Geology and Mineral Resources of the Pico de Itabirito District Minas Gerais, Brazil

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 341-F

Prepared in cooperation with the Departamento Nacional da Produção Mineral of Brazil under the auspices of the Agency for International Development of the United States Department of State

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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By ROBERTS M. WALLACE

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CONTENTS

ILLUSTRATIONS

[Plates are in separate volume]

TABLES

GEOLOGY AND MINERAL RESOURCES OF PARTS OF MINAS GERAIS, BRAZIL

GEOLOGY AND MINERAL RESOURCES OF THE PICO DE ITABIRITO DISTRICT MINAS GERAIS, BRAZIL

By Roberts M. Wallace

ABSTRACT

The Pico de Itabirito district, in the western part of the Quadrilátero Ferrífero in the State of Minas Gerais, Brazil, contains an estimated 225 million metric tons of compact hematite ore that ranges in grade from 66 to 69 percent iron. More than 500,000 tons of material of this grade has been mined, mostly in 1961. In addition, more than 200 million tons of enriched itabirite, soft or disaggregated hematite, canga, and rolado (rubble ore)—containing 60–69 percent iron—is readily available for mining. Further reserves of about 2,350 million tons of weathered itabirite that has an average content of about 45 percent iron are within the district.

About 70 percent of the district is underlain by the Moeda syncline, which is asymmetrical and locally overturned. The upright limb of the syncline is exposed as the Serra da Moeda, and the overturned limb, as the Serra do Itabirito. The remaining 30 percent of the district is underlain by granitic rocks. Precambrian metasedimentary rocks of the Rio das Velhas, Minas, and Itacolomí Series lie within or border the Moeda syncline, and Tertiary(?) and Quaternary lake-bed deposits, canga, and alluvium form the surface cover within the intermontane basin. Deposits of saprolite cover most of the granitic rocks that border the syncline.

A small roof pendant of pre-Rio das Velhas(?) rocks lies within the Engenheiro Corrêa granodiorite, which has the oldest age yet determined for any granite in South America (2,400 million years by the potassium-argon method). The metamorphic rock making up the roof pendant therefore may be the oldest known rock on the South American Continent. It originally may have been a mafic volcanic rock, a graywacke, or perhaps an argillaceous dolomite.

Phyllite, schist, and quartzite of the Nova Lima Group represent the Rio das Velhas Series in this district. The group has a maximum thickness of about 1,000 meters in the north and thins to a featheredge in the south, where it is intruded by granite having a potassium-argon age of 1,350 million years.

Strata of the Minas Series, about 2,300 meters thick, are confined to the Moeda syncline. The rocks of the series are divided into three groups, the upper and lower of clastic origin and the middle of chemical origin. The lower Caraça Group contains the basal Moeda Formation and overlying Batatal Formation. The middle Itabira Group contains the iron-bearing Cauê Itabirite and the Gandarela Formation. The upper Piracicaba Group contains the lower Cercadinho Formation overlain by the Fêcho do Funil Formation, the Taboões Quartzite, and the Barreiro Formation. The Sabará Formation is missing in this district.

Quartzite, coarse conglomerate, siltstone, and phyllite of the Itacolomí Series form a narrow infolded lens that unconformably overlies the Minas Series along the axis of the Moeda syncline in the Lagoa Grande quadrangle. The conglomerate consists of pebbles, cobbles, and boulders of the underlying Minas Series rocks and of a brick-red siltstone of unknown origin.

Parts of two granitic complexes are present in the district. An unnamed complex lies west of the Serra da Moeda and consists of masses of granitic gneiss and porphyritic granodiorite. The western edge of the Bação granitic complex lies east of the Serra do Itabirito and contains various facies of granodiorite and granite gneisses, quartz diorite, and granite.

Age determinations by the potassium-argon method show three separate and distinct ages of intrusion for the granitic rocks. The Engenheiro Corrêa granodiorite, having an apparent age of about 2,400 million years, is encircled by the Itabirito granite gneiss, which has an apparent age of about 1,350 million years. The granite gneiss, in turn, is encircled by the Cachoeira do Campo granite, micas from which yield ages ranging from about 1,080 million years to about 450 million years. The "mixed ages" obtained from the Cachoeira do Campo granite reflect the transformation of older rocks during an orogeny that occurred about 500 million years ago. The mineralogic results of the latest metamorphism are shown along the borders of the Bação complex; in places the rocks are of the garnet-staurolite-amphibolite facies.

The major structural feature of the district, a north-trending syncline, is overturned slightly to the west and plunges gently to the north in the northern part of the district and to the south in the southern part. The enclosed strata display superimposed minor folds, small thrust faults, lateral-slip faults, and a discernible cleavage pattern. These small-scale structures are typical of those found in the troughs of synclines formed in the Precambrian under conditions of mild metamorphism.

Superimposed on the principal structural features are younger crossfolds, another cleavage system, thrust faults, and lateral-slip faults that were rejuvenated as steep normal faults. A well-formed joint system is also present.

The iron ore and protores are contained in and derived from the Cauê Itabirite of the Itabira Group. Most of the iron occurs as hematite which is found as small crystals concentrated in the iron-rich layers of itabirite or as poorly cemented to well-cemented mosaics of crystals in the ore bodies. Limonite and goethite are the dominant minerals in canga, ocher, and laterite.

The iron ore deposits probably have formed by metasomatic replacement of quartz in itabirite by iron. Heated fluids that emanated from the 500 million-year-old granite intrusion that underlies the Moeda syncline were probably the agents that effected the migration of iron and silica in the Cauê Itabirite. The canga, ocher, and laterite were formed by supergene processes.

The loci of the rich hematite deposits show possible structural control of mineralization. All major known high-grade iron deposits lie at the point of intersection of minor northwest- and (or) northeast-trending fold systems with either the upright or overturned limb of the Moeda syncline, and the deposits are always within the Cauê Itabirite. At the points of intersection the rocks are commonly crumpled and buckled. The contorted rocks were higher in permeability and porosity than the uncontorted rocks within the same formation. Mineralization followed the crumpling and buckling of the rocks but preceded jointing.

Supergene manganese deposits crop out within the Moeda syncline in this district and commonly occur as lenses in the contact zone between the Cauê Itabirite and the Gandarela Formation. Probably 100,000 tons of ore containing 35 percent or more manganese has been mined, and possibly 60,000 tons of ore of similar grade still remains in scattered small deposits throughout the area. The manganese minerals are pyrolusite and psilomelane (or wad).

Minor mineral commodities produced at one time or another in the district include high-alumina clay, construction sand and gravel, nonmetallurgical dolomite, marble, kyanite, and talc. Gold was produced at Cata Branca, formerly a small village north of Pico de Itabirito. Only an abandoned adit in the jungle speaks of the past, although each year some few grams of gold are panned in the streams near Bação at the close of the rainy season.

INTRODUCTION

The Pico de Itabirito district, named after a centrally located spire of nearly pure compact specular hematite iron ore, includes four 7½-minute quadrangles: the Lagoa Grande, Marinho da Serra, Itabirito, and Bação (pls. 1–4 and fig. 1).

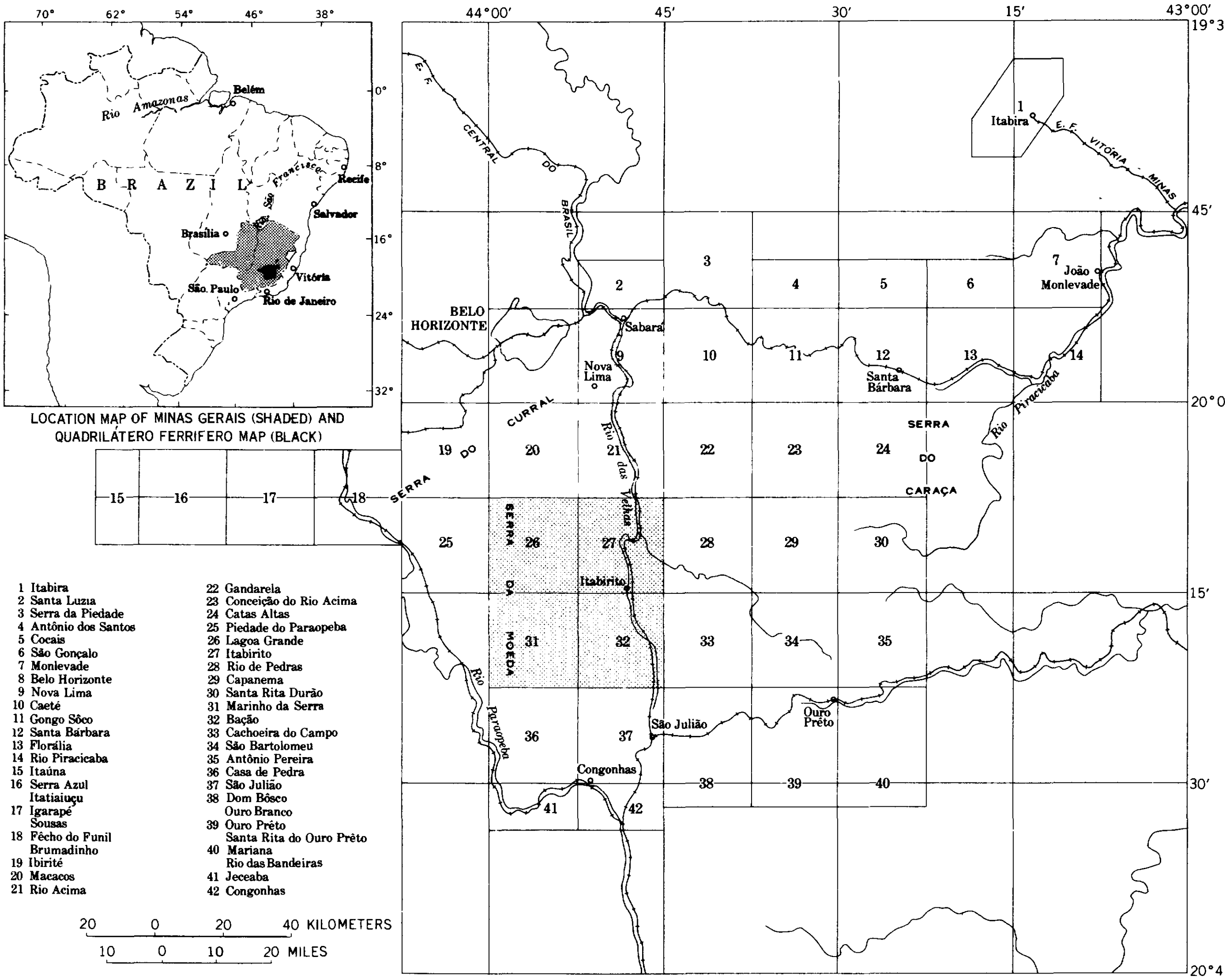

FIGURE 1.—Location of the Pico de Itabirito district in relation to the remainder of the Quadrilátero Ferrífero. Stippling indicates areas covered by this report.

The district is bounded by lat 20° 07′ 30″ and 20° 22′ 30″ S. and long 43° 45′ 00″ and 44° 00′ 00″ W. It lies in the southeastern part of the State of Minas Gerais about 325 kilometers north of Rio de Janeiro, about 375 kilometers east of Vitória, the seaport capital city of the State of Espirito Santo, and 35 kilometers south of Belo Horizonte, the capital of Minas Gerais. The city of Itabirito lies within the geographic boundaries of the district.

PURPOSE OF THE SURVEY

The Lagoa Grande, Marinho do Serra, Itabirito, and Bação quadrangles were geologically mapped as part of a cooperative project in the Quadrilátero Ferrífero by the United States Geological Survey and the Departamento Nacional da Produção Mineral under the auspices of the Agency for International Development of the Department of State. The primary objectives were to assist the Brazilian Government in the assessment and mapping of Brazil's known iron-ore reserves, to help discover the geologic controls of ore deposition as an aid to further exploration for hidden reserves, and to outline areas where potential iron-ore reserves may be found.

HISTORY OF INVESTIGATIONS

The iron deposits of Brazil, largely unknown before 1900, were brought to the attention of the world through a report made by Derby (1910) to the International Geological Congress in Stockholm. Since that time, many investigations have been made by both governmental and private agencies. The entire Quadrilátero Ferrífero was mapped in the second decade of this century by geologists of the Brazilian Iron and Steel Co. under the direction of the geologists Van Hise and Leith, leading authorities on the Lake Superior iron-ore deposits. Harder and Chamberlin (1915), who did much of the work, published an outstanding report on the geology of central Minas Gerais.

Later, Freyberg (1932) made geologic reconnaissance of part of the State of Minas Gerais and gave a brief account of the mountain ranges of the Pico de Itabirito district. He was primarily interested in the relation between the metasedimentary rocks and the granitic rocks in the western part of the Quadrilátero Ferrífero. He expressed the view that the granitic rocks are primarily Archeozoic (early Precambrian) but stated that in some places they may be younger.

In 1934 Guimarães and Barbosa prepared a geologic map of the State of Minas Gerais that incorporated all information available at that time. In addition, A. I. Erichsen and colleagues of the Departamento Nacional de Produção Mineral (hereafter referred to as DNPM) prepared a map of the Itabirito quadrangle,[1] using as a base map the 1:100,000 topographic sheet of the Comissão Geográfica e Geologia de Minas Geraes (now the Departmento Geográfico de Minas Gerais).

Leonardos (1938) made a geologic reconnaissance of Pico de Itabirito and commented on the stratigraphy and structure of areas enclosed in the Lagoa Grande, Marinho da Serra, and Itabirito quadrangles. He estimated the total tonnage of hematite in Pico de Itabirito to be approximately 96 million metric tons. Eight samples of iron ore from the Pico de Itabirito were reported as containing from 65.82 to 69.13 percent iron. O. Barbosa (1949, p. 5–6) published an article on the geology of central Minas Gerais. His interest in the Pico de Itabirito district dealt mainly with the age of the granitic rocks. Park, Dorr, Guild, and A. Barbosa (1951, p. 7–11) described the manganese deposits of the Lagoa Grande quadrangle. Their article included a small map and geologic section of a part of the Serra da Moeda. Rynearson, Pomerene, and Dorr (1954) published a report in which the unconformity between the Minas and pre-Minas metasedimentary rocks was described for the first time.

Guild (1957, p. 14, 19, and fig. 4) prepared a report on the Congonhas district in which he refers to the geology of a part of the Pico de Itabirito district.

PRESENT WORK

Preliminary mapping of parts of the Pico de Itabirito district was done by Garn A. Rynearson. The writer arrived in Brazil in 1957 and accompanied Mr. Rynearson in the field for the first 3 or 4 months. Later Rynearson's notes were used to compile a part of the map of the southern part of the Bação quadrangle and elsewhere. (See author index, Bação and Itabirito quadrangles.) Mapping of the four quadrangles was completed by early 1959.

The detailed surface geologic map of Pico de Itabirito, the topographic base map of which was prepared by Geofoto, S.A., was in large part prepared by Rynearson (1958).

Quadrangle mapping was done on aerial photographs at an approximate scale of 1:25,000. The accumulated data were transferred to a topographic base map at a scale of 1:20,000. These base maps were prepared by the Brazilian firm Serviços Aero-

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[1] Erichsen, A. I., and others, undated, Geologia e recursos minerais da zona de Itabirito: Unpub. map, scale 1:100,000. In files of the Departamento Nacional da Produção Mineral, Rio de Janeiro.

fotogramétricos Cruzeiro do Sul S.A., by the multiplex method, using airphotos made by the same company for the Comissão Vale de São Francisco.

Geologic data recorded during the present survey have led to new interpretations of the geology of the Quadrilátero Ferrífero. Whereas Harder and Chamberlin (1915) believed that all granitic rock was a part of a basement complex, evidence discovered in the Pico de Itabirito district and elsewhere revealed that the granites are of different ages, one being younger than rocks of the Minas Series. Three ages were later indicated by potassium-argon age determinations (Herz and others, 1961).

COORDINATE SYSTEM FOR LOCATIONS

In the present report, many specific locations are indicated by coordinates measured in meters north and east of the southwest corner of each quadrangle. Thus, the notation "8,950 N., 1,900 E., Lagoa Grande" locates a point 8,950 meters north and 1,900 meters east of the southwest corner of the Lagoa Grande quadrangle.

ACKNOWLEDGMENTS

The work resulting in this report was financed jointly by the Departamento Nacional da Produção Mineral (DNPM) of the Brazilian Government and by the Agency for International Development, U.S. Department of State. The former provided certain aerial photographs, chemical analyses, thin and polished sections, parts of the general base maps, and the services of a very capable field assistant, Sr. João Lopes. Dr. José Alves, chief of the Belo Horizonte office of DNPM, and other members of the organization were particularly helpful. The Comissão Vale de Rio São Francisco kindly gave permission for prints to be made from negatives of their aerial photographs. The U.S. Government financed part of the several base maps and the detailed topographic maps of the Pico de Itabirito, the salaries of U.S. Government employees, part of the cost of the map reproduction, transportation in the field, and some other expenses.

Levantamentos Aéreos S.A., a Brazilian geophysical company, kindly made an airborne magnetometer survey of a part of the district at no cost to the project.

Officials of the Usina Queiroz Junior S.A., a company that operates an iron and steel mill at Esperança, permitted the use of their metallographic microscope and other equipment. Thanks are due to Dr. Flavio Bastos, chief engineer of this company, for permission to use certain data contained in his "History of the Esperança Mill" and his "History of development of the general area"; for sharing his wealth of knowledge of forest trails that lead to difficultly accessible places; and for his genial hospitality while the writer was at Esperança.

Thanks are due to the mining companies active in the area who gave the writer unrestricted permission to enter their properties and to map their mines and to publish chemical data, ore reserves, and other data. Individuals who cordially assisted in the work are too numerous to mention but particular assistance was rendered by officials of the St. John del Rey Mining Co., Sociedade Cliffs de Mineração, Cia. de Mineração Novalimense, ICOMINAS, and Cia. Siderúrgica Mannesmann.

The writer's colleagues of the Geological Survey were helpful in many ways. Special tribute is paid to Garn A. Rynearson; although he left the project before his report was completed, his well-organized notes greatly facilitated the compilation of parts of the Bação and Itabirito quadrangles. Although Rynearson's notes were used to the fullest extent, the writer field checked all data, made his own interpretations, and therefore assumes full responsibility for all statements herein.

Norman Herz aided in the study of the granitic rocks of the district and was instrumental in obtaining the potassium-argon age determinations of the various granitic rocks. John Van N. Dorr 2d was chief of the party during the progress of this work.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The area herein described can be separated into three natural topographic divisions. On the west lies the valley of the Rio Paraopeba, a river that flows northward some 10 kilometers west of the boundary of the area. Tributaries of the Rio Paraopeba originate in a linear range of mountains known as the Serra da Moeda, which forms the western edge of a high, gently dissected, north-trending area known as the Moeda Plateau. This plateau is rimmed to the east by the sinuous Serra do Itabirito, which is breached in only two places by eastward-flowing streams tributary to the Rio das Velhas. A part of the Rio das Velhas valley occupies the eastern third of the district.

The Rio Paraopeba valley is a lowland that has moderate slopes. The Moeda Plateau is a gently rolling highland some 400 meters above the adjacent valleys, and the Rio das Velhas valley is a deeply incised lowland that has very steep slopes and intrenched meanders.

The total relief within the district is about 850 meters ranging from about 730 meters above sea level where the Rio das Velhas crosses the northern edge of the Itabirito quadrangle to 1,586 meters above sea level at the top of Pico de Itabirito in the geographic center of the district.

The northern part of the Moeda Plateau is drained by the Rio do Peixe and its three main tributaries: the Córrego dos Pinheiros, the Córrego das Congonhas dos Marinhos, and the Córrego da Maravilha, each of which drains into, or out of, artificial lakes constructed by the St. John del Rey Mining Co. On the plateau, where the gradient is low, all the streams meander through wide valleys into which they are being incised, and the general pattern is dendritic. Where the Rio do Peixe cuts through the Serra do Itabirito at 12,300 N., 11,200 E., Lagoa Grande (pl. 1), the narrow canyon has intrenched meanders, and the river is marked by continuous waterfalls and rapids.

The southern part of the Moeda Plateau is drained by the Rio Mata Porcos and its many tributaries. Here too the streams meander through valleys into which they are being incised, and the general pattern is dendritic. After the Rio Mata Porcos leaves the southern end of the area, it is joined by several large tributaries, changes its course to flow northward, and winds its way through an eastward extension of the Serra do Itabirito at 100 N., 2,500 E., Bação (pl. 4) to join the Rio Itabira, which flows into the Rio das Velhas.

Three relatively large artificial lakes, mentioned above, and two small ones have been built in the northern part of the Moeda Plateau. Lagoa Grande, the largest of the reservoirs, has an average depth at high water of about 7 meters and a maximum depth of about 13 meters in its eastern arm. Lagoa das Codornas has an average depth at high water of about 4 meters and a maximum depth of about 6 meters near its northern end. The southern half of Lagoa Miguelão is within the mapped area and has an average depth at high water of about 3 meters and a maximum depth of 4 meters outside the mapped area. During the dry season Lagoa das Codornas and Lagoa Miguelão are nearly empty. These reservoirs provide hydroelectric power for the Morro Velho gold mine in Nova Lima, and the power plants are located in the Córrego das Congonhas dos Marinhos and the narrow canyon of the Rio do Peixe.

Lagoa Água Limpa at 4,000 N., 4,000 E., Logoa Grande (pl. 1), fills a bowl-shaped depression that has a maximum depth of about 10 meters as does the lake east of Água Limpa. Both lakes, which are reservoirs built for real-estate developments, drain into the Rio Mata Porcos.

CLIMATE AND VEGETATION

The climate is temperate, although the district is in the torrid zone, because of the elevation (730–1,586 m). The average annual temperature is about 21°C (70°F), and the seasonal variation is not more than 15°C from this average.

Rainfall is seasonal: November through February are the rainy months; extremely dry weather prevails from May through October. At other times the weather is intermediate between these extremes and is variable. A 20-year average annual rainfall of 1,608 mm (62.45 in.) was recorded by the St. John del Rey Mining Co. of Nova Lima. The company records show a maximum rainfall of 2,058 mm (81.1 in.) in 1945, and a minimum of 978 mm (38.4 in.) in 1954. The maximum rainfall in a 24-hour period was 100.6 mm (3.96 in.) recorded on October 30, 1945, at Canhão do Rio do Peixe. The maximum monthly rainfall was 634.8 mm (25.35 in.) recorded in January 1924, also at Canhão do Rio do Peixe.

The western half of the district is sparsely forested except in deep valleys and at the bases of high cliffs (fig. 2). The ridgetops, slopes, and Moeda Plateau commonly are covered by bush and shrubs or grass (fig. 3). A large part of the northeastern half of the district is covered by nearly impenetrable forest or mato that surrounds bare grassy hills or knobs.

FIGURE 2.—Dense mato in the Serra da Moeda, Marinho da Serra quadrangle. Rugged cliffs of iron-formation overhang Canhão Estreito. Smooth rounded hill in the upper right is underlain by the Batatal Formation. No trails pass through this canyon.

FIGURE 3.—Grassy highlands within the Moeda synclinal basin. View is to the northwest toward the Serra da Moeda from about the center of the Lagoa Grande quadrangle. Much of the complex structure and also the contacts between various rock formations are masked by grassy slopes such as this.

POPULATION, INDUSTRY, AND TRANSPORTATION

The population of the western and northeastern parts of the district is sparse; no village has more than 50 inhabitants. Most of the people in these outlying areas are engaged in subsistence farming, and only a few work in the mines and quarries or on the highways and railroads. Eucalyptus trees are raised for wood to be used in the production of charcoal.

The population in the other parts of the district, particularly the south-central and southeastern parts, is comparatively heavy. Itabirito (including its industrial suburb Esperança at 3,000 N., 7,500 E., Itabirito), has a population of about 15,000, and is the largest community in the area. It is a rail shipping center for iron and manganese ore. The smelter at Esperança has a daily capacity of about 100 metric tons of pig iron and about 30 metric tons of foundry castings. These products go to Belo Horizonte by truck, where they are transshipped to Volta Redonda, São Paulo, and Rio de Janeiro. About 50,000 metric tons of iron ore was shipped by rail from Itabirito to Rio de Janeiro and Volta Redonda in 1959. Itabirito also has 2 cotton textile mills, 6 leather tanneries, 10 small shoe manufacturing plants, a glue factory, and a pigment factory.

Engenheiro Corrêa, in the southeastern corner of the district at 3,500 N., 10,800 E., Bação (pl. 4), is on the Estrada de Ferro Central do Brasil and has a population of about 2,000. This village is an agricultural community and has facilities for shipping livestock.

A small isolated agricultural town, Bação, population about 1,200, is in the south-central part of Bação quadrangle at 4,000 N., 5,000 E.

Inasmuch as the Pico de Itabirito district lies between Belo Horizonte and Rio de Janeiro, it is well served by various travel routes. Two paved highways pass through the district. The Belo Horizonte-Rio de Janeiro highway (BR-3) extends the full length of the Moeda Plateau and follows the eastern side of the Serra da Moeda. The Inconfidentes highway (MG-56) branches from BR-3 at Fazenda da Cachoerinha (10,600 N., 3,800 E., Lagoa Grande) and crosses the Serra do Itabirito to Itabirito and on to Ouro Prêto.

Two railroads also pass through the district. A narrow-gage (1.00 m) branch of the Estrada de Ferro Central do Brasil follows the Rio das Velhas and Rio Itabira valleys southward from Belo Horizonte to Lafaiete. A wide-gage (1.60 m) track of this same railroad begins at Itabirito and runs southward

523 kilometers to Rio de Janeiro, joining the main line of the Central near Congonhas. A second wide-gage track of the same railroad company passes through the Rio Paraopeba valley 17 kilometers west of the Serra da Moeda. This is the main trunk railroad from Belo Horizonte to Rio de Janeiro.

Although there were no landing fields in the district in 1960, air service is good through the facilities at Belo Horizonte, 34 kilometers north of the district. Belo Horizonte is the hub of air transportation in Minas Gerais with connections to all major cities in Brazil.

GEOLOGY

The Quadrilátero Ferrífero, of which the Pico de Itabirito district forms a part of the western edge, is an area of about 7,000 square kilometers. Its geology is complex: at least three series of Precambrian sedimentary rocks are separated by major unconformities, and three ages of granitic intrusion or granitization are now known. The rocks in this area have been folded, faulted, and metamorphosed to varying degrees. An outline of the geology of the Quadrilátero Ferrífero was prepared by members of the joint DNPM-USGS field party in 1958 and is now available in both Portuguese and English (Dorr and others, 1960).

Three series of Precambrian rocks of sedimentary origin are present in the Pico de Itabirito district. From oldest to youngest they are: the Rio das Velhas, the Minas, and the Itacolomí. Each series is separated by a major unconformity and is described in detail in the following sections of this report. Granitic rocks of three widely separated ages are also present and are described.

Regional metamorphism of the sedimentary rocks within the district has resulted in phyllites of the greenschist facies. A belt of rocks that have attained higher grades of metamorphism, commonly garnet-staurolite-quartz-mica schists, occurs in the contact-metamorphic zone along the boundary of the Bação complex.

PRECAMBRIAN METASEDIMENTARY ROCKS

PRE-RIO DAS VELHAS(?) ROCKS

The unnamed pre-Rio das Velhas(?) rocks crop out as a small roof pendant that has indeterminate borders; the rocks overlie and are intruded by the oldest known granitic rocks of South America. They lie in a small area about 2 kilometers north of Engenheiro Corrêa in the southeastern part of the Bação quadrangle (5,000 N., 11,000 E., pl. 4) and are unknown elsewhere in the Quadrilátero Ferrífero. The stratigraphic thickness of the roof pendant is unknown but is probably in the order of a few hundred meters.

The rock as it appears in outcrops is a medium- to dark-gray thin-banded gneiss. Seams of quartz and aplite follow the foliation in some places and transect it in others.

As seen in thin section the rock contains abundant amphibole, garnet, and biotite, and some quartz, magnetite, plagioclase, and apatite, minerals indicative of the almandine-amphibolite metamorphic facies. The rock does not appear to be genetically related to the surrounding granite. Norman Herz (written commun.) suggested that the original rock may have been a mafic volcanic rock, a graywacke, or perhaps an argillaceous dolomite.

These metasedimentary rocks are obviously older than the enclosing granite. Determinations by the potassium-argon method give an apparent age for the granite of about 2,400 million years (Herz and others, 1961).

RIO DAS VELHAS SERIES

NOVA LIMA GROUP

The Rio das Velhas Series, as originally defined by Dorr and others (1957), is divided into the Nova Lima Group and the overlying Maquiné Group. Only the Nova Lima Group is recognizable in the Pico de Itabirito district; this group crops out in the eastern and northwestern parts and is overlain by the Minas Series rocks throughout the center of the district.

Thickness and Stratigraphic Relations

Measurements of the thicknesses of the Nova Lima Group within the district was not attempted by the writer because of the lack of marker beds. Dorr and others (1957, p. 18) estimated a minimum thickness of 4,200 meters for the Nova Lima Group at the type locality, 17 kilometers north of the Pico de Itabirito district. The group may attain a thickness of more than 1,000 meters in the northern part of the Itabirito quadrangle. It has been obliterated by granitization in the southeastern part of that quadrangle and in most of the Bação quadrangle.

The stratigraphic relation of the Nova Lima Group to the unnamed rocks from Engenheiro Corrêa mentioned above is uncertain. Age determinations reported by Herz and others (1961) seem to indicate that the Nova Lima Group is much younger than the unnamed rocks.

The Nova Lima Group underlies the Minas Series with profound structural and erosional disconformity, first described by Rynearson and others (1954) who illustrated a 90° angular unconformity near the Abóboras iron ore deposit. Dorr (in Dorr and others, 1960, p. 71–72) later described in detail the profound pre-Minas erosion of the older rock.

Lithology

The rocks of the Nova Lima Group in the Pico de Itabirito district are predominantly varieties of quartz-muscovite-sericite schist with lesser quantities of quartz-sericite-calcareous schist. Quartzite, marble, and phyllite are also present as thin to thick bands or lenses in some places. Natural exposures of these rocks are generally small and sparse. The saprolite or weathering product of the various schists, marbles, and phyllites, with the exception of quartzite, differ only in the relative abundance of residual quartz grains. This single difference makes it difficult or impossible to map specific lithologies. Although several types of schist and phyllite have been identified at individual locations, they have been mapped together as a single unit.

SCHIST

Fresh schist ranges in color from medium to dark gray, but the weathered surface is pink, red, maroon, or buff. Specimens of fresh schist were collected from newly driven railroad tunnels at Capivara (11,400 N., 8,300 E., Itabirito, pl. 3) and Bem-te-vi (12,150 N., 8,600 E., Itabirito), from Ponte do Arame (9,200 N., 9,100 E., Itabirito), from quarries near Bonga Dam (7,750 N., 6,250 E., Itabirito), and at Pau d'Oleo (9,300 N., 7,300 E., Itabirito). Specimens 1–6 of table 1 indicate the variation in mineral content of the several schists. Undoubtedly there are many other types of schist within this general area, but fresh-rock specimens were not found. Gair (1962, p. A23) indicated that there are at least five main varieties of schist in the Nova Lima and Rio Acima quadrangles to the north and recorded numerous variations of each variety. He described a "graywacke schist" in the Rio Acima quadrangle that appears to be similar in mineral composition to specimen 3 of table 1.

J. R. O'Rourke (written commun.) described the rocks of the Nova Lima Group in the Rio das Pedras quadrangle, east of this district, as composed of slate and some schist. O'Rourke reported the average size of quartz grains there to be 0.1 millimeter or roughly half the average grain size of the schistose rocks in the Itabirito quadrangle. He also found the maximum carbonate mineral content of the slate and schist to be from 2 to 6 percent in all varieties but suggested that a quartz amphibolite, common in his mapped area, may be a highly metamorphosed carbonate rock.

Schist that borders the granitic mass in the southeastern corner of the Pico de Itabirito district is strongly weathered, and fresh rock suitable for thin sections has not been found. Megascopically the rock is a quartz-biotite schist that has garnet and staurolite as common accessory minerals.

TABLE 1.—*Mineral content and average grain size of fresh rock samples of the Nova Lima Group, Itabirito quadrangle*

Specimen	Field No.	Composition (percent)												Grain size [1] (millimeters)								
		Quartz												Quartz								
		Large grain	Small grain	Calcite	Plagioclase	Muscovite and sericite	Chlorite	Garnet	Zircon	Apatite	Sulfide minerals	Limonite	Graphite(?)	Large grain	Small grain	Calcite	Plagioclase	Muscovite and sericite	Chlorite	Garnet	Zircon	Apatite
1	W-1-6-7	30	40	------	------	25	<2	------	<1	<1	------	<1	------	0.35	0.07	------	------	[2]0.08	------	------	------	[2]0.20
2	W-10983-D-10	------	50	30	------	20	------	<2	[3]<1	[3]<1	[3]<1	[3]<1	[3]<1	------	.08	0.23	------	------	------	------	------	------
3	W-10983-L-12	35	40	------	13	10	<2	------	Tr.	Tr.	Tr.	------	------	.19	.06	------	0.10	[2].04	[2]0.05	------	------	------
4	W-11017-S-14	30	55	------	------	15	------	------	Tr.	Tr.	Tr.	------	------	.55	.06	------	------	------	------	------	------	------
5	W-1-6-5	------	40	30	------	20	------	5	Tr.	Tr.	Tr.	------	Tr.	------	.03	.40	------	[2].04	------	0.03	------	------
6	W-1-6-1	50	40	------	------	5	------	------	<1	Tr.	------	Tr.	------	.13	------	------	------	[2].10	------	------	[2]0.2	------
7	W-10983-D-9	------	------	95	------	------	------	5	------	------	------	------	------	------	------	.78	------	------	------	.08	------	------
8	W-10983-D-9	------	35	30	15	5	------	5	------	Tr.	Tr.	5	------	------	.08	.25	.21	[2].03	------	.06	------	[2].10

[1] Grain size is average of ten readings as determined in thin section viewed under petrographic microscope.

