Geology and Ore Deposits of the Antônio dos Santos, Gongo Sôco and Conceição do Rio Acima Quadrangles, Minas Gerais, Brazil

GEOLOGICAL SURVEY PROFESSIONAL PAPER 341-I

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

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By SAMUEL L. MOORE

GEOLOGY AND MINERAL RESOURCES OF PARTS OF MINAS GERAIS, BRAZIL

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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By Samuel L. Moore

ABSTRACT

The Antônio dos Santos, Gongo Sôco, and Conceição do Rio Acima quadrangles lie in the east-central part of the Quadrilátero Ferrífero, or "iron quadrangle," of Minas Gerais, Brazil. The area is part of the Brazilian shield and is underlain by folded and faulted Precambrian metasedimentary and igneous rocks. The metasedimentary rocks have been divided into two series: the lower, Rio das Velhas Series and the Minas Series, separated by a discordant contact. Granitic gneiss intrudes the Rio das Velhas Series, and gabbro and diabase intrude rocks of both series.

The Rio das Velhas Series has been divided into three units. The lower, Nova Lima Group consists of schist, phyllite, and iron-formation. The middle, Maquiné Group consists of quartzite, conglomeratic quartzite, and quartz-sericite schist. The upper, Cambotas Quartzite consists dominantly of quartzite, and sericitic quartzite with a few layers of iron-formation conglomerate. All units are separated by unconformable, fault, or discordant contacts.

The Minas Series also has been divided into three groups. The lower Caraça Group is composed of the Moeda Formation, consisting of quartzite, conglomerate, and quartz-sericite schist, and the overlying Batatal Formation, consisting of phyllite and argillite. The overlying Itabira Group consists of Cauê Itabirite overlain by the Gandarela Formation. The Cauê Itabirite is made up dominantly of laminated iron-formation, consisting mostly of dolomitic itabirite, siliceous itabirite, and lenses of dolomite. It contains most of the iron deposits. The Gandarela Formation is composed of high-magnesian dolomite interlayered with some dolomitic itabirite and phyllite. Disconformably above the Itabira Group is the Piracicaba Group, composed of the Cercadinho Formation, consisting of ferruginous quartzite, quartzite, quartz-sericite schist, and phyllite, and the overlying Sabará Formation, consisting of schist, phyllite, and feldspathic quartzite. In the mapped area the upper part of the Sabará Formation has been removed by erosion.

Only one granitic rock was recognized in the mapped area. It was correlated with the youngest of four granites that occur in the region (500 million years old on the basis of Ar^{40}/K^{40} ratios in biotite). Granitic gneiss cuts across rocks of Rio das Velhas age and forms part of a regional batholith in the northern part of the mapped area.

Gabbro and diabase, now mostly weathered to lateritic soil and saprolite, intrude the Rio das Velhas and the Minas Series. These intrusive rocks occur as dikes along faults and joints, as plutons, and, rarely, as sills. Quartz veins of several types occur along joints and minor faults in the metasedimentary and igneous rocks. Pegmatite dikes and veins occur only in contact metamorphic zones along the contact with the granitic gneiss and are hydrothermal in origin.

The Rio das Velhas Series was deformed during at least one period of orogeny before the deposition of the Minas Series. After the deposition of the Minas Series, both rock series were broken by high- and low-angles thrust faults and folded into northeast-trending folds that are overturned to the northwest. Evidence of the trends of pre-Minas deformation has been largely destroyed by post-Minas orogeny, and both series of rocks have been metamorphosed to the greenschist facies.

Two major types of iron ore occur in the area: one is high-grade hard and soft hematite ore in the Itabira Group, and the other is surficial canga ore of intermediate grade.

The high-grade hematite ore contains 66–69 percent iron and occurs in the iron-formation of the Cauê Itabirite and in dolomite of the Gandarela Formation. The high-grade hematite ore in the Gandarela Formation occurs along the axial zone of a subsidiary fold. The crosscutting relationships of the high-grade hematite ores to the laminations of the iron-formation and bedding planes of the dolomite show these ores to be replacement bodies rather than sedimentary in origin. It is believed that they were formed by iron-bearing fluids that leached iron from the surrounding itabirite and then replaced the quartz and carbonate of the Cauê Itabirite and dolomite of the Gandarela Formation. Textures of the high-grade hematite range from hard massive ore through schistose, platy ore to soft, powdery ore. Most ore bodies contain all three textures. The schistose and soft ores are believed to be derived from the weathering and disaggregation of the hard ore. The high-grade hematite ore contains minor amounts of chrysotile, quartz, and phosphorus-bearing gangue minerals.

Surficial canga ore contains 50–60 percent iron and occurs as a 1- to 10-meter-thick layer of conglomerate-breccia composed dominantly of fragments of iron-formation cemented by limonite. The canga ore, derived from the weathering of iron-formation, was deposited on a Tertiary erosional surface. The canga ores range in texture from conglomerate-breccia, the dominant type, to limonite enclosing minor amounts of quartz grains, aluminous and ferruginous laterite, and iron-formation fragments. Canga contains widely varying amounts of aluminum- and phosphorus-bearing gangue minerals.

Reserves of high-grade hematite ore in the Gongo Sôco and Conceição do Rio Acima quadrangles are estimated to be 2 million metric tons above the present surface and about 80,000 tons per meter of depth. Reserves of intermediate-grade canga ore are estimated to be 66 million metric tons. Weathered soft Cauê Itabirite averages about 40 percent iron and is a source

of vast tonnages of material that in the future may be beneficiated for use in iron furnaces.

Dolomite, a potential source of dimension and crushed stone; clays, suitable for the manufacture of roofing tile, fire brick, and refractory brick; ferruginous bauxite, a potential source of low-grade aluminum ore, and minor amounts of manganese occur in the mapped area. Lode and placer deposits of gold were mined during the 18th and early part of the 19th centuries, but they were abandoned because of diminishing ore grade and depletion of ore.

INTRODUCTION

It has long been known that the Quadrilátero Ferrífero, or iron quadrangle, of central Minas Gerais contains large tonnages of high-grade iron ore (more than 66 percent iron) as well as other lower grade deposits. Because of this potential, Brazil and the United States in 1946 jointly agreed to make a long-term study of the regional geology and an evaluation of the iron-ore deposits. This study was carried out jointly by geologists of the Departmento Nacional da Produção Mineral and the U.S. Geological Survey. The U.S. Geological Survey work in this program was done under the auspices of the Agency for International Development of the U.S. Department of State.

The Conceição do Rio Acima, Gongo Sôco, and Antônio dos Santos quadrangles are in the east-central part of the Quadrilátero Ferrífero (fig. 1), about 35 kilometers east of Belo Horizonte. The quadrangles are accessible from Belo Horizonte by both a highway and the Central do Brasil railroad, which pass through the central part of the Gongo Sôco quadrangle. The area is traversed by a network of secondary roads and trails that lead northward and southward from the highway to the mines, ranches, and quarries. The main industries of the area are mining of iron, manganese, and dolomite and the manufacture of charcoal for the iron smelters.

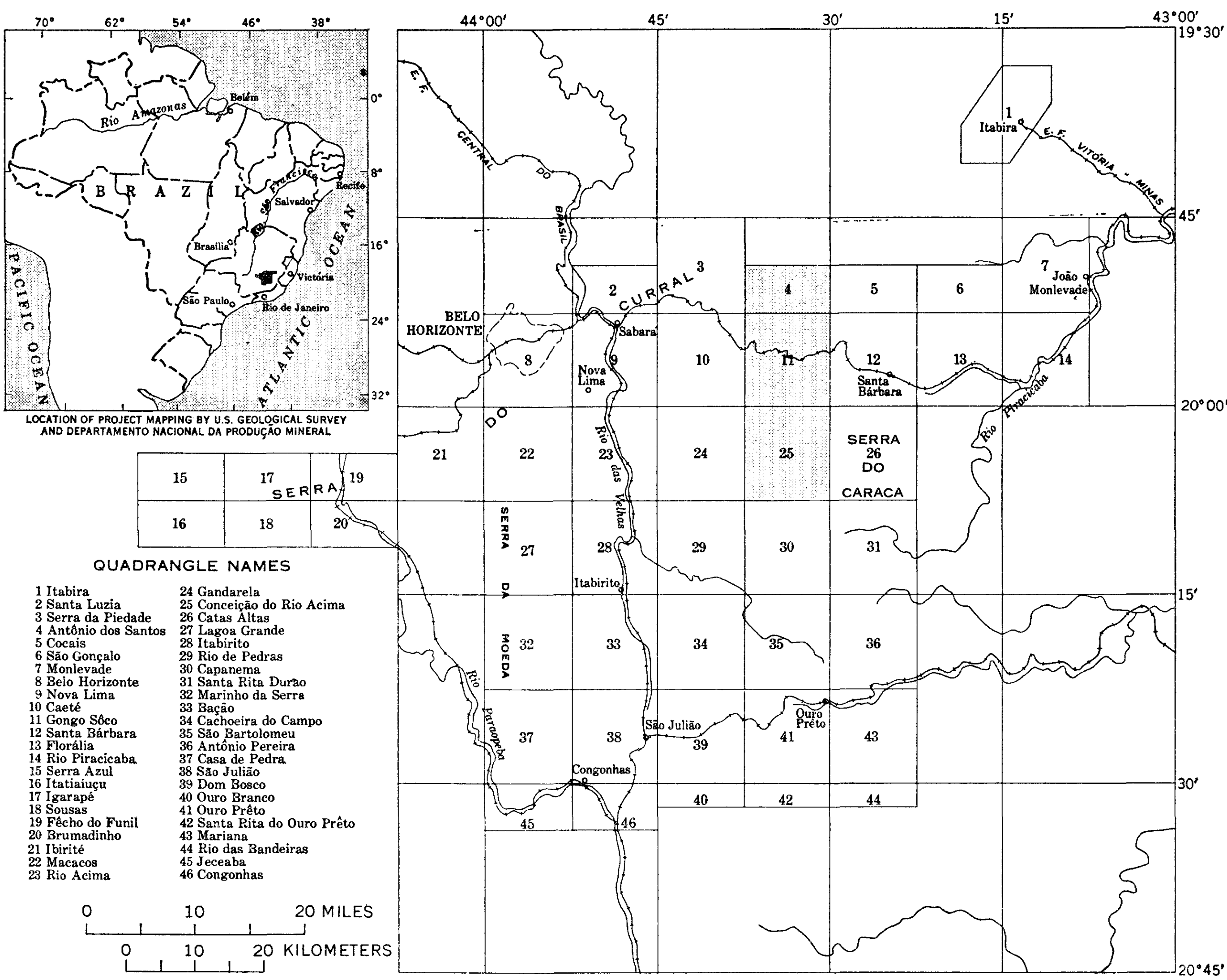

FIGURE 1.—Location of the Antônio dos Santos, Gongo Sôco, and Conceição do Rio Acima quadrangles.

In the east-central part of the Quadrilátero Ferrífero are four major mountain ranges: the Serra do Caraça, the Serra das Cambotas, the Serra Geral, and the Serra da Pedra Formosa. The Serra Geral and the Serra da Pedra Formosa trend northeast and extend diagonally across the area between the north-trending Serra das Cambotas on the northeast and the Serra do Caraça on the southeast. The maximum relief in the area is about 1,180 meters. The highest point in the area, 1,911 meters, is in the Serra do Maquiné; the lowest point about 730 meters, is in the valley of the Rio da Conceição. The Rio da Conceição flows northeast between the Serra do Caraça on the southeast and the Serra da Pedra Formosa on the northwest. The Rio Socorro also flows northeast, between the Serra Geral on the northwest and the Serra da Pedra Formosa on the southeast. These two rivers flow into the Rio Doce and drain about 300 square kilometers of the area that lies south of the Serra Geral. The low rolling country north of the Serra Geral and west of the Serra das Cambotas is drained by a series of small streams that flow northward into the Rio das Velhas.

The region has a subtropical climate; seasonal temperatures range from about 0°C to about 37°C, and the average daytime temperature is about 17°C during the winter and about 23° C during the summer. Rainfall is seasonal and occurs mostly from November to April, when torrential rains are common. From April to November there is little precipitation, and the sky is generally clear. The average annual rainfall is about 1,500 mm.

The valleys are commonly covered with a thick growth of trees, vines, and ferns; the intermediate elevations on the flanks of the serras are generally timbered with a scrubby growth of trees; and the higher areas are covered with grass. Most of the thickly wooded areas have been cut over several times for charcoal, and virgin mato (jungle) remains only on the steeper slopes where timbering is difficult and uneconomical.

Gold was the first metal sought by prospectors and miners in the central part of Minas Gerais. Portuguese settlers prospected widely in the valleys of the Rio da Conceição and the Rio Socorro and operated large placer mines during the early part of the 19th century. Underground mining for gold was started in 1824, when the Imperial Mining Co., a British firm, purchased the Gongo Sôco mine. This mine was in operation until 1856, when it was closed because of depletion of ore.

Open-pit iron mines have been operated since 1935 in the Gongo Sôco quadrangle. The Barra Mansa mine, the Trindade mine, the Gongo Sôco iron mine, and the Cabral mine are on the south slope of the Serra Geral, along the Central do Brasil railroad. The Gongo Sôco open-pit iron mine is operated by Companhia Ferro Brasileiro, Usina Gorceix, which is mining the surficial canga iron ores. The Cabral and Trindade mines, now closed, were operated by Companhia Siderurgica Belgo-Mineira from 1948 to 1954. The Cabeça de Ferro iron mine, near the east boundary of the Gongo Sôco quadrangle, is operated by the Companhia Brasileira da Usinas Metalurgicas.

Dolomite is produced from many small quarries in the Gongo Sôco quadrangle for use as fluxing material. Manganese has been produced in small quantities in the Gongo Sôco quadrangle.

The geology and ore deposits of the Quadrilátero Ferrífero have been studied for more than 130 years, and a large bibliography has accumulated. Most of the studies have been of individual ore deposits. One of the earliest studies of the regional geology of the Quadrilátero Ferrífero was made by Eschwege (1833). Later regional studies of the geology of the Quadrilátero Ferrífero were made by Derby (1906), Harder and Chamberlin (1915), Freyberg (1932), and Guimarães (1951). Dorr and Barbosa (1963), Guild (1957), Gair (1962), and Pomerene (1964) discussed the ore deposits of the region.

Geologic mapping for the present investigations was begun in June 1955 and was finished in October 1957. Rocks of the Minas Series were mapped in greater detail than other rocks because they contain most of the iron-ore deposits and because the outcrops are more abundant. Pre-Minas rocks are deeply weathered, crop out sparsely, and are of slight economic interest.

Mapping data were recorded in the field on aerial photographs at a scale of 1:25,000 and later transferred to topographic base maps at a scale of 1:20,000. To allow location of points that do not have formal names, a coordinate grid system was used on each quadrangle map (pls. 1–3). In this system, the 0 point, or the origin, is at the southwest corner of each map, and tick marks on the sides of the map indicate 1,000-meter intervals away from this point.

The cooperation, both in the field and in the laboratory, of all members of the Departmento Nacional da Produção Mineral is gratefully acknowledged. The writer especially thanks Dr. Jose Alves, Chief of the Belo Horizonte office, for his cooperation in assigning field personnel and providing laboratory facilities during all phases of the study, and Dr. Cassio Pinto, Chemist of the D.N.P.M. laboratory in Belo Horizonte, who made most of the analyses of ores. Mr. Charles Wurth of the Ferro Brasileiro Usina Gorceix and Dr. Francisco Jose Pinto de Souza of the Companhia Brasileira da Usinas Metalurgicas provided company files from

which tonnage and grade of ore were obtained. Dr. Luis Verano furnished lodging at Casa de Hospedes in Barão de Cocais and at Fazenda Capivara.

The field mapping was carried out under the supervision of J. V. N. Dorr 2d, chief of party in Brazil, and W. D. Johnston, Jr., U.S. Geological Survey, Washington, D.C. G. A. Rynearson, U.S. Geological Survey, supervised the initial phases of the work. J. B. Pomerene, a fellow worker, provided much good advice and assistance during the first 2 months of fieldwork. José Roberto da Silva assisted the writer in the field, served as chauffeur, and was a very pleasant companion during the fieldwork.

STRATIGRAPHY

The Antônio dos Santos, Gongo Sôco, and Conceição do Rio Acima quadrangles are underlain by regionally metamorphosed sedimentary and igneous rocks of Precambrian age (pls. 1–3). The metasedimentary rocks are schist, phyllite, quartzite, dolomite, and itabirite. The igneous rocks are granitic gneiss, diabase, and gabbro.

The metasedimentary rocks of the quadrangles are divided into two series (Dorr and others, 1957): an older, Rio das Velhas Series, and a younger, Minas Series. All the sedimentary rocks of the Quadrilátero Ferrífero were defined as Minas Series by Derby (1906, p. 396). Harder and Chamberlin (1915) included most of the metasedimentary rocks of the region in their Minas Series (table 1). Barbosa (1954), Guimarães (1931, p. 8), Oliveira (1956), and Dorr, Gair, Pomerene, and Rynearson (1957) divided Derby's original Minas Series into three series (table 1). They named the upper series Itacolomí (Guimarães, 1931) and the middle series Minas. The lower series was named the Barbacena Series by Barbosa (1954), the pre-Minas Series by Oliveira (1956), and the Rio das Velhas Series by Dorr, Gair, Pomerene, and Rynearson (1957). Barbosa's Barbacena Series included some rocks of known post-Minas age, and he indicated that his Barbacena Series may correlate with the rocks that are now called Rio das Velhas Series (1954, p. 21).

RIO DAS VELHAS SERIES

Rocks of the Rio das Velhas Series (Dorr and others, 1957, p. 11–22) have been divided into three units: the Nova Lima Group (undivided), at the base, consisting of schist, phyllite, and iron-formation; the Maquiné Group (undivided), consisting of quartzite, conglomerate, quartz-chlorite schist, conglomerate schist, and phyllite; and the Cambotas Quartzite, consisting of pebble conglomerates, quartzite, sericitic quartzite, and minor amounts of phyllite. The Cambotas Quartzite is the basal formation of the Tamanduá Group defined by Simmons and Maxwell (1961).

NOVA LIMA GROUP (UNDIVIDED)

DISTRIBUTION

Schist, phyllite, and iron-formation of the Nova Lima Group have been mapped in a northeast-trending belt across the Conceição do Rio Acima quadrangle and the southeastern part of the Gongo Sôco quadrangle (pls. 2, 3). This belt of Nova Lima rocks is overlain by the basal formations of the Minas Series on the northwest and by schist and quartzite of the Maquiné Group on the southeast.

A band of quartz-chlorite schist, iron-formation, and some dolomitic phyllite has been mapped across the north-central part of the Gongo Sôco quadrangle (pl. 2). On the south these rocks are overlain by the basal formations of the Minas Series, and on the north the rocks are intruded by granodiorite gneiss of the Caeté Complex, from the west boundary of the quadrangle to near N. 7,800, E. 6,800 (pl. 2). From this locality to the east boundary of the quadrangle, rocks of the Nova Lima Group overlie and underlie Cambotas Quartzite along the south and north slopes of the Serra Geral (pl. 2).

The stratigraphic position of this belt of schist and iron formation in the column is uncertain. West of the Gongo Sôco quadrangle these rocks have been mapped in the Caeté quadrangle as Nova Lima Group (N. L. Alves, oral commun., 1955). In the Nova Lima quadrangle, Gair (1962, p. 16–26) included rocks of similar lithology in the Nova Lima Group. After the completion of this study, Simmons and Maxwell (1961) measured a section in the northeastern part of the Gongo Sôco quadrangle and the eastern part of the Santa Bárbara quadrangle. They assigned this belt of schist and iron-formation to the upper part of their Tamanduá Group and divided these rocks into three unnamed units. Thrust faults along the north boundary of this belt of rocks further complicate positioning these rocks in the stratigraphic column and determining their age. However, this belt of rocks was traced westward from the Santa Bárbara quadrangle across the Gongo Sôco quadrangle into rocks of unquestioned Nova Lima age in the Caeté quadrangle and they are therefore included in the Nova Lima Group.

LITHOLOGY

In most places where the schist, phyllite, and iron-formation are exposed, they are deeply weathered; outcrops of fresh rock are very sparse. The schist and phyllite weather to a surficial layer of brownish-red to dark-red lateritic soil mantling a deeply weathered

TABLE 1.—*Correlation chart of the principal stratigraphic classifications of Precambrian rocks in the Quadrilátero Ferrífero*

Harder and Chamberlain (1915)

Minas series	Itacolomí quartzite	Quartzite, phyllite, and conglomerate
Minas series	Piracicaba Formation]	Schist, quartzite, and dolomite
Minas series	Itabira Formation	Iron-formation (itabirite)
Minas series	Batatal schist	Schist
Minas series	Caraça quartzite [3]	Quartzite, conglomerate, and quartz and mica schist
		Unconformity
Probable Archean	Basal complex	Gneiss, amphibolite, and granite

Barbosa (1954)

Itacolomí Series		Quartzite, phyllite, and conglomerate
		Unconformity
Minas Series	Piracicaba Formation	Phyllite, quartzite, dolomite, and iron-formation (itabirite)
Minas Series	Itabira Formation	Dolomite, iron-formation (itabirite), and phyllite [1]
Minas Series	Caraça Formation [2]	Quartzite and conglomerate
		Unconformity
Barbacena Series [4]		Greenschist, talc schist, gneiss, and granodiorite
		Unconformity
Mantiqueira Series		Gneiss

Oliveira (1956)

Itacolomí Series		Quartzite, phyllite, and conglomerate
		Large unconformity
Minas Series	Piracicaba Formation	Quartzite, phyllite, ferruginous quartzite, and graphitic phyllite
		Unconformity
Minas Series	Itabira Formation	Itabirite and dolomite
Minas Series	Batatal Formation	Phyllite
Minas Series	Caraça Formation	Quartzite and conglomerate
		Large unconformity
pre-Minas Series		Quartz and mica schist, gneiss, phyllite, graywacke, iron-formation, quartzite, and dolomite
		Unconformity
Mantiqueira Series		Gneiss

U.S. Geological Survey and the Departamento Nacional da Produção Mineral, in 1961, combined with Simmons and Maxwell (1961)

Itacolomí Series		Quartzite, phyllite, and conglomerate
		Large unconformity
Minas Series	Piracicaba Group	Sabará Formation; phyllite, graywacke, subgraywacke, and metavolcanic rocks
Minas Series	Piracicaba Group	Barreiro Formation; schist, phyllite, and graphitic phyllite
Minas Series	Piracicaba Group	Taboões Quartzite; quartzite
Minas Series	Piracicaba Group	Fêcho do Funil Formation; dolomitic phyllite, argillaceous dolomite, phyllite, and ferruginous quartzite
Minas Series	Piracicaba Group	Cercadinho Formation; quartzite, ferruginous quartzite
		Local disconformity
Minas Series	Itabira Group	Gandarela Formation; dolomite, iron-formation, and phyllite
Minas Series	Itabira Group	Cauê Itabirite; itabirite (oxide-facies iron-formation)
Minas Series	Caraça Group	Batatal Formation; phyllite, and minor amount of schist
Minas Series	Caraça Group	Moeda Formation; quartzite, sericite quartzite, and conglomerate
		Large unconformity
Rio das Velhas Series	Tamanduá Group [5]	Quartz-chlorite schist
Rio das Velhas Series	Tamanduá Group [5]	Ferruginous dolomitic quartzite
Rio das Velhas Series	Tamanduá Group [5]	Quartz-chlorite schist
Rio das Velhas Series	Tamanduá Group [5]	Cambotas Quartzite; quartzite and sericitic quartzite
		Unconformity
Rio das Velhas Series	Maquiné Group	Upper part; quartzite conglomerate and schist
Rio das Velhas Series	Maquiné Group	Lower part; quartzite, graywacke, quartz schist, and phyllite
		Unconformity
Rio das Velhas Series	Nova Lima Group	Phyllite, greenschist (metasedimentary and metavolcanic rocks), iron-formation (carbonate), quartzite, and graywacke
		Unconformity
		Gneiss and granitic rock [6]

[1] Includes the Batatal of Harder and Chamberlain (1915).
[2] Includes Rio das Velhas rocks classified as Maquiné Group in the U.S. Geological Survey–Departamento Nacional de Produção Mineral classification.
[3] Includes part of the Rio das Velhas Series in the U.S. Geological Survey–Departamento Nacional de Produção Mineral classification.
[4] Includes some rock of the Itacolomí Series and post-Minas granitic rocks.
[5] Includes Caraça quartzite of Harder and Chamberlain (1915) in eastern part of the Quadrilátero Ferrífero.
[6] Includes igneous rocks of at least three ages ranging from pre-Rio das Velhas to post-Minas.

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saprolite,[1] and most of the rock descriptions are those of weathered material.

Schist, phyllite, iron-formation, and graphitic phyllite and schist of unquestioned Nova Lima age crop out in roadcuts and in valleys in the Conceição do Rio Acima quadrangle (pl. 3). Schist weathers to light-reddish-brown to dark-red friable material. Granular quartz and bleached mica are the only recognizable minerals. Phyllite weathers to light-red and purple or brownish-red and dark-gray earthy material consisting of bleached micaceous minerals and arenaceous material embedded in a clay matrix.

Thin layers of dark-gray graphitic schist and phyllite are exposed in the belt of Nova Lima rocks underlying the Conceição valley (pls. 2, 3). They are interlayered with dark-red quartz-chlorite schist, reddish-brown phyllite, and thin iron-formations in roadcuts. The graphitic schist and phyllite layers are 1–3 meters thick and weather to finely laminated fragments and dark-gray to black residual soils. In places where the graphitic schists are not too severely weathered, the laminae are either crenulated or have a splintery texture.

A belt of quartz-sericite schist, quartz-chlorite schist, iron-formation, and dolomitic phyllite of the Nova Lima Group crops out in roadcuts and along trails on the south slopes of the Serra Geral in the north-central part of the Gongo Sôco quadrangle (pl. 2). Red and gray fine-grained quartz-chlorite schist and quartz-sericite schist compose the upper beds of this belt of Nova Lima rocks. They underlie the Cauê Itabirite of the Minas Series from the Gongo Sôco iron mine to the east boundary of the quadrangle (pl. 2). Conformably beneath the schist is 40–60 meters of interlayered dolomitic iron-formation and dolomitic phyllite. Conformably below the iron-formation and dolomitic phyllite is about 15–30 meters of interbedded reddish-brown ferruginous quartzite and white schistose quartzite. This layer of quartzite is more resistant to erosion and crops out at many localities along the south slopes of the Serra Geral. It is in contact with the Cauê Itabirite of the Minas Series near the open pits of the Camará gold mine and in a railroad cut 300 meters west of the Gongo Sôco iron mine. Elsewhere in the Gongo Sôco quadrangle it occurs 0–150 meters beneath the basal formations of the Minas Series.

Reddish-brown quartz-chlorite schists interlayered with thin iron-formation occur beneath the schistose and ferruginous quartzite and above the Cambotas Quartzite. These schists are deeply weathered and poorly exposed in most localities, but good exposures of saprolite crop out in the railroad cuts about 1,600 meters northeast of the Camará gold mine and in roadcuts along the old road leading southward from João Vasconcelos to the old abandoned Gongo Sôco gold mine. The quartz-chlorite schists are reddish brown and poorly laminated and consist of darker chlorite-rich bands alternating with bands of granular quartz and chlorite interlayered with thin dolomitic iron-formation that is oxidized to limonite and fine granular quartz.

A band of light-gray and silvery-gray quartz-sericite schist and muscovite schist unconformably underlies the Cambotas Quartzite along the north slopes of the Serra Geral and along the southwest escarpment of the Serra das Cambotas. On the north and the east it is truncated by granodiorite gneiss. This narrow belt of Nova Lima rocks consists of muscovite-quartz schist and a few interbeds of reddish-gray conglomeratic phyllite. The lower beds of schist adjacent to the granodiorite gneiss of the Caeté Complex contain metacrysts of feldspar and some disseminated specular hematite, and in places along the Caeté-Barão de Cocais highway they are migmatized over a zone 10–100 meters wide.

