks, the igneous rock grades into surrounding granitoid gneiss through a zone characterized by an increase in accessory garnet, a more pronounced foliation, a local increase of biotite, and—in general—a finer grain size. The granitoid gneiss itself, as described earlier, is either the product of metamorphism of schist or a greater alteration of the rock from which the schist was derived. Similar geologic features are exposed, also, near Aimorés and near Vitória, where the stocks are larger in diameter and contain a great number of inclusions of metamorphic rock.

Irregular dikelike masses of granodiorite are intimately associated with dark schist in many places through the Mica Belt. In the Serra do Caparaó near Espera Feliz, all textural gradations between granitoid gneiss and granodiorite are represented in intrusive bodies in dark schist. Between Bicas and Muriaé, irregular masses of granodiorite are intrusive into schist and into the gneissoid mafic igneous rocks so widely distributed in that area. Specimens of the granodiorite collected at several localities indicate that the most pronounced foliation is in those stocks in which the plagioclase is most calcic. In some stocks that approach granite in composition, such as those near the Laranjeiras mine near Divino, the foliation is barely perceptible.

Near the Rochedo mine, about 25 kilometers north of Conselheiro Pena, irregular masses of pegmatite, aplite, and granodiorite have haphazardly intruded a biotite-rich schist that contains no granitoid gneiss. In many places, such as the Rochedo and Palmital mines in the same general area, pegmatites cut across foliated granodiorite and granitoid gneiss.

The geologic age of the granodiorite and related rocks is not known with certainty. Brazilian geologists classify them as Archean. Stocks of granodiorite have not been reported in terrain underlain by quartzite formations of post-Archean age. They undoubtedly were intruded during the widespread diastrophism that was responsible for the formation of granitoid gneiss and lit-par-lit gneiss in the Serra da Mantiqueira and Serra do Mar.

PHYLLITE AND QUARTZITE YOUNGER THAN THE COMPLEXO FUNDAMENTAL

SUMMARY

In central and northern Minas Gerais, three series of quartzitic rocks younger than the Complexo Fundamental have been recognized. From oldest to youngest they are called the Minas series, the Itacolomí series, and the Lavras series. The first two are assigned to the Proterozoic and the third to the upper Proterozoic or lower Paleozoic. Their distribution and geologic relations are most fully described by Moraes (1937) and Freyberg (1932). All three formations are characterized by massive quartzite members, but the phyllites in both the Minas and Itacolomí series are reported to be more intensely metamorphosed than the phyllite of the Lavras series. A marked unconformity separates the Lavras series from older formations.

In several published geological reports, the basal part of the Minas series is described as being separated from the schist and gneiss of the Complexo Fundamental by an angular unconformity. In the northern part of the Mica Belt, in northeastern Minas Gerais, a prominent phyllite and quartzite sequence rests on the Complexo Fundamental without any apparent unconformity and with transitional beds marking a gradational contact. In the mountains bordering the Rio Doce between Conselheiro Pena and Aimorés, however, a different quartzite formation rests with a marked angular unconformity on the Complexo Fundamental.

PHYLLITE AND QUARTZITE OF THE POAINHA ESCARPMENT

The Poainha escarpment, a prominent landmark some 20 kilometers east of Santa Maria do Suassuí, extends for several kilometers north of the village of Poaia (fig. 13), where it constitutes the western limit of a mountain group, the Serra da Safira, whose highest summits are between 1,100 and 1,500 meters in altitude. The area immediately east and west of the escarpment is underlain by a metamorphic sequence, several hundred meters thick, composed of beds of quartzite, sericitic and ferruginous quartzite, phyllite, and quartzose and ferruginous phyllite. The escarpment itself is held up by a quartzite unit a few hundred meters thick that is best exposed at the Cruzeiro mica mine (fig. 14). Ottoni and Noronha (1942) refer to this quartzite as equivalent to the Itacolomí series of Proterozoic age. At the foot of the escarpment and in the foothills west of it, the sev-

237190 O—53——3

eral varieties of quartzite and phyllite are interlayered and interfolded with the varieties of dark schist so characteristic of the Complexo Fundamental. As no angular unconformity is apparent between

FIGURE 13.—The Poainha escarpment, viewed from the west near the town of Poaia Minas Gerais, Brazil, exposing the quartzite formation overlying the schist of the Complexo Fundamental.

FIGURE 14.—Bedding in the quartzite formation of the Poainha escarpment at the Morro do Cruzeiro, Minas Gerais, Brazil.

the two groups of rocks in this region, it seems probable that the change from one group to the other is a gradational one representing a few hundred meters of stratigraphic thickness.

PHYLLITE AND QUARTZITE OF THE SERRA NEGRA ESCARPMENT

The Serra Negra escarpment between Itamarandiba and Maranhão is a prominent landmark that resembles the Poainha escarpment in its topographic and geologic relations. The quartzite in the Serra Negra locally contains hematite deposits, as described by Moraes and others (1937, pp. 118–20), who assign this quartzite and associated phyllite to the Proterozic.

PHYLLITIC ROCKS NEAR THE CACHOEIRA GRANDE

North and south of the village of Poaia, and especially well exposed in the vicinity of the Cachoeira Grande of the Rio Suassuí Grande (fig. 15), severely folded beds of quartzitic and phyllitic rocks are interlayered with amphibolite and biotite and with chlorite schist.

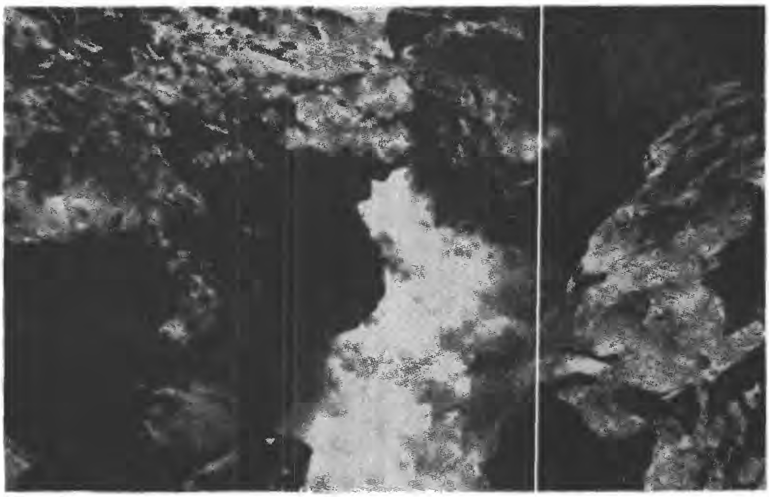


FIGURE 15.—Scalloped abrasion in phyllitic rocks at the Cachoeira Grande of the Rio Suassuí Grande, near Poaia, Minas Gerais, Brazil.

Quartz sand dominates the alluvium in the area. These quartzite and phyllite beds appear to belong to that part of a continuous stratigraphic section younger than the dark schists of the Complexo Fundamental exposed a few kilometers to the south near the Serra dos Lourenços.

QUARTZITE NEAR CRENAQUE

A massive quartzite several hundred meters thick, resting with an angular unconformity on schist and granitoid gneiss of the Complexo Fundamental, is exposed in the high hills and mountains bordering the Rio Doce between Conselheiro Pena and Aimorés. The quartzite in the thickest section, exposed near Crenaque, is more massive than the quartzite in the Poainha and Serra Negra escarpments. Guimarães and Barbosa, who assembled the geologic map of Minas Gerais (1934), assign this quartzite to the Minas series. Of all the quartzites examined in eastern Minas Gerais, that exposed near Crenaque is the only one whose angular unconformity with the Complexo Fundamental is undisputed. The relative geologic age of the quartzite near Crenaque and the pegmatites of that area was not established with certainty, but reconnaissance observations in the vicinity of the Itatiaia mine near Conselheiro Pena suggest that the quartzite is younger than the pegmatites.

CONCLUSIONS

Correlation by lithology alone of the quartzites younger than the schist and gneiss of the Complexo Fundamental is unsatisfactory. If the phyllite and quartzite in the northern part of the Mica Belt are correlated with the phyllite-quartzite sequence in central Minas Gerais, then the supposed angular unconformity separating the Minas series from the older rocks may be questioned. Freyberg (1927, p. 439) reports a concordant relation between gneiss and overlying quartzite and phyllite in an area southwest of Belo Horizonte, and Leonardos (1940, p. 51) states that in central Goiaz the Archean gneiss grades concordantly into phyllite of the Proterozoic. The angular unconformity that separates the Lavras series from older rocks is apparently well established. The quartzite near Crenaque may possibly be the Lavras or at least may be younger than the formations north of Poaia and younger than the pegmatites.

NONFOLIATED ULTRABASIC ROCKS

In eastern and southern Minas Gerais, stocks of peridotite, dunite, and pyroxenite as much as 2 kilometers in diameter are intrusive into schist of the Complexo Fundamental and, according to Moraes (1935), in some places are intrusive also into phyllite and quartzite assigned to the Proterozoic. The olivine in the dunite and peridotite is serpentinized, and the pyroxene and plagioclase show evidence of cataclastic deformation similar to that displayed by the gneissoid mafic rocks between Bicas and Glória. A few of these stocks have weathered to form lateritic nickel deposits. Guimarães (Moraes, 1935, pp. 108–114) has suggested that the stocks were intruded during late Proterozoic time. Field relations indicate that these peridotite stocks are older than the pegmatites in those areas.

AMPHIBOLITE IN QUARTZITE

Irregular masses of amphibolite in quartzite are exposed in the area east and north of Santa Maria do Suassuí. This amphibolite is interpreted as a product of the metamorphism of an ultrabasic rock that was intruded into sedimentary rocks prior to the principal period of metamorphism and prior to the intrusion of the mica-bearing pegmatites. It is not known, however, whether this amphibolite was intruded during the same epoch as the amphibolite that is complexly interfolded with the biotite schist of the Complexo Fundamental. A detailed study of the amphibolite exposed at the Cruzeiro mica mine, where it forms a mappable, lens-shaped unit, reveals that it is composed of olivine and serpentine, pyroxene, hornblende, fibrous amphibole, biotite, chlorite, quartz, and calcite.

Guimarães (1933) and Moraes (1937) describe altered mafic igneous rocks intrusive into quartzite and phyllite of Proterozoic age in northern Minas Gerais and designate them "diabasoid amphibolite." These mafic rocks are composed essentially of epidote and hornblende, but few of them are true amphibolites. The intrusion of these rocks is assigned to the time interval between the Itacolomí and Lavras series. The amphibolite at the Cruzeiro mine may perhaps be related to the same diastrophism that affected the diabasoid amphibolite, and it is certainly older than the mica-bearing pegmatites of that district.

GEOLOGY OF THE MICA-BEARING PEGMATITES

AGE RELATIONS

GENERAL STATEMENT

The geologic age of the mica-bearing pegmatites in the Mica Belt of Minas Gerais is not known with any assurance, nor is it known whether all the pegmatites were introduced during the same epoch. In various published reports, the pegmatites are assigned to diastrophisms ranging from the Laurentian to the Caledonian. Their geological distribution and age determinations based on chemical analyses of a few radioactive minerals suggest that the pegmatites are probably late pre-Cambrian or lower Paleozoic (pre-Lavras series) in age.

GEOLOGICAL DISTRIBUTION OF THE PEGMATITES

The mica-bearing pegmatites are widely distributed in three groups of rocks, all of uncertain age: (1) the dark, intensely folded biotite schist generally considered to represent the oldest (Archean) rocks in the Mica Belt; (2) the quartzitic and phyllitic series east and north of Santa Maria do Suassuí, which rest conformably(?) on the schist of Archean age; and (3) the gneissoid, banded, noritic, dioritic, and anorthesitic rocks between Bicas and Glória. Pegmatites are present, though much less abundant, in three other groups of rocks: (1) the granitoid gneiss, near Espera Feliz and Conselheiro

Pena, that is believed to be a metamorphic product of the same rocks as the dark Archean schist; (2) the gneissoid, granodioritic rocks intrusive into Archean schist between Conselheiro Pena and Teófilo Otoni and into gneissoid and banded mafic rocks between Bicas and Glória; and (3) amphibolite and peridotite intrusive into rocks of probable Proterozoic age.

In central Goiaz, according to Moraes (1931), pegmatites intrude peridotite and gabbro that are intrusive into the Minas series (Proterozoic). Moraes (1936) likewise reports quartz-rich pegmatites in the Itacolomí quartzite (Proterozoic) of central Minas Gerais.

Mica-bearing pegmatites in the Lavras or Bambuí series have neither been observed by the writers nor reported in geological literature, although quartz-crystal deposits are abundant in the rocks of these formations.

USE OF RADIOACTIVE MINERALS FOR DETERMINATION OF AGE

Age determinations based on seven different chemical analyses—Oliveira (1926), Fenner (1928), Hess and Henderson (1925), and Andrade (1930)—of four radioactive minerals from three pegmatites in the schist of Archean age in Minas Gerais range from 340,000,000 years (Ordovician) to 557,000,000 years (late pre-Cambrian). These data, however, do not prove that more than one generation of pegmatites is present, for the discrepancy in the age determinations may perhaps be explained as follows:

1. The atomic weight of the lead in the samples analyzed was not determined; hence the analyses may include common as well as radiogenic lead.

2. In the formula for age determination

$$\frac{Pb}{U+XTh} \cdot Y \cdot 10^{8} = \textit{age in million of years}$$

the value of the constant X ranges from 0.357 to 0.46 and the value of the constant Y from 66 to 80 as used by various authors.

3. The analytical methods were not uniform.

4. The specimens analyzed were derived from deeply weathered pegmatites in association with decomposed feldspar. In such an environment, as reviewed by Palache and others (1944, pp. 615–19), partial and selective leaching and alteration may well affect the original lead-uranium-thorium ratios of some radioactive minerals.

5. The quantity of lead in the different analyses, ranging from 0.09 percent to 0.9 percent, is so small that imperfection in an analysis or sample would significantly alter the age determination.

In view of the above comments and the requirements set forth by Knopf (1931), none of the age determinations from the Brazilian samples is conclusive except to indicate general age. The assignment of the pegmatites to the late pre-Cambrian or lower Paleozoic would be in keeping with the meager geological evidence available.

RELATION OF PEGMATITES TO APLITE AND GRANITE

Granular aplite, spatially and genetically related to mica-bearing pegmatite, is known in many places but is especially well exposed in

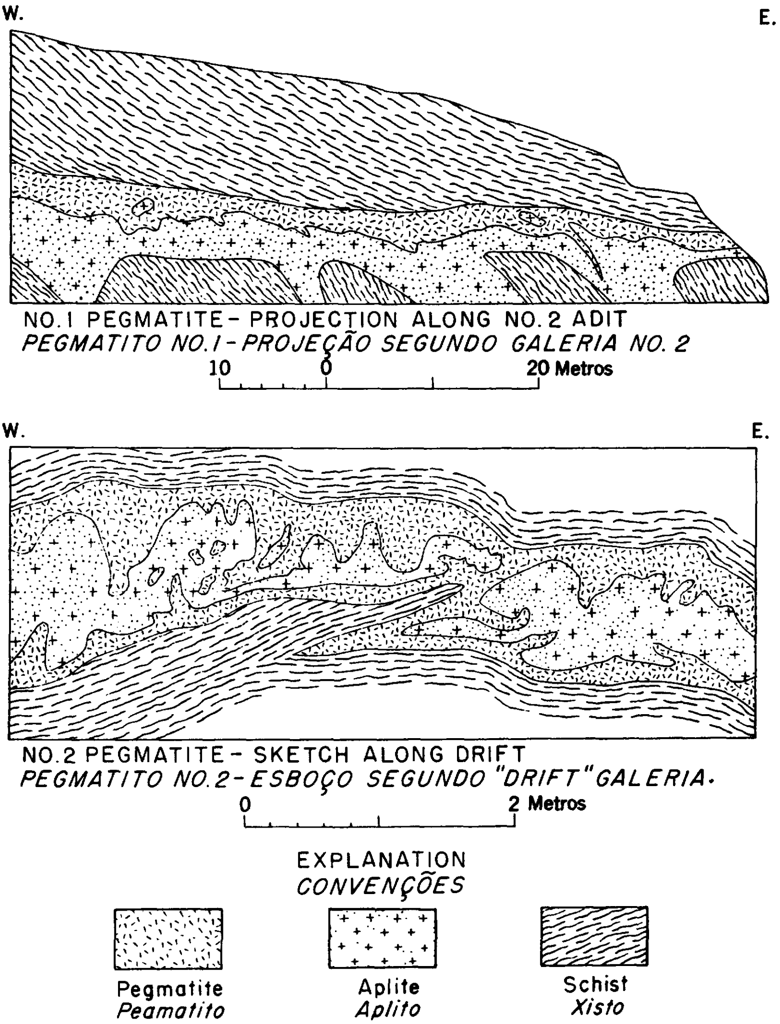


FIGURE 16.—Projection and sketch showing the relations of pegmatite, aplite, and schist at the Serra dos Lourenços mica mine, Minas Gerais, Brazil.

the workings of the Serra dos Lourenços mine. The pegmatite, as shown in figure 16, envelops or invades aplite and lies between aplite and schist.

The same minerals are found in both the aplite and pegmatite, but their proportions and grain size differ in the two rocks. Mica is much more abundant in the pegmatite. Both rocks were apparently formed during one generation of igneous activity.

Coarse-grained, muscovite-rich granite is exposed in contact with mica-bearing pegmatite in the underground workings of the Forat-

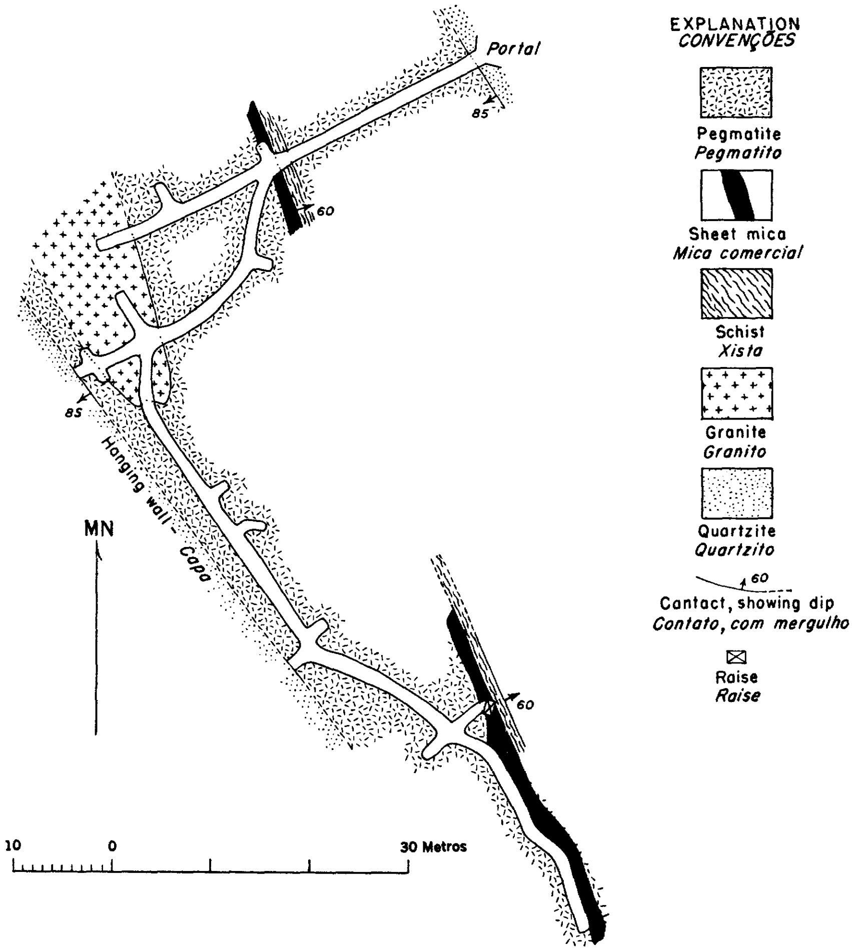


FIGURE 17.—Plan of the main level, Forattini mica mine, Cruzeiro district, Minas Gerais, Brazil, showing relations of pegmatite, granite, schist, and quartzite.

tini mine (fig. 17) in the Cruzeiro mica district. Locally the contacts of the two rocks are well defined, but in many places pegmatite grades into and irregularly intrudes the granite. The pegmatite appears to be younger than the granite, but both formed during the same period of igneous activity.

In many mica districts, particularly those where pegmatites occur in mica schist, aplitic rock is common in the marginal portions of the pegmatites. This kind of aplite is variable in texture and composition and not uncommonly has a streaked appearance. It is believed to be an alteration product of the schist and not an intrusive rock. In many places this kind of aplitic rock is spatially associated with granite gneiss and may well be a fine-grained equivalent of the gneiss.

Certain stocks of the gneissoid granodioritic rocks described earlier approach granite in composition. They contain irregular segregations of pegmatite rich in quartz and feldspar and poor in mica. The presence of clefted open spaces commonly bordered by quartz crystals and of textural graduations from rock to pegmatite is evidence that this kind of pegmatite is a late-stage segregation of the granitic rock. Mica-bearing pegmatites in gneissoid stocks and smaller masses that approach quartz diorite in composition are numerous and have well-defined contacts. They are rare in the granitic rocks but common in the schist surrounding the granitic rocks.

The granular and nonfoliated aplite and granite, as well as the associated pegmatites, may perhaps be the last facies of the magma period which also produced the earlier granodiorite and basic rocks. Such a relationship, however, has not been established.

STRUCTURAL FEATURES OF THE PEGMATITES

GENERAL STATEMENT

The mica-bearing pegmatites differ greatly in form, size, attitude, and structural relations with the wall rock. The form of many pegmatites is influenced by the composition of the country rock surrounding them, whereas their size is independent of such influence. For the purpose of general comparison, transverse sections of 24 selected pegmatites are shown in figures 18, 19, and 20.

These sections, referred to the same scale, are based on detailed surface and subsurface surveys. Five of the pegmatites illustrated—the Pedro Espirito, Golconda, and Levindo Alferes (fig. 19) and the Pontal and Pedra Redonda (fig. 20)—have been entirely or almost entirely exposed on all sides by extensive open-pit operations. Four pegmatites—the Cruzeiro No. 2 and Palmital (fig. 18) and the Lourenços No. 4 and Bananal (fig. 19)—have extensive and informative underground workings in and near the plane of the section. In four others—the Chalet Verde and Pequerí (fig. 18) and the Urubú and Borges (fig. 20)—part of the pegmatite in the plane of the section has been restored and part projected.

