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Geology and Mineral Resources of the Barão de Cocais Area Minas Gerais, Brazil

GEOLOGICAL SURVEY PROFESSIONAL PAPER 341-H

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

U.S. DEPARTMENT OF THE INTERIOR

Geology and Mineral Resources of the Barão de Cocais Area Minas Gerais, Brazil

By GEORGE C. SIMMONS

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A study of Precambrian rocks and associated mineral deposits in the Brazilian shield

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GEOLOGY AND MINERAL RESOURCES OF THE BARÃO DE COCAIS AREA MINAS GERAIS, BRAZIL

By George C. Simmons

ABSTRACT

The Barão de Cocais area is in the northeast part of the Quadrilátero Ferrífero, the famous iron region which covers nearly 7,000 square kilometers in southeastern Minas Gerais, Brazil. A folded Precambrian iron-formation, the Cauê Itabirite, contains high-grade hematite deposits and is the source of other iron ores throughout this region. The Barão de Cocais area covers 270 square kilometers and includes part of a syncline involving the Cauê Itabirite. The area contains a large tonnage of potential iron resources and small reserves of high-grade iron ores and low-grade iron, manganese, and gold ores.

Two Precambrian rock series having an aggregate thickness of 3,600 meters crop out in the Barão de Cocais area. The lower, Rio das Velhas Series is 3,200 meters thick and is represented by the Nova Lima Group, 2,300 meters thick, and the Tamanduá Group, 900 meters thick. The Nova Lima Group is composed of chlorite-sericite, carbonaceous, and ferruginous schist and phyllite, iron-formation, and arenaceous rocks. The Tamanduá Group contains two formations: the Cambotas Quartzite, 600 meters thick, almost entirely made up of fine-grained quartzite; and an overlying unnamed formation, 300 meters thick, containing lithologic units similar to those of the Nova Lima Group. The Tamanduá Group is assigned to the Rio das Velhas Series because the angular discordance at the base of the group is not considered of sufficient magnitude to warrant separation of the group as another series, and because the group has an anomalous distribution in relation to the Minas Series.

The most significant result of the mapping is the recognition of the Cambotas Quartzite as a separate unit. It is distinct from the Maquiné Group, Moeda Formation, and Itacolomí Series, all of which also are chiefly quartzite units of comparable thicknesses at many places in the Quadrilátero Ferrífero.

The Minas Series, 400 meters thick, includes three groups and five formations. From lowest to uppermost, the Caraça Group contains the Moeda and Batatal Formations; the Itabira Group contains the Cauê Itabirite and the Gandarela Formation; and the Piracicaba Group contains the Cercadinho Formation.

The Moeda Formation contains quartzite, phyllite, and conglomerate and is transitional with the Batatal Formation, which contains phyllite and arenaceous phyllite. The Batatal Formation grades within a few meters into the Cauê Itabirite. The Cauê Itabirite is almost entirely itabirite, a low-grade metamorphosed oxide facies iron-formation composed of alternating hematite-rich and quartz-rich laminae. This formation is the source of practically all of the iron deposits in the Quadrilátero Ferrífero. The intergradational zone between the Cauê Itabirite and the Gandarela Formation is 10 meters thick. The Gandarela Formation contains ferruginous and dolomitic phyllite and itabirite. The Cercadinho Formation disconformably overlies the Gandarela Formation. The Cercadinho Formation contains ferruginous phyllite and quartzite, conglomerate, and dolomitic phyllite.

Canga, a Cenozoic rock of some economic interest, is the only post-Precambrian rock in the region, except possibly some gabbroic intrusive rocks. It is an indurated colluvial deposit of itabiritic cemented by limonite.

Three granitic formations occur in the area: the Petí phase of the Borrachudos Granite, and two gneisses, informally designated the gneiss of Cocais and the gneiss of Santa Bárbara. The gneiss of Cocais is a light-gray fine- to medium-grained weakly banded grandiorite containing quartz, microcline, sodic plagioclase, biotite, and muscovite. The gneiss of Santa Bárbara is a light-gray fine- to medium-grained weakly foliated grandiorite containing quartz, plagioclase, microcline, muscovite, epidote, and biotite. The Petí phase of the Borrachudos Granite is a light-gray coarse-grained rock composed of quartz, orthoclase, microcline, albite, biotite, and fluorite.

The relative ages of the granitic rocks are incompletely known. The gneiss of Coacais intrudes and has a metasomatic contact with the Cambotas Quartzite and probably the upper formation of the Tamanduá Group. Structural parallelism of the Minas Series and the Tamanduá Group in the Serra do Tamanduá suggests that the gneiss also is post-Minas Series. The gneiss of Sanata Bárbara is bounded by chlorite-talc-antigorite schist, but its relation to stratigraphic units is unknown. Gneisses similar in appearance to the gneiss of Sanata Bárabara have a metasomatic contact with the Minas Series in adjoining areas. The Petí phase of the Borrachudos Granite only intrudes rocks of the Nova Lima Group, but the Borrachudos is considered younger than the two gneisses, because it lacks foliation.

Three varieties of mafic rocks are present, from oldest to youngest: chlorite-talc-antigorite schist, chlorite schist, and gabbro. The chlorite-talc-antigorite schist occurs in a zone between the Nova Lima Group and gneiss of Santa Bárbara and in dikes crosscutting the Nova Lima Group. The chlorite schist occurs as small sparsely distributed dikes and sills in the gneiss of Santa Bárbara and Minas Series and probably in the Nova Lima Group. The gabbro is dark green, medium grained, and unfoliated and contains pigeonite rimmed by uralite, biotite,

andesine, labradorite, magnetite, ilmenite, and leucoxene. The gabbro occurs in plugs, dikes, and sills in the Cambotas Quartzite and gneiss of Cocais.

Parts of six major structural features are present:

1. The southwest part of the Cocais gneiss dome. Foliation in in the dome strikes north-northwest, at 90° to the trend of the Gandarela syncline. As the Gandarela syncline formed during the last ma'or orogeny in the Quadrilátero Ferrífero, the foliation in the dome is considered the result of earlier tectonic activity.
2. The southeast end of the Cambotas homocline. The homocline dips to the east and has a normal relation to the complex at Caeté, a gneiss dome which is northwest of the mapped area. The homocline is structurally discordant with the Cocais dome.
3. The northeast end of the Gandarela syncline. The Gandarela syncline is a northeast-trending overturned fold which principally involves rocks of the Minas Series.
4. The northeast end of a belt of isoclinally folded rocks of the Nova Lima Group. The belt trends subparallel to the Gandarela syncline. The syncline and isoclinal folds lie between the Cocais and Santa Bárbara gneiss domes.
5. The Fundão thrust fault. The Fundão thrust fault intersects the south limb of the Gandarela syncline and the belt of isoclinal folds at several places and offsets rocks in the Minas Series and Nova Lima Group as much as 500 meters.
6. The northwest part of the Santa Bárbara gneiss dome. The relation of the Santa Bárbara dome to other structural features is obscure.

A seventh feature, a thrust fault, is postulated to explain the structural discontinuity between the Cambotas homocline and the Cocais dome. A gabbro dike was intruded in the position of the postulated fault. A similar fault may have existed between the belt of isoclinal folds and the Santa Bárbara gneiss dome. Chlorite-talc-antigorite schist now lies in this position.

Stratified rocks in the Barão de Cocais area were regionally metamorphosed to the greenschist facies, as shown by typical mineral assemblages of chlorite, white micas, and quartz and small grain sizes in itabirite and other iron-formation. Two periods of metamorphism later than the Rio das Velhas Series are recognized in the Quadrilátero Ferrífero; the first was earlier than the Minas Series, and the second was later than the Minas Series. The effect of the first metamorphism on the Rio das Velhas Series is uncertain because the rocks in that series are of the same metamorphic grade as the Minas Series, which was only affected by the second metamorphism. If the first metamorphism was a higher grade metamorphism than the second, then the second destroyed evidence of the first through retrograde effects. Higher grades of metamorphism are limited to contact zones with, and inclusions in, gneiss of Cocais.

Mineral production, reserves, and potential resources of the Barão de Cocais area include gold, iron, and manganese. The area was an important gold producer in the 18th century and the first half of the 19th century; however, the ancient placer and jacutinga deposits at and between Barão de Cocais and Santa Bárbara, at Cocais, and other places were exhausted long ago. Gold was mined from sulfide replacement deposits between 1860 and 1920 at the São Bento mine and Santa Quitéria deposits. The São Bento mine contains 150,000 tons of low-grade indicated reserves, and further exploration might increase this amount; no reserves are known at Santa Quitéria.

Although the Barão de Cocais area contains potential resources of more than 1 billion tons of soft itabirite, canga, and enriched itabirite averaging 50 percent iron, these potential resources are relatively unimportant economically because large tonnages of high- and low-grade ores are present in the Quadrilátero Ferrífero and other billions of tons of potential resources lie closer to large smelters. The Cabeça de Ferro mine, the only iron mine in the area, has produced 70,000 tons of high-grade compact hematite since 1925 and has 36,000 tons of indicated reserves. Two small rolado deposits near the town of Cocais contain 35,000 tons of indicated low-grade reserves.

The Barão de Cocais area was a small manganese producer during the two World Wars. About 5,000 tons of high-grade ore was mined during World War I from the parts of the Morro Grande alluvial and replacement deposits that lie w'thin the area; other production was from adjoining areas in the Gongo Sôco quadrangle. About 15,000 tons of low-grade ore was mined during World War II at the Brucutú 54 mine, an epigenetic deposit, and that deposit still contains several tens of thousands of tons of reserves. Less than 5,000 tons of low-grade ore was mined during World War II at the Morro Dona Ana mine, a vein deposit that probably contains several thousand tons of reserves.

INTRODUCTION

GENERAL BACKGROUND

Brazilian iron reserves are among the largest known iron reserves in the world. The economic expansion of Brazil has resulted in a national interest in Brazilian iron for domestic manufacturing, and depletion of European sources has led to international interest in these reserves. Most of the iron occurs in the southeast part of the State of Minas Gerais, a region known as the Quadrilátero Ferrífero or iron quadrilateral (fig. 1). Study and mapping of this area was initiated in 1946 by the Brazilian Departamento Nacional da Produção Mineral and the United States Geological Survey under the auspices of the Interdepartmental Committee on Scientific and Cultural Cooperation. The program is presently incorporated in the Aliança Para o Progresso under the auspices of the Agency for International Development, U.S. Department of State.

The Quadrilátero Ferrífero is divided into the equivalent of thirty-seven and a half 7½-minute quadrangles. Topographic base maps of these quadrangles were prepared by multiplex methods from aerial photographs at a scale of 1:25,000. Geologic mapping of the quadrangles has been carried out by various geologists of the United States Geological Survey–Departamento Nacional da Produção Mineral team. This report, one of a series of U.S. Geological Survey professional papers on the entire Quadrilátero Ferrífero, concerns the Barão de Cocais area in the northeast part of the Quadrilátero Ferrífero. This area includes the Santa Bárbara quadrangle (pl. 1) and the south half of the Cocais quadrangle (pl. 2).

COORDINATE SYSTEM

A 1-kilometer (1,000-meter) grid is indicated along the sides of each of the two principal geologic maps

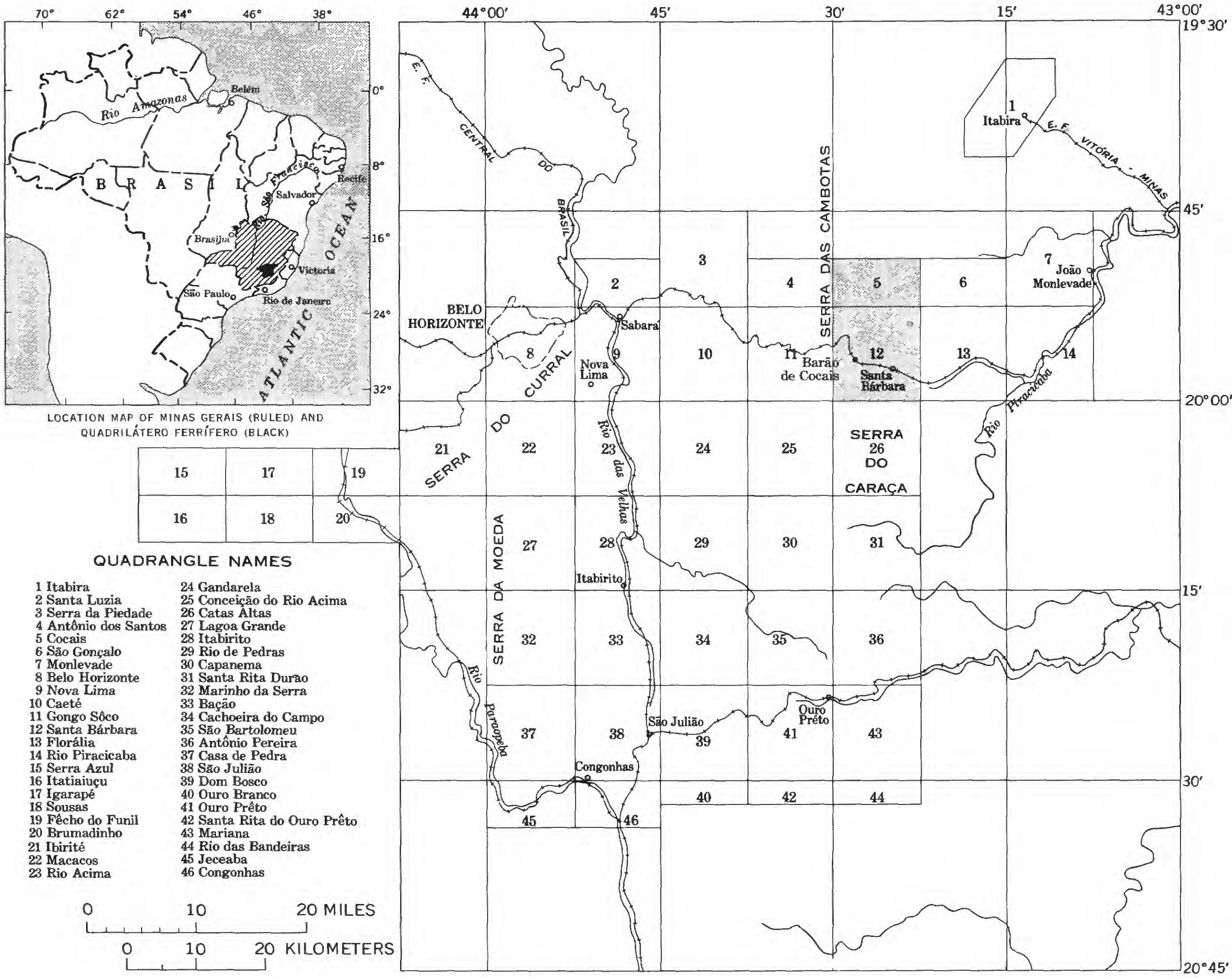

FIGURE 1.—Location of the Barão de Cocais area (stippled) in relation to the remainder of the Quadrilátero Ferrífero.

(pls. 1, 2) to facilitate the location of places referred to in the text. The grid origins are at the southwest corner of both maps; thus, a reference "pl. 1, N. 5,000, E. 6,000" designates a point 5,000 meters north and 6,000 meters east of the southwest corner of the area shown on plate 1.