IRON-FORMATION

Two prominent layers of iron-formation are exposed in the northeastern part the Conceição do Rio Acima quadrangle and the southeastern part of the Gongo Sôco quadrangle (pls. 2, 3). They range from a few meters to about 150 meters in thickness. Good exposures of the iron-formations can be seen along the headwaters of the Córrego do Sitio and in a roadcut about 1,000 meters north of the village of Campo Grande. Elsewhere in Conceição valley, a series of thin lenses of iron-formation from 0 to 10 meters thick is sporadically interlayered with schist and graphitic schist of the Nova Lima Group. In the north-central part of the Gongo Sôco quadrangle (pl. 2), a prominent layer of dolomitic iron-formation interlayered with phyllite was mapped from the west boundary of the quadrangle at N. 5,800 to N. 5,500, E. 4,200, and from N. 8,500, E. 12,000 to the east boundary at N. 9,050, E. 13,100. Thin lenses of iron-formation occur at many levels in the schists of the Nova Lima Group along the south slopes of the Serra Geral.

The thicker layers of iron-formation in the Conceição valley are interlayered with ferruginous quartz-chlorite schist and graphitic phyllite. The upper and lower contacts of well-laminated layers of dolomitic iron-formation are gradational with the schist and phyllite of the Nova Lima Group over a width of about 2–5 meters. The rocks at the contacts grade from well-

[1] Saprolite is an earthy material that has been formed essentially in place as the result of weathering of bedrock. Structures and textures of the rocks are usually partly or totally retained, but the mineralogy is completely changed by weathering.

laminated dolomitic iron-formation through a zone of indistinct laminae showing considerable mixing of the iron-bearing mineral with quartz and dolomitic carbonate, into ferruginous schist and phyllite.

At N. 900, E. 12,800 in the southeast corner of the Gongo Sôco quadrangle (pl. 2), a 150-meter sequence of iron-formation, ferruginous schist, and graphitic schist consists of 30 meters of low-grade poorly laminated iron-formation interlayered with dark-gray graphitic schist overlain by 20 meters of dark-red ferruginous quartz-chlorite schist. Conformably above the schist is 90–100 meters of well-laminated dolomitic iron-formation. The low-grade iron-formation and the well-laminated iron-formation in most places are weathered to a granular mass of hematite, fine powdery talc, limonite, and granular quartz that crumbles with the slightest blow. Fibrous tremolite occurs in the light-colored bands, and a few thin laminae of manganese oxide parallel the laminations in some layers. Quartz veins cut across the laminations in many layers. All the iron-formation is dolomitic and strongly magnetitic. A thin section of weathered but indurated iron-formation from a small open pit at N. 825, E. 12,800 (pl. 2), shows the iron-bearing laminae to be made up of hematite and magnetite partially hydrated to limonite, intercrystallized with minor amounts of quartz and dolomitic carbonate. The light-colored laminae consist of a mosaic of quartz and dolomitic carbonate enclosing a few grains of hematite and magnetite. Hematite and magnetite grains range from about 0.01 mm to 0.4 mm across and have a median size of 0.15 mm; the quartz and carbonate grains range from 0.02 to about 0.25 mm across and have a median size of about 0.10 mm; the thickness of the laminae ranges from 1 mm to about 2 cm.

Iron-formations in the belt of Nova Lima rocks exposed along the south slopes of the Serra Geral in the Gongo Sôco quadrangle are interlayered with dolomitic phyllite and occur in a layer ranging from about 30 to 60 meters in thickness. Individual layers of well-laminated dolomitic iron-formation range from a few centimeters to as much as 10 meters in thickness. The darker colored iron-rich laminae consist of hematite and magnetite and alternate with lighter-colored laminae of granular quartz and dolomitic carbonate. Most of the iron-rich laminae are weathered to very fine grained red limonite, and the quartz and dolomitic carbonate laminae are weathered to talc and iron-stained granular quartz. The thinner lenses of iron-formation are generally weathered to limonite laminae alternating with very fine powdery granular quartz and in most places are either interlayered with thin graphitic schist and phyllite or ferruginous schist and phyllite. They grade along strike over a few tens of meters into ferruginous quartz-chlorite schist.

THICKNESS AND STRATIGRAPHIC RELATIONS

The thickness of the Nova Lima rocks is not known in this area or elsewhere in the Quadrilátero Ferrífero because the base of the group has not been recognized or is not exposed. A thickness of at least 2,000 meters is indicated in the central part of the Conceição do Rio Acima quadrangle (pl. 3), but isoclinal folds and faults may duplicate beds.

Rocks of the Nova Lima Group underlie the basal formations of the Minas Series with slight to moderate discordance in the northwestern part of the Conceição do Rio Acima and the southeastern part of the Gongo Sôco quadrangle. Beds of the overlying Minas Series and the underlying Nova Lima Group are truncated by this discordant contact. A strong angular discordance between schist of the Nova Lima Group and the overlying quartzite of the Moeda Formation of the Minas Series can be seen near the west boundary of the Conceição do Rio Acima quadrangle at N. 5,300, E. 1,400 (pl. 3). Here a difference of 40° in strike and 40° in dip was found between the schist and the overlying quartzite. The contact is well exposed in the Córrego da Gandarela. The basal 2 meters of quartzite and conglomerate of the Moeda Formation is strongly foliated, and quartz pebbles and cobbles are stretched and sheared. Northeastward from the Córrego da Gandarela the contact is well exposed in several córregos, and the discordant contact separating Minas and pre-Minas rocks obliquely truncates and cuts out quartzite of the Moeda Formation and phyllite of the Batatal Formation near N. 8,900, E. 3,700 (pl. 3). At N. 10,000, E. 4,400 (pl. 3), along the south slopes of the Serra da Pedra Formosa, a thin, highly sheared sericitic quartzite conglomerate occurs below the phyllite of the Batatal Formation and above the schist of the Nova Lima Group. From N. 11,000, E. 5,100 (pl. 3), in the northwestern part of the Conceição do Rio Acima quadrangle to the vicinity of Lagôa das Antas in the southeastern part of the Gongo Sôco quadrangle the contact between the thin basal quartzite of the Minas Series and the Nova Lima Group is poorly exposed. In most places it is covered by surficial deposits of canga, talus, and lateritic soil. Little is known about the contact except that the quartzite above and the schist below apparently dip and strike nearly parallel to it. About 700 meters east of Lagôa das Antas, well-exposured Moeda Formation stratigraphically overlies schists of the Nova Lima Group with slight disconformity. Schist of the Nova Lima Group stratigraphically underlies Cauê Itabirite at N. 4,950, E. 12,050 (pl. 2), near the east boundary of the Gongo Sôco quadrangle, whereas 1,600 meters to the southwest and 1,000 meters to the northeast basal Minas quartzite of the Moeda Formation stratigraphically overlies schist of the Nova Lima Group. The Cauê Itabirite 100 meters southeast of the Ponte da Paixão mine is severely distorted by drag folds and is cut by closely spaced shear planes about 20 meters from the contact. About 200 meters southeast of the Fura Ohlo mine, phyllite and lenses of sericitic quartzite conglomerate about 15 meters stratigraphically above the contact are broken and sheared, and lenses of the quartzite are sliced one over the other. The contact is not exposed, but it is evident that the basal formations of the Minas Series are distorted by a fault zone.

Along the south slopes of the Serra Geral, from N. 4,600 on the west boundary to near N. 5,100, E. 4.850 (pl. 2), schist of the Nova Lima Group underlies sericitic quartz schist of the Moeda Formation with apparent conformity. However, about 900 meters to the northeast, near the Camará mine workings, the basal formations of the Minas Series are missing from the section, and Cauê Itabirite of the Minas Series overlies ferruginous quartzite and schistose quartzite of the Nova Lima Group. The contact between the itabirite and the quartzite is well exposed in open pits and in a partly caved inclined shaft and consists of 50–70 cm of sheared and silicified ferruginous quartzite that is overlain by highly crenulated itabirite and underlain by ferruginous quartzite broken by numerous tear fractures. The contact dips 45° S., and the highly distorted laminations of the itabirite are dragged into the contact and truncated by the shear zone.

Cauê Itabirite overlying ferruginous quartzite is well exposed in railroad cuts 300–500 meters northwest of the Gongo Sôco iron mine at N. 6,600, E. 7,100 (pl. 2). Here the laminations in the itabirite above the contact are severely distorted by tight drag folds ranging in amplitude from a few centimeters to a few meters in a zone 10–15 meters wide. The laminations are dragged into the contact and truncated by it. The drag folds fade out upward from the contact through a zone of about 10–15 meters into undistorted laminations that are conformable with the strike and dip of the northwest limb of the Gandarela syncline. The ferruginous and schistose quartzites below the contact strike and dip nearly parallel to the contact and are broken by tear fractures. Eastward from the Gongo Sôco iron mine to near N. 8,500, E. 12,000 (pl. 2), Cauê Itabirite overlies schist of the Nova Lima Group. The itabirite and the schist dip and strike nearly parallel to the contact and are exposed within a few centimeters of one another. Eastward from N. 8,500, E. 12,100 (pl. 2), to the east boundary of the Gongo Sôco quadrangle, iron-formation and underlying ferruginous quartzite of the Nova Lima Group diverge from the contact and form a slight to moderate discordance with the underlying Cauê Itabirite of the Minas Series.

The stratigraphic position of the formations of the Minas Series is well known in the western part of the area (pls. 2, 3), and the absence of the basal Moeda Formation, the Batatal Formation, and part of the Cauê Itabirite from the section along the eastern part of the Gandarela syncline could be due to either nondeposition or fault displacement along the contact separating the rocks of the Minas Series from the rocks of the Nova Lima Group. The stratigraphic and structural discordances along this contact are further discussed on pages I33–I35.

In the southeastern part of the Conceiçáo do Rio Acima quadrangle, schist and quartzite of the Maquiné Group overlie schist of the Nova Lima Group with apparent discordance. A strong discordance in dip of schist above and below the contact can be seen on a ridge about 2,000 meters southeast of Serra Redonda (p. 3). The contact is covered by lateritic soil, but about 20 meters above and below the contact the schists show difference in dip of about 30°. Elsewhere along this contact, only slight to moderate angular discordance is indicated; however, the contact is covered or poorly exposed, and it is not known whether it is an unconformity or a fault.

Schist and phyllite of the Nova Lima Group are cut by granodiorite gneiss of the Caeté Complex in the central and northeastern parts of the Gongo Sôco quadrangle. The chlorite-quartz schist in the central part of the Gongo Sôco quadrangle forms a sharp contact with granodiorite in roadcuts and railroad cuts. In the northeastern part of the Gongo Sôco quadrangle the sericite-schist and muscovite-quartz schist of the Nova Lima Group are migmatized and form a contact zone of hybrid rocks containing numerous metacrysts of feldspar and poorly developed gneissic layering that ranges from a few meters to about 50 meters outward from granodiorite gneiss.

MAQUINÉ GROUP (UNDIVIDED)

The Maquiné Group has been divided into two formations: an older, Palmital Formation (J. E. O'Rourke, unpub. data), comprised of quartz-sericite schist, conglomeratic schist, subgraywacke, and lenses of sericitic quartzite; and a younger, Casa Forte Formation (Gair, 1962, p. 31–33), comprised of massive quartzite conglomerate, sericitic quartzite, and minor amounts of phyllite and schist. During the present study, rocks lithologically similar to those described by O'Rourke and Gair were recognized, but no division could be made because of poor exposure and the lack of marker beds.

DISTRIBUTION

Rocks of the Maquiné Group have been mapped along the north, northwest, and west slopes of the Serra do Caraça in the southeastern part of the Conceição do Rio Acima quadrangle (pl. 3). Cambotas Quartzite overlies quartz-chlorite schist, conglomeratic schist and phyllite, and subgraywacke from the west boundary at E. 8,300 to near N. 5,000, E. 9,500, in the southern part of the Conceição do Rio Acima quadrangle. From the last mentioned locality to the east boundary of the quadrangle Cambotas Quartzite overlies massive quartzite and conglomerate in the upper part of the Maquiné Group. Quartz-chlorite schist of the lower part of the Maquiné Group stratigraphically overlies schist of the Nova Lima Group from the south boundary to the east boundary of the Conceição do Rio Acima quadrangle (pl. 3).

LITHOLOGY

The rocks of the Maquiné Group consist of a belt of massively to very thick bedded light-gray to light-brown coarse-grained quartzite, conglomerate, and sericitic quartzite that is structurally overlain and underlain by brown and reddish-brown thin- to medium-bedded fine- to medium-grained quartz-chlorite schist, conglomeratic quartz-sericite schist, and a few beds of metagraywacke, and lenses of quartzite.

The upper quartzite, conglomeratic quartzite, and sericitic quartzite are composed of angular quartz grains ranging from about 0.5 to 3.0 mm across, and interstitial grains ranging from about 0.02 to 0.5 mm across. The quartzite contains minor amounts of sericite, chlorite, chloritoid, and kyanite. Some quartzite beds contain about 5–10 percent sericite that is crudely alined in thin discontinuous laminae parallel to the bedding. Cobbles and pebbles of vein quartz, quartzite and recrystallized chert, 10–80 mm in diameter, are randomly distributed in irregular zones at many levels within the massive quartzite beds. The conglomeratic zones cut across bedding planes, and the cobbles and pebbles of quartz and quartzite make up less than 10 percent of the quartzite.

These coarse-grained quartzites comprise the core of a syncline overturned to the west, northwest, and north. They grade upward and downward through thick-bedded medium-grained brown and reddish-brown quartz-sericite schist into thin-bedded red and brown quartz-sericite schist, conglomeratic quartz-sericite schist, metasubgraywacke, and a few lenses of quartzite. Good exposures of the middle and lower rocks crop out (pl. 3) along the road to the Colégio Caraça road from N. 7,700, E. 11,600, to N. 7,200, E. 11,650; near N. 450, E. 4,400; and along the Córrego do Capivari from N. 200, E. 8,450, to N. 100, E. 8,250, near the south boundary of the Conceição do Rio Acima quadrangle. Thin sections from these localities show the rocks to be quartz-sericite schist, quartz-chlorite schist, metasubgraywacke, and conglomeratic phyllite. The quartz-sericite schists consist of 50–80 percent angular quartz grains ranging from 0.4 to 1.0 mm across, and 20–50 percent sericite, chlorite, chloritoid, and minor amounts of pyrite and hematite. Sericite is the predominant micaceous mineral in most of the schist; it occurs as thin laminae of compact plates along lines of quartz grains and along boundaries of the quartz grains. Penninite, with its characteristic ultraviolet interference color, and an unidentified brown chlorite are scattered through the sericite laminae in most of the schist. A few beds of pyritized schist, however, contain brown chlorite laminae but only minor amounts of sericite. Chloritoid occurs in widely varying amounts in the schist as rosettes and lath-shaped grains. It comprises as much as 20 percent of some of the schist, but generally it is only 1–5 percent of the rock or is absent. Pyrite and hematite are sparsely disseminated mostly in the fine-grained schist, but both minerals have been either partly or almost completely oxidized and hydrated to limonite.

THICKNESS AND CONTACT RELATIONS

A thickness of 1,000–1,500 meters is indicated for the rocks of the Maquiné Group along the northwestern part of the Serra do Caraça (pl. 3). An undetermined thickness of the lower beds is cut out of the section by the Caraça thrust fault along the northwest escarpment of the Serra do Caraça. Some of the lower schist beds may be cut out on the northwest and north at the contact with the underlying schist of the Nova Lima Group, if this contact is a fault.

The contact between the Maquiné rocks and the overlying Cambotas Quartzite is discordant and has been mapped as a thrust fault. This contact is well exposed in the Córrego do Capivara at N. 200, E. 8,400 (pl. 3), near the south boundary of the Conceição do Rio Acima quadrangle. Here there is a 30° difference in the strike and a 10° difference in the dip between the schist and conglomeratic schist of the Maquiné Group and the overlying Cambotas Quartzite. The contact consists of 50–80 cm of sheared iron-stained quartz and chlorite; it dips about 20° E., strikes north, and cuts obliquely across and truncates the massive beds of Cambotas Quartzite. The quartzite beds are warped into the fault and are progressively cut out of the section to the south of the Córrego do Capivara, where the Cambotas Quartzite is markedly thinned southward along the west escarpment of the Serra do Caraça. The schists of the lower part of the Maquiné Group are also crosscut by the fault and cut out of the section southward from the Córrego do Capivari. Northwestward from the Córrego do Capivari along the northwest escarpment of the Serra do Caraça, the Caraça fault also cuts across the lower beds and obliquely truncates the basal schists of the Maquiné Group. Near N. 5,000, E. 9,500 (pl. 3), the basal schist of the Maquiné Group is cut out of the section. Near N. 4,700, E. 9,400 (pl. 3), there is a strong angular discordance between the schist and quartzite of the Maquiné Group and the overlying Cambotas Quartzite. The schist and quartzite strike N. 30° E. and dip 30° SE., and the overlying Cambotas Quartzite strikes N. 10° W. and dips 40° E. Here the fault contact dips about 25° SE. Northward from N. 4,200, E. 9,800, to N. 6,200, E. 9,500 (pl. 3), the contact between the schist of Maquiné age and the Cambotas Quartzite steepens from a dip of about 30° SE. to nearly vertical. Along the north escarpment of the Serra do Caraça, from the area of N. 6,200, E. 9,500 (pl. 3), to the east boundary of the Conceição do Rio Acima quadrangle, the contact between the quartzite of the Maquiné group and the Cambotas Quartzite dips 40° to about 85° N. Also, along the western part of the north slopes of the Serra do Caraça there is a strong angular discordance between the quartzites of the Maquiné and Cambotas Groups. Here the Cambotas Quartzite strikes N. 10° E. and dips east, and the contact strikes west and dips north. The contact and the quartzite of the Maquiné Group in this area are covered by thick jungle growth; however, the contact is exposed on and near the road that leads southward to the Colégio Caraça at N. 6,800, E. 11,500 (pl. 3). Here the quartzites above and below the contact are separated by about 0.5–1.5 meters of breccia consisting of angular and subrounded quartzite in a sheared quartz-mica matrix. The contact zone and the quartzites above and below the contact strike west and dip 60°–70° N.

TAMANDUÁ GROUP (UNDIVIDED)

CAMBOTAS QUARTZITE

The Cambotas Quartzite crops out as a belt of massive quartzite that forms the Serra das Cambotas, the southernmost part of the Serra Espinhaço, which extends from the eastern part of the Gongo Sôco quadrangle (pl. 2) northward to the State of Bahia.

The age of the quartzite that forms the Serras Espinhaço and Cambotas has been discussed in many reports, and evidence has been presented for several different ages. Harder and Chamberlin (1915, p. 354) correlated these quartzites with the Caraça Quartzite of their Minas Series (table 1), which included some of the quartzites of the Rio das Velhas Series (Dorr and others, 1957, p. 15–22). Bölau (1952, p. 483–487), in a study of the Caeté uplift area, correlated the quartzite of the Serra das Cambotas with the Caraça Quartzite of Harder and Chamberlin. On a preliminary regional map (unpub. data, 1959) Dorr tentatively correlated the quartzite of the Serra das Cambotas with the Moeda Formation (Wallace, 1958).

Because of a marked structural and stratigraphic discontinuity between the quartzite of the Serra das Cambotas and the Minas Series at the south end of the Serra das Cambotas, previous correlations of the north-trending belt of quartzite with the basal quartzite of the Minas Series were open to question. The rocks of the Minas Series are tightly folded into an isoclinal syncline that trends N. 70° E., dips about 35° S., and is overturned to the north. In contrast, the belt of quartzite that forms the Serra das Cambotas trends north and dips 30°–35° E. The basal quartzite of the Minas Series is either missing from the section or less than 20 meters thick along the east end of the Gandarela syncline at the south end of the Serra das Cambotas in the eastern part of the Gongo Sôco quadrangle. It therefore seems questionable to correlate the thick sequence of massive quartzites that form the Serra das Cambotas with the very thin or missing basal quartzite of the Minas Series in this area.

Correlation of the quartzite of the Serra das Cambotas with the post-Minas Itacolomí Series is also doubtful, because the quartzite of the Serras Cambotas and Geral underlies a sequence of schist, iron-formation, and phyllite that is overlain by Cauê Itabirite. This sequence has been traced westward along the north limb of the Gandarela syncline into rocks of unquestioned pre-Minas age in the central part of the Quadrilátero Ferrífero. The belt of quartzite in the Serra das Cambotas was therefore correlated with the Rio das Velhas Series (Dorr and others, 1957). However, the stratigraphic position of quartzite was not known, except that the quartzite was younger than the schist of the Nova Lima Group and older than the rocks of the Minas Series (Dorr and others, 1957).

Simmons and Maxwell (1961) recently studied the quartzite and overlying rocks exposed in the Serras Cambotas, Tamanduá, and Caraça and presented evidence for a new group of rocks in the upper part of the Rio das Velhas Series which they called the Tamanduá Group for the type locality in the Serra do Tamanduá in the western part of the Santa Bárbara quadrangle. The type section for the Tamanduá Group was measured in the eastern part of the Santa Bárbara quadrangle and in the northeastern part of the Gongo Sôco quadrangle, at the south end of the Serra das Cambotas and the west end of the Serra do Tamanduá. The section of Tamanduá rocks included all the rocks from the base of the overlying Cauê Itabirite of the Minas Series to the contact with the granodiorite gneiss of the Caeté Complex. Simmons and Maxwell divided this section of rocks into four units (from oldest to youngest): a thick sequence of quartzite beds with a basal quartz-sericite schist member that was named the Cambotas Quartzite for the Serra das Cambotas, and schist, iron-formation, and phyllite above the Cambotas Quartzite and below the Cauê Itabirite of the Minas Series, which were divided into three unnamed units (table 1).

The quartzite that forms the northwestern part of the Serra do Caraça in the southwestern part of the Conceição do Rio Acima was placed in the basal quartzite of Harder and Chamberlin's (1915, p. 351–356) Minas Series and named the Caraça Quartzite for its type locality, the Serra do Caraça. Guimarães (1931, p. 9; 1958, p. 208) correlated the quartzite of the Serra do Caraça with the Itacolomí Series. During the course of the present study the quartzite of the northwestern part of the Serra do Caraça was at first, with some reservations, tentatively correlated with the basal quartzite of the Moeda Formation (Wallace, 1958) of the Minas Series. However, as the result of the study by Simmons and Maxwell (1961), the quartzite of the Serras Cambotas and Caraça were correlated with the basal Cambotas Quartzite of their Tamanduá Group (fig. 2). The basal quartz-sericite schist unit below the Cambotas Quartzite and the overlying schist, iron-formation, and phyllite have been mapped in this area as part of the Nova Lima Group. This belt of rocks can be traced westward from the south end of the Serra das Cambotas across the Gongo Sôco and Caeté quadrangles and into the Nova Lima quadrangle, the type section for Nova Lima (Dorr and others, 1957, p. 15; Gair, 1962, p. 8), where broad areas of the central part of the Quadrilátero Ferrífero are underlain by rocks of unquestioned Nova Lima age.

Dorr (written commun., 1964) suggested that the Minas Series as defined by Dorr, Gair, Pomerene, and Rynearson (1957, p. 22–29) and by the joint DNPM–USGS team in 1958 (p. I 14) should be revised to include the rocks of the Tamanduá Group (Simmons and Maxwell, 1961) in the eastern part of the Quadrilátero Ferrífero. According to Dorr, there is not a significant angular discordance along the contact between the basal formations of the Minas Series and the upper units of Simmons and Maxwell's Tamanduá Group along the eastern part of the Gandarela syncline. He also stated that about 700 meters of Cambotas Quartzite and about 300 meters of the overlying schist, iron-formation, and phyllite in the upper part of the Tamanduá Group at the south end of the Serra das Cambotas thins westward to a knife edge over a horizontal distance of 4

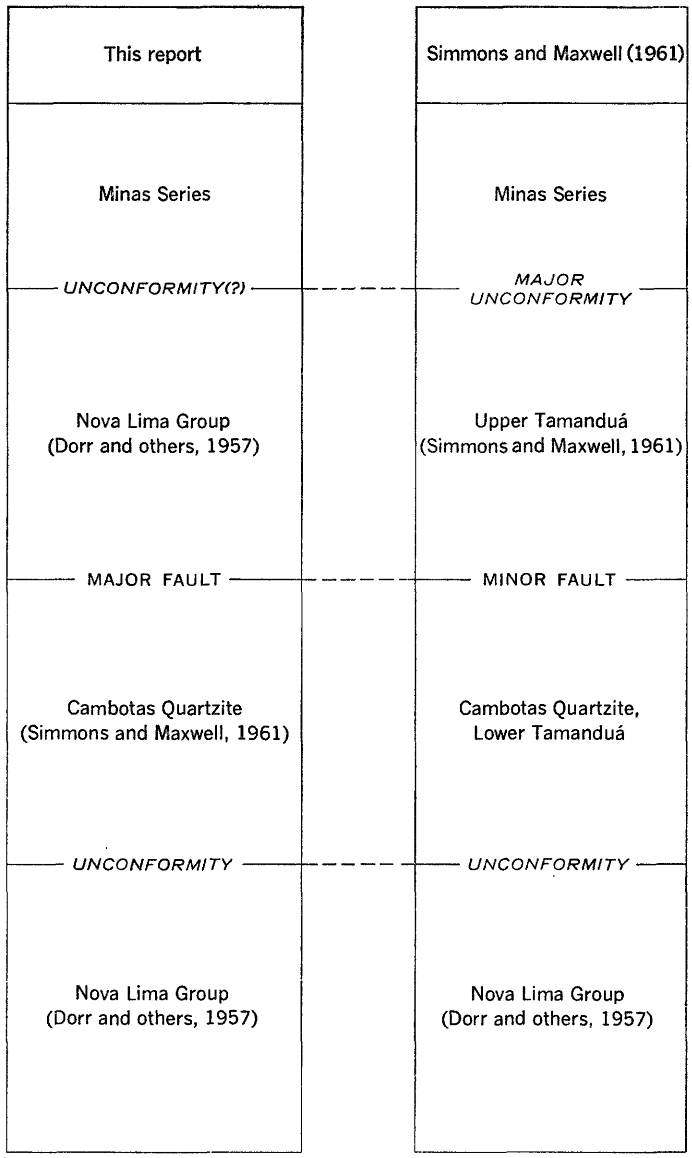

FIGURE 2.—Correlation of the Tamanduá Group of Simmons and Maxwell (1961) with the Nova Lima Group of this report.

kilometers because of an abrupt stratigraphic wedge out. He stated that the upper contact of this stratigraphic wedge out is truncated by segments of two different faults that extend from near N. 7,950, E. 6,400, to N. 7,500, E. 8,800, in the Gongo Sôco quadrangle (pl. 2); the lower contact between the schist of the Nova Lima Group and the overlying Cambotas Quartzite is cut off by the same faults at N. 7,950, E. 6,400 (pl. 2). In the eastern part of the Gongo Sôco quadrangle (pl. 2), the writer mapped a moderate angular discordance between the Cauê Itabirite of the Minas Series and an underlying layer of iron-formation of the pre-Minas Nova Lima Group along the north limb of the Gandarela syncline at the south end of the Serra das Cambotas. Simmons and Maxwell (1961) correlated this iron-formation with the upper part of their Tamanduá Group. Dorr's rearrangement of the faults along the south slopes of the Serra Geral and his truncation of the Cambotas Quartzite along what he considers to be an abrupt stratigraphic wedge out tend to prove that the Cambotas Quartzite and the overlying schist, iron-formation, and phyllite are pre-Minas in age rather than Minas, because from N. 7,800, E. 6,000, to N. 8,000, E. 8,000, in the Gongo Sôco quadrangle (pl. 2) Cambotas Quartzite is overlain and underlain by schist of the pre-Minas Nova Lima Group. Thus, according to his stratigraphic-wedge-out hypothesis, the Cambotas Quartzite intertongues with or is interbedded with the oldest sedimentary rocks of the Quadrilátero Ferrífero. (See fig. 2.)