[2] Maximum size of largest mineral grain.

[3] Between <1 and trace.

1. Quarry on hilltop Esperança–Rio Acima road.
2. Railroad tunnel at Capivara.
3. Ponte de Arame.
4. Railroad tunnel at Bem-te-vi.
5. Railroad tunnel at Bem-te-vi.
6. Near Bonga Dam.
7. Railroad tunnel at Capivara.
8. Contact zone adjacent to aplitic stringer cutting same rock as specimen 7.

Several thin discontinuous iron-formations are interbedded with garnet-staurolite schist a short distance from the contact of the granite and schist. Samples of fresh rock from iron-formation of the Nova Lima were not obtainable in this area, but in quadrangles to the north such samples proved to be carbonate facies (Gair, 1962, p. A17–A18). Iron-formation in the Nova Lima Group also occurs in schist in the northern part of the Itabirito quadrangle at 13,500 N., 7,000 E., and also to the west and southwest of the blast furnaces at Espercança at 3,000 N., 6,500 E.

QUARTZITE

An unnamed quartzite formation of the Nova Lima Group crops out in the northern half of the Itabirito quadrangle as a southwest-trending bold ridge between the Córrego dos Moleques (8,000 N., 6,000 E.) and the Córrego dos Andaimes (10,000 N., 8,000 E.). Intermittent outcrops of a similar quartzite lie several kilometers to the north. In the vicinity of Retiro das Velhas (7,000 N., 3,500 E., Itabirito) and northeastward for about 3 kilometers, the quartzite is about 450 meters thick. In outcrop the quartzite is light gray to pink and is composed of beds of fine-grained (0.2 mm) to granular (2.0 mm) moderately rounded quartz grains of low sphericity. Some outcrops show medium-scale crossbedding, and nearly all exposures show some type of bedding. Farther east the quartzite gradually loses its characteristic bedding and grades into quartz-muscovite-sericite schist as represented by specimen 1 of table 1, collected at Pau d'Oleo (9,300 N., 7,300 E., Itabirito). Most of the quartzite in the intermittent outcrops to the north of Pau d'Oleo is schistose quartzite or quartz-muscovite-sericite schist. Quartz-muscovite-sericite schist is well exposed at 12,100 N., 8,350 E., Itabirito.

Lenses of light-gray fine- to coarse-grained friable quartzite that disintegrates to white sandy soil have been engulfed in granitic rocks that border the western edge of the Serra da Moeda at 7,300–10,400 N., 2,500–4,400 E., Marinho da Serra. This quartzite greatly resembles the quartzite described above and may be undigested remnants of rock from the Nova Lima Group.

MARBLE

Fresh marble of the Nova Lima Group was found during the construction of a railroad tunnel at Capivara (11,400 N., 8,300 E., Itabirito). Marble saprolite was found in a roadcut directly east of this tunnel and on strike with the fresh rock of the tunnel. This saprolite is similar in nearly all respects to saprolite of the enclosing schist but contains less quartz. Material of this type also crops out in a road embankment above Bonga Dam at 7,650 N., 6,250 E., Itabirito.

The fresh tunnel rock specimen (table 1, No. 7), as seen in thin section, is a mosaic of medium-grained calcite and minor subhedral garnet. In hand specimen the rock is medium gray, medium grained, massive, and extremely resistant to the blow of a hammer. The marble is cut by a stringer of granite aplite (table 1, No. 8).

PHYLLITE

Outcrops of weathered phyllite intergradational with schist are seen in road embankments on the Inconfidentes highway at 4,200 N., between 3,500 E. and 7,000 E., Itabirito. Phyllite also crops out in discontinuous bands in railroad cuts of the Central do Brasil between Esperança and the northern boundary of the Itabirito quadrangle. The phyllite bands were not traceable on the surface, away from the roadcuts or embankment, owing to the similarity of the phyllite and schist saprolites. No fresh specimens of phyllite were seen.

Origin and Age

The quartzite and marble are undoubtedly of sedimentary origin. The mineral compositions of the schist and phyllite as shown in table 1 indicate that these rock types also are of sedimentary origin. The schist and phyllite of the Nova Lima Group that lie in the quadrangles north of this district, mapped by Gair (1962, p. A31) and Pomerene (1964) and to the east, mapped by J. R. O'Rourke (written commun.), commonly contain much chlorite. Gair and Pomerene suggested that these rocks were derived in part from metavolcanic sediment. Inasmuch as the schist and phyllite shown in table 1 were the only samples suitable for thin section within this district and inasmuch as they came from within one small area, they cannot be considered as representative of all schist and phyllite of the Nova Lima Group within this district.

Although at least two orogenies have destroyed most vestiges of bedding in the schist and phyllite, the mineralogical composition, the lenticular aspect of the various rock units, and the intergradational nature of these rocks strongly suggests a sedimentary origin. This suggestion is strengthened by evidence of facies changes from west to east: fine-grained to granular crossbedded quartzite on the western edge of the present Rio das Velhas valley grades into fine- to medium-grained schist. Scattered lenses of phyllite are present. In the eastern part of the Rio das Velhas valley, according to O'Rourke, phyllite is abundant, and the grain size of minor schist is half that in the western part. The suggestion of sedimentary origin is strengthened by the mineral composition of specimens 1, 2, 4, 5, 6, and 7 of table 1. Of these specimens, 1, 4, 5, and 6 have similar mineral assemblages and may well be various metamorphic equivalents of siltstone. Specimen 2 may be an intergradational rock between an original siltstone and a calcareous rock similar to specimen 7. On the other hand, specimen 8 is clearly of igneous origin. Specimen 3 could be either a metamorphosed granite or arkose.

MINAS SERIES

The Minas Series, as used in this report, comprises the metasedimentary rocks lying between the major angular unconformity at the top of the Rio das Velhas Series and that at the base of the Itacolomí Series. This definition of the Minas Series, propounded by Dorr and others (1957), is virtually the same as that used by Oliveira (1956, p. 8–13).

Dorr and others (1957) divided the Minas Series into three groups; and these groups were in turn divided into nine formations by geologists of the joint DNPM–USGS team in 1958. The groups and formations are as follows:

- Piracicaba Group
  - Sabará Formation
  - Barreiro Formation
  - Taboões Quartzite
  - Fêcho do Funil Formation
  - Cercadinho Formation
- Itabira Group
  - Gandarela Formation
  - Cauê Itabirite
- Caraça Group
  - Batatal Formation
  - Moeda Formation

All these formations except the Sabará are present in the mapped area.

CARAÇA GROUP

The Caraça Group consists of coarse- to fine-grained clastic sedimentary rocks that unconformably overlie the Nova Lima Group of the Rio das Velhas Series. In the Pico de Itabirito district, the rocks of the Caraça Group consist of the Moeda Formation, predominantly quartzite with an intercalated phyllite member, and the overlying Batatal Formation, a fine-grained phyllite.

Moeda Formation

DISTRIBUTION AND THICKNESS

The Moeda Formation is the basal unit of the Minas Series. It overlies the Nova Lima Group of the Rio das Velhas Series with profound unconformity and is overlain conformably by the Batatal Formation. The contact with the Batatal is commonly sharp (fig. 4). Interfingering contacts between the two formations have been observed within the district, but lithologic gradation between the two rock types is unknown.

The Moeda Formation (Wallace, 1958) was named for exposures in the Serra da Moeda, east of the town of Moeda. The type locality is located in the upper western half of the Marinho da Serra quadrangle where the road to the town of Moeda crosses the Serra da Moeda (10,200 N., 4,500 E., pl. 2; fig. 5). The formation crops out in all the quadrangles in the dis-

FIGURE 4.—Sharp contact between the Moeda Formation (left) and the Batatal Formation (right) exposed near the Cata Branca mine in the Itabirito quadrangle.

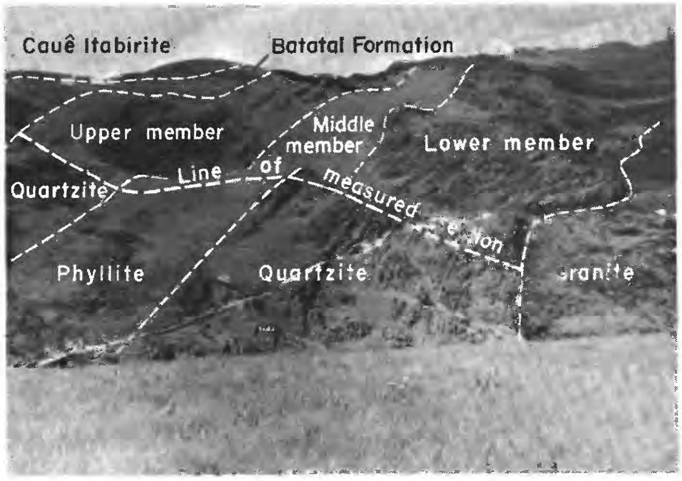

FIGURE 5.—Type locality of the Moeda Formation, showing position of the measured section.

trict and forms a major part of the highlands of the Serra da Moeda and the Serra do Itabirito.

At the type locality the Moeda Formation is about 490 meters thick, but it pinches and swells from about 400 to 700 meters in thickness along strike. It has an average stratigraphic thickness of about 550 meters in the 26 kilometers of continuous outcrops in the Serra da Moeda.

In the Serra do Itabirito, in contrast, the Moeda Formation thins from about 900 meters in the Canhão do Rio do Peixe (12,700 N., 12,700 E., Lagoa Grande) to less than 200 meters in the southern part of the Bação quadrangle at 400 N., 4,500 E. That the Moeda Formation, like other formations of the Caraça and Itabira Groups, thins appreciably in the southern part of the district may indicate that the granitic mass, a part of which lies in the Bação quadrangle, was a positive area during deposition of the Minas Series.

LITHOLOGY

The Moeda Formation, at the type locality as elsewhere within the district, consists of three members; an upper and a lower quartzite, members 1 and 3, and an intercalated phyllite, member 2. A measured geologic section at the type locality is given herein.

The quartzite members 1 and 3 are similar lithologically and, in general, consist of fine- to coarse-grained fairly well sorted slightly sericitic quartzite; this quartzite is light gray or pastel shades of pink, red, and orange on fresh surfaces. The rock weathers to moderately rounded medium-gray blocky outcrops and light-gray sandy soil. Crossbedded lenses are common in both members (fig. 6). Lenses of conglomerate, grit, and sandy phyllite are common in the quartzite and may extend laterally from a few tens to several hundreds of meters at irregular vertical intervals; they are as much as 17 meters thick. The quartzite forms steep cliffs and jagged crags that tower over less resistant neighboring rocks.

A few lenses of basal conglomerate of the Moeda Formation occur in isolated outcrops in the northern part of the Serra do Itabirito but are rarely exposed, or are absent, in the Serra da Moeda and the southern part of the Serra do Itabirito. An outcrop of this conglomerate occurs near a roadside shrine on the Inconfidentes highway above the town of Esperança (Rynearson and others, 1954, p. 9–18). There the basal conglomerate is a few tens of centimeters thick and contains pebbles of quartz, quartzite, amphibolite, and phyllite lithologically similar to rocks of the underlying Nova Lima Group. The lack of continuous outcrops of the basal conglomerate, as suggested by Rynearson and others (1954, p. 18), "may reflect a depositional surface of low relief on which the conglomerate accumulated only in depressions."

Some exposures of the basal conglomerate are thicker and show crude stratification, with larger fragments of quartzite and vein quartz, some of which attain boulder size, grading upward into smaller fragments of quartzite and vein quartz and, locally, pebble-sized fragments of schist and phyllite. The boulder-to-pebble depositional sequence is commonly interrupted by tongues or lenses of coarse-grained to grit-sized quartzite. Other outcrops show no systematic depositional sequence of rock fragments; the fragments, commonly larger, are as much as 30 centimeters long. In both types of conglomerate, the

FIGURE 6.—Crossbedding in the upper quartzite member of the Moeda Formation.

fragments of schist and phyllite apparently are limited to the uppermost part of the conglomerate and closely underlie the normal quartzite found in member 1 of the Moeda Formation. Fragments of schist or phyllite have not been seen in the abundant conglomeratic lenses intercalated higher in the stratigraphic sequence of this formation.

The intercalated phyllite member of the Moeda Formation is a sandy phyllite that is greenish-brown or shades of light brown, orange, light red, pink, and yellowish gray. Sand grains in this member are commonly very fine except at the gradational contact zones with the underlying and overlying quartzite member or with intercalated lenses of quartzite; there the sand grains become larger and increasingly more abundant toward the contact. The rock weathers to a yellow to light-brown sandy soil, and forms smooth low-angle slopes. This phyllite member is present in both the Serra da Moeda and the Serra do Itabirito but is rarely seen farther east in the Quadrilátero Ferrífero.

The rocks of the Moeda Formation appear to reflect the depositional environment of a flood plain and littoral zone of a transgressing sea. Measurements of the dip of crossbedding in quartzite suggest a source to the northwest.

Type section of the Moeda Formation

Serra da Moeda, near Moeda road, Marinho da Serra quadrangle

	Thickness (meters)	Cumulative thickness from base (meters)
Batatal Formation.		
Moeda Formation:		
Member 3:		
Interfingering contact zone	3.5	490.0
Quartzite, massive, light-gray, medium- to coarse-grained, fairly well to poorly sorted. Weathers to pale reddish gray and dark reddish brown. Forms cliffs	59.5	486.5
Quartzite, light-gray to light-pink, medium-grained, fairly well sorted; slightly schistose at top and bottom of unit. Weathers to medium-gray rounded boulders	19.5	427
Sandy phyllite, light-salmon-pink to medium-gray, platy, friable. Weathers to yellowish brown. Crops out on gentle slopes	18.8	407.5
Quartzite, light-gray to light-pink, medium-grained, fairly well sorted. Weathers to medium-gray slightly rounded blocks. Forms low cliffs	21.0	388.7
Schistose conglomerate, salmon-pink to very light gray; contains large (2 cm) angular quartz pebbles, coarse-grained grit, quartzite matrix. Long axes of quartz pebbles are parallel to the dip of beds. Weathers to medium-gray semirounded blocks. Forms low cliffs	31.0	367.7
Quartzitic phyllite, sea-green, fissile. Weathers to yellowish-brown finlike plates that protrude from 1.0 to 1.5 m above the surface of ground	6.3	336.7
Member 2:		
Phyllite, colors variegated from greenish-tan to dark-gray, platy. Weathers to yellowish brown. Forms gentle slopes	166.0	330.4
Member 1:		
Quartzite, light-orange, light-brown, and white, friable, medium-grained, massive. Weathers to medium-gray semirounded blocks	28.0	164.4
Quartzite, white to light-gray, coarse-grained, fairly well sorted, friable; medium-scale crossbedding. Weathers to light-gray semirounded blocks	25.0	136.4
Conglomeratic quartzite and grit, light-gray to light-brown. Grades laterally within 100 m into light-gray and light-brown coarse-grained quartzite. Forms small cliffs	20.0	111.4
Quartzite, light-orange to white, fine-grained, fairly well sorted; somewhat schistose, but in certain strata moderately well crossbedded	27.0	91.4
Phyllite, medium-gray, poorly exposed. Weathers to yellowish-brown soil. Contains lenses of quartzite near center of unit	42.5	64.4
Conglomeratic quartzite, light-gray to white; moderately schistose in lower part of unit; thin veinlets of chromian mica (fuchsite) near bottom; thin quartz veins abundant throughout	4.6	21.9
Quartz-pebble conglomerate, light-brown to light-gray; schistose throughout; contains thin plates of brown and orange mica. Quartz pebbles appear crushed. Forms small cliffs	17.3	17.3
Total thickness	490.0	

"Transition rock"; gneissic structure, schlieren of biotite and altered feldspar and quartz pebbles; grades into a granitic gneiss within 50 m.

Batatal Formation

The Batatal is the upper formation (Maxwell, 1958) of the Caraça Group, originally named the Batatal schist by Harder and Chamberlin (1915). It forms an integral part of the Serra da Moeda and is present in most of the Serra do Itabirito.

The Batatal Formation conformably overlies the Moeda Formation and is conformably overlain by the

Cauê Itabirite of the Itabira Group, the contact being gradational.

The Batatal Formation throughout most of this district is a uniformly dark-gray very fine grained phyllite that weathers readily to form a yellowish-brown soil. It also appears as a light- and dark-gray banded phyllite in a few places and as a light-gray to dark-red fine-grained schist in the southeastern corner of the district. A 50-centimeter bed of almost iron-free metachert was found near the top of the formation in two places in the district; on the road to Piedade do Paraopeba at 8,950 N., 1,900 E., Lagoa Grande, and in Tunnel "F" near the Rio do Peixe canyon at 12,550 N., 11,700 E., Lagoa Grande, where the rock is disaggregated to form a loose mass of clear angular quartz grains. The metachert as seen in Tunnel "F" becomes rich in hematite as the Cauê Itabirite is approached and appears to be a part of the gradational zone between the Batatal Formation and the Cauê Itabirite.

Heavy-mineral studies of rock samples from the Batatal Formation show extremely fine grained iron minerals, some of which are magnetic. A few grains of kyanite are present in samples collected from the southeastern corner of the district where the unit is highly metamorphosed.

The Batatal Formation weathers to gentle slopes. In many places throughout the district, it is covered by rubble, lateritic soil, or canga derived from the overhanging cliffs and steep slopes of the iron-bearing formation.

The formation averages about 100 meters in thickness in the district. It pinches and swells along strike within short distances and has a maximum thickness of about 200 meters in the Canhão Estreito in the southern part of the Serra da Moeda. It thins to a knife edge in the southern part of the Bação quadrangle.

The original rock was probably a shaly mudstone deposited in an environment that was transitional between the deposition of clastic sediments (Moeda Formation) and chemically precipitated sediments (Cauê Itabirite).

ITABIRA GROUP

Economically, the Itabira Group includes the most important rocks in the Quadrilátero Ferrífero. The iron ores, most of the manganese ores, some dolomite, and, rarely, gold ores, are derived from these rocks. The economic aspects of these rocks are discussed in a later section of this report.

The Itabira Group is divided into two formations, the lower Cauê Itabirite and the upper Gandarela Formation; the various lithologic facies have been described by Dorr and Simmons (in Dorr and others, 1960, p. 75–78). In general, the Itabira Group is predominantly itabirite, a metamorphosed banded oxide-facies iron-formation. Dorr and Simmons described the original unmetamorphosed rock as a laminated chert and ferric oxide rock that was deposited in an oxidizing environment in a fairly shallow sea. They stated (p. 76) that it is entirely similar to the normal unmetamorphosed oxide-facies iron-formation as it occurs in most of the shield areas of the world. The unmetamorphosed iron-formation of Morro do Urucum, Mato Grosso, which O. Barbosa (1949, p. 3–14) called proto-itabirite is probably similar to the original unmetamorphosed rocks of the Cauê Itabirite.

Cauê Itabirite

DISTRIBUTION AND THICKNESS

The Cauê Itabirite (Dorr, 1958a; Dorr and Simmons, in Dorr and others, 1960, p. 75–77) is the lower formation of the Itabira Group. It overlies conformably the Batatal Formation of the Caraça Group into which it grades throughout most of the district. Where the Batatal Formation is missing, the Cauê Itabirite disconformably overlies the Moeda Formation. It grades upward into the Gandarela Formation.

Outcrops of the Cauê Itabirite in the Pico de Itabirito district are confined to the crests or the steep flanks of the Serra da Moeda and Serra do Itabirito. The formation has an average thickness of about 350 meters in the Serra da Moeda but pinches and swells from 200 to 700 meters. A measured section (p. F12) taken above the type locality of the Moeda Formation showed a thickness of about 300 meters.

By contrast, the Cauê Itabirite in the Serra do Itabirito gradually thins from about 900 meters near the Canhão do Rio do Peixe in the north to less than 100 meters in the extreme southeastern part of the Bação quadrangle (pl. 4).

LITHOLOGY

The Cauê Itabirite is composed largely of itabirite, which is normally alternating laminae of quartz and hematite, each sufficiently pure enough to give the rock a black-and-white-banded appearance (fig. 7). The laminae range in thickness from less than 0.1 millimeter to more than 5 centimeters and commonly are in groups of lighter and darker layers that have the appearance of much coarser bedding. Individual laminae commonly extend laterally for several meters.

FIGURE 7.—Gently folded itabirite.

Itabirite, if weathered under tropical conditions, disintegrates into a granular mass. The weathering process is highly significant to the formation of canga, an iron hardpan described in a later section of this report. Chemical analyses of weathered Cauê Itabirite are given in table 2. The samples are chip samples taken from exposures along Moeda road. (See measured section below.) About 60 percent of the formation was exposed. Five lithologic units were sampled. Two or more samples were taken from the larger units, each sample representing one-half or one-third of the unit.

TABLE 2.—*Chemical composition of weathered Cauê Itabirite, in percent*

[Analyst: Cássio M. Pinto, DNPM, Belo Horizonte, Nov. 8, 1957]

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	29.5	10.5	15.2	26.4	12.9	11.4	31.7	38.8	13.9	3.0	36.7
Al_2O_3	.5	4.5	.5	.5	8.0	1.5	4.5	.05	.5	.7	.5
Fe	48.8	48.8	58.6	51.5	44.7	56.1	44.6	43.5	59.4	67.0	44.4
Mn	.01	3.6	.01	.03	.12	.35	.02	.01	.51	.28	.01
P	.03	.17	.03	.02	.20	.09	.03	.02	.02	.05	.03

1 and 2. Lowermost itabirite unit of measured section of Cauê Itabirite.
3 and 4. Itabirite, friable, contains plates of blue hematite.
5 and 6. Ocher, massive.
7 and 8. Itabirite, thin plates of soft hematite.
9, 10, and 11. Uppermost itabirite unit.

In thin section the rock is seen as crude bands of quartz grains and platy to granular hematite. The characteristically angular quartz grains range from 0.01 to 0.1 millimeter in the widest dimension. Most specular hematite plates are thin, blood-red, and translucent, whereas granular hematite ranges in grain size from about 0.01 to 0.5 millimeter in the greatest diameter and, unlike the plates, is opaque. In the quartz-rich laminae the hematite grains and plates are either separate or in small irregular groups that are either enclosed in quartz grains or follow the borders within a mosaic of quartz grains. In the iron-rich laminae the hematite plates and grains predominate, and in many laminae quartz is absent. There is an apparent linear arrangement of the irregular groups of specular hematite plates and grains within the various laminae. The lineation is in the plane of the bedding except where microshearing has cut across the bedding; where microshearing has occurred the hematite plates and grains tend to be clustered along the microshear planes.

Fresh itabirite occurs in the 1,280-meter water tunnel of the St. John del Rey Mining Co. near the Rio do Peixe canyon (12,700 N., 11,000 E., Lagoa Grande). Through the courtesy of the St. John del Rey Mining Co., the writer, J. V. N. Dorr 2d, and R. G. Reeves collected 24 samples of mainly unweathered rock during the time the company shut down the water for its powerplants for a period of 6 hours. The tunnel cuts through the Serra do Itabirito and parallels the Rio do Peixe canyon at about 13,000 N., 11,000 E., Lagoa Grande. It penetrated about 270 meters of iron-formation, much of which was unaltered. Samples of fresh itabirite were taken from the tunnel walls, and fragments of these were prepared for thin section.

Petrographic studies of the thin sections indicated virtually pure quartz and hematite. A brief description of the thin sections is presented in table 3.

The itabirite on and near the surface above the tunnel, like much of the weathered itabirite in the region, is disaggregated. This might suggest that itabirite becomes disaggregated owing to leaching of its contained carbonate minerals. The complete lack of carbonate minerals in the fresh samples studied indicates that this leaching hypothesis cannot be used to explain the disaggregation here.

Table 3 can be summarized by saying that the tunnel exploration showed several features seldom seen in field mapping of the Cauê Itabirite within this district:

1. A 20-meter transition zone between the Batatal Formation and the Cauê Itabirite.
2. Intercalated red quartz-rich layers in the hard metallic-blue hematite-rich layers of itabirite.
3. Mica on bedding planes in the itabirite.
4. Yellow and black itabirite ("tiger ore") near the middle of the formation. In surface mapping, it

TABLE 3.—*Itabirite from Tunnel "F," Rio do Peixe canyon, Pico de Itabirito district*

Sample	Distance from Batatal Formation-Cauê Itabirite contact (meters)	Approximate depth below ground surface (meters)	Constituents of the rock[1]			Average grain size of 10 random grains (millimeters)		Remarks
			Hematite Fe_2O_3	Quartz SiO_2	Limonite	Hematite Fe_2O_3	Quartz SiO_2	
TF-2	30	30	XXX	XXX	---	0.10	0.40	The first 20 m above Batatal-Cauê contact is a transitional zone between phyllite and iron-formation. Sample collected of first fresh itabirite above this zone.
3	35	30	XXX	XXX	---	<.02	.12	Sample of fresh itabirite. Tunnel walls contain layers of red and gray quartz-rich rock intercalated with hard metallic-blue hematite-rich rock.
4	39	35	XXX	XX	---	<.02	.06	As above (TF-3). Thin section shows crosscutting iron-free quartz vein (0.24 mm) whose grains are oriented parallel to itabirite bedding planes.
5	46	40	XXX	XX	X	<.02	.10	As above (TF-3) red-stained quartz veins in tunnel walls. Sparse limonite.
6	50	45	XXX	XX	---	<.02	.30	Very fresh itabirite.
7	59	50	XXX	XXX	---	<.02	.11	Thin section shows sparse mica (0.10 mm) oriented normal to itabirite bedding planes.
8	63	60	XXX	XXX	---	<.02	.16	As in TF-3. Tunnel walls show thinly laminated itabirite.
9	70	65	---	---	---	---	---	Calcite stalactites[2] 15 cm long suspended from tunnel near large joint.
11	77	70	XXX	XX	X	.04	.08	Tunnel walls show contorted and sheared itabirite. Thin sections show abundant specular hematite plates in the iron-rich layers of itabirite.
12	80	70	XX	XXX	---	<.02	.20	Fresh itabirite. Tunnel walls show itabirite that appears to be rich in quartz; iron-rich laminae much thinner than quartz-rich laminae.
13	82	70	XXXX	XX	---	<.02	.04	Fresh itabirite. Tunnel walls show itabirite to be iron-rich and quartz-poor in contrast to TF-12.
14	85	85	XX	XXX	---	<.02	.10	Tunnel wall contains fresh itabirite, seams of red quartz-rich rock parallel to itabirite, and small talc blebs (0.16 mm).
15	88	90	XX	XXX	---	<.02	.08-.03	Hard, brittle itabirite in tunnel walls. Sparse mica (0.16 mm) in itabirite laminae.
16	96	120	XX	XXX	---	.06	.12	Similar to TF-15. Tunnel walls fractured; drip water.
17	105	90	X	XXXX	---	.04	.08	Tunnel walls show shattered itabirite. Back of tunnel drips water. Few small calcite stalactites have formed near fissures.
18	116	85	XX	XX	XX	<.02	.06	Tunnel walls show bands of yellow and black itabirite with abundant limonite. Seams of weathered itabirite first appear.
19	124	60	X	XXXX	X	<.02	.06	Sparse fresh itabirite. Tunnel walls show crumpled itabirite. Deep fissures appear in tunnel walls.
20	130	55	XX	XX	XX	<.02	.08	Sparse fresh itabirite. Thin sections show abundant interstitial limonite and replacement of hematite by limonite. Crosscutting quartz veins contain no limonite-stained quartz grains.
21	144	50	X	XX	XXXX	<.02	.06	Similar to TF-20.
22	230	65	XX	XXX	X	<.02	.12	First abundant fresh itabirite in 86 m of tunnel. Some limonite appears in bands in weathered itabirite.
23	240	60	X	XX	XXXX	<.02	.30	Tunnel wall is mostly orange and brown partly to nearly completely limonitized itabirite.
24	270	35	X	XXXX	X	<.02	.02	Tunnel wall is formed of very fine grained moderately weathered itabirite that is sheared and, in places, contorted.

[1] Estimated relative amounts of the constituents of the sample shown by X's.

[2] Calcite stalactites are not a constituent of itabirite; they were more common in the part of the tunnel that penetrated quartzite of the Moeda Formation; none were seen in the Batatal Formation.

has been seen only near the upper limits of the Cauê Itabirite and in the lower part of the Gandarela Formation.

5. Iron-free, crosscutting quartz veins throughout most of the Cauê Itabirite.
6. Lack of contorted and crumpled itabirite in the lower half of the formation.

In addition, in the upper half of the Cauê Itabirite, the formation was shattered and strongly weathered in places. (See TF 20–24 of table 3.) Thin sections of samples taken throughout the tunnel showed a nearly uniform grain size for the hematite and only a small range in grain size for the quartz.

Nearly every thin section examined under the microscope showed a noticeable diminution of size of the quartz grains in the quartz-rich laminae within a millimeter of the contact with iron-rich laminae and an abundance of quartz veinlets commonly less than 1 millimeter in thickness. The grain size of the quartz in the veinlets commonly is larger than the quartz grains in the host rock, and several of the veinlets show parallel orientation of their grains to those of the host rock quite independent of the strike of the veinlets. Other veinlets show random orientation of their quartz grains.

Sparse biotite and chlorite were seen in several sections, and a small amount of talc(?) occurs in one specimen collected near a small fault in the tunnel.

The major geological significance of the tunnel exposures is the fact that no carbonates, neither calcite, dolomite, nor siderite, were found in the thick section of fresh itabirite. Calcite stalactites were found hanging from the roof near major joints. Such calcite stalactites are relatively common in the part of the tunnel within the quartzite of the Moeda Formation, but calcite has never been reported in that formation and was not here observed. When the tunnel is being used, water passing through it and filling it nearly to the top, drains an area in which much dolomite crops out. This dolomite is thought to be the source of the calcite of the stalactites.

Measured section of the Cauê Itabirite along Moeda road, Marinho da Serra quadrangle

	Thickness (meters)	Cumulative thickness from base (meters)
Cauê Itabirite:		
Itabirite, slightly manganiferous; contains laminae 2–3 cm thick of black iron and manganese oxides. Yellow quartz sand beds, 1–2 cm thick near top of the unit. (Samples 9, 10, and 11 of table 4)	26. 5	301. 6
Itabirite, thin plates of soft hematite and quartz sand. (Samples 7 and 8 of table 4)	52. 0	275. 1
Soft limonite and ocher, light-brown to orange; contains much quartz sand	43. 5	223. 1
Itabirite, soft platy hematite and light-gray quartz sand. Laminae somewhat contorted	42. 5	179. 6
Ocher, partly limonite and partly red hematite; grades upward into itabirite	13. 0	137. 1
Itabirite, platy, friable; contains blue hematite in laminae 3–4 cm thick in upper part of unit, and 30-cm thick lenses of ocher in lower part of unit	53. 8	124. 1
Ocher, massive; few noticeable impurities. (Samples 5 and 6 of table 4)	5. 5	70. 3
Itabirite, friable; contains plates of soft blue hematite in laminae 3–4 cm in thickness, and quartz laminae of equal thickness. (Samples 3 and 4 of table 4)	63. 0	64. 8
Itabirite; somewhat contorted laminae of hematite, limonite, and quartz that range from 2 mm to 5 cm in thickness. (Samples 1 and 2 of table 4)	1. 8	1. 8
Total thickness	301. 6	

Gandarela Formation

The Gandarela Formation is the upper unit of the Itabira Group. It grades into the Cauê Itabirite and is unconformably overlain by rocks of the Piracicaba Group of the Minas Series. The formation was named and described by Dorr (1958b) from the type locality near Fazenda Gandarela in the Gandarela quadrangle, near the center of the Quadrilátero Ferrífero.

DISTRIBUTION AND THICKNESS

The Gandarela Formation in the Pico de Itabirito district crops out on the eastern slopes of the Serra da Moeda and the western slopes of the Serra do Itabirito. It decreases in thickness from north to south along these mountain ridges. The formation in the Serra da Moeda is about 500 meters thick near Lagoa Miguelão, a measured 438 meters thick south of Água Limpa, a measured 361 meters thick at Canhão Estreito, and an estimated 160 meters thick at the southern limit of the range. The formation in the Serra do Itabirito thins from more than 400 meters east of the Codorna Dam (10,000 N., 12,300 E., Lagoa Grande), to a knife edge in the southern part of the Serra at 1,800 N., 300 E., Bação.

LITHOLOGY

The Gandarela Formation is composed largely of dolomitic itabirite, dolomitic and argillaceous phyllite, dolomitic limestone, and dolomite. None of these lithologic units is present in the underlying Cauê Itabirite.

Fresh dolomitic itabirite, which resembles the black and white laminated Cauê Itabirite in hand specimen, is extremely sparse; where weathered, it is an orange and black laminated rock locally called pedra do tigre or tiger rock. The orange coloration is due to the weathering of interspersed dolomite in the quartz layers. The black color is caused by manganiferous minerals mixed with granular hematite. Light-gray, greenish-yellow, and chocolate-brown laminae have been noticed in some outcrops. The laminae range in thickness from 1 millimeter to 5 centimeters and extend several meters laterally.

Argillaceous and dolomitic phyllites of the Gandarela Formation are soft and deeply weathered in this district. In general, the argillaceous phyllite is medium gray or sea green; the dolomitic phyllite is commonly maroon, light red, light brown, or yellow. These rocks are commonly discontinuous and overlapping thin to thick beds in the upper part of the formation. Where dolomitic itabirite is missing, the phyllites overlie the Cauê Itabirite with a sharp contact.