GEOGRAPHY

The Barão de Cocais area includes the Santa Bárbara quadrangle and the south half of the Cocais 7½-minute quadrangle (fig. 1). The region forms a rectangle bounded by lat 19°48′45″ and 20°00′00″ S. and long 43°22′30″ and 43°30′00″ W. The rectangle, covering 271 square kilometers (105 square miles), lies in the municípios of Barão de Cocais and Santa Bárbara; about two-thirds of the area, to the north and west, is in the Barão de Cocais município, and the other third, to the south and east, is in the Santa Bárbara município.

The Barão de Cacais area is chiefly an agricultural region although 25 percent of the population is engaged in mining, smelting, and related activities. The principal crops, most of which are locally consumed, are corn, bananas, manioc, potatoes, sugar cane, coffee, garlic, sweet potatoes, and beans. Beef cattle and pigs also are raised.

As a result of Brazil's coal deficiency, much charcoal is used in smelting iron. Near Barão de Cocais, as in many other parts of the Quadrilátero Ferrífero, the forests, which quickly regenerate themselves, are periodically cleared and converted into charcoal. The charcoal is hauled on mule back from small kilns to the smelter at Barão de Cocais (fig. 2). During the last decade many cleared forests have been replanted with eucalyptus trees, which produce better wood for charcoal than the uncultivated indigenous forests.

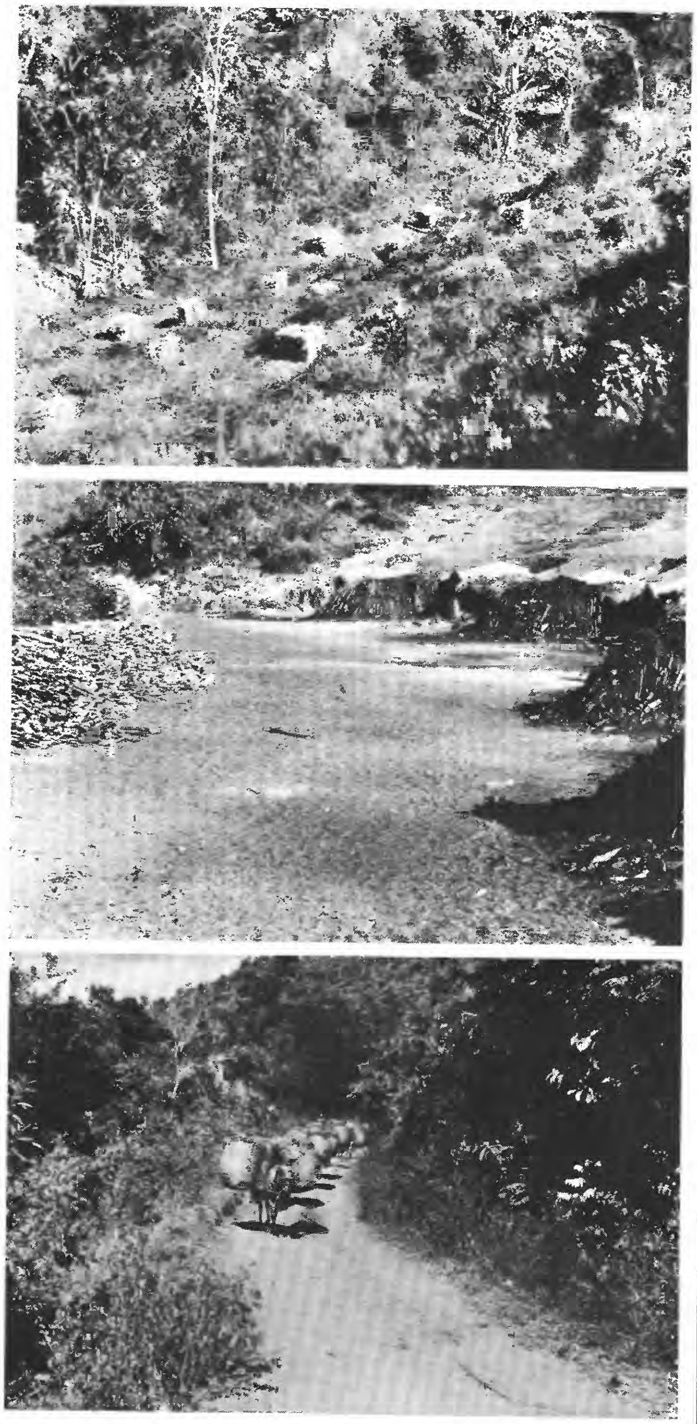

FIGURE 2.—Production of charcoal for smelter at Barão de Cocais. Upper: wood harvest. Middle: wood, kilns, and charcoal. Lower: transporting charcoal to smelter.

The area includes five communities[1], all of which originally were gold-mining settlements during the early part of the 18th century: Barão de Cocais (4,700 inhabitants) and Cocais (700) in the Município of Barão de Cocais, and Santa Bárbara (4,400), Barra Feliz (450), and Brumal (350) in the Municipio of Santa Bárbara.

Barão de Cocais is the center of local iron mining, site of the smelter of the Companhia Brasileira de Usinas Metallurgicas, and a município seat. Cocais, a quiet attractive community, was once more populous and was the headquarters for gold mining at the nearby place known as Taquaríl. Santa Bárbara, oldest and second largest town in the region, is also a município seat. Barra Feliz is a relic of several periods of placer and lode gold mining. The residents of Brumal work on farms which supply food for the Colégio do Caraça. Two other communities in the Município of Santa Bárbara are near the Barão de Cocais area: the town of São Goncalo do Rio Abaixo is about 2 kilometers northeast of the mapped area, and the settlement of Petí, where the staff of the Petí hydroelectric plant lives, is 1 kilometer east of the mapped area.

Two principal roads give access to the area. The old highway from Belo Horizonte to Itabira and Monlevade is an all-weather gravel road which traverses the area in an east-west direction. This road passes through Barão de Cocais, Barra Feliz, and Santa Bárbara, passes near Petí, and enters São Goncalo do Rio Abaixo at an intersection with the new asphalt highway from Belo Horizonte to Monlevade. The new highway, BR–31, called Paralelo Vinte because it is projected to cross Brazil near the 20th parallel, extends in a general east-west direction several kilometers north of the area and cuts the northeast corner of the area near São Goncalo do Rio Abaixo. A partly graveled road extends north from Barão de Cocais and passes near Cocais. Two kilometers north of Cocais this road branches, and both arms intersect the Paralelo Vinte highway. The west arm is the better maintained and is passable except after heavy rain. The east arm has been less usable during the rainy season, but, because of its shorter distance to Paralelo Vinte, it has been selected as the general route of a new road under construction in 1962. Barão de Cocais is 80 kilometers from Belo Horizonte via the old highway, and 97 kilometers via the new; the normal driving time is about 2 hours by either route.

Another all-weather road connects Santa Bárbara with the iron, manganese, and bauxite area of Fazenda Alegria to the south, and generally passable roads lead from Barra Feliz to Colégio do Caraça and from Barão de Cocais to Rio Acima. A few other minor roads give some access within the area.

A meter-gage line of the Estrada de Ferro Central do Brasil (Brazilian Central Railway), which connects Belo Horizonte with Nova Era, passes through Barão de Cocais and Santa Bárbara. The distance from Belo Horizonte to Barão de Cocais is 89 kilometers.

[1] Rounded off population figures from July 1950 census figures, Instituto Brasileiro de Geografia Estatistica (1958, p. 134; 1959, p 118).

A dirt landing strip near Barão de Cocais handles small charter aircraft during the dry season, and it has served as an emergency landing strip for larger planes. There is no scheduled air service.

Electric power for the area is generated at Petí Dam by two units, each of 7,000-horsepower capacity. The Petí plant also provides power for the city of Belo Horizonte and standby power for the Itabira iron mine.

The climate of the Quadrilátero Ferrífero is subtropical. Temperatures range from 5° C (41° F) to 35° C (95° F), and daytime temperatures average 20° C (68° F). About 150 cm (59 unches) of rain fall annually in Belo Horizonte, the State capital, but rainfall is greater at the higher altitudes which prevail over much of the region There are two seasons, a wet summer from November through February and a dry winter from April through September; the months of March and October are transitional. In the middle of the summer there is a dry period of about 10 days' duration which has been compared to the eye of a storm and is known as the veranico, or little summer. Other rainless days occur during the rainy season, and occasionally rains occur during the dry winter season.

The Barão de Cocais area can be divided into six physiographic divisions: the Cocais hills, the Santa Bárbara hills, the Serra das Cambotas, the Serra do Tamanduá, the Conceição valleys and ridges, and the Petí uplands (fig. 3). Each division developed from erosion of different rocks: the Cocais hills from the gneiss of Cocais; the Santa Bárbara hills from the gneiss of Santa Bárbara; the Serra das Cambotas from Cambotas Quartzite; the Serra do Tamanduá from rocks of the Tamanduá Group and Minas Series; the Conceição valleys and ridges from the Nova Lima Group; and the Petí uplands from the Petí phase of the Borrachudos Granite.

The highest altitudes, up to 1,375 meters, are on the east flank of the Serra das Cambotas. The crest of the Serra do Tamanduá is generally between 1,000 and 1,100 meters, and the altitude along the base of the range is 750–800 meters. The Conceição valleys and ridges are parallel. Ridge crests are between 900 and 1,000 meters, and the intervening valley troughs are between 750 and 800 meters. The Petí uplands has an altitude of 950 meters near the center and 700 meters along the sides. The Cocais and Santa Bárbara hills have similar hill topography with most altitudes between 700 and 850 meters. Total relief within the area is 735 meters (2,400 feet).

The area is drained by tributaries of the Rio Piracicaba, whose waters reach the Atlantic Ocean via the Rio Doce. Most of the drainage is from southwest to northeast by the Rio Santa Bárbara. The Rio Santa Bárbara is formed at Barra Feliz by the confluence of

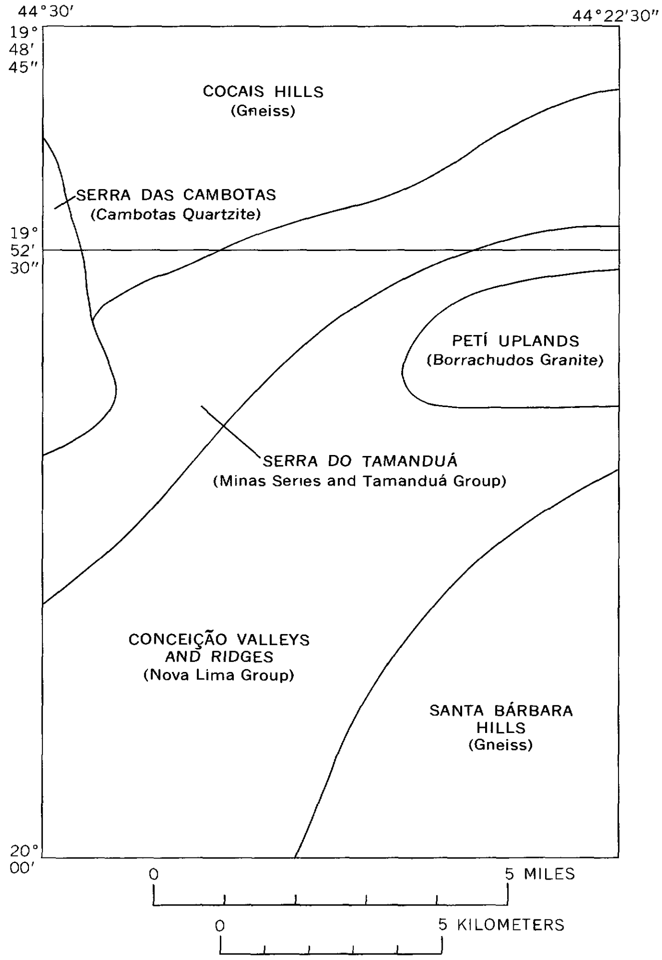

FIGURE 3.—Physiographic divisions and general rock distribution in the Barão de Cocais area.

the Rio da Conceição and the Rio Socorro. These two rivers enter the area at an altitude of about 740 meters, and the Rio Santa Bárbara leaves at the lowest altitude in the area, 640 meters, after being impounded in the Petí reservoir. The country north of the Serra do Tamanduá is drained by brooks, almost all of which flow northward into the Rio Una, which in turn empties into the Rio Santa Bárbara a few kilometers north of São Goncalo do Rio Abaixo. The southeast part of the area is drained by tributaries of the Rio Vermelho, which flows into the Rio Piracicaba to the southeast.

Vegetation is to some extent controlled by soil composition, which in turn reflects the composition of underlying rocks. Thus, vegetation is a guide in geologic mapping. Dense forests cover most of the stratified argillaceous rocks. Luxuriant growth also covered most of the granitic rocks, although much of this growth is on subdued terrane and has been cleared for farming and grazing. Poor soils develop on quartzite, canga, and itabirite, and, as these are also the rocks most resistant

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to erosion, the higher terrain generally is covered by sparse vegetation including grasses and scrubby trees.

Geologists unfamiliar with the region and planning work in central Minas Gerais will be interested in a nongeologic problem affecting fieldwork. The most annoying pests are the carrapatos (ticks), present along all trails and everywhere that animals have been. They usually can be ignored for a month or two after the rainy season, but from June until the rainy season commences they are an annoyance. Poisonous snakes and scorpions are numerous in some areas. The four most common snakes are the coral, cascavel (rattlesnake), jararaca, and jararacuçu.

PREVIOUS INVESTIGATIONS

The geology of the Quadrilátero Ferrífero has been studied for more than 150 years, but in the past the lack of adequate base maps and the principal concern with individual mines or minerals resulted in the region not becoming well known. Among the more significant early papers describing the geology in and near the iron region are those of Eschwege (1817, 1822, 1833).

The modern period of investigation began near the turn of the century with the work of Orville A. Derby (1881, 1896, 1899, 1906, 1910, 1911) and Henri Gorceix (1881, 1883, 1884). About 1910 a group of American geologists including R. T. Chamberlin, E. C. Harder, and C. K. Leith investigated the deposits and regional geology of the iron region and published several important scientific papers (Leith and Harder, 1911; Leith, 1917; Harder, 1914; Harder and Chamberlin, 1915). The most comprehensive accounts of the general geology and mineral resources based on extensive original work and an exhaustive search of the literature were compiled by Freyberg (1932, 1934). A geologic map and bilingual outline of the geology of the Quadrilátero Ferrífero were prepared by geologists of the United States Geological Survey and the Departamento Nacional da Produção Mineral (Departamento Nacional da Produção Mineral, 1959). It synthesizes the studies carried out by the two organizations in their joint program from 1946 to 1958.

Since 1925 the number of studies by Brazilian geologists has steadily increased. Among the more significant contributions to the literature are those of Octávio Barbosa (1934, 1954), Djalma Guimarães (1931, 1935, 1937, 1951, 1953, 1958), Djalma Guimarães and Octávio Barbosa (1934), and L. J. de Moraes and Octávio Barbosa (1939). However, a complete list would include many more geologists and hundreds of papers.

PRESENT INVESTIGATION

Initial fieldwork in the present investigation was done by Amos M. White between October 1956 and May 1958. The author worked in the area from May through October 1959 and from May through December 1960. All mapping, except for a few mineral deposits, was done on aerial photographs and was visually transferred to topographic base maps.