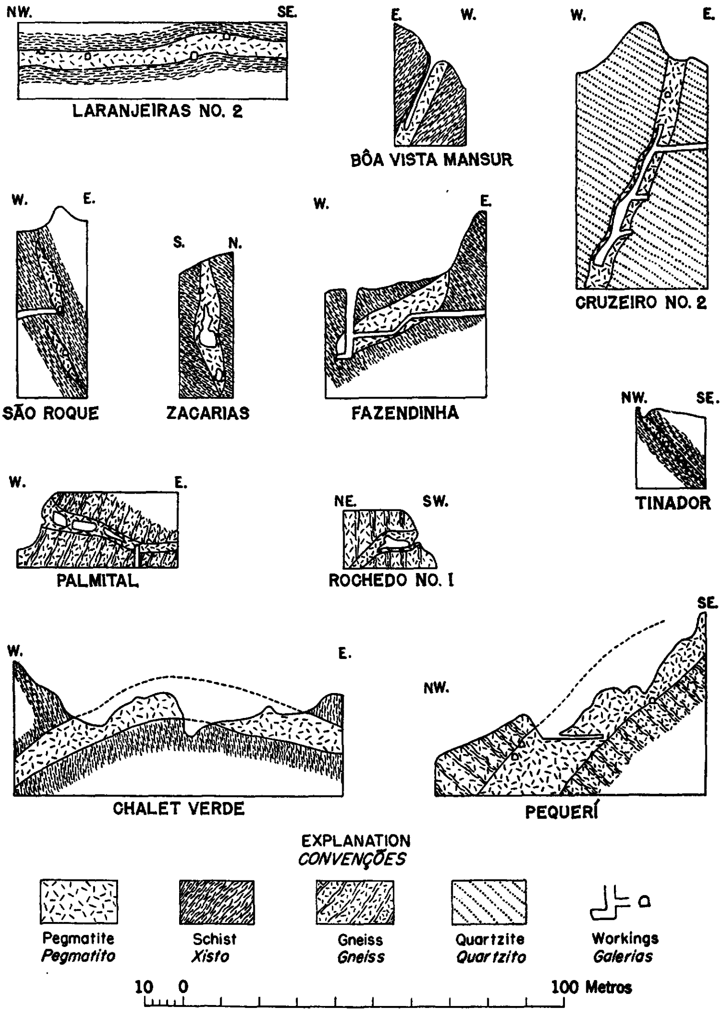


FIGURE 18.—Structure sections showing the size, form, and attitude of 11 tabular and lenticular pegmatites, Minas Gerais, Brazil. Parts of the Chalet Verde and Pequerí pegmatites have been restored or projected.

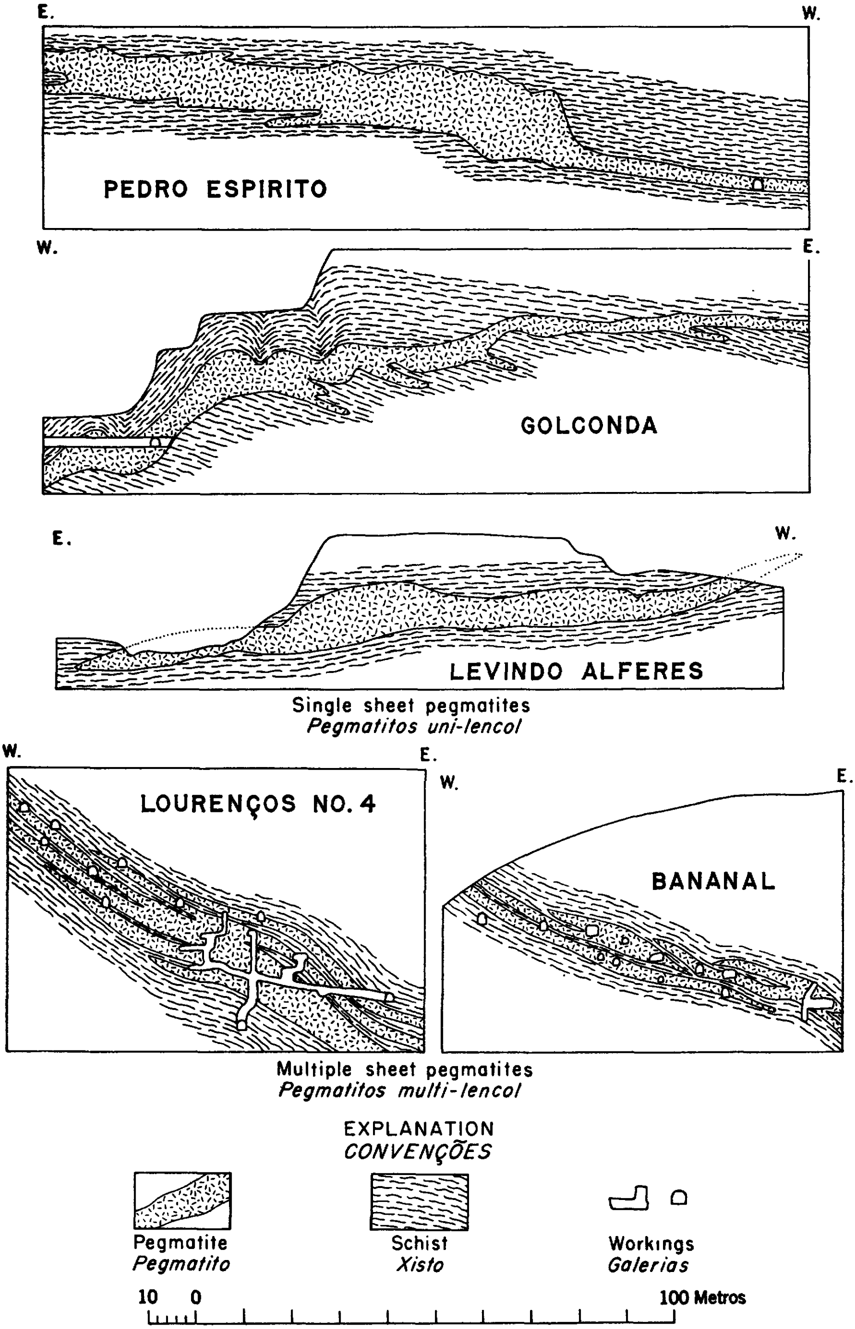


FIGURE 19.—Structure sections showing the size, form, and attitude of three single-sheet pegmatites and two multiple-sheet pegmatites, Minas Gerais, Brazil.

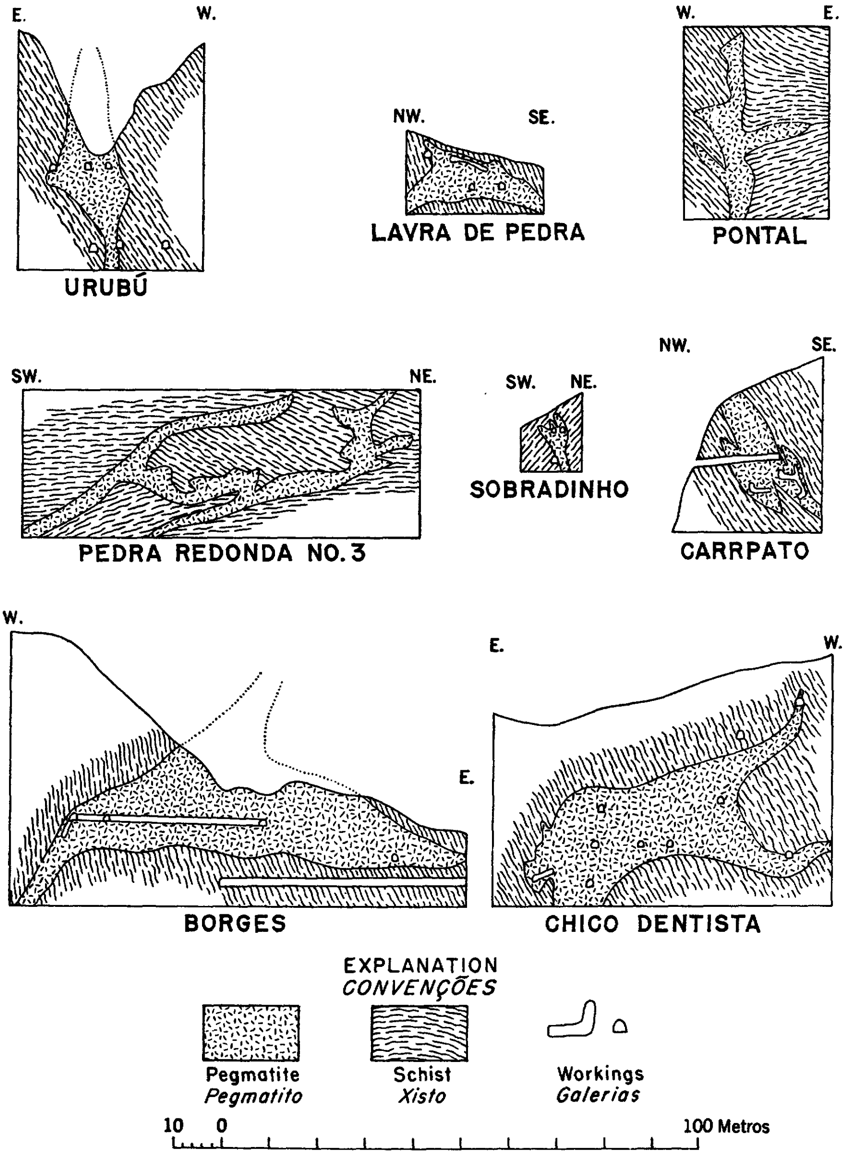


FIGURE 20.—Structure sections showing the size, form, and attitude of eight irregularly formed pegmatites, Minas Gerais, Brazil. Parts of the Urubú and Borges pegmatites have been restored or projected.

FORM AND SIZE

On the basis of general outline in cross section and regularity of contact with wall rock, the mica-bearing pegmatites are classed into two groups, each subdivided, as follows:

1. Regular in form (fig. 18):
   (a) Tabular.
   (b) Lenticular.
2. Irregular in form (figs. 19 and 20):
   (a) Sheetlike, single and multiple.
   (b) Complex.
   (c) Ramiform.

The greatest number of economically important mica deposits are in tabular, lenticular, or sheetlike pegmatites.

Tabular pegmatites are, in general, uniform in thickness, but lenticular pegmatites taper outward from a thicker central part. Minor irregularities in form are not uncommon. The distinction between tabular and lenticular pegmatites can be made only where the pegmatite is extensively exposed along both walls. In a few cases the distinction is an arbitrary one. Only a few of the several dozen commercially significant tabular and lenticular pegmatites examined exceed 10 meters in thickness, 100 meters in strike length, and 50 meters in dip length.

The largest tabular pegmatites are at the Cruzeiro mine, and their known dimensions are as follows:

	Dimensions, in meters			
	Maximum thickness	*Exposed strike length*	*Vertical range of exposure*	*Dip length explored*
Forattini	50	600	85	10
Cruzeiro No. 1	50	1,000	70	40
Cruzeiro No. 2	4	900	120	85
Cruzeiro No. 3	6	1,200	115	20
Cruzeiro No. 4	4	600	70	20

The Pequerí pegmatite, the largest of the lenticular bodies, has a maximum thickness of 18 meters, a strike length of 360 meters, and an explored dip length of 60 meters.

Sheetlike pegmatites (fig. 19) occur either as single bodies or as groups of closely spaced and interconnected bodies. This kind of pegmatite is found only in schist and is too irregular to be classed as tabular. The dimensions for the largest of these bodies are tabulated below:

	Dimensions, in meters		
	Maximum thickness	*Exposed strike length*	*Explored dip length*
Single sheets:			
Pedro Espirito	14	300	175
Golconda	9	250	70
Levindo Alferes	12	135	95
Ipê	18	30	120
Ventura	10	200	125
Velocindo	12	135	50
Onça	5	100	20
Multiple sheets:			
Lourenços No. 4	8	40	90
Bananal	8	120	80

Complex pegmatites that are commercially significant are few in number. The largest and most important of this irregular group are the Urubú, Borges, and Chico Dentista (fig. 20) in the Espera Feliz district. Both the Borges and the Urubú are between 300 and 400 meters long.

Ramiform pegmatites are irregular branching masses that are numerous but rarely commercially significant. The Pontal and Pedra Redonda No. 3 (fig. 20), the largest of ramiform pegmatites, are exposed for linear distances of some 150 meters and vertical distances of 20 to 40 meters.

ATTITUDE

The mica-bearing pegmatites in the Mica Belt range in dip from horizontal to vertical, in strike from north to east. Although their orientation is random, most of the commercially significant ones are oriented within the arc N. 45° E. to N. 45° W. A tabulation of about 150 pegmatites, from which perhaps 90 percent of the total Brazilian mica production has come, shows that the strikes of approximately 80 percent are within this preferred arc. Most of the tabular pegmatites are vertical or steeply inclined, and most of the lenticular ones are moderately to gently inclined. The single and multiple sheetlike pegmatites are horizontal to moderately inclined.

Within some of the mica districts are groups of closely spaced pegmatites that commonly have similar attitudes. Typical are the following six examples:

1. At and near the site of the *Cruzeiro* mine, six tabular pegmatites strike N. 20° to 35° W. and dip steeply to the southwest.
2. In the *Serra dos Lourenços* mine, several multiple sheetlike pegmatites strike N. 10° to 20° W. and dip moderately to the southwest.
3. Near the town of *Espera Feliz*, 14 of 17 commercially significant pegmatites strike N. 15° to 45° E., most of them dipping steeply southeastward.
4. Near the town of *Bicas*, six tabular and lenticular pegmatites, all of them important producers, range in strike from N. 20° to 45° E. and dip steeply to the northwest or southwest.
5. At the *Viuva Valerio* mine, near the town of Manhumirim, two essentially tabular pegmatites strike approximately N. 60° W. and dip steeply southwestward.
6. Near *Conselheiro Pena*, five parallel tabular pegmatites, of which the Barca is one, strike essentially north and dip steeply to the east.

Numerous other small groups of pegmatites in the Mica Belt are known to show much similarity in attitude. It is probable that many pegmatites were tilted by faulting after their formation. In the region north of Governador Valadares, schist containing pegmatites has been displaced along a great number of normal faults.

DISCORDANT, CONCORDANT, AND QUASI CONCORDANT PEGMATITES

With respect to the foliation or bedding of the wall rock, pegmatites are classified as discordant, concordant, or quasi concordant. Discordant pegmatites are the most numerous in the Mica Belt. Completely concordant ones are few in number, small in size, and commercially insignificant.

Most of the large, productive, single and multiple sheetlike pegmatites are in part concordant and in part discordant (fig. 19), but inasmuch as the pegmatite masses are essentially concordant to the general foliation of the wall-rock schist, they are referred to as quasi concordant. For example, the roof and floor of the Pedro Espirito pegmatite are essentially concordant, but discordant steps are numerous. The roof of the Golconda pegmatite is essentially concordant, but the floor is distinctly discordant. The Levindo Alferes pegmatite is more nearly concordant in its entirety but has many local discordances and irregularities. The numerous individual tabular and lenticular pegmatites that make up the multiple sheetlike pegmatites at the Serra dos Lourenços and Bananal mines are locally discordant to the schist, but each assemblage as a unit is essentially concordant to the general foliation of the enclosing schist.

INFLUENCE OF COUNTRY ROCK ON STRUCTURAL FEATURES

The competency and composition of the rocks in the Mica Belt and the different behavior of the various rock types under regional stresses have been important factors in determining the general form, attitude, nature of contacts, and minor structural relations of the pegmatites. Pegmatites of regular form are much more abundant in the competent rocks—quartzite, gneiss, and igneous rocks—where they are commonly vertical or steeply dipping. Irregularly formed pegmatites are more characteristic of the incompetent, schistose rocks. Sheetlike pegmatites, in particular, are known to occur only in schist.

Irregularities in the contacts of pegmatites with competent rocks are angular and well defined. In schistose rocks, on the other hand, contacts are locally ragged and indeterminate (figs. 21, 22). Inclusions and large wedges of schist in pegmatite are not uncommon, and parts of some pegmatites closely conform to drag folds that have developed in the schist (figs. 23–25).

Chemical reaction of magmatic fluids with schist near many pegmatites is evident, but reaction with quartzite or granular igneous rocks has been insignificant. Quartz, tourmaline, garnet, and feldspar have been introduced along planes of schistosity in schistose

FIGURE 21.—Irregular contact of pegmatite and schist at the lower Urubú mine, near Espera Feliz, Minas Gerais, Brazil.

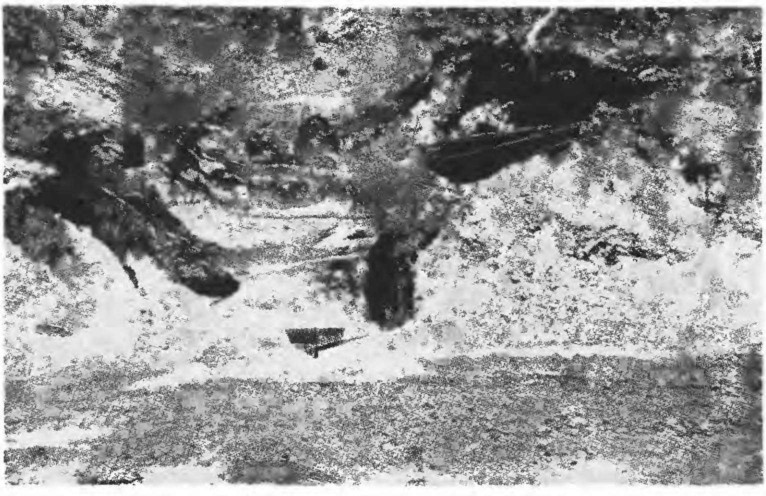


FIGURE 22.—Irregular contact of pegmatite and schist at the Carajáu mine, near Governador Valadares, Minas Gerais, Brazil.

FIGURE 23.—Pegmatite enclosed in a minor drag fold of schist in the roof of the Carajáu pegmatite, near Governador Valadares, Minas Gerais, Brazil.

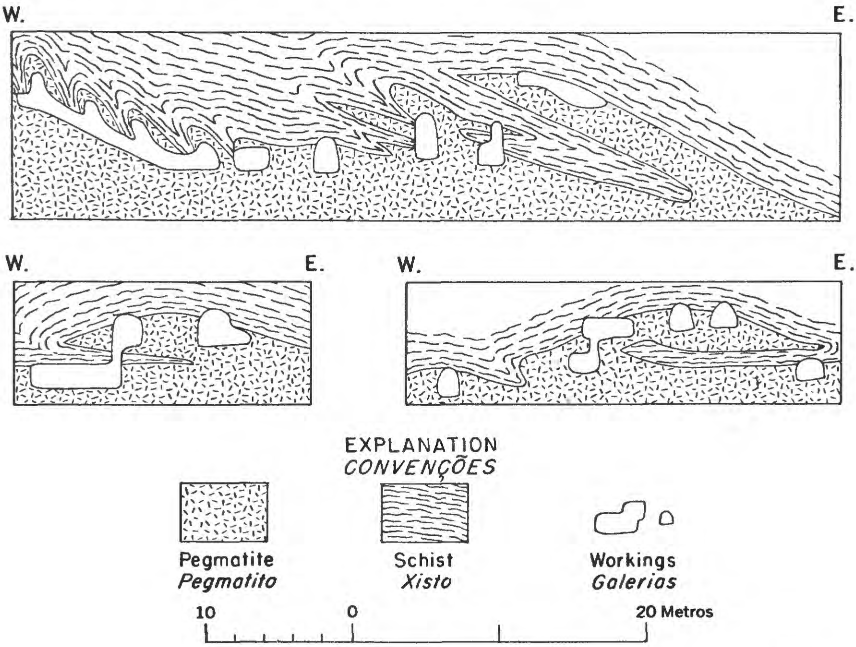


FIGURE 24.—Transverse structure sections, No. 1 pegmatite, Serra dos Lourenços mica mine, Minas Gerais, Brazil, showing the relation of drag folds to the roof of the pegmatite.

237190 O—53——4

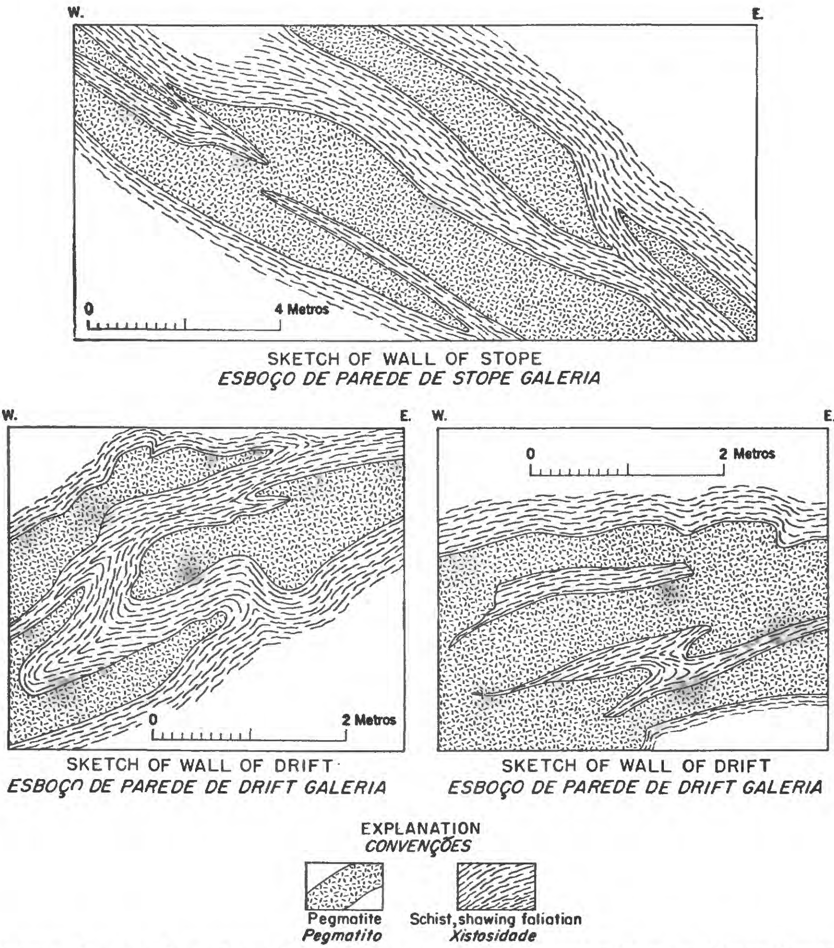


FIGURE 25.—Sketches along drifts and stopes of the Bananal mica mine, Minas Gerais, Brazil, showing the relation of the pegmatite to the foliation of the schist.

rocks. Remnants of schist in pegmatites and exceedingly irregular contact surfaces between schist and pegmatite also indicate that chemical reaction has resulted in partial digestion and replacement of schist.