DISTRIBUTION

Cambotas Quartzite in the southeastern part of the Conceição do Rio Acima quadrangle (pl. 3) forms a series of massive cliffs and hogbacks along the north, northwest, and west slopes of the Serra do Caraça. In the northeastern part of the Gongo Sôco quadrangle (pl. 2) and the southeastern part of the Antônio dos Santos quadrangle (pl. 1) Cambotas Quartzite forms a north-trending line of massive hogbacks along the west side of the Serra das Cambotas. At the south end of the Serra das Cambotas this belt of quartzite narrows, swings to the west, and becomes the crest of the east end of the Serra Geral (pl. 2). A narrow belt of north-trending hogbacks of Cambotas Quartzite occurs within the main body of the granodiorite gneiss of the Caeté Complex and extends southward from the north boundary of the Antônio das Santos quadrangle to the vicinity of N. 2,050, E. 4,750 (pl. 1). Other irregular bodies of Cambotas Quartzite crop out within the granodiorite in the northeastern part of the Antônio dos Santos quadrangle and in the north-central part of the Gongo Sôco quadrangle.

LITHOLOGY

The Cambotas Quartzite of the Serra do Caraça is made up of pebble-conglomerate beds overlain by interbedded very coarse grained orthoquartzite and sericitic quartzite containing a few interbeds of sericite-quartz schist and phyllite.

The lower, pebble-conglomerate beds are well exposed in the Córrego do Capivara and along the west and northwest flanks of the Serra do Caraça. They characteristically weather to rough surfaces of protruding subrounded and rounded quartzite and quartz pebbles. The conglomerate consists of quartz and quartzite granules and pebbles 1–10 mm in diameter in a matrix of angular and subangular quartz grains ranging from about 0.3 to 1 mm across. Some of the matrix quartz fragments show strain patterns in thin sections, and mortar textures are common.

A thick sequence of coarse-grained to very coarse grained white to light-gray sericitic orthoquartzite overlies the lower, conglomerate beds. The orthoquartzite is crossbedded and consists of well-rounded frosted granules of quartzite and quartz 2–4 mm in diameter in a matrix of subrounded and subangular quartz grains ranging from about 0.2 mm up to the size of the smaller granules. Sericite comprises about 5–10 percent of the matrix and occurs in discontinuous compact laminae and along the boundaries of quartz grains. A few beds of medium-gray sericite-quartz schist and sericite phyllite are interlayered with orthoquartzite in the southwestern part of the Conceição do Rio Acima quadrangle. The quartzite beds range in thickness from about 0.3 to 2 meters. Crossbedding is a conspicuous sedimentary feature in the pebble-conglomerate and orthoquartzite beds in the Serra do Caraça. The crossbedded layers are generally 30–50 cm thick and consist of a series of beveled laminations with the foreset laminae dipping in alternate directions, forming a conspicuous herringbone pattern. Scour-and-fill structures are common, and the widespread crossbedding indicates rapid deposition and frequent current changes.

In the Serra das Cambotas the Cambotas Quartzite is very thick bedded to massively bedded sericitic quartzite and quartzite. Weathered surfaces are light gray and light reddish gray. Fresh rocks are white, light yellowish gray, and light greenish gray. Beds of sericitic quartzite weather reddish brown. Weathered surfaces range from very fine grained friable silty texture to rough surfaces of coarse-grained quartz sand. Most beds consist of angular and subrounded quartz grains 1–2.5 mm across. Sericite is present in varying amounts and occurs as thin laminae that impart a rude schistosity to the quartzite. The coarse-grained quartzite is cut by irregularly spaced north-trending and east-dipping shear zones that are flanked by parallel zones of very fine grained light-greenish-gray quartzite. These very fine grained quartzite bands are dense on fresh break but weather to fine silt-sized material; they are zones of cataclasticly crushed quartzite associated with the shear zones.

Bedding features in the quartzite of the Serra das Cambotas can be seen in the massive cliffs and hogbacks. Large-scale crossbedding, scour and fill, and ripple marks are common. Bedding planes are shown by color banding, laminae of sericite and minor amounts of micaceous hematite, and variation in grain size within beds.

The larger quartz grains are either individual grains of quartz or aggregates of subrounded smaller grains that have crushed borders. The grains that appear to be an aggregate of smaller grains may be crushed individual grains. The smaller grains of quartz, ranging from about 0.1 mm to about 1 mm in the matrix, are angular and apparently are poorly sorted. However, the poor sorting may be due to shearing rather than to deposition. Sericite forms thin laminae and is randomly distributed along grain boundaries in the angular quartz grains of the matrix. Minor amounts of plagioclase metacrysts occur in the quartzite in irregular zones near the contact of the granodiorite.

The very thick bedded to massively bedded quartzite of the Serra das Cambotas grades southward toward the south end of the Serra das Cambotas into finer grained quartzite at the east end of the Serra Geral. Here about 700 meters of quartzite is composed of thick-bedded very fine grained to coarse-grained white, light-gray, light-yellowish-white, light-greenish-gray, and light-reddish-brown sericitic and ferruginous quartzite.

The upper 50–70 meters of quartzite is banded by medium-gray laminae of compact micaceous hematite. Underlying the ferruginous quartzites is about 400 meters of thick-bedded white and light-greenish-gray sericitic quartzite. The sericite is mostly randomly distributed in the quartzite, but in some beds it occurs as thin laminae parallel to the bedding planes. Some of the beds are crossbedded and have scour and fill features. The lower beds of quartzite contain about 5–20 percent sericite that is concentrated in laminae. These sericitic rocks are deeply weathered and poorly exposed.

In the coarser grained beds, the larger grains of quartz range from about 0.5 to 1.5 mm across; however, the quartzite in this area is crosscut by irregular zones of cataclastic crushing, and the original grain size of the quartz is not known. Sericite comprises increasing quantities of the lower quartzite beds, and the rocks are strongly foliated near the south end of the Serra das Cambotas. Along the east end of the Serra Geral most of the upper beds of the quartzite are cut out of the section by the Cambotas fault. Iron-formation conglomerates occur in the lower part of the formation along the north slopes of the Serra Geral, and there are excellent exposures of the conglomerate in the vicinity of N. 8,100, E. 6,000, and at N. 9,000, E. 12,000 (pl. 2). They consist of angular plates of well-laminated siliceous iron-formation that are shingled and alined parallel to the foliation of the sericite-quartz schist. Individual plates range from a few millimeters to about 1 cm in thickness and are about 1–8 cm across.

THICKNESS AND CONTACT RELATIONS

The thickness of the Cambotas Quartzite in the central and northeastern parts of the area ranges from a few meters on the crest of the Serra Geral at N. 7,950, E. 6,350, in the Gongo Sôco quadrangle (pl. 2) to 1,200–1,500 meters along the northern and central parts of the Serra das Cambotas (pls. 1, 2). The quartzite of the Serra das Cambotas is bounded on the south by the Cambotas fault and on the east, north, and west by granodiorite; in most places neither the top nor the bottom of the quartzite is exposed. Shear zones paralleled by narrow zones of cataclasite in the quartzite indicate faulting which could have duplicated beds. Thus, any estimates of the total thickness of the Cambotas Quartzite in the Serras Geral and Cambotas are meaningless. A thickness of 1,000–1,200 meters is exposed in a faulted and incomplete section of the Cambotas Quartzite in the northwestern part of the Serra do Caraça (pl. 3).

Along the north slopes of the Serra Geral (pl. 2) from N. 8,100, E. 6,750, to N. 8,900, E. 10,600, and along the southwestern part of the Serra das Cambotas (pl. 2) from N. 9,100, E. 10,800, to N. 10,600, E. 11,100, Cambotas Quartzite overlies schist of the Nova Lima Group with slight to moderate unconformity. Along the south slopes of the Serra Geral from N. 7,550, E. 5,575, to N. 9,400, E. 13,100, schists of the Nova Lima Group are in fault contact with the Cambotas Quartzite. The underlying beds of quartzite are warped to the west and dragged into the fault zone of the Cambotas fault, and at least 700 meters of quartzite is cut out of the section.

Along the western, northern, and eastern parts of the Serra das Cambotas, Cambotas Quartzite is cut by granodiorite, gabbro, and diabase of the Caeté Complex. In most places the contact between the resistant quartzite and the easily eroded and deeply weathered igneous rocks is poorly exposed or covered by talus or lateritic soil thickly overgrown by scrubby jungle. Although the contact is covered in most localities, the granodiorite apparently is intrusive into the quartzite, which is partly altered; the quartz is recrystallized, and metacrysts of feldspar are scattered throughout irregular zones near the contact. The contacts between Cambotas Quartzite bodies and the granodiorite within the main body of the Caeté Complex are also poorly exposed because of lateritic soil cover and an overgrowth of scrubby jungle. The bands and irregular masses of Cambotas Quartzite in the granodiorite gneiss all trend generally northward and dip eastward. They are apparently roof pendants and remnants of either faulted blocks or folded segments of the main belt of Cambotas Quartzite that forms the Serra das Cambotas. The quartzite bodies within the Caeté Complex are locally warped into open folds. Plutons and dikes of gabbro and diabase crosscut the quartzite along the eastern and southeastern parts of the Serra das Cambotas. The gabbro and diabase dikes are intruded into fault and joint planes, and the dikes are deeply weathered to dark-red soil that erodes easily and leaves deep trenches within the quartzite. Mafic dikes in the Serra do Caraça are intruded into high-angle thrust faults. The dikes have sharp contacts with the quartzite. The quartzite has been altered by minor amounts of disseminated pyrite along a zone 0.5–2 meters wide and is cut by numerous fibrous quartz veins.

MINAS SERIES

Derby (1906, p. 396) first named the Minas Series and included all the metasedimentary rocks above a "gneiss and schist basement." Harder and Chamberlin's (1915, p. 345) Minas Series included part of the coarse clastic rocks of Dorr, Gair, Pomerene, and Rynearson's (1957) Rio das Velhas Series. Harder and Chamberlin (1915) divided the Minas Series into five units: the Caraça Quartzite, Batatal Schist, Itabira Formation, Piracicaba Formation, and Itacolomí Quartzite. Guimarães (1931, p. 14) showed a major unconformity at the base of the Itacolomí Quartzite, separated the Itacolomí from Harder and Chamberlin's Minas Series, and redefined this sequence of quartzite as the Itacolomí Series. In the western part of the Quadrilátero Ferrífero Rynearson, Pomerene, and Dorr (1954) described a major unconformity at the base of a widespread layer of quartzite and above a thick sequence of schist and phyllite. Dorr, Gair, Pomerene, and Rynearson (1957) and geologists of a joint DNPM–USGS team in 1958 further restricted the definition of the Minas Series to include the metasedimentary rocks above the unconformity described by Rynearson, Pomerene, and Dorr (1954) and below the major unconformity at the base of the Itacolomí Series (Guimarães, 1931). The joint DNPM–USGS team separated the restricted Minas Series into a lower Caraça Group, a middle Itabira Group, and an upper Piracicaba Group. The Caraça Group is composed of the Moeda Formation (Wallace, 1958), consisting dominantly of quartzite and minor amounts of phyllite, and the overlying Batatal Formation (Maxwell, 1958), consisting of phyllite. The Itabira Group consists dominantly of chemical sediments and includes the Cauê Itabirite (Dorr, 1958a), consisting of itabirite—a metamorphosed oxide-facies iron-formation—and the overlying Gandarela Formation (Dorr, 1958b), consisting dominantly of dolomite interlayered with subsidiary iron-formation and phyllite. The contact of the Cauê Itabirite and the Gandarela Formation is gradational. The Piracicaba Group disconformably overlies the Gandarela Formation and consists of five units: the basal Cercadinho Formation (Pomerene, 1958a), consisting of ferruginous quartzite and phyllite; the Fêcho do Funil Formation (Simmons, 1958) consisting of dolomitic phyllite, argillaceous dolomite, and phyllite; the Tabоões Quartzite (Pomerene, 1958b); the Barreiro Formation (Pomerene, 1958c), consisting of phyllite and graphitic phyllite; and the Sabará Formation (Gair, 1958), consisting of phyllite, schist, and feldspathic quartzite.

CARAÇA GROUP

The basal quartzite of the Minas Series was named the Caraça Quartzite by Harder and Chamberlin (1915, p. 357) for its type locality in Serra do Caraça. They included the main body of quartzites that forms the Serra do Caraça, which is now known to be composed of three ages of quartzite: a thin layer of quartzite of the Moeda Formation, exposed along the south and west flanks of the range, and two massive layers of quartzite, both of pre-Minas age, that form the main mass of quartzite in the Serra do Caraça. The basal quartzite of Minas age was named the Moeda Formation (Wallace, 1958) for the type section in the Serra da Moeda in the western part of the Quadrilátero Ferrífero, because the ages of the quartzites in the Serra do Caraça and elsewhere in the eastern part of the Quadrilátero Ferrífero were open to question. Harder and Chamberlin (1915) named the phyllitic and schistose unit above their Caraça Quartzite the Batatal Schist for the Serra do Batatal. Maxwell (1958) renamed the unit the Batatal Formation because it is composed dominantly of phyllite over broad areas of the Quadrilátero Ferrífero.

MOEDA FORMATION

DISTRIBUTION

Quartzite, conglomerate, and sericite-quartz schist of the Moeda Formation crop out on the western part of the north limb of the Gandarela syncline. Along the southeast limb of the syncline, the Moeda Formation has been mapped from the west boundary of the Conceição do Rio Acima quadrangle northwestward to the east boundary of the Gongo Sôco quadrangle. Moeda Formation is locally missing in the vicinity of N. 9000, E. 4000 (pl. 3), in the northwestern part of the Conceição do Rio Acima quadrangle, and near the east boundary of the Gongo Sôco quadrangle (pl. 2).

LITHOLOGY

The Moeda Formation is composed of quartzite, conglomerate, and quartz-sericite schist. The thicker units of the formation consist of interlayered conglomerate and clean white quartzite, and the thinner parts of the formation consist of quartz-sericite schist interlayered with lenses of pebble conglomerate.

In the western part of the Conceição do Rio Acima quadrangle, excellent exposures of the Moeda Formation crop out as a series of hogbacks along the southeast slopes of the Serra da Pedra Formosa. In this area the formation ranges from about 100 to 200 meters in thickness. The lower and intermediate parts of the formation are composed dominantly of white to light-gray very coarse grained thick-bedded quartzite interlayered with lenses of pebble and cobble conglomerate. The very coarse grained quartzite consists of angular to subangular interlocking quartz grains ranging from about 0.1 to 4.0 mm across; the median size is about 1.5 mm. Sericite in minor amounts is distributed throughout the quartzite as individual plates and clusters of plates. It is randomly oriented except in the lower 10–15 meters of the formation, where it is alined parallel to the basal contact of the formation.

The interlayered conglomerate beds are lenticular and do not persist laterally for more than a few hundred meters. They are as much as 4 meters thick and are composed of well-rounded pebbles and cobbles of quartzite; clear, smoky, and milky vein quartz; and a few angular fragments of quartz-chlorite schist, all enclosed in a coarse-grained to very coarse grained quartzite matrix. The pebbles and cobbles range from about 2 to 250 mm in diameter and have a median size of about 15 mm; the angular to subangular quartz grains of the matrix range from about 0.1 mm up to the size of the smaller pebbles.

The upper part of the formation in this area is composed of white very coarse grained thick-bedded quartzite consisting of subangular to subrounded quartz grains ranging from about 0.2 to about 3.0 mm across; the median size is about 1.5 mm.

Northeastward along the southeast limb of the Gandarela syncline, the conglomerate and very coarse grained quartzite grade into quartz-sericite schist in the northern part of the Conceição do Rio Acima quadrangle and the southern part of the Gongo Sôco quadrangle.

In the southeastern part of the Gongo Sôco quadrangle about 80–100 meters of Moeda Formation is well exposed along the southeast slope of the Serra da Pedra Formosa. Here the formation is composed of a basal pebble conglomerate 1–3 meters thick overlain by 80–95 meters of sericitic quartzite interlayered with a few lenses of pebble conglomerate lithologically similar to the basal conglomerate. The quartzite is weathered in most places to a partly coherent reddish-gray mass of quartz granules and sericite plates. Fresh exposures of the sericitic quartzite are light-gray fine-grained poorly foliated rocks consisting of a mosaic of angular quartz grains that are about 0.1–0.4 mm across. Many of the grains are strained and show mortar textures. Sericite makes up about 5–10 percent of the quartzite and is disseminated throughout the rock as plates and discontinuous laminae oriented parallel to the bedding. The pebble conglomerate consists of well-rounded quartzite and clear, smoky, and milky vein quartz in a matrix of fine-grained sericitic quartzite.

Along the western part of the Gandarela syncline and locally along the southeastern limb of the syncline, the Moeda Formation ranges in thickness from a knife edge to about 25 meters. In these localities the formation consists of sheared, reddish-gray very fine grained quartz-sericite schist interlayered with a few lenses of quartzite, and pebble conglomerate. The sericite is concentrated in laminae and plates parallel to the schistosity. Pebbles in the conglomerate lenses are sheared and flattened, and many of the quartz grains of the quartzite are crushed and shattered and have cataclastic textures.

THICKNESS AND CONTACT RELATIONS

Along the north limb of the Gandarela syncline, the Moeda Formation ranges from 20 to 30 meters in thickness near the west boundary of the Gongo Sôco quadrangle. It thins eastward along a discordant contact that separates it from the underlying Nova Lima Group, and it is cut out of the section in the vicinity of N. 5,200, E. 4,750 (pl. 2). Along the southeast limb of the Gandarela syncline at the west boundary of the mapped area, the Moeda Formation attains its maximum thickness of about 200 meters. Northeastward from the Córrego da Mutuca it thins along its lower contact and is either very thin or absent in the northwestern part of the Conceição do Rio Acima quadrangle (pl. 3). From the south boundary of the Gongo Sôco quadrangle (pl. 2) northeastward along the southeast limb of the Gandarela syncline, the Moeda Formation thickens from about 10 meters to 100 meters at N. 3,750, E. 10,450 (pl. 2). Northeastward from this locality it thins and is either very thin or missing near the east boundary of the Gongo Sôco quadrangle.

The upper contact of the Moeda Formation is gradational over a zone 1–2 meters thick. The formation grades from sericitic quartz schist through sandy medium-gray phyllite into dark-gray phyllite and graphitic phyllite of the Batatal Formation in most places where the overlying Batatal Formation is 20–30 meters thick. Near the Córrego da Gandarela (N. 5,700, E. 1,500, pl. 3), the contact between the Moeda Formation and the overlying argillite of the Batatal Formation is a 5- to 10-cm-thick zone of edgewise breccia consisting of plates of argillite in a sericitic quartz matrix.

BATATAL FORMATION

DISTRIBUTION

The Batatal Formation is covered by soil, canga, and talus and is poorly exposed throughout the mapped area, but it can be mapped along an erosional depression between outcrops of Cauê Itabirite and Moeda Formation in most places. Batatal Formation occurs along both limbs of the Gandarela syncline. Along the southeast limb of the syncline it has been mapped for more than 18 kilometers, from the west boundary of the mapped area to N. 5,000, E. 12,000, near the east boundary (pl. 2). Northeastward from this locality to the east boundary of the Gongo Sôco quadrangle, the Batatal Formation is missing from the section. It is apparently cut out of the section by a fault zone between Cauê Itabirite and the underlying Moeda Formation. Near the east boundary of the Gongo Sôco quadrangle, lenses of phyllite occur over and under Moeda Formation, and they are mapped as Caraça Group (undivided). Along the north limb of the Gandarela syncline, the Batatal Formation has been mapped from the west boundary of the Gongo Sôco quadrangle to the vicinity of Camará gold mine, where it is cut out of the section along a discordant contact that separates Cauê Itabrite from the underlying rocks of the Nova Lima Group.

LITHOLOGY

The Batatal Formation is composed dominantly of phyllite, graphitic phyllite, argillite, and a few lenses of recrystallized chert and ferruginous chert. The thicker parts of Batatal Formation occur in the western part of the Conceição do Rio Acima quadrangle and are composed dominantly of banded light- and medium-gray argillite containing numerous cubic pseudomorphs of specular hematite after pyrite. In the upper part of the section the argillite is interlayered with lenses of recrystallized chert and ferruginous chert. Quartz crystals as much as 2 cm across and specular hematite crystals up to 5 mm across occur in the lenses. The argillite in most places has weathered to saprolite composed of banded light- and medium-gray clay.

The thinner parts of the formation in the mapped area are composed of foliated and intensely sheared dark-gray phyllite and graphitic phyllite containing a few ferruginous phyllite lenses.

THICKNESS AND CONTACT RELATIONS

The Batatal Formation ranges in thickness from about 30 meters to a knife edge along the western part of the north limb of the Gandarela syncline. Along the southeast limb of the syncline the Batatal Formation is variable in thickness and is locally absent. Along the southeast limb it ranges from as much as 200 meters near the west boundary of the Conceição do Rio Acima quadrangle to a knife edge near the east boundary of the Gongo Sôco quadrangle. It is apparently cut out of the section by a discordant contact, probably a fault.

The contact between the Batatal Formation and the overlying Cauê Itabirite is gradational through an interval of about 0.5–1.5 meters. The uppermost bed of dark-gray phyllite and banded argillite grades upward through a poorly laminated ferruginous and quartzitic phyllite into well-laminated Cauê Itabirite.

ITABIRA GROUP

CAUÊ ITABIRITE

DISTRIBUTION

Cauê Itabirite is resistant to erosion and forms the higher ridges of the area; it crops out along both limbs of the Gandarela syncline. Along the southeast limb of the syncline it forms the northeast-trending crest of the Serra da Pedra Formosa, and it has been mapped for more than 18 kilometers from the west boundary of the Conceição do Rio Acima quadrangle to the east boundary of the Gongo Sôco quadrangle. Along the north limb of the Gandarela syncline the itabirite forms an east-northeast-trending high ridge along the south slopes at the Serra Geral, and it has been mapped across the central part of the Gongo Sôco quadrangle.

The name "itabirite" was apparently used very early to describe a "whetstone," and Eschwege (1822) adapted it to describe high-grade hematite ore (Guild, 1957, p. 14). Since 1822 it has been used to describe a wide variety of iron-rich rocks ranging from well-laminated iron-formation to high-grade hard hematite ore. It is currently accepted as the name for metamorphosed oxide-facies iron-formation that consists of alternating laminae of recrystallized iron oxide, chert, and carbonate containing 25–66 percent iron (Dorr and Barbosa, 1963, p. 18). Laminated rocks containing less than 25 percent iron are considered by Dorr and Barbosa to be ferruginous quartzite, and rocks containing more than 66 percent iron are classified as high-grade hematite ore.

Cauê Itabirite may be generally classified as either siliceous itabirite or dolomitic itabirite, depending upon the composition of the light-colored laminae. Both types of itabirite occur in the area mapped, and they are interlaminated in the lower and middle parts of the formation. In most exposures both types of itabirite are deeply weathered to a partly coherent banded friable mass of granular quartz, hematite, and powdery limonite. Hard unweathered poorly laminated iron-poor siliceous itabirite is widely exposed in a series of jagged hogbacks extending northeastward from near the Pião prospect, N. 5,100, to N. 6,100, E. 850, in the western part of the Conceição do Rio Acima quadrangle (pl. 3). This iron-poor itabirite occurs near the hard hematite ore body of the Pião prospect and apparently has been hydrothermally altered, as it is more resistant to surface weathering than the adjacent dolomitic itabirite.

About 300 meters northeast of the hogbacks of hard siliceous itabirite, about 300 meters of hard poorly laminated iron-poor dolomitic itabirite crops out along the base of a steep canyon cut into the Serra da Pedra Formosa by the Córrego da Gandarela (N. 6,200, E. 1,100, pl. 3).

The Cauê Itabirite is well exposed along the south slopes of the Serra Geral in the vicinity of the Gongo Sôco iron mine. It consists mostly of dolomitic itabirite in the upper part of the section and interlaminated siliceous and dolomitic itabirite in the middle and lower parts of the section. Northeastward from the Gongo Sôco iron mine to the east boundary of the quadrangle, the lower part of the Cauê Itabirite is weathered siliceous magnetic itabirite that grades upward into interlaminated siliceous and dolomitic itabirite that in turn grades into dolomitic itabirite in the upper part of the formation.

West of the Gongo Sôco iron mine to near the Gongo Sôco gold mine, the Cauê Itabirite is cut by numerous irregular bodies of hydrothermally enriched itabirite (hard and soft hematite ores). Zones of both hard and soft hematite ores also occur along the crest of the Serra da Pedra Formosa from near the Pião prospect (N. 4,700, E. 200, pl. 3) to near the Santo Antônio mine (N. 6,350, E. 1,300). The enriched itabirites are discussed on page I 36.

Hard dolomitic itabirite is also well exposed along a small córrego that leads south from the Gongo Sôco iron mine in the Gongo Sôco quadrangle. Elsewhere in the quadrangle the Cauê Itabirite either is weathered siliceous itabirite or is covered by lateritic soil and canga.

Itabirite is a laminated dark- and light-gray rock. Dark-gray iron-rich laminae made up of flakes and granules of hematite and minor amounts of magnetite alternate with light-gray laminae consisting of a mosaic of quartz and (or) dolomite grains. Segregation of the minerals in the laminations is not complete; some of the dolomite and quartz grains occur in the hematite-rich laminae, and a few flakes and granules of hematite and magnetite octahedra are scattered through the quartz and dolomite laminae. Laminations range from about 1 to 20 mm in thickness. Individual laminae maintain a constant thickness for several meters in many exposures.

Under the microscope, the iron-rich laminae in siliceous itabirite are seen to be a mosaic of interlocking tabular plates and irregular grains of hematite intercrystallized with minor amounts of quartz. The flakes and granules range from 0.02 to 0.2 mm across, and the quartz ranges from 0.01 to about 0.3 mm across. The light-colored laminae consist of interlocking quartz grains 0.02–0.2 mm across and a few grains of hematite enclosed in individual quartz grains or cutting across the boundaries of quartz grains. Magnetite octahedra were not observed either in the outcrops or in the thin sections of the siliceous itabirite.

Excellent exposures of unweathered or only slightly weathered dolomitic itabirite occur in the Córrego da Gandarela near N. 6,700, E. 1,200 (pl. 3). Thin sections from a 300-meter-thick unit of dolomitic itabirite in the upper part of the formation show that the rock consists of iron-rich laminae made up of plates and irregular grains of hematite, and magnetite octahedra intercrystallized with quartz and dolomitic carbonate. The hematite and magnetite grains range from 0.02 to 0.4 mm across and have a median size about 0.2 mm. Magnetite octahedra are enclosed by or cut across grain boundaries of quartz, dolomite, and hematite. The light-gray laminae consist of a mosaic of quartz grains enclosing grains and crystals of dolomitic carbonate; plates of sericite, biotite, and hematite; and a few crystals of magnetite. Quartz grains range from 0.02 to about 0.2 mm across. Dolomitic carbonate grains are irregular or rhombohedral and range from 0.01 to about 0.2 mm across. Dolomitic carbonate comprises as much as 40 percent by volume of the light-colored laminae and from 5 to 20 percent by volume of the itabirite. Sericite makes up about 0.5–3.0 percent of itabirite and forms prismatic plates that cut across the grain boundaries of quartz and dolomitic carbonate. Light-green biotite occurs in a few thin sections as prismatic grains and as clusters of crystals and is an accessory mineral. The dolomitic itabirite is coarsely laminated (5–20 mm thick), and iron-rich bands and light-colored bands are crudely developed.

Although hard dolomitic itabirite is exposed in deeply eroded rocks and hard siliceous itabirite crops out in the vicinity of hard hematite ore bodies, the Cauê Itabirite in most areas is weathered to a friable mass of banded hematite and quartz that crumbles with the slightest blow.

In a few localities itabirite weathers to a mass of hard plates of iron-oxide and disaggregated granular quartz. This type of weathered itabirite is locally called "Chapinha," and it is used in the local smelters because it is easily concentrated by screening out the quartz.

The most graphic evidence of surface weathering of hard dolomitic itabirite occurs in a steep-walled canyon cut through the Serra da Pedra Formosa near the west boundary of the Conceição do Rio Acima quadrangle (N. 6,200, E. 1,100, pl. 3) by the Córrego da Gandarela. Here at least 300 meters of hard dolomitic itabirite exposed along the base of the canyon grades upward along the canyon walls into partially softened itabirite, which in turn grades into disaggregated soft siliceous itabirite at the top of the canyon. Thin sections of partially weathered itabirite at the top of the canyon show only quartz in the light-colored laminae and iron oxide in the dark-colored laminae, whereas thin sections of hard itabirite from the same layer at the base of the canyon contain about 10 percent by volume of dolomitic carbonate in both the light-colored laminae and the dark-colored iron-oxide laminae. A channel sample across 6 meters of the same band of soft itabirite assayed 40.2 percent iron and 41.2 percent SiO_2. In comparison, a chip sample of hard itabirite from the same band at the base of the canyon assayed 29.4 percent iron, 47.8 percent SiO_2, 0.5 percent Al_2O_3, 3.2 percent CaO, 1.6 percent MgO, and a trace of manganese. Judging from the soft itabirites at the top of the canyon that form the crest of the Serra da Pedra Formosa, and their downward gradation into hard itabirite, it is apparent that surface waters have disaggregated the soft itabirite. The comparative thin-section studies and analyses of the hard and soft itabirite indicate that some of the quartz and most, if not all, of the dolomitic carbonate have been leached from dolomitic itabirite near the surface; this leaching has resulted in residual enrichment and disaggregation of the itabirite.