The carbonate beds of the Gandarela Formation are crystallized to fine-grained marble. This marble crops out as rounded forms near the western end of Canhão do Rio do Peixe (11,700 N., 10,400 E., and 10,600 N., 11,000 E., Lagoa Grande). Fresh rock ranges from reddish brown to deep red and weathers to a brown to black spongy soil that is extremely plastic during the rainy season. Marble breccia at 11,700 N., 10,400 E., consists of sharp angular fragments of deep-red dolomitic limestone in a matrix of light-gray dolomite, clear crystalline quartz, thin to thick plates of specular hematite, and light-brown siderite. Large plates of chlorite are present in some specimens.

A thin section of calcareous dolomite taken from a quarry in this area shows that the rock consists mainly of dolomite grains that range from 0.01 to 0.10 millimeter across. A few strained angular quartz grains are present in the thin section. Most of the dolomite and quartz grains are stained by limonite.

Carbonate rocks in the northern part of the Lagoa Grande quadrangle contain from 10.4 to 21.7 percent MgO (table 4). According to Pettijohn (1957, p. 418), such rocks are classed as dolomitic limestone (2.1–10.8 percent MgO; equivalent to 10–50 percent dolomite), calcitic dolomite (10.8–19.5 percent MgO; equivalent to 50–90 percent dolomite), and dolomite (19.5–21.6 percent MgO; equivalent to more than 90 percent dolomite). No systematic areal distribution of MgO content is apparent.

PIRACICABA GROUP

The Piracicaba Group was originally described by Dorr and others (1957, p. 27) as consisting of a variety of metamorphosed sedimentary rocks including ferruginous quartzite, quartzite, phyllite, dolomitic phyllite, dolomite, graywacke, metatuff, and others. A similar suite of rocks is present in the Pico de Itabirito district.

TABLE 4.—*Chemical composition of marble from the Gandarela Formation in the Lagoa Grande quadrangle*

[Analysts: Nos. 1–3, Cássio M. Pinto, DNPM, Belo Horizonte; Nos. 4–5, analyst unknown, St. John del Rey Mining Co.; No. 6, Eladio Pimentel, DNPM, Belo Horizonte]

	1	2	3	4	5	6
SiO_2	13.2	1.8	1.5	5.43	4.97	1.6
Fe_2O_3 [1]	2.00	2.80	2.50	[2] 3.09	[2] 6.31	5.9
Al_2O_3	.20	.50	.80	.11	None	1.8
CaO	26.7	29.0	29.3	28.00	26.87	39.0
MgO	17.6	20.4	20.2	16.79	21.71	10.4
MnO	.22	.70	.40	2.28	1.15	(3)
Loss on ignition	39.9	44.7	45.1	44.30	39.00	41.3
Total	99.8	99.9	99.8	100.0	100.0	100.0

[1] All iron reported as Fe_2O_3.

[2] FeO.

[3] Not recorded.

1. Calcitic dolomite, Ribeirão dos Marinhos near Usina "A" of Rio do Peixe. Collected by G. A. Rynearson, 1956.
2. Dolomite, Ribeirão dos Marinhos near Usina "A" of Rio do Peixe. Collected by G. A. Rynearson, 1956.
3. Dolomite, drill hole in water tunnel at Ribeirão Capitão do Mato. Collected by G. A. Rynearson, 1956.
4. Calcitic dolomite, Rio do Peixe south of Capitão do Mato. Collected by A. F. Matheson, 1954.
5. Dolomite, Codorna (Lagoa das Codornas). Collected by A. F. Matheson, 1954.
6. Dolomitic limestone, Ribeirão dos Marinhos below Usina "A". Collected by R. M. Wallace, 1960.

An erosional unconformity separates this group from the underlying Itabira Group. In a few places in the Quadrilátero Ferrífero, the unconformity between these two groups might be angular (C. H. Maxwell and G. C. Simmons, oral commun., 1960), but no such relationship was seen in the Pico de Itabirito district. In some localities the contact is marked by a granule to cobble conglomerate. The origin of some fragments has been tentatively identified as the underlying Gandarela Formation, but the origin of fragments that have extrusive igneous aspects is unknown. The length of the hiatus between the Itabira and Piracicaba Groups is unknown but was probably not great.

The Piracicaba Group has been divided into five formations (Pomerene, 1958a, b, c; Simmons, 1958; and Gair, 1958). In ascending order they are: Cercadinho Formation, Fêcho do Funil Formation, Taboões Quartzite, Barreiro Formation, and the Sabará Formation. Dorr and others (1957, p. 29) estimated the total maximum thickness of these units to be at least 4,000 meters. In the Pico de Itabirito district, the Sabará Formation is missing, and the Barreiro Formation is unconformably overlain by rocks of the Itacolomí Series. A cumulative maximum thickness of the Piracicaba Group within the Pico de Itabirito district is estimated to be about 1,000 meters.

Cercadinho Formation

The Cercadinho Formation forms the base of the Piracicaba Group and is one of the most widespread of the formation of the Minas Series in the Quadrilátero Ferrífero. The formation is composed of clastic rocks and is named for excellent exposures of quartzite, ferruginous quartzite, and phyllite that crop out at Córrego de Cercadinho, about 20 kilometers northeast of the nearest outcrop in the Pico de Itabirito district (Pomerene, 1958a).

The Cercadinho Formation in the Pico de Itabirito district is confined to the Moeda syncline. The average thickness of the formation there is about 550 meters, although it varies from 400 to 900 meters. The variation seems to be due to structural thickening along fold axes and to thinning on fold limbs rather than to variation in deposition.

LITHOLOGY

The Cercadinho Formation in the Pico de Itabirito district consists of phyllite and intercalated long, thin quartzite lenses. Both are distinct in composition and color from other phyllite and quartzite of the Minas Series.

A thin dark-gray sandy basal conglomerate that consists of poorly sorted well-rounded pebbles and cobbles of vein quartz and quartzite, semirounded fragments of uncontorted itabirite, and irregularly shaped boulder-size masses of white clayey material is exposed near Canhão do Rio do Peixe, in the north-central part of the district. There also is a lens of dark-gray silty quartzite that contains abundant dark-red elliptical sandy pellets commonly several millimeters thick, 10–35 millimeters long, and 3–20 millimeters wide. The conglomerate crops out only at this single location within the Pico de Itabirito district.

The phyllite, which makes up about 80–85 percent of the formation, has been given the colloquial field term "silver phyllite" because of its distinctive silver-white color and brilliant sheen. The sheen results from the light reflecting from the minute plates of white mica that constitute most of the rock. The rock consists of about 70 percent muscovite and sericite, 20 percent specular hematite plates, 10 percent quartz grains, and less than 1 percent black tourmaline, calcite, zircon, and limonite.

In some well-exposed outcrops the phyllite appears to be crudely banded in layers that range in thickness from a few centimeters to more than a meter. Laterally, individual layers cannot be traced more than a few tens of meters. The banding is apparently caused by a local abundance of quartz grains or hematite plates.

The phyllite weathers to a light-brown to light-gray clayey soil that cannot be distinguished from that derived from other phyllites of the Minas Series.

Ferruginous quartzite makes up about 15–20 percent of the Cercadinho Formation in the Pico de Itabirito district. This rock forms long, thin lenses, from less than 5 meters to more than 100 meters thick, that may be traced laterally from a few hundreds of meters to more than 2 kilometers. Such lenses commonly mark the top and the base of the Cercadinho Formation but are also irregularly spaced throughout the formation. The quartzite ranges from dark to light gray, from coarse to fine grained, from tough to brittle, and from structureless and massive to crossbedded (fig. 8). Ripple-marked quartzite crops out in the Rio do Peixe near power station "A" (fig. 9).

In many places in the Quadrilátero Ferrífero, ferruginous quartzite is the dominant rock of the Cercadinho Formation; it forms long high ridges edged by steep cliff faces that tower over the surrounding phyllites. The topographic expression is subdued in the Pico de Itabirito district because of the preponderance of phyllite over quartzite, and only low, moderately rounded ridges are present. The quartzite lenses, however, are mappable in this district, and their outcrops indicate the structural complexities of the Piracicaba Group within the Moeda syncline (pl. 2).

FIGURE 8.—Crossbedded ferruginous quartzite of the Cercadinho Formation in the Rio do Peixe. Reconstruction of dips and strikes of crossbedding in this rock throughout the district gives no preferred orientation. The coin in the upper left part of the photograph is about the size of a U.S. quarter.

FIGURE 9.—Ripple marks in a vertical outcrop of ferruginous quartzite of the Cercadinho Formation exposed near power station "A" on the Rio do Peixe. Ripple marks are extremely scarce in the Minas Series.

The ferruginous quartzite as seen in thin section is composed of rounded, clear, commonly unstrained, quartz grains that measure from 1 to 3 millimeters in diameter. These grains are enclosed in a matrix of smaller subangular white quartz grains that average about 0.25 millimeter across the longest dimension. The interstices between the grains are filled with small thin plates and grains of specular hematite that constitute about 5–10 percent of the rock. Locally, hematite exceeds 50 percent. Small plates of muscovite and shreds of sericite wrap around some of the small quartz grains but constitute less than 1 percent of the rock. Several 0.5- to 1.0-millimeter aggregates of quartz grains are seen in thin section. The individual quartz grains in the aggregate have an average diameter of 0.02 millimeter; each quartz grain contains irregular unoriented plates and angular grains of specular hematite that average about 0.008 millimeter in maximum dimension.

Large crystals of specular hematite were found by G. A. Rynearson in crumpled phyllite that borders buckled lenses of ferruginous quartzite of the Cercadinho Formation at 7,150 N., 400 E., Itabirito. They lie near the axis of a small southeast-plunging anticline. Kyanite-bearing quartz veins are common near the large crystals. These hematite crystals are euhedral and show both penetration and polysynthetic twinning. Individual crystals weigh from several kilograms to several tons; Mr. Rynearson found one estimated to weigh about 4 metric tons. Several weighing from about 20–50 kilograms apiece are on exhibition in museums in Brazil and in the National Museum in Washington, D.C.

Fêcho do Funil Formation

The Fêcho do Funil Formation (Simmons, 1958, p. 65) was named for exposures of dolomitic phyllite and argillaceous dolomite beds on the north flank of the Serra do Curral, 18 kilometers northwest of the nearest outcrop of the formation in the Pico de Itabirito district. The formation conformably overlies the Cercadinho Formation, and in the Pico de Itabirito district, the contact has been placed between the "silver phyllite" or the uppermost lens of ferruginous quartzite of the Cercadinho Formation and the lowermost dolomitic limestone bed of the Fêcho do Funil Formation. Where the dolomitic limestone beds or ferruginous quartzite lenses are missing, the contact is arbitrarily placed where the "silver phyllite" is in contact with varicolored argillaceous and dolomitic phyllite.

The Fêcho do Funil Formation crops out in the Lagoa Grande and Marinho da Serra quadrangles where it is confined to the lowlands of the Moeda Plateau. The formation is 100 meters to more than 600 meters thick; the wide variation appears to be related to structural thickening along fold axes and to thinning on fold limbs rather than to variations in deposition. The average thickness of the formation is about 300 meters.

LITHOLOGY

The rocks of the Fêcho do Funil Formation in the Pico de Itabirito district differ considerably from the rocks of this formation at the type locality. The dolomite apparently makes up less than 10 percent of the formation, the remainder being dolomitic and arenaceous phyllite, whereas at the type locality, dolomite is the predominant rock. The magnesia content of 12 carbonate rock samples ranges from 0.8 to 18.9 percent (tables 5 and 10). No systematic areal pattern is evident.

TABLE 5.—*Chemical composition of limestone and dolomite from the Fêcho do Funil Formation in the Marinho da Serra quadrangle*

[Analysts: Nos. 1–2, Eladio Pimentel, DNPM, Belo Horizonte; Nos. 3–7, Cássio M. Pinto, DNPM, Belo Horizonte]

	1	2	3	4	5	6	7
SiO_2	1.6	1.0	6.8	7.3	5.2	4.1	1.6
Fe_2O_3 [1]	5.9	2.2	1.5	2.40	1.46	4.6	0.9
Al_2O_3	1.8	.1	.92	1.80	1.10	.4	.4
CaO	39.0	29.4	44.1	27.5	49.8	28.7	50.9
MgO	10.4	18.9	5.6	18.9	1.4	17.1	3.0
MnO	(2)	(2)	.02	.07	.02	2.2	.12
Loss on ignition	41.3	48.4	40.9	42.0	40.9	43.0	43.3
Total	100.0	100.0	99.8	99.9	99.9	100.1	100.2

[1] All iron reported as Fe_2O_3.
[2] Not recorded.

1. Dolomitic limestone, Rio Mata Porcos, east of Bocâina da Serra. Collected by R. M. Wallace, 1960.
2. Calcitic dolomite, Rio Mata Porcos near Água Quente. Collected by R. M. Wallace, 1960.
3. Dolomitic limestone, average of 3 specimens from Jazidas do Urubu. Collected by R. M. Wallace, 1960.
4. Calcitic dolomite, average of 2 specimens from Jazida Siema. Collected by R. M. Wallace, 1960.
5. Magnesian limestone, average of 3 specimens from Jazida do Urubu. Collected by G. A. Rynearson, 1956.
6. Calcitic dolomite, Rio Mata Porcos, southeast of Bocâina da Serra. Collected by G. A. Rynearson, 1956.
7. Dolomitic limestone, Rio Mata Porcos, southeast of Bocâina da Serra. Collected by G. A. Rynearson, 1956.

The dolomitic and arenaceous phyllites of the Fêcho do Funil Formation are poorly exposed in the Pico de Itabirito district although they make up a considerable part of the floor of the Moeda Plateau. In outcrop the phyllitic unit appears as an assemblage of colorful bands 10 centimeters to more than a meter thick. The colors, which range from dark gray through maroon, light red, light brown, pale yellow to light gray, are thought to be controlled by the amount of iron minerals and dolomite. Dark bands are relatively richer in iron and dolomite, whereas the pale-yellow and light-gray bands contain lesser amounts and consist mainly of light-colored micas, clay, and silt-sized quartz grains.

The carbonate rocks in the Pico de Itabirito district prominently crop out in the lower valley walls as irregular lenses a few tens of meters to more than 100 meters thick; these lenses may be followed along strike in some places for as much as 600 meters. They are scattered throughout the formation although in the northern half of the Marinho da Serra quadrangle, they appear to be concentrated near the base. The rock is fine to coarse grained, calcareous, dark gray to light gray, light pink to maroon, and light brown to greenish yellow. Locally, it has been intensely contorted. The contact between fresh and weathered rock commonly is sharp (fig. 10). The weathered product is a black or brown spongy mass, locally named "splash rock" (Guild, 1957, p. 42), that contains manganese and hydrous iron oxide minerals.

FIGURE 10.—Sharp contact produced by tropical weathering of marble of the Fêcho do Funil Formation. The weathered product of the light-colored rock is a dark spongy mass (right half of the photograph), locally named "splash rock", which commonly contains more than 10 percent manganese oxide minerals. A sample of the rock to the left of the hammer contains about 2 percent manganese oxide, and the black material to the right contains more than 25 percent manganese oxide.

Taboões Quartzite

The Taboões Quartzite of the Piracicaba Group (Pomerene, 1958b) was named for exposures of quartzite in the headwaters of the Córrego Taboões in the Ibirité quadrangle west of Belo Horizonte. The type locality is about 15 kilometers northwest of the nearest outcrop of the Taboões Quartzite in the Pico de Itabirito district.

The Taboões Quartzite crops out in scattered exposures in the center of the Moeda synclinal basin in the Lagoa Grande quadrangle. It is about 10 meters thick on the average, ranging from about 40 meters in thickness near Lagoa Miguelão in the north to about 2 meters in the valley of the Córrego do Gavião near the central boundary of the Lagoa Grande quadrangle. The thinning of the formation southward and its disappearance south of the Córrego do Gavião are probably due to depositional wedging out. The Taboões Quartzite conformably overlies the Fêcho do Funil Formation with a sharp contact.

The Taboões Quartzite in the Pico de Itabirito district is a light-gray to white very fine grained poorly cemented rock that disintegrates readily to a white powdery sand. It has no distinct topographic expression and rarely is exposed.

Specimens of the rock as seen under a binocular microscope show many small irregular cavities that appear to lie along otherwise invisible bedding planes. The largest cavity noticed was about 1 millimeter in diameter and extended into the rock about 2 millimeters.

As seen in thin section the rock is a mosaic of clear, subrounded quartz grains that have an average diameter of about 0.1 millimeter mixed with a few shreds of sericite.

Barreiro Formation

The Barreiro Formation of the Piracicaba Group (Pomerene, 1958c) is the youngest formation in the Minas Series in this district. It consists of phyllite, schist, and graphitic phyllite. The type locality is near the town of Barreiro, about 18 kilometers northwest of the nearest outcrop of the Barreiro Formation in the Pico de Itabirito district.

The Barreiro Formation, which crops out near the center of the Moeda Plateau in the Lagoa Grande quadrangle, conformably overlies the Taboões Quartzite. The thickness ranges from about 80 meters to more than 300 meters; the wide range seems to be related to structural thickening along fold axes and to thinning on fold limbs rather than to variation in deposition. The average thickness of the formation is about 120 meters.

The Barreiro Formation in the Pico de Itabirito district consists of varicolored argillaceous phyllite similar to phyllite of the Fêcho do Funil Formation but in addition contains irregularly distributed lenses of graphitic phyllite which make up less than 5 percent of the formation. All phyllitic members weather to a light-brown sandy soil. The graphitic phyllite lenses as seen in outcrop are very dark gray to black; they range in thickness from 1 to 5 meters and can commonly be traced laterally for less than 100 meters. Some graphitic lenses contain dark-brown to black elliptical sandy ferruginous concretions that average about 3 centimeters along the major axes.

Crushed fragments of graphitic phyllite as seen under the petrographic microscope show extremely fine grains of graphite that seem to be evenly distributed throughout the rock.

ITACOLOMÍ SERIES

The rocks of the Itacolomí Series are the youngest known metasedimentary rocks of the Quadrilátero Ferrífero; they overlie rocks of the Minas Series with a profound angular unconformity. The present erosional surface constitutes the upper limit of the series. The type locality for the series is at Pico do Itacolomí, south of Ouro Prêto, about 50 kilometers southeast of the Pico de Itabirito district, where the thickness is estimated by Barbosa (in Dorr and others, 1960, p. 81–84) to be more than 1,000 meters.

Lacourt (1936) divided the Itacolomí Series into three zones: (a) a lower zone of sericitic quartzite with interbedded conglomerate, (b) a middle zone of phyllite, and (c) an upper zone of sericitic quartzite that is in part crossbedded. More recent work by Barbosa (in Dorr and others, 1960, p. 82) suggests that the phyllite of Lacourt's middle zone of Itacolomí rocks may be phyllite of the Minas Series rocks involved in thrust faulting at Pico do Itacolomí and that Lacourt's upper zone rocks may be the lower quartzite in an overthrust block. Barbosa explained the apparent absence of conglomerate in Lacourt's upper quartzite as due to the lack of persistent lenses and stated (p. 82), "Careful observation of the distribution of the various petrographic types in this * * * series * * * reveals absolutely no continuity of the beds: the thickest and most persistent conglomerate * * * [lenses] * * * are not more than 2 kilometers long."

Barbosa (1949) mapped and named a conglomerate containing cobbles and rock fragments apparently derived from the Minas Series in the Casa de Pedra quadrangle immediately south of the Marinho da Serra quadrangle. He named this unit the Santo Antônio Formation and originally considered it as the uppermost part of the Minas Series. Guild (1957, p. 22–25), who referred to these rocks as the Santo Antônio facies, considered them to be a part of the Itacolomí Series, and most geologists familiar with the region, including O. Barbosa (written commun.), agree with this age assignment.

The conglomerate in the area mapped by Guild is somewhat different from the conglomerate that occurs in lenses at the type locality of the Itacolomí Series. The conglomerate lenses at the type locality consist of pebbles, cobbles, and boulders of quartz and, in a few places, quartzite, with local concentration of itabirite pebbles and cobbles, in a coarse quartzite or grit matrix. The Santo Antônio conglomerates contain cobbles and rock fragments derived from most of the Minas Series in a matrix which commonly is highly argillaceous. A characteristic rock fragment in the Santo Antônio facies conglomerate is that of a brick-red siltstone of unknown origin; this material is not known in the type locality of the Itacolomí Series.

A conglomerate, similar to, if not identical with, that described by Octavio Barbosa, crops out in the Lagoa Grande quadrangle between 8,000 N., 9,000 E., and 7,700 N., 10,000 E. C. H. Maxwell (written commun.) also described a similar conglomerate in the Santa Rita Durão quadrangle on the east-central part of the Quadrilátero Ferrífero and assigned those rocks to the Itacolomí Series.

The Itacolomí Series as found in the Pico de Itabirito district was first mentioned by Barbosa (1949, p. 7), and later by Guimarães (1958, p. 208). Guimarães referred to the rocks on the Inconfidentes highway at 7,700 N., 9,900 E., Lagoa Grande, as quartzites of the Itacolomí. The embankment of a new roadcut in this vicinity shows lenses of quartzite, conglomerate, phyllite, and siltstone that overlie phyllite of the Minas Series. The angular unconformity between the two series is visible in a narrow ravine west of Capão Redondo (8,850 N., 8,900 E., Lagoa Grande), where the rocks of the Minas Series strike N. 5° E. and dip 55° E., and the overlying rocks, which the writer correlates with the Itacolomí Series, strike N. 70° W. and dip 15° NE.

The rocks of the Itacolomí Series within the Pico de Itabirito district lie within the Moeda syncline, west of Lagoa das Codornas in the Lagoa Grande quadrangle. The synclinal axis plunges gently both north-northwest and south-southeast from about the center of the outcrop area, where the series has an estimated maximum stratigraphic thickness of about 150 meters.

LITHOLOGY

The rocks of the Itacolomí Series in the Pico de Itabirito district may be divided into four lithologies: conglomerate, quartzite, siltstone, and phyllite. In some places the contacts between these rocks are relatively sharp, and in other places they are gradational. There are no marker beds, and any one lithology may lie at the base, near the center, or on top of the formation.

Conglomerate

The presumption that the rocks overlying the Minas Series in the Pico de Itabirito district are a part of the Itacolomí Series is based on the similarity of the lithology of these rocks and those at Morro de Santo Antônio; conglomerate lenses in both areas occupy comparable stratigraphic positions.

The conglomerate of the Itacolomí Series in the Pico de Itabirito district (fig. 11) is composed of pebble, cobble, and boulder fragments similar to most of the rocks of the underlying formations of the Minas Series. The most abundant fragments consist of ferruginous quartzite, very fine grained light-gray quartzite, chloritic and muscovitic phyllite and schist; graphitic schist, and dolomitic and siliceous itabirite.

Boulders of ferruginous quartzite in the conglomerate in the Pico de Itabirito district are commonly well rounded and have high sphericity; in some places

FIGURE 11.—Conglomerate of the Itacolomí Series, in a roadcut near Lagoa das Codornas. The small rounded boulder to the left of the hammer head is composed of crossbedded ferruginous quartzite, and the light-colored irregular cobbles and boulders are composed of Taboões Quartzite. The lower part of the hammer handle overlies a fragment of itabirite that is similar to itabirite of the Cauê Itabirite. Other pebbles, cobbles, and small boulders are made up of schist and phyllite similar to rocks of the Minas Series.

they are greater than 50 centimeters in diameter. Few other rock types appear as boulders in this district. The boulders accentuate graded bedding in some outcrops.

A brick-red well-indurated siltstone, unknown in the Minas Series, appears as subrounded, elongated pebbles that are heterogeneously dispersed in many of the conglomerate lenses of the Itacolomí Series throughout the Quadrilátero Ferrífero. These pebbles, where present, may aid in identifying the Itacolomí conglomerates from conglomerates of older rock series. Their source is unknown, but because of their widespread distribution and their heterogeneous dispersal within the various conglomerate lenses, it is this writer's opinion that they were derived from a formation that once overlay the youngest-known formation of the Minas Series.

Quartzite

Quartzite of the Itacolomí Series in the Pico de Itabirito district is fine to medium grained, pale lavender to light gray, well sorted, extremely friable, and sericitic; it commonly exhibits small- to medium-scale crossbedding (fig. 12). At Capão Redondo (8,700 N., 9,000 E., Lagoa Grande), where the quartzite unconformably overlies the Barreiro Formation of the Minas Series with marked angular unconformity, the quartzite is about 60 meters thick. It grades upward into a sandy phyllite overlain by lenses of fine-grained purple quartzite and purple siltstone that in turn are overlain by a thick conglomerate that caps the hill. In contrast, a similar quartzite lens exposed in a roadbank of the Inconfidentes highway about 1,300 meters to the south is less than 4 meters thick and is intercalated between two lenses of purple phyllite that overlie a lens of coarse conglomerate.

Siltstone

Siltstone lenses of the Itacolomí Series in the Pico de Itabirito district are light gray to purple and are crudely banded. The gray and purple bands range from 5 centimeters to 1 meter in thickness but cannot be traced laterally more than a few tens of meters.

In thin section a sample of purple siltstone was seen to contain about 70 percent quartz in the form of subrounded grains that measure about 0.01 millimeter in average diameter, 5 percent rounded quartz grains that average 0.04 millimeter, and 25 percent hematite that averages 0.01 millimeter in diameter. A dark-gray siltstone was seen to have a similar composition except that it contains only about 15 percent hematite. A sample of a light-gray siltstone contains about 40 percent subrounded quartz grains averaging about 0.02 millimeter in diameter, 40 percent chlorite and sericite, 10 percent hematite grains averaging

FIGURE 12.—Crossbedding in weathered quartzite of the Itacolomí Series at Capão Redondo, Lagoa Grande quadrangle. The quartzite is extremely friable, and the exposure was shaved with a machete before it was photographed.

about 0.013 millimeter in diameter, and 10 percent coarse-grained quartz and fragments of ferruginous quartzite and chlorite schist.

Phyllite

Purple to lavender arenaceous to argillaceous phyllite crops out in about 60 percent of the areal distribution of the Itacolomí Series in the Pico de Itabirito district. The phyllite is commonly very fine grained and has a soapy feel. The lenses of phyllite, which range from about 10 meters to more than 40 meters in thickness, show no bedding but commonly contain irregular lenses 50 centimeters to more than 2 meters in thickness of intercalated lavender, purple, dark-gray, and light-gray siltstone, and in a few places, greenish-gray schist. The maximum lateral extent of the phyllite lenses is unknown because of soil cover, but one lens near Lagoa das Codornas was traced for more than 800 meters.

Crushed fragments of the phyllite studied under the petrographic microscope revealed an abundance of fine plates or shreds of sericite and clay and a small amount of limonite, chlorite, and very fine quartz grains.

Fragments of phyllite collected at random and measuring 3 or 4 centimeters in length and width were placed in beakers of water. They disaggregated quickly and, if the beakers were agitated, formed cloudy suspensions that took an average of about 65 minutes to settle completely. Suspensions formed from similar fragments of phyllite from the Nova Lima Group settled in 50 minutes, from the Cercadinho Formation in 45 minutes, from the Fêcho do Funil Formation in 35 minutes, and the Gandarela Formation in 10 minutes. A more complete analysis of the settling velocities of suspensions of various phyllites in the region might prove to be a useful tool in the identification of strata in structurally complex areas.

The phyllite of the Itacolomí Series in the Pico de Itabirito district is uniquely marked with elliptically shaped spots of unknown origin. These spots are bleached white; they commonly measure from 11 to 50 millimeters in length, 3 to 15 millimeters in width, and 2 to 3 millimeters in thickness. They lie in the planes of schistosity or cleavage, and their long axes are parallel to the dip.

AGE AND CORRELATION

The Itacolomí Series clearly is of post-Minas age, as it contains fragments derived from the Minas Series as well as fragments of a presumed younger unit, but it has been equally deformed and metamorphosed. Further analysis of the age and correlation of the unit is not warranted on the basis of the meager and isolated outcrop of the series in this district.

GRANITIC ROCKS

Parts of two granitic complexes are present in the Pico de Itabirito district: an unnamed western complex that lies west of the Serra da Moeda and the Bação complex (Herz in Dorr and others, 1960, p. 85) that lies east of the Serra do Itabirito.

The western complex, most of which is outside the mapped area, has an estimated area of about 700 square kilometers. It is probably roughly oval shaped and may extend from about Brumadinho in the north (G. C. Simmons, written commun.) to Jeceába in the south, a distance of approximately 40 kilometers; it is about 25 kilometers wide near Moeda.

Earlier workers studying this complex considered these granitic rocks, with reservations, to be Archeozoic (Freyberg, 1932, p. 24–27; Barbosa, 1949, p. 5). The present writer, working with students from the University of São Paulo, concluded that the granitic rocks near Bocaina da Serra (10,000 N., 4,000 E., Marinho da Serra (pl. 2)) were post-Minas in age (Wallace and others, 1959). These conclusions were later supported by potassium-argon ages determined from various rock specimens collected within the complex by Herz (Herz and others, 1961, p. 1112), who concluded that the ages range from about 462 to 600 million years.

The Bação complex, which lies east of the Serra do Itabirito, is also roughly oval; it is approximately 27 kilometers long from east to west, and about 20 kilometers long from north to south. More than half of this granitic complex lies outside the area mapped for this report. The extreme southern part of the complex was described by Guild (1957, p. 27), the southeastern one-third by Johnson (1962, p. B19), and the northeastern part by J. R. O'Rourke (written commun.)

More recently Herz and Dutra (1958) and Herz and others (1961, p. 1111–1112) studied the Bação complex as a whole and furnished ages as determined by the potassium-argon method. Correlating all previous fieldwork, the age determinations, and petrographic and spectrographic studies, these authors showed that the complex consists of granitic rocks formed at three different stages during Precambrian times.

Granitic rocks in both complexes commonly are deeply weathered, and outcrops of fresh rock are scarce, particularly in the Bação complex. Granitic rocks form lowlands throughout the Quadrilátero

Ferrífero and its surrounding area. The saprolites of many of the various types of granitic rocks appear to be nearly identical in the field, and it is impossible to know more than generally the area underlain by each type of granitic rock. Furthermore, moderately thick forests and heavy brush are common in the granitic lowlands, and this vegetation masks much of the outcrops of both saprolite and fresh rock. In spite of such difficulties, it was possible to determine that in the Pico de Itabirito district the different granitic rocks are more or less zonally arranged. The younger granites appear near the metasedimentary rock highlands on the periphery of the complex, and the older granites crop out in the lowlands nearer the central part of the complex. The oldest granite in the Bação complex lies approximately in the center of the oval-shaped outcrop pattern (Herz and others, 1961, fig. 1).

Apparently the western complex and the Bação complex are related. Herz and Dutra (1958, p. 75–78) showed a similarity of trace elements among the rock types within each complex but a lesser similarity of trace elements between rock types of the two complexes.

COMPLEX WEST OF THE SERRA DA MOEDA

The granitic rocks that lie within the mapped area west of the Serra da Moeda include granite gneiss and porphyritic granodiorite. The contact between the two rock types was not seen. In some places the two rock types are separated by lenses of quartzite from 4 to 10 meters thick, although elsewhere the contact is obscured by soil or vegetation.

GRANITE GNEISS

The granite gneiss lies in a zone between the porphyritic granodiorite to the west and the metasedimentary rocks of the Minas Series to the east. This zone parallels the Serra da Moeda for at least 30 kilometers and pinches and swells from about 400 meters to more than 2 kilometers in width within the mapped area. The zone is not traceable in the northeastern corner of the district because of thick soil but has been traced well beyond the southern boundary of the Marinho da Serra quadrangle. Near the village of Boa Morte in the Casa de Pedra quadrangle, the granite gneiss is estimated to be more than 500 meters wide.

The contact between the granite gneiss and quartzite of the Moeda Formation is gradational. The transitional zone ranges in width from a few meters to several tens of meters but is apparently present throughout the entire length of the granite gneiss border zone. Near Boa Morte the transitional zone is more than 90 meters wide, whereas the same zone as seen on the Moeda road (10,000 N., 4,500 E., Marinho da Serra) is less than 30 meters wide. Farther north a few isolated exposures of moderately weathered rock indicate that the contact zone is less than 10 meters wide. These exposures led Rynearson, Pomerene, and Dorr (1954, p. 13–14) to consider the zone a pre-Minas regolith; at the time they wrote, the better exposures to the south had not been mapped.

A chemical analysis of the transitional rock, which is somewhat granitic in appearance, suggests an arkose or feldspathic sandstone. The chemical composition of this rock, as compared to an average of five typical arkoses (described by Pettijohn, 1957, p. 324) in table 6, leaves little doubt that the rock is not a granite at the location where the sample was collected. As the observer proceeds toward the granitic mass, however, the rocks gradually become more feldspathized until the rocks in the inner side of the transitional zone are granite gneiss.

TABLE 6.—*Transitional rock between Moeda Formation and granite gneiss, compared with average arkose*

	Transitional rock [1]	Average of 5 arkoses [2]		Transitional rock [1]	Average of 5 arkoses [2]
	Percent			Percent	
SiO_2	76.2	76.37	Na_2O	1.5	1.84
TiO_2	.22	.41	K_2O	4.5	4.99
Al_2O_3	11.1	10.63	H_2O	.85	.83
Fe_2O_3	.8	2.12	P_2O_5	.04	.21
FeO	1.4	1.22	CO_2	.84	.54
MnO	.06	.25			
MgO	1.1	.23	Total	99.81	100.94
CaO	1.2	1.30			

[1] Analysts: P. L. D. Elmore, S. D. Botts, and I. H. Barlow, U.S. Geological Survey Mar. 18, 1959. Collected on road to Moeda east of Bocâina da Serra, Marinho da Serra quadrangle.