Published references to the geology of the Barão de Cocais area are few and brief and emphasize gold mining. Older references are given by Freyberg (1934, p. 103–104). More recent papers include one by Moraes and Barbosa (1939, p. 137–138, 142–146), which describes old mine workings near Cocais and Barra Feliz, and another by Dorr, Coelho, and Horen (1956, p. 334–335), which describes the Brucutú manganese deposit. An unpublished report by G. C. McCartney, prepared in 1947 for the South America Gold Areas Co., was useful in the preparation of the section on the São Bento mine. Another unpublished report by J. D. Conover, prepared in 1921 for the Brazilian Iron and Steel Co., was helpful in the preparation of the section on the Morro Grande manganese deposits.

Several published geologic studies of the Quadrilátero Ferrífero (Guild, 1957; Gair, 1962; Johnson, 1962; Dorr and Barbosa, 1963; and Pomerene, 1964) and also unpublished maps and manuscripts were useful in providing a background for the present investigation.

ACKNOWLEDGMENTS

The author thanks many persons for courtesies and services throughout the preparation of this report and is particularly grateful to the members of the Departamento Nacional da Produção Mineral for their cooperation and provision of aerial photographs and base maps, chemical analyses, thin sections, and library facilities. Special thanks are due to Avelino Ignacio de Oliveira, Director General; José Alves, Chefe da Divisão do Centro; Aida Espinola, Chemist; Elysario Tavora, mineralogist; and Sr. Santana, who prepared the 79 thin sections studied during the course of this work.

The Instituto de Tecnologia Industrial offered its library facilities in Belo Horizonte, and Dr. Djalma Guimarães and Dr. Manoel Teixeira were helpful with advice on Brazilian geologic literature. Dr. Claudio V. Dutra was of much assistance in making spectrochemical determinations.

Maria H. Falabella of the Brasil Comissão de Energia Nuclear, Rio de Janeiro, supplied X-ray analyses whenever needed.

At field headquarters in Barão de Cocais, Mayor Wilson Alvarenga de Oliveira and Sr. Joaquim Duarte made every effort to fulfill all working and living needs. Dr. Hélio Pereira da Silva and Dr. Luiz dos Santos Pinho, Directors of the Companhia Brasileira de Usinas Metallurgicas in Barão de Cocais, provided information concerning the mines which supplied the Barão de

Cocais smelter and the production records of the Cabeça de Ferro mine, and they did many personal favors which made the author's stay in Barão de Cocais more enjoyable.

The author expresses his appreciation to various members of the U.S. Geological Survey who were helpful in certain aspects of the work. Full use was made of the notes and samples taken by Amos M. White, who initiated mapping in the area. Charles H. Maxwell introduced the author to the area and assisted on several field trips. Norman Herz supplied invaluable aid in the study of granitic rocks. Alfred J. Bodenlos and Jacob E. Gair reviewed the manuscript, and their suggestions and criticisms have been most helpful. Francis X. Lopez and Robert Kojima directed the final preparation of the maps and illustrations.

STRATIGRAPHY

Stratified rocks occupy about 170 square kilometers, or 65 percent, of the Barão de Cocais area and occur in all but the north and southeast parts and a small area in the west-central part of the area. The rocks are assigned to two major divisions, the Rio das Velhas and Minas Series, both of Precambrian age and having a combined calculated and measured thickness of about 3,600 meters (11,800 feet) (table 1).

TABLE 1.—*Precambrian stratigraphic column for the Barão de Cocais area*

[Numbers in parentheses are thicknesses, in meters]

Series	Group	Formation	Description
		Unconformity	
Minas (400)	Piracicaba (225) [1]	Cercadinho Formation (225) [1]	Ferruginous quartzite, phyllite.
		Disconformity	
	Itabira (129)	Gandarela Formation (65)	Dolomitic itabirite and phyllite.
		Cauê Itabirite (64)	Itabirite.
	Caraça (18)	Batatal Formation (9)	Phyllite.
		Moeda Formation (9)	Quartzite, phyllite.
		Unconformity	
Rio das Velhas (3,200)	Tamanduá (924)	Unnamed formation (286)	Schist, phyllite (34).
			Iron-formation, phyllite (41).
			Schist, quartz schist, quartzite (211).
		Cambotas Quartzite (638)	Quartzite.
		Unconformity	
	Nova Lima (2,300) [1]	Undivided	Schist, phyllite, iron-formation.

[1] Estimated thickness.

The Rio das Velhas Series includes all stratified rocks older than the Minas Series in the Quadrilátero Ferrífero. A profound unconformity separating the Minas Series from the older rocks was first described by Rynearson, Pomerene, and Dorr (1954, p. 5–18). The pre-Minas rocks were subsequently defined and named the Rio das Velhas Series by Dorr, Gair, Pomerene, and Rynearson (1957, p. 16–17) from the type area along the Rio das Velhas and bordering uplands in the Nova Lima, Itabirito, and Rio Acima quadrangles. The Rio das Velhas Series contains three major divisions—from oldest to youngest, the Nova Lima, Maquiné, and Tamanduá Groups—but only the Nova Lima and Tamanduá Groups occur in the Barão de Cocais area.

The Nova Lima and Maquiné [2] Groups were named and described by Dorr, Gair, Pomerene, and Rynearson (1957, p. 17–22). The Nova Lima and Maquiné Groups were later described in greater detail by Gair (1962, p. 8–33). The Tamanduá Group was named in the Santa Bárbara and Gongo Sôco quadrangles and was described in that area and the Serra do Caraça by Simmons and Maxwell (1961).

The Minas Series, according to Derby (1906), comprised all schistose rocks overlying the crystalline Archean complex. Harder and Chamberlin (1915) divided the Minas Series from base to top, into Caraça Quartzite, Batatal Schist, Itabira Formation, Piracicaba Formation, and Itacolomí Quartzite. Later the Minas Series was redefined because of the recognition of two unconformities within Derby's original Minas Series. An unconformity separates the Itacolomí Quartzite from the underlying rocks of the Minas Series, so the Itacolomí was raised to series rank by Guimarães (1931). The other unconformity occurs at the base of the Caraça Quartzite (Rynearson and others, 1954); hence, the underlying schistose rocks were defined as an older series and later named the Rio das Velhas.

Detailed mapping by geologists of the United States Geological Survey and the Departmento Nacional da Produção Mineral resulted in considerable refinement of units within the Minas Series. The Minas Series has been divided into the Caraça, Itabira, and Piracicaba Groups, from base to top (Dorr and others, 1957), and into nine formations.

The three groups of the Minas Series are present in the Barão de Cocais area, but the Caraça Group is very thin, and only the lowest formation of the Piracicaba Group is present.

RIO DAS VELHAS SERIES

NOVA LIMA GROUP

Rocks assigned to the Nova Lima Group are present on the south side of the Gandarela syncline, but they are not recognized on the north side of that structure within the Barão de Cocais area. The group is exposed

[2] The designation Maquiné and the description of the group bearing that name is partly based on unpublished data of J. E. O'Rourke.

in a band which trends diagonally across the Santa Bárbara quadrangle (pl. 1) from southwest to northeast and extends into the southeast part of the Cocais quadrangle (pl. 2). The band is 8 kilometers wide to the southwest and 4 kilometers wide to the northeast.

The group is bounded on the northwest by the Minas Series and on the southeast by chlorite-talc-antigorite schist. The northwest contact, nowhere exposed, is probably an angular unconformity at its northeast and southwest ends and a thrust fault in the intermediate part. In the areas of unconformity the Nova Lima Group and Minas Series have an angular divergence in strike of 20°. The southeast contact with chlorite-talc-antigorite schist is also unexposed, but its trend is subparallel to the strike of foliation in both the schist and Nova Lima Group.

A maximum thickness of the Nova Lima Group in the area is estimated to be 2,300 meters. The generally poor exposures prevent a more reliable estimate of thickness. The thickness given is derived from the calculated apparent thickness corrected for estimated duplication of beds caused by folding.

SCHIST AND PHYLLITE

Schist and phyllite compose 90 percent of the Nova Lima Group. The rocks are everywhere weathered, commonly to shades of brown, gray, and red; fresh rocks are unknown in the area. The best exposures occur in railroad cuts between Barão de Cocais and Santa Bárbara, in roadcuts along the main road between them, and along another road connecting the towns via the west side of the Petí Reservoir (pl. 1). Natural outcrops are sparse and small. Varieties of weathered schist and phyllite that have been recognized at specific localities cannot be followed laterally, so the schist and phyllite are mapped as one unit.

Four principal varieties of phyllite and schist are recognized in the mapped area: chlorite-sericite, chlorite-talc-antigorite, carbonaceous, and ferruginous. Chlorite-sericite phyllite and schist are shades of brown, gray, red, violet, and green. Some varieties contain very fine grained quartz, and others contain no quartz. Chlorite-sericite phyllite and schist are commonly interbedded with other varieties of phyllite and schist and locally grade into quartzite. Chlorite-talc-antigorite phyllite and schist are dark brownish red. Chlorite is the most abundant mineral at most places, but it is second to talc at others. Similar rock occurs in a few dikes, and some of these rocks possibly are sills rather than part of the Nova Lima Group. Carbonaceous phyllite and schist are light to dark gray. They contain sericite, chlorite, and, in places, very fine grained quartz and carbonaceous material. Locally they grade into quartzite. Ferruginous phyllite and schist appear to be lateral facies of iron-formation, and they occur at the ends of ridges formed by iron-formations. They contain sericite, chlorite, limonite, and locally quartz. No primary iron minerals were found, and possibly the limonite in the phyllite and schist was derived from weathering of adjacent iron-formation rather than from indigenous minerals.

Sedimentary structures have been almost completely destroyed in the phyllite and schist of the Nova Lima Group. In places, alternating carbonaceous-rich and carbonaceous-poor layers can be seen, or contacts between the phyllite and schist and interbedded quartzite and iron-formation can be seen.

Carbonaceous phyllite and schist and some of the phyllite and schist interbedded with these rocks are probably of sedimentary origin. Although Gair (1962, p. 9–16) concluded that fresh phyllite and schist in the type area of the Nova Lima Group are of both sedimentary and volcanic origin, such refined determinations could not be made on the weathered material in the Barão de Cocais area.

IRON-FORMATION

Iron-formation makes up less than 10 percent of the Nova Lima Group in the Barão de Cocais area, but it is more conspicuous than the other rocks because it dominates the topography and forms straight, narrow ridge crests, some of which are several kilometers long. Locally the iron-formation grades into quartzite which has the same topographic expression.

Individual iron-formations range from less than 1 to 35 meters in thickness, and they superficially resemble itabirite. The rock is composed of alternating laminae of quartz and limonite. Individual laminae are from less than 0.1 to 0.5 cm thick.

Fairly fresh exposures of iron-formation occur in a few roadcuts. The best of these are near the bridge in the water gap where the Rio Santa Bárbara enters the Petí Reservoir (pl. 1, N. 6,800, E. 8,500); there, several iron-formations are interbedded with carbonaceous phyllites. A measured section including these units is given below. It was not determined if the section is overturned, but the south part of the section was assumed to be the top for the purpose of description.

Partial section of Nova Lima Group measured near bridge in the water gap where the Rio Santa Bárbara enters the Peti Reservoir about 3 kilometers north of Santa Bárbara (pl. 1, N. 6,800, E. 8,500)

[Section given from assumed top to assumed base; thicknesses in meters]

Description	*Top*	*Base*	*Thickness*
Phyllite, gray, carbonaceous	0.	100. +	100. +
Iron-formation and phyllite. Iron-formation consists of alternating layers of very fine grained white and gray quartz and brown limonite; some quartz layers contain disseminated specks of hematite partially altered to limonite; the iron-formation is interbedded with brown phyllite layers as much as 0.3 meter thick which have high limonite content	100.0	108.6	8.6
Covered, probably phyllite	108.6	131.9	23.3
Iron-formation; laminae of very fine grained gray quartz alternate with brown and tan linonite laminae; laminae as much as 0.5 cm thick; few layers of gray carbonaceous phyllite concentrated toward top of interval	131.9	136.2	4.3
Covered, probably phyllite	136.2	152.6	16.4
Phyllite, gray and dark-purplish-red, carbonaceous; contains limonite pseudomorphs after pyrite(?)	152.6	160.3	7.7
Phyllite, orange-red; contains possible relict feldspar laths	160.3	162.4	2.1
Phyllite, dark-grayish-red	162.4	164.7	2.3
Phyllite, dark-gray, carbonaceous; contains trace of dark-red phyllite	164.7	173.5	8.8
Iron-formation; contains alternating laminae of dark- and light-gray very fine grained quartz; gray layers have high hematite content; individual laminae as much as 3 cm thick	173.5	207.0	33.5
Phyllite, brownish-red; grades downward into grayish-red	207.0	209.3	2.3
Phyllite, gray, carbonaceous	209.3	215.7	6.4
Phyllite, gray, carbonaceous, poorly exposed	215.7	230.0	14.3
Phyllite, gray carbonaceous	230.0	244.4	14.4
Iron-formation, very fine grained, laminated gray, brown, and white; gray results from high concentration of hematite; brown layers result from alteration of hematite to limonite; laminae as much as 0.1 cm thick	244.4	252.2	7.8
Phyllite, gray, carbonaceous	252.2	260.2	8.0

A partial analysis of fresh iron-formation from a drill core at the São Bento mine was made by J. B. de Araujo, Departamento Nacional da Produção Mineral (written commun., 1962). The analysis indicated (in percent): Fe, 34.8 (FeO, 20.5; Fe_2O_3, 26.9); CaO, 1.05; MgO, 1.30; MnO, 0.08; loss on ignition, 4.71. The FeO content is high in comparision with that usually found in itabirite of the Minas Series, but it is common for iron-formation of the Rio das Velhas Series. The FeO occurs in magnetite and sideritic carbonate. The carbonate is seen in thin sections made from a drill core of the fresh iron-formation but is not found in surface outcrops.

QUARTZ-RICH ROCKS

Conglomerate, quartzite, quartz schist, and quartz-sericite schist make up only a small fraction of the Nova Lima Group. Most of the arenaceous units contain abundant sericite, and a few contain biotite and chlorite. None of these rocks have been found in thicknesses of more than several meters, and it is not certain that they persist laterally.

CORRELATION OF ROCKS ASSIGNED TO THE NOVA LIMA GROUP

The correlation of rocks assigned to the Nova Lima Group is problematical. Information concerning the stratigraphic succession within the group is almost completely lacking; so, the assignment of rocks to the group is based on general lithologic similarities and relations rather than on specific identification of formations or beds. Structural differences within the Nova Lima Group suggest that it contains rocks of different ages at different places. Iron-formations in the Barão de Cocais area are isoclinally folded and crop out in long narrow bands of uniform strike for as much as several kilometers (pl. 1). Thirty-five kilometers west of the area) at the type locality of the Nova Lima Group, iron-formations are intricately folded (Gair, 1962, pls. 1, 2, p. 50). The contrast in folding indicates a more complex orogenic history at the type locality than in the Barão de Cocais area and suggests that the Nova Lima Group there may have been deformed prior to the deposition of rocks assigned to the Nova Lima Group in the Barão de Cocais area.