A small part of the iron oxide in the dolomitic itabirite is magnetite, whereas the iron oxide in the soft itabirite is dominantly hematite. Both types of itabirite are magnetic, and most of the magnetic soft itabirites probably are derived from the weathering of dolomitic itabirite. Exposures of magnetic soft siliceous itabirite unsually contain ocher and talc, which suggest weathering of dolomitic itabirite. Pomerene (1964, p. 13), however, noted that magnetic siliceous itabirite is a surface phenomenon. He noted that the subsurface soft weathered itabirite is rarely magnetic and suggested that weathering or possibly reduction by sunlight may cause magnetic itabirite.

THICKNESS AND CONTACT RELATIONS

The apparent stratigraphic thickness of the Cauê Itabirite within the Conceição do Rio Acima and Gongo Sôco quadrangles ranges from about 100 to 650 meters. The Cauê Itabirite crops out along both limbs of the Gandarela syncline. Along the north limb on the south slopes of the Serra Geral the thickness is variable; it ranges from about 100 meters in the vicinity of N. 5,050, E. 4,700 (pl. 2), to 400 meters near the west boundary of the Gongo Sôco quadrangle. Westward from N. 5,050, E. 4,700, the Cauê Itabirite thickens to about 400 meters near the west boundary of the Gongo Sôco quadrangle, and eastward from the same location it thickens to about 300 meters near the Gongo Sôco iron mine. Eastward from about N. 5,150, E. 4,800 (pl. 2), to the east boundary of the Gongo Sôco quadrangle, the Cauê Itabirite overlies schist and ferruginous quartzite of the Nova Lima Group. Discordant features of this contact suggest that some of the lower beds of the Cauê Itabirite may be cut out of the section by fault displacement along this contact in the eastern part of the north limb of the Gandarela syncline. Eastward from the Gongo Sôco iron mine, the Cauê Itabirite thins from about 300 meters to about 200 meters near the east boundary of the Gongo Sôco quadrangle; however, a fault cuts out some of the upper beds of the formation.

In the western part of the Conceição do Rio Acima quadrangle, the Cauê Itabirite is about 650 meters thick near the Pião prospect. Northeastward from the Pião prospect along the crest of the Serra da Pedra Formosa, Cauê Itabirite thins to about 300 meters near Pedra Vermelha (N. 750, E. 6,000, pl. 2) in the southern part of the Gongo Sôco quadrangle. Northeastward from Pedra Vermelha, Cauê Itabirite crops out in a series of fault blocks, and little is known about its thickness. Although the Cauê Itabirite is locally thinned by faults, its thickness ranges from about 650 meters at the west boundary of the Conceição do Rio Acima quadrangle to about 300 meters in the central and southern parts of the Gongo Sôco quadrangle. It reaches an apparent thickness of 800 meters southwest of the Pião prospect in the Gandarela quadrangle (J. E. O'Rourke, unpub. data).

The upper contact of the Cauê Itabirite is gradational over a 20- to 30-meter-thick zone into dolomite of the Gandarela Formation. This gradational contact is in most places deeply weathered and covered by soil; it is exposed in only two places. An exceptional view of this gradational contact zone can be seen in a massive overhanging cliff, locally called Pedra Vermelha, on the northwest slopes of the Serra da Pedra Formosa at N. 950, E. 5,800 (pl. 2). Here, well-laminated dolomitic itabirite grades into about 15 meters of coarsely laminated alternating gray dolomite, specularite, and quartz, which in turn grades into about 10 meters of gray quartzitic dolomite stratigraphically overlain by massive beds of red and pink dolomite of the Gandarela Formation. Another excellent exposure of this contact zone between the Cauê Itabirite and dolomite of the Gandarela Formation crops out in a canyon cut through the Serra da Pedra Formosa at N. 6,250, E. 1,050, in the southwestern part of the Conceição do Rio Acima quadrangle (pl. 3). Here well-laminated hard dolomitic itabirite of the Cauê Itabirite grades upward into a zone of coarsely laminated ferruginous gray dolomite about 25 meters thick, which in turn grades into massive beds of varicolored gray and red dolomite of the Gandarela Formation.

Because the gradational zone between the overlying dolomite of the Gandarela Formation and the underlying laminated itabirite of the Cauê Itabirite is in most places covered by lateritic soils and canga, the contact zone has been mapped either where the light-tan argillaceous soils of the weathered dolomite grade into reddish-brown granular soils of the weathered dolomitic itabirite or between outcrops of dolomite and well-laminated dolomitic itabirite. Where the contact is covered by canga, the contact between the Cauê Itabirite and the dolomite of the Gandarela Formation can only be projected across the canga.

Dorr (1958 a, b), proposed that the contact between the Cauê Itabirite and the Gandarela Formation be drawn where siliceous itabirite becomes subordinate to dolomitic itabirite. This definition is useful in areas in the Quadrilátero Ferrífero where the Cauê Itabirite consists mostly of siliceous itabirite. In the mapped area, however, dolomitic itabirite comprises a large part of the Cauê Itabirite, and it is not possible to divide the Itabira Group on the basis of this criterion.

GANDARELA FORMATION

The Gandarela Formation in the Conceição do Rio Acima and Gongo Sôco quadrangles consists of dolomite, dolomitic itabirite, siliceous itabirite, and a few interbeds of phyllite and conglomerate.

In 1954, during the early stages of mapping in the Quadrilátero Ferrífero, J. E. O'Rourke (unpub. data) mapped the lower dolomite beds of the type locality in the Gandarela quadrangle as a separate unit of what was then called the Itabira Formation. He was the first to recognize and map the dolomite as a separate formation and he subdivided the dolomite into three members on the basis of color. A similar division in the quadrangles mapped for this report is not possible because color changes are not confined to a narrow stratigraphic interval.

DISTRIBUTION

Dolomite of the Gandarela Formation crops out on the southeast limb of the Gandarela syncline and has been mapped for more than 17 kilometers. Near Lagôa das Antas (pl. 2), the dolomite is offset by a northeast-trending fault, but it then continues to the northeast to where it is cut off by another fault at N. 3,900, E. 1,000 (pl. 2). Northeastward, the dolomite does not crop out on the southeast limb of the Gandarela syncline except near N. 6,150, E. 12,300 (pl. 2). Dolomite also crops out on the north limb of the Gandarela syncline and forms a belt approximately 1 kilometer wide that has been mapped completely across the Gongo Sôco quadrangle (pl. 2).

The dolomite of the Gandarela Formation is deeply weathered to saprolite and lateritic soils and forms a rounded topography of moderate relief. Low cliffs of resistant varicolored banded dolomites protrude from the saprolite and lateritic soils in the Rio do Socorro valley and along the lower slopes of the Serra Geral. Dolomite is exposed in prominent cliffs, hogbacks, and ledges in the vicinity of the Córrego da Gandarela (N. 6,300, E. 500, pl. 3). Northeastward from the Córrego da Gandarela, the dolomites of the Gandarela Formation underlie an erosional surface overlain by canga and form the low rolling topography of the Lagôa Grande plateau (pl. 3).

LITHOLOGY

The Gandarela Formation is made up of thick-bedded gray, red, pink, purple, white, and cream-colored dolomite interbedded with itabirite and phyllite. The lower strata are medium-gray and white dolomite banded by laminae of quartz and hematite. These strata grade upward into massive white and cream-colored dolomite banded by very light gray to dark-gray mica laminae. The upper strata are dark-red dolomite interbedded with laminated purple, pink, and light-gray dolomite.

The lower dolomite is banded by numerous laminae of quartz and specular hematite. Magnetite octahedra are disseminated in the dolomite layers and in the hematite laminae. Thin lenses of well-laminated dolomitic itabirite are interlayered at many levels within the lower dolomite beds. Phyllite layers are concentrated in the lower part of the formation and are in most places exposed only as weathered soils; however, good exposures of grayish-green phyllite crop out on a ridge southeast of the Capim Gordura manganese prospect (N. 3,600, E. 1,050, pl. 2).

The intermediate dolomite beds of the Gandarela Formation are well exposed in numerous ledges, hogbacks, and quarries along the south slopes of the Serra Geral in the central and eastern parts of Gongo Sôco quadrangle. The fresh dolomite is light gray to cream colored, fine to medium grained and thick bedded and is banded by laminae of light-gray to cream-colored phlogopite. A few beds of ferruginous dolomitic quartzite are interbedded with the micaceous dolomite. The micaceous dolomite weathers to a medium-gray granular surface, and the phlogopite laminae weather to talc and reddish-brown limonite.

Thin sections of the cream and white dolomite show a mosaic of interlocking dolomite (85–95 percent) and quartz (5–15 percent) grains ranging from 0.04 to 0.5 mm across. The phlogopite has a light-gray to light-cream pearly luster and comprises about 5–10 percent of the rock by volume; it occurs in regular and wavy compact laminae ranging from 1 to 5 mm in thickness. Pyrite is sparsely disseminated in most dolomite beds and is not associated with fractures or linear structures. It occurs as small cubes and aggregates of cubes ranging from a fraction of a millimeter to about 10 mm across. Quartz veins are common and occur as fillings in joints and in minor faults.

Ferruginous and dolomitic quartzite beds consist of about 55–65 percent angular quartz intercrystallized with about 35–45 percent angular and rhombohedral dolomite. They are crudely laminated by compact specular hematite containing some octahedral magnetite. Magnetite is also sparsely disseminated in the dolomitic quartzite layers.

Massively bedded very fine grained dark-red manganiferous dolomite interbedded with layers of finely laminated very fine grained purple and light-gray manganiferous dolomite comprise the upper part of the Gandarela Formation in the western part of the area. Outcrops of these manganiferous dolomites are rare as the rocks generally are deeply weathered to bluish-black plastic manganiferous lateritic soil and nonplastic black manganiferous material a few meters below the surface. Excellent exposures of the dark-red dolomite and laminated purple and light-gray dolomite can be seen in the Socorro quarry at N. 3,600, E. 4,600, and in the Paracatú quarry at N. 4,110, E. 4,650, in the central part of the Gongo Sôco quadrangle (pl. 2). Thin sections of the dark-red dolomite show the rock to be an interlocking mesh of dolomite grains, 0.01–0.04 mm across, enclosing and replacing widely scattered quartz grains that make up about 1–3 percent of the rock by volume. Disseminated throughout the mosaic of dolomite and quartz are minute ragged flakes of an unidentified opaque mineral ranging from 0.004 to 0.02 mm across. Under the microscope the banded purple and light-gray dolomite is seen to be composed of alternating light-gray laminae of dolomite grains 0.01–0.06 mm across and purple laminae consisting of a mosaic of about 90 percent dolomite, 5 percent quartz, and widely disseminated anhedral flakes of an unidentified opaque mineral. The dolomite and quartz range from 0.01 to about 0.04 mm across, and the opaque mineral is about 0.004–0.01 mm across. Although this mineral has not been identified, it is apparently a manganiferous mineral that imparts a darker color to the dark-red and purple laminations of the dolomite. Analyses of the dark-red dolomite show it to contain 0.07–1.2 percent manganese as compared with about 0.2 percent manganese in the lighter colored dolomite. The manganese must occur in the opaque mineral because no other manganese-bearing minerals were identified in the thin-section studies.

The finely laminated purple dolomite and the dark-red dolomites are cut by numerous veinlets of specular hematite ranging from about 0.5 to 5 mm in width. The veinlets occur along the laminations and in crosscutting fractures and joint planes. The specular hematite may be indigenous iron that was mobilized by through-going hydrothermal fluids, or it may have been introduced by iron-bearing hydrothermal fluids. The dolomite contains sufficient iron to account for a mobilization and transfer of iron within the formation. Evidence for large-scale hydrothermal transfer of iron can be seen in the Cabeça de Ferro mine, where the dolomite is replaced along the axial zone of a fold by hard hematite; this relation indicates an outside hydrothermal source for the iron. However, the specular hematite in the veinlets probably was derived from the iron contained in the enclosing dolomite.

A conglomerate bed occurs about 50 meters below the top of the formation in the face of the Socorro quarry at N. 3,600, E. 4,600 (pl. 2). The conglomerate is about 1 meter thick and is composed of white and gray fragments of dolomite 2–20 cm across in a dark-gray poorly foliated matrix consisting of dolomite, iron oxide, and mica. Another layer of conglomerate is exposed in the face of a quarry south of the Pedra Vermelha at N. 1,000, E. 5,950, in the Gongo Sôco quadrangle (pl. 2). This conglomerate bed is about 50 cm thick and is composed of rounded and subrounded gray and red dolomite fragments 5–15 cm across in a dark-gray phyllite matrix. The dolomite fragments in both conglomerate layers are stretched and compressed, and the long axes lie in the plane parallel to the foliation in the matrix. The conglomerates exposed in these two quarries may represent the same horizon, but limited exposures make it difficult to use them as a marker bed. Similar conglomerates in the Gandarela Formation have been found elsewhere in the Quadrilátero Ferrífero.

A thick layer of manganiferous siliceous itabirite crops out in the upper part of the formation in a low hogback at N. 5,060, E. 6,750 (pl. 2). The itabirite consists of dark-brownish-black laminae made up of granules and flakes of hematite and magnetite and minor amounts of manganese oxide. The light-gray laminae consist of granular quartz and a few scattered flakes and granules of hematite and magnetite. The hematite and magnetite grains range from 0.02 to 0.10 mm across, and the quartz grains range from 0.01 to about 0.03 mm across. The dark laminae contain fine black powdery manganese oxide that smudges the hand. Analyses of the itabirite show it to contain 3.2 percent manganese.

Dolomite of the Gandarela Formation weathers to lateritic soils of two main types: light-tan aluminous soil and manganiferous soil that ranges from reddish brown to bluish black and forms a plastic, wadlike material near the surface. A few meters below the surface, the manganiferous plastic soil grades abruptly into a black vitreous nonplastic material that resembles low-grade lignite in color and texture; however, when struck with a hammer it splatters in the same manner as mud. This material was first recognized as a weathering product of dolomite by Guild, who named it "splash rock" (Guild, 1957, p. 42). Outcrops of "splash rock" are initially dry to the touch, but when a fragment is squeezed between the fingers it collapses to a mass of black mud. This material is formed in place by meteoric waters leaching the carbonate from the fine-grained manganiferous dolomite. The iron oxide probably is in part indigenous iron, and an undetermined amount may have been introduced by meteoric water.

Excellent exposures of "splash rock" can be seen within a dolomite layer in the Socorro quarry (N. 3,650, E. 4,650, pl. 2). Here the black "splash rock" is exposed as lenses overlain and underlain by fresh dolomite. The lenses of "splash rock" in the Socorro quarry contain relict lenses and rounded nodules of partially weathered dolomite. The boundaries between the "splash rock" and the dolomite are narrow gradational zones of brown flaky material 1–2 cm wide. The dolomite appears to have weathered in place, without slumping, leaving a microscopic boxwork of iron and manganese oxides of the same volume as the unweathered dolomite. The weathered products when saturated with water have a specific gravity probably half that of the unaltered dolomite. Analyses of fresh and altered dolomite from which the "splash rock" is derived are shown in table 2.

TABLE 2.—*Analyses (in percent) of fresh dolomite and weathered dolomite from the Socorro quarry (N. 3,650, E. 4,650, pl. 2) Gongo Sôco quadrangle*

[Analyst: Dr. Cassio Pinto, Departmento Nacional da Produção Mineral, Belo Horizonte]

	1	1a	2	2a	3	3a
CaO	30.3	9.3	30.4	9.3	29.6	5.4
MgO	20.8	8.1	20.7	8.1	20.1	4.3
MnO_2	1.4	37.8	1.6	35.1	1.2	29.5
FeO	1.1	17.8	1.0	16.8	3.6	40.5
SiO_2	.2	3.5	.2	4.4	.2	1.7
Al_2O_3	.3	.5	.1	.5	.4	.5
Loss on ignition	46.5	25.0	46.4	30.0	46.0	18.4
Total	100.6	102.0	100.4	104.2	101.1	100.3

1. Fresh dark-red dolomite.
1a. Black "splash rock" derived from red dolomite of sample 1.
2. Fresh dark-red dolomite enclosing lens of black "splash rock."
2a. Black "splash rock" lens enclosed by dark-red dolomite of sample 2.
3. Lens of dark-red dolomite enclosed by black "splash rock."
3a. Black "splash rock" enclosing dark-red dolomite of sample 3.

The light-tan honeycombed aluminous soils occur at many places throughout the Lagôa Grande Plateau. The residual soil contains as much as 35 percent Al_2O_3 and is derived from weathered dolomite. No subsurface exposures of fresh dolomite were observed, and the nature of the weathering process and the type of dolomite that weathers to these highly aluminous soils is not known. It is known only that these aluminous soils occur near the eroded and undercut perimeter of the canga fields where there is rapid downward percolation of meteoric waters. Thus, the alumina-rich residual soil may be the residue of micaceous dolomite leached of its more soluble constituents such as CaO and MgO, leaving the less soluble Al_2O_3. The mica probably accounts for the Al_2O_3.

THICKNESS AND CONTACT RELATIONS

A thickness of about 70–1,000 meters is indicated for the dolomite of the Gandarela Formation in the Gongo Sôco and Conceição do Rio Acima quadrangles. The formation attains its maximum thickness on the southeast limb of the Gandarela syncline near the west boundary of the Conceição do Rio Acima quadrangle (pl. 3). Northeastward from this locality it thins to about 750 meters in the vicinity of Lagôa Grande (N. 13,300, E. 4,600, pl. 3.) Northeastward from Lagôa Grande to the east boundary of the Gongo Sôco quadrangle the Gandarela Formation apparently thins to about 100 meters; however, faulting makes any estimate of its true stratigraphic thickness meaningless in the eastern part of the mapped area.

Along the north limb of the Gandarela syncline the dolomite ranges from about 100 to 800 meters in thickness. It is thickest near the west boundary of the Gongo Sôco quadrangle and thins northeastward to about 500 meters near the village of Gongo Sôco (N. 5,400, E. 8,000, pl. 2). Eastward from Gongo Sôco the dolomite is faulted and folded and its stratigraphic thickness is not known. Simmons reported (written commun.) a thickness of 30–70 meters for the Gandarela Formation along the northeasetern part of the Gandarela syncline in the Santa Bárbara quadrangle east of the Gongo Sôco quadrangle.

Like the Cauê Itabirite, the Gandarela Formation is thickest at the west boundary of the area along both limbs of the Gandarela syncline and thins northeastward across the area along both limbs of the Gandarela syncline. The proportionate thinning of both formations of the Itabira Group along the northwestern part of the Gandarela syncline may indicate tectonic thinning by plastic flow of rock in the limbs of the Gandarela syncline. A second possibility could be depositional thinning of both formations northeastward along the syncline; however, it is unlikely that both formations would show almost identical depositional thinning. A third possibility is that the upper beds of the Gandarela Formation were eroded prior to the deposition of the Cercadinho Formation. At the Socorro dolomite quarry (N. 3,600, E. 4,600, pl. 2) and near the west boundary of the Gongo Sôco quadrangle (N. 2,000, E. 100, pl. 2) dark-red dolomite beds of the Gandarela Formation are overlain by ferruginous quartzite of the Cercadinho Formation. In contrast, the upper beds of the Gandarela Formation at a quarry at N. 3,650, E. 8,600 (pl. 2), are white and cream-colored dolomite that is stratigraphically overlain by ferruginous quartzite of the Cercadinho Formation. Also, from near N. 4,850, E. 8,100 (pl. 2), to the east boundary of the Gongo Sôco quadrangle (N. 7,700, E. 13,050, pl. 2) quartzite and quartz-sericite schist of the Cercadinho Formation overlie white, light-gray, and cream-colored dolomite that is lithologically similar to the dolomite beds that form the intermediate part of the Gandarela Formation in the western part of the Gongo Sôco and Conceição do Rio Acima quadrangles.

PIRACICABA GROUP

The Piracicaba Group comprises the upper part of the Minas Series and is overlain unconformably by the Itacolomí Series (Guimarães, 1931, p. 8) in other areas of the Quadrilátero Ferrífero. Harder and Chamberlin (1915, p. 362) named the Piracicaba Formation and included part of the underlying Gandarela Formation in it. Dorr, Gair, Pomerene, and Rynearson (1957) elevated this formation to group status and included the clastic rocks above the chemical sedimentary rocks of the Itabira Group and below the quartzite of the Itacolomí Series.

The Piracicaba Group consists of quartzite, phyllite, ferruginous quartzite, and feldspathic quartzite in the Conceição do Rio Acima and Gongo Sôco quadrangles. In the western part of the Quadrilátero Ferrífero the Piracicaba Group has been divided into five formations, but in these quadrangles only two of these formations have been recognized. The basal formation is composed of quartzite, ferruginous quartzite, and phyllite and is correlated with the Cercadinho Formation described by Pomerene (1964, p. 20–25). The upper formation is composed of phyllite, feldspathic quartzite, and quartz-sericite schist. Its stratigraphic position and lithology are similar to those of the Sabará Formation described by Gair (1958), and it is therefore correlated with the Sabará Formation.

CERCADINHO FORMATION

DISTRIBUTION

The Cercadinho Formation is exposed along the lower part of the south slopes of the Serra Geral on the north limb of the Gandarela syncline as hogbacks and ledges and as bluffs of quartzite and ferruginous quartzite. In the southeastern part of the Gongo Sôco quadrangle and the northwestern part of the Conceição do Rio Acima quadrangle on the southeast limb of the Gandarela syncline the quartzite and ferruginous quartzite of the Cercadinho Formation are deeply weathered and poorly exposed. At the east boundary of the Gongo Sôco quadrangle the Cercadinho Formation forms the axial zone of the Gandarela syncline.

LITHOLOGY

The Cercadinho Formation is composed of ferruginous quartzite, quartzite, phyllite, and quartz-sericite-chlorite schist. Individual beds lens out and can be traced for only a few hundred meters. In the western part of the Gongo Sôco and Conceição do Rio Acima quadrangles, the formation consists principally of medium to coarse-grained quartzite and ferruginous quartzite and interbeds of sericite phyllite and reddish-brown chlorite phyllite. Eastward along both limbs of the Gandarela syncline numerous lenses and interbeds of phyllite and ferruginous phyllite occur in the section.

In the western part of the area the upper beds are white, light-yellow, buff, and light-gray medium- to coarse-grained thick-bedded quartzite containing minor laminae of sericite, chlorite, and hematite. The quartzite beds are separated by thin partings of dark-gray graphitic phyllite and sericite phyllite. A unique sandstone bed occurs near the top of the formation at N. 3,900, E. 6,150 (pl. 2). It consists of rice-shaped frosted granules of quartz whose long axes are crudely alined with the bedding planes. This type of quartzite has been found only in the Cercadinho Formation in the Quadrilátero Ferrífero (Pomerene, 1964, p. 23).

The lower beds of the Cercadinho Formation in the western part of the area consist of poorly laminated medium-gray and purplish-gray ferruginous quartzite separated by 1- to 50-cm-thick interbeds of chlorite phyllite and ferruginous sericite phyllite. The quartzite weathers to reddish-brown friable soil consisting of limonite, mica, and quartz granules. The chlorite phyllite partings in many places show finely crenulated laminae. Good exposures of the lower part of the section can be seen in a roadcut near N. 3,900, E. 6,000 (pl. 2).

The amount of argillaceous material in the Cercadinho Formation increases northeastward, and in the eastern part of the Gongo Sôco quadrangle the formation is made up of well-laminated ferruginous quartzite interbedded with sericite phyllite and ferruginous quartz-sericite schist.

The ferruginous quartzite contains widely varying amounts of granular and micaceous hematite. The hematite occurs mostly in thin laminae in the quartzite, but in a few beds it is evenly disseminated throughout the quartzite. The hematite laminae range from 1 mm to about 5 mm in thickness and locally show low-angle crossbedding. Plates and granules of specularite are arranged in poorly defined bands and comprise about 5–15 percent of the quartzite by volume.

Thin sections of unweathered ferruginous quartzite show it to be a subangular mosaic of quartz grains ranging from 0.05 to 1.0 mm across and a few porphyroblasts of quartz as much as 8 mm across. The iron-rich laminae are 0.2–6.0 mm thick and consist of granules and flakes of specular hematite intergrown with quartz, green chlorite, and chloritoid. The green chlorite and chloritoid are minor constituents and occur mostly in the iron-rich laminae. The green chlorite occurs in sheaves and plates curving about and between quartz grains and is crudely alined with the bedding planes of the quartzite. Chloritoid is almost completely altered to limonite. It occurs as flakes and granules and replaces the quartz. Accessory minerals are zircon, titanite, and a micaceous mineral tentatively identified as stilpnomelane.

THICKNESS AND CONTACT RELATIONS

The thickness of the Cercadinho Formation ranges from about 400 meters in the western part of the Conceição do Rio Acima quadrangle to 150 meters near Lagôa das Antas and Lagôa do Couto. The thickness along the south slopes of the Serra Geral ranges from about 350 meters near the southwestern part of the Gongo Sôco quadrangle to about 200 meters near N. 5,500, E. 10,000, in the eastern part of the Gongo Sôco quadrangle (pl. 2). Near the east boundary of the Gongo Sôco quadrangle, the formation forms the axial zone of the Gandarela syncline and is displaced by faults; its thickness is not known.

The Cercadinho Formation, like the underlying formations of the Minas Series, is thicker in the southwestern part of the Gandarela syncline than in the northeastern part. This parallel variation in thickness of the formations of the Minas has generally been considered to be the result of plastic flow of the rock along the more tightly folded parts of the Gandarela syncline rather than of stratigraphic variations in the thickness of the formations of the Minas Series.

The contact between the Cercadinho Formation and the overlying phyllite of the Sabará Formation is poorly exposed in most localities; however, it appears to be gradational through an interval about 3–5 meters thick. Although the contact is covered at N. 3,300, E. 7,850 (pl. 2), the ferruginous quartzite of the Cercadinho Formation crops out within 3 meters of the overlying phyllite of the Sabará Formation. Elsewhere in the quadrangles the contact is covered with soil, but it has been mapped within about a 10- to 20-meter stratigraphic interval on the basis of soils and outcrops.

SABARÁ FORMATION

DISTRIBUTION

Phyllite, schist, and feldspathic quartzite of the Sabará Formation are exposed in the Socorro valley as a broad belt that extends from the east boundary of the Gongo Sôco quadrangle southwestward across the area to the southwestern part of the Gongo Sôco quadrangle and northwestern part of the Conceição do Rio Acima quadrangle (pls. 2, 3). The Sabará Formation is overturned and is overlain on the southeast by the Cercadinho Formation, on the northeast it overlies the Cercadinho Formation. Its southeast contact with the Cercadinho Formation is offset by a segment of the Fundão thrust fault in the northwestern part of the Conceição do Rio Acima quadrangle and in the southern part of the Gongo Sôco quadrangle.

LITHOLOGY

In the Gongo Sôco and Conceição do Rio Acima quadrangles the schist and phyllite of the Sabará Formation have been deeply weathered to form saprolites mantled by a thin layer of lateritic soil. The schist and phyllite form rounded topography of moderate relief, and the feldspathic quartzite, which is relatively more resistant to erosion, forms steep slopes and cliffs. Most exposures of the weathered schist and phyllite are saprolite and were unsuitable for sectioning and microscopic study. Also, because of deep weathering, faulting, folding, and erosion of the upper beds, it was not possible to determine the stratigraphic distribution of the schist, phyllite, and quartzite in the Sabará Formation.