Groups of commercially important mica-bearing pegmatites occurring in the same rock formation in the same district have many features in common. Near the headwaters of the Ribeirão da Onça and Ribeirão do Bugre, in the Serra das Escadinhas some 20 kilometers northwest of Governador Valadares, are a great number of sheetlike pegmatites in dark schist—Pedro Espirito, Golconda, Vitória, Incerta, Jacó, Fortaleza, Bugre, Campos, Botelho, Ipê, Mical, Pedra Redonda, Evangelista, Ferreirão, Corrego Alto, and Carajáu. Most of these are horizontal or gently dipping and are located within an area about 10 kilometers in diameter. Near Espera Feliz, the irregular pegmatites of complex form, such as the Borges, Urubú, and Chico Dentista, all occur in schist within a few kilometers of each other. In the quartzite east and north of Santa Maria do Suassuí, several pegmatites—Cruzeiro, Serra Negra, and others—are arranged in parallel sets. In the Serra dos Lourenços, multiple sheetlike pegmatites are situated along several shear zones in quartz-biotite schist characterized by intense isoclinal drag folds.

MINERALOGY OF THE PEGMATITES

PRINCIPAL COMPONENT MINERALS

Quartz and one or more kinds of feldspar—microcline, microperthite, or plagioclase—make up more than 90 percent of most, if not all, of the pegmatites in the Mica Belt. The two varieties of potash feldspar—microcline and microperthite—occur either in graphic intergrowth with quartz or in equant masses or crystals up to 2 meters across a single cleavage face. Five distinct kinds of plagioclase are known in the pegmatites: (1) "blocky" sodic plagioclase in equant masses up to 25 centimeters across a single cleavage face; (2) terminated, well-formed stubby white crystals of albite lining vugs or fissures; (3) irregular grains of albite disseminated in microperthite; (4) a sugary-textured albite that appears to be an alteration product of potash feldspar; and (5) a porous aggregate of lamellar cleavelandite crystals. In a great many pegmatites, the feldspar minerals are decomposed by weathering to a white or iron-stained clay, and the identity of the original feldspar is obscured.

The blocky sodic plagioclase, as determined petrographically from specimens collected at many mines, ranges in composition from median albite to median oligoclase. In a single pegmatite, however, little or no variation in the composition has been observed. There are all proportions of plagioclase to potash feldspar. In a few pegmatites, as at the Bananal, Serra dos Lourenços, and neighboring mines and prospects, blocky plagioclase makes up the bulk of the feldspar and is disseminated throughout the pegmatite, but in most other pegmatites in the Mica Belt potash feldspar predominates and the blocky plagioclase is restricted to the borders of the pegmatites.

In all but a few mica-bearing pegmatites, quartz is subordinate to feldspar in quantity. In most pegmatites it makes up 20 to 40 percent of the rock, but in a few it makes up only 10 to 20 percent. Three varieties of quartz are recognized: (1) glassy to milky, (2) smoky, and (3) rose. The glassy variety is the most abundant. It is commonly badly fractured and forms granular mixtures with other minerals. In parts of some pegmatites it forms a giant framework; in others it occurs as lenses in massive potash feldspar. Rarely, well-terminated glassy quartz crystals occur in vugs in granular pegmatite. Rose quartz is rare and occurs as barely perceptible masses within and gradational to glassy feldspar. Smoky quartz forms either veinlets in feldspar or terminated but distorted crystals lining cavities.

MINERALOGICAL TYPES OF PEGMATITES

The mica-bearing pegmatites can be classed as mineralogically simple or complex according to the number and variety of accessory minerals in them. Muscovite, biotite, black tourmaline, wine-red garnet, and—rarely—green beryl are the accessory minerals in most simple pegmatites. In addition, the complex pegmatites contain one or more of the following minerals: tantalite, columbite, spodumene, amblygonite, apatite, triphylite, arrojadite, brazilianite, lazulite and related phosphates, pyrite, arsenopyrite, molybdenite, magnetite, chrysoberyl, axinite, topaz, zircon, samarskite, uraninite, polycrase, monazite, phenacite. No single pegmatite contains all these accessory minerals.

In general, simple pegmatites characterize the mica districts south of the Rio Doce, whereas complex pegmatites are characteristic of the region north of the river. Certain accessory minerals occur more commonly in specific districts or in geographic groups of pegmatites; for example, phosphate minerals are most abundant in the area north of Conselheiro Pena, tantalite and columbite in the district near Governador Valadares and Poaia, and beryl in the districts near Conselheiro Pena and Governador Valadares.

Certain well-defined relationships have been observed between the kinds of feldspar in the pegmatites and the complexity of the accessory-mineral assemblage:

1. In the simple pegmatites that are exceedingly rich in blocky albite-oligoclase, as at the Bananal, Serra dos Lourenços, and neighboring mines, tourmaline and beryl have not been observed during several years of mining.
2. Pegmatites that have the most complex mineral assemblage also have an abundance of lamellar or sugary-textured albite.
3. In the complex pegmatites, the inner parts commonly contain a complex mineral assemblage; the mineralogy of the borders is simple.
4. Black tourmaline and ruby muscovite are associated with parts of pegmatites composed of potash feldspar, blocky plagioclase, and quartz, whereas other colors in tourmaline and mica are associated with the cleavelandite-rich parts of the pegmatites.
5. Lithium-bearing minerals such as spodumene and lepidolite are associated with the albite-rich central parts of complex pegmatites adjacent to quartz masses.

INDUSTRIAL AND GEM MINERALS IN SIMPLE AND COMPLEX PEGMATITES

The industrial minerals recovered by mining from the pegmatites of eastern Minas Gerais include muscovite, kaolin and feldspar, beryl, tantalite, and columbite. Lithium minerals occur in many complex pegmatites north of the Rio Doce, but they have not yet been mined on a commercial scale. Muscovite, kaolin, and feldspar occur in quantity in pegmatites irrespective of the accessory-mineral assemblage, but muscovite in the complex pegmatites is generally inferior in quality to that obtained from the simple ones. The other industrial minerals, however, occur only in the complex pegmatites.

Of the gem-stone minerals, only blue-green beryl is found in both simple and complex pegmatites. Yellow and pink beryl; rose and green spodumene; green, rose, and blue tourmaline; blue and white topaz; axinite; and chrysoberyl are present only in the complex pegmatites containing abundant albite. Blue-green beryl (aquamarine) and green tourmaline are the most abundant gem stones in the pegmatites. Most of the complex pegmatites with accessory gem-stone minerals are in the region north of the Rio Doce.

INTERNAL FEATURES OF THE PEGMATITES

The internal features of pegmatites of the Mica Belt may conveniently be described in terms of the texture and the structure. All the pegmatites are holocrystalline, but they differ markedly in granularity, or size of the constituent crystals, and in fabric, or shape and arrangement of the constituent crystals. Internally, most of the pegmatites are either massive or zoned. A few are characterized by irregular features such as segregation clots, replacement masses, veins, or cavities.

TEXTURE

Four distinct types of texture are represented in the pegmatites of the Mica Belt: (1) granitic, (2) pegmatitic, (3) graphic, and (4) "mica canga." Some simple pegmatites are of uniform texture throughout. In many complex pegmatites two or three different textures are found, and in a few pegmatites all four are represented.

"Granitic" texture, as used in this report, refers to an irregularly granular aggregate of quartz, feldspar, and mica in which the individual grains are somewhat larger than those of a coarse-grained granite. In pegmatites or parts of pegmatites that have a granitic texture, the mica (biotite or muscovite, or both) ranges in size from submicroscopic flakes to books several centimeters in diameter, whereas the quartz and feldspar masses are nearly uniform in size and rarely exceed 25 centimeters in diameter. In different pegmatites with granitic texture, or in parts of them, the proportions of the component minerals vary within wide limits. In general, the orientation of the minerals is random. Insignificant quantities of garnet and black tourmaline are dispersed throughout many of the pegmatites with a granitic texture. Some pegmatites, a few of them well-known sources of mica, have a granitic texture throughout, but most of the commercially significant ones have a granitic texture only near their margins (fig. 26).

"Pegmatitic" texture, as used in this report, is a gigantesque variation of the granitic pattern. Quartz and microcline or microperthite are the two principal minerals of the pegmatitic parts of pegmatites, and mica, beryl, and other minerals are subordinate in quantity. The quartz and microcline masses and beryl crystals range from 20 or 30 centimeters to 2 meters in size. The quartz is commonly distributed in the more abundant potash feldspar as an irregular framework and also as irregular masses without systematic orientation. Pegmatitic texture is characteristic of the internal parts of many pegmatites (fig. 27).

FIGURE 26.—Granitic texture in the upper border zone of the Ipê pegmatite, near Governador Valadares, Minas Gerais, Brazil.

"Graphic" texture differs from both the granitic and the pegmatitic in that it is characterized by a distinctive mixture of quartz and potash feldspar in definite proportion and orientation. The potash feldspar, commonly microperthite, makes up an estimated 70 to 80 percent of the mixture, and the quartz is distributed in the feldspar as irregular tabular rods oriented parallel to some crystallographic direction of the feldspar. In a section normal to the elongate direction of the quartz rods, the pattern strikingly resembles runic or cuneiform script. The graphic pattern is most common in the mineralogically simple pegmatites but also occurs in the marginal parts of some complex pegmatites. Perceptible gradations exist between graphic and mica-poor granitic textures in the same pegmatite.

The term "mica canga" is widely used in the mica districts to connote an intimate mixture of quartz and small, clear muscovite books. Mica canga differs from the granitic-textured pegmatite in the absence of feldspar and in the uniformity of the size of the mica books. The

FIGURE 27.—Pegmatitic texture in the central zone of the Ipê pegmatite, near Governador Valadares, Minas Gerais, Brazil.

proportion of quartz to mica ranges from 2:1 to 1:1. No crystallographic orientation has been noted for this mixture, and the size of the mica books rarely exceeds 2 centimeters. Many of the mica books are free of imperfections, but the prism boundaries of the books are highly irregular. Biotite has not been observed in this association. In most pegmatites, the mica-canga mixture is distributed in potash feldspar, is distinct from the granitic-textured part, and is an important guide in mining. If numerous patches of the mica canga are examined, some will be seen to contain mica books that are fewer in number but larger in size than those in adjacent patches.

ZONING

GENERAL STATEMENT

The internal structure of many pegmatites is characterized by an orderly variation in texture and mineral composition. This variation is commonly so marked and so regular that the pegmatite can be divided, in mapping, into well-defined structural units or zones. (See pls. 14–17 and figs. 26–33.) In different pegmatites there is a wide variety in the number, distinctness, and symmetry of these zones.

Symmetrically zoned pegmatites are more abundant than asymmetrically zoned pegmatites. Mica investigations in the United States, as well as in Brazil, have shown the importance of zoning in commercially significant pegmatites. Pertinent reference material for United States pegmatites is contained in the appendix of this report.

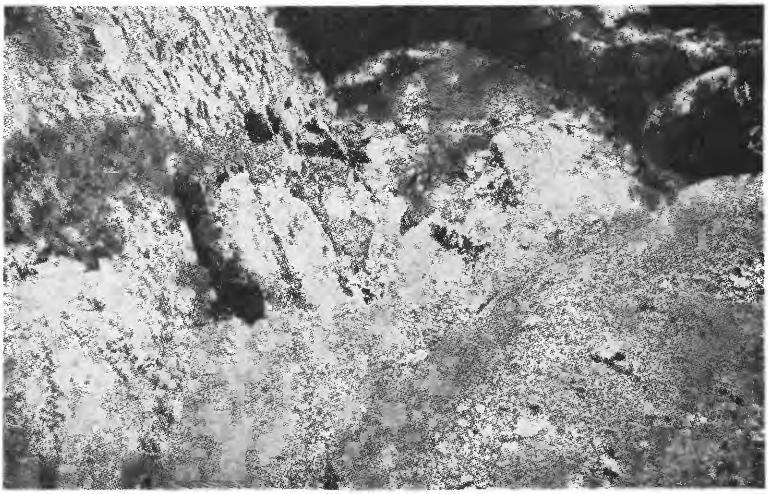


FIGURE 28.—Zoning in the Pedra Redonda No. 1 pegmatite, near Governador Valadares. Minas Gerais, Brazil.

SYMMETRICAL ZONING

In symmetrically zoned pegmatites, one or more approximately concentric layers or zones lie between the central part of the pegmatite and the contact of the pegmatite with the wall rock. The thickness of a zone is rarely uniform and is commonly greater on one side than on the other. Only in vertical or steeply dipping pegmatites does a zone have a relatively uniform thickness on both sides of the pegmatite. The simply zoned pegmatites have two units—a central zone and an enveloping border zone. Pegmatites more than 3 meters thick commonly have one or more intermediate zones between the central and border zones. Symmetrically zoned pegmatites with mica concentrations are illustrated in plates 14 and 15 and figures 29, 30, and 31.

The spatial distribution of the textural types and of the diagnostic minerals that characterize the zones in a symmetrically multiple-zoned pegmatite is shown schematically in plate 14. Commonly the border zone is a rock of granitic texture, but in a few pegmatites it is composed partly or completely of graphic granite of quartz-feldspar rock without mica. In multiple-zoned pegmatites the outer intermediate zone may be exceptionally rich in muscovite books, or it may be granitic, graphic, or mica-canga rock; the inner intermediate zone is composed essentially of potash feldspar; and the central zone commonly consists

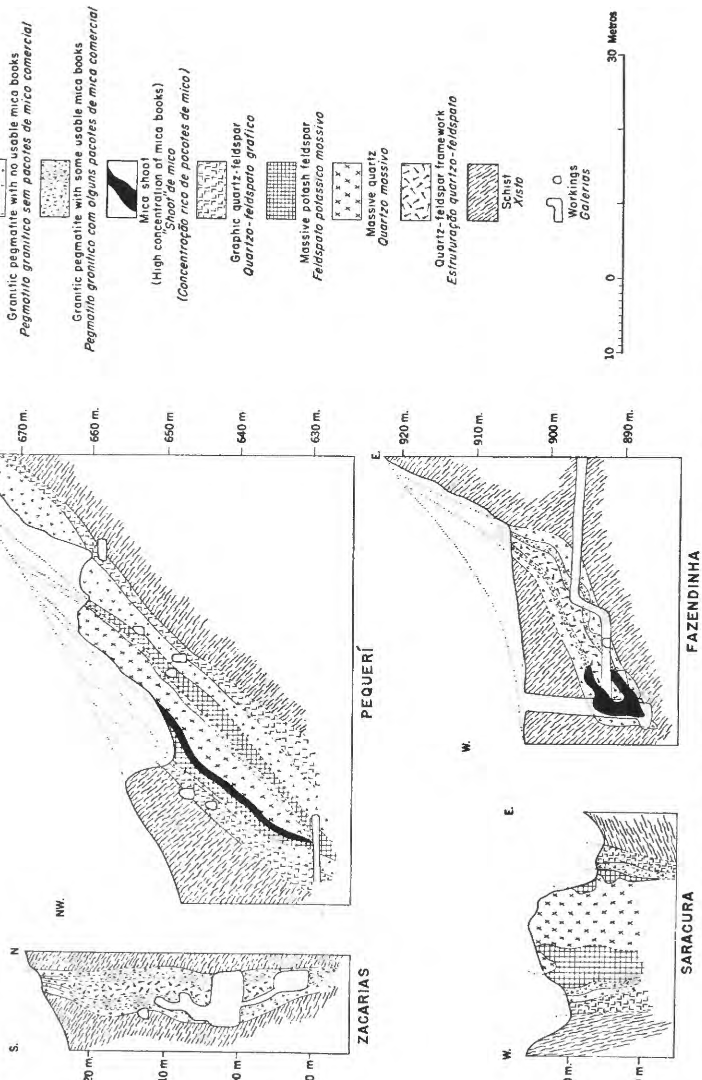


FIGURE 29.—Structure sections of the Zacarias, Pequerí, Saracura, and Fazendinha pegmatites, Minas Gerais, Brazil, showing symmetrical zoning and mica shoots.

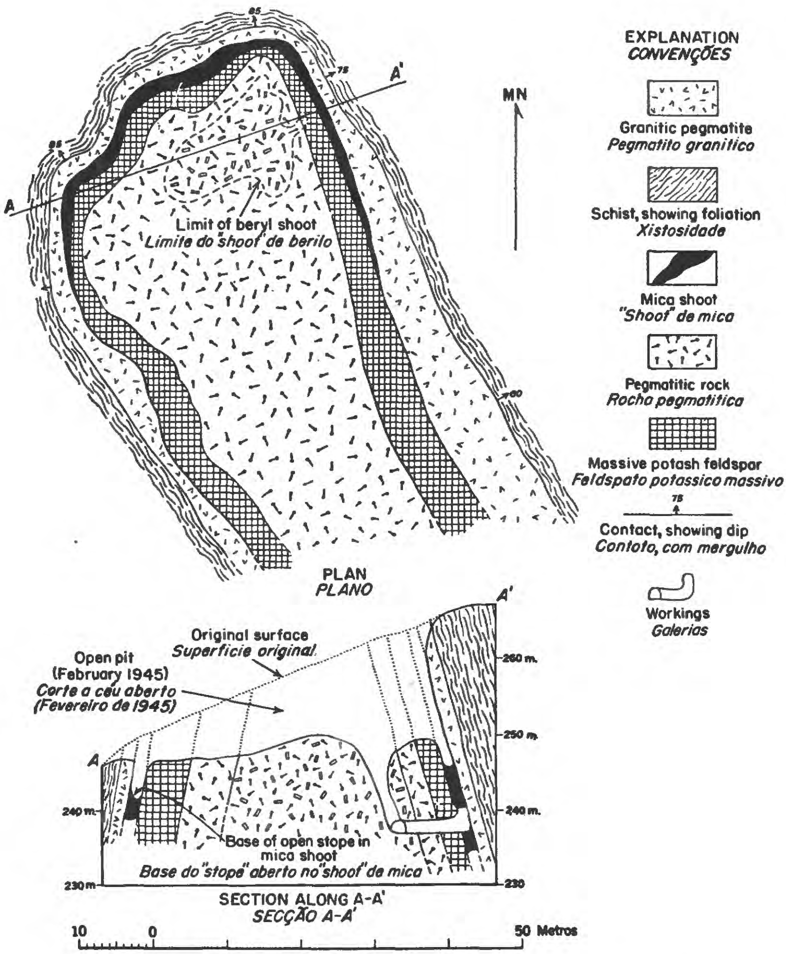


FIGURE 30.—Plan and structure section of the Sapucaia pegmatite, Minas Gerais, Brazil, showing symmetrical zoning, a mica shoot, and a beryl shoot.

of coarsely crystalline quartz and potash feldspar and, in some pegmatites, is characterized by a central nucleus or core of massive quartz.

Border and intermediate zones.—In those pegmatites where muscovite is abundant in both the border and outer intermediate zones, the separation of the two zones is poorly defined. The following features are, however, noteworthy: (1) In the border zone, blocky sodic plagioclase with black tourmaline or biotite, or both, is associated with muscovite, but these minerals are absent in the outer intermediate zone. (2) The muscovite of the two zones is essentially of the same variety. (3) The size of the muscovite books increases markedly away from the border contact. (4) The muscovite books of the border zone are commonly oriented edgewise to the contact with the wall rock. (5) In the

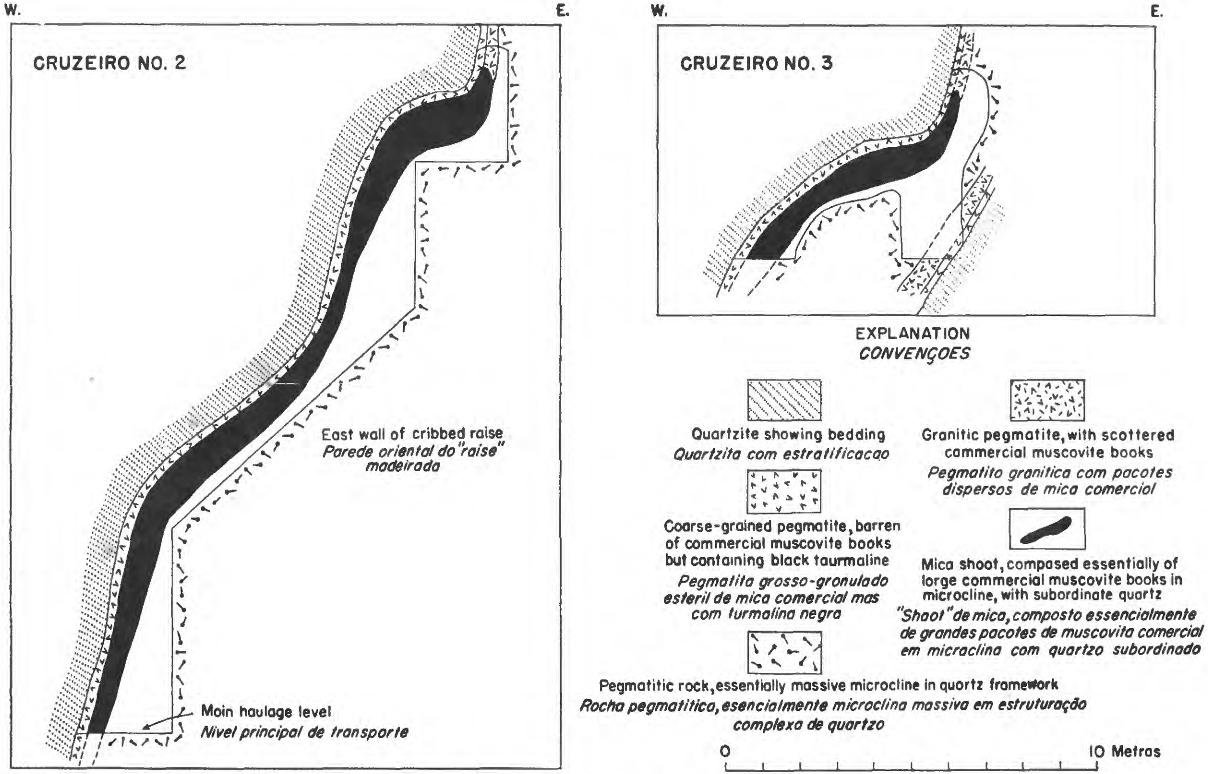


FIGURE 31.—Sketches transverse to stopes in the Cruzeiro No. 2 and No. 3 pegmatites, relation of zones and mica shoots to arches in the hanging wall.

intermediate zone there is a higher percentage of muscovite and a lower percentage of quartz than in the border zone.