TAMANDUÁ GROUP

The Tamanduá Group crops out in a belt 100–1,500 meters wide on the north side of the Serra do Tamanduá (pl. 1), and its lower formation, the Cambotas Quartzite, extends from the north side of the Serra do Tamanduá northward in an irregular zone as much as 1,900 meters wide on the east flank of the Serra das Cambotas (pls. 1, 2). On the north side of the Serra do Tamanduá, the lower part of the group has been metasomatically altered adjacent to the gneiss of Cocais. East of the Serra das Cambotas the group is in contact with a gabbro dike. To the south the group is in contact with the Minas Series.

The Tamanduá Group was originally described from this area and the adjoining Gongo Sôco quadrangle as comprising the Cambotas Quartzite and three unnamed overlying formations (Simmons and Maxwell, 1961). The three upper units are now considered local members of one formation. The Tamanduá Group, thus, contains two formations in the Barão de Cocais area: the Cambotas Quartzite and an overlying unnamed formation.

CAMBOTAS QUARTZITE

The Cambotas Quartzite is made up entirely of quartzite, except for rare thin phyllite beds, and it weathers into bold topographic forms and crops out better than any other rock unit in the area (figs. 4*A*, *B*). The quartzite is white, light gray, buff, and shades of light green; it is generally fine grained, although coarse and very fine grains are present. Many grains are sheared into silt-sized particles. In thin section the quartzite shows a strong mortar structure in which the original grains are highly fractured and set in a matrix of crushed quartz. Some specimens are augen schist or phyllonite in which little of the original grain structure is preserved.

The only abundant mineral besides quartz is white mica, which occurs in small flakes disseminated throughout the rock. Argillaceous material which occurs as thin

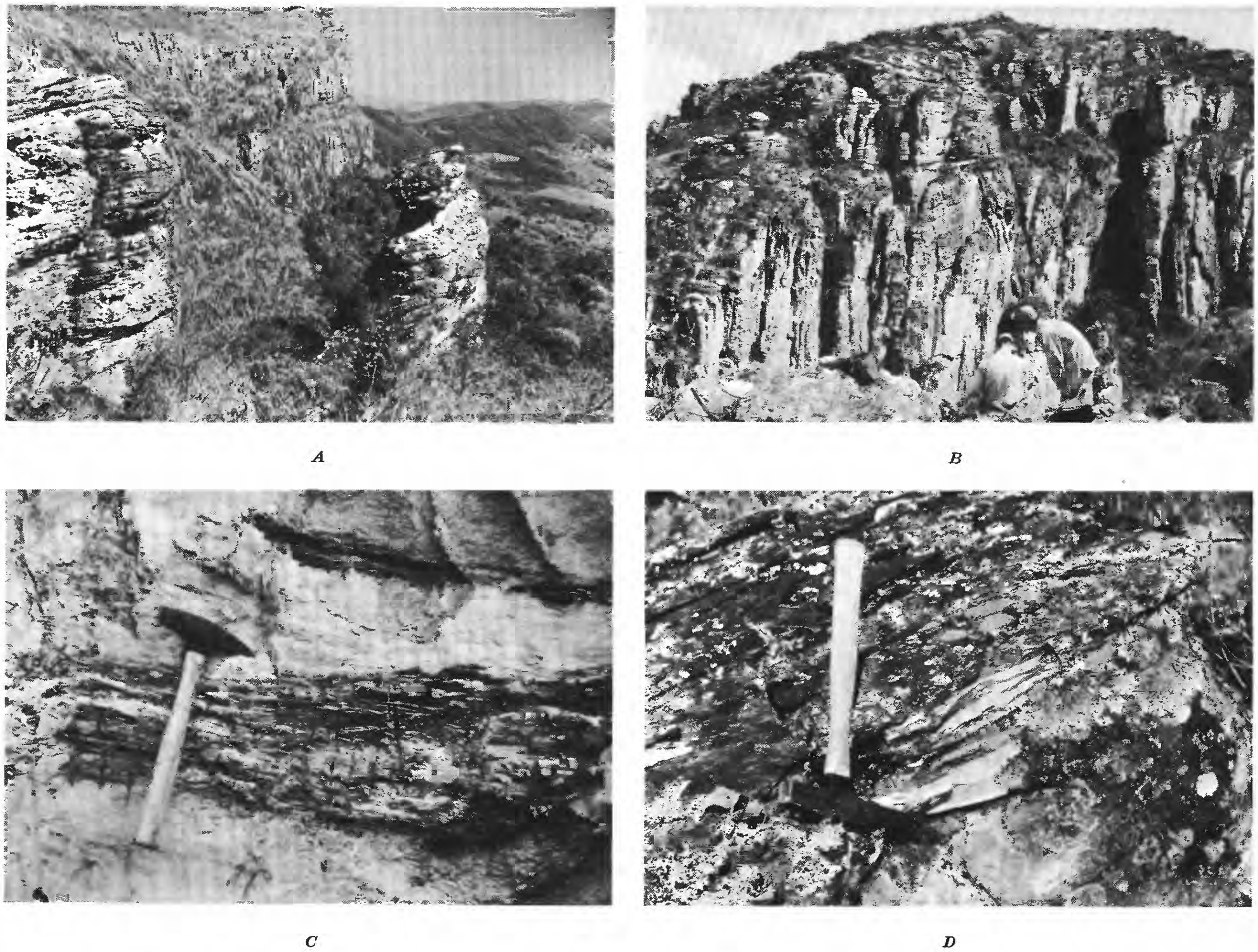

FIGURE 4.—Cambotas Quartzite. *A*, At the east end of the Serra do Tamanduá. *B*, At Morro Grande. *C*, Thin shale beds in quartzite at Morro Grande. *D*, Hematite-rich layers in quartzite; gray streaks on chipped surface to right of hammer are hematite-rich layers.

films on some bedding planes and also as disseminated grains in the quartzite is probably derived from the weathering of mica; thin shale beds (fig. 4*C*) are very uncommon. Fine specks of hematite can be seen with a hand lens in most specimens, and in a few places the hematite is concentrated in thin layers (fig. 4*D*) so that small pieces have a superficial resemblance to some iron-formations. Weathered quartzite of this latter type is bright orange brown. Kyanite was found on the bedding planes at a few places.

Despite the destruction of original sand grains by fracturing, the sedimentary structures are preserved. Bedding is conspicuous, and most beds range from 0.5 to 1 cm in thickness. Cross-stratification of the trough or festoon type is common and occurs in sets of beds, some of which are many meters thick (fig. 5). Ripple marks were found at one place north of the mapped area where Highway BR–31 crosses the Serra das Cambotas (fig. 6).

As originally defined, the Cambotas Quartzite contained two units; a relatively thin lower part containing schist, quartz schist, quartz-sericite schist, conglomerate schist, and quartzite and a thick upper part of quartzite (Simmons and Maxwell, 1961, p. 16). The lower unit, only recognized in the Gongo Sôco quadrangle, is now excluded from the formation, and the author is in agreement with S. L. Moore (written commun., 1963), who had previously mapped the unit as Nova Lima Group. The Cambotas Quartzite as now defined is 638 meters thick at its type locality. The type section of the Cambotas Quartzite was originally published in Portuguese (Simmons and Maxwell, 1961, p. 11–16). Only that part of the section included in the formation as restricted above is reproduced here.

FIGURE 5.—Cross-stratified Cambotas Quartzite in the Serra do Tamanduá.

FIGURE 6.—Ripple marks in Cambotas Quartzite in the Serra das Cambotas. Scale shown by Brunton compass.

Type section of Cambotas Quartzite measured in the northeast part of the Gongo Sôco quadrangle along and near the Barão de Cocais–Caeté road

[Section given from top to base; thickness in meters]

Description	Top	Base	Thickness
Quartzite, buff, thin-bedded; contains many thin layers of compact hematite. Top of Cambotas Quartzite. Upper contact with unnamed formation of the Tamanduá Group is bedding-plane fault	0	4.0	4.0
Quartzite, buff, thin-bedded; contains numerous small specks of hematite	4.0	12.0	8.0
Quartzite, white to buff, thin-bedded; contains many thin beds and laminae of compact hematite	12.0	20.9	8.9
Quartzite, white to buff, poorly exposed	20.9	26.1	5.2
Quartzite, white to buff, thin-bedded; contains few gray streaks of hematite	26.1	28.8	2.7
Quartzite, white to buff, thin-bedded; contains few thin beds and laminae of hematite	28.8	32.5	3.7
Quartzite, buff, thin-bedded; contains many thin layers of hematite and reddish-orange limonite	32.5	36.7	4.2
Quartzite, buff, thin-bedded; contains few thin beds of reddish-orange limonite showing traces of hematite	36.7	43.5	6.8
Quartzite, white, thin-bedded, poorly exposed	43.5	54.4	10.9
Quartzite, white to buff, thin-bedded	54.4	60.9	6.5
Quartzite, white, thin-bedded, poorly exposed	60.9	84.4	23.5
Quartzite, brown, thin-bedded, contains few thin laminae of hematite	84.4	105.2	20.8

Type section of Cambotas Quartzite measured in the northeast part of the Gongo Sôco quadrangle along and near the Barão de Cocais–Caeté road—Continued

Description	Top	Base	Thickness
Quartzite, brown, thin-bedded and crossbedded; contains abundant white mica	105.2	134.2	29.0
Quartzite, brown, thin-bedded; contains abundant white mica	134.2	144.0	9.8
Quartzite, light greenish-gray, thin-bedded and crossbedded	144.0	149.4	5.4
Quartzite, white, tan, and buff, thin-bedded, soft, slightly argillaceous	149.4	190.7	41.3
Quartzite, light grayish-green, massive, hard	190.7	192.0	1.3
Quartzite, white, thin-bedded, poorly exposed	192.0	213.2	21.2
Quartzite, grayish-green to buff, thin-bedded; contains abundant white mica	213.2	248.5	35.3
Quartzite, greenish-gray to tan, thin-bedded	248.5	253.3	4.8
Quartzite, white, thin-bedded; scattered poor exposures	253.3	291.2	37.9
Quartzite, light greenish-tan, thin-bedded, poorly exposed; contains abundant white mica	291.2	314.8	23.6
Quartzite, pale grayish-green, tan, white, thin-bedded, hard; contains few specks and flakes of hematite	314.8	317.8	3.0
Quartzite, pale greenish-gray to tan, hard; intercalated with friable white quartzite	317.8	338.2	20.4
Quartzite, white to tan, thin-bedded	338.2	365.6	27.4
Quartzite, pale greenish gray, massive, hard	365.6	371.6	6.0
Quartzite, pale greenish-gray; hard lenses intercalated with friable white quartzite	371.6	384.1	12.5
Quartzite, pale grayish-green, tan, white, thin-bedded and crossbedded, friable, poorly exposed	384.1	418.7	34.6
Quartzite, greenish-gray to tan, thin-bedded and crossbedded, friable	418.7	445.4	26.7
Quartzite, pale greenish-gray, thin-bedded and crossbedded, friable; contains abundant interstitial argillaceous material	445.4	463.5	18.1
Quartzite, white to tan, thin-bedded; contains few streaks of limonite stain and abundant white mica	463.5	472.4	8.9
Quartzite, greenish-gray, thin-bedded; contains few thin beds of gray-green schist	472.4	490.2	17.8
Quartzite, light greenish-gray, thin-bedded, slightly argillaceous	490.2	501.1	10.9
Quartzite, white to tan, thin-bedded; contains few laminae gray-green phyllite; traces of kyanite present on some bedding planes	501.1	507.4	6.3
Quartzite, white to tan, thin-bedded; contains abundant white mica	507.4	522.8	15.4
Quartzite, brown, thin-bedded; shows abundant orange-brown limonite stain	522.8	523.5	.7
Quartzite, white to tan, thin-bedded; contains very abundantwhite mica	523.5	534.7	11.2
Quartzite, tan and white, thin-bedded; contains abundant white mica; shows local limonite stain	534.7	537.3	2.6
Quartzite, light-brown, thin-bedded; contains few thin beds and veins of dark orange-brown limonite; contains abundant white mica	537.3	538.4	1.1
Quartzite, tan and white, thin-bedded; shows abundant local limonite stain; contains abundant white mica	538.4	553.0	14.6
Quartzite, gray to tan, thin-bedded; shows abundant limonite stain	553.0	553.5	.5
Covered (quartzite)	553.5	554.3	.8
Quartzite, white to brown, thin-bedded; shows few thin gray streaks of hematite; contains abundant white mica	554.3	557.4	3.1
Quartzite, gray to tan, thin-bedded; shows few thin streaks of hematite	557.4	562.2	4.8
Quartzite, gray to tan, thin-bedded; contains few thin beds of grayish-green schist	562.2	563.9	1.7
Quartzite, gray to tan, thin-bedded; shows traces of limonite on a few bedding planes	563.9	569.6	5.7
Quartzite, white to buff and brown, thin-bedded; contains sparse white mica	569.6	571.6	2.0
Quartzite, light greenish-gray to creamy white, poorly exposed	571.6	585.2	13.6
Covered (quartzite)	585.2	588.4	3.2
Quartzite, gray to greenish-gray, poorly exposed	588.4	592.3	3.9
Diabase dike.			
Quartzite, white, tan, and pink, thin-bedded; outlines of some coarse grains visible; grains are sheared and crumble to very fine powder; traces of white mica; some beds contain concentrations of dark red limonite	592.3	596.5	4.2
Quartzite, white and tan, thin-bedded; few beds contain concentrations of brown limonite	596.5	604.5	8.0
Quartzite, tan and brown, thin-bedded; many layers have concentrations of brown limonite stain	604.5	613.7	9.2
Quartzite, white, tan, pink, and greenish-gray, thin-bedded, mostly fine-grained; contains trace white mica. Base of Cambotas Quartzite	613.7	638.1	24.4

UNNAMED FORMATION

An unnamed formation containing schist, quartz schist, carbonaceous schist, ferruginous schist, iron-formation, phyllite, and quartzite overlies the Cambotas Quartzite and underlies the Minas Series. It occurs in a belt about 200 meters wide and 16 kilometers long on the north side of the Serra do Tamanduá.

The formation is best exposed, although weathered, on the Barão de Cocais–Caeté road at the boundary of the Santa Bárbara and Gongo Sôco quadrangles. There, from base to top, the formation contains schist, quartz schist, and phyllite; iron-formation and phyllite; and schist and phyllite. The measured section below has an aggregate thickness of 285 meters. In the central and east parts of the serra the formation contains ferruginous and carbonaceous schist interbedded with iron-formation; the best of the poor exposures are at the ancient gold workings near Taquaríl (pl. 1, N. 13,500, E. 4,800).

Because of the poor exposure and uncertain stratigraphic relations of the rocks in the upper part of the Tamanduá Group, these rocks are not assigned a formal name at this time. Future regional studies should result in a more complete description and definition of the relations so that these rocks can be given an appropriate name.

The quartz schist is mostly light colored and is white to gray and light shades of red, brown, and green. It contains considerable white mica and argillaceous material and some chlorite, and a few beds contain feldspar porphyroblasts. The schist is grayish red to brownish red, and most of it is weathered to clay, although white mica, chlorite, and some quartz are present. The carbonaceous schist is light to dark gray and besides carbonaceous material contains sericite, chlorite, and in places very fine grained quartz. The ferruginous schist is yellowish brown and contains sericite, chlorite, limonite, and locally quartz. All the ferruginous schist is interbedded with iron-formation, and the limonite possibly was derived from the weathering of adjacent iron-formation rather than from the minerals indigenous to the schist. The iron-formation contains alternating iron-rich and quartz-rich laminae and resembles itabirite. Most iron-rich layers are hydrated to limonite, but fairly fresh exposures contain hematite and numerous small magnetite crystals. The quartz-rich layers are vuggy and ocherous in the manner characteristic of dolomitic iron-formations, and some fresh iron-formation contains abundant carbonate.