The phyllite weathers to reddish-brown to light-gray saprolite in which fine flakes of sericite and chlorite are the only recognizable minerals. Some of the exposures of saprolite have well-developed slaty cleavage. The quartz schists weather to dark-red arenaceous clay in which platy casts are the only remains of the micaceous minerals.

Excellent exposures of feldspathic quartzite form low cliffs that extend for more than 4 kilometers along a faultline scarp on the northwest slopes of the Serra da Pedra Formosa from near N. 12,800, E. 2,880 (pl. 3), to N. 3,000, E. 8,000 (pl. 2). Weathered quartzites show poorly developed foliation and are coarse grained, medium gray, and schistose. Fresh quartzite is light gray, and speckled with green epidote and mica. Thin sections show the rock to be feldspathic quartzite consisting of about 75 percent quartz, 15 percent feldspar, 5 percent epidote, and 5 percent chlorite and sericite. Quartz and feldspar grains are subrounded to angular, have crushed boundaries, and range from about 0.02 to 1.0 mm across, the median being about 0.5 mm. Most quartz and feldspar grains show considerable recrystallization and are crudely alined parallel to the bedding of the quartzite.

A few larger metacrysts of feldspar lie at various angles to the foliation. Quartz is replaced along grain boundaries by epidote, sericite, and chlorite. The plagioclase is andesine, partly replaced by albite. Epidote occurs as aggregates of subhedral grains in the interstices of the quartz and feldspar grains. Chlorite and sericite occur as interbladed crystal aggregates and form folia about the quartz and feldspar grains. Accessory minerals are apatite and hematite; both are randomly distributed throughout the rock.

THICKNESS AND CONTACT RELATIONS

The original thickness of the Sabará Formation cannot be detemined because the upper beds have been removed by erosion and tight folding and plastic flow have deformed the rocks in the axial zone of the Gandarela syncline. A thickness of about 1,200–1,500 meters is indicated for a partial section of the formation near the southeast corner of the Gongo Sôco quadrangle (pl. 2).

SURFICIAL DEPOSITS

CANGA

Canga is the local name for a pavementlike surficial layer of iron-rich material that ranges from breccia-conglomerate, consisting of plates of itabirite and some fragments of hard hematite cemented by limonite, to a fine-grained material made up of limonite cementing subordinate amounts of aluminous and ferruginous soils. Three types of canga are present in the mapped area: Common canga, canga derived from weathering of Cauê Itabirite essentially in place, and chemical canga. Common canga consists of fragments of itabirite and minor amounts of hard hematite and other rock fragments cemented by limonite. The ratio of itabirite fragments to the limonite cement varies over a wide range, and the iron content ranges from about 50 to 60 percent. Canga derived from the weathering of Cauê Itabirite essentially in place consists of disaggregated and partly slumped fragments of itabirite cemented by limonite. Chemical canga (Simmons, 1960; Pomerene, 1964, p. 30) consists mostly of limonite cementing aluminous and ferruginous soils. All types of canga may grade into all other types, saprolite, lateritic soil, or itabirite.

Canga forms a hard resistant layer from 1 to 10 meters thick and covers about 22 square kilometers of an old erosion surface that is thought to be Tertiary in age. The canga is porous and very resistant to erosion. The edges of the canga layer are in most places terminated by low undercut cliffs and ledges. Erosion has removed the softer underlying weathered rocks, leaving overhangs that break off, littering the slopes beneath the canga cliffs.

Originally the canga field in the mapped area probably covered a broad area of low relief between what are now the ridges of Cauê Itabirite that form the crests of the Serra da Pedra Formosa and the Serra Geral. Most of the canga was formed before the Tertiary uplift, when rejuvenation of streams rapidly eroded large areas of the canga sheet downslope from the higher elevations along the crests of the Serras Geral and da Pedra Formosa.

Most of the canga is common canga; it occurs along the ridges of Cauê Itabirite and extends downslope from the crests as much as 1,000 meters. The layers of common canga are enriched by leaching of carbonate and silica from the itabirite fragments and concurrent precipitation of limonite cement. Enriched common canga is widely used as a charge ore for the local charcoal smelters because of its light weight and high porosity.

Canga derived from weathering of Cauê Itabirite in place occurs in irregular patches along the crests of ridges underlain by itabirite. The itabirite weathers along cleavage planes into partly collapsed and disaggregated rock. The rock fragments are partly slumped but retain vestiges of the original attitude of the itabirite bedrock. During the weathering process some of the silica and carbonate is leached out, and limonite is deposited along the fractures of the itabirite fragments and minor amounts are disseminated and deposited in the intervening itabirite fragments. The iron enrichment may extend down into the unbroken itabirite.

Chemical cangas are widespread in the Lagôa Grande Plateau area in the northwestern part of the Conceição do Rio Acima quadrangle. They are irregularly exposed in small patches by recent erosion that has stripped off soil, and presumably they comprise large areas of the Lagôa Grande Plateau—a large field of canga deposited on a deeply weathered erosional surface of dolomite. This surface forms a gentle depression of low relief, interrupted by a few sinkholes, that is flanked on the southeast by a ridge of Cauê Itabirite and on the northwest by a ridge of ferruginous quartzite of the Cercadinho Formation. The chemical canga grades southeastward into common canga that occurs above the itabirite on the northwest slopes of the Serra da Pedra Formosa. Locally within the plateau area the chemical canga grades laterally into ferruginous lateritic soils and high-alumina lateritic soil derived from the weathering of dolomite of the Gandarela Formation.

The chemical canga forms beneath a shallow soil cover and consists of very fine grained hydrous iron oxide cementing varying but minor amounts of pebble- to sand-sized rock fragments and ferruginous and aluminous lateritic soil. Chemical canga that has recently been uncovered by erosion characteristically has a botryoidal surface, whereas weathered chemical canga has a rough surface.

LATERITIC SOILS

Ferruginous, aluminous, and manganiferous residual soils occur essentially in place as the result of subtropical weathering of pelitic, dolomitic, and igneous rocks. In areas of moderate or low relief these residual soils form a 1- to 10-meter-thick layer of laterite overlying and grading downward into saprolite that is as much as 50 meters thick.

Ferruginous lateritic soils are widespread in these quadrangles and are derived from the weathering of schist and phyllite. These laterites occur mostly at lower elevations and along the intermediate and upper slopes of the areas underlain by pelitic rocks. The laterite is medium- to dark-red residual soil ranging from about 1 to 10 meters in thickness and averaging about 1–2 meters in thickness.

Aluminous lateritic soils overlie granodiorite gneiss and, locally, dolomite of the Gandarela Formation. The granodiorite is easily eroded and forms low topography mantled by white, light-yellow, light-gray, and light-reddish-gray aluminous laterite consisting mostly of kaolin. Locally, where dolomite is exposed at higher elevations—as on the Lagôa Grande Plateau—where drainage and circulation of meteoric waters are good, the dolomite weathers to aluminous laterite consisting of a medium-reddish-brown low-grade bauxite soil. The bauxite occurs mostly as small irregular masses in the canga field that caps the Lagôa Grande Plateau, and they grade laterally into chemical canga. These aluminous laterites consist of either medium-reddish-brown structureless dense earthy material or honeycombed dense earthy material. A channel sample of typical bauxite lateritic soil cut across a 6-foot width at N. 9,500, E. 2,250, in the Conceição do Rio Acima quadrangle (pl. 3) contained 35.2 percent Al_2O_3, 26.4 percent SiO_2, and traces of phosphorus, sulfur, and manganese.

Manganiferous laterite occurs along the projected strike of the upper beds of the Gandarela Formation. Excellent exposures of these manganiferous laterites can be seen in the face of the Socorro quarry at N. 3,650, E. 4,650 (pl. 2). They occur in a 300- to 400-meter-wide band extending from N. 4,200 on the west boundary of the Gongo Sôco quadrangle to near N. 4,000, E. 6,000 (pl. 2).

The manganiferous laterite is a dark-brown to black plastic residual soil. It can be seen in quarry faces and along stream bottoms as a 1- to 2-meter-thick layer that grades downward through a few centimeters into either nonplastic black saprolite or red manganiferous dolomite. The manganese in these laterites apparently resulted from the weathering of manganiferous dolomite, with attendant leaching of CaO and MgO from the dolomite and concentration of residual manganese, iron, and some silica. These laterites occur in areas of low relief and limited circulation of ground water.

ALLUVIUM

Recent deposits of unconsolidated gravel, sand, and clay occur in the major stream valleys. Remnants of older alluvial deposits are found along the lower slopes of the valleys as much as 30 meters above the present stream level. Most of the recent deposits consist of tailings from the extensive placer mining of the auriferous alluvial deposits during the 19th century.

The alluvium consists of cobbles and pebbles of vein quartz, quartzite, hard hematite, minor amounts of itabirite, and schist in a matrix of clay and sand.

TALUS

Talus accumulations are common at the base of cliffs. Steep slopes are in many places covered with irregular areas of material transported by soil creep, slump, and landslides. A major landslide near the Fazenda Gongo Sôco consists of masses of schist and iron-formation in crumbled schist and phyllite, saprolitic material, and lateritic soil.

IGNEOUS ROCKS

Igneous rocks of these quadrangles include granitic and granodioritic gneiss, gabbro, and diabase. These rocks are deeply weathered to saprolite mantled by lateritic soil, and exposures of fresh rock are sparse. Large areas of the Antônio dos Santos and Gongo Sôco quadrangles are underlain by gneissic rocks of granitic to granodioritic composition. The gneissic rocks form only a small part of a regional batholith that extends east, north, and west of the mapped area for many kilometers. The part of this regional batholith that lies within this area is referred to as the "Caeté Complex", and this name will be used for the gneissic rocks underlying the Nntônio dos Santos and Gongo Sôco quadrangles.

Diabasic dikes have been intruded into thrust faults in the Cambotas Quartzite of the Serras das Cambotas and Caraça. Plutons of gabbro and diabase intrude the Cambotas Quartzite of the eastern part of the Serra das Cambotas and the gneiss of the Caeté Complex (pls. 1, 2).

Dikes and veins of pegmatite are found in the schists of the Nova Lima Group at or near the contact with the gneiss of the Caeté Complex. Quartz-tourmaline veins are also found at or near the contact of the gneiss and the schist of Nova Lima age in the central part of the Gongo Sôco quadrangle. Quartz-kyanite veins occur locally in the quartzite of the Maquiné Group and in the phyllite and ferruginous quartzite of the Cercadinho Formation. Milky quartz veins, fibrous quartz veins, and quartz-hematite veins occur in the dike rocks and metamorphic rocks of the area.

GRANITIC AND GRANODIORITIC GNEISS

DISTRIBUTION

Granitic and granodioritic gneiss of widely varying composition makes up most of the igneous rocks of the Caeté Complex north of the Serra Geral and along the west, north, and east flanks of the Serra das Cambotas in the Gongo Sôco and Antônio dos Santos quadrangles.

The gneiss of the Caeté Complex is easily weathered and forms low rolling hills. Fresh exposures of gneiss are shown on plates 1 and 2 by patterned areas within the deeply weathered saprolite and lateritic soil.

LITHOLOGY

Although most of the gneiss is deeply weathered to laterite and saprolite, textures are well preserved in the saprolite. The saprolite shows textures ranging from equigranular to porphyritic. Fresh exposures of gneiss are white to light-gray medium-grained rocks consisting of plagioclase, potassium feldspars, quartz, biotite, sericite, and chlorite with granitoid textures that are faintly to moderately foliated.

Petrologic studies of thin section of fresh gneiss show it to range in composition from granite to granodiorite. The gneiss is composed of about 20–70 percent oligoclase, 20–55 percent microline, 20–30 percent quartz, and 2–20 percent biotite by volume.

Plagioclase grains are in part zoned and range from An_{10} to An_{25}. A few of the zoned grains are selectively altered along zones to sericite and rarely to epidote. Some of the oligoclase grains are corroded by myrmekitic quartz. Microcline and orthoclase make up varying amounts of the potassic feldspar. Microperthite intergrowths with the orthoclase are common. Quartz grains are intergrown with the feldspars and form sutured boundaries with them in some sections; in other sections the quartz and feldspar grains are broken. Most quartz grains are severely strained. Biotite is greenish brown and occurs as plates between grain boundaries of the feldspar and quartz. Biotite is widely altered to aggregates of chlorite, epidote, and sericite, some of which are pseudomorphous after biotite books.

CONTACT AND AGE RELATIONS

The contact between the gneiss and the schist, phyllite, and quartzite of the Rio das Velhas Series is obscured in most places by deeply weathered saprolite, lateritic soils, talus, and a thick growth of scrubby jungle; however, the contact is well exposed in roadcuts and railroad cuts in the central part of the Gongo Sôco quadrangle (pl. 2).

An excellent exposure of the contact between the gneiss and quartz-chlorite schist of the Nova Lima Group can be seen in a roadcut at N. 6,800, E. 950 (pl. 2). Here the quartz-chlorite schist is in sharp contact with gneiss saprolite. The foliation of the schist strikes west and dips 40°–50° S., and the contact strikes west and dips 70°–80° S. A narrow layer of tourmalinized schist about 15 cm thick is in sharp contact with the gneiss. Outward from this tourmalinized zone, the schist is pervaded by clusters of tourmaline crystals and veinlets of smoky quartz in a zone about 50 meters wide. This zone of disseminated tourmaline crystals and smoky quartz veinlets grades over a few meters into a zone of pegmatite veins that is about 150 meters wide.

The contact between the gneiss and sericite-quartz schist and phyllite of the Nova Lima Group is well exposed at many places on the Caeté-Barão de Cocais road from near N. 8,500, E. 600, to N. 8,900, E. 10,800, in the Gongo Sôco quadrangle (pl. 2). In these localities the contact is gradational from a gneiss saprolite through a migmatite saprolite into weathered quartz-sericite schist and phyllite. The width of the migmatized zone is variable and ranges from about 30 to 200 meters across.

The contact between the Cambotas Quartzite and the gneiss along the west, north, and east flanks of the Serra das Cambotas is covered by lateritic soils and talus at the base of cliffs and steep slopes, and the contact was not directly observed. The gneiss cuts across the regional strike of Cambotas Quartzite near the Serra do Garimpo, in the northeastern part of the Antônio dos Santos quadrangle (pl. 1). Similar crosscutting relationships can be seen between the gneiss and the Cambotas Quartzite exposed within the main body of the gneiss.

Near the contact between the Cambotas Quartzite and the gneiss, the quartzite contains irregular zones of disseminated feldspar grains. These feldspathic quartzites are believed to be alteration zones associated with an intrusive contact, rather than a sedimentary feature, because they do not occur within a definite stratigraphic interval.

The intrusive contact between the gneiss and the quartz-chlorite schist of the Nova Lima Group in the western part of the Gongo Sôco quadrangle is sharp.

The gradational contact between the gneiss and the sericite-quartz schists of the Nova Lima Group in the central and east-central parts of the Gongo Sôco quadrangle is believed to be a zone of mobilized sericite schist between gneiss and sericite-quartz schist. These sericite quartz schists had a higher potassium content than the quartz-chlorite schist and may have been more easily migmatized, and, therefore, the gneiss of the Caeté Complex in the Gongo Sôco and Antônio dos Santos quadrangles is probably intrusive.

The age of the granitic and granodioritic gneiss of the Caeté Complex in the Antônio dos Santos and Gongo Sôco quadrangles is uncertain because the gneiss is found only in contact with metasedimentary rocks of the Rio das Velhas Series. Direct stratigraphic relations with the rocks of the Rio das Velhas series indicate a post-Rio das Velhas age. However, the schist, phyllite, and quartzite of the Rio das Velhas Series underlie rocks of Minas age that lie in the core of the Gandarela syncline and apparently were deformed by a post-Minas orogeny prior to the emplacement of the gneiss of the Caeté Complex. This structural relationship indicates that the age of the granitic and granodioritic gneiss of the Caeté Complex is post-Minas.

The granitic rocks of the Quadrilátero Ferrífero were thought to be Archean by early workers in the area. Barbosa (1954, p. 20), however, recognized that some of the gneissic granitic rocks were derived from metasedimentary rocks of the Rio das Velhas Series. Herz and Dutra (1958) presented evidence for at least four ages of intrusive rocks in the Quadrilátero Ferrífero.

The ages of the granitic gneisses were determined by Prof. P. M. Hurley, Geology and Geophysics Department, Massachusetts Institute of Technology, who measured Ar^{40}/K^{40} ratios in biotite. Four different ages were determined: 2,500 m.y., 1,350 m.y., between 1,350 m.y. and 500 m.y., and 500 m.y. The nearest dated granitic rock is in the east-central part of the Cocais quadrangle (Simmons, 1968) about 9 kilometers east of the Antônio dos Santos quadrangle. Herz and Dutra (1957, p. 93) determined the age of a gneiss from the Cocais area to be 460 m.y. and correlated the gneiss of the Caeté Complex east of the city of Caeté and west of the Serra das Cambotas with the 500-million-year-old post-Minas granitic rocks. Guimarães (1951, p. 37) also believed the granitic gneiss of the Caeté Complex in the mapped area to be post-Minas in age.

MAFIC INTRUSIVE ROCKS

Mafic igneous rocks occur in metasedimentary rocks of all ages and in the granodiorite gneiss of the Caeté Complex.

A swarm of mafic dikes occurs in the Cambotas Quartzite of the Serra do Caraça and is intruded into fault and joint planes. Along the east flanks of the Serra das Cambotas a pluton of mafic rocks intrudes the Cambotas Quartzite. This pluton is about 4 kilometers long, and only the western part of it lies within the mapped area (pls. 1, 2). A few dikes and plutons of mafic rocks occur in the granodiorite gneiss of the Caeté Complex, and small segments of dikes and sills of mafic rocks are poorly exposed locally within the pelitic, calcareous, and ferruginous metasedimentary rocks; however, they were not mapped, as they are deeply weathered and could not be traced for more than a few tens of meters.

The mafic dikes that comprise the swarm in the Serra do Caraça are in most places weathered to reddish-brown saprolite or lateritic soil, but a few fresh pieces of float were found in some of the outwashed alluvial material. The dikes are easily mapped within the resistant Cambotas Quartzite, where they form shallow depressions along the crests of the ridges and deep ravines along the valley slopes.

The weathered saprolite of the mafic dikes consists of a reddish-brown clay matrix that contains pseudomorphic phenocrysts of limonite after hornblende and pyroxene. The original fine- to coarse-grained porphyritic textures of the dikes are partially preserved in the saprolites. The borders of the dikes frequently have chilled zones ranging from a few centimeters to 15 cm in width and contain numerous pseudomorphs of hematite and limonite after pyrite.

The Cambotas Quartzite wallrock is apparently unaltered by the dikes, except that it contains minor amounts of disseminated cubes of pseudomorphous hematite after pyrite over a width of 5–10 cm. Numerous fibrous quartz veins occur in fractures in the dike rock and the Cambotas Quartzite wallrock.

The mafic rocks of the large pluton exposed along the eastern part of the Serra das Cambotas also weathers in most places to reddish-brown saprolite and lateritic soil. A few fresh exposures show the rock to be dark-green medium-grained diabase consisting of plagioclase, pyroxene, and magnetite. Thin sections showed the rock to be made up of a calcic andesine and pyroxene matrix containing sparsely disseminated magnetite and ilmenite, and a few phenocrysts of pyroxene. The augite phenocrysts and the augite in the matrix are altered to an unidentified pleochroic amphibole. The magnetite is altered to limonite and the ilmenite to leucoxene.

QUARTZ VEINS

Quartz veins occur in all the metasedimentary and igneous rocks of the mapped area, but they are most conspicuously exposed in the more resistant rocks such as quartzite, iron-formation, and feldspathic quartzite. The veins are of four types: milky (bull) quartz, the most common type; fibrous quartz; quartz-kyanite; and quartz-hematite. Quartz-tourmaline veins and smoky quartz veins are associated with pegmatite dikes and veins near the contact of granodiorite gneiss.

Most of the quartz veins are composed of milky, or bull, quartz; a few clear quartz crystals occur as isolated aggregates in the milky quartz or as druses in vuggy parts of the veins. The veins occur in all the rock units but are most conspicuous in the Cambotas Quartzite and quartzite of Maquiné age. The veins range in width from a few millimeters to about 50 cm.

Quartz veins consisting of fibrous crystals alined at right angles to the vein walls occur in association with the mafic dike swarms in the Cambotas Quartzite of the Serra do Caraça. This type of quartz vein is particularly abundant at N. 6,000, E. 10,000 (pl. 3). The veins range from about 0.5 to 5 cm across and crosscut the mafic dikes and the Cambotas Quartzite wallrock. They are composed of thin, nearly parallel, matted rodlike crystals alined at right angles to the vein walls. The veins are in joint planes that generally have a northerly trend and dip steeply to the east.

Quartz-kyanite veins were observed in the Cercadinho Formation and in the Maquiné Group but were not observed in the other rocks of the mapped area.

Quartz-kyanite veins are exposed in a railroad cut in the Cercadinho Formation near the east boundary of the Gongo Sôco quadrangle (N. 7,500, E. 13,300, pl. 2). Here the edges of the veins are composed of milky quartz with a central zone of felted blades of blue-green kyanite. Elsewhere debris from veins in the Cercadinho Formation can be seen, but exposures of veins are not easily found.

Quartz-kyanite veins are found at many places within the quartzite of the Maquiné Group along the northwest flanks of the Serra do Caraça (pl. 3) and consist of milky quartz enclosing large individual (2–5 cm long) laths of blue and blue-green kyanite. The kyanite laths have ragged edges and are honeycombed by irregular holes.

Quartz-hematite veins are common in the Batatal Formation and in the Cauê Itabirite of the Minas Series; they occur as crosscutting veins about 1–5 cm across and consist of aggregates of quartz crystals intergrown with coarse curved plates of specularite.

Pegmatite veins of quartz, feldspar, and muscovite and of quartz and tourmaline are common in the migmatized and metamorphic quartz-chlorite schist and quartz-muscovite schist of Nova Lima age near the contact of the granodiorite gneiss of the Caeté Complex.

A pegmatized zone within the schist of Nova Lima age can be seen in a roadcut near N. 6,800, E. 950, in the western part of the Gongo Sôco quadrangle (pl. 2). The pegmatite veins occur in a zone about 200 meters wide. The contact between the granodiorite gneiss and the schist is marked by a selvage of dark-green tourmaline crystals. The schist beyond the selvage of tourmaline is cut by numerous veinlets and veins of smoky quartz and contains aggregates of disseminated tourmaline and smoky quartz over a width of about 50 meters. This zone grades over a few meters into another zone about 150 meters wide that consists of numerous quartz-feldspar-muscovite veins intruded into the foliation of the schist and into crosscutting joint planes. The veins range in width from about 4 cm to 4 meters. Some are discontinuous and form lenses parallel to the foliation of the schist.

The pegmatite veins consist of quartz, potassic feldspar, muscovite, and some actinolite. They are crosscut by smoky quartz veinlets, and some have borders of smoky quartz. Most of the narrower (5–10 cm) veins are zoned and consist of coarsely crystalline clear quartz and potassic feldspar borders and a central zone of muscovite and quartz. Some of the wider veins pinch out; and where they do, the vein consists of a central zone of dark-gray acicular actinolite crystals and borders of highly fractured dark-brown to black quartz.

The intervening quartz-chlorite schists within the pegmatized zone are deeply weathered to saprolite that preserves a well-developed migmatic texture. Numerous lenses of smoky quartz occur along the foliation of the schist, and the minerals of the schist are moderately well crystallized into alternating dark- and light-colored bands. Migmatization of the schist is associated with the pegmatized zones and does not occur in the schists above or below the pegmatized zone.

METAMORPHISM

Most of the Precambrian rocks of the mapped area have been subjected to a period of post-Minas low-grade metamorphism. Typical mineral assemblages, characteristic of the greenschist facies, are quartz, sericite, chlorite, and chloritoid; and tremolite, carbonate, phlogopite, and biotite. The Rio das Velhas Series may have been subjected to an older period of metamorphism; however, little evidence was observed in the schists, phyllite, or quartzite that would suggest retrogression from a higher level of metamorphism.

Precambrian sandstones and impure sandstones of both the Rio das Velhas and the Minas Series have been crystallized to quartzite and sericite, chlorite, and chloritoid-quartz schist. The iron-formations of both series have been crystallized to siliceous and dolomitic itabirite and minor amounts of tremolite and biotite. Shales, arenaceous shales, and volcanic rocks have been metamorphosed to phyllite and schist. The dolomite of the Minas Series has been crystallized to dolomite marble, phlogopite, and talc. Feldspathic sandstones of the Minas Series have been crystallized to epidote, chlorite, and sericite.

Granitic gneiss of the Caeté Complex has formed a contact-metamorphic zone in schist and quartzite of the Rio das Velhas Series along the east and west flanks of the Serra das Cambotas and along the north slopes of the Serra Geral. The contact-metamorphic zone in the schist ranges from about 100 to 300 meters in width and consists of pegmatitic dikes of quartz, feldspar, and muscovite and quartz-tourmaline veins crosscuting migmatized schist. Contact metamorphism of the quartzite of the Serra das Cambotas is indicated by irregular zones of feldspar and specularite in the quartzite that generally parallel the contact of the granitic gneiss.

The granitic gneiss of the Caeté Complex has been deuterically altered by epidote, sericite, and chlorite. In most places alteration of the mafic rocks is unknown because of deep weathering. The plutons and dikes of gabbro and diabase do not have contact-metamorphic aureoles in the adjacent metasedimentary rock or granitic gneiss.

STRUCTURAL GEOLOGY

The Precambrian metasedimentary rocks of these quadrangles are deformed into three major northeast-trending isoclinal folds overturned to the northwest and broken by northeast-trending and generally southeast-dipping low- to moderate-angle thrust faults. The major elements of structural framework of these quadrangles are the Capivara syncline, the Conceição anticline, the Gandarela syncline, the Caraça thrust fault, the Fundão thrust fault, the Cambotas thrust fault, and the Cambotas homocline. High-angle north-trending east-dipping thrust faults occur in the upper plate of the Caraça thrust fault in the Serra do Caraça, and numerous drag folds modify the major folds of the area.

FOLDS

CAPIVARA SYNCLINE

In the southwestern part of the mapped area along the west, northwest, and north flanks of the Serra do Caraça, quartzite of the Maquiné Group occurs as a canoe-shaped syncline overturned to the northwest. The syncline is named for the nearby Fazenda Capivara.

The southeast limb of the Capivara syncline is bounded on the west, northwest, and north by the Caraça thrust fault. Cambotas Quartzite has been thrust over the southeast limb of the syncline, and part of the quartzite has been cut out by the Caraça thrust fault (pls. 3 and 4, sections *A–A′–A″*, *B–B′–B″*, and *C–C′*). The northwest limb of the syncline is in schist of the Nova Lima Group and quartzite of the Maquiné Group. The contact between the schist and the quartzite is apparently discordant, but because of our poor exposures the nature of this contact is not known. It may be an unconformity or a thrust fault.

The exial zone of the Capivara syncline is most clearly defined near the south boundary of the Conceição do Rio Acima quadrangle near N. 2,000, E. 6,200 (pl. 3). Here quartzite beds double back in a closed pattern. The axial zone was mapped northeastward between the northwest limb, which dips 55°–75° SE., and the overridden southeast limb, which dips about 25°–35° SE., to near N. 6,000, E. 9,000 (pl. 3). Here, the axial trace swings abruptly eastward along the north face of the Serra do Caraça and the syncline is overturned to the south (pl. 4, section *A–A′–A″*). The axial zone of the syncline is well exposed in roadcuts and in hogbacks of quartzite that are deformed by numerous drag folds along the north face of the Serra do Caraça. Both limbs of the syncline dip steeply to the north (pl. 4, section *A–A′–A″*).

Along the west flanks of the Serra do Caraça the axial zone of the syncline trends north and dips about 30° E. (pl. 4, section *C–C′*). Northeastward, along the northwest face of the Serra do Caraça, the axis curves to a northeasterly trend; and near N. 6,000, E. 9,000 (pl. 3), the dip steepens from about 30° to 85° SE. (pl. 4, section *B–B′–B″*). Eastward from this locality the trace of the axis curves abruptly eastward, and along the north face of the Serra do Caraça the syncline is overturned to the south (pl. 4, *A–A′–A″*).