The contact of the outer intermediate zone, whether muscovite-rich, granitic, graphic, or of mica canga, with the feldspar-rich inner intermediate zone is well defined although locally irregular.

Central zone.—The inner intermediate zone grades imperceptibly into the pegmatitic-textured central zone. The principal difference is the higher proportion and coarser framework of quartz in the central zone. In some lens-shaped pegmatites, the two zones are easily distinguishable in the center but merge to form a single zone near the edge. Not uncommonly the central zone, which is for the most part a coarse framework of quartz interstitial to massive potash feldspar crystals, contains a number of irregularly distributed quartz lenses.

Quartz-core lenses.—In a few large pegmatites, the thickest part of the central zone is characterized by a single large lens of massive quartz that reflects, in its form and attitude, the general form and attitude of the pegmatite itself. The term "quartz core" has been widely used by geologists for such lenses and the term "quartz-core pegmatite" for pegmatites that contain these lenses. In many such pegmatites the quartz-core lens is encrusted with muscovite books that are in part suitable for processing into sheet mica. In most large quartz-core pegmatites only a single lens of quartz is evident, but in a few pegmatites, as at Saracura, two large quartz lenses are exposed. The southern part of the Mica Belt contains the greatest number of quartz-core pegmatites, and they are simple in mineralogy. The dimensions of some of its quartz cores that have been revealed by surface mining operations are as follows:

	Dimensions in meters		
	Maximum thickness	*Length*	*Breadth*
Pequerí	8	310	55
União	10	55	20
Perereca	20	75	25
Saracura:			
North lens	10	25	16
South lens	13	50	22
Chalet Verde	6	25	10
Urubú	5	14	7
Paraiso da Barra	4	15	6

The volumetric proportion of the single quartz core to the rest of the pegmatite varies within wide limits. The single lenses are entirely enclosed in a feldspathic sheath that is poor in quartz. The surface of these lenses is very irregular and is characterized by many indentations occupied by crystals of potash feldspar. Central zones that contain a number of small, separate quartz lenses up to a few meters long are characterized by potash feldspar with a quartz framework in addition to the lenses, and in many pegmatites branches of quartz connect the lenses with the quartz of the adjoining framework. The small quartz lenses are commonly encrusted with muscovite books so marred by imperfections as to be of little value commercially, but in the pegmatites of complex mineralogy that contain highly albitized feldspar, these small lenses are more commonly encrusted with crystals of albite, green tourmaline, spodumene, amblygonite, lepidolite, or green muscovite.

ASYMMETRICAL ZONING

In the asymmetrically zoned pegmatites, one or more zones that are present on one side of the central zone are not present on the other. The zones that most frequently are incomplete are the outer and inner intermediate zones (pl. 16). Many pegmatites display asymmetrical zoning in the central, thicker, parts but symmetrical zoning near the edges. For example, a number of sheetlike pegmatites near Governador Valadares show asymmetrical zoning in their central parts (fig. 32). In all these pegmatites the proportion of mica is greatest in the upper zones, and albitization is more intense in the lower half of the central zones. Asymmetrical zoning in other pegmatites is illustrated in plate 17 and figure 33.

OTHER INTERNAL FEATURES

A number of other internal features, distributed at random within a specific zone or throughout a pegmatite, include: (1) segregation clots, (2) cavities, (3) veins, and (4) replacement masses. Some of the large, mineralogically complex pegmatites contain all these features.

SEGREGATION CLOTS

Clots of coarse-grained mica, quartz, and potash feldspar, or of any one or two of these minerals, are commonly disseminated in pegmatites that have a granitic texture. In a few pegmatites of this kind, these clots supply the only source of commercial mica. The concentration of such clots in the central part of a pegmatite, as at the Incerta mine near Governador Valadares, suggests a rudimentary zoning. Many such segregation clots are visible on the face of the open pit at the Levindo Alferes mine (pl. 16).

CAVITIES

Crystal cavities are numerous in the central zones of many pegmatites, particularly those of complex mineralogy. The cavities are lined with crystals of terminated quartz, albite, beryl, tourmaline, and other minerals. In a few localities the quartz is glassy and of commercial value, but commonly it is imperfect or smoky. Tourmaline is either intergrown with the glassy variety of quartz or attached to the outer surfaces of the imperfect quartz crystals. The gem variety of tourmaline extends into the cavities from the quartz crystals.

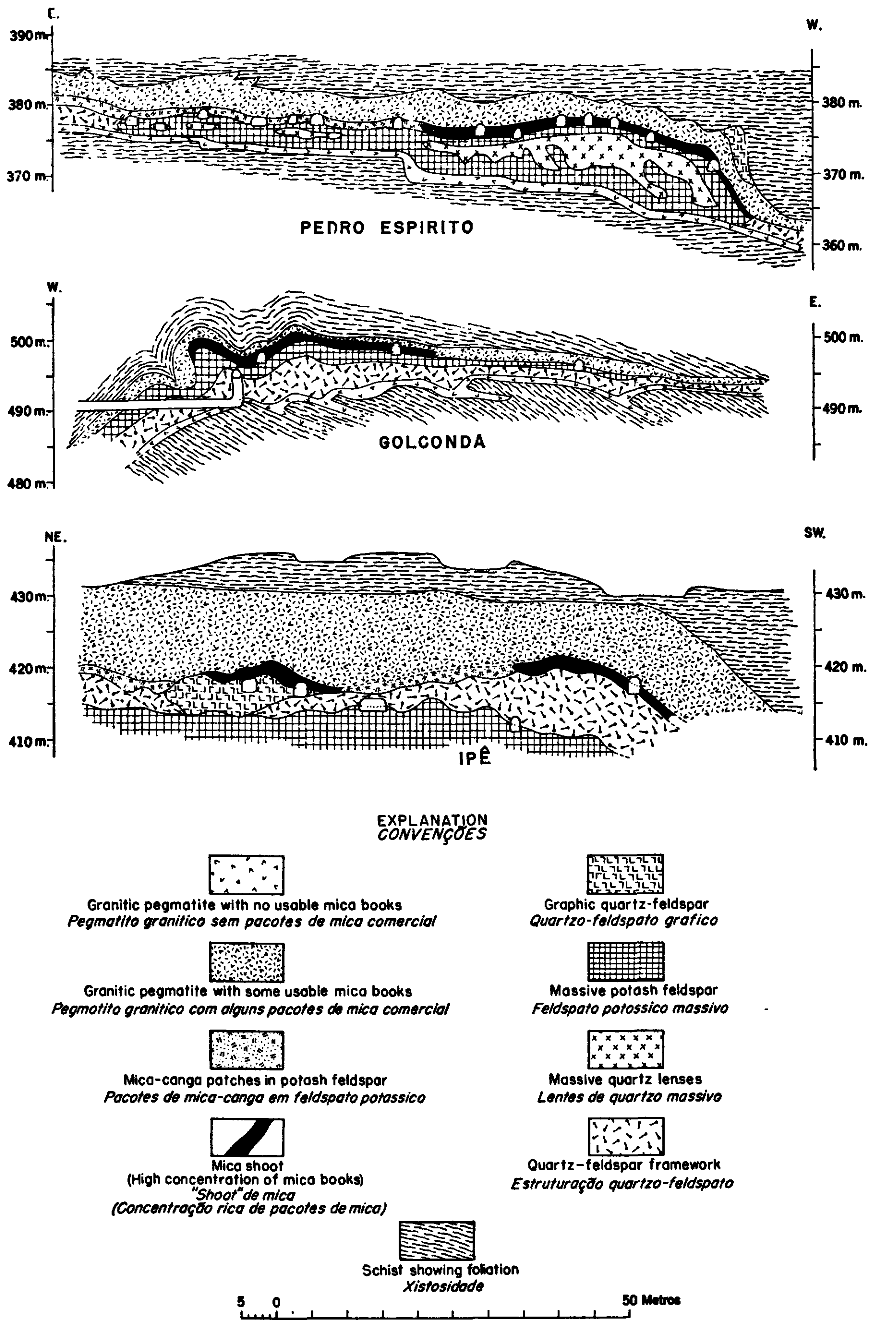


Figure 32.—Transverse sections of the Pedro Espirito, Golconda, and Ipê pegmatites, Minas Gerais, Brazil, exposed in open pits and showing the relation of asymmetrical zoning and mica shoots.

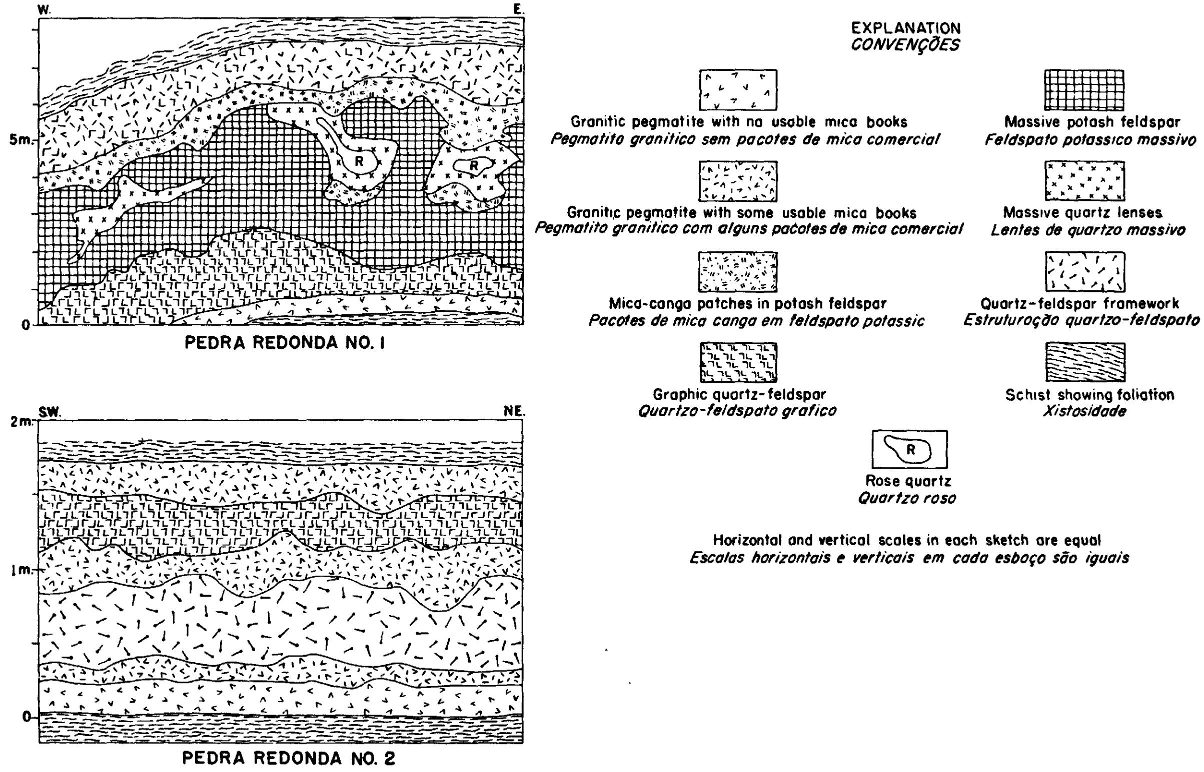


FIGURE 22.—Sketches of the pegmatites exposed at the Pedra Redonda No. 1 and No. 2 open pits, Minas Gerais, Brazil, showing asymmetrical zoning.

Albite is attached to the walls of quartz and intergrown with tourmaline in the cavities. Hexagonal books of white muscovite are present in most cavities. In some pegmatites the gem stones recovered from crystal cavities exceed in value the mica recovered from other parts of the pegmatite.

VEINS

Discontinuous veins or veinlets of one or more minerals occur in the central zones of many pegmatites. None has been observed to extend beyond the border of a pegmatite, and rarely does one traverse the intermediate zones. Most of the veins are less than 10 centimeters thick and less than 3 meters long. Some are monomineralic, composed of quartz, muscovite, or albite, but most are a mixture of two or of all three of these with or without rare minerals. The quartz is commonly of the smoky variety, the albite of the cleavelandite variety, and the muscovite of the white, green, or yellow variety. The contacts of most of these veins are so well defined as to suggest fracture filling, but the contacts of a few have local irregularities suggestive of partial replacement. Gem beryl or tourmaline occurs in some vuggy albite veins, as at the Palmital mine, and lepidolite in others.

In the Cruzeiro district, cleavelandite veins a few centimeters thick traverse massive quartz, and in other pegmatites veinlike masses both of cleavelandite and of white or light-colored muscovite are formed between a quartz core and albitized potash feldspar.

REPLACEMENT MASSES

Irregular masses of interlocking cleavelandite crystals or of white-green muscovite, or of both, are distributed in the central zones of some pegmatites, particularly in contact with quartz lenses, or in contact with a quartz framework. These mineral aggregates have formed in large part by replacement of potash feldspar.

In the Bôa Vista Mansur pegmatite near Conselheiro Pena, replacement is indicated by remnants of the original potash feldspar scattered in a field of cleavelandite. In the Sapucaia pegmatite (fig. 30), a mixture of cleavelandite, albitized microperthite, and diamond-shaped, greenish-white muscovite fringes a beryl-rich part of the central zone, whereas elsewhere in that zone the potash feldspar is more uniformly albitized. In several sheetlike pegmatites near Governador Valadares, the lower part of the central zones—particularly in the thickest parts of the pegmatites—is rich in cleavelandite, which in places contains masses of tantalite, muscovite, and rare minerals.

WEATHERING

GENERAL STATEMENT

The rocks in eastern Minas Gerais are decomposed by weathering to depths as great as 65 meters below the surface. In this process, schist containing biotite, chlorite, amphibole, magnetite, and other iron-bearing minerals alters to a soft, red-brown mineral called "moledo" in the mica districts. Quartzite, quartzose phyllite, sericitic quartzite, and granitoid gneiss alter to a light-brown, sandy material easily distinguished from the moledo. In some parts of the Mica Belt, on gentle slopes at higher altitudes, peridotitic rocks have altered to magnesia-rich clays, locally nickeliferous; and gabbro, diorite, and feldspar-rich gneiss have altered to alumina-rich clays, locally bauxitic. In general, pegmatites are weathered to greater depths than other rocks.

LAYERS OF WEATHERED PEGMATITE

Weathered pegmatites are called "soft" in the mica districts, in contrast to the "hard," or unweathered, pegmatites. The feldspar minerals are more rapidly decomposed by weathering than are the other pegmatite minerals and alter to a white or discolored claylike material generally referred to as "kaolin."

In vertical or steeply dipping pegmatites the weathered zone is composed of two perceptibly different layers: (1) an upper, discolored layer and (2) a lower, white, layer. In the upper layer, the decomposed feldspars are discolored to red, brown, purple, yellow, or green by compounds of hydrated iron oxide. The mica and quartz of the upper layer are discolored both by iron compounds and by black manganese oxide. In the lower layer, the decomposed feldspars are soft but white, and some iron staining is present in the mica books. The transition between the two layers in many pegmatites is perceptible over a distance of a few meters and in a few is characterized by an irregular layer, a few centimeters thick, stained by manganese oxide. This black-stained layer sharply defines the lowest limit of feldspar discoloration and of heavily stained quartz and mica.

The lower layer in the weathered zone grades imperceptibly downward into unweathered pegmatite. The following criteria have been used in the field to distingnish weathered from unweathered pegmatite: (1) Unweathered feldspar commonly has a green or cream-colored cast. (2) Unweathered feldspar has a sharp tone instead of a dull thud when hit with a metallic implement such as a hammer or pick. (3) Unweathered feldspar breaks with a dry surface instead of one that readily becomes moist from occluded water. The contact between the lower weathered layer and the unweathered rock is much more irregular than that between the lower and upper weathered layers, for the latter is largely governed by the profile of the surface. In a number of vertical or nearly vertical pegmatites examined, the upper discolored layer ranged from a minimum of 20 meters to a maximum of 35 meters in thickness. The deepest root of weathering in the lower weathered zone of several pegmatites studied was 65 meters below the surface.

DISTRIBUTION OF MICA IN THE PEGMATITES

GENERAL STATEMENT

Commercial muscovite in the pegmatites of the Mica Belt has three general modes of occurrence: (1) in well-defined zones, (2) disseminated in granitic-textured pegmatite, and (3) in random clots or pockets. It is estimated that 80 percent of Brazilian mica production has come from zoned deposits, 15 percent from disseminated deposits, and 5 percent from pocket deposits.

In some pegmatites, exceptional concentrations of mica books, or "mica shoots," that occur within a single zone have been the most profitable sources of mica for mining. Exploration of pegmatites that contain only scattered mica books or uniformly disseminated books of small size has proved profitable only when the price of mica was abnormally high. In the majority of known pegmatites in Minas Gerais, the mica books are of submarginal size or concentration. Among the commercially important mica-bearing pegmatites, however, zoned mica deposits are more abundant than disseminated deposits or pocket deposits.

ZONED DEPOSITS

Although commercial muscovite may be present in several zones in the same pegmatite, the principal yield is commonly from a single zone. In vertical, symmetrically zoned deposits, the mica is more or less equally distributed on both sides of the central zone or within it. In horizontal or gently inclined pegmatites, commercial mica is commonly more abundant in the zones above the central zone.

MICA IN BORDER ZONES

In border zones that are granitic in texture, muscovite books make up 2 to 10 percent of the rock, but only rarely are the books large enough to yield sheet mica. The most extensive and highly concentrated border-zone deposit is in the Cruzeiro No. 1 pegmatite. It is in contact with a rooflike pendant of amphibolitic schist and is 400 meters long, 30 to 50 meters wide, and half a meter to 2 meters thick. In this deposit, mica books suitable for trimming form 7 to 15 percent of the rock by weight (pl. 15). In the upper part of the Borges mine, the hanging-wall border zone has been mined for 40 meters along the strike, 20 meters down the dip, and in a thickness of 1 meter has a concentration of 5 to 10 percent by weight of mica books suitable for trimming (pl. 16). In some pegmatites (pl. 17) rich border-zone deposits occur in contact with tongues or inclusions of biotitic schist.

MICA IN INTERMEDIATE ZONES

The majority of commercial mica deposits are in intermediate zones. In some pegmatites, such as the Viuva Valerio, the intermediate zone is separated from the wall rock by a border zone of graphic-textured rock or quartz-feldspar rock nearly free of mica. In most other pegmatites the intermediate zone is gradational into, and only rarely distinct from, a mica-bearing border zone. As the two zones differ markedly in size and concentration of mica books, however, the distinction between them is valid. Because the mica in the border zones is small in size and yields little or no sheet mica, most of the mine openings follow the intermediate zones. In vertical, symmetrically zoned pegmatites, the intermediate zones on both sides of the central zone yield usable mica books. In a number of sheetlike, asymmetrically zoned pegmatites near Governador Valadares, an upper intermediate mica-bearing zone half a meter to 2 meters thick is distinct from a mica-bearing border zone ranging in thickness from half a meter to 12 meters. In many pegmatites containing local irregularities, well-defined and highly productive intermediate zones merge laterally into less productive or nonproductive border zones. Mica books of suitable size for trimming occur in the footwall counterpart of the upper intermediate zone in a great number of pegmatites, but they are not sufficiently abundant to repay the cost of mining and trimming.

MICA IN CENTRAL ZONES

In many pegmatites less than 3 meters thick, the only muscovite books large enough for commercial use are disseminated in the central zone. Commonly, as in the Bratac section of the Pedro Espirito mine, these books are in altered potash feldspar in the immediate vicinity of irregular or lenticular masses of quartz. Zoned deposits of this kind are few in number and supply only an insignificant part of the mica production of the Mica Belt.

Mica concentrations that incrust parts of large quartz-core lenses, or are in the potash feldspar immediately adjacent to these quartz-core lenses, have yielded most of the output from such mines in southeastern Minas Gerais as the Pequerí, Saracura, União, Sobradinho, Upper Urubú, Onça, Retiro, and Paraiso da Barra. However, the yield of mica from the quartz-core crust zone of a few pegmatites is less than that from the border or intermediate zones on their hangingwall sides. Greater concentrations of mica books are found along the upper than along the lower flanks of the lenses; in all the deposits in which the quartz-core lenses were totally removed by mining, the bottoms of the lenses were free of mica books, and in three deposits originally concealed but later exposed by open-pit mining—Paraiso da Barra, Borges, and Chalet Verde—the greatest concentrations of mica books were on the tops of the lenses. At the Pequerí mine also (fig. 29), the concentration of mica books on the upper flank of the inclined quartz lens was greater than that on the lower.

MICA SHOOTS IN ZONED DEPOSITS

"Mica shoots" are exceptional concentrations of mica books within a well-defined mica-bearing zone. In most deposits, shoots are related to structural features of the pegmatites; in some the presence of a mica shoot is related only to a thickening of the pegmatite; in a few, there is no apparent control of the shoots. The largest shoots are those controlled by structural features. In almost all the deposits, the mica shoot can be delimited from the rest of the mica-bearing zone within a few meters. Several varieties of shoots have been distinguished on the basis of general form, attitude, and structural control.