Section of the upper formation of the Tamanduá Group measured on the Barão de Cocais–Caeté road at the boundary of the Santa Bárbara and Gongo Sôco quadrangles

[Section given from top to base; thicknesses in meters]

Description	Top	Base	Thickness
Contact with overlying Minas Series marked by several centimeters of vein quartz, but the two units apparently are conformable.			
Phyllite, gray, grayish-red, and greenish-brown; traces of thin-bedded quartzite. Top of unit 3	0	6.7	6.7
Alternating laminae of brown phyllite and white to tan quartzite	6.7	7.6	.9

Section of the upper formation of the Tamanduá Group measured on the Barão de Cocais–Caeté road at the boundary of the Santa Bárbara and Gongo Sôco quadrangles—Continued

Description	Top	Tase	Thickness
Phyllite, gray, grayish-red, and greenish-brown; contains few thin layers of quartzite	7.6	13.1	5.5
Schist, gray, grayish-red, and brown	13.1	25.1	12.0
Schist, gray, grayish-red and grayish-violet; upper 7.3 meters poorly exposed. Contact with underlying unit sharp but conformable. Base of unit 3. Total thickness 33.6 meters	25.1	33.6	8.5
Dolomitic itabirite or iron-formation, red to yellowish-brown. Top of unit 2	33.6	37.4	3.8
Phyllite, dolomitic and ferruginous, yellowish-brown	37.4	38.8	1.4
Interbedded yellowish-brown phyllite and brown iron-formation	38.8	39.7	.9
Iron-formation, brown to brownish-red; content of yellowish-brown dolomitic phyllite decreases downward	39.7	41.7	2.0
Phyllite, dolomitic, yellowish-brown; content of dolomite decreases downward	41.7	43.4	1.7
Iron-formation, brown; has low hematite content	43.4	45.6	2.2
Phyllite, yellowish-brown	45.6	46.8	1.2
Phyllite, yellowish-brown to reddish-brown; contains few thin beds of iron-formation	46.8	48.8	2.0
Phyllite, brown; contains few thin beds of light yellowish-brown iron-formation	48.8	52.5	3.7
Phyllite, yellowish-brown	52.5	53.7	1.2
Iron-formation, gray to brown; content of yellowish-brown phyllite decreases downward	53.7	62.3	8.6
Iron-formation, dolomitic and phyllitic, yellowish-brown; has low hematite content	62.3	63.0	.7
Iron-formation, brownish-gray. Contains few layers of yellowish-brown phyllitic	63.0	65.8	2.8
Iron-formation, yellowish-brown	65.8	66.0	.2
Iron-formation, gray to brownish-red	66.0	67.6	1.6
Dolomite, phyllitic, yellowish-brown	67.6	68.3	.7
Iron-formation, gray to light-brown; contains few layers of yellowish-brown iron-formation	68.3	69.5	1.2
Dolomite, phyllitic, yellowish-brown, contains few thin layers of iron-formation	69.5	70.1	.6
Iron-formation, light-brown to gray, has low iron content and high silica content	70.1	72.6	2.5
Iron-formation, phyllitic, yellowish-brown to gray	72.6	73.6	1.0
Phyllite, yellowish-brown	73.6	73.9	.3
Iron-formation, phyllitic, yellowish-brown; has low iron content. Base of unit 2. Total thickness 40.6 meters; contact with underlying unit conformable	73.9	74.2	.3
Schist, brownish-red and tan, poorly exposed. Top of unit 1	74.2	82.7	8.5
Schist, brown, tan, and brownish-red; contains few thin layers of quartzite in the lower 0.7 meters	82.7	91.1	8.4
Quartzite, ferruginous, banded light and dark gray	91.1	92.6	1.5
Interbedded white quartz and tane schist	92.6	93.3	.7
Quartz schist, argillaceous, white	93.3	94.0	.7
Interbedded tan schist and quartzite schist	94.0	95.1	1.1
Not exposed	95.1	98.8	3.7
Quartzite, white to pastel pink and green; contains few feldspar porphyroblasts	98.8	104.3	5.5
Quartz schist, white; contains few thin layers of green schist	104.3	107.7	3.4
Hybrid gneiss-quartzite schist; abundant feldspar porphyroblasts at top grades downward to sparse porphyroblasts near thebase	107.7	111.6	3.9
Quartz schist, white to tan; contains abundant argillaceous material in upper 0.9 meters	111.6	114.5	2.9
Quartzite; weathers to a very fine white silt-sized powder	114.5	115.5	1.0
Quartz schist, white to tan; contains trace argillaceous material	115.5	118.9	3.4
Quartz schist, white, pale-green, pale-red, and lavender; contains abundant phyllite and some feldspar porphyroblasts	118.9	127.3	8.4
Not exposed. Gray and red schist float probably representative of rocks underlying this interval	127.3	159.8	32.5
Not exposed (probably schist)	159.8	183.5	23.7
Schist, grayish-red; poorly exposed except for upper 1.5 meters	183.5	199.7	16.2
Not exposed except for one small possible exposure of schist in the upper third of the interval	199.7	274.1	74.4
Schist, gray, pink, and brown; contains few thin beds of quartzite	274.1	280.7	6.6
Quartzitic phyllite, gray and tan; grades downward into quartz schist	280.7	282.8	2.1
Phyllite and quartz schist, silvery-gray to tan	282.8	284.3	1.5
Quartz schist, argillaceous, silvery-white. Base of unit 1. Total thickness 211.4 meters. Contact with the underlying Cambotas Quartzite is a bedding-plane fault	284.3	285.6	1.3

Much of the quartz and all the carbonate present in some iron-formation at Taquaríl (pl. 1) were replaced by hematite and magnetite. Except for the presence of magnetite crystals (fig. 7), some of which are more than 1 cm in diameter, parts of the formation resemble

FIGURE 7.—Magnetite crystals in hematite from iron-formation in the upper formation of the Tamanduá Group. Actual width of specimen is 12.7 cm.

hematite ore from the Cauê Itabirite. A channel sample 50 cm long, 3 cm wide, and 1 cm deep, cut from a rich-appearing zone contained, in percent: Fe, 71.2 (FeO, 21.8; Fe_2O_3, 77.6); SiO_2, 0.2; Al_2O_3, 0.15; P, 0.021 (analyzed by J. B. de Araujo, Departamento Nacional da Produção Mineral, Belo Horizonte, Brazil, written commun., 1962).

The three units of the upper formation of the Tamanduá Group in the west part of the area (described in the measured section above) were mapped eastward from the boundary of the Gongo Sôco quadrangle for 2.5 kilometers (pl. 1). Farther east the formation is undivided because of poor exposures. At Taquaríl (pl. 1, N. 13,500, E. 4,800), 2.5 kilometers east of where the formation has been divided, nine schist and iron-formations crop out, but it was impossible to determine whether any of these beds are the same ones that are exposed to the west. The units recognized at the boundary of the Gongo Sôco and Santa Bárbara quadrangles crop out intermittently farther west, and S. L. Moore traced the units across the width of the Gongo Sôco quadrangle except for a gap of a few hundred meters where the upper two units are truncated by the Minas Series (S. L. Moore, written commun., 1963).

The only known exposures of the top and base of the formation are at the measured section on the Barão de Cocais–Caeté road. There, the top of the formation is exposed for a length of only 1 meter and is separated from the base of the Minas Series by a vein of quartz 2–3 cm thick; the bedding above and below the quartz vein is apparently conformable. The base of the formation is separated from the Cambotas Quartzite by a 1-meter-thick fault zone. Although bedding in phyllite of the unnamed formation is contorted adjacent to the fault, the attitude of bedding away from the fault is apparently conformable with that of the Cambotas Quartzite.

DISCUSSION

Detailed mapping in the Serra Geral (S. L. Moore, written commun., 1962), Serra do Caraça (C. H Maxwell, written commun., 1961), and Serra do Tamanduá led to the apperception of the Cambotas Quartzite as a separate lithologic unit. The Cambotas Quartzite is well exposed and fairly thick in those ranges and had been mistaken for the Moeda Formation because of similarities in thickness and lithology to that formation elsewhere. The Moeda Formation is the basal unit of the Minas Series over most, if not all, of the Quadrilátero Ferrífero, and it is poorly exposed and less than 15 meters thick in most parts of the Serras Geral, do Caraça, and do Tamanduá. A unit containing schist, iron-formation, and phyllite lies between the Cambotas Quartzite and Moeda Formation, and this unit and the Cambotas Quartzite are the two formations included in the Tamanduá Group.

As a result of the lack of critical exposures, three interpretations have been set forth to explain the stratigraphic relations of rocks assigned to the Tamanduá Group. According to one interpretation, the Cambotas Quartzite and a unit of schist, iron-formation, and phyllite compose a group which, although assigned to the uppermost part of the Rio das Velhas Series, was recognized as possibly belonging in another series (Simmons and Maxwell, 1961, p. 9). Another interpretation maintains that the Cambotas Quartzite occurs at the top of the Rio das Velhas Series and that the unit of schist, iron-formation, and phyllite is an older part of the same series (S. L. Moore, written commun., 1962). The third interpretation proposes that the Tamanduá Group is the basal part of the Minas Series (J. V. N. Door 2d, written commun., 1965).

The validity of the Tamanduá Group depends on the existence of conformity between the Cambotas Quartzite and the unit of schist, iron-formation, and phyllite. The parallelism in distribution and structural attitude of the two formations for 15 kilometers on the north side of the Serra do Tamanduá and 6 kilometers on the east side of the Serra do Caraça indicates that conformity exists. As previously mentioned, the two formations are in fault contact at their only known mutual exposure; Simmons and Maxwell (1961, p. 25) interpreted the fault as a bedding fault which has no significant effect on the normal rock succession. Conversely, S. L. Moore (written commun., 1962) mapped this fault in the Gongo Sôco quadrangle and considered it a major thrust fault separating rocks of the Nova Lima Group from the Cambotas Quartzite. A fundamental doubt exists, therefore, in regard to the presence of a Tamanduá Group.

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The series designation of the Tamanduá Group depends on the relation of the group to major unconformities. If an unconformity exists below the Cambotas Quartzite but not above the unit of schist, iron-formation, and phyllite, then the group belongs in the Minas Series (J. V. N. Door 2d, written commun., 1965). Conversely, if an unconformity is present above the unit of schist, iron-formation, and phyllite but not below the Cambotas Quartzite, then the group belongs in the Rio das Velhas Series (Simmons and Maxwell, 1961). If the group is bounded by major unconformities, then it should be raised to series rank. As only a few rock relations can be determined by direct observation of their contacts, the authors of the interpretations are confronted chiefly with explaining the different distribution patterns of the Tamanduá Group and the Minas Series.

The Minas Series is present throughout the Quadrilátero Ferrífero; its subdivisions are fairly consistent in thickness and occur in eroded synclines. The Tamanduá Group crops out in only three limited areas; its thickness varies so abruptly that the group nowhere crops out on both flanks of a syncline involving rocks of the Minas Series. According to Simmons and Maxwell (1961) the anomalous occurrences of the Tamanduá Group are best explained by a period of profound erosion prior to the deposition of the Minas Series. According to J. V. N. Dorr 2d (written commun., 1965), the Cambotas Quartzite represents long, narrow shoreline deposits laid down on a fairly plane surface that was downwarped during deposition of the sediments; the upper formation had a similar distribution but was deposited in deeper water. Dorr also thought that a period of slight erosion took place before the deposition of the Moeda Formation and that a slight disconformity may exist between that formation and the Tamanduá Group. Some evidence supports this contention at the only exposure common to the two units in the Barão de Cocais area; there the upper part of the Tamanduá Group and the lower part of the Minas Series are lithologically similar and apparently conformable, although they are separated by a thin vein of quartz.

The base of the Cambotas Quartzite is not extensively exposed but is generally agreed to be an unconformity; however, doubt exists as to whether the magnitude of unconformity warrants a division of series rank. In the Gongo Sôco quadrangle, S. L. Moore (written commun., 1962) observed that the Cambotas Quartzite overlies schist of the Nova Lima Group with slight to moderate angular unconformity; he did not consider the magnitude of the unconformity sufficient to separate the Cambotas Quartzite from the Rio das Velhas Series. In the Serra do Caraça, C. H. Maxwell (written commun., 1961) observed that the Cambotas Quartzite generally overlies the Maquiné Group with slight angular unconformity; Maxwell also placed the Cambotas Quartzite in the Rio das Velhas Series. J. V. N. Dorr 2d (written commun., 1965) believed that the contacts mapped by Moore and Maxwell are a major unconformity between the Minas and Rio das Velhas Series. The fact that the Cambotas Quartzite overlies different rock groups suggests this possibility, which was considered but rejected, as a basis of assigning the Tamanduá Group to series rank by Simmons and Maxwell (1961).

MINAS SERIES

Rocks of the Minas Series occur in the Gandarela syncline, which strikes N. 60° E. across the central part of the Barão de Cocais area in a belt 1,000–2,700 meters wide. The series, from base to top, consists of the Caraça Group, Itabira Group, and Piracicaba Group. The Caraça and Piracicaba Groups are composed mostly of clastic rocks, apd the Itabira Group is composed mostly of chemical precipitates.

CARAÇA GROUP

The Caraça Group contains two formations; the Moeda Formation (lower) and the Batatal Formation (upper). The group is poorly exposed, and its thickness is estimated to range between 15 and 30 meters; each formation is about half of the thickness.

On the south limb of the Gandarela syncline the Moeda and Batatal Formations are mapped as separate units to the east but are undivided to the west where they underlie the town of Barão de Cocais. The group is covered by canga and is missing as a a result of faulting along the central part of the south limb.

The Caraça Group is only exposed at one place on the north limb of the Gandarela syncline (pl. 1, N. 9,000, E. 100) within the mapped area. Chiefly on the basis of that exposure and another exposure a few hundred meters east of the mapped area, the group is assumed to be present throughout the length of the north limb in the mapped area, but the formation is too thin to be shown at the map scale (1:25,000).

A complete section of the Caraça Group was measured in a roadcut on the north limb of the Gandarela syncline (pl. 1, N. 9,000, E. 100; given below). The section is somewhat atypical in that the Moeda Formation is less areanaceous and more argillaceous than it is elsewhere in the area. The section was selected because it represents the only place where a complete thickness of the group is exposed.

The contact of the Caraça Group with underlying rocks is discussed in previous sections. The upper contact of the group, between the Batatal Formation and the Cauê Itabirite, is sharp and conformable where the section of the group was measured, and the formations are gradational at most other exposures in the area. This contact is well exposed at many places in the Quadrilátero Ferrífero and is everywhere conformable, and a gradational zone 2–3 meters thick is common.