CONCEIÇÃO ANTICLINE

The Conceição anticline consists of a complexly folded belt of schist and iron-formation of Nova Lima age. The anticline is 4–12 kilometers wide and extends across the mapped area from the southwest corner to the east boundary; it is here named for the Conceição valley, which roughly parallels part of the axial zone of this anticline (pl. 3). The anticline is a major feature in the mapped area and in the adjacent quadrangles. The structural details are largely obscured by deep weathering of the schist, phyllite and iron-formation of Nova Lima age that make up the core of the anticline.

The overturned northwest limb includes rocks of the Minas Series and the Nova Lima Group that dip about 30°–85° SE. The contact between the Minas Series and the Nova Lima Group is discordant and may be either an unconformity or a fault. The quartzite of the Maquiné Group and the Cambotas Quartzite are missing from the column along the northwest limb of the anticline (pl. 4, section *A–A′–A″* and *B–B′–B″*). The southeast limb dips about 30° E. in the southern part of the Conceição do Rio Acima quadrangle and about 35°–85° SE. along the northwest foothills of the Serra do Caraça (pl. 4, sections *B–B′–B″* and *C–C′*). The southeast limb is made up of quartzite of the Maquiné Group and Nova Lima rocks separated by a discordant contact. This discordant contact is poorly exposed and may be either a fault or an unconformity.

In the southwestern part of the mapped area the axial zone of this anticline plunges northeastward along a curving, north- to northeast-trending axis. The axial zone can be traced northeastward to near N. 10,000, E. 8,000, in the Conceição do Rio Acima quadrangle (pl. 3). Eastward from that locality the axial zone of the Conceição anticline is poorly defined because a series of subsidiary folds is superimposed on the crestal zone of the anticline.

GANDARELA SYNCLINE

The Gandarela syncline extends more than 40 kilometers along an axis that trends between north and N. 70° E. and is a major structure in the eastern part of the Quadrilátero Ferrífero. The southwestern part of the fold is open and underlies the greater part of the Gandarela quadrangle. Northeastward in the Gandarela quadrangle the dip of the southeast limb of the syncline steepens, and at the west boundary of the mapped area the dip is nearly vertical (pls. 2, 3). Northeastward, in the northwestern part of the Conceição do Rio Acima quadrangle (pl. 3) and in the southern part of the Gongo Sôco quadrangle, the southeast limb is overturned and dips about 85° S. in the western part of the mapped area and about 20°–45° S. along the northeastern part of the syncline (pl. 4, sections *A–A′–A″* and *B–B′–B″*). Both limbs of the Gandarela syncline are made up or rocks of the Minas Series and of schist of Nova Lima age; the core of the syncline is in rocks of Minas age. The contact between the rocks of Minas and Nova Lima ages is discordant and could be either an unconformity or a folded thrust fault.

Both limbs of the Gandarela syncline are broken and displaced by longitudinal thrust faults that generally parallel the dip and the strike of the axial plane of the syncline. A few minor transverse faults with near-vertical dips displace the southwestern part of the southeast limb of the syncline.

The northwest limb of the syncline is bounded by the Cambotas thrust fault, and along the southern part of the Serra das Cambotas and the eastern part of the Serra Geral the northwest limb of the syncline is thrust northwestward over Cambotas Quartzite (pl. 4, section *A–A′–A″*). The northwest limb dips 45°–55° SE. in the western part of the Gongo Sôco quadrangle and about 20°–35° SE. along the eastern part of the syncline. In the vicinty of the Cabeça de Ferro iron mine, the northwest limb is deformed by drag folds and broken by a high-angle thrust fault. The southeast limb is broken by the Fundão thrust fault from the west boundary to the east boundary of the mapped area.

The core of the syncline is in schist and phyllite of the Sabará Formation, and the axial zone can only be generally inferred because of poor exposures. The syncline is modified along both limbs by numerous small, open cross folds. The syncline plunges southwestward in the eastern part of the mapped area and northeastward in the western part of these quadrangles (pls. 2, 3).

FAULTS

CARAÇA FAULT

The Caraça fault is a folded thrust fault that extends across the southeastern part of the Conceição do Rio Acima quadrangle (pl. 3). It is named for the Serra do Caraça, a major mountain range in the eastern part of the Quadrilátero Ferrífero.

The Caraça fault marks the leading edge of a massive overthrust salient of Cambotas Quartzite in the Serra do Caraça. The Cambotas Quartzite of the upper plate has been warped into open folds, and at one place an isoclinal fold, that are broken into a series of imbricated blocks by north-trending and east-dipping high-angle thrust faults. Most of these high-angle thrust faults are cut off by the Caraça fault along the north and northwest flanks of the Serra do Caraça.

The imbricated Cambotas Quartzite in the upper plate of the Caraça fault has been thrust west-northwest over the southeast limb of the Capivara syncline along the west, northwest, and north escarpments of the Serra do Caraça. The plane of the Caraça fault is highly undulatory and was folded after the fault was formed. Along the north face of the Serra do Caraça, the fault is overturned to the south (pl. 4, section *A–A′–A″*).

The Caraça fault extends along the base of the massive hogbacks of Cambotas Quartzite that form the west, northwest, and north escarpments of the Serra do Caraça (pl. 3). Along the west escarpment of the Serra do Caraça the fault trends north and dips about 15°–25° E. (pl. 4, section *C–C′*). Northeastward along the northwest escarpment of the serra, the fault curves to a northeasterly trend and gradually steepens in dip from about 25° to 85° SE. Near N. 6,400, E. 9,400 (pl. 3), the fault swings abruptly from a north to an easterly trend and is overturned to the south along the north escarpment of the Serra do Caraça (pl. 4, section *A–A′–A″*).

The Caraça fault zone is well exposed in the Córrego do Capivara at N. 200, E. 8,400 (pl. 3), near the south boundary of the mapped area. Here and at a number of other localities along the west and northwest escarpments of the Serra do Caraça, the zone consists of about 50–80 cm of sheared iron-stained quartzite and mica separating Cambotas Quartzite above from quartzite of the Maquiné Group below. Above and below the fault the quartzites are dragged into the fault zone and obliquely truncated by it. Along the north escarpment of the Caraça range, the fault zone is covered in most places by soil and obscured by a thick jungle growth; however, the fault is partly exposed at N. 6,800, E. 11,500 (pl. 3), along the road leading southward to the Colégio do Caraça. Here the fault zone is about 1–1.5 meters wide and is made up of breccia consisting of angular to subrounded iron-stained quartzite fragments in a crushed and sheared matrix of granular quartz and mica.

FUNDÃO FAULT

The Fundão thrust fault trends northeast and dips southeast, and it extends for more than 50 kilometers across the eastern part of the Quadrilátero Ferrífero. It was named for a prominent valley in the eastern part of the Gandarela quadrangle by J. E. O'Rourke (written commun., 1956). O'Rourke traced the Fundão fault northward from the Rio das Pedras quadrangle across the crest of the Serra da Pedra Formosa to the headwaters of the Rio Socorro. Here the Fundão fault splits into two faults. The main fault turns northeastward and continues across the northwestern part of the Conceição do Rio Acima quadrangle and the southeastern part of the Gongo Sôco quadrangle (pls. 2, 3). The branch fault trends north in the Gandarela quadrangle, to the west of the mapped area, then turns eastward and crosses into the Conceição do Rio Acima quadrangle at N. 12,250, and rejoins the Fundão fault in the northwestern part of the Conceição do Rio Acima quadrangle (pl. 3). A third fault splits from the south end of the branch fault in the Gandarela quadrangle and joins the Fundão fault at N. 9,600, E. 600, in the Conceição do Rio Acima quadrangle (pl. 3). In the northwestern part of the Conceição do Rio Acima quadrangle the Fundão fault system is made up of three imbricate plates, all of which are thrust northwestward. Most of the displacement apparently occurred on the southernmost fault, which offsets the contact of the Cercadinho Formation and the Sabará Formation about 2,400 meters (pls. 3; pl. 4, section B–B'–B''). The estimated throw of the main Fundão fault in the same area is about 700–1,000 meters.

Northeastward from the junction of the northernmost branch fault and the Fundão fault in the northwestern part of the Conceição do Rio Acima quadrangle to the vicinity of Pedra Vermelha in the southern part of the Gongo Sôco quadrangle, the Fundão fault forms a faultline scarp; the relatively more resistant feldspathic quartzite is thrust over the less resistant phyllite and schist. Near Pedra Vermelha (N. 900, E. 5,700, pl. 2) the basal Minas formations and the Pedra fault are offset about 1,000 meters. The throw of the fault apparently diminishes northeastward and is estimated to be about 400–600 meters near Pedra Vermelha.

Near Lagôa do Couto (N. 2,000, E. 8,000, pl. 2) the trace of the fault curves to an easterly trend, and schist of the Nova Lima Group occurs in both the upper and lower plates. Because these rocks of similar lithology are poorly exposed, the trace of the fault is projected to a point near N. 4,000, E. 11,000 (pl. 2), on the southeast slopes of the Serra da Pedra Formosa, where the basal formations of the Minas Series are laterally offset about 1,000 meters. From the last locality to the east boundary of the Gongo Sôco quadrangle, the trace of the fault is easily mapped with Cauê Itabirite and dolomite of the Gandarela Formation overridden by schist of Nova Lima Age. The throw of the fault near the east boundary of the Gongo Sôco quadrangle is estimated to be about 300–400 meters.

CAMBOTAS FAULT

The Cambotas thrust fault has been mapped across the central part of the Gongo Sôco quadrangle, where it forms a boundary between a belt of north-trending east-dipping Cambotas Quartzite and the Gandarela syncline. The fault was named for the Serra das Cambotas—part of the regional Serra Espinhaço. The strike of the Cambotas fault trends from N. 70° E. to due east, and dips range from 40° to 50° S. The fault is cut off on the east by a pluton of gabbro about 100 meters beyond the east boundary of the mapped area (Simmons, 1968). From the east boundary of the Gongo Sôco quadrangle the Cambotas fault can be traced for 7 kilometers west along the south end of the Serra das Cambotas and the south slopes of the Serra Geral to near N. 8,000, E. 6,500 (pl. 2). Here the fault splits into three faults that continue west for about 600–1,000 meters, where they are cut off by granite gneiss of the Caeté Complex. The southernmost fault, from N. 6,800, E. 5,400, to N. 6,050, E. 4,200, is alined with the contact between schist of Nova Lima age and granitic gneiss; apparently the fault either controlled the intrusion of the gneiss or forms the gneiss–Nova Lima contact. Westward from N. 6,050, E. 4,200 (pl. 2), the southernmost branch of the Cambotas fault extends along the north slopes of the Serra Geral to the west boundary of the Gongo Sôco quadrangle (pl. 2).

An excellent exposure of the Cambotas fault is in a roadcut along the Caeté–Barão de Cocais highway (BR–31), near the east boundary of the Gongo Sôco quadrangle (N. 9,150, E. 12,500, pl. 3). Here the fault strikes N. 70° E. and dips 40° S.; the fault zone contains 15–20 cm of gouge consisting of quartzite granules and a shredded mica matrix enclosing angular fragments of vein quartz. The fault zone separates the cataclastic Cambotas Quartzite below from the schist of the Nova Lima above. The cataclasite and the schist layers dip and strike nearly parallel to the fault zone, but they are sheared and dragged into the gouge zone and are there obliquely truncated. At the south end of the Serra das Cambotas the schist of Nova Lima age and the overlying rocks of Minas age in the north limb of the Gandarela syncline have been thrust northwestward over the homoclinal belt of north-trending east-dipping Cambotas Quartzite that forms the Serra das Cambotas. The overridden Cambotas Quartzite has been dragged and warped sharply to the west along the eastern part of the Serra Geral (pl. 4, section *A–A′–A″*), and at least 700 meters of quartzite has been cut out of the section by the overriding upper plate of Nova Lima and Minas rocks. Near the east boundary of the Gongo Sôco quadrangle the overriding rocks in the north limb of the Gandarela syncline are deformed by isoclinal folds overturned to the north and broken by a thrust fault. The isoclinal folds extend beyond the east boundary of the Gongo Sôco quadrangle for more than 4 kilometers into the Santa Bárbara quadrangle (G. C. Simmons, written commun. 1959).

The magnitude of displacement along the Cambotas thrust fault is not known with certainty; however, zones of cataclasite in the lower plate and large-scale dragging and truncation of at least 700 meters of Cambotas Quartzite along the south end of the Serra das Cambotas and the east end of the Serra Geral indicate a large displacement.

HIGH-ANGLE THRUST FAULTS

High-angle thrust faults occur along both limbs of the Gandarela syncline and in the Cambotas Quartzite of the Serra do Caraça and Serra das Cambotas. The Pedra fault occurs along the southeast limb of the Gandarela syncline and can be traced from the northern part of the Lagôa Grande Plateau (N. 13,700, E. 5,000, pl. 3) along the northwest slopes of the Serra da Pedra Formosa to near N. 5,000, E. 11,500 (pl. 2), in the southern part of the Gongo Sôco quadrangle, where it is offset by the Fundão thrust fault. Northwestward from its offset on the Fundão fault to N. 5,000, E. 11,400 (pl. 2), Cauê Itabirite in the upper plate is thrust over dolomite of the Gandarela Formation and ferruginous quartzite of the Cercadinho Formation.

The displacement of the fault is not known. Movement on the fault seems to increase toward the northeast because the Gandarela Formation and most of the Cercadinho Formation are cut out of the lower plate at N. 4,700, E. 11,000 (pl. 3).

The Pedra fault is covered by canga and soil, but it is easily mapped along a zone of contrasting lithology and lateritic soils. It strikes about N. 50° E., and its calculated dip is about 60°–70° SE.

Along the south slopes of the Serra Geral in the Gongo Sôco quadrangle, a high-angle thrust fault in the upper plate of the Cambotas fault (N. 7,600, E. 8,300, pl. 2) branches from the Cambotas fault and is traced eastward along offset contacts of the Minas formations on the north limb of the Gandarela syncline. Dolomite of the Gandarela Formation is thrust northwest over Cauê Itabirite along much of the trace of the fault east of the village of Henrique Fleuisse to N. 8,450, E. 12,800 (pl. 2). Here the upper plate of the thrust fault is tightly folded; the dolomite of the Gandarela Formation is cut out of the upper plate, and ferruginous quartzite of the Cercadinho Formation is thrust northwestward over Cauê Itabirite.

The fault trends about N. 70°–80° E., and its calculated dip is about 65°–75° S. The throw is not known, except that it apparently increases eastward along the fault. The fault cuts the Gandarela Formation out of the upper plate near the east boundary of the Gongo Sôco quadrangle.

In the Serra do Caraça a series of north-trending east-dipping high-angle thrust faults cuts across and displaces open folds and an overturned syncline of Cambotas Quartzite in the folded upper plate of the Caraça thrust fault. The quartzite blocks moved from east to west and overrode one another, imbricating the upper plate of the Caraça thrust fault. These high-angle thrust faults form the western part of a series of imbricated slices of quartzite in the eastern part of the Serra do Caraça.

These faults all dip about 70°–80° E. and trend north to northwest. Displacements along the faults are not known. Most of the faults are intruded by mafic dikes and are cut off by the Caraça thrust fault along the northwest and north escarpments of the Serra do Caraça.

West-trending reverse faults that dip steeply to the south are exposed along the crest and slopes of the southern part of the Serra das Cambotas in the northeastern part of the Gongo Sôco quadrangle (pl. 2). The magnitude of movement along these faults is uncertain; they displace a sequence of thick quartzite beds of Cambotas age and are truncated on the east by a pluton of mafic rocks and on the west by granodiorite of the Caeté Complex.

CAMBOTAS HOMOCLINE

A north-trending and east-dipping belt of Cambotas Quartzite forms a homocline throughout most of the Serra das Cambotas in the northeastern part of the mapped area. It is bounded on the north, east, and west by granodiorite and gabbro of the Caeté Complex, and on the south by the Cambotas fault. Neither the top nor the bottom of the quartzite is exposed, except at the southwestern part of the homocline, where Cambotas Quartzite unconformably overlies schist of the Nova Lima Group. It is not known whether the Cambotas homocline is a tilted fault block, a limb of a fold, or an isoclinal fold. Zones of cataclasite, generally parallel to the bedding plane, occur throughout the homocline, suggesting widespread shearing within this belt of quartzite. The relationship of the Cambotas homocline to the north-trending and east-dipping belt of quartzite in the central part of the Antônio dos Santos quadrangle is not known because of the intervening gneiss of the Caeté complex. The western body of Cambotas Quartzite within granodiorite gneiss probably is a roof pendant and either a remnant of a faulted block or a limb of a fold.

SUMMARY

The Precambrian rocks of the eastern part of the Quadrilátero Ferrífero were folded and faulted during several periods of orogeny. The correlation of the major folds and faults, and to a certain extent of rock units of pre-Minas age, is made difficult by the lack of precise structural and stratigraphic detail and by poor exposures in much of the region. This difficulty in correlation and mapping has led to different interpretations of structural and stratigraphic features in the eastern part of the Quadrilátero Ferrífero. Perhaps the most controversial subject is the discordant contact at the base of the Minas Series and the discordant contacts separating major rock units of the Rio das Velhas Series. In the Cocais and Santa Bárbara quadrangles (Simmons, 1968) and in the Catas Altas and Capenema quadrangles (Maxwell, unpub. data) east and south of the mapped area, these discordant contacts have been mapped as unconformities. This interpretation was also followed by O'Rourke (unpub. data) in the Gandarela quadrangle and by Alves (unpub. data) in the Caeté quadrangle. Structural features on and along these contacts are commonly associated with thrust faults. Therefore an alternate interpretation of the structure of the mapped area, and the interpretation currently followed by Maxwell, Simmons, Alves, and O'Rourke is given in figure 3, sections 1 and 2. Inasmuch as the geologic maps and cross sections show only the surface contacts and their projection to a few thousand meters below the surface, further inference of the structural features may be shown by projecting the contacts above the surface and to a greater depth.

The projected contacts shown in section 1 are based on the assumptions that (1) the Caraça and Cambotas thrust faults are unconformable contacts; (2) the quartzites of Maquiné and Cambotas ages that form the Serra do Caraça on the south and the Cambotas homocline on the north either were removed by one or several periods of erosion or were not deposited throughout the central, eastern, and western parts of the mapped area; and (3) the Minas and pre-Minas rocks were then folded into three subparallel northeast-trending folds overturned to the northwest. This reconstruction of the structural evolution of the Precambrian rocks, if valid, does not adequately explain why the schist of the Nova Lima Group, the oldest known rock in the mapped area, overlies younger Cambotas Quartzite along the south slopes of the eastern part of the Serra Geral. Simmons and Maxwell (1961) described this belt of schist as the upper part of their Tamanduá Group and interpreted the Cambotas fault as a minor bedding-plane thrust fault. Dorr, Gair, Pomerene, and Rynearson (1957, p. 17–21), on the other hand, described a belt of schists in the Nova Lima quadrangle, the type locality, and included them in the Nova Lima Group. The upper part of this belt of schists was then mapped westward from the Nova Lima quadrangle (Gair, 1962) across the Caeté quadrangle (N. L. Alves, unpub. data) into the western part of the Gongo Sôco quadrangle. Thus, the upper part of the Nova Lima Group as defined by Dorr, Gair, Pomerene, and Rynearson (1957) and the upper part of the Tamanduá Group as defined by Simmons and Maxwell (1961) are apparently correlative in age.

According to this interpretation, Cambotas Quartzite and the quartzite of Maquiné age along both limbs of the Gandarela syncline were either removed by erosion or not deposited. The thickness of the Cambotas Quartzite in the mapped area indicates a rapid eastward thickening in the Serra do Caraça on the south and along the eastern part of the Serra Geral on the north. Thus, it does not seem reasonable to assume that these thick clastic units are absent from the stratigraphic column along the eastern part of the southeast limb of the Gandarela syncline and along the eastern part of the northwest limb of the Capivara syncline because of nondeposition or erosion.

An alternate interpretation of the structural development of the Precambrian rocks of the mapped area is shown in section 2. It is based on the assumption that the discordant contact between the basal formations of the

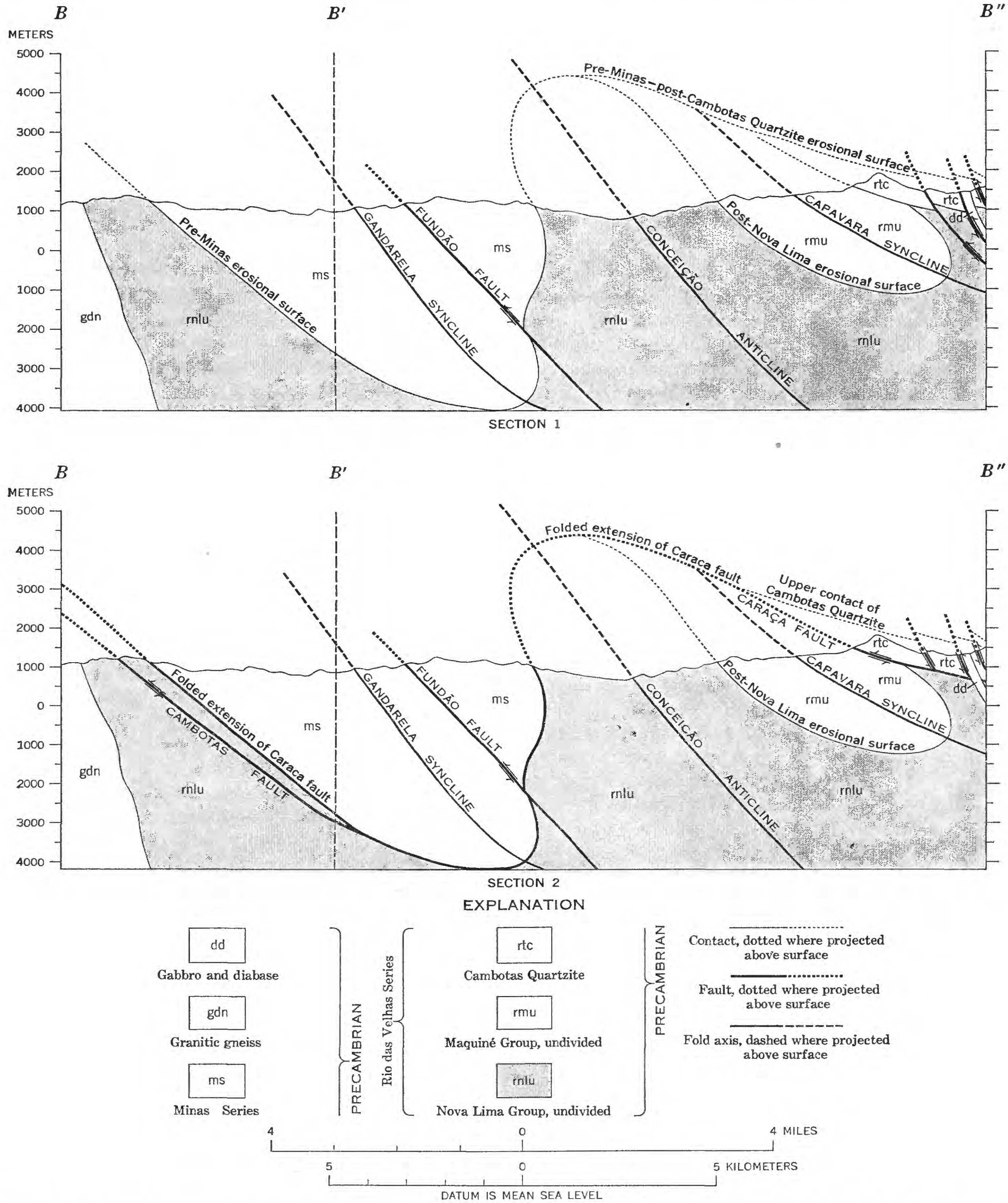

FIGURE 3.—Inferred structural development in the Gongo Sôco and Conceição do Rio Acima quadrangles, Minas Gerais, Brazil. Section 1—Inferred relationships of folded unconformable contacts to folds after post-Minas deformation. Section 2—Inferred relationships of folded thrust-fault contacts to folds after post-Minas deformation. Section based on section *B–B′–B″*, plate 4.

Minas Series and the schist of Nova Lima age, and the Caraça and Cambotas thrust faults are all segments of a regional thrust fault that developed during the early stages of the post-Minas orogeny and was folded during the later stages of the same orogeny.

This projection assumes that a fault developed along an initial break in the schists of the Nova Lima Group, ascended abruptly through the more competent clastic units between the Minas and Nova Lima rocks, and then followed along the less competent beds of the basal formations of the Minas Series. Evidence supporting this interpretation can be seen along the west, northwest, and north escarpments of the Serra do Caraça, where the Caraça fault ascends westward through the overriding Cambotas Quartzite and the overridden quartzite of the Maquiné Group. A similar relationship can be seen along the eastern part of the Serra Geral, where the Cambotas fault descends eastward through the overridden Cambotas Quartzite. Throughout the central, eastern, and western parts of the mapped area the fault followed along the basal beds of the Minas rocks. Although the schists of Nova Lima age and the overlying basal rock of the Minas Series dip and strike nearly parallel to each other and to the contact that separates them, the basal beds of the Minas rocks and the schist of the Nova Lima Group are both obliquely truncated by this discordant contact. This indicates that the contact between the basal formations of the Minas Series and the schist of the Nova Lima Group is a fault. Similar relationships can be seen along the Caraça fault in the Serra do Caraça, where the overriding beds of Cambotas Quartzite are also obliquely truncated by the Caraça fault.

In the Serra do Caraça the Cambotas Quartzite of the upper plate of the Caraça fault is broken by a series of north-trending east-dipping high-angle thrust faults, and the blocks of quartzite are sliced one over the other from east to west, which suggests that the initial displacement of the thrust was toward the west in the southern part of the mapped area. The abrupt warping of the south end of the quartzite of the Cambotas homocline also suggests an initial east-to-west movement along the Cambotas thrust fault in the central part of the area. The forward movement of the thrust apparently was followed by folding of all the Precambrian rocks into three northeast-trending folds overturned to the northwest.

The fault zone in places where quartzite has overridden quartzite consists locally of breccia zones, but in most places it consists of granular quartzite and mica. Along the Gandarela syncline where the basal phyllite and iron-formation of the Minas Series have overridden schist of Nova Lima age, the fault zone is an inconspicuous zone containing little gouge; in most places it is a clean cut surface separating the Minas iron-formation and phyllite from the underlying schist of the Nova Lima Group. Along the southwestern part of the southeast limb of the Gandarela syncline, where the quartzite of the Moeda Formation has overridden schist of the Nova Lima Group, the quartzite is extensively sheared, and the overridden schists are deformed and crumpled. A reverse, but similar, relationship can be seen along the north limb of the Gandarela syncline near the Camará gold mine, where Minas iron-formation has overridden quartz schist of Nova Lima age. Here the overriding iron-formation is deformed and crumpled, and the overridden schists are sheared and torn by numerous tear fractures.

Along the north, northwest, and west escarpments of the Serra do Caraça, the overriding Cambotas Quartzite apparently dragged the quartzite of the Maquiné Group into an asymmetrical syncline overturned to the northwest, and the thrust sheet was emplaced by the forward movement of the upper plate and shortening of the lower plate by folding. Gair (1962, p. 50) suggested that a large syncline of quartzite of Maquiné age in the Nova Lima and Rio Acima quadrangles formed prior to the deposition of the Minas Series. Although it is possible that the Capivara syncline was folded in pre-Minas time, regional trends of the iron-formation and schist of Nova Lima age in the Conceição anticline generally parallel the axial zones of the Capivara syncline and the Gandarela syncline in Minas rocks, suggesting that all three folds were formed during a single period of post-Minas deformation.

IRON DEPOSITS

Iron ore is the most important mineral resource of the area and includes high-grade hard and soft hematite ore, intermediate-grade surficial canga ore, and itabirite.

Hard hematite ore contains about 66–69 percent iron. It is low in silica, phosphorus, and sulfur and is widely used as charge ore for the local open-hearth furnaces, but none has been mined for export.

Canga is the principal ore of intermediate grade and contains about 50–60 percent iron. Although canga has a fairly low and variable iron content and a fairly high phosphorus content (0.12–0.18 percent), it is widely used in the local charcoal blast furnaces because it is light in weight and porous and is therefore easily smelted.