The simplest kind of shoot is essentially tabular with but minor irregularities in form. In the Pedro Espirito, Golconda, and similar sheetlike pegmatites, the mica shoots are in the intermediate zone in the hanging wall (fig. 32).

Some shoots are irregular curved sheets. The shoot in the Sapucaia pegmatite (fig. 30) is a vertical to steeply inclined curved sheet that is concave to the south. It is in the northern, thickest part of the pegmatite. In the central deposit of the Cruzeiro No. 1 pegmatite (pl. 15), the shoot is a curved sheet that is concave upward and is located where the contact with roof rock is essentially horizontal or gently inclined. In some quartz-core lens deposits, the shoot is a hood capping the top of the lens, a sheath encircling the upper edge of the lens, or a crust on one flank.

The most common form of mica shoot is an elongate lens-shaped, pod-shaped, or lath-shaped mass related to a sharp arch or minor irregularity in the hanging wall or footwall of the pegmatite. This kind of shoot is present in a great number of pegmatites, among which are those in the Cruzeiro district (pl. 15; fig. 31), the Taquara Preta mine, the Viuva Valerio mine, and the central part of the Borges mine (pl. 16).

The greatest measured thickness of a single shoot is 3 meters. Only a few are known that exceed 100 meters in length. Mica shoots that contain more than 500 tons of usable mica books are exceptional. Some dimensions and a general description of the principal mica shoots in the Mica Belt are listed in table 5. Several of these shoots were partly eroded before their discovery and therefore were originally larger than the present mine workings indicate. Others have been only partly explored and developed.

TABLE 5.—*Dimensions and general description of 15 principal mica shoots, Minas Gerais, Brazil*

Name of pegmatite and municipio	Name and location of mica shoot	General description	Length, in meters	Average breadth, in meters	Average thickness, in meters	Estimated content mine-crude mica, in metric tons	Estimated percent mined to Sept. 1, 1945	Remarks
Cruzeiro No. 1 (Santa Maria do Suassuí).	Roof Pendant shoot (pl. 15).	Curved sheet concave upward and pitching about 15° S.	325	20	1.5	4,500	60	Largest single deposit in Mica Belt. Exploration incomplete in north and south parts. Central part almost completely mined out. Shoot structurally controlled by roof pendant of amphibolitic schist.
Do	West Arch shoot (pl. 15).	Essentially pod-shaped; pitches about 12° S. and dips west.	275	8	1.5	1,500	90	South end exposed and eroded. Central and south parts completely mined out. Shoot structurally controlled by distinct arch in hanging wall.
Do	East Arch shoot (pl. 15).	Essentially pod-shaped. with pitch of about 12° S. and dip to east.	80+	8	1.5	300+	50	Extension of shoot below main haulage level offers future reserve. Shoot structurally controlled by distinct arch in hanging wall.
Cruzeiro No. 2 (Santa Maria do Suassuí).	Charles Gomes shoot (fig. 31).	Irregular sheet composed of several pod-shaped shoots all pitching about 12° S. and dipping west.	250+	25	1.5	2,500	90	Extension of shoot below main haulage level offers future reserve. Shoot controlled by series of local arches in hanging wall that are offset en echelon to south.
Cruzeiro No. 3 (Santa Maria do Suassuí).	Coringa shoot	Essentially lath-shaped, pitching south.	350	6	1.0	1,200	90	South end exposed and eroded. Shoot controlled by distinct arch in hanging wall.
Do	Aricanga shoot	Essentially pod-shaped, pitching south.	150+	6	1.0	450	90	Extension of north end offers future reserve. Shoot controlled by single arch in hanging wall.
Pequerí (Bicas)	West flank of quartz lens.	Tabular shoot, dipping about 45° NW.	100	18	1.0	700	100	Scattered deposits along east flank of same quartz lens only partly explored.
Zacarias (Espera Feliz)	Central part (fig. 29).	Two vertical tabular shoots on either side of central zone, pitching about 45° SE.	35	25	1.0	400	100	Shoot located in thickest part of pegmatite and in intermediate zones.
Pedro Espirito (Governador Valadares).	Main section (fig. 32).	Essentially tabular. pitching few degrees north.	160	40	.8	1,200	75	Shoot located in thickest part of pegmatite.
Golconda (Governador Valadares).	Main section (fig. 32).	Essentially tabular shoot with western part curved concave downward and pitching north.	65+	30	.5	300	30	Extension of shoot assured in northerly direction.

TABLE 5.—*Dimensions and general description of 15 principal mica shoots, Minas Gerais, Brazil*—Continued

Name of pegmatite and municipio	Name and location of mica shoot	General description	Length, in meters	Average breadth, in meters	Average thickness, in meters	Estimated content mine-crude mica, in metric tons	Estimated percent mined to Sept. 1, 1945	Remarks
Saracura (Bicas)	Open pit (fig. 29)	Irregular sheet, essentially vertical and bordering a quartz lens.	50	12	1.5	160	100	Top of shoot exposed and eroded.
Borges (Espera Feliz)	North section (pl. 16).	Tabular shoot with steep dip to northwest; pitches south.	35+	20+	1.0	150	90	Extension of shoot probable to north and down dip along border zone. Shoot in central section below arch only initially explored.
Sapucaia (Conselheiro Pena).	Northwest workings (fig. 30).	Curved sheet, essentially vertical and concave to southeast.	70	15+	1.5	200	100	Extension of shoot at depth assures future reserve.
Paraiso da Barra (Cataguazes).	Open pit	Curved sheet, concave downward and pitching to southeast as a hooded sheath on a quartz lens.	30	12	1.0	120	100	Only hooded quartz-lens deposit discovered. High concentration of small-sized mica books.
Urubú (Espera Feliz)	Upper section	Essentially vertical sheet surrounding a quartz lens.	75	6	1.5	140	100	Top part of shoot eroded.

DISSEMINATED DEPOSITS

Disseminated deposits of mica occur in pegmatites of rather uniform granitic texture. In these deposits, the mica books are scattered throughout the pegmatite instead of being concentrated in one or more zones. The orientation of the mica books within the pegmatites is random. Some books have planar dimensions greater than the width of the pegmatites that contain them. Most pegmatites that contain disseminated deposits of mica are less than 1 meter thick, but exceptionally, as at the Bananal mine, parts of a pegmatite are as much as 3 meters thick. All the pegmatites containing disseminated mica of commercial size occur in schist.

In most disseminated deposits, the mica books are so small or so scattered that only a few tons of usable mica can be profitably extracted. Notable exceptions are the multiple sheetlike deposits of the Serra dos Lourenços and Bananal mines, from which substantial quantities of high-quality mica have been recovered. Other noteworthy disseminated mica deposits are those in a few tabular, vertical, or steeply inclined pegmatites—for example, the Viuva Alegre and Barro Branco near Espera Feliz and the Machado near Resplendor.

SEGREGATION DEPOSITS

Scattered segregation clots of muscovite and quartz, much coarser grained than the granitic-textured or quartz-feldspar rock that surrounds them, provide most of the output of mica from such mines as the Levindo Alferes, Corrego de Tijuco, and Corrego Grande in southeastern Minas Gerais and the Incerta, Ferrugem, and Pontal mines near Governador Valadares. At other mines, such as the Fortaleza and Cobiça-Chapeu Duro, the mica-bearing segregation patches are distributed in a matrix that itself contains some mica books of commercial size. In most pegmatites of this kind, however, the mica books in the matrix are too small to be useful. The segregation clots are commonly scattered, but in a few pegmatites the patches are concentrated in the central part and suggest a rudimentary zoning. In no pegmatite, however, have segregation patches been noted in the border zones. Only a few pegmatites of the segregation type have achieved prominence as sources of mica; among these the Levindo Alferes is outstanding (fig. 15).

DESCRIPTION OF THE MICA

GENERAL PROPERTIES

Muscovite mica is essentially a hydrosilicate of potassium and aluminum expressed by the chemical formula $(H,K)AlSiO_4$. The mineral possesses such a perfect basal cleavage that it can easily be separated into films as thin as one-thousandth of an inch (0.025 millimeter, or 25 microns). Its low heat conductivity and its dielectric properties make the mineral especially desirable as a thermal and electrical insulator. Muscovite crystallizes with a monoclinic symmetry, but only rarely is the crystal form perfectly developed. Numerous structural and mineralogical features occur in mica and markedly affect its preparation and uses. With respect to origin, these features are primary (formed during the crystallization of the mica) or secondary (formed after crystallization). In general, structural imperfections prevent the obtention of perfectly cleaved sheets, and mineralogical imperfections spoil the homogeneity and quality of the sheets. Unusually large mica sheets are shown in figures 34 and 35.

FIGURE 34.—Exceptionally large full-trimmed sheet mica from the Manoel Blum mine, near Tombos, Minas Gerais, Brazil.

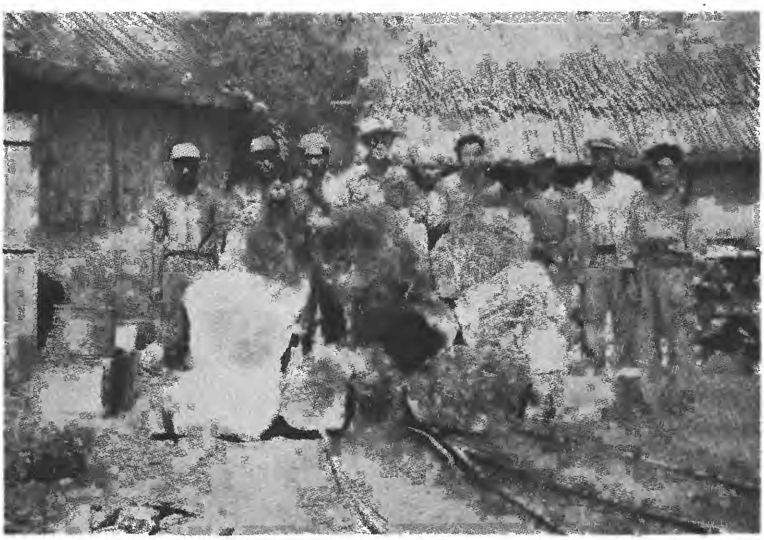


FIGURE 35.—Rifted mica split from a single large book from the Cruzeiro No. 1 pegmatite, near Santa Mario do Suassuí, Minas Gerais, Brazil.

STRUCTURAL FEATURES OF PRIMARY ORIGIN

SHAPES OF MICA CRYSTALS

Perfect muscovite crystals are either hexagonal or rhombic in outline with plane angles of 120° or 60°. The crystals are tabular or columnar. Well-formed crystals free from imperfections are rare or lacking in most pegmatites. Several crystals with perfect hexagonal outlines have been discovered from pegmatites at the Ferrugem and Pedra Redonda mines near Governador Valadares, at the Chalet Verde mine near Espera Feliz, and at several mines near Jequerí and Matipo. Well-formed rhombic or diamond-shaped mica crystals occur commonly in pegmatites that contain a high proportion of blocky plagioclase, such as those at the Bananal, Serra dos Lourenços, Rochedo, and Carrapato mines. In diamond-shaped plates, the prism (110) is the dominant form, and the side pinacoid is subordinate.

Mica crystals that are irregularly shaped but of excellent quality commonly occur in the quartz-muscovite mixture known as mica canga, but because of their small size, these mica crystals yield little or no sheet mica. Mica books that are incompletely crystallized, with only a few faces present, are much more abundant than complete crystals. Partial or complete crystals that are free of any imperfection account for only a small fraction of 1 percent of all the Brazilian mine-crude mica.

Inasmuch as all primary and some secondary imperfections in mica are related to crystallographic directions, it is sometimes possible to determine in a hand specimen the crystallographic orientation of a crystal or book of mica. By such orientation guides one may, in some hand specimens, relate many of the structural and mineralogical features to the crystallographic axes of the mineral. If a plate or mica book is more than a centimeter thick, the basal face may be oriented in most cases by identifying one or more prism or side pinacoid faces. The side pinacoid face of the mica book is at right angles to the basal face; front prisms are at angles greater than 90° and rear prisms at angles less than 90°. The six plane angles on the hexagonal-shaped basal face are each 120° and, in plates with a rhombic outline, are 60° for side angles and 120° for front and rear angles. With basal plates, a petrographic microscope can be used very easily to determine the general orientation of imperfections by relating them to the acute bisectrix figure.

REEVES AND RELATED STRUCTURES

"Reeves" are sets of parallel lines, ridges, crenulations, and distortions that mar the perfect cleavage of a mica plate. The principal set of reeves in a mica crystal is commonly parallel to the *b*-crystal direction of the crystal and is intersected by a second set at an angle of 60°. In its complete development, reeved mica has three sets of linear imperfections that intersect in a central, knotted area and resemble six spokes of a wheel emanating at angles of 60° from the central area (fig. 36). In six-sided mica crystals, one linear set intersects the side pinacoid at right angles, and the other two sets intersect the prism edges at right angles. These directions are coincident with the well-known percussion figure in mica.

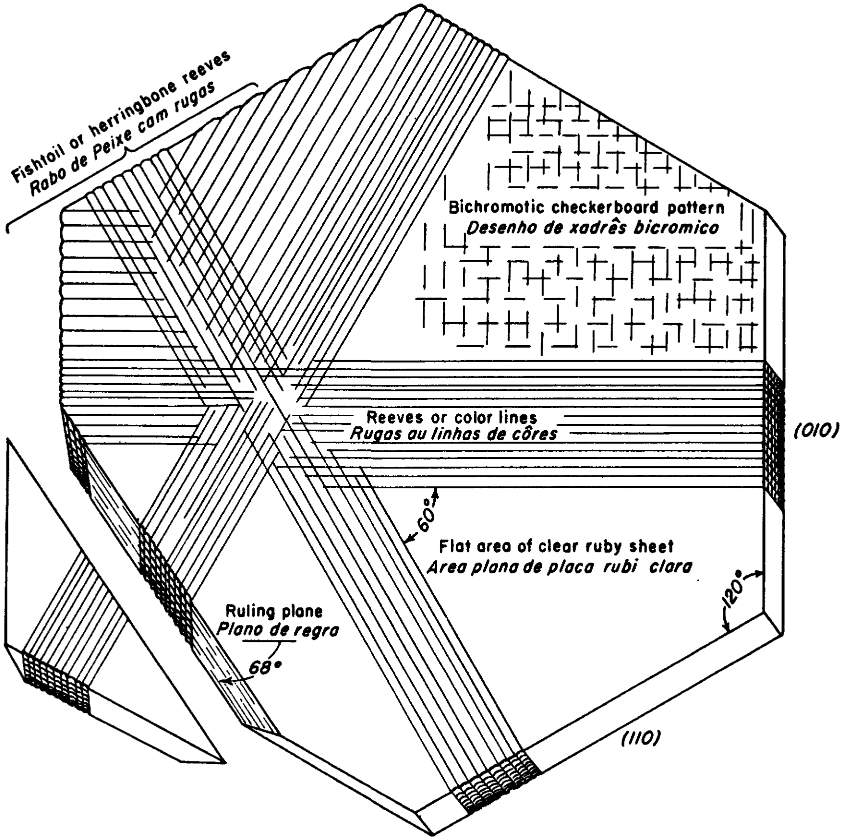


FIGURE 36.—Sketch of a mica plate, showing schematically the relation of the principal structural imperfections to the crystallographic orientation.

In much of the mine-crude mica only two sets of reeves are developed, and the reeve sets give the appearance of a V-shaped pattern on mica plates. This imperfection is called "A" structure in the trade, and if the area between the two reeve sets is structurally perfect the plate is called "flat-A" mica. Much of the finest sheet mica in Brazil has been trimmed from flat-A mica.

"Fishtail," "fishbone," and "herringbone" mica are terms used to describe mine-crude mica in which the reeves are developed across the entire face of mica plates. Such mica is useless as a source of sheet. Herringbone structure is more properly that seen in plates having two principal reeve sets, at an angle of 120° to each other, which are joined at a center line equivalent to the third and subordinate reeve set. In Brazil the term "rabo de peixe" is used as a general term for reeved mica.

TANGLESHEET STRUCTURE

The term "tanglesheet" is applied to mica books that yield torn films when split instead of well-cleaved plates. The structure is probably a result of mutual intergrowth of layers or books. The knotted area, or locus, of a set of reeves commonly has a tanglesheet structure in spite of excellent flat-A areas adjacent to it.

WEDGE STRUCTURE

Mica books with an aggregate growth of interlayered basal sheets of unequal thickness and unequal size are wedge-shaped and rarely can be cleaved into commercial sheet mica. "Wedge" structure (mica de cunha) is a common imperfection in mica that is characterized by full development of herringbone, fishtail, and tanglesheet structures.

STRUCTURAL FEATURES OF SECONDARY ORIGIN

Structural imperfections caused by stresses active after the crystallization of the mica include those commonly called "ruling," "hair cracks," "buckling," and "waviness."

RULING

One of the commonest structures in mica books is "ruling," which is defined as smooth-faced, straight parting in the mica book at an angle of about 68° to the cleavage face. Displacement of the parted blocks is common, but the movement is only a small fraction of the total thickness of the book. The parting surface is generally coated with fibrous or shredded mica. Several partings, all of them oriented in the same direction, are not uncommon in the same book. Subparallel partings give rise to rectangular blocks often referred to as "ribbon sheets." Some mica books display two intersecting sets of ruling planes, one of which is generally dominant. On basal-cleavage plates, the traces of these ruling planes are rhomb-shaped. The ruling plane in some mica blocks is a clean-cut parting on one side or edge of a cleavage plate but continues as a sharp ridge or "crease" on the other. In some specimens examined, a rotational displacement is indicated, for the crease is on opposite edges and different sides of the cleavage plates. On plates that are reeved, the traces of each set of ruling planes are invariably parallel or nearly parallel to one of the three reeve directions in the mineral.

A petrographic study of a great number of ruled mica plates indicates that the ruling planes are pyramidal planes of parting (glide planes?). These planes are apparently a result either of stresses on the mica books that prevailed after crystallization and during cooling of the pegmatite (volume readjustment) or of stresses that were transmitted during the deformation of the region at some later geologic period.

HAIR CRACKS

Some mica books, including ones that are not ruled, have "hair cracks." These hair cracks are well-defined, but not readily discernible, curved fractures along which even, hard, and otherwise perfect mica plates break into one or several pieces. Hair cracks have no orderly crystallographic orientation. It is not known by what stresses they were induced in mica books. A noteworthy example of hair-cracked mica was that produced at the Paraiso da Barra mine in 1943–44.

BUCKLING

Mica books that have been contorted or twisted into sharp flexures are referred to as "buckled" mica (mica dobrada). Buckled mica has been recovered from a number of deeply weathered pegmatites and is especially common in the hanging-wall mica zone of the Cruzeiro No. 3 pegmatite; it yields no sheet mica. The buckling has probably resulted from some sort of movement within the pegmatite. According to Smythe (1946, p. 19), this movement was caused by volume readjustments in the kaolinized portion of the pegmatites. Buckled mica, however, has been observed by the writers in hard-rock pegmatites also. Faults with displacements of less than a meter cut the hard No. 3 pegmatite at the Serra dos Lourenços mine, for example, and adjacent to those faults the mica is buckled.

WAVINESS

Mica books that yield sheet mica with a "wavy" (undulada) instead of a flat surface are particularly abundant in some pegmatites. At the Pedro Espirito mine, waviness is characteristic of the mica books that are not ruled. At the Cruzeiro mine, where ruled mica is a rare feature, the high proportion of wavy mica in the mine-crude mica significantly reduces the commercial value of the sheet mica. Wavy mica has been obtained from unweathered as well as from deeply weathered pegmatites. Waviness is generally more pronounced in a weathered pegmatite and in the upper, weathered part of the same pegmatite.

MINERALOGICAL FEATURES OF PRIMARY ORIGIN

DIFFERENTIAL LIGHT ABSORPTION

Mica plates free of primary structural imperfections and more than a centimeter thick are opaque or almost so in the direction perpendicular to the basal plane and translucent in the direction parallel to the base. This differential absorption is more pronounced in some colored varieties of muscovite than in others.

COLOR

The wide variation in the color of muscovite is not evident from the color terms used in the mica industry. For proper comparison of colors, some standard thickness between half a millimeter and 2 millimeters—the range in thickness of most rifted mica (mica desplacada)—is most appropriate. Most of the sheet mica produced in Brazil is called "ruby" mica, even though it displays a wide variety of mixtures of pink, red, buff, yellow, cinnamon, and brown. This variation in composite color apparently has no influence on commercial value. In mica called "rum ruby," olive brown is the dominant color. "Green" sheet mica is not considered as valuable as the ruby mica.

Ruby mica with a decided reddish cast is characteristic of the diamond- and rhombic-shaped books recovered from the pegmatites rich in blocky plagioclase. Rum-ruby mica is the variety obtained at the Serra Negra mine near Maranhão and at the Gunther Sauer mine near Glória. A great many pegmatites in the gneissoid mafic rocks between Bicas and Cataguazes are characterized by mica with a cinnamon-brown cast that is intermediate between the red ruby and the rum ruby. Green mica is abundant near Caratinga and Muriaé.

COLOR PATTERNS

Bichromatic sheet mica, displaying regular or irregular color patterns, is common at certain mines. The color patterns are believed to represent minor differences in chemical composition. Symmetrically zoned color patterns, hexagonal in outline, are sharply defined and most commonly are composed of recurrent zones of two different tints of ruby. Rarely, a rhomb-shaped ruby core is surrounded by hexagonally shaped zones of lighter-colored ruby. In some specimens, cores of ruby mica are surrounded by zones of green and yellow-green mica.

Three well-defined linear patterns are known. In one, linear bichromatic streaks are oriented along two sets of reeves, and the flat-A area between two intersecting sets is clear ruby or zoned after the hexagonal pattern. In another linear pattern, called checkerboard (xadrez) or plaid, the bichromatic lines are at right angles to each other. One set of lines is parallel to a reeve set, and the other is parallel to the side pinacoid (or prism) face. A third linear pattern has been called "hen track" (pé de galinha). The hen track is best developed in the flat-A areas between the sets of reeves and is a pattern of three sets of color lines. Two sets are parallel to the adjacent reeve sets, and the third is parallel to the limiting crystal face (010 or 110). The most easily perceptible linear patterns are formed by linear streaks of light ruby in a background of dark ruby. The mica mines near Governador Valadares are a rich source of linear color patterns.