Section of the Caraça Group measured in the Santa Bárbara quadrangle on the Barão de Cocais–Caeté road (pl. 1, N. 9,000, E. 100)

[Section given from top to base; thicknesses in meters]

Description	Top	Base	Thickness
Top of section is in sharp conformable contact with Cauê Itabirite.			
Phyllite, bluish-gray. Top of Batatal Formation	0	0.2	0.2
Quartzite schist, greenish-gray	.2	.5	.3
Phyllite, brownish-gray, grayish-green, and brownish-red; contains few thin layers of white to tan quartzite	.5	7.9	7.4
Phyllite, bluish-gray. Base of Batatal Formation. Contact with Moeda Formation conformable. Total Batatal Formation thickness 9.0 meters	7.9	9.0	1.1
Quartzite, white, very fine grained; contains traces of specularite. Top of Moeda Formation	9.0	9.4	.4
Phyllite, grayish-red and bluish-gray; contains few thin beds of quartzite; content of bluish-gray phyllite decreases toward base	9.4	16.0	6.6
Quartzite, light-gray to tan, very fine grained; band of bull quartz several centimeters thick at base. Base of Moeda Formation. Total thickness 8.8 meters. Contact with underlying Tamanduá Group of the Rio das Velhas Series apparently conformable	16.0	17.8	1.8

MOEDA FORMATION

The Moeda Formation was named by Wallace (1958) for exposures in the Serra do Modea in the east part the Quadrilátero Ferrífero. In the Barão de Cocais area the formation is composed of quartzitic phyllite, quartzite, and conglomeratic quartzite. The phyllites are mostly grayish red, bluish gray, and grayish green. In thin section they are seen to consist of sericite, quartz, and chlorite. All phyllite of the Moeda Formation contains some arenaceous material. Most of the quartzite is light shades of gray and tan, is fine grained, and contains variable amounts of sericite. Coarse-grained and conglomeratic facies are poorly sorted and poorly bedded. The conglomerate contains well-rounded quartz pebbles, some of which are fractured and others distorted by shearing.

BATATAL FORMATION

The Batatal Formation was named the Batatal Schist by Harder and Chamberlin (1915, p. 356–357) for exposures in the Serra do Batatal in the southeast part of the Quardrilátero Ferrífero; the unit was redesignated Batatal Formation by Maxwell (1958). In the Barão de Cocais area the formation is composed of brownish-gray, grayish-green, brownish-red, and bluish-gray phyllite interbedded with a few beds of arenaceous phyllite, schist, and quartzite. A few thin beds of ferruginous phyllite and itabirite occur in the upper 1–2 meters of the formation. Sericite, quartz, and chlorite were the only minerals identified in phyllite thin sections.

Bluish-gray phyllite, though only a small percentage of the formation, is the most distinctive constituent. It is dark bluish gray on slightly weathered surfaces and light bluish gray on strongly weathered surfaces, but it always has a bright sheen. Natural exposures of the Batatal Formation are uncommon, but where bedrock is poorly exposed or near the surface it is this phyllite which most commonly crops out or forms a rubble of small flat shiny pieces.

Arenaceous phyllite occurs in the formation only in a few localities, including the measured section given above; quartz grains are generally limited to within 1–2 meters of the transitional contact with the underlying Moeda Formation. However, similar occurrences of arenaceous phyllite elsewhere in the Quadrilátero Ferrífero were previously noted by Maxwell (1958, p. 61).

ITABIRA GROUP

The Itabira Group contains two formations, the Cauê Itabirite (lower) and the Gandarela Formation (upper). These formations are made up mainly of chemical metasedimentary rocks, and largely on this basis the Itabira Group is distinguished from the underlying Caraça and overlying Piracicaba Groups, most of which are clastic rocks.

The Cauê Itabirite and Gandarela Formation are intergradational in the Barão de Cocais area and outside of the mapped area they are known to intergrade through zones more than 100 meters thick. This raises a question as to whether these formations might not better be considered as members of a single formation. However, in parts of the Quadrilátero Ferrífero the lithologies of the two units are distinct and as the two formations are well established, the same nomenclature divisions are used in this report.

CAUÊ ITABIRITE

The Cauê Itabirite was named by Dorr (1958a) for exposures in the Itabira district, a northeast outlier of the Quadrilátero Ferrífero. The Cauê Itabirite is principally composed of several varieties of itabirite, which are locally interbedded with phyllite. Itabirite is more resistant to erosion than other Precambrian rocks in the Barão de Cocais area, except the Camotas Quartzite, and therefore tends to form topographic prominences. Despite this resistance, much itabirite is covered by canga, a surficial rock derived from weathering of itabirite, and the itabirite is not as well exposed here as in many other areas of the Quadrilátero Ferrífero.

Pure itabirite is a banded iron-formation containing alternating laminae of specular hematite flakes and granular quartz (figs. 8, 9). The laminae are not pure;

FIGURE 8.—Itabirite in the Cauê Itabirite. Granular-quartz lens in lower left. Scale indicated by cigarette package.

FIGURE 9.—Small overturned folds in itabirite.

a small amount of quartz occurs in the hematite laminae and vice versa. In this area the hematite and quartz grains range in diameter from 0.01 to 0.06 mm; quartz grains average 0.04 mm, and hematite 0.03 mm. Most of the laminae are between 1 and 5 mm thick, and at many places they can be traced for more than 10 meters, the maximum length of outcrops. Fresh itabirite is gray but weathers to shades of brown as a result of the hydration of hematite to limonite.

Itabirite has been defined by Dorr and Barbosa (1963, p. 18–19) as follows:

> The term itabirite denotes a laminated, metamorphosed, oxide-facies formation, in which the original chert or jasper bands have been recrystallized into granular quartz and in which the iron is present as hematite, magnetite, or martite. The quartz bands contain varied but generally minor quantities of iron oxide, the iron-oxide bands may contain varied but generally minor quantities of quartz. The term should not include quartzite of clastic origin with iron-oxide cement even though such rocks are sometimes grossly banded. It should only include rocks in which the quartz is megascopically recognizable as crystalline, in order to differentiate it from unmetamorphosed oxide-facies iron-formation. A certain amount of impurity in the form of dolomite or calcite, clay, and the metamorphic minerals derived from these materials may be included, but these may never be dominant constituents over any notable thickness. Where they are, the rock term must be qualified by the use of the appropriate mineral name as a qualifier (for example, dolomitic itabirite, a rock in which the dolomite largely takes the place of the quartz). Rarely itabirite grades into ferruginous chert which, when recrystallized, may look like low-grade itabirite, although commonly it is finer grained and whiter. To prevent confusion, a cutoff point of about 25 percent iron should be established. This figure is a practical one, as few itabirites are so lean in iron and most ferruginous cherts do not contain so much iron. Itabirite may grade into pure hematite through enrichment in iron or removal of quartz: the cutoff point might well be set at 66 percent iron because at and above this grade quartz is rarely concentrated in regular laminae.

The four chemical analyses given in table 2 are representative of the freshest itabirite available in recent excavations. The compositions of samples 1, 2, and 3 are similar to those of fresh itabirites elsewhere in the Quadrilátero Ferrífero (Guild, 1957, p. 45). Sample 4, more softened by weathering, has a high iron content and a low silica content which undoubtedly result from the partial dissolution and removal of quartz.

Other varieties of this rock such as dolomitic itabirite, phyllitic itabirite, and tremolitic(?) itabirite are not nearly so abundant or well exposed in the report area as is hematite-quartz itabirite. Only a few thin beds of fresh dolomitic were seen along a roadcut in the narrow canyon of Córrego Morro Grande where a section of Cauê Itabirite was measured. (See section on p. H12.) Dolomitic itabirite is more extensively exposed in the Gongo Sôco quadrangle west of the Santa Bárbara quadrangle (S. L. Moore, written commun., 1962). Dolomite occurs at the expense of quartz, and magnetite occurs at the expense of hematite, so that quartz-dolomite-rich laminae alternate with hematite-magnetite-rich laminae.

Magnetite is less soluble than dolomite and might be used as an indicator of the former presence of

TABLE 2.—*Partial analyses of itabirite, in percent*

[Samples from recent excavations; all slightly softened by weathering. Analyzed by Jayme B. de Araujo, Ministério das Minas e Energia, Belo Horizonte]

Sample	Fe	Fe_2O_3	FeO	SiO_2	Al_2O_3	P
1	43.8	58.7	4.7	33.7	0.4	0.13
2	47.3	66.0	1.6	32.2	.2	.046
3	46.4	61.4	4.4	32.1	.5	.090
4	64.3	91.2	.6	1.7	2.3	.15

SAMPLE LOCALITIES

1. South limb of Gandarela syncline in Barão de Cocais (pl. 1, N. 6,100, E. 300).
2. North limb of Gandarela syncline on east side of Córrego Morro Grande (pl. 1, N. 9,000, E. 900).
3. South limb of Gandarela syncline in Barão de Cocais (pl. 1, N. 6,900, E. 1,900).
4. North limb of Gandarela syncline on west bank of the Rio Santa Bárbara, São Gonçalo quandrangle, 2,300 meters east of northeast corner of Santa Bárbara quadrangle.

dolomite in weathered itabirite even though the dolomite has been completely dissolved. This concept appears applicable at one place in the Serra do Tamanduá where a solution cave occurs in itabirite (Simmons, 1963, p. 70–72). The wallrock is chiefly composed of magnetite, its oxidation products maghemite and martite, and very little hematite and quartz. About one-third of the volume of the rock is microscopic and small megascopic cavities, some of which are filled with leucophosphite and other secondary minerals (Simmons, 1964). Although quartz is known to dissolve during weathering of itabirite, the high magnetite, maghemite, and martite contents and the low hematite content suggest that the cave and cavities resulted from the solution of dolomite.

A few beds of phyllitic itabirite and ferruginous phyllite occur in the Cauê Itabirite, but they are poorly exposed. They are most common near the top and base of the Cauê Itabirite where it is transitional with other formations.

The varieties of itabirite are intergradational with each other and with phyllite. Ferruginous phyllite is phyllite containing laminae of hematite. At most exposures the hematite laminae are hydrated to limonite, and some limonite impregnates the phyllite and imparts a yellowish-brown color to it. Ferruginous phyllite grades into similarly colored phyllitic itabirite, which is itabirite containing laminae of phyllite. Phyllitic itabirite in turn grades into hematite-quartz itabirite and other varieties.

Weathered tremolitic(?) itabirite was found at one locality on the south limb of the Gandarela syncline (pl. 1, N. 13,600, E. 9,300). Laminae containing quartz and limonite pseudomorphs of tremolite(?) alternate with hematite-rich laminae. The limonite pseudomorphs have radiating and acicular structures and resemble similar limonite pseudomorphs in the western Serra do Curral (Simmons, 1968, p. H15), where the pseudomorphs have the same structures as the associated cummingtonite and tremolite in fresh itabirite.

Because itabirite contains a fairly high percentage of hematite and is, therefore, a potential source of ore if concentrated, the degree of disaggregation of the rock is of economic interest. Itabirite is classified into four principal types. Hard itabirite is itabirite in which the hematite and quartz grains are intact or only slightly disaggregated. In soft itabirite both hematite and quartz grains are disaggregated into sand. Intermediate itabirite is transitional between hard and soft itabirite. Chapinha is a variety in which the quartz is disaggregated into sand and the hematite is broken into plates; it is uncommon in the Barão de Cocais area but does occur at several places on the east end of the south limb of the Gandarela syncline.

The Cauê Itabirite crops out in a belt along both the north limb and the south limb of the Gandarela syncline. The north belt, which forms a hogback along the crest of the Serra do Tamanduá, ranges in width between 100 and 900 meters. The maximum width is an estimate because wherever the dips are low the contact of the Cauê Itabirite with the overlying Gandarela Formation is covered by canga. The Cauê Itabirite ranges in thickness on the north limb from about 25 meters in the east to 65 meters in the west. The section of the formation given below was measured along a roadcut and in a narrow canyon about 2 kilometers north of Barão de Cocais (pl. 1, N. 9,000, E. 900).

The Cauê Itabirite on the south, overturned limb of the Gandarela syncline, like the Caraça Group on the south limb, is discontinuous, as it is truncated by the Fundão fault. The itabirite forms a ridge in the town of Barão de Cocais but is not topographically prominent farther east. The band of itabirite ranges from 100 to 450 meters in width on the south limb. Outcrops on the limb are such that the thickness is difficult to determine, but the formation seems to thicken and thin irregularly between 25 and 40 meters and is in general thinner in the east.

Section of Cauê Itabirite measured along dirt road and in narrow canyon of Córrego Morro Grande (pl. 1, N. 9,000 E. 900)

[Section given from top to base; thicknesses in meters.]

Description	Top	Base	Thickness
Itabirite, gray; upper 5.1 meters not exposed. Position of contact with overlying Gandarela Formation estimated on basis of topography	00	21.1	21.1
Itabirite, gray; interbedded with yellowish-brown itabirite	21.1	22.7	1.6
Itabirite, yellowish-brown; grades downward into yellowish-brown phyllite	22.7	23.3	.6
Itabirite, gray	23.3	27.9	4.6
Itabirite, gray; interbedded with yellowish-brown itabirite	27.9	28.7	.8
Itabirite, gray; contains few thin layers of dolomitic itabirite	28.7	35.7	7.0
Itabirite, gray; interbedded with yellowish-brown itabirite	35.7	39.7	4.0
Phyllite, yellowish-brown, ferruginous	39.7	41.3	1.6
Itabirite, gray; contains few thin beds of dolomitic itabirite in lower 0.4 meters	41.3	42.5	1.2
Itabirite, gray; interbedded with yellowish-brown itabirite	42.5	46.1	3.6
Itabirite, gray	46.1	49.8	3.7
Itabirite, gray; contains few thin beds of dolomitic itabirite	49.8	51.7	1.9
Itabirite, gray	51.7	53.4	1.7
Itabirite, yellowish-brown, phyllitic	53.4	54.2	.8
Itabirite, yellowish-brown	54.2	55.9	1.7
Itabirite, gray to yellowish-brown; sheared vien of bull quartz at top of unit	55.9	57.5	1.6
Itabirite, yellowish-brown	57.5	58.2	.7
Phyllite and itabirite, yellowish-brown; phyllite increases downward	58.2	59.7	1.5
Phyllite, light-brown	59.7	62.5	2.8
Quartz, sheared vein(?)	62.5	63.0	.5
Itabirite, yellowish-brown	63.0	63.4	.4
Itabirite, brown, phyllitic; sheared bull quartz in upper 0.2 meters	63.4	64.1	.7
Phyllite, yellowish-brown; contains few thin ferruginous layers. Contact with underlying Batatal Formation conformable and gradational. Total thickness of Cauê Itabirite 64.4 meters	64.1	64.4	.3

GANDARELA FORMATION

The Gandarela Formation was named by Dorr (1958b) for exposures in the central part of the Quadrilátero Ferrífero. The formation is composed of dolomitic and ferruginous phyllite, itabirite, and dolomitic itabirite. Dolomite, common in the upper part of the formation and locally present in the lower part of the formation elsewhere, does not crop out in the Barão de Cocais area. The greatest part of the formation is covered by canga; where it is not covered, it weathers to a subdued terrain and is poorly exposed.

Dolomitic and ferruginous phyllites range in color from yellowish-brown to brown and black. Although dolomite was identified in only a few thin sections and in these was sparse, its former presence in larger quantities is indicated by the porosity of the phyllite. The iron of these phyllites occurs as very thin laminae of specularite, as brownish hydrous iron oxide along some of the specularite bands, and as disseminated grains throughout the rock. The color of the black phyllites is due both to specularite and to manganese oxide, which is considered to be a residue from the dissolution of dolomite. Chlorite is a common mineral in these phyllites; sericite and quartz are less common.