Iron content of itabirite varies widely, ranging from about 25 to 50 percent and averaging about 40 percent. The deeply weathered itabirite is soft and friable in most places. It can be easily mined, is amenable to concentration, and is a source of very large tonnages of material that can be concentrated to a 65–67 percent iron product. Itabirite is enriched beneath the widespread layer of canga, in most places, to as much as 55 percent iron and is locally mined along with the canga ore.

HIGH-GRADE HARD HEMATITE ORE

High-grade hard hematite ore occurs as irregular replacement bodies in the itabirite and dolomite of the Itabira Group. Hard hematite ore occurs in the Cauê Itabirite at the Pião prospect and at the Santo Antônio mine near the west boundary of the Conceição do Rio Acima quadrangle (pl. 3). It occurs in dolomite of the Gandarela Formation in the Cabeça de Ferro mine near the east boundary of the Gongo Sôco quadrangle (pl. 2).

The hard hematite ores are composed dominantly of very fine grained specularite with only very minor amounts of gangue minerals, which include quartz, talc, and chrysotile. Hard hematite ore in the Cauê Itabirite contains only a few widely spaced tiny blebs of quartz that are visible on weathered surfaces. Otherwise the ore appears to be pure hematite. Gangue minerals are more abundant in the replacement bodies of hard hematite in the dolomite of the Gandarela Formation and occur as layers and lenses of talc and chrysotile.

Harder and Chamberlin (1915, p. 395) suggested that the high-grade hematite ore bodies were deposited as iron-rich layers in the itabirite. Dorr, Guild, and Barbosa (1952, p. 295) observed that hard hematite ore, in many places, crosscuts the laminations of the itabirite, and they presented evidence that the high-grade hematite ores were formed by metasomatic replacement of quartz and carbonate of the itabirite by iron-bearing fluids. Guild (1957, p. 55) suggested that brecciated zones in the itabirite in the Congonhas district acted as channels for iron-bearing fluids that replaced the quartz and carbonate with hematite. Dorr and Barbosa (1963, p. 73) believed that the high-grade hematite ore bodies in the Itabira district were localized along the axial zones of folds because of the relatively lower pressure and attendant relatively higher porosity there; these conditions facilitated the flow of iron-bearing fluids that replaced the quartz of the itabirite.

Hard hematite ore bodies in the mapped area crosscut the lamination of the itabirite and dolomite of the Itabira Group and formed either during or after the deformation and metamorphism of the Precambrian rocks of the region by post-Minas orogeny.

The hard hematite ore body exposed in the Cabeça de Ferro mine is in the axial zone of an anticline superimposed on the north limb of the Gandarela syncline. Although this anticline is isoclinal at the east boundary of the quadrangle, it becomes open about 1,000 meters west of the mine area and then becomes parallel to the regional dip and strike of rocks in the north limb of the Gandarela syncline. This westward structural transition from an isoclinal anticline through an open anticline to a regional trend is accompanied by westward diminishing of the replacement of the dolomite by hematite in the core of the anticline. This relationship suggests that folding was the primary control for the emplacement of the hard hematite ore body exposed in the Cabeça de Ferro iron mine.

The hard and soft hematite ores at the Pião prospect are in the lower part of the Cauê Itabirite. Both retain the original laminations of the itabirite, which dip and strike nearly parallel to the enclosing hard siliceous itabirite (fig. 4). The contact between the hard hematite ore and the hard itabirite is variable, ranging from sharp to a gradational zone as much as 4 meters wide. Individual laminae of the hard itabirite grade through a narrow zone of enriched itabirite into hard high-grade hematite ore with no apparent volume change. The contact between the softened platy hematite ore and the hard itabirite is concealed, but in a few places the soft ore crops out with ledges of hard hematite, and it is apparent that the contact between the soft ore and the itabirite is either sharp or gradational over a few meters.

The crosscutting nature of the hard and soft hematite ores and the presence of the well-preserved laminae in the high-grade hard and soft ores indicate that the ores formed by metasomatic replacement of itabirite by iron-bearing fluids. The source of the iron apparently is the enclosing itabirites, which are poorly laminated, unusually low in iron (25–30 percent), and very hard. The hard itabirite enclosing the ore forms hogbacks extending southwest and northeast from the ore body for more than 1,000 meters. The itabirite was apparently indurated by through-going fluids that mobilized the iron and concurrently deposited silica that was later replaced by hematite in the ore body.

The hard and soft ores of the Pião prospect lie within an area of regular laminations in the itabirite and hard hematite, and there is no obvious structural control for the localization of ore.

PIÃO PROSPECT

The Pião prospect is at the west boundary of the Conceição do Rio Acima quadrangle (N. 4,700, E. 100, pl. 3) approximately 2 kilometers southwest of the Fazenda da Mutuca in the Gandarela quadrangle. The prospect is accessible by a road that leads southeastward from the village of Rio Acima through the village of Gandarela to the Fazenda da Mutuca. From the fazenda a trail leads southeastward to the Pião prospect.

The Pião ore body consists of a prominent tor of hard hematite on the northwest slopes of a small valley. It is flanked on the northwest by a ridge of Cauê Itabirite and on the southeast by a ridge of phyllite and quartzite of the Cacaça Group (fig. 4). The tor of hard hematite extends above the general slope of the valley to a height of about 70 meters; it averages about 200 meters across at the base and about 30 meters across at the top. About 2 million tons of high-grade hard hematite is exposed above the level of the valley slope. The computation of reserves is based on the volume of a cone 70 meters high and 200 meters in diameter and an assumed 4 metric tons of ore per cubic meter. Projected ore reserves below the present erosional surface are 80,000 tons of high-grade hard hematite per meter of depth. At the time of mapping no ore had been mined from the Pião ore body.

The Pião ore body is stratigraphically within the lower 200 meters of the Cauê Itabirite. The ore consists of a crude U-shaped body of high-grade hard hematite bounded on the east, north, and west by high-grade platy, partly softened hematite and soft powdery hematite, and on the south by hard siliceous itabirite. The hard hematite grades over a few meters into the platy hematite, which apparently is partially disaggregated by weathering. The hard and soft hematite and the disaggregated platy hematite grade laterally over a few meters through partially enriched itabirite into poorly laminated iron-poor (25–30 percent iron) hard itabirite.

The hard hematite consists of very fine grained specularite with only a few blebs and druses of quartz deposited in small vugs that form along the relic laminae preserved in the ore. These vugs are sparsely distributed and are about 0.5–1.0 mm wide and about 3–6 mm long. Laminations of the replaced itabirite are well preserved as relic textures in hard hematite. The relic laminations are regular, trend N. 60° E., and dip steeply to the southeast or northwest. The hard hematite is cut by anastomosing linear shatter zones in which fragments have

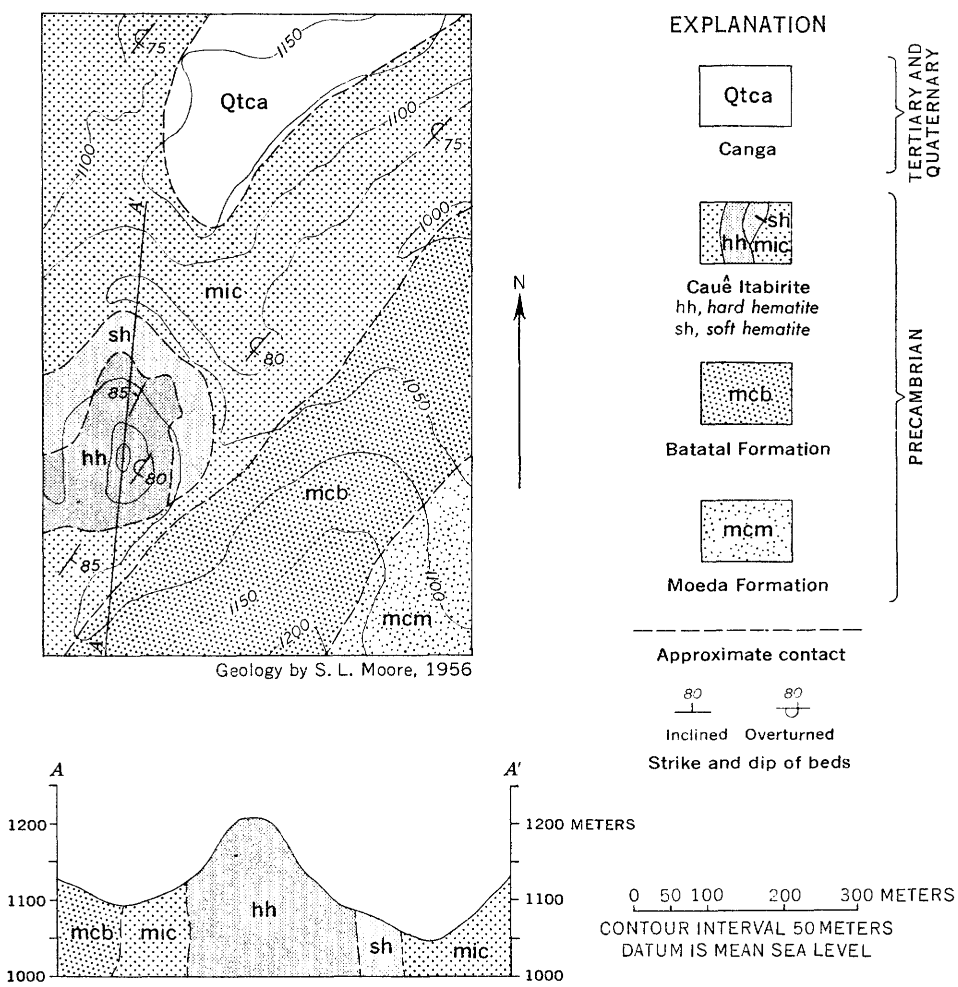

FIGURE 4.—Geologic map and section of the Pião prospect, Conceição do Rio Acima quadrangle.

been only slightly rotated. The fragments range from about 1 to 20 cm across and are poorly cemented with hematite, limonite, and minor amounts of quartz and manganese oxide. The fractures in the shattered zone fade out laterally into massive hard hematite over a zone of about 10–20 cm. A few joints cut the massive hard hematite and trend N. 40°–45° W. and have a near vertical dip.

The hard hematite of the Pião ore body is bounded on the east, north, and west by an irregular mass of high-grade soft powdery hematite and by partly softened and disaggregated hard hematite consisting of a well-laminated mass of hematite plates. Both types of ore are apparently derived from the weathering of the hard hematite ores. They grade laterally over a few meters into one another and into the hard hematite of the ore body. On the east side of the central mass of hard hematite, excellent exposures of partly weathered hard hematite crop out as a partly disaggregated mass of platy hematite. The plates of hematite are separated by thin laminae of finely divided flakes of specular hematite that formed as the result of weathering parallel to the relic laminations of the metasomatically replaced itabirite.

The soft hematite ore is mostly covered by soil and talus; however, recent erosion has exposed irregular areas along the base of the hard hematite. The soft ore is characteristically a bluish-gray noncoherent mass of finely divided plates of hematite containing some fragments of hard hematite.

A chip sample taken from the base of the tor of hard hematite at 2-meter intervals assayed 69.6 percent iron, 0.03 percent phosphorus, and traces of manganese, sulfur, and SiO_2.

CABEÇA DE FERRO MINE

The Cabeça de Ferro mine includes three open pits and several smaller pits and prospect pits in hard and soft hematite near the east boundary of the Gongo Sôco quadrangle (N. 8,000, E. 13,000, pl. 2); other open pits in hard hematite are located in the Santa Bárbara quadrangle, which joins the Gongo Sôco quadrangle on the east. Only the deposits in the Gongo Sôco quadrangle are described. The mine workings are accessible by a road leading west from the town of Barão de Cocais in the Santa Bárbara quadrangle.

Iron and manganiferous iron ore have been mined intermittently from the Cabeça de Ferro mine for more than 20 years by the Companhia Brasileira de Usinas Metalurgicas of Barão de Cocais. Although ferruginous manganese ore has been extracted from some parts of the mine, the ore is principally hard and soft high-grade hematite. The ore is screened, and the lump ore is used for charging open-hearth furnaces.

No complete record of the ore mined was available to the writer, but the size of the three major open pits indicates that several tens of thousands of tons of hard hematite ore has been mined. The hard and soft hematite ore is exposed in an area approximately 200 meters long and 200 meters wide; the projected reserves of ore containing more than 65 percent iron are about 150,000 metric tons of hard and soft hematite ore per meter of depth. The grade of ore is variable, however, because of incomplete replacement of phyllite and talc layers in the dolomite and varying amounts of vein chrysotile in faults and joint planes.

The hematite ore exposed in the Cabeça de Ferro mine is a replacement of dolomite of the Gandarela Formation in the core of an east-plunging isoclinal anticline overturned to the north. Bedding-plane features of the dolomite are preserved in hard and soft hematite ores in the form of talc laminae, phyllite partings, and fibrous chrysotile parallel to laminae in hematite, and by vugs that parallel the relic laminae of the hematite ore. The bedding in the core of the anticline trends N. 59° W. to N. 70° E. and dips 20°–45° SSE. The ore body is flanked on the north by an east-plunging isoclinal syncline of ferruginous quartzite, and on the southeast by ferruginous quartzite, both of the Cercadinho Formation. The ore body is localized mostly on the axis and the north limb of the anticline. This isoclinal anticline and the isoclinal syncline both were traced east from the mapped area for more than 4 kilometers in the Santa Bárbara quadrangle by Simmons (1968). Westward from the mine area the isoclinal anticline rapidly becomes asymmetrical in form, then flares into an open fold, and then becomes part of the north limb of the Gandarela syncline about 1,500 meters west-southwest of the mine area. This westward structural transition from an isoclinal anticline to an open anticline is accompanied by a decrease in the grade of ore, which suggests that only the more tightly folded part of the dolomite in the anticline was metasomatically replaced.

The ore of the Cabeça de Ferro mine consists of alternating layers of hard and soft hematite, a few interbeds of phyllite, and talc partings. The hard hematite retains the original bedding laminae of the dolomite, and numerous small lenticular vugs 1–5 mm in length parallel the relic laminae in the hard hematite. Soft hematite layers consist of irregular partings of finely divided flakes of specularite and separate layers of hard hematite. A few partings of dark-gray ferruginous phyllite and laminae of light-gray talc and white chrysotile are interlayered with the hard and soft hematite. The hematite ore along the crest of the fold is broken by numerous northeast-trending southeast-dipping joints and minor faults, and some of these joints and faults are filled with an opalescent fibrous chrysotile alined at right angles to the fractures. Chrysotile also occurs as partings in the ore. The fibers are alined parallel to the bedding plane and form herringbone patterns.

Analyses of eight channel samples cut vertically from the faces of pits 1, 2, and 3 of the Cabeça de Ferro mine are shown in table 3.

SANTO ANTÔNIO MINE

The Santo Antônio mine is at N. 6,080, E. 1,250 (pl. 3), in the Conceição do Rio Acima quadrangle on the east slopes of the Córrego da Gandarela valley. The mine can be reached by trails leading southeastward from the Fazenda da Mutuca along the Córrego da Gandarela. The deposit was prospected by J. Morgan da Costa of the village of Rio Acima, and about 500 tons of high-grade hard hematite ore was transported to the Fazenda da Mutuca by mules and thence to Rio Acima by truck.

The mine consists of two open pits cut into two 5-meter-thick layers of hard hematite. The hard hematite layers are interbedded with soft siliceous itabirite and are bedding replacements in itabirite. The exposed length of the layers of hard hematite is about 50 meters. There are no surface exposures beyond the ore laid open by the open pits, and the true horizontal extent of the ore body apparently is about 50 meters.

The hard hematite layers are interlayered with laminae of soft, powdery, finely divided flakes of specular hematite. The hard hematite ore is broken by numerous fractures into rhombic fragments that are about 2 cm across or more. The original itabirite laminae are well preserved in the hard hematite layers.

Analyses of two channel samples cut across both layers of hematite show an average of 69.7 percent iron, 0.4 percent SiO_2, 0.20 percent manganese, 0.02 percent phosphorus, and traces of Al_2O_3.

HIGH-GRADE SOFT HEMATITE ORE

High-grade soft hematite ore occurs around the west, north, and east flanks of the Pião ore body, and as replacement layers in the Cauê Itabirite intercalated with high-grade hard hematite and itabirite. Soft ore in most places contains various amounts of hard hematite and grades through platy or schistose partly coherent hematite ore into hard hematite. The intercalated layers of soft ore generally parallel the bedding and foliation, but in places they crosscut the bedding and foliation and occur as irregular bodies enclosed by itabirite.

The soft hematite ore was derived from the hard hematite ore by supergene leaching of hematite along grain boundaries, which produced either platy partly coherent hematite or soft micaceous hematite ore.

Soft platy hematite layers are common in the Cauê Itabirite in an area about 3 kilometers long extending from the Gongo Sôco iron mine west to the western part of the Gongo Sôco gold mine area. At many places along this belt of itabirite, surface exposures contain numerous lenses and layers of soft hematite ore intercalated with some hard hematite layers, and poorly laminated itabirite. These replacement layers of soft ore and some hard layers occur in itabirite that has been highly deformed by drag folds and broken by closely spaced shear planes. The itabirite between the layers of soft ore is poorly laminated because the carbonate and quartz of the light-colored laminae have been partly replaced by hematite and the laminae, thus, obscured.

Most of the intercalated lenses and layers of soft and hard hematite occur in dolomitic iron-formation in the middle and upper parts of the Cauê Itabirite. According to Henwood (1871), the itabirite and the soft hematite layers contain pockets of metallic gold, and the itabirite apparently contains small amounts of fine gold. The richer pockets of gold occur in "jacutinga" [2] along drag folds. The surface exposures of soft hematite layers occur in zones of highly deformed itabirite; apparently soft and hard layers of hematite replaced the itabirite in areas that were highly deformed.

The source of the iron for the soft and hard iron-ore replacement layers near the Camará and Gongo Sôco gold mines may have been through-going iron-bearing fluids that dissolved iron from the adjacent itabirite, or the iron could have been precipitated from

[2] See discussion of the term "jacutinga" on page I 45.

TABLE 3.—*Analyses (in percent) of hard hematite ore from the Cabeça de Ferro mine*

[Analyst; Dr. Cassio Pinto, Departmento Nacional da Produção Mineral, Belo Horizonte]

	1	1a	1b	2	2b	2c	2d	4	4b
Fe	68.5	68.4	68.5	68.4	68.5	68.0	68.4	68.1	67.3
SiO_2	.9	1.0	.8	1.3	1.0	1.4	1.4	1.8	1.6
Al_2O_3	.5	.5	.6	.5	.5	.5	.5	.5	.6
Mn	.4	.5	.5	.5	.5	.6	.2	.3	.4
P	.02	.02	.02	.02	.02	.02	.02	.02	.02

1, 1a, 1b. Channel samples taken from open pit 1.
2, 2b, 2c, 2d. Channel samples taken from open pit 2.
, 4b. Channel samples taken from open pit 3.

hydrothermal fluids emanating from the granitic gneiss of the Caeté Complex.

The soft hematite ores of the Gongo Sôco mine could be cheaply mined, the hard hematite fraction used for charge ore in open-hearth furnaces, and the soft ore used as sintering ore for charging charcoal blast furnaces. It also may be possible to recover the disseminated metallic gold in the ore.

ITABIRITE

Soft siliceous itabirite and hard dolomitic and siliceous itabirite are exposed in the mapped area. However, most of the itabirite along the crest and slopes of the Serras Geral and da Pedra Formosa and beneath the widespread canga field is soft noncoherent siliceous itabirite.

The soft itabirite could be easily mined by open-pit methods without drilling, blasting, or crushing because it is deeply weathered in most places to a noncoherent mass of granular quartz and hematite that can be easily concentrated to a product of more than 65 percent iron (Dorr and Barbosa, 1963, p. 54). The soft itabirite contains about 35–45 percent iron, and the hard dolomitic and siliceous itabirites contain about 25–35 percent iron. At present the soft itabirite is a source of vast tonnages of concentrating material and constitutes a valuable reserve of hematite for future use.

Most geologists who have worked in the Quadrilátero Ferrífero generally agree that the soft siliceous itabirites have been disaggregated by ground waters. There is some question, however, regarding the chemical nature of the ground water, how it disaggregates the itabirite, and the mineralogic composition of the original unaltered itabirite.

Guild (1957, p. 45) and Pomerene (1964, p. 44) believed that soft siliceous itabirite once contained small amounts of carbonate that was easily dissolved, along with some silica, by meteoric water; and as the meteoric water became more alkaline, it further increased its ability to dissolve silica along the boundaries of the quartz grains and thus disaggregated the itabirite. Dorr and Barbosa (1963, p. 26–27), however, believed that most of the soft itabirite of the Itabira region was once siliceous itabirite that was disaggregated because of its physiographic position, textures, and duration of exposure to surface weathering. They believed that the hard siliceous itabirite in the deeply incised canyon in the Itabira area has retained essentially the original crystalline texture of itabirite after it was metamorphosed during the post-Minas orogeny.

Although both hard dolomitic and siliceous itabirite crop out locally, most of the itabirite of the mapped area has been weathered to partly coherent granular quartz and hematite.

Excellent exposures of hard siliceous itabirite crop out along the crest of the Serra da Pedra Formosa near the west boundary of the mapped area. These hard siliceous itabirites enclose, and extend outward from, the high-grade hard and soft hematite of the Pião ore body. The hematite and the quartz of the hard itabirite are poorly segregated, the laminae are indistinct, and the itabirite contains relatively little iron (25–30 percent). The writer believes that these extensive exposures of hard siliceous itabirite near the Pião ore body are resistant to weathering because they have been altered by through-going fluids that mobilized part of their iron content and concurrently precipitated silica which changed original crystalline textures.

Exposures of hard dolomitic itabirite crop out locally as small ledges at many levels in the upper and middle parts of the Cauê Itabirite along both limbs of the Gandarela syncline. Hard dolomitic itabirite is present along the base of a canyon cut through the Serra da Pedra Formosa by the Córrego da Gandarela. The hard dolomitic itabirite can be traced upward along near-vertical laminations from the base of the canyon into softened siliceous itabirite that forms the upper walls of the canyon and the crest of the serra. The relationship of the hard dolomitic itabirite to the present erosional surface and the numerous isolated exposures of hard dolomitic itabirite in the middle and upper parts of the Cauê Itabirite suggest that much of the itabirite of the mapped area contained carbonate.

The writer believes that presence of carbonate in the itabirite and physiographic position are the major factors in softening of the itabirite. Siliceous itabirite may also disaggregate through the leaching of silica, as does the dolomitic itabirite, but carbonate-bearing itabirite apparently is more easily disaggregated by meteoric waters because the carbonate is easily dissolved, partly disaggregating the itabirite, and the alkaline waters continue to dissolve silica at an accelerated rate, completely disaggregating the itabirite.

Many small exposures of hard dolomitic and siliceous itabirite are either enclosed by or intercalated with soft siliceous itabirite; thus, for these small exposures physiographic position and the absence or presence of carbonate apparently have not been factors in weathering of the itabirite. In many places the hard itabirite is not near ore bodies or in zones of structural compression. It apparently remains hard because of differences in the crystallization of the chert, carbonate, and iron minerals during the post-Minas orogeny. Where hard siliceous itabirite encloses or occurs near hard and soft hematite ore bodies, as at the Pião prospect, the original crystal textures of the itabirite probably were changed by through-going fluids that deposited the replacement hematite.

CANGA

Ore-grade canga in these quadrangles has been mined only from common canga made up mostly of fragments of itabirite and a few fragments of hard hematite and schist. Chemical cangas are of ore grade, but most are covered by soil and are hard and heavy; they are therefore not suitable for use in the charcoal furnaces. Canga that forms in place is generally low grade, occurs only in small areas, and is not suitable for use in the local furnaces.

Common canga often has a higher iron content than the itabirite from which it is derived because of both natural mechanical concentration and chemical enrichment. The weathered and softened itabirite fragments are partly disaggregated during transport by water or by downslope migration, and some of the quartz and carbonate granules are separated from the itabirite fragments, upgrading the iron content of the fragments. In places where high-grade hard hematite fragments are deposited along with itabirite fragments, the iron content of the detritus is further increased. The itabirite and hard hematite fragments are then cemented by limonite precipitated from iron-bearing meteoric waters.

Although the thickness of the canga sheet ranges from about 1 to 10 meters and average about 1.5 meters, all the canga mines in the mapped area, which include the Gongo Sôco, Barra Mansa, Cabral, Trindade, and Ponte da Paixão, are developed on a 1- to 3-meter-thick layer of common canga overlying Cauê Itabirite. The iron content of the canga ranges from about 55 to 60 percent; however, at all the mines, about 1–2 meters of the underlying enriched Cauê Itabirite is removed along with the canga layer. The enriched itabirite is somewhat lower in grade than the canga and contains about 50–55 percent iron.

The depth of enrichment of the itabirite beneath the canga is quite variable in the mine workings; it ranges from about 0.5 to 3 meters and averages perhaps 1.5 meters. Some of the quartz and most of the carbonate have been leached by downward circulation of meteoric water, and limonite has been precipitated so that the itabirite beneath the porous layer of canga is enriched.

The common canga and the underlying enriched itabirite have been mined by hand methods in most of the mines. Blocks of the canga layer are spalled off with hand tools from an undercut ledge and broken into smaller pieces with sledge hammers; the canga fragments and the itabirite fragments are then screened through a 1-cm screen, and only the coarser fractions are sent to the charcoal blast furnaces.

The composition, origin, and methods of mining of the canga ores make it difficult to generalize the average grade and physical characteristics of the ore. However, the average composition of 142,908 tons of canga shipped from the Cabral mine to the steel plant of the Companhia Siderurgica Belgo-Mineira from 1947 to 1952 was 58.25 percent iron, 7.31 percent SiO_2, 1.71 percent Al_2O_3, 0.16 percent phosphorus, and 0.47 percent manganese. Canga contains varying amounts of iron and has a high phosphorus content, but it is widely used as charge ore in the local charcoal smelters because, owing to its light weight, it will not crush the charcoal.

Canga covers an area of approximately 22 square kilometers within the mapped area. Total reserves, assuming a 1-meter thickness and three tons of ore per cubic meter, are about 66 million tons of material ranging from about 50 to 60 percent iron. Large areas within the canga sheet are unsuitable for use as ore, however, because canga grades laterally into lateritic soils and itabirite. On the other hand, many areas in the canga field are more than 1 meter thick. Also, in most areas beneath the canga there is a 1- to 3-meter layer of enriched itabirite that can be mined along with the canga ore and which would increase the total tonnage of ore between 55 and 60 percent iron that could ultimately be mined.

Because of the irregular thickness and extent of the canga layer and the unmarked boundary lines of the mines, reserves have not been estimated for the mines discussed below.

GONGO SÔCO MINE

The Gongo Sôco iron mine (pl. 2) is about 1 kilometer north of the village of Venda Velha. The mine workings are bisected by the Central do Brasil railroad, which leads east from Belo Horizonte to Nova Era. The area is also accessible by a road that leads south from the Caeté-Barão de Cocais road. Canga and enriched itabirite have been mined from this area since 1937 by Companhia Ferro Brasileira for reduction in the Caeté smelter. The grade of ore shipped and the total production of this mine from 1937 to October 1956 are shown in tables 4 and 5.

The mine has been developed along a random series of benches over an irregular area 500 meters long by 400 meters wide, on both sides of the Central do Brasil railroad. The benches are cut to the base of the enriched zone in the underlying itabirite. The height and width of the bench face are correspondingly greater where the depth of enrichment is greater.