[2] From Pettijohn, 1957, table 56–F.

The granite gneiss is well foliated and has well-defined planar parallelism of mafic minerals. It is light gray to buff and commonly contains light- to medium-gray laminae that vary from 1 to 20 millimeters in thickness, the color depending upon the proportions of felsic and mafic minerals. The gneiss is medium grained and contains approximately equal parts of quartz and microcline phenocrysts and minor amounts of fine-grained plagioclase, muscovite, and biotite. Many specimens contain about 5 percent rounded pale-blue quartz grains that average 4 millimeters in diameter.

As seen in thin section, the granite gneiss consists of subhedral phenocrysts of microcline that range from 1 to 3 millimeters in length; anhedral quartz phenocrysts, many of which show undulatory extinction; small subhedral crystals of oligoclase; and the accessory minerals sericite, muscovite, green and brown pleochroic biotite, epidote, and recrystallized zircon. Modal analyses of this rock by Norman Herz (Wallace and others, 1959, p. 48–49) average as follows:

Average composition of granite gneiss west of the Serra da Moeda, in percent

Quartz	32. 3
Microcline	38. 0
Biotite	5. 2
Sericite and muscovite	16. 2
Epidote and allanite(?)	. 5
Plagioclase (An_{16})	6. 8
Calcite	1. 0
	100. 0

According to Johannsen's classification (1939, p. 144) and other widely used classifications, this rock is a granite.

GRANODIORITE

The granodiorite zone lies parallel to and west of the granite gneiss zone; its areal extent is unknown but probably reaches at least from the Serra do Curral in the north to Jeceába in the south, a distance of more than 50 kilometers. It does not extend west of the Rio Paraopeba at Moeda, 13 kilometers west of the Serra da Moeda, where it is separated from a gneissic rock by a gradational contact zone. The area west of the Rio Paraopeba is geologically unmapped.

Granodiorite within the mapped area is predominantly porphyritic. A few small outcrops near the western boundary and at Moeda expose medium- to coarse-grained granodiorite. Although a contact between the porphyritic and nonporphyritic rock types was not seen, the writer assumes that both rocks are facies of a large granodioritic mass.

In contrast to the granite gneiss, the granodiorite has an intrusive igneous aspect. Some outcrops indicate that more than one-third of the rock consists of unoriented phenocrysts of quartz and microcline that average 2–3 centimeters in diameter. Modal analyses of specimens of the porphyritic facies (Herz and Dutra, 1958, p. 90) show more than 2 percent xenotime and minor amounts of allanite, minerals not generally associated with regional metasomatism.

In fresh outcrop the granodiorite is medium gray and spotted and has medium to very large light-gray to light-yellow quartz and feldspar phenocrysts in a groundmass of light and dark micas, quartz, and plagioclase.

As seen in thin section the porphyritic rock consists of large subhedral phenocrysts of microcline, anhedral crystals of quartz, green and brown biotite, epidote, sericite, muscovite, zircon, and the rare earth minerals xenotime and allanite.

Modal analyses by Norman Herz (Wallace and others, 1959, p. 49) of the porphyritic facies gave the following average composition:

Average composition of granodiorite west of granite gneiss zone, in percent

Quartz	41. 9
Microcline	18. 2
Biotite	12. 6
Sericite	. 7
Epidote	5. 6
Allanite	. 7
Xenotime	. 7
Plagioclase (An_{15})	19. 6
	100. 0

According to the classification of Johannsen (1939, p. 144), this rock is a quartz granodiorite.

Quartz-granodiorite is an uncommon rock in the Quadrilátero Ferrífero compared to granodiorite. The high percentage of quartz in the quartz-granodiorite is due to the abundance of large quartz phenocrysts in the rock. Petrographic analyses of three samples of nonporphyritic granodiorite collected within 2 kilometers of the porphyritic facies gave an average of about 27 percent quartz, 27 percent microcline, 27 percent plagioclase (An_{25}), 7 percent biotite, 2 percent chlorite, 1 percent muscovite, 6 percent epidote, and less than 1 percent xenotime and allanite. Herz and Dutra (1958, p. 94) showed that the trace elements of these two rock types are similar, and they concluded that the rocks are comagmatic.

BAÇÃO GRANITIC COMPLEX

The granitic rocks of the Bação complex vary in composition from place to place and include various facies of granodiorite, quartz-diorite, granite, and granite gneisses.

On the basis of potassium-argon age data, Herz and others (1961, p. 1111) suggested that the granitic rocks of the Quadrilátero Ferrífero can be assigned to three distinct periods of intrusion, their apparent ages being approximately 2,400, 1,350, and 500 million years. The type locality for two of the three rocks with distinct ages lies within the Pico de Itabirito district and within the Bação complex. The oldest age, about 2,400 million years, is represented by the Engenheiro Corrêa granodiorite in the south-central part of the Bação complex near the eastern edge of the district. This granite has not been recognized outside of the Bação complex.

The next oldest period, about 1,350 million years, is represented by the Itabirito granite gneiss, the type locality of which is a quarry above the city of Itabirito in the central-eastern part of the Pico de Itabirito district.

Biotite from one rock in the Bação complex, the Cachoeira do Campo granite, yielded apparent ages ranging from 720 to 760 million years. Herz (in Dorr and others, 1960, p. 92) considered these ages to reflect loss of argon from the biotite of rocks of Itabirito age as a result of later disturbances such as remobilization of the granite or introduction of metasomatizing fluids. This interpretation is based on the fact that a large number of values fall between 1,350 million years and 500 million years with no specific concentration apparent within that range (Herz and others, 1961, p. 1112). All the intermediate apparent ages are considered to be the result of the 500-million-year-old disturbance on rocks of Itabirito age (Herz, written commun.).

The Engenheiro Corrêa granodiorite in fresh specimens typically is dark gray and fine to medium grained (average grain size 0.5 mm); it has a weak banding of felsic layers and a very poor foliation. Coarse microcline phenocrysts are scattered irregularly through the matrix and are slightly concentrated in some layers. Microcline perthite is found in the groundmass. As seen in thin section, the plagioclase is generally untwinned or twinned according to the albite twin law, with a few broad bands; some grains are rimmed by potassium feldspar.

Pegmatites associated with the granodiorite consist of very coarse grained potassium feldspar, fine-grained plagioclase, quartz, and some muscovite. The pegmatites are restricted to joints and show no gradational contacts with the granodiorite.

The Itabirito granite gneiss at the type locality is medium to coarse grained, well foliated, and banded with alternating felsic and biotite-rich layers. Augen of microline as much as 10 millimeters in length are common. The large augen are apparently more abundant in the darker layers of the gneiss. The average grain size of the microcline is about 5 millimeters. Other feldspars are slightly smaller, quartz averages about 0.5 millimeters in diameter, and biotite, 0.3 millimeters. Pegmatites associated with the Itabirito granite gneiss consist of very coarse potassium feldspar, quartz, plagioclase, muscovite, biotite, and tourmaline, and sparse pyrite along the margins.

Spectrochemical studies by Herz and Dutra (1958, p. 93) reveal that the minor element suite of the felsic parts of the Itabirito granite gneiss is similar to that of the Engenheiro Corrêa granodiorite. A different suite of minor elements was found for the mafic parts of the gneiss.

The Cachoeira do Campo granite commonly crops out between the Itabirito granite gneiss and the metasedimentary rocks that surround the complex in this district, and in most places this granite has metamorphosed the metasedimentary rocks to garnet-staurolite schist in the contact zone.

Pegmatites are common and most are crosscutting; less commonly they are lit-par-lit and folded with the host rocks. The pegmatites are composed of feldspar, quartz, and muscovite; they are mostly a few centimeters in thickness and show both definite and indefinite boundaries. Some pegmatites contain abundant black tourmaline, which is a common mineral in the Cachoeira do Campo granite.

RELATION OF BAÇÃO GRANITES TO MINAS SERIES

Granitic rocks, probably a part of the Bação complex, intrude rocks of the Minas Series in the southeastern part of the Bação quadrangle (pl. 4, *B–B′* and *C–C′*). The probability that this granite is a part of the Bação complex is based on the fact that it is separated from a similar appearing granite, known to be a part of the complex, by less than 200 meters of strongly contact-metamorphosed rocks of the Minas and Rio das Velhas Series (700 N., 9,400 E., Bação). There the granitic rocks that lie on the north and south contacts of the metasedimentary rocks have weathered to similar saprolites. No fresh granitic rock was found within a radius of 1 kilometer. Most likely, the rocks are one and the same granite at depth, and the metasedimentary rocks are roof pendants.

A thin section of fresh granite collected from about 400 N., 8,500 E., Bação, contains about 54 percent quartz grains that average 1.0 millimeter across the largest dimension, 30 percent plagioclase grains that also average 1.0 millimeter, 15 percent biotite flakes that average 0.4 millimeter across, and 1 percent tourmaline, one subhedral crystal of which was about 1.5 millimeters in length. Rutile is present in bent crystals in some quartz grains and to a much lesser extent in some biotite plates. Some biotite and also some tourmaline contain small grains of zircon that are surrounded by strong pleochroic halos. Other specimens of granite collected in this vicinity are virtually similar to that described above but in addition contain minor amounts of potassium feldspar.

Thin sections of the quartzite of the Moeda Formation at the granite contact are seen under the microscope as a quartz-rich rock having variable amounts of biotite, sericite, and plagioclase. Pleochroic halos surrounding small grains of zircon were noticed in some biotite in this rock. Where the granite intruded stratigraphically higher zones in the Minas Series, the rocks at or near the contact are varieties of garnet-biotite schist (Batatal? Formation), moderately iron-rich hornblende-biotite-garnet schist (dolomitic itabirite of the Gandarela? Formation) and iron-poor hornblendite (dolomite of the Gandarela Formation or Piracicaba? Group). Some biotite in these rocks also contains zircon with pleochroic halos.

A contact between Cauê Itabirite and intruded granite occurs in an area south of this district. Except for partial recrystallization of quartz grains, the formation of magnetite and hematite crystals, and an increase in grain size, the common Cauê Itabirite remains virtually unchanged mineralogically at or near the contact zone, although it commonly becomes extremely platy, probably due to the redistribution of silica cement within the iron- and quartz-rich laminae. This platyness has been seen in many places where the Cauê is near outcrops of granite. The obvious relation between the granite in this part of the Bação complex and the Minas Series is that the granite is younger than the Minas Series and intrusive into it.

DIKE ROCKS AND QUARTZ VEINS

Dikes of medium- to coarse-grained granodiorite and pegmatite are common in the border zone surrounding the Bação granitic complex and are probably similar to those in the southeastern part of the complex described by Guild (1957, p. 27). The dikes, which are related to the granite that intrudes the Minas Series, radiate outward into the metasedimentary rocks that border the Bação complex. Diabase dikes, which are younger still and much less common, have intruded the granitic rocks, cut the granodiorite dikes, and intruded the Minas Series rocks. Amphibolite dikes are present in a few places within metasedimentary rocks that border the Bação complex. Quartz veins are present in all types of Precambrian rocks in the district.

GRANODIORITE DIKES AND PEGMATITE

Granodiorite dikes and pegmatites are common in the granitic and metasedimentary rocks along the southern border of the Bação quadrangle. They are especially prevalent near the contact between granite and sedimentary rocks, where they range from less than 1 meter to more than 10 meters in thickness. Generally, they cannot be traced laterally more than about 100 meters because of thick soil cover.

The granodiorite and pegmatite dikes commonly contain a small amount of tourmaline, and a few contain tourmaline crystals and biotite plates that are hosts for small grains of zircon surrounded by pleochroic halos similar to those described in the preceding section of this report. The dikes cut all rocks of the Minas and Rio das Velhas Series in this area. A large pegmatite dike occurs at the base of the Cauê near 520 N., 8,750 E., Bação, but the actual contact is marked by a lens of amphibolitic rock 1.5 meters wide. Contacts between granodiorite and dikes of pegmatite, diabase, or quartz were not observed.

The granodiorite and pegmatite dikes are related to the surrounding granite and have similar mineral assemblages, although the percentages of minerals may vary from dike to dike. This relationship is emphasized by the presence of pleochroic halos around zircon in biotite and tourmaline, as described above; zircon accompanied by these halos has not been reported in other granites of the Bação complex.

DIABASE AND OTHER MAFIC DIKES

Diabase dikes have intruded rocks of the Nova Lima Group and quartzite and schist of the Minas Series and have cut granodiorite dikes, pegmatite, and amphibolitic rocks in the southern part of the Bação quadrangle. Diabase has also intruded the granitic rocks within the district that have an apparent age, as determined by the potassium-argon method, of 500 million years.

The complete age span of the intrusion of diabase in this area is unknown. Dikes in some places have been folded with the Minas Series but in other places have been intruded into the northeast and northwest joint systems formed in the younger granitic rocks.

In thin section the diabase is seen to contain about equal parts of plagioclase (labradorite) and hornblende. Small amounts of pyroxene, apatite, biotite, epidote, magnetite, and pyrite are present in some dikes.

Mafic dikes, some of which may have the composition of diabase but which do not have diabasic texture, cut the rocks of the Nova Lima Group, the Minas Series, the Itacolomí Series, and the granitic rocks in the complex west of the Serra da Moeda and in the Bação complex. Dikes, which range from less than 1 meter to more than 10 meters in thickness, are weathered to the extent that the original minerals are unidentifiable. Weathered phenocrysts in these dikes have a definite lineation parallel to the trend of the dike. A large dike of this type may be seen in an embankment of the BR-3 highway west of Lagoa Grande at 8,450 N., 3,400 E., and can be traced northwest for about 1,200 meters. A similar dike at 9,950 N., 2,800 E., Lagoa Grande, was exposed during construction of the access road for Pau Branco mine.

These dikes cut the Cauê Itabirite and the Gandarela Formation.

A weathered plug of rock in gneissic granite at 11,800 N., 2,400 E., Marinho da Serra, contains minable concentrations of talc. As mafic rocks normally do not alter to talc during weathering, the plug originally may have been an ultramafic rock. Elsewhere in the Quadrilátero Ferrífero, steatitic rocks are found in the Rio das Velhas Series as alteration products of original ultramafic rocks (Dorr and Barbosa, 1963, p. C34–C35; Gair, 1962, p. A46; Guild, 1957, p. 25; and others).

Two weathered mafic dikes that contain well-oriented phenocrysts cut the Itacolomí Series rocks and can be seen in an embankment of the Inconfidentes highway at 8,100 N., 10,000 E., Lagoa Grande. There the dikes lie parallel to the foliation of the rocks but at an angle to the bedding planes. Whether the dikes were folded with or later than the host rocks is not evident.

AMPHIBOLITIC ROCKS

Lenses and dikes of amphibolitic rocks are common in the contact zone surrounding the Bação complex and are best exposed in the contact zones between the granite and Minas Series and Nova Lima Group along the southern border of the Bação quadrangle. There the amphibolitic rock occurs as black to dark-gray lenses and dikes that lie within the metasedimentary rocks, or in a contact zone, commonly about 50 meters wide, between the recognizable metasedimentary rocks and the intruded granite. The exposures of the amphibolitic rocks range from less than 1 meter to more than 20 meters in width, and the rocks can be traced laterally from a few meters to as much as 100 meters in some places. Fresh rock is extremely sparse.

Hornblende makes up more than 50 percent of a dike in the contact zone between the granitic intrusion and the Nova Lima Group at about 650 N., 8650 E., Bação; it also makes up 50 percent of the lenses of amphibolitic rock that crop out within the schists of the upper Minas Series at about 50 N., 8,100 E., Bação. Specimens taken from the lenses contain 10–20 percent garnet, less than 5 percent chlorite, and 5–10 percent of an opaque iron mineral, whereas the thin section of the dike rock showed more than 30 percent quartz, 10 percent chlorite, less than 2 percent opaque iron minerals, and no garnet. The amphibolite dike contains more than 10 percent plagioclase, whereas the amphibolite lenses contain none.

Conclusions based on the examination of only three fresh specimens would be hazardous, but detailed petrographic studies may further indicate that there are two types of amphibolitic rocks: (a) dike rocks that may be the metamorphic products of ancient mafic intrusions, and (b) lenticular bodies that may be the metamorphic products of dolomite, dolomitic phyllite beds, or beds of dolomitic itabirite, all three of which are fairly common in the upper part of the Minas Series.

QUARTZ VEINS

Quartz veins, abundant in all rocks of the area, range from small stringers to masses more than 2 meters thick and several hundreds of meters long. They consist chiefly of cloudy white barren quartz but in places contain small amounts of kyanite and pyrophyllite, or very small amounts of pyrite, arsenopyrite, pyrrhotite, stibnite, tourmaline, and gold. Small veins of very dark smoky quartz cut the barren white quartz veins in some places. Quartz veins of the Cata Branca gold mine were said to have contained large stibnite crystals. This mine is now caved, but crystals of stibnite several centimeters long were reported. Stibnite is generally considered an epithermal mineral, and its presence in this district would imply relatively near-surface, possibly post-Cambrian sulfide mineralization. Additional evidence of a younger mineralization may be the presence of copper sulfide minerals in the marble at Córrego do Eixo at 3,500 N., 8,500 E., Marinho da Serra, described in a later section of this report. Cinnabar has been reported in the Ouro Prêto area, southeast of the district.

Quartz veins containing intermixed crystals and shreds of kyanite and pyrophyllite are intruded into an aluminum-rich phyllite of the Cercadinho Formation that lies adjacent to the iron ore bodies at Pico de Itabirito, Andaime, and Abóboras.

Quartz veins are also present along low-angle thrust faults and steep normal faults throughout the area. These veins are not deformed and thus were formed after the faulting ceased. The quartz along the fault planes also contains sparse pyrite, arsenopyrite, and pyrrhotite, suggestive of deep-seated hydrothermal activity.

SURFICIAL DEPOSITS

Materials derived from bedrock mantle about 90 percent of the surface. These materials are in place (saprolite); or have rolled, slumped, or in some other manner moved slightly to moderately down slope (eluvium); or have been transported by running water and redeposited at a distance from their source (alluvium). Most of the surficial material in the mapped area weathered in place and can be used to identify the underlying bedrock.

Canga, clay, lateritic soil, talus, residual sand, and alluvium are also present as surficial materials in the mapped area. Of these, canga and clay have economic interest and are shown on the geologic maps of the district (pls. 1–4).

CANGA

Economically, canga is by far the most important surficial deposit in the Pico de Itabirito district. It has been defined as "a porous but resistant rock that forms at or near ground surface and which consists of detrital rock fragments, commonly either hard hematite or itabirite, cemented by a matrix of porous limonite" (Dorr, in Dorr and others, 1960, p. 108). It is an iron-rich rock of combined mechanical and chemical origin.

The canga deposits in the Pico de Itabirito district are confined to the vicinity of the Cauê Itabirite and Gandarela Formation although the canga may, in some places, overlie other formations. Canga caps and topographically controls many ridges that are underlain by the Cauê Itabirite and forms slopes extending from these ridges. Canga deposits on the western slopes of the Serra do Itabirito are not as common as the deposits formed on the eastern slopes of the Serra da Moeda.

The most common form of canga in the district is horizontal to slightly sloping blanketlike deposits of variable thickness that may cover an area of 3–4 square kilometers. These deposits overlie the more gentle slopes of the iron-bearing formations and commonly have dark-red to black moderately smooth vegetation-free surfaces which in many respects resemble the hardened surface of a nonviscous lava flow.

Canga deposits also are formed on and near the ridgetops in this district. These deposits are mostly thin, blocky, and rough; they are in the process of being weathered. They have little economic value except where they surround hematite ore deposits as at Pico de Itabirito, Abóboras, or Pau Branco.

FERRUGINOUS SOIL

Ferruginous soil as used in this report refers to the uncemented iron-formation debris mixed with dark-red ferruginous sand and clay. This ferruginous soil is widespread but was not mapped separately. It is ubiquitous on the eastern slope of the Serra da Moeda, where it has been derived from the Cauê Itabirite; there it ranges from a few centimeters to more than 3 meters in thickness. This soil is also present in irregular patches along the western sides of the Serra da Moeda and Serra do Itabirito; it is more prominent at Vargem dos Veados and Vargem Grande da Botica near the lakes and occurs at Vargem do Pico near Pico de Itabirito; it forms a thin surface covering in many small meadows within the Moeda Plateau.

Many of the thicker deposits on the eastern flank of the Serra da Moeda have been quarried for road metal used in the construction of the Rio de Janeiro-Belo Horizonte highway (BR–3) and the Inconfidentes highway. If mixed with asphalt, this material produces an excellent weather-resisting road cap. Much of the material used contains more than 60 percent iron. The thicker deposits of ferruginous soil contain a high percentage of hematite and limonite.

CLAY

Several small- to medium-sized high-alumina clay deposits are in the Pico de Itabirito district. Because of the cost of trucking the clays to the processing plants at Cidade Industrial, west of Belo Horizonte, these deposits are of limited value as of 1961. The geologic map of the Lagoa Grande quadrangle (pl. 1) shows several deposits within the Moeda Plateau that may have future value as raw material for high-alumina fire-clay products. Outside of the Moeda Plateau, a group of white sandy clay deposits that overlie granitic rocks near Saboeiro (7,000 N., 1,500 E., Bação) have been used, after washing, as a source for kaolin.

The clay deposits commonly occur near the center, although not necessarily on the lowest part of the Moeda Plateau. Most of them overlie the Fêcho do Funil Formation, but some overlie other formations of the Piracicaba Group or the Gandarela Formation of the Itabira Group.

Many of the outcrop patterns of the clay deposits are lenticular or irregularly rounded and resemble the outlines of small lakes or ponds. The deposits normally occur within a few meters to 10 meters above the present stream level. All the deposits within the Moeda Plateau are within about 50 meters of 1,300 meters above sea level; they crop out on sides of the valleys but rarely extend to the ridgetops. A deposit at 11,200 N., 7,200 E., Lagoa Grande, extends below the present drainage level.

Lithology and structure of the underlying rocks have no control on the location of the clay deposits, whose general trend is controlled by streams. A single deposit may overlie several different lithologies, as shown at 11,300 N., 7,200 E., and 10,300 N., 7,800 E., Lagoa Grande. Chemical analyses of clay samples taken from deposits in the north, south, east, west, and central parts of the Lagoa Grande quadrangle show that the deposits are related to each other but not to the underlying rocks (table 7).

TABLE 7.—*Chemical composition of some clays from the Lagoa Grande quadrangle*

[Analyses by Cia. Magnesita S.A., Belo Horizonte, October 1958]

	1	2	3	4	5
SiO_2	46.44	41.98	45.64	43.11	42.16
TiO_2	4.34	5.20	4.16	4.73	4.52
Al_2O_3	32.77	36.43	33.15	35.25	36.91
Fe_2O_3	1.75	1.50	1.50	1.50	1.65
Loss on ignition	11.73	14.09	12.75	14.00	14.50
Total	97.03	99.20	97.20	98.59	99.74

1. Roadcut north of Água Limpa reservoir; overlies dolomite.
2. Roadcut north of Água Limpa reservoir; overlies dolomitic phyllite.
3. Pit 2.5 km northwest of Pico de Itabirito; overlies sericitic phyllite.
4. Roadcut, Inconfidentes highway 2 km southeast of Lagoa das Codornas; overlies sericitic phyllite.
5. Streambed 2 km southeast of Lagoa Miguelão; overlies a contact zone of quartzite and sericitic phyllite.

A thin horizontal quartz-pebble conglomerate overlain by thin beds of grit, sand, silt, and clay is exposed at the base of a small clay deposit in the embankment of the Inconfidentes highway at 8,510 N., 7,350 E., Lagoa Grande. Underlying dolomitic phyllite of the Fêcho do Funil Formation dips 80° NNE. directly below the contact. Obviously, this deposit of clay is not the result of this phyllite weathering in place.

The high percentage of titanium oxide (table 7) is not readily explained. The average percentage of titanium oxide in sedimentary rocks according to Rankama and Sahama (1950, p. 564) ranges from about 0.4 to 0.6 percent, although some bauxite ores in laterite may contain about 3.2 percent. In the Quadrilátero Ferrífero, bauxite ore may average about 2.5 percent titanium oxide, the maximum being less than 4 percent.[1] Goldschmidt (1954, p. 419) stated that the titanium content in the inorganic matter of ordinary soils is of the order of one percent by weight of titanium oxide. He also stated that in certain soils derived from rocks very rich in titanium, the titanium oxide content may reach several percent as is the case of certain Hawaiian soils derived from basalt and that the titanium oxide content of bauxite derived from gabbroid or basaltic igneous rocks may attain 5 percent or more. The writer suggests that the high percentages of titanium oxide may have been derived from large preexisting Tertiary or Quaternary laterite or bauxite deposits removed from the general area by recent erosion.

QUARTZITE TALUS AND RESIDUAL SAND

Quartzite talus is abundant along the base of the quartzite cliffs of the Serra da Moeda, where it forms narrow aprons and talus cones. Quartzite blocks as large as 10 meters in diameter may be found several hundreds of meters from the base of the cliffs, but most blocks are less than a few meters across and are found in the aprons of the cliffs. The quartzite blocks eventually weather to loose quartz sand, forming several deposits large enough to be mapped. Other sand deposits commonly are near or overlie fault zones or zones of intense crumpling or shearing in the Moeda Formation, where the deformation has promoted leaching of the cement.

Sand from these deposits, when seen under the microscope, appears as a mixture of medium-grained well-sorted subangular clear quartz grains surrounded by shreds of sericite, plates of white mica, and irregular blobs of white clay. Because of these impurities, the sand cannot be used for cement for construction purposes without first being thoroughly washed. Neither iron nor iron staining of the quartz grains has been seen in the sand pits or under the microscope, and the material may be a potential source of glass sand. One deposit of this type is described on page F46 of this report. Two of the sand deposits are being quarried for road metal at the present time (1961). The sand is mixed with asphalt and laterite in the construction of the road cap.

A sand deposit in the Serra do Itabirito, about 2 kilometers east of Fonte da Água Quente, was mined for gold by slave labor more than 100 years ago.

ALLUVIUM

Alluvium and terrace gravel are found along the larger streams in the lowlands east of the Serra do Itabirito. Because of their small areal extent, these deposits have not been mapped. Gold-bearing gravel is known along the banks of the Rio Mata Porcos and is intermittently mined at the confluence of this stream and the Rio Sardinha, about 6 kilometers south of Itabirito.

Alluvial deposits are not common in the district, as the stream gradients are too high and valleys too narrow to permit accumulation. The sand and gravel of the deposits consist of fragments of vein quartz, quartzite, schist, granite, hematite, and limonite.

LANDSLIDE DEBRIS

A few exposures of landslide debris have been seen in roadcuts of the Inconfidentes highway. In a quarry at 6,700 N., 12,700 E., Lagoa Grande, the debris contains angular, unsorted, and unoriented pebbles, cobbles, and a few small boulders of canga, hematite, quartzite, phyllite, and vein quartz near the base of a red-and-white-spotted light-brown high-alumina clay deposit.

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[1] Written communication to John Van N. Dorr 2d from office of Alumínio Minas Gerais, S.A.

Because the sliding plane of the debris is nowhere exposed, the direction of slide is not clear, but the slide probably had a westerly component of movement, away from the present Serra do Itabirito.

This slide and others that contain similar material probably are older than Recent and may be of Tertiary age. Many landslides form each year during the rainy season owing to oversteepening of hillsides by erosion; the material in these recently formed landslides contains little clay and sand and consists mainly of debris from the hillside from which it slid. By contrast, the landslides of proposed pre-Recent age commonly have no supporting hills in their immediate vicinity and have abundant clay in the matrix.

STRUCTURE

The formation of the Quadrilátero Ferrífero as a geologic unit embraces a time span of about 2,000 million years during which several periods of orogeny and emplacement of granite occurred. The role of the granitic complexes has been important in forming the structure of the Pico de Itabirito district. The Bação complex shielded the area from certain orogenic effects in pre-Minas and Minas deformations that were produced elsewhere in the Quadrilátero Ferrífero.

In post-Minas times, however, the Bação mass was a major element in the deformation of all rocks in the mapped area. All sedimentary rocks in the district that lay between the western complex and the Bação complex were virtually caught in a huge vise; the western jaw was fixed in its position and the eastern jaw, the Bação complex, moved. Thus the Moeda syncline formed between two large anticlinoria, one to the east and one to the west. Most of the root structures of the anticlinoria have been obscured by granitization of the sedimentary rocks or by the intrusion of great masses of granite.

MOEDA SYNCLINE

The most significant structure in the Pico de Itabirito district is the north-trending, doubly plunging, overturned Moeda syncline, a remnant of a syncline between two anticlinoria. The syncline contains most of the formations of the Minas Series and a small part of the basal strata of the Itacolomí Series. It is assumed that the northern part of the structure is underlain by the Nova Lima Group, but the southern part is probably underlain in part by granite. The Serra da Moeda is the upright limb, and the Serra do Itabirito is the overturned limb. Minor folds within the syncline suggest that it is W-shaped in cross section. Minor folds range from simple to complex; simple folds parallel the major structure and are asymmetrical. Complex folds occur in three systems, trending north, northwest, and northeast.

Repetition of some of the outcrop patterns of younger formations in the center of the syncline shows that most of the structure is W-shaped (secs. *A–A′* and *A′–A′′* of pls. 1 and 3, and *B–B′* of pl. 3) and that the syncline plunges north at the northern end of the mapped area and south at the southern end. An airborne magnetometer survey by Levantamentos Aéreos S.A. indicates that the basement rocks are relatively close to the surface near the center of the syncline, which also suggests a W-shaped cross section.

The eastern limb of the syncline is overturned, as shown by the attitude of the rocks in the Serra do Itabirito. The dip of the overturned beds is somewhat variable and in part reflects the intersection of the cross folds. The dip of the beds in the northern and southern ends of the Serra are nearly vertical, or slightly overturned; beds in the same formations in the central-southern part of the Serra are commonly overturned as much as 45°. The intersection of a cross-fold system at Pico de Itabirito has warped the beds in the Serra to upright positions at this place. This particular area is described in a section of this report concerned with the Pico de Itabirito mine.

The western limb of the syncline is upright as shown in the attitude of the rocks in the Serra da Moeda. Bedding dips uniformly 55° to the east except in area of crossfolding.

MINOR FOLDS

With few exceptions all minor folds are related to the Moeda syncline and are found within the physical limits of this structure. The minor folds are, in general, relatively simple in the southern part and more complex in the northern part. Minor folds close to the flanks of the major syncline tend to be simple.

Simple folds.—Simple folds in the southern part of the Moeda syncline form a system whose axes are parallel to the axis of the major syncline. Axes of the minor folds plunge gently northward in some places and southward in others. Many of the minor folds are asymmetrical although symmetrical folds are not uncommon. The axial planes of these folds, in general, dip steeply toward the axis of the Moeda syncline.

Incompetent strata on the flanks of minor folds are commonly deformed into smaller asymmetrical, symmetrical, and isoclinal folds whose axial planes dip at steeper angles than those of the minor fold on whose flank they occur. The smaller folds in turn may show still-smaller crenulations that measure only a few centimeters in width. The folds in incompetent rocks have thickened crests and troughs and thinned flanks; this thickening and thinning is commonly indicative of flowage folding under deep-seated conditions. Folds in more competent strata show little to no thickening or thinning, but their internal structure is indicative of drag folding, such as would result from the same stresses that produced flowage folding. Strikes of the smaller-scale folds, although not precisely determined, appear to be parallel to their host folds.

Complex folds.—Minor fold systems in the northern part of the Moeda syncline strike in three directions (pl. 5): north, following the trends of the serras; northwest; and northeast. Where any two systems intersect, a complex fold occurs. A dome in the central part of the Moeda syncline is interpreted as a point where all three of the fold systems intersect.

The north-trending minor fold system lies parallel to and is near the flanks of the Moeda syncline. This system consists of simple folds similar to those described above. Those folds that follow the northeastern end of the Serra do Itabirito ultimately lose their identity by becoming parallel to the northwest-trending minor fold system in that area.

The northwestern minor fold system (pl. 5) is parallel to the axis of the Moeda syncline only as reflected in the outcrop patterns of the rocks of the Itacolomí and upper Minas Series in the northern part of the district. Elsewhere the axes of this fold system lie at an angle to the major axis. The folds most commonly are asymmetrical (pl. 1, cross sections) and in general are overturned to the south. Drag folding and, to a lesser extent, flowage folding are present in some incompetent rocks.

The northeast-trending fold system (pl. 5) is the least significant of the minor fold systems within the Moeda syncline but is shown in all rock units within the district. This system is more significant throughout a large part of the central, northern, and eastern parts of the Quadrilátero Ferrífero.

FAULTS

Faults in the mapped area are small and are of two types: (a) steep normal, reverse, and strike-slip faults, and (b) low-angle thrust faults.

All steep faults in the Serra da Moeda are related to stresses that originated southeast of the district. They are mostly right-lateral strike-slip faults and are shown on plate 5 and on the geologic maps as the Cachoeirinha fault (12,400 N., 1,500 E., pl. 1), Sobradinho fault (8,200 N., 6,000 E., pl. 2), Santa Efigênia fault (6,000 N., 6,000 E., pl. 2), and Marinho da Serra fault (2,000 N., 6,000 E., pl. 2). The Pau Branco fault (10,000 N., 1,500 E., pl. 1) is a left-lateral strike-slip fault as is the Cata Branca fault (3,500 N., 3,500 E., pl. 3) in the Serra do Itabirito; the two may be related, but their traces cannot be followed across the Moeda syncline.

Thrust faulting from the east is clearly shown in the rocks of the Nova Lima Group in the northeastern part of the district (sec. *A′–A″*, pl. 3). The heaves of separate thrust plates are thought to range from a few tens to perhaps 1,000 meters, but most of the movement is considered to have occurred along microshears along the cleavage planes of the schistose and phyllitic rocks. The great thrust faults mapped in the southern and south-central parts of the Quadrilátero Ferrífero have no known counterparts in the Pico de Itabirito district.