Two irregular color patterns are known. In one, an irregularly outlined central area of one variety of ruby is bordered by a second variety. In the second, called "tiger skin" (tigrada) the cleavage plate is speckled with irregular areas or blotches of two different shades of ruby mica.

In full-trimmed sheet mica, which generally ranges in thickness from 0.007 to 0.010 inch (0.17 to 0.25 millimeter, or 170 to 250 microns), the color patterns are not easily perceptible and are disregarded in qualifying the mica.

AIR-STAINED MICA

The inclusion of gas bubbles in sheet mica, a feature called "air staining" or "silver staining" (prateada), is a very common mineralogical imperfection in mica and has an important bearing on the qualification of sheet mica. Commonly these stains are grouped or alined along one or more sets of reeves. In flat-A segments between sets of reeves, air stains are grouped near the apex, near the outer margin, or scattered throughout. Zoned patterns of air stains follow the hexagonal outline of the crystal, and in many specimens, several zonal bands of air stains are separated by bands of clear ruby mica.

Air staining is thought to have been caused by the trapping of gases of unknown composition within the structure of mica crystals during growth. The stains cannot be trimmed out, and in this respect they differ from the water or air bubbles that have infiltrated the leaves of mica books during weathering, mining, handling, and trimming.

MINERAL INTERGROWTHS

A number of minerals with a wide variety of habits are intergrown with muscovite books in different pegmatites. These minerals include biotite, chlorite, garnet, tourmaline, quartz, microcline, albite, magnetite, zircon, apatite, fibrous amphibole, and pyrite. The intergrown minerals are most abundant in the reeved parts of mica books either along sets of reeves or in the apex area of the reeves. An orientation of elongate minerals along the direction of reeving is not uncommon.

These foreign minerals commonly occur as flattened plates between leaves of the mica books, and except where the plates are extremely thin, they can be eliminated from the mica by trimming. Distorted crystals of garnet and prismatic crystals of quartz or tourmaline may pierce several layers in mica books so as to make the books useless for sheet mica. Even where the crystals are extremely small, they may cause "pinholes" that preclude the use of the sheet mica for dielectric purposes. Many of the large mica books in the mica zones of the pegmatites in the Cruzeiro district are valueless because of the abundance of tourmaline crystals intergrown with the mica.

Biotite and muscovite are intercrystallized in the border zones of many pegmatites. The two minerals are easily separable during trimming, but much of the muscovite derived from this source is too small or too thin to be sold as qualified sheet mica, although some of it is of unusually high quality. In the intermediate or central zones of the same pegmatites, the muscovite is free of biotite. Nowhere were both biotite and tourmaline observed in the same mica book.

Abundant inclusions of magnetite, occurring as flattened plates or as particles too thin to be trimmed out of sheet mica, have given rise to the terms "black-spotted" mica (mica manchada de preto), "iron-stained" mica (mica manchada de ferro), or "electrical" mica. Such sheet mica cannot be used as a dielectric. Often the magnetite shows some crystal outline or forms skeletal growths having trigonal or hexagonal patterns. Magnetite inclusions commonly occur throughout a mica plate but at some mines are more abundant in the flat-A areas than along reeves. A certain green staining, called "vegetable stain," results from local discoloration of ruby mica or from ferrous chlorite inclusions too thin to be trimmed out of sheet mica. "Vegetable stain" is therefore an improper term.

Sheet mica from certain mines is characterized by red-brown spots scattered throughout the ruby mica. These defects are termed "dark eyes" (olhos oscuros) or "pigeon eyes" (olhos de pomba) in the mica districts. Microscopic study has revealed that the brown spots are colored aureoles around minute crystals of zircon, rutile(?), or one of several other, unidentified, minerals. If these minute mineral inclusions are removed in rifting or trimming, "pinholes" result in the sheet mica.

MINERALOGICAL FEATURES OF SECONDARY ORIGIN

WETNESS

Mica books recovered from wet, weathered rock contain water that has infiltrated along folia of the books. In drying, some water inclusions remain in the mica, but these can easily be removed during trimming. Some books or rifted plates, however, acquire a wavy surface when dried. Wet mica that is flexible becomes less flexible when dried.

STAINS

Two sources of clay staining are recognized—the weathering of thin plates of feldspar originally included in the mica and the precipitation of clay films from infiltrated ground water.

Various kinds of red-stained mica (mica manchada de vermelho) have formed through weathering. The most common stain is that which results from precipitation of hydrated iron oxide from ground water and adheres to included clay or to mica films. This kind of staining is prevalent in mica that is heavily air-stained and reeved. A second variety of red stain is caused by alteration of iron-bearing mineral inclusions in place—magnetite, garnet, tourmaline, biotite, chlorite, sulfides. Red-stained mica is characteristic of many mines in weathered pegmatite.

Black manganese-oxide films are characteristic of mica books in some deeply weathered pegmatites. The stains are commonly localized along the edges of books that are in contact with quartz but also are present in the folia where included minerals are decomposed. The manganese oxide has a particular affinity for quartz inclusions in mica.

SIGNIFICANCE OF WEATHERING

Except for increased flexibility and partial parting of folia, mica books have an extreme resistance to weathering. In contrast to the general supposition in the mica districts that mica from unweathered parts of pegmatites is far superior in quality to that recovered from weathered parts, the writers witnessed innumerable times the recovery of hard, fine-quality mica books from weathered pegmatites. Certain defects of primary origin, however, are accentuated by weathering because they offer channels for the infiltration of ground water. Mica that contains reeves, air stains, and mineral inclusions is more susceptible to the chemical action of ground water than more perfect mica. Mica of high quality is an inherent feature of a pegmatite and is not marred as much by weathering as has hitherto been supposed.

MINE-CRUDE MICA AND SHEET-MICA PRODUCTION ANALYSES

GENERAL STATEMENT

Preparation of detailed topographic and geologic maps and studies of partial or complete records of the production of mine-crude mica and sheet mica during 1943–45 enabled the writers to obtain production analyses of several mica mines in Minas Gerais. These analyses vary in reliability and were intended primarily as guides in (1) estimating the strategic-mica content in the mine-crude mica, (2) evaluating past and current production, and (3) estimating and evaluating reserves and probable future production. The recovery of mine-crude mica, expressed in kilograms per cubic meter or as weight percent of total material excavated, or of pegmatite alone, is in itself insufficient to evaluate mica deposits because of the wide range in size and quality of the sheet mica that is processed from the mine-crude mica. An important part of the analytical program, therefore, involved an appreciation of the sheet-mica recovery and trimming technique. Mine operators can estimate the value of the mine-crude mica that is being mined, as well as that being developed as a future reserve, by referring to an established price tabella or to any prevailing price tables, but prior to the war-emergency program few operators had bothered to make such estimates.

Information and data concerning the mine-crude mica recovery ratios, sheet-mica recovery ratios, and tabella evaluation of mine-crude mica and sheet mica are discussed in the following sections and presented in tables 6, 7, and 8.

MINE-CRUDE MICA PRODUCTION ANALYSES

MECHANIZED OPEN-PIT MINES

GENERAL STATEMENT

The deep mantle of weathered rock so prevalent in the Mica Belt is amenable to open-pit mining with the use of simple implements such as pick, shovel, and wheelbarrow and, at a few mines, by sluicing. At some mines, several thousand cubic meters of material have been excavated over a period of years entirely by manual labor. By 1942 many mines had been excavated deeply and with little regard for engineering principles. Consequently, during the rainy season, landslides impeded work in the open pits and also endangered entries to underground workings. At these mines, as well as at many where open-pit mining had ceased, underground workings suffered from lack of ventilation, poor drainage, improper haulage, and unskilled timbering. It was evident that such hazards to mining were seriously hampering the effort to increase mica production. In 1942, therefore, a group of interested technical observers recommended that, as a war-emergency measure, stripping with heavy mechanical equipment could advantageously be used for open-pit mining (figs. 37, 38) and would augment mica production from those pegmatites that were favorably situated with respect to geology and topography. In addition, new underground workings with proper haulage and drainage facilities could be made into parts of the pegmatites hitherto unexplored. A

237190 O—53——6

number of bulldozers, tractors, and scrapers (carry-alls) acquired by the United States Purchasing Commission were introduced into the mica districts and, in 1943 and early 1944, were employed by contractual arrangement at several mines under technical supervision. In

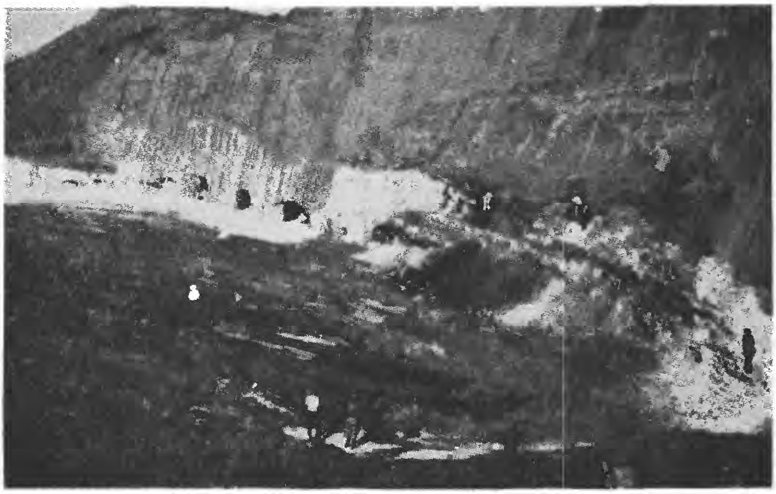


FIGURE 37.—Pedro Espirito mica mine, near Governador Valadares, Minas Gerais, Brazil, showing open pit in March 1944.

FIGURE 38.—Pedro Espirito mica mine, near Governador Valadares, Minas Gerais, Brazil, showing the working of benches by bulldozer mining in May 1945.

the latter part of 1944 and in 1945, the same equipment was rented to mine owners to be used at their own discretion. In the period 1943–45, 31 mica mines used such equipment—not continuously, however, because of numerous mechanical failures.

STRIPPING

A general economic analysis of the 31 open-pit stripping operations is presented in table 6. A total of approximately 2,500,000 cubic meters of material was excavated, of which about 20 percent was estimated, from surveys by the authors, to be pegmatite. The stripping ratios of overburden to pegmatite (table 6, column 5) ranged from 14 : 1 to 0.6 : 1 and averaged about 4 : 1 for the entire program. Millard (1946) concluded from a survey of a few mines under his purview that the stripping ratio should not exceed 3 : 1 to be commercially profitable. Subsequent studies have shown that a stripping ratio as high as 5 : 1 may be feasible if the quality and concentration of muscovite in a pegmatite is high, if the price for mica is abnormally high, or if the reserve of mica that can be mined by underground methods subsequent to stripping is large. In general operations at properties that had been surveyed and that were supervised and controlled by technical personnel in 1942–43 proved to be much more effective than the later independent enterprises at these same properties.

PRODUCTION AND RECOVERY OF MINE-CRUDE MICA

The total production of mine-crude mica obtained directly from the mechanized open-pit operations in the period 1943-45 is estimated to have been 3,685 metric tons (table 6, column 6). In addition, an estimated 1,000 metric tons was obtained by subsequent manual operations in the open pits or in new underground workings driven after excavation of the open pits (table 6, column 9). The combined production of 4,685 metric tons made possible by the mechanized operations is approximately 80 percent of the total production in 1943–45 of the 31 mines listed in table 6 and approximately 15 to 20 percent of the total Brazilian production for the same 3-year period.

Production at most of the mines in table 6 had either ceased or was negligible prior to the initiation of the strip mining. At several mines, such as the Pedro Espirito and the Golconda, unexplored parts of the pegmatites were made more readily accessible, and significant reserves for future production were more quickly established than would have been possible by manual methods. At others—for example, the Corrego da Mata, Urubú, and Chalet Verde mines—mica was recovered from dangerous or inaccessible ground adjacent to old workings. The relatively small reserves remaining at a few mines were rapidly depleted under this program. Mechanized operations accelerated mica production from threefold to fifteenfold in all the mines that were active prior to 1943. Mechanical stripping was undoubtedly responsible for a much greater output of mica from the 31 mines listed in table 6 than would have been possible in the same period of time by manual labor alone. The writers assert, in addition,

TABLE 6.—*Production analysis of 31 open-pit mica mines in Minas Gerais,*

Mine and municipio	Months operated, 1943–45 (1)	Cu. m. excavated (2)	Cu. m. overburden (3)	Cu. m. pegmatite (4)	Stripping ratio, overburden to pegmatite (5)
Pedro Espirito (Governador Valadares)	29	230,000	200,000	30,000	6.6:1
Golconda (Governador Valadares)	17	200,000	170,000	30,000	5.7:1
Mical (Governador Valadares)	8	40,000	30,000	10,000	3:1
Pedra Redonda (Governador Valadares)	12	30,000	25,000	5,000	5:1
Ipê (Governador Valadares)	3	10,000	5,000	5,000	1:1
Pontal (Governador Valadares)	10	70,000	60,000	10,000	6:1
Fortaleza (Governador Valadares)	11	30,000	25,000	5,000	5:1
Carajâu (Governador Valadares)	10	25,000	20,000	5,000	4:1
Evangelista (Governador Valadares)	21	170,000	150,000	20,000	7.5:1
Incerta (Governador Valadares)	1	9,000	6,000	3,000	2:1
Borges (Espera Feliz)	20	275,000	245,000	30,000	8:1
Chalet Verde (Espera Feliz)	18	210,000	185,000	25,000	7.4:1
Urubú (Espera Feliz)	21	350,000	325,000	25,000	13:1
Pedra (Espera Feliz)	8	45,000	40,000	5,000	8:1
Bôa Vista Padula (Espera Feliz)	3	15,000	14,000	1,000	14:1
Mexinqueira (Espera Feliz)	4	30,000	25,000	5,000	5:1
Amaral (Espera Feliz)	6	35,000	25,000	10,000	2.5:1
Morro Redondo (Espera Feliz)	12	50,000	30,000	20,000	1.5:1
Pepita Diaz (Espera Feliz)	4	20,000	10,000	10,000	1:1
Vista Alegre (Espera Feliz)	6	35,000	25,000	10,000	2.5:1
Pequerí (Bicas)	16	40,000	20,000	20,000	1:1
União (Glória)	19	50,000	20,000	30,000	0.6:1
Cebola (Glória)	7	20,000	15,000	5,000	3:1
Paraiso da Barra (Cataguazes)	6	15,000	7,000	8,000	0.9:1
Levindo Alferes (Matipó)	16	120,000	90,000	30,000	3:1
Velocindo (Matipó)	15	100,000	75,000	25,000	3:1
Corrego da Mata (Matipó)	6	135,000	100,000	35,000	3:1
Ventura (Caratinga)	9	35,000	25,000	10,000	2.5:1
Belmiro (Matipó)	3	15,000	13,000	2,000	6.5:1
São Vicente (Galho)	4	10,000	5,000	5,000	1:1
Salim (Raul Soares)	8	30,000	25,000	5,000	5:1
Total or average	----------	2,449,000	2,010,000	[1] 439,000	4.5:1

[1] Or 17.9 percent of the excavation in column 2.

that with a more judicious choice of properties and more efficient operation of mechanical equipment the stripping program during the war period would have been even more effective and less costly as a war-emergency measure. The use of heavy mechanical equipment in mica mining in postwar years depends on many economic factors beyond the scope of this report.

The recovery of mine-crude mica per cubic meter of pegmatite mined (table 6, column 1) ranges from 1.2 to 100 kilograms. This wide range is largely a result of two important factors: (1) the extent of earlier mining operations and (2) the natural variation in the original content of usable mica in the different pegmatites. All but a few of the mines had a long history of operations prior to the inauguration of the stripping program. At a few mines where underground operations continued after the cessation of open-pit mining, the recovery from these underground operations exceeded that from the open pits. Mechanical strip mining is a much less selective mining method, although a more rapid one.

Brazil, employing mechanical earth-moving equipment during 1943–45

Crude mica production from open pit (m. tons) (6)	Kg. crude mica per cu. m. pegmatite (7)	Kg. crude mica per cu. m. excavation (8)	Crude mica production from new workings to Sept. 1, 1945 (m. tons) (9)	Total production available by stripping (m. tons) (10)	Total mine production, 1943–45 (m. tons) (11)	Pct. strategic sheet mica of mine-crude (12)
400	13.3	1.7	250	650	700	2.8
405	13.5	2.0	65	470	500	3.3
270	27.0	6.7	40	310	325	2.7
150	30.0	5.0	None	150	160	3.2
15	3.0	1.5	95	110	125	4.5
150	15.0	2.1	None	150	170	2.5
60	12.0	2.0	None	60	75	3.0
30	6.0	1.2	None	30	35	2.0
80	4.0	.5	None	80	95	2.5
25	8.3	2.8	None	25	30	3.0
200	6.6	.7	200	400	900	2.0
200	8.0	.9	50	250	275	1.0
225	9.0	.6	100	325	350	2.0
100	20.0	2.2	None	100	100	1.5
100	100.0	6.6	10	110	110	1.0
20	4.0	.6	None	20	20	2.0
50	5.0	1.4	None	50	50	2.0
40	2.0	.8	10	50	60	2.0
40	4.0	2.0	None	40	50	2.0
50	5.0	1.4	25	75	80	3.0
25	1.2	.6	100	125	475	3.0
175	5.8	3.5	None	175	175	5.0
70	14.0	3.5	None	70	75	4.0
95	11.9	6.3	None	95	125	2.0
200	6.6	1.7	20	220	250	1.5
175	7.0	1.7	25	200	225	1.0
200	5.7	1.5	None	200	210	3.5
45	4.5	1.3	10	55	65	1.5
10	5.0	.7	None	10	25	1.0
30	6.0	3.0	None	30	50	3.0
50	10.0	1.6	None	50	65	2.0
3,685	8.4	1.5	1,000	4,685	5,950	--------------

UNDERGROUND MINES

GENERAL STATEMENT

Prior to 1943 all the underground mica mining in Minas Gerais was conducted on a primitive basis—without mine surveys or geological guidance, with no concern for proper development with a view to the mining of reserves, and with little concern for effective haulage, ventilation, drainage, or timber support. Most mines were in weathered rock, and most mining and exploration was done through adits rather than through shafts, raises, or stopes. At a few mines where the rock was unweathered, hand drilling and blasting were practiced, but for the most part operations in hard rock were not attempted.

In 1943, as part of the war-emergency program of the United States Purchasing Commission, modern mining methods and modern mine equipment such as air compressors, jackhammers, hoists, pumps, mine track, and mine cars were introduced at several properties. Instruction to miners concerning proper use of this equipment, as well as in timbering and other features of mining, was given. About 16 prominent mines used such equipment during part of the period 1943–45: Cruzeiro, Bananal, Serra dos Lourenços, Café Feijão, Palmital, Sapucaia, Rochedo, Bôa Vista Alves, Ipê, Carrapato, Zacarias, Jacutinga, Fazendinha, Taquara Preta, Borges, and Paraiso. As a result of mechanization and instruction, the output from the hard-rock parts of these mines was increased between threefold and tenfold.

PRODUCTION AND RECOVERY OF MINE-CRUDE MICA

A correlation of measured underground excavation with recorded mine-crude mica production for nine mica-mining operations is presented in table 7. Of these operations, only two—the Pedro Espirito and Golconda mines—were in rock soft enough not to require drilling and blasting. Of the operations in hard rock, the Sapucaia and Bôa Vista Mansur mines employed manual labor in drilling and blasting, the Serra dos Lourenços and Bananal used mechanical drilling as the principal means of mining, and the Cruzeiro and Palmital mines used mechanical drilling entirely and employed other modern features such as systematic stoping and two- and three-shift operations.

The advantage, for increased production alone, of mechanical drilling and modern mining technique over hand drilling and primitive mining technique in hard-rock mines can best be illustrated by comparing production statistics for four principal mines. Production obtained by means of the old manual method at these mines was as follows:

		Mine-crude mica production, in metric tons	
	Period	*Total for period*	*Monthly average*
Cruzeiro Nos. 1 and 2	5 years (1938–43)	2, 500	41. 6
Palmital	3 years (1940–42)	90	2. 2
Bananal	5 years (1938–43)	200	3. 3
Serra dos Lourenços	5 years (1938–42)	300	5. 0

Compare these figures with the production obtained from these same mines after the introduction of modern technique.

		Mine-crude mica production, in metric tons	
	Period	*Total for period*	*Monthly average*
Cruzeiro Nos. 1 and 2	16 months (1944–45)	2, 790	175
Palmital	6 months (1943)	205	34
Bananal	20 months (1944–45)	595	29. 7
Serra dos Lourenços	29 months (1943–45)	490	17

TABLE 7.—*Production analyses for underground workings of nine principal mines in mica districts north of the Rio Doce, Minas Gerais, Brazil*

Mine	Municipio	(1) Period of survey	(2) Material excavated (cu. m.)	(3) Production of mine-crude mica (m. tons)	(4) Kg. mine-crude mica per cu. m. excavation	(5) Kg. mine-crude mica in mica-bearing zone (recalculated)			(6) Mining method
						A Kg. per cu. m.	B Est. pct. by wt.	C Sp. gr.	
Cruzeiro (Toquinho section, No. 1 pegmatite).	Santa Maria do Suassuí.	16 mos. (June 1944–Sept. 1945)	4,200	1,440	350	450	16	2.8	Cut-and-fill stopes. Some stopes timbered and filled.
Cruzeiro (Charles section, No. 2 pegmatite).	do	17 mos. (May 1944–Sept. 1945)	6,900	1,340	195	240	10.4	2.3	Cut-and-fill stopes with cribbed raises at 20-meter intervals.
Serra dos Lourenços (pegmatites 1, 3, 4, and 6).	Peçanha	11 mos. (May 1944–Apr. 1945)	3,600	205	57	105	4.2	2.5	Open room-and-pillar stopes.
Bananal (both sections)	do	11 mos. (May 1944–Apr. 1945)	2,500	301	120	160	6	2.7	Do.
Pedro Espirito (principal workings).	Governador Valadares.	19 mos. (Aug. 1943–Mar. 1945)	3,500	250	70	175	7.3	2.4	Developed with rectangular net of drifts and crosscuts.
Golconda (new workings)	do	8 mos. (Jan.–Sept. 1945)	450	59	130	325	13	2.5	Do.
Palmital (two stopes)	Conselheiro Pena	7 mos. (Apr.–Nov. 1943)	2,900	204	70	115	4	2.8	Two open stopes with intervening pillars.
Bôa Vista Mansur	do	10 mos. (Nov. 1944–Aug. 1945)	460	55	120	170	6	2.8	Underhand open stope.
Sapucaia	do	8 mos. (Nov. 1944–Aug. 1945)	160	35	220	350	14	2.6	Old underhand open stope tapped by raise from new haulage level.