Some itabirite in the Gandarela Formation is lithologically identical with itabirite in the Cauê Itabirite but can be distinguished in the field by its lack of lateral continuity. No lens of itabirite in the Gandarela Formation is known to be over 100 meters long. Some itabirite in the Gandarela Formation has quartz-rich layers three or four times the thickness of the hematite-rich layers, whereas in the Cauê Itabirite the layers are about equal in thickness.

The Gandarela Formation crops out on each limb of the Gandarela syncline in the west half of the Barão de Cocais area. On the north limb it forms a band 200–600 meters wide, and on the south limb, a band 250–500 meters wide. As a result of the general westward plunge of the syncline, the belts converge to occupy the core of the syncline and form a band 600–1,400 meters wide to the east. The thickness of the Gandarela Formation ranges from an estimated 40 meters in the east to a measured 65 meters near the west boundary of the area. (See measured section below.) Accurate estimates of thickness cannot be made elsewhere because of poor exposures. In the Gongo Sôco quadrangle to the west the formation is several times thicker than it is to the east (Moore, written commun., 1963).

Although flowage during folding possibly could have caused some variation in the thickness of the Gandarela Formation, some variation resulted from erosion prior to deposition of the Cercadinho Formation. Dolomite lenses, some of which are several tens of meters thick, are particularly prominent in the upper part of the Gandarela Formation in the southwest part of the Gandarela syncline, but they are unknown in the Barão de Cocais area. Inasmuch as the lithology of the lower part of the Gandarela Formation in the Gongo Sôco quadrangle closely resembles and may be equivalent to that of the entire Gandarela Formation in the Barão de Cocais area, the upper part of the Gandarela in the Gongo Sôco quadrangle does not appear to be represented in the Barão de Cocais area.

Section of Gandarela Formation measured along Barão de Cocais—Caeté road and in a railroad cut about 1 kilometer north of Barão de Cocais (pl. 1, N. 8,500 E. 400)

[Section given from top to base; thickness in meters]

Description	Top	Base	Thickness
Quartzite of the Cercadinho Formation. Weathered mafic sill, tan to reddish-brown, 3.3 meters thick.			
Phyllite, brown to black; has high content of manganese oxide; contains many thin laminae of specular hematite. Top of Gandarela Formation	0	4.8	4.8
Phyllite, yellowish-brown; few itabirite layers decrease downward; contains trace of manganese oxide	4.8	5.6	.8
Itabirite, gray; alternates with layers of phyllite containing manganese oxide	5.6	9.7	4.1
Specularite laminae alternating with thin layers of phyllite, some of which is arenaceous and others which contain manganese oxide	9.7	10.9	1.2
Itabirite, gray; content of yellowish-brown dolomitic itabirite decreases downward	10.9	13.8	2.9
Itabirite, dolmitic, light- and dark-brown; shows abundant manganese oxide stain	13.8	21.8	8.0
Itabirite, dolomitic, light-yellowish-brown; contains some greenish-yellow itabirite and arenaceous dolomitic phyllite and a few thin laminae of specular hematite	21.8	28.3	6.5
Phyllite, yellowish-brown	28.3	35.1	6.8
Itabirite, gray	35.1	43.2	8.1
Itabirite, gray, contains thick quartz layers and trace of dolomite	43.2	47.0	3.8
Itabirite, gray; contains quartz layers as much as 3 cm thick; grades downward into yellow arenaceous dolomitic phyllite	47.0	47.9	.9
Phyllite, gray to yellow, ferruginous and arenaceous	47.9	53.3	5.4
Phyllite, light yellowish-brown; contains few thin layers of itabirite	53.3	58.1	4.8
Covered, probably phyllite. Base of Gandarela Formation. Total thickness of Gandarela Formation 65.4 meters	58.1	65.4	7.3

PIRACICABA GROUP

CERCADINHO FORMATION

The Piracicaba Group is represented in the Barão de Cocais area only by its lowest formation, the Cercadinho Formation. The Cercadinho Formation was named by Pomerene (1958) for exposures in the west part of the Quadrilátero Ferrífero. The formation contains several distinctive types of lithology and crops out well in many places. The formation contains quartzite, conglomerate, phyllite, and schist. In general, it is more arenaceous toward the base and more phyllitic toward the top.

Most of the quartzite is gray, tan, or pale grayish green, is very fine to medium grained, and contains abundant disseminated white mica. Hematite generally is disseminated through the quartzite and locally is concentrated in thin beds, but some beds, particularly those near the base of the formation, have little if any hematite. Beds are several millimeters to several centimeters thick and are both interbedded with phyllite and schist and in sets as much as several meters thick. Some bedding sets of quartzite form lenses 10 meters or more thick and several hundred meters long. Much of the bedding was originally horizontal, but small scale cross beds from 1 to 10 cm long are common.

Where hematite is concentrated in layers, quartzite resembles itabirite, but, the hematite-rich layers are less continuous than hematitic laminae in itabirite, and at places they are crossbedded, a feature not found in itabirite.

Hematite apparently was mobilized at one place in the quartzite of the Cercadinho Formation and redeposited in several veins 1–3 cm thick (pl. 1, N. 7,700, E. 300). A chip sample from one vein contained, in percent: Fe, 67.9 (Fe_2O_3, 97.9; FeO, 1.1); SiO_2, 1.2; P, 0.14. (Analyzed by J. B. de Araujo, Ministério das Minas e Energia, Belo Horizonte.)

Many thin beds of micaceous quartzite schist are interbedded with typical phyllite and schist. In thin section the original quartz grains are seen to be crushed and strained, and many mica flakes lie obliquely at low angles with the bedding.

Granule conglomerate and pebble conglomerate occur in the Cercadinho Formation, and granule conglomerate is the more abundant rock. At many places the quartz granules were deformed by shearing along bedding into spindle-shaped ricelike grains. The field term "rice grit" is sometimes used in describing such conglomerate (Pomerene, 1964, p. 23). Pebble conglomerate is uncommon, but occurs at several places near the northern outskirts of Barão de Cocais. Most pebbles, consisting of rounded quartzite and some quartz, are 1 cm or less in maximum diameter; a few as large as 4 cm were found. The lenses in which the pebbles occur are 1–2 meters long and 10–30 cm thick.

Most phyllite and schist in the Cercadinho Formation is silvery gray to pink or shades of brown; all are weathered. The silvery-gray to pink phyllite has a lustrous sheen resulting from the presence of hematite. The hematite is too fine grained to be resolved by the hand lens in many samples, yet is in such abundance that the rock yields a red streak where scratched. The field terms "silver phyllite" and "silver schist" (Pomerene, 1964, p. 24) have been used to describe this rock. In thin section "silver phyllite and schist" are seen to consist of sericite with considerable fine-grained quartz and hematite.

Brown phyllite containing little or no hematite occurs interbedded with other phyllite only locally in the incomplete section in the Barão de Cocais area; this phyllite is common in the upper part of the Cercadinho Formation where the entire formation is present. Some brown phyllite is slightly porous and is stained with manganese oxide. This staining is a common feature of weathered dolomitic phyllite in the upper part of the Cercadinho Formation in the western Serra do Curral where the formation undergoes a transition into the dolomitic phyllite and argillaceous dolomite of the overlying Fêcho do Funil Formation. The manganese oxide suggests that dolomite was present in some phyllite of the Cercadinho Formation in the Barão de Cocais area before weathering, even though no dolomite is now found in thin sections of this rock.

The Cercadinho Formation occupies the core of the isoclinally folded Gandarela syncline in the west half of the mapped area and crops out there in a belt as much as 1,320 meters wide. To the east the formation appears in two locally downfolded areas along the synclinal axis.

A complete section of the Cercadinho Formation could not be measured because the axis of the Gandarela syncline is difficult to locate, the rocks are complexly folded and faulted, and continuous outcrops are sparse. The maximum thickness of the Cercadinho Formation, estimated at the west boundary of the Santa Bárbara quadrangle, is 225 meters. The following partial section, typical of much of the formation, was measured near Barão de Cocais:

Partial section of the Cercadinho Formation measured in railroad cut one-half kilometer north of Barão de Cocais (pl. 1, N. 8,200, E. 1,500).

[Section given from top to base; thickness in meters]

Description	Top	Base	Thickness
Phyllite, dark bluish-gray; contains pits from weathered secondary mineral	0	1.2	1.2
Phyllite, gray, pink, and brown	1.2	2.0	.8
Quartz schist, bluish-gray, very fine grained to medium-grained; contains many thin plates of specularite disseminated and concentrated in thin bands; numerous streaks of gray phyllite present; larger quartz grains have spindle shapes resembling grains of rice; most of specularite in lower 0.8 meters hydrated to limonite	2.0	4.8	2.8
Schist, silvery-gray; contains many laminae of quartzite schist containing white mica; hematite content of phyllitic schist high enough to give red streak; pulverized quartz present in some laminae	4.8	5.2	.4
Alternating laminae of silvery-gray schist and gray, pink, and orange quartzite schist and schist	5.2	5.8	.6
Quartzite, tan to gray, fine- to medium-fine,-grained, crossbedded; gray layers contain concentrations of specularite	5.8	6.9	1.1
Phyllite, gray to tan; contains few thin beds of specularitic quartzite	6.9	7.3	.4
Quartzite, brown, fine-grained, friable; contains abundant argillaceous material	7.3	7.4	.1
Quartzite, gray, fine-grained; contains abundant flakes of specularite and many laminae of gray phyllite	7.4	7.7	.3
Phyllite, light to dark silvery-gray; yields red to pink streak; content of thin layers of tan quartzite increases downward	7.7	9.0	1.3
Quartz schist, light- to dark-gray, very fine grained to medium-grained; contains abundant white mica and many layers of dark silvery-gray phyllite	9.0	10.5	1.5
Phyllite, silvery-gray, poorly exposed; contains thin layers of "rice grain" quartzite	10.5	11.0	.5
Quartzite, white to pink, tan, and brown, fine-grained containing a few coarse grains; contains abundant white mica and many thin laminae containing high concentration of specularite, some of which has weathered to limonite; shows few streaks of gray phyllite	11.0	12.1	1.1

A disconformity at the base of the Piracicaba Group has been recognized over most of the Quadrilátero Ferrífero since 1956 (Oliveira, 1956, p. 7, 10–11). Although it is not exposed in the Barão de Cocais area, this contact of the Cercadinho Formation with the underlying Gandarela Formation is considered a disconformity or low angular unconformity. The thinning of the Gandarela Formation from west to east across the

Barão de Cocais area (p. H18) suggests that the contact of the Cercadinho and Gandarela Formations is discordant and truncates successively lower beds to the east.

The only exposure of the base of the Cercadinho Formation and the top of the Gandarela Formation is in a railroad cut 100 meters south of the intersection of the Barão de Cocais–Caeté road and the Central do Brasil Railroad (pl. 1, N. 8,700, E. 700). There, a weathered mafic sill 3.3 meters thick separates quartzite in the Cercadinho Formation from phyllite in the Gandarela Formation. Differential movement along the base of the quartzite resulted in drag folding in the sill and in the phyllite of the Gandarela Formation. If an angular difference originally existed between the two formations, it is not evident at this outcrop.

CENOZOIC DEPOSITS

Cenozoic deposits in the Barão de Cocais area consist of alluvium, colluvium, canga, and laterite. Canga, including some laterite that is difficult to separate from canga, and colluvial deposits with economic potential are indicated on the geologic maps (pls. 1, 2). Other colluvial deposits, laterite, and alluvium were not studied or mapped. Economic colluvial deposits and the economic aspects of canga are discussed in the section concerning mineral deposits; their geologic aspects are discussed here.

CANGA

Canga is an indurated colluvial deposit composed of detritus of itabirite and compact hematite cemented by limonite. The detritus may contain other types of rocks (fig. 10), and part of the cement may be admixed aluminum hydroxide and manganese oxide. Detritus ranges in size from silt to boulders, and either itabirite or hard hematite may be the sole constituent. The percentage of limonite ranges from the minimum necessary to form a coherent mass to more than 90 percent of the rock.

Canga is light yellowish brown to very dark brownish black. Lighter colors are associated with recently exposed canga and with aluminum hydroxide mixed with the limonite cement. Though usually porous, canga is fairly impermeable and resistant to erosion. Canga occurs on and in unconsolidated sediments (fig. 11*A*), on itabirite (fig. 11*B*), and, less commonly, on other rocks (fig. 11*C*).

Three principal types of canga are recognized: canga, canga rica, and chemical canga. Canga, sometimes referred to as ordinary canga and normal canga, generally occurs on slopes near the source of detritus and is exposed at the surface or covered by 1–2 meters of soil. Canga in which hard hematite is so abundant that the iron tenor is more than 64 percent is called canga rica. It occurs down slope from hard-hematite bodies or places from which hard hematite was eroded. Canga made up almost entirely of limonite and containing only fine detritus is known as chemical canga. It occurs at some distance from the source of detritus, generally in valley flats and in unconsolidated sediments and residuum. Structure canga (p. H37) is weathered itabirite; it closely resembles canga, and at many places the two rocks are indistinguishable.

FIGURE 10.—Canga containing a small pebble of quartzite (at pencil point).

In the Barão de Cocais area canga covers 22 square kilometers, mostly in erosional remnants of a large sheet, 15 kilometers long and 4 kilometers wide, which once lay over the entire south flank of the Serra do Tamanduá. A few small sheets occur on the north slope of that range, and an isolated sheet covers three-quarters of a square kilometer near the southwest corner of the area.

The crest of the Serra do Tamanduá coincides with the outcrop of the Cauê Itabirite on the north limb of the Gandarela syncline. Canga derived from that band extends downslope to the south across the axis of the syncline and onto the topographically lower south limb of the structure, where additional canga is derived from the Cauê Itabirite in the south limb. Detritus from the Cauê Itabirite is the chief source of canga, but itabirite in the Gandarela Formation and iron-formation in the Rio das Velhas Series are minor sources.

Several unusual occurrences of canga are noteworthy. The sheet of canga in the southwest corner of the mapped area (pl. 1) is derived from iron-formation in the Nova Lima Group. The sheet is only a few centimeters thick at most places, and it appears to have been continuous with limonite-cemented gravel along the Rio Conceição at one time.

A

B

C

FIGURE 11.—Occurrences of canga. *A*, In unconsolidated sediments; scale shown by camera. *B*, Overlying itabirite; contact exposed in cave in the Serro do Tamanduá. *C*, Overlying Cambotas Quartzite.

Canga on the north slope of the eastern Serra do Tamanduá (pl. 2) makes up an alluvial fan in contact with Cambotas Quartzite. Botryoidal structures are found on the upper surface of the sheet, and the underlying quartzite is devoid of traces of limonite. Botryoidal structures are considered diagnostic of "growing surfaces" (Pomerene, 1964, p. 30–31; Simmons, 1960); their presence on the upper surface in conjunction with the lack of limonite in the quartzite indicates that waters carrying iron oxide did not migrate upward through the quartzite. The limonite was evidently precipitated at the place of solution or was transported slightly downslope before precipitation.

A layer of manganiferous chemical canga is exposed in a pit at the Brucutú 54 mine (p. H40). The layer is 1–3 meters thick and lies 5 meters below the surface; locally it contains more than 8 percent manganese. The canga occurs in an argillaceous residuum, presumably derived from argillaceous dolomite. The manganese is considered a residual concentration from the dolomite, and the limonite was undoubtedly precipitated from extraneous solutions.