CLEAVAGE

The term "cleavage" as used in this report refers to that property of a rock which causes it to part along smooth surfaces. Cleavage planes are planes of parting; they commonly are closely spaced and may be due to rock texture—that is, mineral arrangement—or to closely spaced fractures. Many rocks have cleavage parallel to bedding or flow structure; this cleavage is referred to as primary. Secondary cleavage is that superimposed on the rock during late stages of metamorphism. Secondary cleavage may be classified as: flow cleavage, due to arrangement in subparallel planes of planar minerals, such as mica and chlorite, as a result of recrystallization in foliation planes; and fracture cleavage, due to fracturing either with or without mechanical rearrangement of minerals. The two types of secondary cleavage may grade into each other. Flow cleavage may develop from complete recrystallization without fracturing but, by definition, fracture cleavage cannot.

Cleavage is present in nearly all rock units within the district; general trends are shown on plate 5. In some places, especially within metasedimentary rocks of the Minas and Itacolomí Series, primary and secondary cleavage are readily distinguishable in the field, but fracture cleavage and longitudinal joints are commonly indistinguishable in the more competent rocks and are shown as joints on plate 5.

By definition, the trend of primary cleavage follows the strike of the metasedimentary beds or banding in gneissic rocks, and secondary cleavage cuts across these planar structures. Plate 5 shows the general trends in the granitic complexes within the district, but there are many exceptions.

An example of the coexistence of primary and secondary cleavage is shown in the granitic gneisses near

Bocaina da Serra west of the Serra da Moeda. At this location the primary cleavage, portrayed as fracture cleavage, follows the strike of the banding in the gneissic rocks and is parallel to the strikes of the bedding in the bordering sedimentary rocks. The secondary cleavage at this location is portrayed as a planar parallelism of dark minerals within the rock. These minerals do not lie in a plane parallel to the banding in the gneiss but in a plane forming an angle to the banding. The angle between these two planes is small at this locality. Larger and more pronounced angular differences were found in the Nova Lima Group rocks north of the Cata Branca fault near the town of Esperança and also west of the city of Itabirito.

Secondary fracture cleavage is superimposed on some primary cleavage planes in the banded gneisses in the Bação granitic complex. The secondary cleavage may indicate a later westward thrust of the granitic complex.

Some of the most obvious exceptions to the general cleavage trends are seen at 2,400 N., 11,100 E., Bação (pl. 4), south of Engenheiro Corrêa. There the pattern strongly suggests that the rocks were unaffected by a later period, or periods, of orogeny that produced the general cleavage patterns of the district. This suggestion was advanced by Herz (in Dorr and others, 1960, p. 99) and is discussed in a later section of this report.

LINEATION

The terms "linear structures" or "lineation" denote the parallelism of structural features that are lines rather than planes. These lines may be fold axes, long dimensions of minerals, long axes of pebbles, pencil structure, slickensides, streaks of minerals, cleavage-bedding intersections, and intersections of two cleavages. In order to simplify the presentation of these linear structures (pl. 5), the structures were divided into three groups: (a) lineation defined by minor fold axes, (b) lineation measured on the long axes of alined minerals, pencil structures, and slickensided surfaces, and (c) lineation formed by the intersection of two planar elements, such as bedding or banding, with cleavage.

The most conspicuous group of linear structures shown on plate 5 is that of fold axes. These are tectonic *b* axes. As described above, three trends were mapped: a northwest trend, a northeast trend, and a north trend. The folds range in size from small crenulations to minor folds. Shear folds are extremely scarce in the district; where present, their geometric relations indicate that they were formed by the same stresses that formed the normal folds nearby.

The second group of linear structures mapped (pl. 5) are the long dimensions of minerals, long axes of pebbles, pencil structures, slickensided surfaces, and streaks and blebs of minerals. Most of these linear structures are related to slippage within the rock units and are conspicuous in the low-angle thrust planes formed in the Nova Lima Group rocks in the northeastern part of the district. Most are interpreted as tectonic *a* axes, indicating the direction of movement of the rocks in response to the stresses accompanying regional metamorphism. Lineation in the Bação granitic complex is due to alinement of mafic minerals that formed parallel to the direction of the latest stresses. Lineations in the granitic complex west of the Serra da Moeda, especially those west of Bocaina da Serra, are parallel to the axes of folds within the granitic rocks and may be related to structures formed before the granitization of the preexisting rocks at this place. Those structures that lie within the granite that has an apparent age of 2,400 million years and east of Engenheiro Corrêa are thought to be related to primary flowage of that granite.

The third group of linear structures consists of lines formed by the intersection of bedding and cleavage planes or of two intersecting cleavage planes. The lineation formed by bedding-cleavage intersection in folds is commonly parallel to the fold axes where the cleavage is primary. Because of this relationship, the axes of broad folds were traceable in areas of infrequent outcrops. Where folded bedding is intersected by secondary cleavage such as at Bocaina da Serra, or north of Pau Branco, or north of Pico de Itabirito, the angle formed between the axial plane of the fold and a line formed by the intersection of the bedding and secondary cleavage planes will vary from 0° on the west to 90° on the flank of the fold. More accurate knowledge of the folds was gained in areas of infrequent outcrop within the Moeda syncline by the measurements of these types of linear structures.

JOINTS

The district contains a regular cross-joint set and two regular longitudinal-joint sets, which combine to form a conjugate joint system (fig. 13). The joints are smooth and transect all structures without deviation.

The cross-joint sets transect the axes of the northeast and northwest trending folds and lineations within the Moeda syncline at approximately 90°.

FIGURE 13.—Conjugate joint system in the Cauê Itabirite, Rio do Peixe canyon. About 160 meters of a nearly vertical wall are shown. The longitudinal-joint set produces the wide, flat faces of the cliff, and the cross joints lie parallel to the line of sight and plunge steeply to the left. A third and nearly horizontal set is also present.

The longitudinal-joint sets commonly lie parallel with the axes of the major north-trending folds within the Moeda syncline and are superimposed on all the rocks, independent of their lithology. One of the longitudinal-joint sets dips at steep angles, whereas the dip of the other is nearly horizontal.

METAMORPHISM

The grade of metamorphism within the Pico de Itabirito district ranges widely. The rocks within the Moeda syncline have been metamorphosed to low-grade phyllite and quartzite, whereas those surrounding this syncline reach the staurolite isograd in some places and locally are granitized.

Herz (in Dorr and others, 1960, p. 99–104) described the metamorphism of the Quadrilátero Ferrífero. He divided Precambrian time into three metamorphic periods: early, middle, and late. The various rocks of the Pico de Itabirito district exhibit the effects of metamorphism during these three periods.

Herz considered that the gneisses of granitic aspect located in the vicinity of Engenheiro Corrêa (pl. 4) formed during the early metamorphic period as a result of high-temperature, high-pressure regional metamorphism of sediments having a suitable composition, for example, feldspathic quartzite or arkose. He suggested that more-mafic preexisting rocks, such as graywacke, mafic volcanic rocks, and argillaceous dolomite, were metamorphosed to form a garnet-amphibolite facies gneiss.

The middle Precambrian metamorphism became active after the deposition of the Rio das Velhas Series. According to Herz these rocks generally show the lowest grade of metamorphism, the greenschist facies, except where the middle and late Precambrian granites lie nearby. Around the Bação complex the intrusive granites have thermally metamorphosed the country rock from its greenschist facies to the albite-epidote-amphibolite facies of Turner and Verhoogen (1951, p. 461).

The late Precambrian metamorphism affected the rocks of the Rio das Velhas, Minas, and Itacolomí Series. A general low-grade metamorphism produced rocks of the chlorite zone, but in places granitization and contact metamorphism produced rocks as high grade as the staurolite zone.

Structural and metamorphic data are interpreted as indicating that the general large-scale structural patterns in the rocks throughout most of the Quadrilátero Ferrífero are present in this district but are commonly smaller in scale. The large thrust sheets, dislocated anticlines and synclines, and accompanying tear faults of the southern part of the Quadrilátero Ferrífero are shown in the southern part of this district by small-scale thrusting and steep faults, by the tightly folded southern end of the Moeda syncline, and by the north-trending minor fold system. The large-scale crumpling and buckling in the central-eastern part of the Quadrilátero Ferrífero is shown in the relatively open folding of the northern part of the Moeda syncline, by small-scale thrusting and high-angle faulting in the rocks of the Nova Lima Group in the northeastern part of the district, and by the folding of the northwest-trending minor fold system. The intensely folded, crumpled, and buckled patterns found in the Serra do Curral in the northwestern part of the Quadrilátero Ferrífero are shown by the small-scale, northeast-trending fold system in the northern part of this district.

The rocks throughout the Quadrilátero Ferrífero were deformed during two periods of orogeny with apparent ages of about 1,350 million years and 500 million years. The orogenies produced low-grade metamorphism of all strata in the district in spite of the fact that the Nova Lima Series rocks underwent both periods of metamorphism. Local areas of high-grade contact metamorphism were produced by intrusive granitic bodies.

GEOLOGIC HISTORY

Most of the history of the rocks invaded during the oldest period of granite intrusion is lost. Only a small roof pendant remains from strata predating the oldest-known granite in South America (determined as about 2,400 million years old by the potassium-argon method of age dating). The intruded strata were believed to have been of sedimentary and perhaps of volcanic origin; these strata have not been seen elsewhere in the Quadrilátero Ferrífero. The structural patterns within these oldest-known strata match no others within this district.

A period of quiescence followed the oldest granite intrusion and may have lasted until about 1,350 million years ago, the indicated age for an intermediate period of granite intrusion. During this quiet period the Rio das Velhas Series was deposited. Deposition was interrupted or terminated by the upwarping of the Bação granitic complex and the folding of the rocks into a series of tightly folded northeast-trending anticlines and synclines. The type and attitude of the folds is suggested by: (a) the steeply dipping crossbedded quartzite of the Nova Lima Group that forms a prominent ridge beginning at 7,800 N., 3,000 E., Itabirito, (b) the steeply dipping bedding planes of quartzite of the Nova Lima Group near the Bem-te-vi tunnel at 11,500 N., 8,500 E., Itabirito, (c) the steeply dipping northeast-trending foliation of the granitic rocks in the northern half of the Bação complex (these granites have been interpreted as originating through processes of granitization of the rocks of the Rio das Velhas Series), and (d) the attitude of several north-northeast-trending quartzite lenses found west of the Serra da Moeda near 9,000 N., 3,500 E., Marinho da Serra. The quartzite in these lenses is similar to the quartzite of (a) and (b) above and is enclosed in, or forms, the western boundary of a metasomatic granite with similar trends as (c) above.

A period of erosion followed the folding of the rocks, and the area was reduced to a surface of low relief cut as deep as the Nova Lima Group rocks. The erosion was followed by a period of downwarping during which the transgressing Minas seas covered the district. The first stage of transgression of the seas resulted in the deposition of the clastic sediments of the Caraça Group and included the coarse-grained, commonly crossbedded nearshore sediments of the Moeda Formation, followed by fine-grained deep-water sediments of the Batatal Formation. The second stage of the depositional sequence of the Minas Series rocks involved the precipitation of chemical sediments of the Itabira Group in quiet shallow seas. This stage was followed by a second deposition of clastic sediments, those of the Piracicaba Group. The thinning of the Moeda, Batatal, Cauê, and Gandarela Formations in the southern and southeastern parts of the Serra do Itabirito, but not in the Serra da Moeda, suggests that the Bação complex remained unstable until Piracicaba time and may have been rising at a rate less than the rate of deposition. It is probable that the complex was never above sea level during Minas times.

A local upwarping of the southern part of the Quadrilátero Ferrífero followed the deposition of the Minas Series, and erosion cut at least as deep as the Barreiro Formation in the Pico do Itabirito district. Pebble-cobble-boulder conglomerate, siltstone, and quartzite lenses of the basal part of the Itacolomí Series suggest a rapid deposition of material derived from the Minas Series. The abrupt grading of the rock fragments in the conglomerate and the abrupt changes from quartzite to siltstone or conglomerate suggest that the general region became unstable and that the level of the depositional area fluctuated rapidly. The Bação complex probably became a fast-rising positive area, shedding its cover of rocks on the Minas Series over the southern part of the Quadrilátero Ferrífero.

Field data indicate the following sequence of events during the 500-million-year-old orogeny:

(1) Folding of the Rio das Velhas, Minas, and Itacolomí Series to form the north-trending Moeda syncline and the north-trending minor simple folds. Initiation of small-scale thrust faulting and steep strike-slip faulting in the northern part of the Itabirito quadrangle.

(2) Pinching or tightening of the northern end of the Moeda syncline (north of the district) and the subsequent folding of the northwest-trending minor complex fold system. Geologic sections *B–B′*, *C–C′*, *D–D′* and *E–E′*, Lagoa Grande (pl. 1), cut a northwest-trending fold.

(3) Pinching or tightening of the southern end of the Moeda syncline by a westward migration of the Bação granitic complex, and the subsequent folding of the northeast-trending minor complex fold system. This fold system is superimposed on all preceding folds. Small-scale thrusting was renewed in the northern part of the Itabirito quadrangle; vertical movements were initiated in the high-angle faults at Abóboras (10,500 N., 1,000 E., pl. 3) and in the Bonga fault (6,300 N., 4,000 E., pl. 3), and in left-lateral strike-slip faults, such as the

Cata Branca fault (4,000 N., 3,000 E., pl. 3), the Pau Branco fault (9,500 N., 2,000 E., pl. 1); and a small group of faults developed in the southeast corner of the Marinho da Serra quadrangle. In the Marinho da Serra quadrangle (pl. 2), the following right-lateral strike-slip faults also formed: the Sobradinho fault (8,300 N., 5,500 E.), the Santa Efigênia fault (6,200 N., 6,000 E.), and the Marinho da Serra fault (1,800 N., 6,500 E.). The small faults that form a steplike outcrop pattern of the displaced rocks from 500 N., 11,300 E., to 500 N., 13,000 E., Marinho da Serra, are interpreted as a part of a large system of tear faults bordering a thrust sheet that lies south of the district boundary. Drag folds indicate that these faults have had a late vertical movement probably related to a westward surge of the Bação complex. The westward movement of the complex also provided stresses relieved by many small high-angle normal and reverse faults such as the Cachoeirinha fault (12,500 N., 1,500 E., pl. 1) and those at 11,000 N., 1,000 E. and 5,000 N., 5,500 E., Lagoa Grande.

(4) The development of a ubiquitous joint system with northeast- to northwest-trending sets.

ECONOMIC GEOLOGY

The Pico de Itabirito district contains vast iron resources in the Itabira Group, most of which are in the Cauê Itabirite. The iron ore is dominantly hematite which occurs in deposits that have been classified as: (a) massive high-grade hard hematite, (b) high-grade soft or disaggregated masses of hematite, (c) intermediate-grade iron ore, (d) enriched itabirite, (e) rolado or eluvial deposits consisting of an aggregate of uncemented pebbles, cobbles, and boulders of hard hematite, and (f) canga, a type of hardpan consisting of fragments of hard hematite cemented by limonite. Soft ocher is present in some itabirite but commonly occurs only in small lenses. Hematite, magnetite, and other iron minerals occur in rock formations other than the Cauê Itabirite but only in intermittent lenses or dispersed; if dispersed, they commonly constitute a very low percentage of the total mineral assemblage. Hence, the term iron-formation as used in this report denotes the Cauê Itabirite unless otherwise specified.

The iron-formation has an average thickness of about 300 meters in this district and crops out only in the Serra da Moeda for 28 kilometers and in the Serra do Itabirito for 24 kilometers. Most of the ridge lines of both Serras are formed by the iron-formation. The rocks make up, for the most part, dip slopes in the Serra da Moeda. Both belts have been exposed at the surface at least since Tertiary time, but little is known of the nature of the iron-formation more than a few meters below most outcrops. Where the iron-formation has been penetrated by roadcuts, by tunnels, or, in a few places, by drill holes (50 m or more in depth), no perceptible change in the physical properties of the rock are apparent; no systematic change in the iron content has been determined although the iron content probably decreases with depth as elsewhere in the Quadrilátero Ferrífero (Dorr, oral commun.).

Assuming the iron-formation has a specific gravity of 3.5 and that it contains an average of 45 percent iron, a total of 54.6 million metric tons of rock per meter depth containing 24.1 million metric tons of iron per meter depth are present in this district.

In addition to the iron reserves in the iron-formation, the district contains blanketlike deposits of rolado and canga. The rolado commonly has a grade of more than 66 percent iron after screening, and the the canga generally ranges from about 56 to 62 percent iron, depending on the ratio of limonite cement to hematite fragments. Rolado and canga deposits are estimated to contain about 55 million metric tons per meter depth in this district. Some of the deposits of canga and rolado (undivided) that are at least 1 meter thick are shown on the geologic maps (pls. 1–4).

One large and three small deposits of high-grade hematite ore that ranges from 66 to 69 percent iron are known within this district. They contain a total of about 115 million metric tons of hard compact ore and nearly as much soft friable ore, making a total of about 225 million metric tons of ore, in these deposits. The deposits are lenticular and extend to undetermined depths.

Manganese oxide minerals are present in the weathered itabirite of the Cauê and Gandarela Formations and in the weathered carbonate rocks of the Fêcho do Funil Formation. The Batatal Formation contains a small amount of manganese oxide. Lenticular and podlike deposits of manganese minerals are found within these formations in a few places, but most manganese minerals are found in the contact zone between the Cauê and Gandarela Formations. Manganese oxide minerals are also present in very small amounts in canga that overlies itabirite.

Marble occurs in lenses in the Gandarela and Fêcho do Funil Formations, surrounded by dolomitic phyllite. Small quantities of copper sulfide and carbonate minerals are associated with some marble in the southern part of the district (pl. 2).

Other mineral resources within the district include deposits of high-alumina clay; building stone; sand, including several potential glass-sand deposits; and small deposits of kaolin, talc, and kyanite (pls. 1–4). The district also contains a small amount of placer gold and the rare earth minerals xenotime and allanite.

IRON ORES

For descriptive purposes, the iron ores of the Quadrilátero Ferrífero are divided into four general types: (a) hard, intermediate, and soft high-grade hematite ore, (b) supergene medium-grade ore (intermediate-grade iron ore and enriched itabirite), (c) rolado, and (d) canga, all found in the Pico de Itabirito district. In this district, medium-grade ore also includes several varieties of disaggregated itabirite that are being mined by several local companies.

HIGH-GRADE HEMATITE

In the Quadrilátero Ferrífero, hematite ore considered as high grade contains 66 percent or more iron. The ore is largely ferric oxide. Most ore contains small amounts of silica and alumina, generally less than 2 percent, but some contain less than 1 percent of these impurities. Silica is present as quartz, and alumina as clay, kaolin, talc, and tourmaline. The maximum sulfur content of the ore is 0.04 percent.

The physical properties of the high-grade hematite ore vary widely. The reasons for the physical differences in materials of similar chemical composition are not fully known, but the variations are thought to be caused by differences in genetic history. The most conspicuous physical variation is in the uneven tendency to break down into fines (less than ½-inch size) during mining and subsequent handling. The high-grade ore is classified as hard, intermediate, or soft, depending upon how readily it disintegrates. The following classification has been proposed by Dorr and Barbosa (1963, p. C55):

Classification of ore	*Half-inch size or above after mining, crushing, and screening (percent)*
Hard	75–100
Intermediate	25–75
Medium hard	50–75
Medium soft	25–50
Soft	0–25

High-grade hematite ore bodies in this district are known at Pico de Itabirito (1,200 N., 700 E., Itabirito), Andaime (8,500 N., 1,300 E., Itabirito), Abóboras (10,800 N., 200 E., Itabirito, pl. 3) and at Pau Branco (11,000 N., 1,800 E., Lagoa Grande, pl. 1). All lie within the Cauê Itabirite, and their locations are determined by the intersection of either northeast or northwest minor folds with the main trend of the Moeda syncline. The Várzea do Lopes mine (10,000 N., 5,700 E., Marinho da Serra, pl. 2) also contains high-grade hematite ore in Cauê Itabirite, but its relation to intersection of folds is not clear.

The Pico de Itabirito mine area (pl. 6) has been chosen to illustrate the structural control of the deposition of high-grade ore. This area shows many crumpled and buckled fragments of rock, now solid hematite ore, that were completely replaced by the iron after they were deformed (fig. 14).

The iron ore formed at a place on the eastern limb of the Moeda syncline where that limb is intersected by a system of northeast-trending folds which have been traced for some kilometers southwest of the deposit.

ORIGIN

Several hypotheses have been advanced for the origin of the high-grade hematite ore of the Quadrilátero Ferrífero, among the most important of which are the sedimentary hypothesis (Leith and Harder, 1911), the supergene enrichment hypothesis (Gathmann, 1913; Park, 1959), and the metasomatic replacement hypothesis (Dorr, Guild, and Barbosa, 1952, p. 295).

The metasomatic replacement hypothesis, to which this writer subscribes, has been presented in two major versions. According to Guild (1957, p. 55–58), the high-grade hematites that replaced itabirite and dolomite were mobilized by hydrothermal solutions while these solutions were passing through thick deposits of itabirite. Guild believed that brecciation caused by thrust faults localized the ore deposition. The water that moved the iron was thought to be connate, and the source of heat may have been metamorphic rather than igneous.

Dorr (in Dorr and others, 1960, p. 106–108) believed that the metasomatic replacement was synmetamorphic, effected by high-temperature fluids, perhaps at supercritical temperatures, and that the source of the fluids was from the granite with a potassium-argon age of about 500 million years. He also suggested that the source of the iron was the Cauê Itabirite; that the siliceous itabirite was the preferred, although not the exclusive host rock for the replacement; and that low pressures in zones of relatively high porosity in the host rock, particularly in the axial zones of folds, channeled the ore-forming fluids into the sites of ore deposition. The coincidence of the ore bodies with the intersections of fold systems appears to be a critical addendum to Dorr's metasomatic hypothesis and a controlling factor within the Pico de Itabirito district.

Although the origin of the soft and intermediate high-grade hematite ores has been discussed by many geologists, the problem is not fully solved. One school of thought maintains that the soft ores were formed by the supergene or hypogene leaching of quartz or dolomite from itabirite, leaving the residually enriched and disaggregated soft hematite. Another school of thought suggests that the hematite was deposited as a primary sediment and never was hardened. A third school believes that the soft and intermediate high-grade hematite ores were originally hard but have been softened by the leaching of small quantities of hematite from individual grains or clusters of grains, thereby partially or completely disintegrating the mass. No chemically detectable new materials have been added to the ore. The agency of leaching is believed by most geologists to have been circulating ground water.

Guild (1957, p. 45) was the first to find blocks of soft hematite buried deeply in alluvium. Later Dorr and Barbosa (1963, p. C74–C76) found other blocks. The blocks of hematite, which formed ancient talus piles, clearly could not have accumulated in their present completely disaggregated state. Dorr, Guild, and Barbosa (1952, p. 294) emphasized that the disintegration took place in environments where there was a continuing slow circulation of ground water. Because in such environments adjacent blocks may be hard and others soft, a second control must have been operative. Dorr and Barbosa (1963, p. C74) suggested that the metasomatic process was not complete in many places and that for this reason some high-grade hematite ores had much higher porosity than others. They argued that the more porous ores formed the intermediate and, if subjected to long continued leaching, the soft ores.

Conditions seem to be favorable for the groundwater leaching hypothesis in such deposits as (a) the Pau Branco, which overlies phyllite, because the lower part of the ore is continuously saturated with water in a perched water table, and (b) in the soft ore parts of Pico de Itabirito bodies, where the ore is continuously wet.

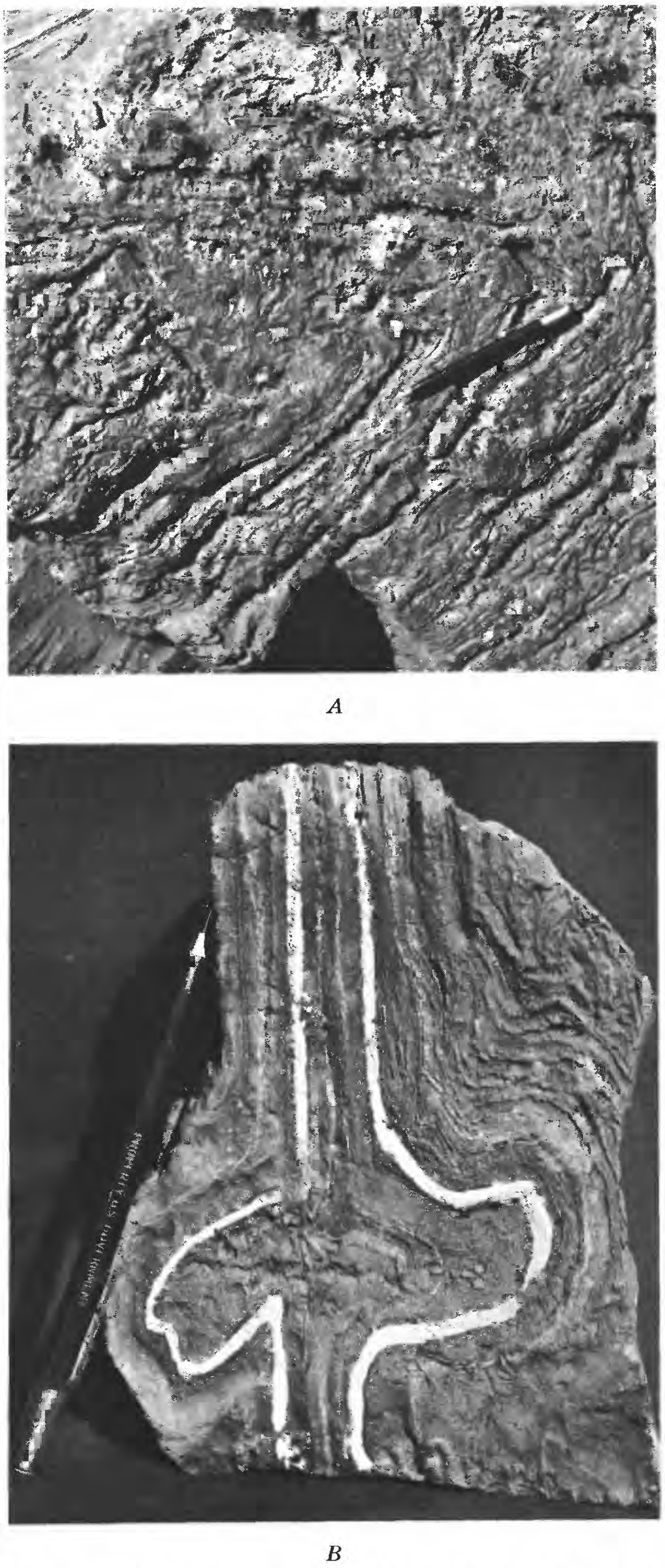


FIGURE 14.—Crumpled bedding in itabirite. A, Itabirite completely replaced by hematite. This replacement is common in most leached outcrops of the iron ores at Pico de Itabirito and Abóboras. B, Compact hematite ore from Pico de Itabirito. Two of the laminae in this specimen have been painted white to emphasize their deformation.

A hypothesis of hydrothermal alteration of some hard high-grade hematite ores to soft ores of the same grade is offered by the present writer. Many samples of soft and hard high-grade hematite collected across the contacts in the Pico de Itabirito adit 1 show little or no difference between the iron content of the two types of ores. Presumably nothing has been added or subtracted from either one; the difference appears to be that of compactness.

Polished sections made from hard ore specimens appear surprisingly porous under the metallographic microscope at a magnification of 1,000 times, and the cementing material between the very fine hematite grains that compose the rock is hematite itself. Crushed fragments of the soft ore as seen under the microscope are composed of similar very fine grains of hematite mixed with somewhat larger grains that probably are cemented aggregates of the finer grains. It was noted that the smaller aggregates and free grains are magnetic and that the larger aggregates are not.

These facts suggest that the ores as originally deposited were one and the same rock type and that a solution capable of leaching most of the hematite cement acted upon certain parts of the rock mass. The random pattern of the locations of hard and soft ore pods in the Pico de Itabirito adit seems to indicate that the leaching solutions followed steep permeable channelways rather than saturating the entire area, as would be expected of ground water. The preexisting overburden of at least the upper Minas Series and the Itacolomí Series has been eroded from the deposit. Today, rainwater percolates downward through these permeable channelways and continues the leaching process once performed by solutions that this writer suggests emanated from below.

The presence of deep-seated soft high-grade hematite ore bodies underlying thick hard high-grade hematite ores is not uncommon in the Quadrilátero Ferrífero. Many such ore bodies are near known granitic intrusions. It is doubtful that cold circulating ground waters could selectively accomplish the leaching process necessary in the Pico de Itabirito mines or in places where a thick protective layer of hard ore or layers of impermeable phyllite, quartzite, and canga are present.

The hypothesis calls for ascending hydrothermal solutions emanating from a cooling magma in the vicinity of the ore body. It is this writer's belief that the granitic body that lies below the Pico de Itabirito not only furnished the solutions in the early metasomatic process of ore formation but subsequently provided the leaching solutions that disaggregated parts of the same ore.

MINERALOGY

The mineralogy of the high-grade hematite ore is relatively simple. Hematite, the chief mineral, is nearly always the fine-grained equigranular well-crystallized variety; the red earthy variety is unknown. Magnetite occurs only in crystals intermixed with hematite. Martite, the isometric nonmagnetic, iron sesquioxide pseudomorph after magnetite, is present but scarce. Quartz is very sparse and occurs as widely scattered residual grains. Silica also occurs in small amounts in talc and kaolin. Manganese appears only as a trace in chemical analyses of most high-grade hematite. Phosphorus is present in all chemical analyses of hematite but in less than 0.05 percent in most high-grade ore bodies; it seems to decrease to about 0.02 percent at depth in many compact hematite deposits. Some surficial deposits such as canga contain as much as 0.3 percent or more phosphorus. Alkalic tourmaline (green and red varieties) as well as iron tourmaline (commonly black) have been seen in polished sections of compact ore from the Pico de Itabirito deposit.

High-grade hematite ore consists of aggregate of specular hematite or masses of very small crystals. These masses and aggregates are well cemented to form an extremely hard and brittle rock (hard ore) or poorly cemented to form relatively loose masses (soft ore).

Compact hematite, as seen under the metallographic microscope, appears as a uniform mosaic of interlocking anhedral to subhedral crystals. Compact hematite grains in the Pico de Itabirito ore body average about 0.06 millimeter in diameter and range from 0.02 to 0.08 millimeter in diameter. A few cobbles of compact ore, from talus surrounding the Abóboras and Pico de Itabirito deposits, show interlocking rhombohedra which range from 1 to 4 millimeters or more across. Material of this texture has not been found in place.

Although the compact type hematite in hand specimens appears to be dense and nonporous, the rock when seen under the microscope shows considerable porosity.

Disaggregated hematite, soft ore at Pico de Itabirito does not differ significantly from the hematite of the compact ore. Individual crystals of soft hematite tend to be slightly magnetic.

Large plates of micaceous hematite are scarce but have been found at Abóboras, Pico de Itabirito, Pau Branco, and elsewhere. Most of the material was found in boulders of float that are more resistant to weathering than the surrounding rocks. In a few places this material occurs in small faults that cut itabirite and hard ore bodies. Plates of the micaceous variety attain a width of 60 millimeters or more; they are locally called "espelhos de macacos" (monkey mirrors). The manganese content within any deposit of hematitic material may vary considerably, but, in general, most compact hematite ore contains only a trace of manganese, whereas soft ore may contain from a trace to more than 35 percent manganese. The ratio of manganese to iron is high in some itabirites of the Gandarela Formation and low in the Cauê Itabirite. Among the common manganese minerals present are psilomelane and wad admixtures; pyrolusite is less common.

SUPERGENE ORE

Two types of supergene iron ore occur in the Pico de Itabirito district. Both are associated with and derived from the itabirite of the iron-formation, and field evidence indicates no genetic relationship of such ore with the high-grade hematite deposits. One type, called intermediate-grade iron ore, ranges between 66 and 57 percent iron with a maximum of 7 percent silica. The other, called enriched itabirite, contains less than 63 percent iron and more than 7 percent silica. Intermediate-grade ore may be used directly in the blast furnace, with agglomeration of fines; enriched itabirite would need to be both concentrated and agglomerated before use.

Ore of intermediate grade locally lies as a blanket over enriched itabirite and commonly is covered by canga. Exploration of the large Tutamea deposit (12,500 N., 2,750 E., pl. 1) by Cia. Mineração Novalimense by drill holes and adits revealed a body averaging about 63 percent iron, 1.7 percent alumina, and about 2.8 percent silica, with about 4.7 percent water of hydration (J. V. N. Door 2d, written commun.). Such ore has a very irregular lower boundary, locally extending as deep as 90 meters, although commonly much shallower.

Certain beds and zones in the itabirite near the surface are enriched locally to intermediate grade and may persist to unknown distances along strike; they are commonly covered at the surface by canga indistinguishable from that overlying enriched itabirite.

Enriched itabirite is itabirite which has been disaggregated by the leaching of silica or other soluble constituents; this leaching has produced a wide range of degree of residual enrichment. Enriched itabirite commonly is covered by canga. The drilling at Tutamea confirms observations made elsewhere in the region (Dorr and Barbosa, 1963, p. C79–C80) that the enrichment is related to the present erosion surface because, unlike the high-grade hematite deposits, tenor decreases with depth. Grade of enriched itabirite not only varies with depth but also varies between beds or zones in the itabirite, probably because of slight differences in the permeability of the rock.