TABLE 4.—*Analyses (in percent) of canga ore and enriched itabirite ore from the Gongo Sôco mine*

[Analyses represent bulk samples taken from the ore storage bins of the Companhia Ferro Brasileira smelter at Caeté, Minas Gerais, 1956. Analyst unknown]

Date	Fe	SiO_2	Mn	Al_2O_3	H_2O	Loss on ignition
April 4	61.90	5.2	0.30	0.30	4.0	2.8
June 13	55.17	15.6	.16	1.11	13.0	2.7
25	55.70	11.5	.14	1.30	9.0	4.7
30	58.20	8.9	.17	1.10	6.5	4.5
July 6	57.10	11.0	.10	1.00	8.0	4.5
20	58.20	10.2	.14	1.30	6.0	2.8
26	53.80	16.3	.15	1.30	6.5	3.7
Aug. 2	56.20	12.3	.14	1.40	8.0	3.3
9	57.60	9.9	.12	1.10	7.0	4.4
16	59.10	8.0	.14	1.30	6.0	4.5
23	58.80	9.2	.16	1.70	7.0	2.8
30	58.80	7.0	.16	1.30	5.0	5.8
Sept. 6	59.30	8.3	.10	1.00	4.0	3.7
9	58.80	8.7	.18	1.30	4.5	3.6
20	59.30	7.3	.12	1.40	5.0	4.3
27	57.80	9.5	.20	1.10	4.0	4.5
Oct. 10	59.10	8.4	.16	1.30	3.5	4.5
11	60.60	7.8	.10	1.20	4.5	2.6
25	59.30	7.0	.25	1.20	4.0	4.8
Nov. 3	60.10	7.2	.20	1.40	6.0	4.0
11	57.09	10.8	.10	1.10	6.0	3.9
Average	58.05	9.35	0.12	1.22	5.5	3.9

TABLE 5.—*Annual production from the Gongo Sôco iron mine*

[Records of the Companhia Ferro Brasileira, Caeté]

Year	*Metric tons*	*Year*	*Metric tons*
1937 [1]	956	1948	45,324
1938	13,896	1949	32,615
1939	29,445	1950	8,179
1940	43,880	1951	9,108
1941	52,213	1952	11,636
1942	52,128	1953	15,771
1943	57,183	1954	25,765
1944	72,207	1955	21,626
1945	55,619	1956 [2]	19,216
1946	50,004	Total	669,863
1947	53,091		

[1] December only.
[2] January–October.

BARRA MANSA MINE

The Barra Mansa mine is about 1,500 meters east of the Gongo Sôco iron mine at N. 6,900, E. 8,600 (pl. 2). The mine is worked as a series of benches cut into the south slope of the Serra Geral in an area 500 meters long and about 100 meters wide. Production at the time of mapping (1957) was about 20 tons per day. The ore, composed of canga and enriched itabirite, is shipped to the Barra Mansa smelter in the State of Rio de Janeiro.

CABRAL MINE

The Cabral mine (Mina do Cabral) is north of the Central do Brasil railroad at the small village of Henrique Fleuisse, near N. 7,350, E. 9,700 (pl. 2). The mine area is on the south slopes of the Serra Geral and can be reached by a road leading south from the main road leading east from Belo Horizonte through Sabará and Caeté to Barão de Cocais. The mine was opened in 1935 by the Companhia Siderurgica Belgo-Mineira. Production of canga and enriched itabirite ores began in 1947 and continued until 1953, when mining was temporarily suspended. The grade and tonnage of ore extracted from the Cabral mine are given in table 6.

The mine was worked as a series of benches cut into the south slopes of the Serra Geral. The benches have exploited an area of canga about 600 meters long and 125 meters wide.

TABLE 6.—*Tonnage and analyses (in percent) of canga and enriched itabirite ore from the Cabral mine*

[Tonnage figures and analyses were recorded by the Companhia Siderurgica Belgo-Mineira]

Year	Metric tons shipped	Number of samples analyzed	Fe	SiO_2	P	Mn	Al_2O_3	Loss on ignition
1947	59,798	11	59.23	6.50	0.16	0.31	1.51	6.20
1948	31,890	12	59.78	6.06	.16	.20	1.46	6.06
1949	20,800	12	58.40	9.10	.12	.14	1.53	9.10
1950	9,300	8	56.25	9.11	.17	.60	2.00	6.38
1951	10,920	6	58.05	6.67	.17	.77	1.90	6.65
1952	10,200	11	57.76	6.44	.18	.79	1.85	6.44
1953	6,330							
Average			58.25	7.31	.16	.47	1.71	6.80
Total	149,238							

MINA DA TRINDADE

The Mina da Trindade is near N. 7,700, E. 11,000 (pl. 2). The mine is on the south slopes of the Serra Geral, north of the Central do Brasil railroad. It was operated by the Companhia Siderurgica Belgo-Mineira in 1952 and 1953, and approximately 80,000 tons of canga and enriched itabirite was mined. Company records show that monthly samples of the ore from the storage bins averaged 57.83 percent iron, 8.29 percent SiO_2, 1.78 percent Al_2O_3, and 0.14 percent phosphorous.

The mine area is 350 meters long and 150 meters wide. The ore, composed of surficial layers of canga overlying a thin layer of enriched itabirite, is similar to the ores exposed in the other mines along the south slopes of the Serra Geral.

FURA ÔLHO MINE

The Fura Ôlho mine is at N. 5,900, E. 12,850 (pl. 2). It was worked as a series of low benches cut into a canga capping. No production figures are available. The canga overlies itabirite, and the ore is composed of canga made up of fragments of itabirite and some fragments of hard hematite cemented with hydrous iron oxides.

PONTE DA PAIXÃO MINE

The Ponte da Paixão mine is in the eastern part of the Gongo Sôco quadrangle at N. 5,250, E. 12,000 (pl. 2).

The mine can be reached by a road leading southwest from Barão de Cocais to the Rio Conceição valley. The mine is operated by the Companhia Brasileira da Usinas Metalurgicas. Production started in June 1956, and at the time of this survey (1957), 6,000 tons of ore averaging 55.3 percent iron had been mined. The mine is opened by three benches cut into the north east slopes of Alto Fernandez.

The canga layer, 1–2 meters thick, is composed of ore ranging from poorly cemented chips of enriched itabirite and some hard hematite fragments to porous honeycombed canga.

OTHER MINERAL RESOURCES

In addition to iron, mineral resources of the mapped area include gold, manganese, dolomite, and bauxite. Iron, manganese, and dolomite have been mined for more than 20 years for use in the local iron smelters. Gold was mined from placer and lode deposits during the latter part of the 18th century and the early part of the 19th century by the Portuguese and British settlers. Aluminous lateritic soils in the Lagôa Grande Plateau have not been mined but are a potential source of low-grade aluminum ore.

GOLD DEPOSITS

Gold was obtained in the mapped area as early as 1599 by the Indians, who used it to barter with early settlers, but it was not until 1695 that gold was discovered in bedrock at the headwaters of the Córrego do Gongo, near N. 5,000, E. 4,000 (pl. 2), in the Gongo Sôco quadrangle (Henwood, 1871, p. 360). From 1695 to the middle of the 18th century, gold placers were mined extensively along the Rio Socorro and the Rio Conceição; the remnants of extensive placer washings can be seen along these major drainages across the mapped area. Records of placer mining operations are not known to the writer, and it is likely that few reports were ever prepared. Records of the earliest underground mining ventures are scant, but according to Burton (1860), in his description of the highlands of Brazil, Coronel Manoel da Camará de Noronha intermittently mined the lode deposits of the Gongo Sôco mine, at the headwaters of the Córrego do Gongo, from about 1800 to 1808. Systematic mining of these lode deposits of the Gongo Sôco gold mine was started in 1826 by Captain Lyon of the Imperial Mining Association, and gold was produced until 1856, when the mine was closed because of depletion of ore.

LUÍS SOARES MINE

The Luís Soares mine, which is now abandoned, is along the north slopes of the Serra Geral (N. 6,000, E. 1,300) in the western part of the Gongo Sôco quadrangle (pl. 2). The mine area can be reached by a road leading south from the village of João Vasconcelos to the Gongo Sôco gold mining area.

Gold ores were mined from the Luís Soares mine during the early part of the 19th century, but there is no record of production. The quartz veins of the mine area were again prospected in 1945 by the Departamento Nacional da Produção Mineral of the Brazilian government. Core drilling along the crest of the Serra Geral intersected an auriferous quartz vein striking N. 85° E. and dipping about 45° S. The vein was explored at two levels by three adits driven into the north slopes of the Serra Geral. Approximately 600 meters of underground workings was completed. The veins and wallrock were too low in gold content to be economically mined, and the prospect was abandoned. At the time of the survey all workings were either collapsed or flooded.

Although the vein prospected in the Luíz Soares mine is poorly exposed at the surface in the mine area, it is exposed in a roadcut about 300 meters west of the old working at N. 5,800, E. 1,200 (pl. 2). The vein strikes west and dips 40°–45° S.; it occurs along the thrust plane of the Cambotas fault. The vein is strongly sheared and contains limonite along the shear planes. Quartz stringers cut the dolomitic phyllite and quartz schist; they also cut dolomitic itabirite in the upper plate and the quartz-chlorite schist of the lower plate.

Informal reports by the Departmento Nacional da Produção Mineral state that the veins consist of milky vein quartz, a few veinlets and clusters of pyrite crystals, sericite, and rare folia of metallic gold.

CAMARÁ MINE

The Camará mine is at N. 5,950, E. 5,250, in the Gongo Sôco quadrangle (pl. 2). The mine was apparently developed during the early part of the 19th century, and the trenches, open pits, and waste dumps are now overgrown by bushes and trees. The mine was prospected by a series of west-trending open pits and trenches that were excavated across and along a sheared discordant contact between overlying itabirite and quartz schist. The contact is exposed over an area 600 meters long on the north slopes of a hill underlain by Cauê Itabirite. The mine was developed by an inclined shaft on the sheared contact that dips 40°–45° S. There is no record of production, but a large waste dump at the western part of the mine area shows that there was considerable underground exploration of the quartz schist and itabirite.

The quartz schist of Nova Lima age beneath the shear zone is cut by numerous tear fractures filled by stringers of milky (bull) quartz. The laminations in the itabirite are deformed by complex drag folds. The itabirite is dragged into the shear zone and obliquely truncated by it. The shear zone is well exposed in the partly collapsed collar of the inclined shaft; it is about 50 cm wide and is made up mostly of granular quartz and itabirite cut by stringers of quartz.

The quartz veins in the surface exposures contain minor amounts of sericite and clusters of hematite crystals, and some of the fractures in the quartz schist contain earthy dark-brown limonite and brownish-black manganese oxide. The rocks of the waste dump are mostly banded brown and white quartz schist cut by narrow quartz veinlets and stringers containing sericite and specular hematite. Henwood (1871, p. 182) described the gold mineralization as follows:

> Quartz and earthy brown iron ore are thinly spotted with gold of the finest quality in many isolated beds which—from a mere line perhaps to three feet wide, and from a few feet to eight or ten fathoms long—occur throughout the formation and accommodate themselves to all its undulations.

Henwood's brief description does not indicate whether the gold occurs in the itabirite above or in the quartz schist below the shear zone that separates them; however, the undulations he described may refer to the drag folds in the itabirite.

GONGO SÔCO (GOLD) MINE

The Gongo Sôco gold mine was abandoned in 1856, and only ruins of the buildings and old mine workings can be seen. The mine area, about 2 kilometers long, is at the base of the Serra Geral in the general vicinity of N. 4,800, E. 4,500 (pl. 2). The mining area can be reached by a road that leads westward from the town of Barão de Cocais along the Rio Socorro valley through the village of Venda Velha.

The Gongo Sôco mine was developed by Coronel Manoel da Camará de Noronha from about 1800 to 1808, when small tonnages of ore were mined from surface and shallow underground workings. At his death the mine was willed to his son Isador, who sold the mine to Capitão Mor Alves da Cunha. Captain Cunha operated the mine intermittently from 1808 to 1824 and then sold it to the British Imperial Mining Association for £70,000 (Burton, 1860).

The Imperial Mining Association started operations in 1826, and the mine was developed by a series of vertical shafts and crosscuts. A surface sketch map of the mine workings and a cross section of the underground workings by Henwood show the mine workings along the base and lower slopes of the Serra Geral in an area approximately 1,500 meters long by about 400 meters wide. According to Henwood (1871, p. 250), "the northern or Gongo Sôco deposits has been laid open by scores of shafts and miles of levels."

The Imperial Mining Association produced gold from 1826 to 1856 but then closed the mine because of the diminishing grade of ore (Henwood, 1871, p. 331). Total production during this period by the Imperial Mining Association was 34,427 pounds of gold. About 23,381 pounds was produced by screening and hand sorting of the coarser nuggets, wires, and folia of metallic gold, and about 11,146 pounds of fine gold was recovered from stamp mills (Henwood, 1871).

According to Henwood (1871) the wallrock of the mine was generally divided into the "Gongo Sôco series" in the northern part of the mine workings and the "Cunha series" in the southern part of the mine area. The grade of the ore in the "Gongo Sôco series" was richer and the ore shoots were more persistent in depth and strike length; most of the production came from rich pockets of metallic gold in the "Gongo Sôco series."

Correlation of Henwood's surface sketch maps of the mine area with the surface (pl. 2) shows the mine area to be traversed by the contact between the dolomite of the Gandarela Formation and the Cauê Itabirite. Henwood's "Cunha series" apparently correlates with lower dolomite beds of the Gandarela Formation and his "Gongo Sôco series" with the dolomitic itabirite in the upper part of the Cauê Itabirite. Apparently most of the richer "jacutinga" ores of the "Gongo Sôco series" came from the gradational contact zone between the dolomite and the dolomitic itabirite in the upper part of the Cauê Itabirite, and the lower grade ores of the "Cunha series" apparently occurred in lower dolomite beds of the Gandarela Formation.

Henwood described a number of structural features that were associated with the richer ore shoots in the "Cunha" and "Gongo Sôco" series. He noted (1871, p. 270–71) that the richer ore shoots in both series occurred in steeply dipping beds, whereas the lower grade ore shoots occurred in shallow or flattened areas of the wallrock. He stated (p. 259): "Near the richer (shoots-bunches) masses of ore, certain strata exhibit broad undulation (fig. 22, *A–A′*)." Henwood's figure 22 and section *A–A′* show asymmetrical folds with numerous small-scale drag folds superimposed on the limbs of the asymmetrical folds.

The gold occurred mostly in lenses of "jacutinga," and Henwood (1871, p. 271) stated: "The richest bodies of jacutinga are seldom more than a few feet in length and depth." He also stated (p. 259): "Wherever hard crystalline, massive iron-glance [hard hematite(?)] touches or approaches the auriferous bands, they cease to be productive." He further noted (p. 341) that both itabirite and "jacutinga" are traversed by cross veins of quartz that seldom exceed a fathom (6 feet) in length or depth and are less than an inch in width.

Henwood's (p. 271–274) description of the gold mineralization in the "Gongo Sôco series" is as follows:

> Near the middle of each bed the matrix, already described, encloses rough (nuggets) lumps, usually but a few ounces, though here and there two or three pounds, in an instance or two of still greater weight. Some of these are isolated; others at unequal intervals are either irregularly clustered, or united by thin laminae and reticulating threads; but all are gold.—Nuggets are common near the centers of aggregation; foliae towards their circumferences. But whilst clusters, such as these, form a striking characteristic, smaller nuggets (prills), flakes, threads and granules, slightly coherent or, more frequently isolated in the surrounding matrix furnish the chief riches of this formation. Grain particles and, sometimes, small nuggets occur in numbers gradually diminishing toward the confines of every bunch; on both sides of large masses however, adjoining strata are for short distances thinly sprinkled with gold.

The term "jacutinga" has been used for describing soft itabirite and soft high-grade hematite ore within the region of the Quadrilátero Ferrífero. It is a local term that has no clear scientific use; however, Henwood apparently used it to describe either partly disaggregated schistose high-grade hematite or soft high-grade hematite layers, rather than soft itabirite, because he noted that "jacutinga" was the most important host rock for gold mineralization, whereas itabirite was an unfavorable host rock. Henwood (1871) stated:

> Itabirite consists for the most part of granular quartz and iron glance [specularite] irregularly mixed with oxydulated iron [magnetite crystals(?)] earthy brown iron ore, and hydrous oxide of iron in alternating beds, some times separated by laminae of talc * * * in this part of the series gold is rarely found * * *. Jacutinga is composed in a great measure of iron-glance [soft hematite(?)] mixed generally with small quantities of earthy manganese and frequently with minute proportions of oxydulated iron, earthy iron-ore, titaniferous iron ore, or hydrous oxide of iron also, but seldom with all these at once.

Hussak (1908) described fragments of gold-bearing "jacutinga" from the Gongo Sôco mine as "schistose hematite, containing very little pyrolusite, earthy limonite, some scales of talc, and certain masses which had the appearance of kaolinite." Hussak's (1908) and Henwood's (1871) descriptions of "jacutinga" are very similar, and it seems likely that the "jacutinga" of the Gongo Sôco mine was softened or partly softened high-grade hematite lenses interlayered in the itabirite and dolomite of the Itabira Group.

Henwood's description of the gold mineralization along drag folds cut by quartz veins in the Gongo Sôco mine seems to indicate a hydrothermal origin for the gold. Henwood observed (p. 329) that in all parts of the mine, hard, crystalline, massive iron-glance (hard hematite) seems to have an unfavorable influence upon the grade of the gold in the ore shoots. The relation of the hard iron-glance to the gold-bearing "jacutinga" is not known; however, judging from Hussak's and Henwood's descriptions, "jacutinga" consisted mostly of schistose hematite or soft hematite and may have been derived from the hard hematite. If this assumption is valid, the question still remains whether the hard "iron glance" was softened by ground waters that enriched the "jacutinga" or by hydrothermal fluids that precipitated gold in the "jacutinga."

The occurrence of the higher grade ore at or near the surface suggests supergene enrichment of the ores of the Gongo Sôco mine. Henwood stated (p. 331): "Thus, at progressively greater depths, the productive beds—so far as they have been wrought—continue to yield smaller averages of gold." Dorr and Barbosa (1963, p. 105) described gold in the "jacutinga" of the Itabira district as follows: "The concentration of gold into incredibly rich pockets and seams is most reasonably attributed to secondary enrichment by through-passing supergene waters, since the distribution of the ore was related to the present erosion surface." Dorr and Barbosa further suggested that manganese oxide in the weathered dolomitic iron-formation, which is in a very finely divided state and therefore chemically active, serves as a precipitating agent in the "jacutinga" ores.

The reason for the diminution of grade with depth is not known. The diminution could be related to surface weathering and supergene enrichment of the dolomitic itabirite, as suggested by Dorr and Barbosa (1963, p. 105), or it could be due to lack of suitable host rock, namely dolomitic itabirite, for the precipitation of gold from through-going hydrothermal fluid. At a depth of 150 meters, in the northern part of the mine area, the lower-most mine workings were probably in the lower beds of the Cauê Itabirite, which are in most areas siliceous itabirite, whereas the itabirite in general becomes increasingly more dolomitic upward and grades through itabiritic dolomite into dolomite of the Gandarela Formation.

The origin of the gold is not known, but a possible source could be gold-bearing hydrothermal solutions emanating from the batholithic body of granitic gneiss that forms the Caeté Complex.

MANGANESE DEPOSITS

Manganese ores have been mined in the Gongo Sôco quadrangle from the Capim Gordura and Lagôa das Antas mines since 1940 for use in the charcoal blast furnaces of the Companhia Brasileira da Usinas Metalurgicas in Barão de Cocais. The total production of manganese ore is not known, but it may be about 1,000 tons.

The manganese ore occurs almost exclusively within the dolomite of the Gandarela Formation as supergene concentrations of manganese oxide generally parallel to the bedding planes of the dolomite. The dolomite contains varying amounts of manganese ranging from a trace to 1.2 percent, and upon weathering the indigenous manganese of the dolomite is apparently concentrated by meteoric waters along bedding planes and shear zones in the dolomite (Dorr and others, 1956).

CAPIM GORDURA MINE

The Capim Gordura mine is in the western part of the Gongo Sôco quadrangle (N. 3,650, E. 1,080, pl. 2) at the foot of the south slopes of the Serra Geral. The mine area is accessible by a road leading west from the town of Barão de Cocais along the Socorro valley.

The Capim Gordura mine is owned and operated by the Companhia Brasileira da Usinas Metalurgicas of Barão de Cocais, and manganese has been mined intermittently since 1940 for use in their charcoal blast furnaces. No accurate data of total production of manganese ore from the Capim Gordura mine have been recorded, but it is estimated that approximately 1,000 tons have been mined. Three pits were being mined at the time of the survey, but there are numerous caved and abandoned pits. The ore is mined by hand tools, and it is hand sorted to increase the grade of the ore. The reserves are small, and the lenses and stringers of manganese oxide are discontinuous in most pits and cannot be projected laterally or vertically, with confidence, for more than a few meters. Prospecting for new lenses of ore is costly, and the outlook for finding additional reserves is not encouraging.

The manganese ore of the Capim Gordura workings occurs in saprolite derived from dolomite at horizons ranging from 100 to 300 meters above the base of the Gandarela Formation. In most places in the mine area the dolomite is weathered to red and brownish-black saprolite, although low ledges of fresh dolomite crop out in a few places. The ore consists of pods, lenses, and stringers of manganese oxide ranging from about 1 cm to 1 meter across. They are crudely alined parallel to the bedding planes of the saprolite, strike west, and dip 40°–45° S.

The ore consists of either massive reddish-gray very fine grained manganese oxide containing disseminated clusters of hematite and quartz crystals and some limonite or vuggy botryoidal light-gray very fine grained manganese oxide enclosing numerous silvery-gray acicular crystals tenatively identified as manganite. The vugs between the botryoidal growths of manganese oxide contain druses of acicular psilomelane crystals.

Analyses of ore samples taken from the hand-sorted ore at the mine, and analyses of the hand-sorted ore made by the company are shown in table 7.

LAGÔA DAS ANTAS MINE

The Lagôa das Antas mine is on the crest of the Serra da Pedra Formosa (N. 3,700, E. 8,850, pl. 2) in the southwestern part of the Gongo Sôco quadrangle and is named for a nearby lake. A road leads southeastward from the Rio Acima–Conceição road along the crest of the Serra da Pedra Formosa to the mine area. The prospect was developed by the Companhia Brasileira da Usinas Metalurgicas of Barão de Cocais. The mine consists of one open pit trending N. 55° E. that is 50 meters long, 25 meters wide, and 3–5 meters deep. No production is recorded, and the grade and the potential tonnage of available ore probably are not high enough to warrant commercial mining.

The manganese minerals occur along a shear zone in the lower 50 meters of dolomite of the Gandarela Formation. This shear zone trends N. 50° E. and is vertical.

The manganese minerals in the shear zone occur as dark-gray, sooty material and nodules and a few silver-gray crystals of manganese oxide in highly sheared red saprolite derived from dolomite of the Gandarela Formation. An analysis of a channel sample cut across the 1-meter-wide mineralized shear zone shows that the sample contains 19.0 percent manganese (table 7).

DOLOMITE

Dolomite has been mined sporadically from small quarries in the Socorro valley by the Companhia Brasileira da Usinas Metalurgicas of Barão de Cocais for use in their charcoal blast furnaces. Most of the dolomite is not desirable for use as flux because of the high MgO content, and the dolomite forms a highly viscous slag that is difficult to remove from the furnaces. Analyses of fresh blocks of dolomite from the quarries of the Socorro valley are given in table 8.

Hogbacks of dolomite exposed in Corrego da Gandarela valley near the west boundary of the Conceição do Rio Acima quadrangle (N. 7,000, E. 1,000, pl. 3) consist of massive banded, red and white, white and gray, and cream-colored rock that could be quarried for ornamental stone or dimension stone.

FERRUGINOUS BAUXITE

Ferruginous bauxite soil derived from the weathering of dolomite of the Gandarela Formation occurs as irregular layers within the canga field of the Lagôa Grande Plateau in the northwestern part of the Conceição do Rio Acima quadrangle. The ferruginous bauxite grades laterally into hard chemical canga consisting almost entirely of limonite. It is yellowish-red to medium-red earthy material in which some layers are honeycombed by cellular cavities. It can easily be mined and may be a source of low-grade aluminum ore.

TABLE 7.—*Analysis (in percent) of manganiferous laterite from Lagôa das Antas mine and manganese ore from Capim Gordura mine*

[Analyses 1, 2, 3, and 4 made by Departamento Nacional da Produção Mineral, Belo Horizonte; analyst, Dr. Cassio Pinto. Analyses 1387, 1401, 1400, 1397, 1392, 1409, and 1920 made by Companhia Brasileira da Usinas Metalurgicas; analyst unknown]

	Lagôa das Antas mine	Capim Gordura mine									
	1	2	3	4	1387	1401	1400	1397	1392	1409	1920
SiO_2	3.5	6.6	2.6	17.5	12.7	9.48	10.22	9.74	7.16	11.86	10.44
Al_2O_3	4.5	1.2	1.2	1.3							
Fe	37.2	7.4	19.8	18.4	21.2	16.0	17.4	16.5	20.4	19.0	18.5
Mn	19.0	38.8	38.5	30.4	40.3	39.4	36.3	41.3	39.3	35.1	40.0
P	.06	.02	.09	.04							

1. Manganiferous laterite taken from Lagôa das Antas mine at N. 4,000, E. 10,500 (pl. 2). Channel sample.
2–4. Manganese oxides taken from stockpile of ore at open pit at N. 3,700, E. 1,080 (pl. 2).
1387, 1401, 1400, 1397, 1392, 1409, and 1920 taken from ore bins at the smelter of Companhia Brasileira da Usinas Metalurgicas, Barão de Cocais.

TABLE 8.—*Analyses (in percent) of dolomite from the Gongo Sôco quadrangle (pl. 2)*

[Analyst: Dr. Cassio Pinto, Departamento Nacional da Produção Mineral, Belo Horizonte]

Sample	Location	Color	CaO	MgO	Fe_2O_3	SiO_2	Al_2O_3	Mn	S	Loss on ignition
70	N. 6700, E. 10,850	White	28.8	18.6	2.1	7.6	0.2	0.2	0.04	43.2
71	N. 6700, E. 10,850	Gray	28.7	18.9	1.7	7.3	.2	.2	.04	43.2
72	N. 6700, E. 10,850	do	29.5	18.5	2.3	4.7	.2	.2	.04	44.6
73	N. 6700, E. 10,850	do	25.8	16.7	1.9	16.7	.2	.2	.07	38.7
74	N. 6600, E. 10,400	do	29.0	19.5	1.5	6.1	.2	.2	.03	43.7
75	N. 6600, E. 10,400	do	30.9	20.2	1.4	1.3	.2	.2	.04	46.1
76	N. 6600, E. 10,400	do	29.1	17.2	1.8	9.7	.2	.2	.03	42.1
84	N. 3000, E. 9600	Cream	29.9	13.0	3.1	15.3	.3	.2	.02	37.9
84a	N. 3000, E. 9600	Gray	24.7	17.3	2.0	17.2	.5	.2	.02	38.3
87	N. 4950, E. 7900	Cream	28.7	17.9	2.0	8.6	.3	.2	.02	42.5
78	N. 6100, E. 9450	Gray	29.7	18.6	2.5	4.7	.3	.2	.05	44.1
79	N. 6100, E. 9450	do	26.0	16.5	3.6	12.7	2.2	.2	.04	38.6
81	N. 3600, E. 4600	Red	30.3	20.8	.9	.15	.3	.9	.03	46.5
82	N. 3600, E. 4600	do	30.4	20.7	.8	.15	.1	.1	.02	46.6
82g	N. 3200, E. 2800	do	31.0	19.9	1.5	.10	.3	.9	.02	46.2
83	N. 3200, E. 2800	do	29.6	20.1	3.6	.15	.4	1.2	.02	44.8
86	N. 1040, E. 5950	do	27.6	17.7	5.0	6.8	.4	.7	.02	41.8

The thickness and horizontal extent of the exposures of ferruginous bauxite are not known because of a thin soil cover and thick overgrowth of scrubby jungle. A sample cut across a 30-meter traverse of ferruginous bauxite along the trail southwest of Lagôa Grande contained 35.2 percent Al_2O_3, 26.4 percent iron, 3.5 percent SiO_2, and traces of manganese, phosphorus, and sulfur.

CLAY

Clay deposits occur in a number of places as a surficial layer of lateritic soil mantling granitic gneiss saprolite in the Caeté Complex. The residual clay soils range from a few centimeters to as much as 10 meters in thickness, but in most exposures along roadcuts and railroad cuts they average about 2 meters thick. The powdered specimens were tentatively identified in oils as kaolin clay. The color of the clay ranges from white through yellowish white, yellow, and reddish yellow to red. The white clay may be a source of material for refractory brick, and the yellow to red clay is suitable for firebrick and roofing tile.

None of the kaolin clay deposits have been prospected within the mapped area, but similar clay deposits have been mined for many years west of the mapped area near the city of Caeté, where the clay is used in the manufacture of firebricks, refractory bricks, and roof tiles.

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