The total production of mine-crude mica obtained by direct application of modern equipment and mining technique in 16 prominent underground hard-rock mica mines in Minas Gerais, for various parts of the period 1943–45, is estimated to have been about 4,500 metric tons, or between 15 and 20 percent of the total Brazilian production for 1943–45. This is probably 5 to 10 times more than the output of these mines would have been had manual drilling methods continued.

The recovery of mine-crude mica at the nine principal underground mining operations listed in table 7 ranges from 57 to 350 kilograms per cubic meter, or from 2.5 to 13 percent, of the rock broken. The total rock excavated (column 2) includes country rock and pegmatite devoid of commercial mica books. At the Bananal mine, for example, 20 percent of the volume of rock broken in mining was schist and aplite. At the Pedro Espirito and Golconda mines, the underground workings measured were entirely in pegmatite, but the height of the mine openings was two to five times the thickness of the mica zone being mined. The recovery statistics listed in column 5, accordingly, show the content of mine-crude mica in the mica shoot or mica zone mined. The specific gravity of the weathered or unweathered rock at these mines is estimated to range from 2.4 to 2.8 (column 5*C*).

Production analyses made at these properties over shorter periods may be summarized as follows:

1. At the *Cruzeiro mine, No. 1 pegmatite, Toquinho section*, the mica recovery from the East Arch stope (pl. 15) was calculated to be 150 kilograms per cubic meter of excavation, or 250 kilograms per cubic meter of the mica zone, or 9 percent of the rock in the mica zone by weight. Unfortunately, the mica from different stopes in this section of the mine was not weighed separately. The stopes in the Roof Pendant mica shoot, as determined by surveys over a period of several months, ranged from 400 to 800 kilograms of mine-crude mica per cubic meter of excavation. Not uncommonly the recovery of mine-crude mica obtained from the daily blasting round of a block 2 meters wide and 1 meter deep ranged from 1 to 3 metric tons.

2. At the *Cruzeiro mine, No. 2 pegmatite*, stopes 1, 2, and 3 yielded 160 kilograms of mine-crude mica per cubic meter of excavation in a 4-month period in 1944. This excavation, however, was in the lower, leaner, part of the mica shoot. Surveys made in the richer part of the mica shoot showed the recovery to be almost twice as high.

3. At the *Serra dos Lourenços mine*, hard-rock mining operations were discontinued in the No. 5 and No. 6 pegmatites because the recovery was too low to be profitable. From the No. 5 pegmatite, only 3 kilograms of mine-crude mica per cubic meter of excavation was recovered, or 0.1 percent by weight of the pegmatite; and from the No. 6 pegmatite, the recovery was 20 kilograms per cubic meter, or 0.7 percent by weight. The highest recovery at the Serra dos Lourenços mine was obtained from the No. 4 pegmatite, where the recovery from the mica zone averaged about 145 kilograms per cubic meter, or 5.6 percent by weight.

4. At the *Pedro Espirito mine*, the workings in the mica zone outside the limits of the mica shoot yielded about 25 kilograms per cubic meter of excavation—a profitable operation only because of inflated mica prices and relative ease of mining due to weathering of the rock.

Production analyses based on less precise control were made at a number of other mica mines at different periods during their operation in 1943–45. Some of the results of these investigations are:

1. At the *Viuva Valerio mine, municipio of Manhumirim,* the calculated recovery in certain measured parts of the hanging-wall mica shoots ranged from 125 to 250 kilograms of mine-crude mica per cubic meter of rock, or 5 to 10 percent by weight.
2. At the *Borges mine, municipio of Espera Feliz,* the workings along the hanging-wall zone in the north section of the mine yielded an estimated 220 kilograms of mine-crude mica per cubic meter of excavation, or 8 percent by weight.
3. At the *Zacarias mine, municipio of Espera Feliz,* the hard-rock underground workings in 1944 yielded an estimated 125 kilograms of mine-crude mica per cubic meter of excavation, or 4.5 percent by weight. The mining operations here involved hoisting in an underground underhand stope, an operation more costly than was current for most small mines.
4. At the *Fazendinha mine, municipio of Espera Feliz,* the workings in 1945 near the base of the shaft (fig. 29) yielded 150 kilograms of mine-crude mica per cubic meter of excavation, or 6 percent by weight.
5. At the *Taquara Preta mine, municipio of Espera Feliz,* workings in the mica shoot on the 1,005-meter level are estimated to have yielded 375 kilograms of mine-crude mica per cubic meter of excavation, or 15 percent by weight, over a linear distance of 15 meters.

In 1943–45, the soft-rock pegmatites could be operated profitably if the mica zones or shoots contained more than 25 kilograms of mine-crude mica per cubic meter, but operations in the hard-rock mines were generally suspended if the recovery did not exceed 50 kilograms per cubic meter of rock mined, or 2 percent by weight. Most of the prominent mines averaged between 100 and 500 kilograms per cubic meter of rock in the mica zone or shoot, or 4 to 20 percent by weight.

SHEET-MICA PRODUCTION ANALYSES

PREPARATION OF SHEET MICA FROM MINE-CRUDE MICA

MINE-CRUDE MICA

"Mine-crude" mica (mica bruta) is the term applied to all the crude muscovite books and plates collected at the mine headings and the dumps for the purpose of rifting and subsequent trimming by knife. Mine-crude mica is not a uniform mine product because of the wide variation in (1) the inherent size and quality of the mica in different pegmatites and (2) the selection of the material by the miners themselves. The mine-crude mica at most mines in Minas Gerais is either partly or completely hand-cobbed and does not correspond to the mine-run mica recovered at the mica mines in the United States and India, where processing of crude mica yields in addition to sheet mica other marketable products such as scrap, washer, and punch.

RIFTED MICA

Crude mica is commonly "rifted" at the mines, either on the dumps or in a rifting shed. In this process the crude mica is split by knife into plates up to 2 millimeters thick and cleaned of adhering rock and much of the waste mica. Recovery of rifted mica (mica desplacada) from mine-crude mica ranges from 15 to 60 percent. At a given mine the rifted mica is commonly a standard product, and the percentage of recovery varies within small limits. At such mines as the Pequerí or Serra dos Lourenços, where the mine-crude mica is a carefully selected, hand-cobbed product, the rifting recovery from week to week ranges from 40 to 60 percent. At the Cruzeiro and other mines, where the mine-crude mica is poorly selected and where the rifting is a very careful procedure, the recovery percentage from mine-crude mica ranges from 15 to 25 percent. Production records at many small mines in Minas Gerais refer to rifted and not mine-crude mica.

HALF-TRIMMED MICA

Rifted mica is subsequently split into thinner plates, two or three edges of which are trimmed by knife to remove major imperfections. Such knife-trimmed sheet mica is called "half-trimmed" sheet (mica passada). At a great number of mines, particularly in the Espera Feliz district, mine-crude mica is processed directly into half-trimmed sheet, and mine production records refer to this product. The recovery of half-trimmed mica directly from mine-crude mica ranges from 15 to 40 percent. Partly processed mica that is well rifted (bem desplacada) in the northern mica districts represents the same processing stage as that called half-trimmed in the southern districts, the only distinction being the nomenclature usage in the districts.

FULL-TRIMMED AND CLASSIFIED MICA

Full-trimmed sheet mica (mica beneficiada) is prepared from rifted or half-trimmed sheet mica. Full-trimmed sheet mica commonly ranges in thickness from 0.010 to 0.040 inch (0.5 to 1 millimeter), has a beveled knife trim on all edges, and is classified into about a dozen size groups based on rectangular areas ranging from 1 square inch to 80 square inches. These size groups and the corresponding grades are:

Grade	Size of rectangular area: In square inches	Size of rectangular area: In square centimeters
6	1	6. 45
5½	2½	16. 12
5	3	19. 35
4	6	38. 70
3	10	64. 50
2	15	96. 75
1	24	154. 80
A–1	36	232. 20
Special	48	309. 60
Extra special	60	387. 00
Extra extra special	80	516. 00

Prior to 1943, the classified full-trimmed sheet mica prepared in the mica districts was bought by mica companies, sent to Rio de Janeiro and São Paulo, and exported with or without further trimming and qualification. In 1943–44 a number of qualifying shops were established in Governador Valadares and Conselheiro Pena to qualify the full-trimmed sheet mica for export. The southern mica districts continued the practice of sending full-trimmed sheet mica to Rio de Janeiro for qualification.

QUALIFIED SHEET MICA

In the period 1942–45, the demand for high-quality sheet mica for war-time uses became increasingly important. In order to meet this demand, the trimming technique was modified to provide for export a higher proportion of full-trimmed and qualified sheet mica than had previously been available. For this reason, the recovery ratios of sheet mica from mine-crude mica subsequent to 1942 are not strictly comparable to those prior to 1942.

The quality groups based on the India standard, in the order of increasing imperfection, are, as already stated:

Quality	*Description*
C	Clear
CSS	Clear and slightly stained
FS	Fair stained
GS	Good stained
SA	Stained "A"
SB	Stained "B"
HS	Heavy stained

Qualified sheet mica has a minimum thickness of 0.007 inch (7 mils, or about ⅕ millimeter). Any sheets of less than the prescribed minimum thickness are called " thins " or " scalings " and are sold according to a different price schedule. An increasing quantity of thins (folhas finas) and scalings (laminas) was recovered in 1944–45 as a byproduct of the rigorous trimming for qualification.

RECOVERY OF SHEET MICA

In 1943–45 the recovery of commercial sheet mica from mine-crude mica or rifted mica was calculated or estimated from complete or partial records for more than 100 mica mines in Minas Gerais. The most reliable data are those supplied by mica companies that were both mine operators and mica exporters, for correlation of mine-crude mica production and final sheet-mica product could be made over a period of several months. Table 8, columns 1 to 10, lists the calculations—based on recorded data—of the recovery of sheet mica from mine-crude mica for 10 different mines. With respect to size, staining, cleavage, hardness, color, and the like, the mica from these 10 mines represents a fair sample of that which occurs in hundreds of mines in the Mica Belt of Minas Gerais. With few exceptions, therefore,

TABLE 8.—*Recovery ratios and sales value of sheet mica,*

[Calculations based on recorded

Mine	Period of analysis	(1) Mine-crude mica (m. tons)	(2) Qualified sheet mica (m. tons)	(3) Half-trimmed sheet mica (m. tons)	(4) Total sheet mica (m. tons)	(5) Pct. total sheet of mine-crude mica	(6) Pct. qualified of total sheet mica
Serra dos Lourenços	1943	(?)	17.5	15.9	33.4	(?)	52
	1944	206	28.0	7.6	35.6	17	78
Bananal	1943	(?)	7.6	3.7	11.3	(?)	67
	1944	270	16.4	3.5	19.9	8	82
Pedro Espirito	1943	126	12.7	4.3	17.0	13.5	75
	1944	295	31.2	4.7	35.9	12.2	87
Bôa Vista Alves	1943	67	6.2	.5	6.7	10	92
	1944	80	8.2	(?)	(?)	(?)	(?)
Cruzeiro	1943	(?)	19.7	63.8	83.5	(?)	24
	1944	1,150	63.8	26.8	90.6	8.0	70
Golconda	1944	390	25.1	19.4	44.5	11	56
Evangelista	1944	48	2.9	1.8	4.7	10	67
Mical	1944	110	6.0	(?)	(?)	(?)	(?)
Ipê	1944	72	5.9	(?)	(?)	(?)	(?)
Café Feijão	1944	18	1.0	.9	1.9	11	53

the recovery in 1943–45 of Brazilian sheet mica from mine-crude mica falls with the limits indicated in table 8.

The total recovery of sheet mica from mine-crude mica (table 8, column 5) ranges from 8 to 17 percent and the recovery of qualified sheet mica (column 7) from 5.5 to 13.3 percent. Qualified sheet mica makes up 24 to 92 percent (column 6) of the total for those mines that prepare both half-trimmed and full-trimmed sheet mica. In 1944–45 the percentage of qualified sheet mica of the total of all the sheet mica recovered was uniformly higher than in earlier years.

The strategic part (GS, FS, and CSS) of the total qualified sheet mica ranges from 22 to 70 percent (table 8, column 8). The recovery of strategic mica from mine-crude mica ranges from 1.4 to 6 percent. In a majority of the mica mines examined in Minas Gerais, the strategic sheet mica represents 2 to 3 percent of the mine-crude mica. At a few mines, some of which are important producers, the mine-crude mica is so heavily stained that the recovery of strategic sheet mica is lower than 1 percent. Only a few mica properties are known at which normal trimming practice results in both a high recovery (more than 3 percent) of strategic sheet mica from the mine-crude mica and a high percentage (50 to 80 percent) of the total full-trimmed qualified sheet mica. Some of the better-known high-quality mines include the Serra Negra near Maranhão, the Serra dos Lourenços and Bananal near Ramalhete, the Rochedo and Palmital near Conselheiro Pena, the Carrapato near Governador Valadares, the União and Gunther Sauer near Glória, the Descoberta or Santa Therezinha near Cataguazes, the Pequerí, Saracura, and Santa Clara near Bicas, and the

1943–44, from mine-crude mica of 10 mines in Minas Gerais, Brazil

data of mica companies]

(7) Pct. qualified sheet of mine-crude mica	(8) Pct. strategic of qualified sheet mica	(9) Pct. strategic sheet of mine-crude mica	(10) Pct. grade 4 and larger of total sheet mica	(11) Sales value in U. S. dollars per metric ton			
				A Qualified sheet mica	B Half-trimmed sheet mica	C Total sheet mica	D Mine-crude mica (calculated)
(?)	28	(?)	50	3,800	600	2,270	(?)
13.3	45	6.0	30	3,960	525	3,200	545
(?)	40	(?)	9	2,500	510	1,850	(?)
6.5	70	4.6	18	4,150	575	3,500	280
10.1	22	2.2	35	1,610	690	1,380	185
10.6	28	2.9	27	1,720	580	1,600	195
9.2	27	2.5	22	2,300	260	2,150	210
11	25	2.8	37	(?)	(?)	(?)	(?)
(?)	20	(?)	40	(?)	(?)	(?)	(?)
5.6	25	1.4	45	(?)	(?)	(?)	(?)
6.5	50	3.3	15	2,400	620	1,600	175
6.7	60	4.0	11	2,500	540	1,830	180
5.5	70	3.8	7	2,550	(?)	(?)	140
8.2	60	4.9	9	2,300	(?)	(?)	190
5.8	50	2.9	11	2,500	550	1,600	175

Corrego da Mata near Raul Soares. At a few of these mines the combined recovery of FS and CSS qualities exceeds that of GS.

The percentage of sheet mica, of grades 4 and larger, of the total commercial sheet mica (table 8, column 10) ranges from 7 to 50 percent. Of the 10 mines listed in table 8, the Cruzeiro is the outstanding producer of the larger sizes of sheet mica—an advantage that compensates for its low recovery of high-quality mica. At several mines near Raul Soares the recovery of strategic sheet mica from mine-crude mica is less than 1 percent, but these mines produce a significant percentage of larger sizes. In 1943–45 sheet mica of grade 4 and larger accounted for 16 to 20 percent (p. 211) of the total purchases of the United States Purchasing Commission. The Pequerí and Serra dos Lourenços mines are well known as consistent producers of unusual percentages of large-size strategic sheet mica. The Jacó, Sabão, and other mines with a low recovery of strategic mica (less than 1 percent of the mine-crude mica and less than 20 percent of the qualified sheet mica) and a low recovery of grade 4 and larger (less than 10 percent) did not operate during most of the period 1943–45.

ANALYSES OF TABELLA VALUES OF MICA

TABELLA VALUE OF SHEET MICA

All the sheet mica produced from the mine-crude mica of the 10 mines listed in table 8 was sold to the United States Purchasing Commission in Rio de Janeiro. The tabella evaluation of the sheet mica sold in 1943–44 and the recalculated approximate value of the mine-crude mica are given in column 11 of table 8.

The range in dollar value per ton of the qualified sheet mica sold in 1943 was $1,610 to $3,800, United States currency; in 1944 it was $1,720 to $4,150 (table 8, column 11*A*). The range in value per ton of half-trimmed sheet mica was $260 to $690 per ton, with most of the values between $500 and $600 (column 11*B*). The range in value per ton of total commercial sheet mica from these mines (column 11*C*) was, in 1943, $1,380 to $2,270 and, in 1944, $1,600 to $3,500. The total purchases by the United States Purchasing Commission averaged $1,840 per ton in 1943 and $2,620 in 1944, excluding premium and bonus. Including premium and bonus payments, the total purchases of sheet mica in Rio de Janeiro averaged $3,620 per ton in 1944 and $3,700 per ton in 1945. The premium and bonus payments in 1944 and 1945 were approximately 40 percent of the tabella value of all the sheet mica bought by the United States Purchasing Commission.

The average tabella purchase price of strategic, qualified sheet mica in 1943 (250.4 tons) was $3,380 per ton; in 1944 (544.6 tons), $3,700. Premium and bonus payments in 1944–45 represented about 50 percent of the tabella value of the strategic sheet mica.

TABELLA VALUE OF MINE-CRUDE MICA

The tabella value of mine-crude mica, calculated by utilizing sheet-mica recovery and tabella prices of sheet mica, is analogous in a general way to grade or tenor of sorted ore as applied to metalliferous deposits. Unfortunately, sheet-mica recovery may vary at the same mine because of changes in the mine-crude mica or in the trimming policy, and mica prices fluctuate with the economic conditions of the times. The tabella value or "tenor" of mine-crude mica, therefore, is a fluctuating indication of value, whereas assays of the metals in metalliferous deposits are more permanent references for values.

The tabella value of mine-crude mica in Brazil for the two periods 1942–43 and 1944–45 can be estimated with reasonable accuracy. The total sheet-mica purchases of the United States Purchasing Commission in 1942–43 were estimated to represent about 10 percent of the output of mine-crude mica; in 1944–45 they are believed to have made up about 8 percent of the output. The tabella value of mine-crude mica in the first period was approximately $175 per ton; in the second period, $220 per ton. With the additional premium and bonus payments in 1944–45, the average value of Brazilian mine-crude mica was more nearly $300 per ton. Relatively close estimates can be made of the tabella value of mine-crude mica at the 10 mines listed in table 8 (column 11*D*); the range of tabella value was from $175 to $545 per ton and, including premium and bonus payments in 1944–45, from $225 to $650 per ton. The tabella value, for 1943–45, of the mine-crude mica at most of the mica mines in Minas Gerais ranged from

$150 to $300 per ton; only the mine-crude mica of exceptionally large size and high quality exceeded $400 per ton.

TABELLA VALUE OF MICA SHOOTS AND MICA ZONES

The value per cubic meter and per ton of 23 mica shoots and mica zones in underground mica mines in Minas Gerais has been estimated by the writers from calculations based on mine surveys, recorded mica production and recovery, and established price schedules for 1943–45. Five of these mica deposits are in deeply weathered pegmatites, and eighteen are in hard pegmatites that require drilling and blasting. Both groups of deposits represent a wide range of concentration, size, and quality of the mine-crude mica. The range in value of the mica shoots and zones, in place and according to the tabella, is shown below:

	Value in U. S. dollars	
	Per cubic meter	*Per ton*
5 soft deposits	33 to 94	14 to 36
18 hard deposits	34 to 112	12 to 45
Total (23 deposits)	33 to 112	12 to 45

A group distribution of these 23 deposits is shown below:

Value per ton, in U. S. dollars:	*Number of deposits*
12 to 20	9
21 to 30	8
31 to 40	5
45	1
Total	23

Material excavated from underground workings in these mines includes pegmatite devoid of mine-crude mica as well as wall rock that is not pegmatite. If the value of the mine-crude mica output is distributed over all the rock that was excavated, the value of the total rock excavated at these mines ranged from $6 to $32 per ton, or $13 to $88 per cubic meter. In 1944–45 the additional premium and bonus payments for sheet mica of strategic quality increased the value of all the mica-bearing rock mined.

With few exceptions all the productive mica zones and mica shoots examined by the writers fall within the ranges given. The most noteworthy exceptions are those few deposits of high-quality mica such as the Pequerí, Saracura, Serra Negra, and Gunther Sauer for which the tabella value is estimated to range from $50 to $80 per ton of mica-bearing rock excavated from underground workings.

It is evident that in 1943–45 the principal mica mines in Minas Gerais were exploiting deposits that compared favorably in value with many profitable operations in metalliferous deposits in Brazil and elsewhere. The gold mines of Minas Gerais, for example, yield ore that ranges in value from $5 to $15 per ton. The mica deposits would have an even higher value if the Brazilian mica industry were expanded to include the preparation of ground mica and splittings and thereby utilize some of the scrap and small-size mica that is now discarded as waste.

MICA RESERVES AND FUTURE OUTLOOK

GENERAL PICTURE

The period 1942–45 was the most active period of production, prospecting and discovery of new deposits, and establishment of reserves in the history of mica mining in Brazil. Although the known reserves at a few mines were essentially depleted during this period, the reserves at other mines were significantly augmented despite the accelerated production. Reserves of mica remaining in known deposits are of three classes: (1) measured, (2) indicated, and (3) inferred.

1. "Measured" reserve is defined as pillars or blocks of mica-bearing pegmatite that are exposed, or almost entirely exposed, on four sides. For some 50 of the principal mines in Minas Gerais the total measured reserve in September 1945 was 3,000 metric tons of mine-crude mica. This is a very conservative estimate and probably should include some of the reserve classified as indicated.