The mineralogy of both the intermediate-grade ore and enriched itabirite is simple. The main constituents are quartz and hematite, with significant amounts of limonite in the intermediate-grade ore and in some enriched itabirite as shown by the high percentage of water of crystallization. Minor constituents are gibbsite(?), manganese oxides, and an unknown phosphorus mineral.

Reserves of such ores are unknown but very large. The Tutamea deposit might contain as much as 100 million metric tons (Dorr, written commun.), and it is quite possible that other yet undiscovered deposits of similar intermediate-grade ore may be found under the canga cover. The amount of enriched itabirite is undoubtedly large but, without subsurface exploration, an estimate would be unwarranted.

Disaggregation and residual enrichment of itabirite is known to have reached depths of over 200 meters in the Serra da Rola Moça, some 10 kilometers north of this area (Pomerene, 1964). Drilling in the João Perreira area some 10 kilometers south of the area revealed no unenriched or hard itabirite to depths of 184 meters (Jurgen Eichler, written commun.). Drilling in the Tutamea deposit in this area showed no unenriched or hard itabirite to depths of more than 100 meters. On the other hand, fresh unenriched itabirite crops out in a few places in the Serra do Itabirito and is found in the Rio do Peixe canyon floor, where rapid erosion below old erosion surfaces has bared fresh rock.

ROLADO ORE

The term "rolado," from the Portuguese word meaning rolled, has been referred to as rubble ore by Dorr and Barbosa (1963, p. C76). As a part of their definition, these authors include fragments of high-grade hematite that have accumulated as talus or rubble below outcrops of hard ore. The huge boulders of hard high-grade hematite that surround the Pico de Itabirito and angular boulders and cobbles of similar material found in the exploration adits (pls. 7, 8) would be classified as rubble ore to comply with this definition. In the present report, however, the blocks are considered as part of the mine and are discussed in a later section. Rolado is considered as accumulations of loose high-grade hematite fragments of pebble, cobble, and small boulder sizes that have rolled down the slopes from outcrops and, in places, come to rest on the surface far out on the valley floor. The source area is not apparent for rolado relatively distant from potential sources. Blankets of canga are associated with the rolado deposits in some areas.

Most fragments of high-grade hematite that constitute the rolado deposits are well rounded and elongated. They resemble stream-worn fragments, even though they may have moved by creep less than a few meters from their original source. The rounded effect is explained by Dorr and Barbosa (1963, p. C76) as probably resulting from intermittent heating by the tropical sun and quick drenching by heavy showers, a process that would promote both chemical and mechanical weathering. The effect of abrasion on individual pieces is almost nonexistant.

Deposits of rolado in this district are numerous, but most are small. A few are as much as 3 or 4 meters thick. Those that are at least 1 meter or more thick have been shown on the geologic maps but are not divided from canga deposits (pls. 1–3).

The grade of the rolado deposits averages about 66 percent iron after screening (table 8). A high percentage of iron is to be expected inasmuch as rolado is derived from hard high-grade hematite. Screening and (or) washing of the rolado removes much of the soil from the fragment surfaces, thus yielding an excellent export-grade iron ore easily recoverable in surface operations.

CANGA

The term "canga" originated in Brazil and is now used in many countries to describe a weathering product widely distributed in tropical and subtropical regions that have oxide-facies iron-formations.

The essential characteristic of the rock is hydrated iron oxide (limonite) which has been precipitated at or near the surface to form a type of iron hardpan. The limonite may cement fragments of iron-formation, iron ore, or, more rarely, nonferruginous rocks. The rock formed is commonly porous to cavernous but has low permeability; it is practically inert chemically and is strongly resistant to mechanical erosion. Thus canga commonly forms a capping over iron-formation outcrops and retards the erosion of underlying rock. The protective cap also gives the leaching solutions more time to penetrate to greater depths within the iron-formation than otherwise would be possible if erosion kept pace with leaching of the rock.

TABLE 8.—*Chemical composition of dry screened rolado, Pico de Itabirito district*

[Analyst: No. 1, analysis by Cia. Mineração Novalimense; No. 2, Cássio M. Pinto, DNPM, Belo Horizonte, December 1957. Abbreviation used: nd, not determined]

	1	2		1	2
Fe	67.08	63.6	P	.06	.07
SiO_2	.41	4.4	FeO	nd	1.8
Al_2O_3	1.89	3.0	Loss on ignition	1.76	nd
Mn	.19	.85			

1. Average of 1 ton of samples collected by Cia. Mineração Novalimense from their property at 10,300 N., 3,700 E., Lagoa Grande quadrangle.
2. A 2-kilogram sample from Várzea do Lopes mine at 10,000 N., 5,700 E., Marinho da Serra quadrangle. Unwashed sample contains a small amount of soil intermixed with the pebbles of high-grade hematite.

The origin of the canga in the Quadrilátero Ferrífero has been a subject of controversy among the geologists who have studied the region. They are in agreement concerning the formation of the mechanically derived part of the canga, that is, the pebbles, cobbles, or fragments of high-grade hematite, but they disagree concerning the chemical fraction, that is, the limonitic cement. The problem of precipitating iron as limonite involves (a) whether the iron-rich solutions traveled a few centimeters or several tens of meters, and (b) whether precipitation was due to evaporation in conjunction with upward movement of the solution by means of capillary action or to downward-moving solutions finding the proper chemical environment.

The canga in the Pico de Itabirito district may have formed in several different ways. That on the ridgetops may have formed where iron precipitated as limonite from solutions that moved upwards a few centimeters or meters, whereas the canga formed in the basin between the serras could have formed where iron precipitated from solutions that traveled from the slopes of the serras hundreds of meters away and then descended through the soil cover until a favorable chemical environment was reached.

The percentage of iron in the canga varies widely in this district. Where the limonite has cemented fragments of nonferruginous material such as quartzite, phyllite, or soil, the tenor of iron may be only a few tens of percent; in other places where limonite has cemented fragments of hard high-grade hematite, the rock may contain more than 64 percent iron. The latter type of canga is commonly called canga rica.

Nearly all canga contains relatively high percentages of alumina and phosphorus. There is no "typical" canga in this district; because of the heterogeneous composition of the rock, as indicated in table 9. In general, the canga used in local blast furnaces ranges from 56 to 62 percent iron.

Table 9.—*Chemical composition of some canga from Marinho da Serra quadrangle*

[Analyst: Cássio M. Pinto, DNPM, Belo Horinzonte, December 1957]

	1	2	3	4	5	Average
Fe	48.8	44.7	58.6	51.5	63.3	53.4
SiO_2	10.5	12.9	15.2	26.4	5.4	14.0
Al_2O_3	4.5	8.0	<.5	.5	2.5	3.2
P	.17	.20	.03	.02	.03	.09
Mn	3.6	.12	<.01	.03	.50	.85

1 and 2. High-phosphorus canga overlying Gandarela Formation on flank of Serra da Moeda near 7,200 N., 7,000 E.

3 and 4. High-silica canga in valley floor overlying the Cercadinho Formation near 700 N., 8,000 E.

5. Canga rica from north of Várzea do Lopes mine at 10,000 N., 5,600 E.

OCHER

Ocherous limonite occurs in the iron-formation as thin films to lenses several meters thick. It is a very soft brownish-yellow rock that readily disaggregates to powder when exposed to surface conditions. Outcrops of ocher have been noted in steep cliff faces or in narrow gullies, and the material does not seem to be related to canga; in places, it occurs more than 100 meters below canga sheets. Guild (1957, p. 62) suggested that the ocher deposits in the Congonhas district are related to fault breccia or superposition of different rock types in thrust fault areas. Faults have not been seen near most of the ocher lenses in the Pico de Itabirito district although one deposit in the bed and embankments of the road to Moeda at 11,850 N., 4,150 E., Marinho da Serra, is in an area of local hillside slump. Another deposit about 300 meters to the west occurs in undisturbed iron-formation.

ITABIRITE

Unenriched itabirite contains a district-wide average of about 45 percent hematite, the remaining composition being mostly quartz. Samples of itabirite collected by the writer and by G. A. Rynearson from 34 widespread areas within this district have the following average composition:

Average composition of unenriched itabirite from the Pico de Itabirite district, in percent

Fe_2O_3	45.2
SiO_2	53.2
Al_2O_3	.05
P	.5
Mn	.03
Total	98.98

This material is below present ore grade.

MANGANESE

Manganese deposits of Brazil have been divided into the following genetic types (Park and others, 1951, p. 5):

1. Original sedimentary beds (Morro do Urucum; Mato Grosso).
2. Deposits formed by weathering and surficial enrichment of manganese-bearing protore:
   - (a) Deposits derived from unknown manganese minerals, probably primary manganese oxides in itabirite.
   - (b) Deposits formed by the oxidation of manganese silicate-carbonate-sulfide bodies.
   - (c) Deposits formed by the oxidation of other rocks that contain manganese.
   - (d) Deposits formed in nonmanganiferous rocks or soils by solutions transporting manganese from unknown sources.

Deposits of the Pico de Itabirito district fall into categories 2(a), 2(c), and 2(d). Most of the deposits of any significance are of the Lagoa Grande type, 2(a), described by Park and others (1951).

The mineralogy of each type is similar, and ores consist of psilomelane-type minerals and small amounts of pyrolusite and wad. These minerals form small to large podlike and lenticular ore bodies that parallel the bedding planes of the host rocks. The percent of manganese varies widely within each body. The ore deposits may occur in clusters or separately, making large-scale mining for high-grade manganese a difficult operation.

MANGANIFEROUS ROCKS

ITABIRITE

Most itabirite of the iron-formation in this district contains a very low percentage of manganese, less than 1 percent and generally less than 0.1 percent manganese. Table 2 shows that the percentage of manganese in a typical cross section of iron-formation ranges from more than 3 percent manganese to less than 0.01 percent and that the average is less than 0.13 percent manganese. This average does not include a 5.5 meter-thick lens of manganiferous itabirite, sample 2, table 2. These percentages agree very closely with those given by Dorr and others (1956, p. 305).

Manganese oxide occurs in itabirite as soft black layers that are concordant with the bedding; these layers range from a few centimeters to a maximum of 6 meters in thickness. The layers or lenses thin out along strike and at most are only a few hundred meters long. Zones of discontinuous lenses have been followed the length of the Serra da Moeda and continue in the quadrangles to the north and south of this district. The Serra do Itabirito also contains many discontinuous thin to thick lenses of manganiferous itabirite throughout its length. In some places as many as five individual manganiferous lenses may be found in one cross section of iron-formation although, in general, only one zone is commonly present in the Serra da Moeda, and manganiferous lenses in the Serra do Itabirito are the exception rather than the rule.

The high-grade deposits of manganese containing 46 percent or more manganese all show signs of supergene enrichment as described on page F40. Although lower-grade deposits may have undergone some supergene enrichment the original protore of the manganese deposits has not been recognized in an unaltered state, and it is therefore impossible to know how much manganese the original deposits contained.

The iron and manganese minerals are intimately mixed in the rock. Dorr and others (1956, p. 306) showed that the sum of the metallic constituents in the medium-grade manganiferous material in itabirite varies within a few percent of 60. When the manganese is higher, the iron is lower. Material containing more than 25 percent manganese is termed ferromanganese in this part of Brazil. Dorr and others (1956, p. 306) interpreted this close reciprocal relationship as a sign that much of the manganese in the medium- and low-grade manganese ores in the itabirite is primary.

The writer found a similar reciprocal relationship in the manganese-bearing itabirite in the Pico de Itabirito district. Ten samples collected throughout the district average 21.7 percent iron and 35.9 percent manganese or a combined average of 57.6 percent iron and manganese. Samples of both high and low percentages of iron (6.2–55.5 percent) and manganese (3.0–55.8 percent) were included in the average. Although the high-grade samples were hand picked, they differ little in total iron and manganese from total iron and manganese in grab samples of medium-grade material. These results strengthen the suggestion of Dorr and others that much of the manganese in the itabirite is primary. The original percentage of manganese seems to have been extremely variable.

CARBONATE ROCKS

The carbonate rocks of the Gandarela and Fêcho do Funil Formations of the Minas Series contain manganese, but the exact mineral form is unknown. Rhodochrosite has been reported on joint faces in dolomitic marble from São Julião (formerly Miguel Burnier) (Dorr and others, 1956, p. 302), but its presence on these joint faces would indicate an epigenetic or possibly supergene origin. Carbonate rock from the Pico de Itabirito district contains more than 2 percent manganese oxide in a few places, but rhodochrosite has not been seen in these carbonate rocks. The average manganese oxide content for the district is about 0.50 percent (table 10).

TABLE 10.—*Chemical composition of carbonate rocks, Gandarela and Fêcho do Funil Formations*

[Analyst: Cássio M. Pinto, DNPM, Belo Horizonte, August 1956. Samples collected by G. A. Rynearson, 1956]

Sample	Field No.	Location of sample	Nature of sample	Chemical analysis (percent)							
				SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	MnO	Ignition loss	Total
Gandarela Formation, Lagoa Grande quadrangle											
1	Gar-3	Rio do Peixe, 11,100 N., 11,000 E	Grab sample	22.6	2.20	0.20	23.2	16.0	0.32	35.8	100.3
2	4	do	do	3.1	2.10	.15	29.5	19.9	.40	44.7	99.8
3	5	Rio do Peixe, 11,300 N., 10,800 E	do	13.2	2.00	.20	26.7	17.6	.22	39.9	99.8
4	6	Rio do Peixe, 11,800 N., 10,500 E	do	28.0	1.60	.20	21.6	15.0	.30	33.3	100.0
5	7	do	do	1.8	2.80	.50	29.0	20.4	.70	44.7	99.9
7	9	Ribeirão Capitão do Mato, 12,200 N., 9,800 E	Samples of diamond-drill core scattered on floor of water tunnel.	1.5	2.50	.80	29.3	20.2	.40	45.1	99.8
8	10	do	do	2.2	5.50	1.10	27.6	19.7	1.00	42.7	99.8
Average				10.3	2.7	.45	26.7	18.4	.48		
Fêcho do Funil Formations, Marinho da Serra quadrangle											
9	Gar-20	Jazida do Urubu, 1,100 N., 11,100 E	Chip sample (11.0 m)	7.3	2.20	1.80	47.4	1.6	0.02	39.6	99.9
10	21	do	Gray marble	5.6	1.40	1.10	49.2	1.9	.02	40.8	99.9
11	22	do	Pink marble	2.7	.80	.40	52.8	.8	.01	42.4	99.9
12	23	do	Chip sample (1.5 m)	11.7	1.60	.40	27.2	18.3	.05	40.8	100.1
13	30	Jazida Siema, 1,500 N., 10,500 E	Chip sample	7.3	2.40	1.80	27.5	18.9	.07	42.0	100.0
14	31	Quarry, 12,500 N., 6,450 E	Dark-red brecciated marble	4.1	4.60	.40	28.7	17.1	2.20	43.0	100.1
15	32	do	Light-red brecciated marble	1.0	6.30	.20	29.3	17.2	1.60	44.6	100.2
16	33	Outcrop, 12,000 N., 6,300 E	Chip sample	1.6	.90	.40	50.9	3.0	.12	43.3	100.2
Average				5.2	2.5	.81	39.1	9.9	.51		
Average all samples				7.7	2.6	.63	32.9	14.1	.50		

The carbonate rocks that contain manganese in this district are various shades of red, pink, and gray; some are white. The dark-red varieties appear to be richest in manganese, and the white, leanest. Table 10 gives the chemical composition of typical carbonate rocks of the Lagoa Grande and Marinho da Serra quadrangles. These rocks, which range from calcitic to dolomitic, contain a significant percentage of both iron and manganese. Dorr and others (1956, p. 303–304) considered that, because many samples of white carbonate rock in the Minas Series contain appreciable percentages of iron and manganese, the rocks may be in part ferroan calcite and dolomite and manganoan calcite and dolomite and that possibly some of the manganese may occur as kutnahorite, $Ca(Mg,Mn,Fe)(CO_3)_2$.

A small manganese prospect in black spongy soil overlies an outcrop of brecciated red carbonate rock in the Fêcho do Funil Formation at 12,500 N., 6,450 E., Marinho da Serra (samples 14 and 15, table 10). Ore from this prospect was analyzed by Dr. Cássio M. Pinto, DNPM (analysis 2461, August 1956). For comparison, the compostion of the underlying red marble is converted as follows: MnO to Mn and Fe_2O_3 to Fe.

Analyses of ore and underlying carbonate rock from small manganese prospect at 12,500 N., 6,450 E., Marinho da Serra, in percent

	Ore from mine dump	Underlying carbonate rock	
		Light red	Dark red
Mn	33.7	1.2	1.7
Fe	23.7	4.2	3.2
SiO_2	4.0	1.0	4.1
Al_2O_3	.05	.2	.4
P	.08	nd	nd
MgO	.8	17.2	17.1
CaO	nd	29.3	28.7

The close spatial relationship between the weathered carbonate rock and the small manganese deposit seems to justify the statement of Dorr and others (1956, p. 304) that certain manganese oxide deposits in Minas Gerais were derived from carbonate rock.

MIXED ITABIRITE AND CARBONATE ROCK PROTORE

The Gandarela Formation in this district contains both manganiferous carbonate rock (samples 1–8, table 10) and manganiferous itabirite. Some of the itabirite contains dolomite which has substituted completely or in part for the quartz, which is metamorphosed chert or jasper. This type of itabirite, commonly referred to as "dolomitic itabirite," may interfinger and intergrade with lenses of carbonate rock in some places, but the rock becomes silica-rich and carbonate-poor as its stratigraphic distance from the carbonate rock increases. This fact suggests that the transitional sedimentary environment between the deposition of the pure bivalent carbonate sediments and the deposition of pure ferric iron-silica itabirite deposits was favorable to deposition of small amounts of manganese. Dorr and others (1956, p. 307) suggested that in some places, deposition of manganese in these transitional sediments produced manganoan dolomite and calcite, but more commonly the manganese deposition was primary manganese oxide and iron oxide. These authors noticed that over a wide area magnetite is commonly associated with the dolomitic itabirite, which suggested to them that the Eh was low in the depositional environment. They considered that the pH of the depositional environment must have been very near or slightly above 7.8 to have permitted the deposition of carbonate with the iron-formation, but that a higher pH inhibited the deposition of both manganese and iron in oxide form. These elements then entered into the lattice of calcite and dolomite to form the manganoan and ferroan calcite or dolomite. The ubiquitous presence of magnetite in the transitional zone between pure carbonate rock and pure silica-iron itabirite in the Pico de Itabirito district seems to bear out the conclusions of Dorr and others.

CLASTIC ROCKS

Some quartzite and phyllite of the Minas Series in this district contain manganese oxides. One small abandoned mine in the Taboões Quartzite of the Piracicaba Group at 4,300 N., 7,300 E., Lagoa Grande, contained small high-grade lenses of manganese oxide in extremely friable host rock. Because of the nearly complete disaggregation of the quartzite and the consequent caving of the workings, the manganese oxide lenses could not be followed more than a few meters underground, but the impression gained by this writer from brief visits to the mine was that the high-grade lenses resulted entirely from supergene enrichment and that the source rock was an overlying phyllite or carbonate rock now removed by erosion.

Phyllite that contains manganese oxide crops out near the Jazida do Urubu carbonate rock quarry (900 N., 11,200 E., Marinho da Serra), and conspicuous outcrops occur at a point several hundred meters to the southwest of the quarry on the access road. These outcrops are from 2 to 10 meters wide and lie within 100 meters of weathered manganiferous dolomitic marble similar to sample 12 (table 10) collected by G. A. Rynearson. The phyllite is black and readily smudges the hand if touched.

Two representative samples, collected by Rynearson in 1956 and analyzed by Dr. Cláudio Pinto (DNPM, Belo Horizonte, analysis 2460, August 1956) contain the following:

Analyses of phyllite near Jazida do Urubu, in percent

Sample	Mn	Fe	SiO_2	Al_2O_3
1	16.6	15.6	30.5	8.5
2	8.3	30.9	15.4	11.1

It would be difficult to evaluate the percentage of primary and secondary manganese in the phyllites of this area, but this writer believes that most of the iron and manganese are supergene enrichments formed during the erosion of overlying dolomitic or phyllitic beds.

PRODUCTION

In the past 50 years or more, perhaps 100,000 metric tons of manganese ore ranging from 35 to 50 percent or more manganese was extracted from the Pico de Itabirito district; most of the ore was hand picked to achieve export grade. The time of high-grade ore has passed in this district, and so has the time of small hand-operated hand-cobbed pick-and-shovel mines. Only a few deposits having very limited high-grade ore reserves remain. This fact does not imply that the mining of manganese has come to an end in this district. On the contrary, it implies that manganese-rich rock will be classified as manganese ores when large-scale nonselective mining commences.

Mining operations in the future could extract the manganiferous itabirite in the Serra da Moeda and in the Serra do Itabirito that ranges from about 25 to 45 percent manganese, the overall average being about 25–35 percent manganese, 30–40 percent iron, and about 10 percent silica. This itabirite could be used for slagging and dephosphorizing in the blast furnace reduction of Quadrilátero Ferrífero iron ores, or it could be used to make manganiferous pig iron.

Reserves of this manganiferous itabirite are not accurately known because of lack of deep exploration, but this writer believes that they are large. The calculation of ore reserves is difficult because outcrops of some sections of iron-formation contain five lenses of manganiferous itabirite, each of which may have a tenor greater than 40 percent manganese. Other outcrops of iron-formation may show only one lens of itabirite that may average less than 15 percent manganese. Still other sections of iron-formation may contain no outcrops of manganiferous lenses.

In addition to manganiferous itabirite, several small but high-grade deposits of manganese oxide, those above 45 percent manganese, have been mined in supergene enriched soil, clay, canga, and quartzite. These deposits are the products of, or overlie, weathered manganiferous marble. Perhaps a total of about 25,000 metric tons of manganese ore containing more than 45 percent manganese has been extracted in the past from deposits of these types. Whether large-scale mining operations of deposits of these types would be advisable or inadvisable could only be determined by extensive exploratory drilling.

ORIGIN OF MANGANESE ORE

The evidence for the supergene origin of the high-grade manganese ores in this district is similar to that found throughout the Quadrilátero Ferrífero and the State of Minas Gerais as described by Dorr and others (1956, p. 312–314). Although none of the mines in this district have penetrated deeper than a few tens of meters, it is known that here, as elsewhere in the Quadrilátero Ferrífero, the tenor of the ore becomes progressively poorer at depth. Had high-grade ore been of syngenetic or hypogene origin, or concentrated in lenses before the rocks of the area were folded into their present attitudes, the high-grade ore would be expected at depth in some places. In the hundreds of mines throughout Minas Gerais, however, high-grade ore at depth has not been found.

Further evidence for the supergene origin of high-grade ore is the presence of small, nearly vertical hanging crystals of pyrolusite, small vertical stalactites of manganese oxide minerals, and small, nearly horizontal mammilary forms of amorphous psilomelene in voids in the manganese-rich near-surface steeply dipping itabirite. No jacobsite, hausmannite, or other metamorphic manganese minerals have been identified in the ores of this district.

On the other hand, the lower-grade manganese deposits may well contain considerable proportions of primary manganese oxides, as was previously discussed. No criteria have been developed to distinguish between the primary and secondary oxides where vuggy, stalactitic, or mammilary forms are absent.

The physiographic setting of the manganese-bearing rocks and the physiographic history of the region influence ore formation. Dorr and others (1956, p. 316–317) considered that the supergene formation of ore depends upon the circulation of ground water through protores. They noted that most high-grade manganese deposits in Minas Gerais crop out on or near ridge lines, on dissected old erosion surfaces, or on high plateaus and that no large ore bodies occur in valley bottoms. The larger ore bodies in the Pico de

Itabirito district are along dip slopes or on well-drained high plateaus.

The highest and largest known deposits of high-grade ore, at Lagoa Grande (6,300 N., 2,200 E.) were in itabirite near the crest of the Serra da Moeda (fig. 23). These deposits were between 1,430 meters and 1,480 meters above sea level. The lowest known deposit of ore, about 1,250 meters above sea level, is at 12,200 N., 6,400 E., Marinho da Serra; it is about 30 meters above a tributary of the Rio Mata Porcos but is more than 200 meters above the stream as it leaves the south-central part of the district. The deposit is underlain by carbonate rock. Although the lowest known deposit appears to be in a valley bottom, circulation of ground water in this valley was probably ample enough in the past, as it is today, to have formed the ore body near the carbonate rock. Many similar deposits may lie above carbonate rocks but be hidden beneath the valley soils.

MARBLE

Multicolored marble that takes a brilliant polish and that is used in decorative construction is quarried on a small scale at the Jazida do Urubu quarry at 1,500 N., 10,400 E., Marinho da Serra. There the colored marble occurs in large, irregular blocks that are separated from massive light-gray marble lenses in the Fêcho do Funil Formation by thick crosscutting seams of sandy and clayey weathered rock. The colorful marble is sawed into blocks measuring 3 by 3 by 1 meter and shipped by truck to Rio de Janeiro for cutting and polishing. The gray marble is crushed at the quarry and sold as concrete aggregate, road metal, or railroad ballast.

Calcareous rocks that contain less than 1.0 percent silica are of interest to the local smelters as flux in blast furnaces. Analyses of marble samples from the Gandarela and Fêcho do Funil Formations (table 10) show an average of 7.7 percent silica. As only a few samples approach the low critical limit, marble in this district is not used as a source of flux. Table 10 also indicates that the percentages of magnesia range from less than 2 percent to more than 20 percent. The petrologic classification of the samples therefore ranges, according to Pettijohn (1957, p. 418, and table 80), from a limestone through dolomitic limestone and calcitic dolomite to a dolomite, with the average composition being that of calcitic dolomite.

CLAY

At least five large and several dozen small clay deposits are known in the Lagoa Grande quadrangle. The clays from the general region are classified for commercial use as pottery, tile, terra cotta, paper filler, and refractory clays.

Chemical analyses by Cia. Magnesita S. A. of clays from five of the larger deposits are shown in table 7. Results of physical tests are not available, but according to the analyst, to be commercial the clays must be sufficiently plastic to be pressed into various shapes and to withstand temperatures above 1,500° C under a pressure of 2 kilograms per square centimeter. The clays that were analyzed apparently do not meet the requirements but may have some commercial value if mixed with clays that have higher plasticity.

SAND

Deposits of loose, gray to white, fine to coarse sand occur in the Moeda Formation at 7,200 N., 2,300 E.; 6,300 N., 2,700 E.; 5,200 N., 3,050 E.; and 1,900 N., 1,700 E., Itabirito. Most are small, but a few have been quarried for road material. The sand in most of the deposits contains an abundance of interstitial clay and grains of hematite and limonite, necessitating thorough washing before use in concrete or plaster.

GLASS SAND

A deposit of clean white sand is at the east side of Vargem da Botica (6,300 N., 2,700 E., Itabirito) directly north of the Bonga fault. A quarry in this deposit was developed by Sociedade Queiroz Junior Ltda., of Esperança, and the sand was used in their foundry for molding sand. Samples of fine-, medium-, and coarse-grained sands were taken from stockpiles in this company's sand-washing plant near the quarry.

The samples were thoroughly washed and dried and from 500 to 1,000 grams of each sample were screened into 8 sizes by 5 minutes agitation in a Rotap screen. Sands that came within the ranges of 20 to 40 mesh, the specification size range for the manufacture of glass (Ries, 1949, p. 973), were chemically analyzed (table 11). The samples were finely ground with a steel mortar and pestle, as no other equipment was available. Therefore the Fe_2O_3 content shown in table 11 may be somewhat higher than the true Fe_2O_3 content of the sand. The present analyses indicate that the sand is of the lowest glass-making quality, but this statement must be qualified because of the mode of sample preparation. Additional care in the preparation of sand samples may raise the result of the analyses to correspond to several quality grades higher.

Size analyses of these glass sands show that about 80 percent of the sand exposed in the deposit may be used in glass manufacture and that the medium-size sands have the most usable percentages by weight (table 12 and fig. 15).

TABLE 11.—*Chemical composition of glass sands from the vicinity of the Bonga fault, Pico de Itabirito district*

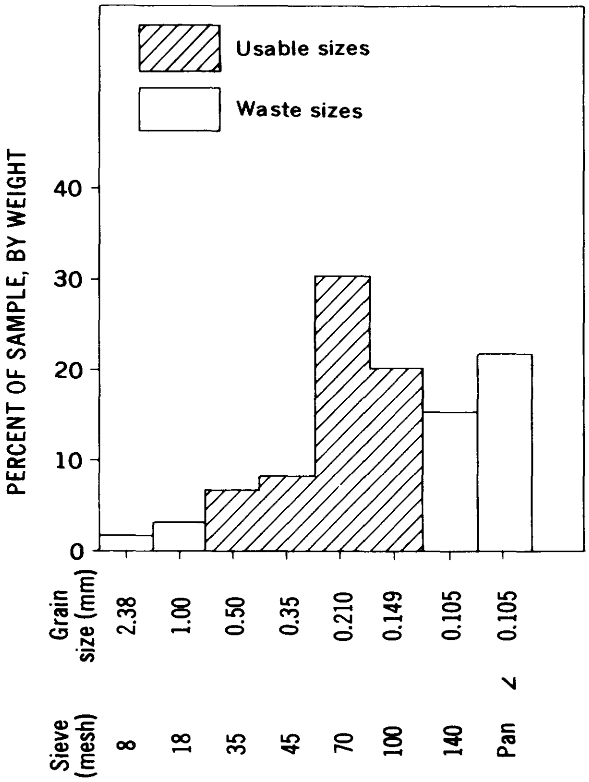
[Analyst: Eladio Pimental, DNPM, Belo Horizonte, Feb. 27, 1961]

Size	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO
Fine	98.7	0.9	0.0	0.0	0.0
Medium	99.1	.8	.0	.0	.0
Coarse	98.8	.8	.0	.0	.0

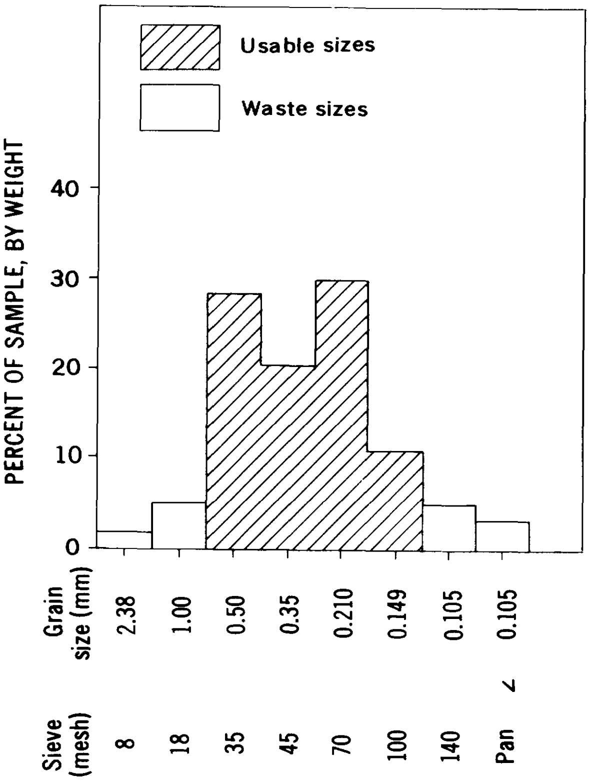
TABLE 12.—*Statistical analyses of the glass sand from the vicinity of the Bonga fault, Pico de Itabirito district*

Size	Weight of sample (grams)	Weight of usable part (between 0.15 and 0.50 mm) (grams)	Percent usable	Percent waste		
				Total	Undersize	Oversize
Fine	503.2	323.8	64.34	35.66	34.09	1.57
Medium	1,003.5	880.1	87.70	12.30	8.20	4.10
Coarse	1,007.2	778.7	77.31	22.69	6.09	16.60
Total	3,017.1	2,416.4	80.09	19.91	13.21	6.70

The outcrop of the deposit is 260 meters long by 210 meters wide, and the sand has been exposed to a depth of 6 meters in some places. If a specific gravity of 2.0 is used for the sand, the deposit contains about 100,000 metric tons per meter depth. As the deposit has not been explored in depth, the total tonnage is unknown.



A



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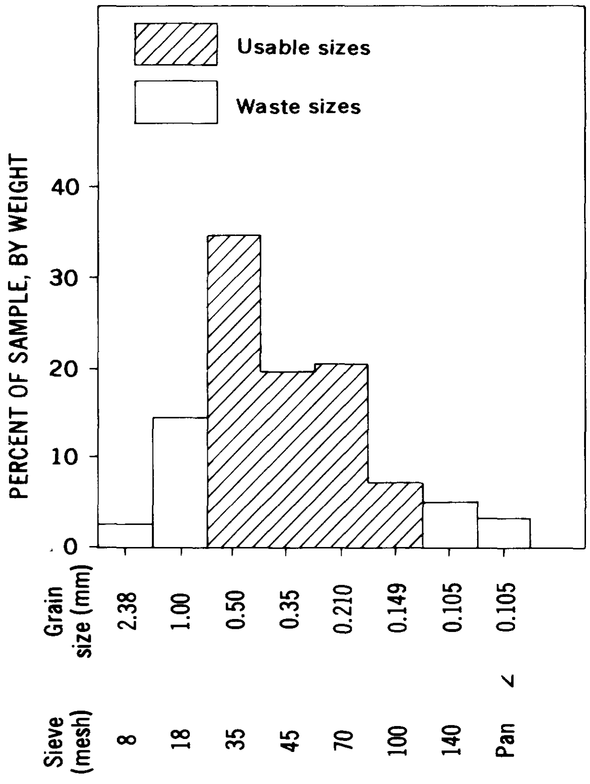

C

FIGURE 15.—Mechanical size-grade distribution of samples of glass sand near Bonga fault, Pico de Itabirito district. U.S. standard sieves. *A*, Fine; *B*, medium; *C*, coarse.

KYANITE

Thin seams of kyanite that border quartz veins and in some places penetrate surrounding phyllite are found in the Cercadinho Formation and are apparently confined to an arcuate zone that roughly parallels the eastern slope of the Serra do Itabirito. The zone has been traced by the alinement of sporadic outcrops from a prospect pit north of Lagoa das Codornas at 10,700 N., 10,900 E., Lagoa Grande, southward to a warm springs area at Água Quente near 11,000 N., 9,000 E., Marinho da Serra. A large part of the zone is covered by soil, but where the soil is thin it contains fragments of kyanite-rich quartz-vein material. The zone is as wide as 200 meters in the area of the abandoned Botica mine at 5,000 N., 1,000 E., Itabirito, and is less than 10 meters wide in an embankment of the Inconfidentes highway at 6,500 N., 200 E., Itabirito. The kyanite-bearing quartz veins are not continuous and occur at different stratigraphic levels in the Cercadinho Formation throughout this zone.

Where best exposed, the kyanite-bearing quartz veins seem to have been emplaced in local shear zones where the host rocks are shattered and crumpled. Most quartz veins are shattered, but seams of kyanite bordering the quartz are unshattered. The kyanite seams are as much as 40 centimeters thick, but most are about 10 centimeters thick. At the Botica kyanite mine (see p. F65), some of the seams are in the core of the quartz-vein host rock, but some of the kyanite crystals in the fringes of the quartz veins penetrate the bordering phyllite of the Cercadinho Formation. Where this penetration occurs, small rosettes of pyrophyllite commonly lie between and surround large kyanite blades. The kyanite and the pyrophyllite probably formed late, under low pressure and temperature conditions, and after formation of the quartz veins.

GOLD

Except for intermittent panning for gold at the confluence of the Rio Mata Porcos and the Rio Sardinha during times of low water, gold mining has ceased in the Pico de Itabirito district. Legends are told of the gold mining activity of more than 100 years ago in Cata Branca, a small village north of the Pico de Itabirito. Today, not even the foundation of the houses of this village remain. Accurate records of the gold production of the area are not available.

CATA BRANCA MINE

The Cata Branca[3] mine is described in an interesting travelog by Captain Richard F. Burton (1869, p. 178–180). According to him, the land, which included all the Serra do Itabirito, originally belonged to poor Brazilian and Portuguese settlers and later passed into the hands of the Count of Linhares. The Count then sold the mining concession to a Dr. Cliffe, who parted with the rights to the Brazilian Co. on January 28, 1833. The company was under the supervision of Mr. A. F. Mornay until November of the same year when Commander Cotesworth, of the British Royal Navy, became supervisor. Burton described Commander Cotesworth as a strict disciplinarian and "... zealous in the discharge of his duty * * *." Cotesworth mechanized the Cata Branca mine, importing machinery from England. According to Burton, by 1835 "besides hired labourers, 'Cata Branca' employed 38 Europeans, 76 negros and 34 negresses * * *." In 1844 the mine collapsed because of improper timbering. It is said that 13 workmen were killed.

SANTO ANTÔNIO LODE

The Brazilian Co. dug many mines in what was known as the Santo Antônio lode, actually the contact zone between the quartzite or basal conglomerate of the Moeda Formation of the Minas Series and the Nova Lima Group of the Rio das Velhas Series. The "lode" extends from the Cata Branca mine to the southwest for about 18 kilometers. Many of the old mine workings seen during the course of field mapping were recorded on the geologic maps of the district (pls. 2, 3). One of these, the Sumidouro mine, is reported by Burton to have been successful. An old mine about 4 kilometers southwest of Pico de Itabirito at 10,000 N., 9,600 E., Marinho da Serra, fits Burton's description of the "Sumidouro", and ruins of large slave quarters may still be seen at this place.

Captain Burton (1869, p. 182) described the mining of the Santo Antônio lode as follows:

> * * * The Serra of Cata Branca trends were mined from east of north to west of south. The containing rock proved to be micaceous granular quartz with visible gold, as in California. The strike was N. 15° W., and the dip from 80° to 85°; in some places the stratification was nearly vertical, in others it was bent to the slope of the mountains, and generally it was irregular. The lode, narrow at the surface, widened below from 6 to 18 feet, and the greatest depth attained was 32 fathoms. The quartz formation was of many varieties, soft sugary, hard smoky, common white, and blue, which proved to be the richest: and the sides were hard quartzose matter equally bad for spalling and blasting. The southeastern end was most productive. On the western sides of the quartz were found the ferruginous formations "Canga" and "Jacutinga": the latter was struck by drivings made below the Serra ridge, here a mass of iron oxide ore: the works, however, wanted ventilation, and were abandoned.
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> * * * The lode, which could not be called a "constant productive", abounds in "vugs", or vein-cavities, tubes, pipes and

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[3] "Cata", from the verb, "catar", to hunt for, or seek out; "branca" for white: the miners applied the word "cata" to any pit sunk in overburden where they were looking for the gold-bearing quartzite.

> branches, called by the Brazilian miner "olho"—eyes, surrounded by a soft material, mainly running vertically, and richer in free gold than the average. Near these pockets, but not disseminated through the vein, was a small quantity of auriferous pyrites, iron and arsenical. A little fine yellow dust, oxide of bismuth, ran down the middle of the lode, and gave granular gold. The best specimens averaged from 21.75 to 22 carats, our standard gold.

In April 1954, almost 85 years later than Burton's report, geologist A. F. Matheson submitted a report[4] to the St. John del Rey Mining Co. Ltd. (formerly the Brazilian Co.); in it he described the geology and mineralogy of the Cata Branca mine. Through the courtesy of the St. John del Rey Mining Co. a small part of this report is quoted as follows:

> * * * Deposits in the Lower Minas quartzite and conglomerate are commonly sharply defined quartz veins occupying tension cracks. The gold is in the quartz or, as is common, along the margins of the quartz. Some see in the number of gold prospect pits that are scattered along the contact of the quartzite with the Nova Lima series, a suggestion that the gold is in part old placer gold laid down when the quartzite was deposited. But many quartz veins cut this contact area as might be expected. They are probably the source of the gold and if any gold in the basal quartzite is of placer origin it is probably in minor amount, certainly not worth basing prospecting procedure upon it * * *.

Matheson compared the quartzite-conglomerate deposits with various other gold-bearing rocks within the company's properties and came to the following conclusions:

> * * * The deposits in the quartzite and conglomerate of the Lower Minas series so far as is known have less sulphide than the others and this sulphide is pyrite. In the Cata Branca Mine, which is an old mine apparently worked profitably in slave days, stibnite (antimony) occurs with the gold quartz veins * * *.

Since the time of Matheson's report, the Cata Branca mine has become too dangerous to enter, and the upper workings have caved. It would be unprofitable to reopen this, or any other gold mine in the district, under the present economic circumstances because of the low tenor of the ore.

IRON MINES

The first smelting of iron ore in the Pico de Itabirito district of which there is any record was in 1892. The iron was smelted in a rock-walled furnace operated by Cia. Nacional de Forjas e Estaleiros at Esperança (fig. 16). The furnace lining, a locally manufactured poor-grade brick, lasted through about 2 to 3 months of intermittent operation. According to the blast records, this furnace produced a maximum of 4 metric tons of iron per day. The initial construction of this furnace began in 1884 under the auspices of a group of engineers that included Albert Gerspacher, Amaro da Silveira, and Carlos Wigg. The mines that furnished the iron ore were near the old Cata Branca mine, 4 kilometers west of the smelter. The mines were merely pits dug into thick deposits of rolado or rubble ore located at the head of the valley above Esperança. Transportation of the ore was by burros and mules.

In 1896 Cia. Nacional de Forjas e Estaleiros became bankrupt, and the mines were idle until 1899 when Engineer Dr. J. J. Queiroz, Jr., under contract with the Banco da Lavoura e Comércio of Rio de Janeiro reorganized the company and resumed production. A year later Dr. Queiroz bought the company from the bank, and in 1910 he constructed one of the first steel-jacketed blast furnaces in South America. This furnace at Esperança was still in operation in 1961, producing about 50 metric tons of iron per day. Another furnace constructed more recently by this company produces 65 tons per day.

In 1938 Cia. Mineração Novalimense, a subsidiary of the St. John del Rey Mining Co., consolidated the operations of all the small mines in the Cata Branca area and began mining on a larger scale. In 1941 these mines were leased to Sociedade Usina Queiroz Junior Ltda., the owners and operators of the smelter and foundry at Esperança. From 1941 to 1961 Sociedade Usina Queiroz Junior Ltda., mined about 850,000 tons of iron ore and produced about 410,000 tons of pig iron.

In 1961 three iron mines, the Pico de Itabirito, the Pau Branco, and the Várzea do Lopes, were mining ore; and two others, the Abóboras and the Andaime, were dormant. The combined reserves of these mines are as follows:

Combined reserves of the Pico de Itabirito, Pau Branco, Várzea do Lopes, Abóboras, and Andaime mines, in metric tons

Measured ore	82,000,000
Indicated ore	15,000,000
Inferred ore	130,000,000

Itabirite, a potential ore, is listed as tons per meter depth and included within the description of the appropriate mines.

PICO DE ITABIRITO

The mines that surround the Pico de Itabirito were in operation intermittently from 1943 until 1961. The land is owned by the St. John del Rey Mining Co. and was leased and first mined by Sociedade Indústria e Comércio de Minério Ltda. (SICOM), under the direction of Dr. Augusto T. A. Antunes. SICOM reor-

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[4] A. F. Matheson, 1954, Report on geology and mineral deposits of St. John del Rey Mining Co., Ltd., property, Minas Gerais, Brazil: company files, Nova Lima, Minas Gerais, Brazil.

FIGURE 16.—Foundations of a blast furnace built about 1884 by Cia. Nacional de Forjas e Estaleiros at Esperança. It is reported to be the oldest blast furnace in South America. The large stone blocks were hand hewn, and the round disks on the front and side are handwrought iron washers holding tie rods that pass completely through the structure. Daily capacity was 4 metric tons.

ganized in 1948 to form Indústria e Comércio de Minérios (ICOMI) with Dr. Clemente de Faria as chairman and Dr. Antunes as director of this and other mines in the State of Minas Gerais. Later the company changed the name of the Minas Gerais company to ICOMINAS. The production of iron ore from the Pico de Itabirito from 1943 to 1953 was about 45,000 metric tons. An additional 500,000 tons has been mined during the period of this writing, and much of it was stockpiled in early 1961 at the edge of the railroad yards in Itabirito, where it awaits transportation to Rio de Janeiro. Transportation today is the critical factor that restricts large-scale mining operations in the Pico de Itabirito district.

The Pico de Itabirito is a spinelike peak of nearly pure compact hematite. This peak, shown in figure 17 as it appeared in 1958, before mining began, is one of the most unique outcrops of hematite in the world. One of the first references to the peak was made by Couto (1801). The original name given to the peak by the aboriginal Tupi Indians, according to Couto, was "The Stone Girl." Couto claims to have found "crystals of copper upon its flanks" (literal translation from Portuguese). Cornish miners at the Morro Velho and other gold mines, referred to it as the "Peak of Cata Branca." Captain Richard F. Burton (1869,

FIGURE 17.—Pico de Itabirito in 1958. The spine, which lies about 800 meters from the camera, juts about 75 meters above the rubble pile surrounding its base. The spine as well as the rubble consists of nearly pure compact hematite.

p. 179–181) devoted several pages of his travelog to the description of the peak and the legends of magic and enchantment connected with it.

The Pico de Itabirito deposit is 6 kilometers west of the city of Itabirito and the same distance west of the stockpiles. The road distance from the mine to the stockpiles is about 18 kilometers, 5 kilometers of which are over graveled roads and the remainder of which is on the asphalt Inconfidentes highway. The elevation of the mine area ranges from about 1,380 to 1,560 meters above sea level; that part that lies east of the peak averages about 1,520 meters in elevation, and that to the west, about 1,450 meters. The stockpile at the railroad near Itabirito is about 845 meters in elevation, or about 675 meters below the mine. Trucks with 10-ton capacity are used to carry the ore to the railroad. The average grade of the Inconfidentes highway between the crest of the Serra do Itabirito and the flats bordering the Rio das Velhas at the base of the serra is slightly greater than 5 percent, but some short curved sections of the highway approach 10 percent, thus prohibiting the use of trucks with greater hauling capacity. Conveyor belts or an aerial tramway from mine to stockpile are under consideration.

Also under consideration is a railroad staging area in the Moeda Plateau, west of the peak. A relatively flat area 3 kilometers southwest and 200 meters lower than the mine area may be suitable. The area is 400 meters above the ore loading platforms on the Estrada de Ferro Central do Brasil in Congonhas, about 40 kilometers to the south. With careful engineering a grade of less than 1 percent could be maintained in the construction of this spur.

EXPLORATION

The exploration of this ore deposit and the mining of its high-grade ores has only recently begun, and it is too early to give an accurate quantitative statement of what ore types are present and in what proportions. In late 1961 the exploration consisted of the following:

1. A diamond-drill hole shown in the cross section of the peak (pl. 6), driven downward at an angle of 72° into the main spine. The drill hole reached a depth of 98.5 meters below the collar of the hole or about 135 meters below the highest outcrop.
2. Two adits (pls. 7, 8): Adit 1, portal elevation 1404 meters, was 287.7 meters long with an east crosscut 116.8 meters long, a west crosscut 114.2 meters long and a 15-meters winze about 140 meters in from the portal. Adit 2, portal elevation 1,390 meters, was 245 meters long in November 1961.
3. Twenty-four prospect pits averaging about 7.25 meters in depth, sunk on a 100-meter grid around the main spine (pl. 6).

Except for the prospect pits, which were sunk to prospect for surficial ore, virtually no prospecting had been accomplished on the northwestern end of the ore body nor on the eastern and southeastern sides in late 1961.

The exploratory work, coupled with the detailed geologic mapping by Rynearson (pl. 6) reveals the presence of much hard high-grade hematite ore, much soft high-grade hematite ore, and an undetermined but probably large tonnage of intermediate high-grade hematite ore. Lenses and beds of enriched itabirite, which do not crop out, will undoubtedly be found as the mine is further developed. The hard high-grade hematite ore is among the most homogeneous and hardest in the Quadrilátero Ferrífero.

Distribution of High-Grade Hematite

The detailed geologic map of the Pico mine area (pl. 6) coupled with the exploration described above, indicates that the hard high-grade hematite ore crops out as oval to irregular patches measuring from a few square meters to about 90,000 square meters in area. The spaces between the high-grade hematite outcrops are covered by canga, rolado, and soil. The nature of the bedrock under these covered areas was revealed by several prospect pits although most of them did not penetrate to bedrock. The adits revealed that in some places the bedrock is soft high-grade hematite and in other places hard and intermediate high-grade hematite. Itabirite was found in the end of adit 2 (pl. 8).

With the information now available, it appears that the outcropping compact high-grade hematite occurs as nodes in a matrix of softer high-grade hematite, enriched itabirite, and itabirite. Two of these nodes now form impressive outcrops; the main Pico and the little Pico (pl. 6). Although the other nodes have relatively subdued outcrops today, they too may have formed rugged and spectacular outcrops in the past, and the large masses of broken ore exposed on the surface in the area of the main peak may be remnants of smaller nodes that became overbalanced and collapsed on their own talus. The node found in the west crosscut of adit 1 may be of this type.

The main Pico node is known to extend at least 180 meters below the outcrop, and that at little Pico, about 30 meters. Whether or not these nodes connect at depth to form a large homogeneous ore body is not known. Probably some will so merge, but not all of them, and probably the deposit will prove to consist of several bodies larger than the individual bodies now cropping out.

Soft high-grade hematite ore does not crop out, and the extent can only be established by subsurface exploration. The presence of 85 meters of soft high-grade hematite ore in place was proved by adit 1; adit 2 also revealed 70 meters of this type of ore. Prospect pits indicate the presence of similar ore on the southeastern side of the area, as does a roadcut at the extreme northwestern end of the area.

Enriched itabirite was revealed below canga on the southeastern side of the main Pico and in adit 2, but the potential tonnage is unknown.

Broken Ore

An unusual feature of the Pico de Itabirito ore deposit is the relatively large tonnage of broken hard high-grade hematite ore. The western and the northwestern apron of the spine are covered with a deep mantle of hematite blocks fallen from the main spine (fig. 18) and from other hard hematite bodies no longer visible in outcrop. This mantle covers the bedrock ore to a depth of at least 30 meters in some places, as seen in adit 1 (pl. 7), and seems to grade downward into a large body of fractured hard hematite which may well have formed by slumping of parts of the ore body. This broken rock is virtually in place and is shown in the mine map of adit 1 (pl. 7) as brecciated ore.

Rynearson suggested (written commun.) that this deposit of broken ore was shattered by slumping

FIGURE 18.—Broken lump ore on the upper bench at the Pico de Itabirito mine.

caused by underground leaching of carbonate rock of the Gandarela Formation a few hundreds of meters west of the portal of adit 1; he believed that this deposit of broken ore was separate from the main peak. The area underlain by carbonate rock is topographically much lower than the area occupied by the peak, and the enormous weight of the apron area might cause it to slide into the space provided by the solution of the carbonate rock, thereby fracturing the material but not displacing it very far from its original position or structural attitude. The attitude of the material as mapped in the east and the west crosscuts of adit 1 (pl. 7) strengthens this hypothesis. The alined cobbles and boulders of brecciated ore plunge to the west, away from the main peak. This hypothesis might also explain the abundance of hematite talus on the northwest slope of the peak in relation to the thin mantle of talus on the southeast slope.

It is here suggested that the topography surrounding this large deposit has had nearly the same shape from perhaps Pliocene time, or earlier, to the present day. Fossils found in clay near Lagoa Miguelão in the northern end of the Moeda Plateau were described by Pomerene (1964) and have been identified as of Tertiary age. In the past, as the various compact hematite nodes were exposed by the erosion that formed the Moeda Plateau, their debris fell upon the surrounding apron. As erosion continued and a valley formed between the Serra da Moeda and the Serra do Itabirito, the phyllite, carbonate rock, and quartzite of the Minas and Itacolomí Series were stripped, and the apron surrounding the iron peaks of the deposit slowly slumped towards the valley floor, thereby exposing more of the nodes in the mine area. This process of valley creep of the apron and the consequent exposure of more of the peaks could have continued throughout Tertiary time and to the present.

The same process of talus creep caused by differential erosion of the rocks could well have taken place on the eastern side of the deposit, although perhaps on a reduced scale because the resistant nature of the quartzite of the Moeda Formation protected the weaker phyllite of the Batatal Formation which lies close to the peaks.

The occurrence of enormous blocks of ore now lying on the modern apron, in contrast to the small boulders of ore found in the exploration adits is difficult to explain. The larger blocks may be related to a difference in the hardness of the rock exposed in Tertiary times compared with that exposed today, to a slower rate of erosion now than in the past, or to a structural difference in the rocks, such as a difference in the space between the joint patterns of the shallower and the deeper rocks within each peak. This difference in the space between joint patterns is seen in today's outcrops and is shown in figure 19 in a face of the main peak; the space between joint planes in the rocks that form the top of the peak is much smaller than the spaces about 75 meters lower in the same face of the peak. Lastly, large blocks may have fallen from the nodes exposed in Tertiary times but may have been crushed and broken during subsequent talus creep.

MINING METHODS

The topography of the ore deposit makes bench mining the best method of ore extraction. In 1961 three irregular benches had been excavated in the broken ore on the northwestern side of the hard core of the peak (pl. 6).

The ore is extracted from the face by placing dynamite (40 percent gel) between boulders of broken ore, a method which requires only a small amount of drilling. Blasting loosens the pebbles, cobbles, and boulders, and they fall onto the benches. Material less than about 6 inches across is hand loaded with fork and shovel into 5-ton caçambas (buckets). Larger chunks are broken by hand sledging or secondary blasting. The buckets are picked up by specially equipped trucks which carry the ore to a loading chute located below.

RESERVES

The measured reserves of high-grade hematite ore that contains more than 66 percent iron in the Pico de Itabirito mine is estimated to be about 720,000

FIGURE 19.—The western face of Pico de Itabirito. This solid mass of nearly pure compact hematite rises about 75 meters above the treetops in the lower part of the photograph. Nearly 8 million metric tons of hard ore are visible in this outcrop.

metric tons per meter depth. A measured 160,000 square meters of outcrop of compact hematite ore in place is shown in plate 6. This material averages 4.5 metric tons per cubic meter. Pico de Itabirito is known to be 185 meters from crest to tunnel depth as shown in the geologic section (*A–A′*) of plate 6. The body of compact hematite ore that lies about 150 meters northwest of the peak was found at the end of the east crosscut of the adit, about 65 meters below the surface, as is shown on plate 7. In all probability this hematite body continues another 50 meters below the adit level. Mining experience in the Quadrilátero Ferrífero has shown that no major deposit has been bottomed by exploration although some have been probed more than 200 meters below the lowest outcrop. It is reasonable to expect that the ore in place in this particular deposit continues for 100 meters below the surface and that 72 million metric tons of high-grade material is present.

It is estimated that about 11.5 million metric tons of broken ore consisting mainly of cobbles and boulders of compact hematite that average more than 66 percent iron lie within the apron surrounding the outcrops. This material is considered as indicated ore and underlies an area of about 132,000 square meters and ranges from about 1 meter to more than 75 meters in thickness. The 132,000-square-meter area has been outlined in the geologic map of the mine area, and the attitudes of the blocks of broken ore are shown in section *A–A′* of plate 6. The material averages about 3.5 tons per cubic meter. Using this factor, about 460,000 tons of this material per meter of depth is indicated. This writer estimates that within the area outlined on the geologic map, the average depth of the material is 25 meters.

In addition to the measured and indicated ore reserves above, adits 1 and 2 penetrated ore bodies—below the broken ore—which may be classified as inferred reserves. Adit 1 was driven through 186 meters of broken ore before penetrating 101 meters of a hematite ore body that had no surface expression. The east crosscut of this adit cut hematite ore after penetrating 90 meters of broken ore. Hence, the broken ore overlies a sizable hidden ore body in the vicinity of this adit.

Adit 2 (pl. 8), driven in 1961 toward the peak from a point near the western boundary shown on the detailed geologic map (pl. 6), penetrated 45 meters of broken ore which was followed by 70 meters of soft high-grade hematite. This sequence seems to indicate that the broken ore on the entire northwestern side of the peak overlies one or more hidden ore bodies. The dip of the beds suggests that this ore body or ore bodies extend downward.

As the ore body is lenticular and more than 1 kilometer long, it could be assumed to extend to a depth of one-half of its length. The total surface area underlain by ore is 292,000 square meters, and the average specific gravity is assumed to be 4.0, producing an inferred reserve of 1.6 million metric tons per meter depth. For purposes of calculation, it is assumed here that the ore body extends only 100 meters below the deepest workings, producing a total of 160 million tons, or a grand total of measured, indicated, and inferred tonnage of more than 200 million tons of high-grade hematite material in and surrounding Pico de Itabirito.

No attempt was made to break the reserves into the categories of hardness of high-grade hematite ore because of the abundance of broken-surface and near-surface ore available for mining. The lower-grade material which is not being mined or which is being mined for road material was not calculated.

PAU BRANCO

The Pau Branco deposit is the largest and one of two-known high-grade hematite deposits in the Serra da Moeda. It consists of soft, intermediate and hard high-grade hematite, enriched itabirite, canga, rolado, and itabirite. About 50,000 metric tons of ore had been mined to September 1961, and this ore ranged in grade from 65.6 to 68.7 percent iron, 0.63 to 1.05 percent silica, 0.52 to 0.86 percent alumina, and 0.02 to 0.06 percent phosphorus. Most ore was recovered from an open-pit cut into a heterogeneous mass of broken high-grade hematite; fragments range in size from pebbles to boulders. The northern part of the deposit consists of broken ore; the southern, of ore in place (pl. 9).

The deposit is located at about 10,000–11,000 N.; 1,800–2,000 E., Lagoa Grande, about 2 kilometers west of the junction of the Inconfidentes highway and BR–3. The mine, at an elevation about 1,500 meters above sea level, is reached by an all-weather road that branches off BR–3 (160 m below). The closest loading docks for railroad transport are near Congonhas, 40 kilometers south on BR–3. Truck haulage to Rio de Janeiro is 425 kilometers, and most of the shipped ore has reached that seaport by truck.

The ore deposit is located in the area of intersection of three folds: the upright limb of the north-trending Moeda syncline, a northwest-trending anticline clearly expressed in the outcrop pattern of the Gandarela and Cercadinho Formations at Lagoa Grande (pl. 1), and a curving northeast-east-trending minor anticline within the mine area (pl. 9). The relationship of the northwest-trending anticline to the localization of the ore deposit is not clear; the intersection of the anticline with the limb of the Moeda syncline appears to be north of the mine area. The source area for the broken ore, found only in the northern part of the deposit, is also unknown, and the cobbles and boulders of hard high-grade hematite ore may well have slumped from some place northeast of their present location.

The relationship of the intersection of folds and ore deposition in this deposit is further complicated by the unknown heave and throw of a postore left-lateral strike–slip fault, the Pau Branco, (pl. 9) that determines the southern limit of the deposit. The crumpled and buckled solid ore and the itabirite exposed in adit 7 clearly substantiate the direction of fault movement indicated by the displacement of the Batatal Formation-Cauê Itabirite contact (pl. 1).

The broken ore in part overlies the Cauê Itabirite and in part the Batatal Formation. It consists of pebbles, cobbles, and boulders of high-grade hematite similar to that mined on the apron of Pico de Itabirito.

The soft and intermediate high-grade ores, enriched itabirite, and itabirite are in the southern part of the deposit and are mostly covered by a thin mantle of canga, rolado, or soil. The maps of the adits (pl. 9) show the types of iron-rich rock present within this part of the deposit. Only broken ore was being mined in 1961. This ore, mined from a shallow bench by fork and shovel, was hand-loaded into 5-ton caçambas and trucked to the loading chutes or stock piles.

RESERVES

The measured reserve of hard high-grade broken ore (pl. 9) is estimated to be about 1.6 million metric tons; it is found in an area 200 meters long by 200 meters wide and has an average depth of about 10 meters. The specific gravity of the hematitic material is presumed to average 4.0. No measured reserves of soft high-grade ores, enriched itabirite, canga, or rolado were available in 1961.

Indicated reserves were computed within a triangular area between diamond-drill holes 1, 2 and 3 (pl. 9), and the resulting tonnage figures increased by 50 percent as a reasonable projection of the drill-core results surrounding these holes. Using a factor of 4 tons of high-grade hematite per cubic meter, about 2.4 million metric tons of this material may be expected. There is an average of 3.5 tons of enriched itabirite per cubic meter, or about 4.5 million tons of this material in this area. Canga and rolado average about 3 tons per cubic meter; therefore, about 800,000 tons may be expected on or near the surface of this area (See fence diagram on plate 9.)

If the triangular area between the diamond-drill holes 1, 2, and 3 is representative of the entire mine area and is considered as about one-fifth of its volume, then the inferred ore reserves would amount to about 12 million tons of high-grade hematite ore, 23 million tons of enriched itabirite, and 4 million tons of canga and rolado present within the mine area.

VÁRZEA DO LOPES

The Várzea do Lopes deposit, the smaller of two high-grade hematite deposits in the Serra da Moeda, Marinho da Serra quadrangle, consists of soft to hard high-grade hematite, enriched itabirite, canga, rolado, and itabirite. About 40,000 metric tons of ore had been mined to September 1961, ranging in grade from 64 to 68 percent iron, 0.68 to 0.74 percent silica, 1.0 to 2.2 percent alumina, and from 0.13 to 0.16 percent phosphorus. The ore was extracted from two open pits, one containing a heterogeneous mixture of iron-rich fragments that range from pebbles to large boulders and the other containing lenses and beds of hard, soft and intermediate high-grade hematite and enriched itabirite.

The Várzea do Lopes deposit (fig. 20) is just west of kilometer 410 on the Rio de Janeiro-Belo Horizonte highway (BR–3). The highway cuts through the mining concession, which is owned by Cia. Usina Wigg. Most ore is shipped by truck to the company smelter at São Julião about 30 kilometers to the southeast. The nearest railroad loading facilities are near Congonhas, 25 kilometers to the south.

In the deposit area the Cauê Itabirite strikes N. 55° W. and dips 55° NE. Its contact with the Gandarela Formation is within 50 meters of the main ore bodies; the underlying Batatal Formation lies several hundred meters to the west, beyond the crest of the Serra da Moeda. Although much of the area is covered by soil and canga, the available evidence indicates an absence of cross folds or cross faults. In this respect the structural environment differs from that at other major iron deposits in the district. Observations at the property were limited at the request of the company management.

Three lenses of hard high-grade hematite, one about 375 meters long and two about 200 meters long, occur in the Cauê Itabirite. Recent excavations under two of these lenses have shown the hard high-grade hematite to grade downward into soft and intermediate high-grade hematite within a few meters. The high-grade hematite grades into enriched itabirite. Sufficient broken ore overlying the Gandarela Formation forms a mineable body close to highway BR–3 (fig. 20).

The ore is extracted by pick and shovel on benches cut into the hillsides. It is not separated into grades at the mine; the hard ore, when undercut, is stockpiled below the benches, and the softer material is shipped immediately.

RESERVES

The reserve of hard high-grade hematite, occurring in three lenses, is estimated to be 250,000 metric tons. The longest lens, 375 meters long and averaging 15 meters in width, grades into soft ore 6 meters below the surface; it contains 135,000 tons. The smaller lenses are estimated to contain 72,000 and 50,000 tons. An additional 495,000 tons of mixed ore per meter depth occurs in the remainder of the deposit; the grade of the material is 64 percent or more iron.

ABÓBORAS DEPOSIT

The Abóboras iron ore deposit is located at 10,800 N., 200 E., Itabirito (pl. 3) and 11,400 N., 12,500 E., Lagoa Grande (fig. 1), at an elevation between 1,300 and 1,380 meters above sea level. It contains hard high-grade hematite ore, both in place and as broken material; soft high-grade hematite; and enriched itabirite, covered in places with thin sheets of canga. Unweathered low-grade itabirite surrounds the outcrops of ore. There are no mines at Abóboras; an all-weather road leads from the Inconfidentes highway north 4.5 kilometers to the upper part of the deposit (pl. 10).

The deposit is the lower part of the Cauê Itabirite which forms the crest and dip slope of a ridge in the Serra do Itabirito. There the beds are overturned and dip from 45°–85° E. (pl. 10). The structural environment at Abóboras is similar in many respects to that at Pico de Itabirito and Pau Branco; the deposit overlies an intersection of the northwest-trending limb of the Moeda syncline with a northeast-trending anticline. Crumpling and buckling of the rock is common.

The Abóboras fault, a steep left-lateral strike-slip fault, borders the southern end of the deposit. The outcrop patterns of the various formations in this area (pls. 1 and 3) indicate that the fault preceded the smaller normal faults that lie immediately to the south.

The deposit consists of three large and at least two small outcrops of hard high-grade hematite ore containing 66 percent or more iron intercalated with thin to thick lenses of unweathered itabirite containing 45 percent or less iron. They crop out on the dip slope and extend about 1 or 2 meters above the surrounding topography. There are no peaks of ore in this area, but the eastern limits of the large deposits form nearly vertical cliffs, the southern most of which shows a thickness of about 50 meters of hard high-grade hematite ore.

The lenses of hard ore and hard itabirite have a sharp contact and in places form a closely intermixed irregular mosaic, a unique feature of the Abóboras deposit. This feature not only prohibits accurate estimates of ore reserves but presents a special mining problem in the separation of ore from gangue. Accurate estimates of ore reserves are also difficult to make owing to lack of exploration at depth. The ore appears to be only 1 or 2 meters thick in the northern part of the area and to overlie moderately weathered itabirite.