2. "Indicated" reserve includes blocks exposed on two or three sides and reasonable, geologically controlled extensions of blocks exposed on only one side. The limit of error in the calculations is estimated to be about 25 percent. The total indicated mica reserve of some 150 pegmatites examined by the writers is about 10,000 metric tons.

3. "Inferred" reserve is that for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. The total inferred reserve of the known pegmatites of the Mica Belt is estimated to be several times greater than the total indicated reserve.

Continued prospecting will undoubtedly result in the discovery of new pegmatites, particularly in the region north of the Rio Doce. Many of the mica districts south of the Rio Doce have passed their peak of discovery and production. A large number of the prospects and new discoveries north of Conselheiro Pena and east of Peçanha may require drilling and blasting for mining, because here the rocks are weathered less deeply than in southeastern Minas Gerais. The less populous and less accessible region of northeastern Minas Gerais and southern Baía offers much promise for new discoveries and successful exploration of many prospects, should the demand for mica and consequent high prices warrant such activity. The completion of the Rio-Baía highway will immeasurably facilitate prospecting, exploration, and development in this region.

The writers conclude that over a long period (1) the Mica Belt can provide at least as much mica as has been produced in the past (100,000 metric tons of mine-crude mica); (2) favorable prices and strong demand will be required; (3) mechanical equipment, modern mining techniques, and technical guidance will become increasingly important; and (4) new discoveries will be made, particularly in the northern part of the Mica Belt.

The industrial and gem minerals present in many pegmatites of the Mica Belt will serve as an additional incentive for future prospecting. Pegmatite districts in Rio de Janeiro, São Paulo, and Espirito Santo have yet to be developed and may in the future increase the general mica reserve of Brazil. Mica districts in other States, particularly Goiaz and Matto Grosso, have not been fully prospected, and their mica reserves are unknown.

In spite of the accelerated sheet-mica production in 1943–45, the Brazilian mica industry was better situated technically in 1946 than it was before the war. Technique in the preparation of mica splittings and scalings has improved markedly, and this improvement should increase the utility of mine-crude mica. In the event of the establishment of a ground-mica industry in Brazil, several thousands of tons of mine scrap and scrap from trimming will be readily available for grinding.

MICA MINES WITH DEVELOPED RESERVES

Only a few mica mines in Minas Gerais have a substantial unmined reserve that is properly developed. These properly developed reserves are the result of technically directed programs that were begun in 1944 or 1945 for the purpose of developing reserve blocks during mining. The measured and indicated reserves of seven prominent mica mines, calculated in September 1945, are summarized below. Inferred reserves have not been included.

Mine	*Reserves, in metric tons*	
	Measured	*Indicated*
Serra dos Lourenços:		
No. 1 section	120	400
No. 3 section	60	200
No. 4 section	75	350
Miscellaneous	20	30
Total	275	980
Bananal:		
Pedra Louca section	550	400
Bôa Vista section	420	900
Total	970	1, 300
Pedro Espirito	270	400
Golconda	60	150
Cruzeiro:		
No. 1 pegmatite	450	1, 800
No. 2 pegmatite	50	250
Total	500	2, 050
Pequerí	25	150
Borges	40	225
Grand total	2, 140	5, 255

237190 O—53——7

Continued exploration in depth will undoubtedly increase the measured and indicated reserves at most, if not all, of the mines. At the Serra dos Lourenços, Bananal, and Golconda mines continued exploration by means of inclined winzes is warranted; at the Cruzeiro, by means of shafts; and at the Borges, by means of drifts and raises above the main haulage level. The Pedro Espirito mine already is nearly completely developed.

DEPOSITS GEOLOGICALLY FAVORABLE FOR EXPLORATION

In a great number of prominent mica mines whose known reserves were essentially depleted in 1942–45 but whose geological setting is favorable for future production, intensive exploration through shafts, winzes, and other underground openings is necessary to insure continued production. Among these mines are some whose production was obtained principally from open-pit operations but at which vertical or inclined shafts are warranted for future operations. Outstanding examples are the Santa Clara and Saracura mines near Bicas, the Santa Therezinha and Paraiso da Barra near Cataguazes, and the Laranjeiras No. 1 near Conselheiro Pena.

Some hard-rock mines obtained their principal production from open, underhand stopes in the bottoms of which mica-bearing rock was exposed. Intensive exploration at depth seems warranted at a number of these, such as the Bôa Vista Mansur, Bôa Vista Alves, Sapucaia, and Barca near Conselheiro Pena, the Carrapato near Governador Valadares, and the Serra Negra near Maranhão.

At a number of other mines in both hard and soft rock the mica-bearing zone has been well explored, and the development of reserves should not be difficult. A few of these mines are the Ipê and Evangelista near Governador Valadares, the Laranjeiras No. 2 near Conselheiro Pena, the Cobiça-Chapeu Duro and Ventura near Bom Jesus do Galho, the Salim near Raul Soares, and the Gunther Sauer near Glória.

DEPOSITS WITH RESERVES ESSENTIALLY DEPLETED

At a number of mica mines whose production during 1943–45 was large, the known reserves were essentially depleted, and at most of them the limits of the mica-bearing pegmatites have been ascertained. Mines in such an unfavorable position include the Urubú, Verde, Zacarias, and Fazendinha near Espera Feliz, the Palmital near Conselheiro Pena, the União and Cebola near Glória, the São Miguel near Braz Pires, and the Corrego da Mata near Raul Soares. Future production from these mines is expected to be merely a small percentage of the past production.

INDUSTRIAL IMPORTANCE OF PEGMATITE MINERALS

The mineral products of the pegmatite-mining industry in Minas Gerais in the 10-year period 1936-45 had an average annual market value of $2,000,000 to $3,000,000, United States currency, and represented the partial or sole livelihood of several thousand people. As an industry, pegmatite mining commands public attention and merits geological and technical guidance during peacetime as well as during emergency periods. In value the output of mica has far exceeded that of any other mineral from the pegmatites of Minas Gerais, but the output of kaolin, industrial beryl, tantalite and columbite, and various gem stones has been significant.

According to available State statistics, about 115,000 metric tons of kaolin and 6.5 metric tons of gem stones were shipped out of Minas Gerais during the 10-year period 1936–45. The market price for kaolin of different qualities ranged from $20 to $60 per ton. The pegmatite gem-stone minerals, after lapidation, are used in industry or worn for decorative purposes. This value and use depends on the mineral (beryl, tourmaline, spodumene, chrysoberyl, and the like), its quality and color, and the size and perfection of the lapidated stones. The better gem stones have wholesale-market prices ranging from $5 to $25 per carat.

Exports of tantalite and columbite from the ports of Rio de Janeiro and Vitória in the period 1936–42 totaled 110 metric tons. No analyses of this material are available, but 75 tons were provisionally classed as tantalite. The bulk of the exports originated in Minas Gerais. In addition to the exports, stocks totaling nearly 20 tons were known to exist in warehouses in Governador Valadares and Rio de Janeiro in September 1945. Exports of industrial beryl from Rio de Janeiro and Vitória in 1936–42 totaled 40 tons, and 370 tons were shipped in 1943–44 from Rio de Janeiro. Stocks of industrial beryl at mines and in warehouses in Rio de Janeiro, Governador Valadares, and Conselheiro Pena in September 1945 were estimated to total 120 tons. Almost all of this originated in Minas Gerais. In 1944–45, Brazilian Government regulations concerning the export of tantalite, columbite, and beryl reduced the incentive for exploration and the mining of these minerals in the pegmatites of Minas Gerais.

Lithium-bearing and other useful minerals, as well as hard feldspar, occur in many pegmatites, but industrial demands have not been sufficient to stimulate production.

REFERENCES

Albuquerque, O. R. de, Moraes Rego, L. F. de, and others, 1926, Estudos geologicos e mineralogicos feitos na bacia do Rio Doce: Brasil, Servico Geol. Mineralog., Bol. 19, pp. 15–60.

Andrade, José Ferreira de, Jr., 1930, Estudos sobre os niobo-tantalatos: Brasil, Serviço Geol. Mineralog., Bol. 46, pp. 19–65.

Barbosa, A. L. de Miranda, 1944, Mica em Governador Valadares: Mineração e Metalurgia, vol. 8, no. 43, pp. 29–34.

Barbosa, Octavio, 1936, Contribuição ao conhecimento das formacões predevoneanas no Brasil: Mineração e Metalurgia, vol. 1, no. 1, pp. 21–23; no. 4, pp. 170–172.

Branner, J. C., 1919, Outlines of the geology of Brazil: Geol. Soc. America Bull., vol. 30, no. 2, pp. 189–328.

Derby, O. A., 1879, Observações sobre algumas rochas diamantiferas da Provincia de Minas Geraes: Mus. Nac. Rio de Janeiro Archivos 4.

———, 1895, A denominação Serra da Mantiqueira: Inst. Hist. Geog. São Paulo Rev. 1, pp. 3–15.

———, 1906, The Serra do Espinhaço, Brazil: Jour. Geology, vol. 14, no. 3, pp. 394–401.

Dutra, Eugenio Bourdot, 1926, Reconhecimentos geclogicos nos municipios de Santa Luzia do Carangola e Manhuassú: Brasil, Serviço Geol. Mineralog., Bol. 18, pp. 1–19.

Eschwege, W. L. von, 1822, Geognostlicher Gemälde von Brasilien und das wahrscheinliche Muttergestein der Diamanten, 44 pp., Weimar.

Fenner, C. N., 1928, Radioactive minerals from Divino de Ubá, Brazil: Am. Jour. Sci., 5th ser., vol. 16, no. 95, pp. 382–391.

Florencio, Willer, and Castro, Celso de, 1943, Uranantia em Minas: Acad. Brasileira Sci. Annaes 15, pp. 27–29.

Freise, W., 1933, Brasilianische Zuckerhutberge: Zeitschr. Geomorphologie, vol. 8, pp. 49–66.

Fróes Abreu, Silvio, 1945, Fundamentos geograficos da mineração brasileira: Rev. Brasileira Geografia, vol. 7, no. 1, pp. 1–125.

Freyberg, Bruno von, 1927, Beobachtungen in der Minas Serie, Brasilien: Neues Jahrb., Beilage-Band 17, pp. 428–465, Berlin.

———, 1934, Die Bodenschätze des Staates Minas Geraes, Brasilien, 453 pp., Stuttgart.

Guimarães, Djalma, 1925, Breve noticia sobre uma jazida de samarskita, columbita, e monazita: Brasil, Servico Geol. Mineralog., Bol. 13, pp. 115–118.

———, 1925, Aspectos economicos de mica: Brasil, Serviço Geol. Mineralog., Bol. 9, pp. 5–29.

———, 1926, Nota sobre o mineral radio-activo da Fazenda Santa Clara, municipio de Pomba: Inst. Brasileira Sci. Bol., anno 2, no. 4, pp. 114–124.

———, 1931, Contribuição a geologia de Minas Gerais: Brasil, Serviço Geol. Mineralog., Bol. 55, 34 pp.

———, 1933, Os amphibolitos da região diamantifera do norte de Minas Gerais: Acad. Brasileira Sci. Annaes, vol. 5, no. 4, pp. 237–258.

———, 1936, Quadro chrono-geologico do Brasil: Mineração e Metalurgia, vol. 1, no. 2, pp. 65–71.

———, 1938, Metalogenese e a teoria migratoria dos elementos: Brasil, Serviço Fomento Produção Mineral, Bol. 24, 67 pp.

Guimarães, Djalma, and Barbosa, Octavio, 1934, Mappa geologico do Estado de Minas Gerais, escala 1 : 1,000,000: Minas Gerais Dept. Serviços Geog. Geol. Bol. 3, annexo, Belo Horizonte.

Harder, E. C., and Chamberlin, R. T., 1915, Geology of central Minas Geraes, Brazil: Jour. Geology, vol. 23, no. 4, pp. 341–378.

Hess, F. L., and Henderson, E. P., 1925, Polycrase from Brazil: Franklin Inst. Jour., August 1925, pp. 235–238.

Knopf, Adolph, 1931, The age of the earth; summary of principal results: Nat. Research Council Bull. 80, pp. 3–9.

Knouse, F. L., 1946, Deposits of quartz crystal in Espirito Santo and eastern Minas Gerais, Brazil: Am. Inst. Min. Met. Eng. Tech. Pub. 1962, 12 pp.

Lamego, A. R., 1937, Theoria do protogneis: Brasil, Serviço Geol. Mineralog., Bol. 86, 73 pp.

Leonardos, O. H., 1936, Uma jazida de beryllo, mica, columbita, annerodita, e monazita em Sabinopolis, Minas Gerais: Mineração e Metalurgia, vol. 1, pp. 15–16.

———, 1940, Niquel no Estado de Goiaz: Brasil, Div. Fomento Produção Mineral, Bol. 41, pp. 103–120.

Martonne, Emmanuel de, 1940, Problèmes morphologiques du Brésil tropical atlantique: Annales de géographie, vol. 49, no. 278, pp. 106–129.

Millard, W. J., 1946, The mining of Brazilian mica in stripping operations: Am. Inst. Min. Met. Eng. Tech. Pub. 2023, 15 pp. (previously published in Portuguese in 1944 as Div. Fomento Produção Mineral Bol. 60).

Moraes, L. J. de, 1926, Beryllo e mica no valle do Rio Doce: Brasil, Serviço Geol. Mineralog., Bol. 18, pp. 23–32.

———, 1926, Jazidas de quartzo no norte de Minas Gerais: Brasil, Serviço Geol. Mineralog., Bol. 18, pp. 61–62.

———, 1932, Beryllo e outros mineraes de glucinio: Brasil, Serviço Geol. Mineralog., Bol. 60, 26 pp.

———, 1935, Niquel no Brasil: Brasil, Div. Fomento Produçao Mineral, Bol. 9, 168 pp.

———, 1936, Quartzo no norte de Minas Gerais: Mineração e Metalurgia, vol. 1, pp. 152–154.

———, 1938, Rochas niqueliferas de Mar de Espanha, Minas Gerais: Mineração e Metalurgia, vol. 3, no. 15, pp. 169–170.

Moraes, L. J. de, and Guimarães, Djalma, 1931, The diamond-bearing region of northern Minas Gerais, Brazil: Econ. Geology, vol. 26, no. 5, pp. 502–530.

Oliveira, A. I. de, and Leonardos, O. H., 1940, Geologia do Brasil: Brasil, Comm. Brasileira Centenarios de Portugal, 472 pp.

Oliveira, E. P. de, 1925, Epochas metallogenicas do Brasil: Brasil, Serviço Geol. Mineralog., Bol. 13, pp. 121–127.

———, 1926, Idade de minerais radioactivos do Brasil: Brasil, Serviço Geol. Mineralog., Bol. 18, pp. 53–57.

———, 1933, Geologia historica do Brasil: Brasil, Serviço Geol. Mineralog., (a geological column revised from the 1929 edition).

Ottoni, A. B., and Noronho, F., 1942, Jazida de mica do Cruzeiro: Mineração e Metalurgia, vol. 6, no. 34, pp. 169–170.

Palache, Charles, Berman, Harry, and Frondel, Clifford, 1944, The system of mineralogy of James Dwight Dana and Edward Salisbury Dana, 7th ed., entirely rewritten and greatly enlarged, vol. 1, pp. 615–619.

Pecora, W. T., and Barbosa, A. L. de M., 1944, Jazidas de niquel e cobalto de São José do Tocantins, Goiaz: Brasil, Div. Fomento Produção Mineral, Bol. 64, 69 pp. (earlier printing in English as U. S. Geol. Survey Bull. 935–E).

Smythe, D. D., 1944, Abecedario do prospetor de mica: Brasil, Div. Fomento Produção Mineral, Avulso 56, 26 pp.

———, 1946, Muscovite mica in Brazil: Am. Inst. Min. Met. Eng. Tech. Pub. 1972, 24 pp.

APPENDIX

CONCURRENT MICA INVESTIGATIONS IN THE UNITED STATES

Concurrent with the mica investigations in Brazil, about 70 geologists of the United States Geological Survey were engaged in pegmatite studies in mica districts throughout the United States. The results of such investigations in New England, the Southeastern States, the Black Hills of South Dakota, the Rocky Mountain States, and New Mexico are in process of publication through a number of channels. Some of the more comprehensive reports are listed below:

Bannerman, H. M., 1943, Structural and economic characteristics of New England mica deposits: New Hampshire Min. Resource Survey, pt. 7, New Hampshire State Planning and Development Commission, Concord.

Bannerman, H. M., and Cameron, E. N., 1946, The New England mica industry: Min. Technology, Tech. Pub. 2024.

Cameron, E. N., Jahns, R. H., McNair, A. H., and Page, L. R., Internal structure of granitic pegmatites: Econ. Geology, Mon. 2.

Cameron, E. N., Larrabee, D. M., McNair, A. H., and others, 1945, Structural and economic characteristics of New England mica deposits: Econ. Geology, vol. 40, no. 6, pp. 385–394.

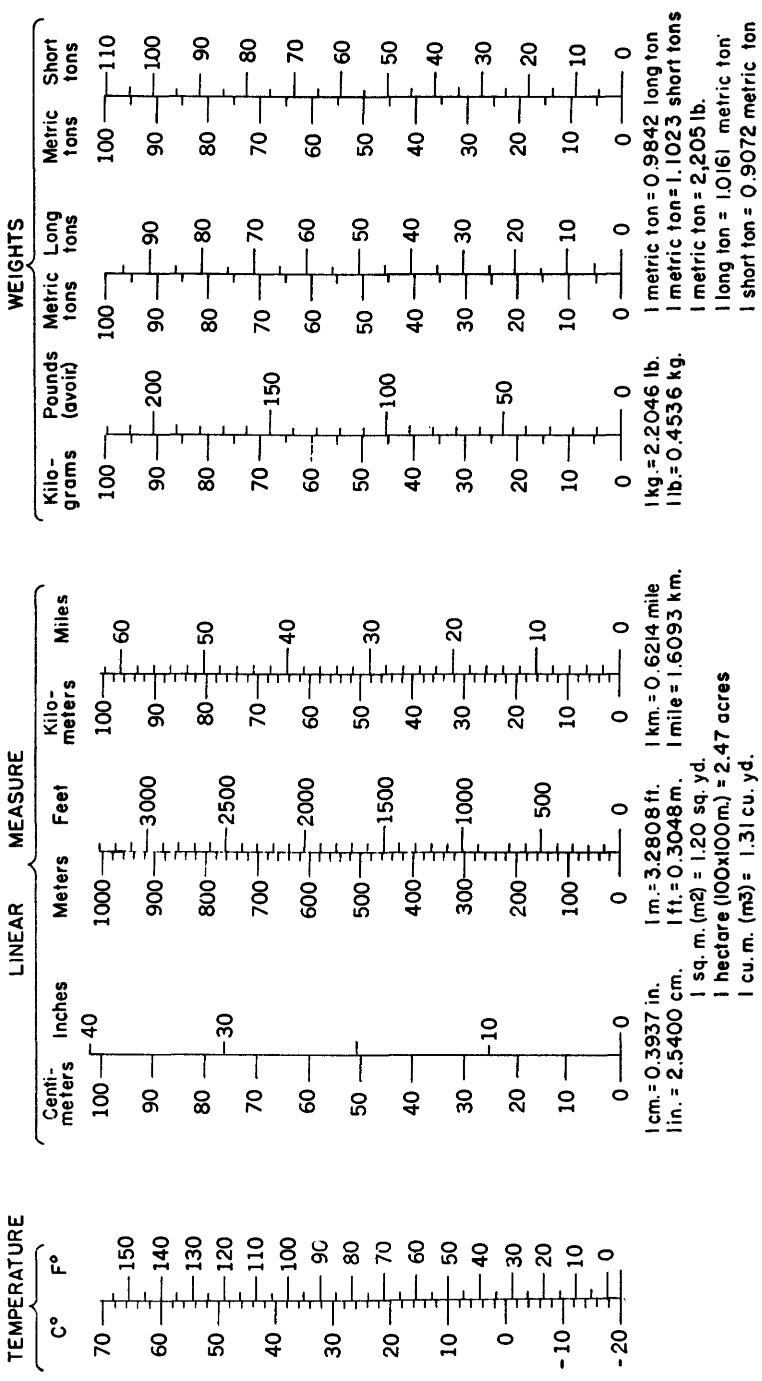
Hanley, J. B., Heinrich, E. W., and Page, L. R., Pegmatite investigations in Colorado, Wyoming, and Utah, 1942–44: U. S. Geol. Survey Prof. Paper 227 (1950).

Jahns, R. H., 1946, Mica deposits of the Petaca district, Rio Arriba County: New Mexico Bur. Mines and Min. Resources Bull. 25, 285 pp.

Jahns, R. H., and Lancaster, F. W., Physical characteristics of commercial sheet muscovite in the southeastern United States: U. S. Geol. Survey Prof. Paper 225 (in preparation).

Olson, J. C., and others, 1946, Mica deposits of the Franklin-Sylva district: North Carolina Dept. Cons. and Development Bull. 49, 58 pp.

Page, L. R., and others, Pegmatite investigations, 1942–45, Black Hills, S. Dak.: U. S. Geol. Survey Prof. Paper (in preparation).


METRIC EQUIVALENTS
LINEAR MEASURE
Centi-meters
Inches
Meters
Feet
Kilo-meters
Miles
1 cm. = 0.3937 in.
1 in. = 2.5400 cm.
1 m. = 3.2808 ft.
1 ft. = 0.3048 m.
1 km. = 0.6214 mile
1 mile = 1.6093 km.
1 sq. m. (m2) = 1.20 sq. yd.
1 hectare (100x100m.) = 2.47 acres
1 cu. m. (m3) = 1.31 cu. yd.
WEIGHTS
Kilo-grams
Pounds (avoir.)
Metric tons
Long tons
Metric tons
Short tons
1 kg. = 2.2046 lb.
1 lb. = 0.4536 kg.
1 metric ton = 0.9842 long ton
1 metric ton = 1.1023 short tons
1 metric ton = 2,205 lb.
1 long ton = 1.0161 metric ton
1 short ton = 0.9072 metric ton
TEMPERATURE
C°
F°

INDEX

U. S. GOVERNMENT PRINTING OFFICE : O—1953