Using a factor of 4.0 tons of hard high-grade hematite per cubic meter and an average thickness of 20 meters for the northern ore bodies and 50 meters for the southern ore body, about 2 million metric tons of hard high-grade hematite ore is inferred in this

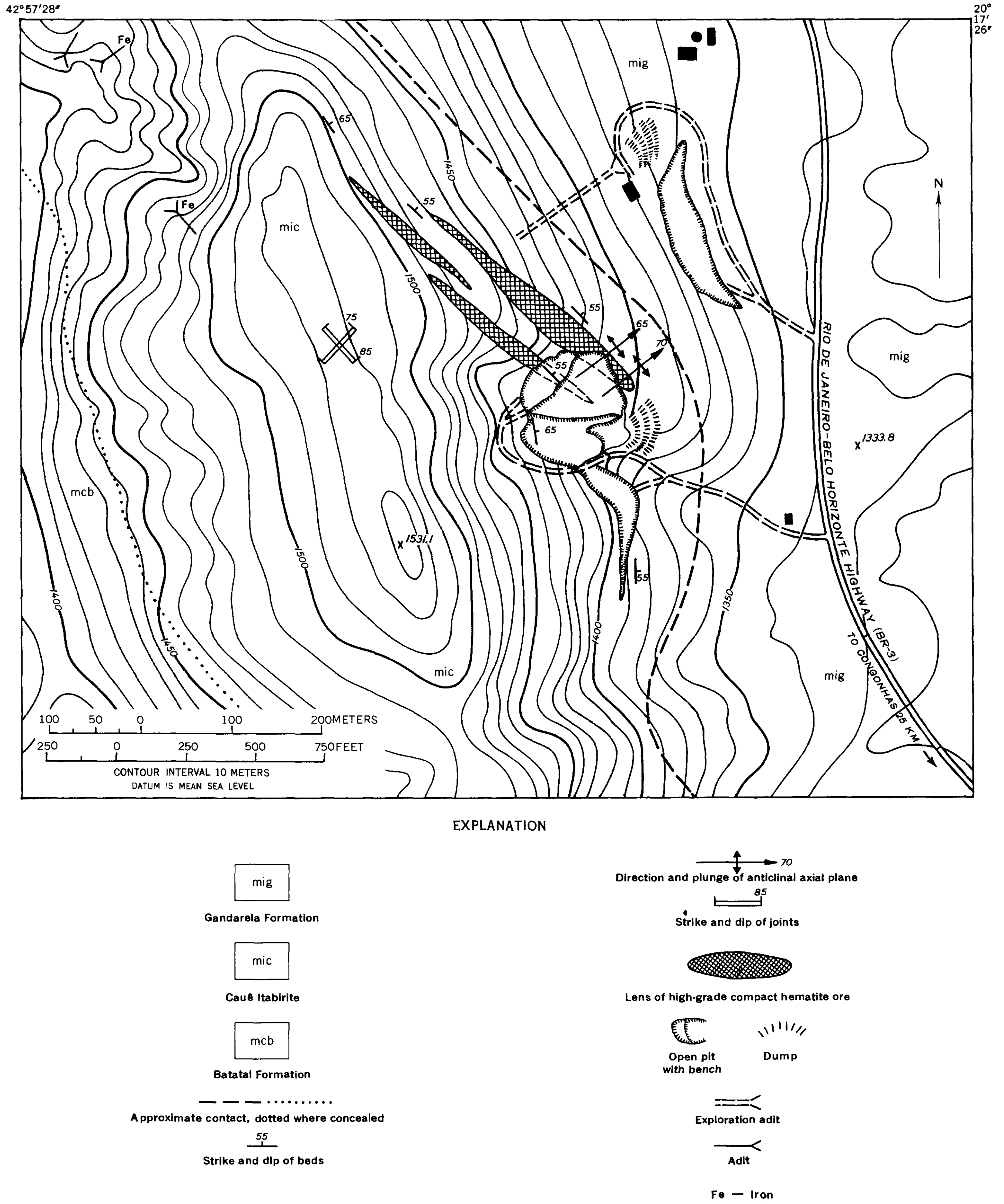


FIGURE 20.—Várzea do Lopes iron mine, Marinho da Serra quadrangle.

deposit. No soft ores were seen, and the canga cover is thin.

ANDAIME

The inactive Andaime mine lies about 1,240 meters above sea level at 9,500 N., 1,300 E., Itabirito (pl. 3). It contained enriched itabirite, soft high-grade hematite, and small amounts of hard high-grade hematite, mined by Cia. Mineração Novalimense from 1957 to 1960. Mining discontinued when the grade of mine-run ore became too low. About 50,000 metric tons of rock were extracted from the hillside.

The mine is of geological interest because of its structural setting. It is similar to the Abóboras deposit, in that it is in the lower part of the Cauê Itabirite which forms the crest and dip slope of the Serra do Itabirito and in that it overlies the intersection of the overturned limb of the Moeda syncline with a northeast-trending anticline. Steeply plunging tight secondary folds lie within this northeast-trending anticline, and high-grade hematite was found only in these secondary folds.

An exploratory adit north of the northeast-trending anticline pentrated phyllite of the Batatal Formation and low-grade itabirite of the Cauê Itabirite. No adit was driven near the axis of the anticline.

CATA BRANCA ROLADO DEPOSITS

The deposits of rolado are in a break in the eastern slope of the Serra do Itabirito at 4,600 N., 2,600 E., Itabirito (pl. 3) at an elevation of about 1,350 meters above sea level. The ore was mined, transported 5 kilometers to Esperança, and smelted by the Sociedade Usina Queiros Junior, S.A. of Esperança until 1960.

The ore slumped down the steeply plunging slope of the Serra do Itabirito during erosion of the Cauê Itabirite which still forms the crest of a ridge west of the deposit. It came to rest for the most part on phyllite of the Batatal Formation and in part on the overlying Cauê Itabirite. Canga now covers the crest of the ridge above the deposit.

The ore extracted from these deposits consisted of a heterogeneous mixture of pebbles, cobbles, and small boulders of hard high-grade hematite, enriched itabirite, and canga that, according to the company records, averaged about 66 percent iron. Leached, solid itabirite found during the termination of mining activities dropped the "run-of-mine" grade to about 62 percent iron.

The deposit contained six bench mines excavated into the lower slopes of the hillside south of the Cata Branca fault. Most of the mining on the benches was done by fork, shovel, and wheeelbarrow. Trucks carried the ore down hill to a small loading and weighing station above the smelter in Epserança where it was loaded into small cars and drawn to the smelter by electric locomotives.

The deposit was mined out by 1960, and the smelter began buying ores from other local mines.

MANGANESE MINES

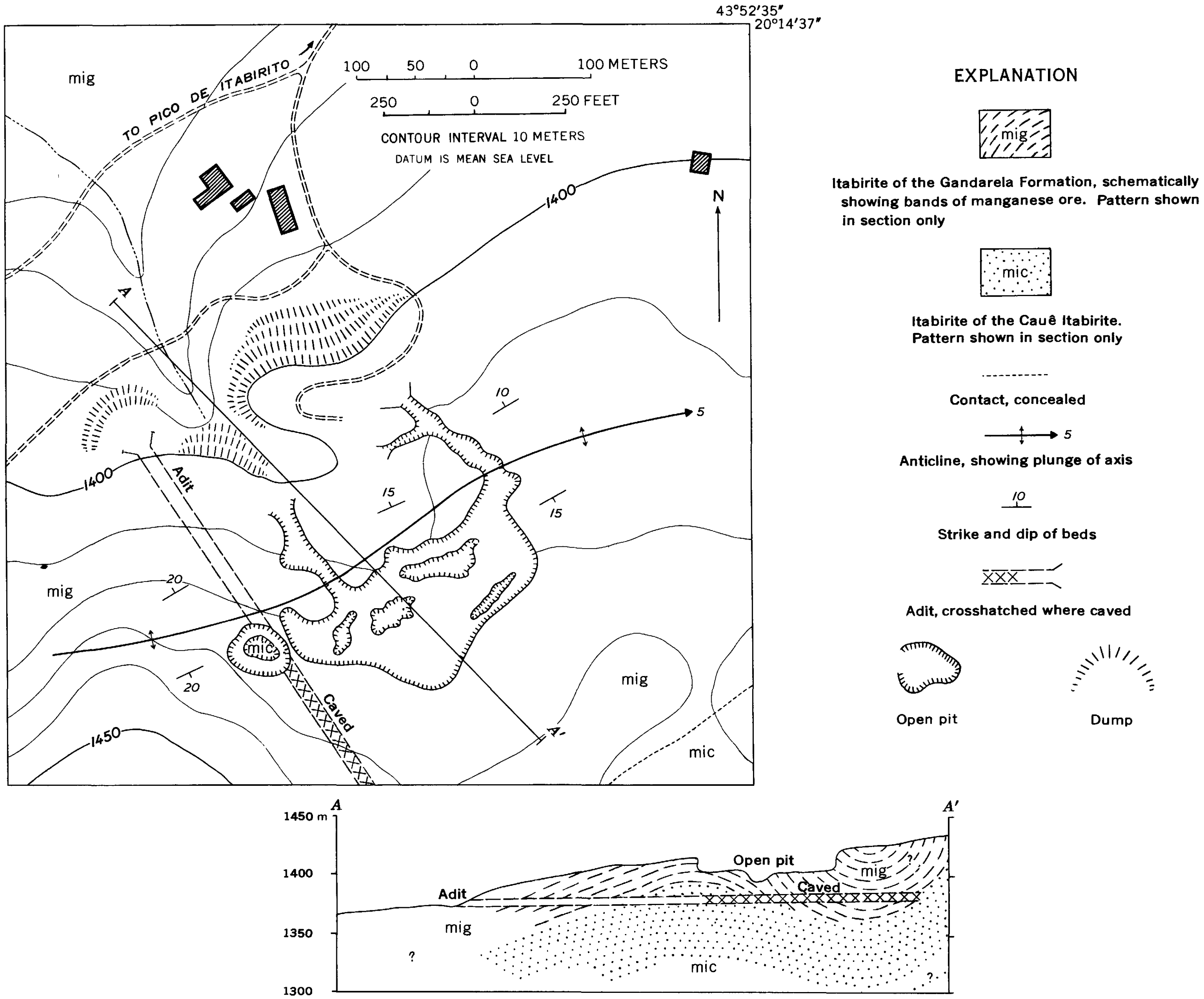
The mining of manganese ores in the Pico de Itabirito district in 1961 is restricted to small pick-and-shovel hand operations. Most ore bodies overlie the contact between the Cauê Itabirite and the Gandarela Formation, but others overlie areas of weathered carbonate rock in the Gandarela and Fêcho do Funil Formations. There are perhaps 13 or 14 dormant open-pit mines that have each produced at least 1,000 metric tons of manganese ores that averaged at least 35 percent manganese (pls. 1–3); six of these are in the Serra da Moeda; two more overlie weathered carbonate rock, and another is in friable quartzite on the Moeda Plateau; four or five more were excavated along the western foot of the Serra do Itabirito in the Gandarela Formation. At least 40 prospect pits that produced no significant quantity of ore dot the hillsides of both serras or follow the Rio Mata Porcos on the Moeda Plateau. In 1961 only the Sapecado mine was active.

SAPECADO MINE

The Sapecado mine of the Companhia de Mineração Retiro de Sapecado Ltda., is located about 1.5 kilometers southwest of Pico de Itabirito at 400 N., 12,300 E., Lagoa Grande (pl. 1). It is reached by an all-weather road that branches off the Pico de Itabirito mine road.

The deposit lies on the crest of a northeast-trending anticline that gently plunges northward (sec. *A–A′*, fig. 21) within the gradational contact zone of the Gandarela Formation and the Cauê Itabirite. The beds of these formations are nearly horizontal in the mine area; the contact is concealed, and its location is extrapolated from data outside the area shown in figure 21.

The Gandarela Formation in the vicinity of this mine consists mostly of dolomitic itabirite in which certain layers are rich in manganese minerals. Other layers contain relatively abundant iron minerals, dolomite, and quartz. The high-grade manganese ore occurs as hard, pitted, and somewhat porous concretions of cobble and boulder sizes, whereas the protore is mostly disaggregated itabirite of the Gandarela Formation. Fine-grained gangue surrounds the concretions of ore and sifts to the floor of the benches



SCHEMATIC GEOLOGIC SECTION ALONG LINE *A-A'*

FIGURE 21.—Sapecado manganese mine, Lagoa Grande quadrangle.

during mining. Sorting and hand cobbing is done at the face of each bench.

An exploratory adit driven at right-angles to the anticline early in the 1940's penetrated the contact zone of the Gandarela and Cauê Formations at a depth of about 40 meters below the mine. Although most of the adit has caved, the area of the contact zone was accessible in 1961. The itabirite of the Cauê Itabirite is megascopically free of manganese minerals.

Random samples of hard ore collected from several layers of the working face of the mine were chemically analyzed by Cássio M. Pinto of DNPM, Belo Horizonte laboratory, June 1961; these samples showed an average of about 56 percent manganese, 3.9 percent iron, 0.5 percent alumina, 0.7 percent silica, and 0.2 percent phosphorus. Random samples of fine-grained gangue from the floor of the mine averaged about 16 percent manganese, 17 percent iron, and 25 percent silica, and showed no change in the percentages of alumina or phosphorus.

The mine is an open pit, and several levels or benches differ less than 10 meters in height. The material is excavated with pick and shovel and transported from the mine by wheelbarrow. It is hand loaded into trucks.

The adit shown on the map (fig. 21) and laterally extended into the plane of section *A–A′*, was about 300 meters long before it caved, according to miners who worked in it. These miners stated that it terminated in manganese-free itabirite (Cauê Itabirite?) after penetrating more than 100 meters of "rich ore." If this is true, then the surface contact as shown on the map may be fairly accurate, and the schematic diagram (sec. *A–A′*), within reason.

RESERVES

According to the company records about 100,000 metric tons of rock, of which about half was ore, has been extracted within the past 50 years. This material was reported to average 46–52 percent manganese, 6–10 percent iron, 0.5 percent silica, and 0.03 percent phosphorus. No record was kept of the alumina content of the ore. No exploratory drilling or trenching had been done by 1961. Surface mapping indicates that perhaps one-half of the ore was removed from this mine area.

LAGOA GRANDE DEPOSITS

The dormant Lagoa Grande manganese ore deposits lie near the crest of the Serra da Moeda at 6,500 N., 2,000 E., Lagoa Grande. They are from 500 to 700 meters west and about 100 meters higher in elevation than the Belo Horizonte-Rio de Janeiro highway (BR–3) and are reached by steep access roads suitable for jeep or small truck, (fig. 22 and pl. 1). Some of the ore from the small mines on the western side of the ridge was carried by pack mules to the base of the ridge. There are no access roads to these mines.

The geology of the Lagoa Grande mines was described in an earlier report by Park and others (1951, p. 7–11) and more recently by Dorr and others (1956, p. 332). Recent work in this area has confirmed the conclusions of these authors, and later mining showed that the richest ore and the thickest and most persistent pods of ore lay in the contact zone between the Cauê Itabirite and dolomitic itabirite of the Gandarela Formation. These pods of ore range from less than a meter in thickness to about 10 meters in thickness and have lengths of as much as 550 meters. The ore minerals are thought to be pyrolusite, cryptomelane, or wad, but no detailed study of the ore minerals has been made. The manganese minerals commonly occur in stalactitic and mammillary forms, as well as in vugs which have splendent crystals that Dorr and others described as polianite. The stalactitic forms are vertical, cutting the itabirite host rock, which has a constant dip of 55° E in this area. Dorr and others mentioned a 10–50 centimeter band of yellow clay, containing no manganese and lying a few meters stratigraphically above the pods of ore in the mine face. Yellow clay commonly is associated with the weathering of dolomite in some localities but has not been seen by this writer in the Pico de Itabirito district.

The abandoned open its on the eastern side of the ridge shown in figure 23 contained groups of lenses of ore in close proximity which were separated by thin bands of itabirite. The ore was separated from the gangue of the mine bench. Mining ceased when the lenses became too thin or too widely spaced to be economically extracted or when the overburden became too thick. Records show that about 70,000 metric tons of ore, ranging from 35 to 46 percent manganese, has been extracted from this mine during the last 20 years.

Individual lenses of manganese ore in itabirite are exposed in shallow prospect pits and in narrow canyon walls; these lenses underlie thin zones of manganiferous canga throughout the entire length of the Serra da Moeda. They seem to be in about the same stratigraphic position as the lenses in the Lagoa Grande mines. Many outcrops of these lenses are

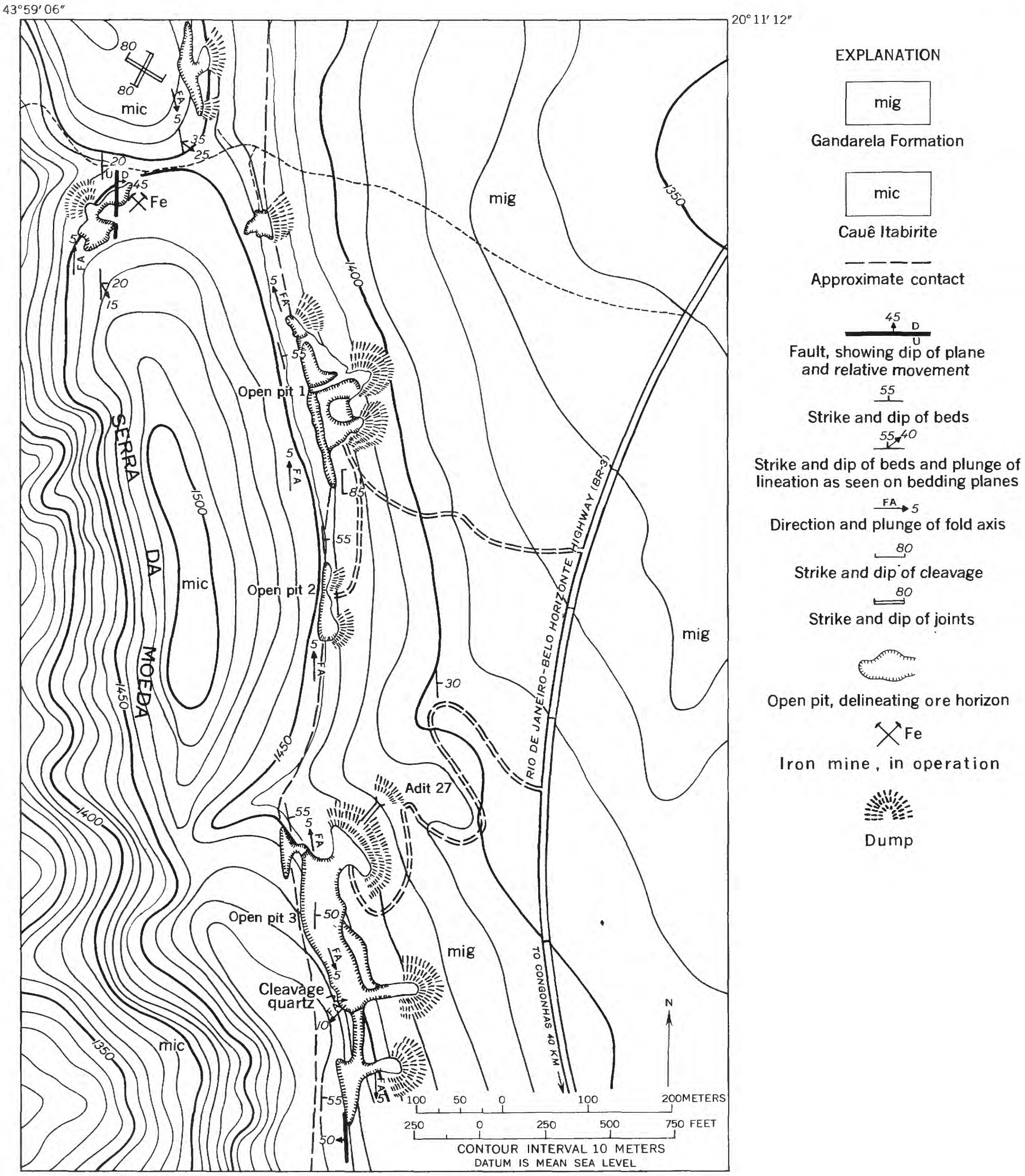


FIGURE 22.—Lagoa Grande manganese mines, Lagoa Grande quadrangle.

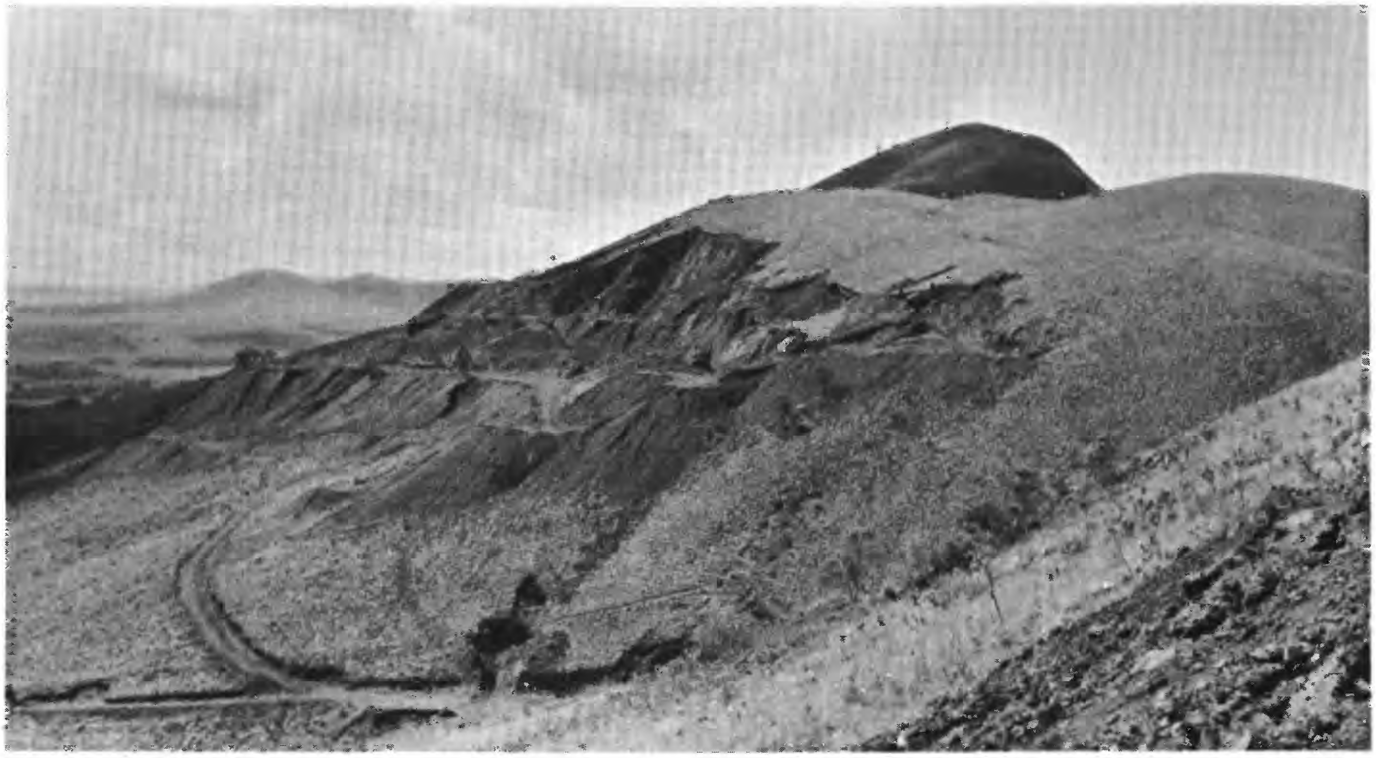


FIGURE 23.—Open-pit manganese mine in the Serra da Moeda near Lagoa Grande. The manganese ore forms lenses in the contact zone between the Cauê Itabirite (top of ridge) and the Gandarela Formation (flank of ridge).

shown on the geologic maps of the Lagoa Grande and Marinho da Serra quadrangles (pls. 1 and 2).

MARBLE QUARRIES

Two marble quarries at the southern end of the district were in operation in late 1961 (pl. 2; figs. 24 and 25) and at least seven others, now dormant, were excavated for road metal and concrete aggregate for construction of the paved highways in this district. The rocks at various localities were sampled by iron and refractory manufacturers, but the chemical analyses showed a silica content too high for use as blast-furnace flux or dolomite firebrick (tables 4, 5, and 10).

JAZIDA DO URUBU

The Jazida do Urubu quarry, owned and operated by the OBRAMIL Co. of Rio de Janeiro (1961), is on the west bank of the Rio Mata Porcos at 1,500 N., 10,500 E., Marinho da Serra (pl. 2). It is reached by a dry-weather access road that branches off the Rio de Janeiro-Belo Horizonte highway (BR-3) at the northern end of the Viaducto das Almas Bridge, south of the boundary of the Pico de Itabirito district. The quarry is about 400 kilometers from Rio de Janeiro and about 55 kilometers from Belo Horizonte. About 1,500 tons of colored marble and 4,000 tons of crushed marble were extracted from 1954 to 1961.

The quarry is in a part of a complexly folded zone within the Fêcho do Funil Formation. The structure in the rock of this area reflects the marginal effects of large-scale thrusting (Guild, 1957, p. 33–35), superimposed on the regional north-trending minor fold system. The north-trending minor anticlines and synclines are best shown in phyllite exposed in cuts of the access road (fig. 24). The superimposed southeast-trending folds are colorfully shown in layers of the marble on the quarry walls (fig. 25). Steep reverse faults formed during a part of the period of folding, and earlier faults were later folded and subsequently healed by recrystallization of the rocks; they are not planes of weakness in the cut slabs. Minor folds and small crenulations conform to the southeast-trending fold patterns.

The left-lateral strike-slip fault that follows the Córrego do Urubu, below the quarry, has a horizontal displacement of about 300 meters and is one of five similar left-lateral strike-slip faults in the vicinity.

The geology and the mineralogy of the marble deposits were described previously in this report; the chemical composition is shown in table 10.

QUARRYING METHODS

The outcrops of marble are quarried by sawing the rock with a wire saw into large slabs 1–2 meters thick,

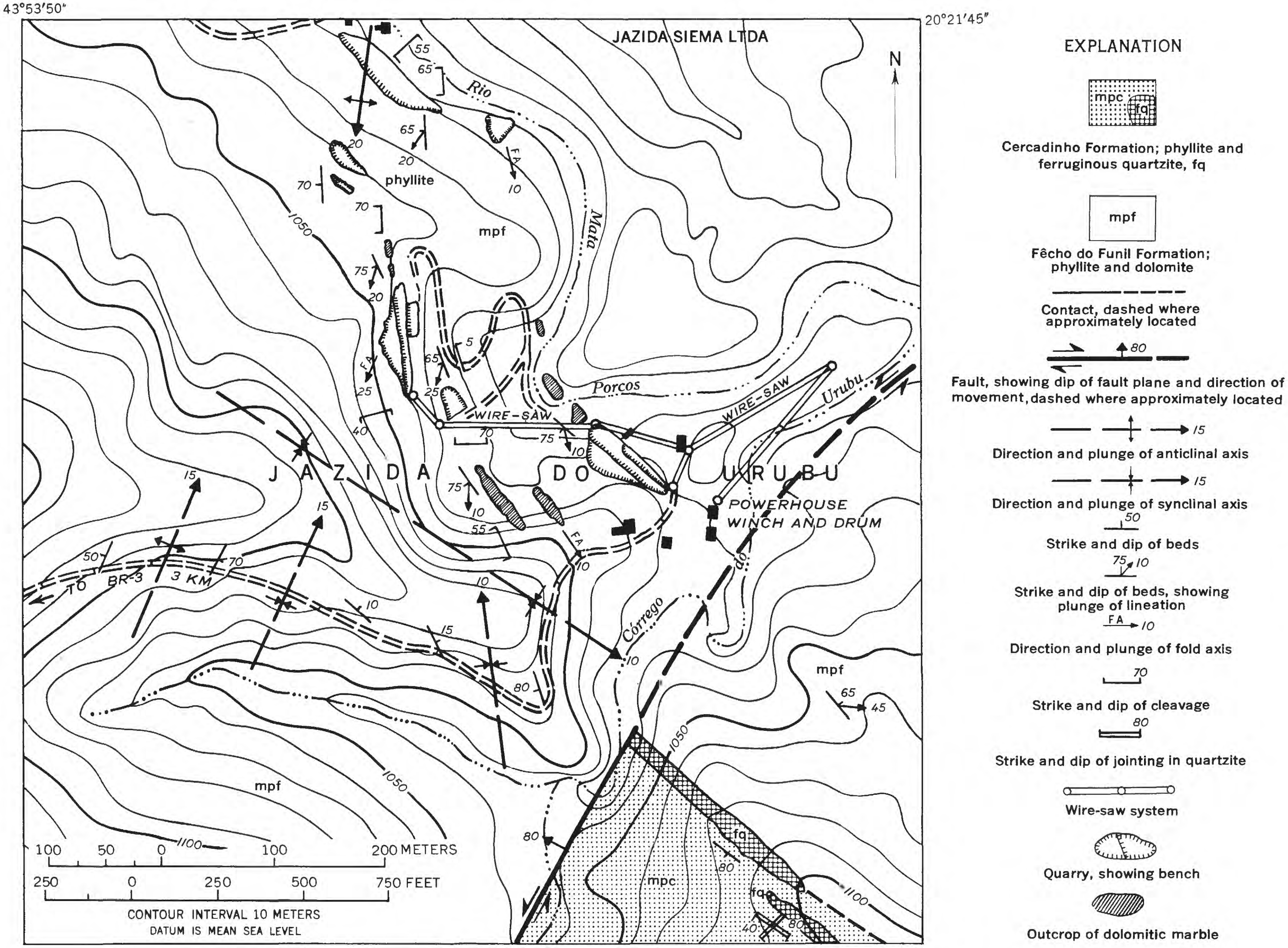


FIGURE 24.—Jazida do Urubu marble quarry and the Jazida Siema Ltda. dolomite quarry, Marinho da Serra quadrangle.

FIGURE 25.—Steep reverse fault in dolomitic marble at the Jazida do Urubu. Drag folds near the foot of the face are well defined along the fault plane but less distinct above. Small crenulations conforming to the regional fold pattern appear in a dark layer in the face, about 0.3 meter above the man's head.

10–30 meters long, and 5–15 meters high. The slab cuts commonly follow the steep bedding planes or steep cleavage planes. After a slab is detached it falls onto a previously prepared surface, and each of the blocks must be cut into smaller blocks that weigh from 2 to 10 tons. The material weighs about 3 metric tons per cubic meter.

The slabs and blocks are sawed by passing an endless ¼-inch two-strand steel wire along bedding or cleavage planes. Angular grains of quartz sand are used as the abrasive, this sand is slowly poured on the moving wire as it enters the cut. The quartz grains do the cutting; the wire merely carries the quartz grains through the cut. Pulleys that range from about 15 to 65 centimeters in diameter guide the endless wire through the cut and to and from the drum of a diesel motor-driven windlass. The endless wire is long enough to permit simultaneous cutting of slabs in several places throughout the quarry (fig. 24). Slab cuts that measure about 10 meters high and 50 meters long require from 30 to 35 days of continuous sawing.

JAZIDA SIEMA

The Jazida Siema quarry is about 250 meters north of the northernmost quarry of the Jazida do Urubu (fig. 24). This quarry was in operation in June 1961 by Cia. Siema Ltda., of Belo Horizonte. It produces about 25 metric tons of crushed marble per month and has produced about 1,250 tons of crushed and block marble from 1956 to 1961. The quarry contains no colorful marble.

The geology is similar to that of the Jazida do Urubu. The marble contains sparse veinlets of pyrite and copper-antimony-zinc sulfide minerals, similar to those at Jazida do Eixo. Quartz veins that range in thickness from a few tens of millimeters to several tens of centimeters are seen on some walls in the Jazida Siema quarry.

COPPER DEPOSITS

JAZIDA DO CÓRREGO DO EIXO

An unpublished report to DNPM by G. A. Rynearson in 1951 described a marble deposit on the south bank of the Córrego do Eixo at 3,500 N., 8,500 E., Marinho da Serra. In this quarry, many of the small lenses of marble that lie within thick beds of dolomitic phyllite in the Fêcho do Funil Formation contain small pods of tetrahedrite as much as 15 centimeters wide and 50 centimeters long. Rynearson estimated the copper content to be less than 1 percent. The present writer agrees with this estimate and has seen no evidence to suggest greater copper content at depth inasmuch as all the lenses of marble themselves, with or without copper, are small and are separated by phyllite that contains no visible copper minerals. The age of copper mineralization is unknown.

About 450 square meters of copper-bearing marble is exposed in this area. If one assumes the rock to contain as much as 1 percent tetrahedrite, the reserves of copper are calculated as about 9 metric tons per meter depth. To extract this ore, a minimum of 1,300 tons of copper-bearing marble per meter depth must be mined; this tonnage includes all the surrounding phyllite and the barren dolomite and marble. Any attempt to mine for copper would necessitate small-scale, selective mining methods of the copper-bearing marble lenses, which probably are less than 20 percent of the total marble lenses in the immediate area.

A sample of the tetrahedrite from Jazida do Córrego do Eixo analyzed at the Instituto de Technologia Industrial do Estado de Minas Gerais in Belo Horizonte, by Dr. Claudio V. Dutra gave the following semiquantitative spectrochemical results:

Semiquantitative spectrochemical analysis of tetrahedrite from Jazida do Córrego do Eixo, in percent

Cu	Major constituent	As	2.0
		Bi	.01
Sb	2.5	Ag	.02
Zn	5.3	Ni	.0005
Fe	4.0	Co	.005

The mineral is zincian tetrahedrite (Palache and others, 1944, p. 374–378).

KYANITE MINES

Kyanite was mined in the Lagoa Grande and Itabirito quadrangles in the early 1940's by the St. John del Rey Mining Co. of Nova Lima. The company records show that mining ended in 1944 after about 1,600 metric tons of kyanitic material was produced and stock piled. About 211 tons were sold in 1946 to a firm in Rio de Janeiro.

The Botica mine is at 5,000 N., 500 E., Itabirito (pl. 3). The workings consist of a series of shallow trenches underlain by a small exploration tunnel. The trenches follow a kyanite-rich quartz vein that pinches and swells from a few tens of centimeters to nearly a meter in thickness; this vein follows the bedding of phyllite of the Cercadinho Formation for about 200 meters. The inclined tunnel transected the quartz vein about 30 meters below the outcrop; the vein was then followed by driving a small raise to the surface. About 1,450 metric tons of kyanitic material were extracted from this mine, of which 211 tons were sold; afterwards the mine timbering was withdrawn and the workings caved.

The Codorna mine (10,700 N., 11,000 E., Lagoa Grande, pl. 1) consists of a simple opencut in a hillside of phyllite of the Cercadinho Formation. The cut is caved, but a small stockpile nearby indicates that the kyanite was associated with vein quartz similar to that of the Botica mine. Company records show that 124 metric tons of material were extracted from the mine before it caved.

Samples of kyanite from the Codorna and Botica mines were analyzed by the laboratories of the St. John del Rey Mining Co. Ltd., of Nova Lima. Their average composition is as follows:

Al_2O_3	55.61
SiO_2	42.48
Fe_2O_3	2.11
Total	100.20

Inasmuch as even 0.2 percent iron in kyanite may render it commercially useless (Riddle and Foster, 1949, p. 916), the high iron content of these deposits may have been the cause for the closing of the mines.

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INDEX

[Italic page numbers indicate major references]