Different origins for cangas are indicated by the different environments in which limonite has been precipitated. In surficial cangas, such as those blanketing the south slope of the Serra do Tamanduá, obviously the limonite was precipitated near its source in the hematite-rich colluvium. Chemical cangas occur interbedded with unconsolidated sediments at depths of several to several tens of meters. The weathered condition and lack of iron in sediments which overlie chemical canga and the presence of hematite in unweathered underlying sediments suggest that iron was leached from the upper sediments and deposited in the canga layer below. At other places such as the Brucutú 54 mine the fairly low iron content of sediments above and below the chemical canga indicates that the limonite was precipitated from waters that had dissolved iron elsewhere. Thus, geologic evidence indicates at least two different chemical processes in the formation of canga: one in which iron is precipitated at or very close to its source, and another in which iron remains in solution long enough to be carried into the subsurface before it is precipitated.

Several recent papers concerning the chemistry of iron in natural water explain chemical reactions that provide a new insight to the formation of canga (Hem and Cropper, 1959; Hem, 1960a, b; Oborn, 1960; Oborn and Hem, 1961). Relatively simple inorganic chemical reactions may account for the precipitation of limonite to form canga at and near the surface; the formation of chemical canga in the subsurface apparently involves more complex inorganic and organic reactions.

Two factors controlling the solution and precipitation of ferric iron are the pH and Eh of aqueous solutions. Hem and Cropper (1959, p. 2) pointed out that,

> Iron in aqueous solutions is subject to hydrolysis. The iron hydroxides formed in these reactions, especially the ferric form, have low solubility. The retention of iron in solution is consequently affected by the pH of the solution. In most natural waters, the pH is not low enough to prevent hydroxides from forming, and under oxidizing conditions, practically all the iron is precipitated as ferric hydroxide * * *.

Thus, when hematite is taken into solution it is hydrolized, probably to $Fe(OH)_3$. In the normal pH range of natural water (5–8), ferric hydroxide has a very low solubility (Hem and Cropper, 1959, p. 3), and limonite would be readily precipitated under oxidizing conditions.

Three conditions, then, must be met before canga can form: abundant hematite must be present because of its low solubility; rainfall must be high so that significant amounts of relatively insoluble hematite are dissolved, and oxidizing (near-surface) conditions must prevail close to the hematite source so that limonite is precipitated rapidly. All these conditions are at an optimum in the Barão de Cocais area. The mechanical weathering of itabirite has covered slopes with hematite-rich debris; the rainfall, though seasonal, is abundant; and many slopes covered with hematite-rich colluvium are in a highly oxidizing environment.

Because of the low solubility of ferric iron and the facility with which it is precipitated under oxidizing conditions, the ground water probably contains little iron derived from inorganic chemical reactions, perhaps too little for the formation of chemical canga. However, soluble iron complexes that oxidize very slowly are derived from numerous biochemical reactions, and these reactions are probably responsible for much of the iron in ground water. Soluble complexes result from the decay of plant matter (Oborn, 1960, p. 117), the combination of organic compounds with inorganic iron (Hem, 1960b, p. 93), and the action of microorganisms (Oborn and Hem, 1961).

Ground water in the Quadrilátero Ferrífero is generally acidic, undoubtedly as the result of carbon dioxide derived from plant respiration and decay (Hem, 1960a, p. 35). Dissolved iron which is able to remain in solution until it is below the zone of oxidation is therefore carried in acid solutions. As preveiously mentioned, the pH normally has little effect on the solution and precipitation of iron in an oxidizing environment, but it is the controlling factor in a reducing environment. For iron to be precipitated, the acid solutions must be diluted or neutralized by contact with alkaline substances or mixture with alkaline solutions, or the acid solutions must enter an oxidizing environment where pH will be ineffective in preventing the hydrolysis of iron and precipitation of limonite.

Oxidation may take place at the surface of the water table during the dry winter season. At this time of year the position of the water table is stable and relatively low. Limonite precipitated under these conditions would be expected to occur in a layer subparallel to the surface, and the attitude of chemical canga exposed in excavations confirms that this is possible. Neutralization is most likely to take place near bodies of carbonate rock. Although no body of carbonate rock is exposed in the Barão de Cocais area, the precipitation of limonite at the Brucutú 54 mine may be partly attributed to the presence of dolomite at one time (p. H41).

IGNEOUS ROCKS

GRANITIC ROCKS

Five principal petrologic types of granitic rock are present in the Quadrilátero Ferrífero. On the basis of potassium-argon ages determined from biotite, Herz and others divided the granitic rocks into four age groups, one with two facies (Herz and Dutra, 1958; Herz, 1959; Herz and others, 1961). Subsequent to the completion of mapping in the Quadrilátero Ferrífero, other age studies were made by L. T. Aldrich (unpub. data). These studies include rubidium-strontium and potassium-argon determinations on feldspars and micas; they indicate that the history of granitic rocks is more complicated than previously envisioned. For this reason Herz' groups are used in this report only in the sense of their petrologic connotations.

Rocks in Herz' Groups I and II do not occur in the Barão de Cocais area. Two gneisses of Group IV in the area, however, may be partly derived from rocks of Group II.

Rocks of Group III occur in two very different facies, a granitic gneiss facies and a granitic facies. Although the granitic gneiss is the most abundant granitic rock in the Quadrilátero Ferrífero, it does not occur in the Barão de Cocais area, but it may be genetically related to rocks of Group IV, which are present.

A phase of the granitic facies of Herz' Group III is present in the area. It is a coarse-grained granite composed of aggregates of perthitic feldspar, quartz, and biotite. This granite occurs only in the east part of the Quadrilátero Ferrífero and was first mapped in the Itabira district, where it was named the Borrachudos Granite by Dorr and Barbosa (1963, p. 42). In the Barão de Cocais area, this granite is named the Petí phase of the Borrachudos.

The two larger parts of the Barão de Cocais area underlain by granitic rocks are underlain by rocks of Herz' Group IV, here informally termed the gneisses of Cocais and Santa Bárbara. Both gneisses extend into adjoining areas where their relations with unnamed and formally named granitic rocks are incompletely known. J. V. N. Dorr 2d (written commun., 1965) considered the gneiss of Cocais the same as and continuous with the complex at Caeté to the west and with the unnamed gneiss to the north in the Itabira district, and he considered the gneiss of Santa Bárbara the same as the Monlavade Gneiss to the east in the Monlevade district.

In the Barão de Cocais area the gneisses are fine- to medium-grained granodiorite composed of perthitic microcline, sodic plagioclase, quartz, biotite, muscovite, and epidote. These gneisses of Herz' Group IV may have resulted from the partial remobilization of rocks of Group II when the gneissic facies of Group III was emplaced.

GNEISS OF COCAIS

The informal term gneiss of Cocais is here applied to the granodiorite gneiss in the north part of the Barão de Cocais area. The name is taken from the town of Cocais, situated on the gneiss and near which the gneiss crops out at several places. Biotite from this gneiss (pl. 2, north boundary, E. 9,200) yielded a potassium-argon age of 690 million years (Herz and others, 1961, p. 1112, table 1, sample 18). This is one of the younger ages obtained from rocks of Group IV.

The gneiss of Cocais underlies 65 square kilometers in the Barão de Cocais area. It is bounded on the south by Cambotas Quartzite in the Serra do Tamanduá but is separated from that rock by a gabbro dike to the west in the Serra das Cambotas. The areal distribution of the gneiss is incompletely known, but the gneiss extends for at least 20 kilometers north and northeast of the mapped area. The gneiss of Cocais closely resembles some of the gneiss in the complex at Caeté west of the Serra das Cambotas in the Antônio dos Santos quadrangle, which adjoins the Cocais quadrangle on the west.

Like most granitic rocks in the Quadrilátero Ferrífero, the gneiss of Cocais weathers to a low-lying hilly topography. Most of the few natural exposures occur near hilltops and stream bottoms. The best exposures are in roadcuts along the new highway passing through the northeast corner of the mapped area and extending into the north half of the Cocais quadrangle.

The gneiss is light-gray fine- to medium-grained granodiorite containing quartz, sodic plagioclase, microcline, biotite, and muscovite and accessory epidote and apatite: it is weakly foliated and has discontinuous biotite-rich bands 1–2 mm thick alternating with felsic-rich bands 1 mm to 2 cm thick.

The quartz occurs as separate grains, many of which are fractured, and as vermicular replacements of oligoclase and microcline. Plagioclase is present as oligoclase and albite. The oligoclase is twinned according to the albite law and commonly contains numerous inclusions of sericite. The albite is clear and untwinned and occurs as large crystals and as replacements of oligoclase and microcline. Oligoclase and microcline occur as small crystals, many of which are myrmekitically replaced by albite and quartz. Most biotite is pleochroic from dusky yellow to olive gray.[3] A modal analysis of gneiss of Cocais is presented in table 3.

TABLE 3.—*Modal analyses (in percent) of granitic rocks in the Barão de Cocais area*

[Modified from Herz and others (1961, p. 1116); P, present; ?, presence questionable]

	Gneiss of Cocais	Gneiss of Santa Bárbara	Petí phase of Borrachudos Granite
Plagioclase	21.5	24.8	4.0
Potassium feldspar [1]	21.5	16.9	47.4
Quartz	39.8	41.3	43.2
Biotite	10.7	3.7	2.4
Muscovite	5.4	8.5	.8
Epidote	1.1	4.8	
Chlorite			P
Apatite	?	?	
Fluorite			2.0
Zircon		P	
Allanite		?	
Carbonate		P	
Opaques		P	

[1] Includes perthite.

Some trace-element values of the gneiss of Cocais are uncommonly low. The amounts of trace elements in rocks of Group IV generally are intermediate between those in rocks of Group II and those in rocks of Group III gneissic facies. However, the chromium, niobium, nickel, lead, scandium, and yttrium contents of the gneiss of Cocais are lower than the known ranges of values for rocks of both Groups II and III (table 4). The gneiss is similar to other rocks of Group IV in regard to its content of barium, cobalt, copper, gallium, lanthanum, tin, strontium, vanadium, and zirconium.

The gneiss of Cocais is younger than the Tamanduá Group and probably is younger than the Minas Series.

[3] Petrographic description partly based on unpublished data of Norman Herz (written commun., 1961).

The gneiss intrudes and has a metasomatic contact with the Cambotas Quartzite and is therefore younger than the quartzite. The unusually large size of magnetite crystals in the upper formation of the Tamanduá Group is considered the result of contact effects caused by the gneiss (pl. 1, N. 12,600, E. 5,300; fig. 7). The structural parallelism of the Cambotas Quartzite, the upper formation of the Tamanduá Group, and the Minas Series in the Serra do Tamanduá suggests that the gneiss of Cocais was not emplaced between the times of deposition of these units and that the gneiss is younger than the Minas Series.

TABLE 4.—*Trace-element analyses of gneisses of Cocais and Santa Bárbara compared with analyses of gneissic rocks of Group II and Group III, in parts per million*

[Adapted from Herz and Dutra (1960, p. 86) and Norman Herz, unpub. data. Analyzed by C. V. Dutra, Instituto de Tecnologia Industrial. n.d., not detected]

	Group II		Gneiss of Santa Bárbara	Gneiss of Cocais	Group III	
	Range	Average			Range	Average
Ba	895 -1610	1250	360	900	450 -1030	710
Co	5.2- 17	8.2	2.8	2.0	n.d. - 4.4	2.0
Cr	2.1- 55	25	1.9	.3	.9- 2.9	1.6
Cu	1.8- 36	13	6.0	1.9	.5- 2.0	1.2
Ga	7.4- 21	17	14	14	13 - 16	15
La	62 - 210	98	n.d.	n.d.	n.d. - 110	63
Nb	11 - 49	26	33	n.d.	11 - 28	19
Ni	2.2- 70	19	8.2	n.d.	2.0- 6.3	3.5
Pb	15 - 50	28	7.0	5.5	10 - 29	16
Sn	7.0- 61	36	15	5.0	3.5- 68	25
Sr	72 - 575	280	110	280	52 - 130	98
Sc	7.2- 15	8.8	3.0	2.1	2.5- 8.0	4.3
V	20 - 68	41	38	26	1.3- 29	10
Y	24 - 87	59	63	6.3	24 - 245	87
Zr	185 - 370	270	107	120	96 - 290	190

GNEISS OF SANTA BÁRBARA

The informal term gneiss of Santa Bárbara is here applied to the granodiorite gneiss in the southeast part of the Barão de Cocais area. The name is taken from the town of Santa Bárbara in and near which the gneiss is well exposed in several quarries. The gneiss of Santa Bárbara is assigned to Herz' Group IV. Biotite from this gneiss (pl. 1, N. 4,400, E. 9,000) yielded a potassium-argon age of 810 million years (Herz and others, 1961, p. 1112, table 1, sample 19).

Gneiss of Santa Bárbara underlies 30 square kilometers in the Barão de Cocais area. It is separated from the Nova Lima Group on the northwest by a band of chlorite-talc-antigorite schist. The areal distribution of the gneiss is incompletely known, but the gneiss has been observed to the south in the Catas Altas and Santa Rita Durão quadrangles by Maxwell (written commun., 1961) and to the east in the Florália quadrangle by Herz (written commun., 1961).

The gneiss weathers to low hilly topography. Natural exposures are rare, but the gneiss is well exposed in quarries and railroad cuts in the southeast part of the Santa Bárbara quadrangle.

The gneiss is light-gray fine- to medium-grained granodiorite containing quartz, plagioclase, microcline, muscovite, epidote, and biotite; accessory apatite, carbonate, zircon, and allanite; and opaque minerals. It is weakly foliated owing to the subparallel orientation of evenly disseminated biotite, which makes up about 4 percent of the rock.

Quartz and plagioclase are finer grained constituents, and microcline and microcline perthite are coarser. Most plagioclase is oligoclase that is polysynthetically twinned according to the albite law and that contains numerous inclusions of sericite. The biotite contains acicular rutile inclusions.[4] A modal analysis of gneiss of Santa Bárbara is presented in table 3.

A chemical analysis of gneiss of Santa Bárbara indicates its intermediate composition between rocks of Herz' Group II and gneissic rocks of Group III (table 5). The values for most of the major chemical constituents fall between the average values of those constituents in rocks of Group II and gneissic rocks of Group III and closely correspond to values obtained for analyzed rocks of Group IV in the Bacão Complex (Herz and Dutra, 1960, p. 87). The normative mineral percentages upon which the gneiss is classified as granodiorite are listed in table 6.

The amounts of trace elements in the gneiss of Santa Bárbara differ from those in other rocks of Group IV in that they lie within the range of trace elements for rocks of either Group II or Group III rather than between the ranges. Copper, niobium, and vanadium are within the range of these elements in rocks of Group II; cobalt, chromium, lanthanum, scandium, and zirconium are within the range for rocks in Group III, gallium, tin, strontium, and yttrium are within the ranges of both groups; and barium and lead in the gneiss of Santa Bárbara are below the ranges of barium and lead in both Groups II and III (table 4).

The relative age of the gneiss of Santa Bárbara could not be determined from field relations. The gneiss is in contact with a band of chlorite-talc-antigorite schist along its entire margin in the Santa Bárbara quadrangle (pl. 1). The relation between the schist and gneiss is indeterminable at their one known exposed contact (N. 4,300, E. 8,100). Gneisses similar in appearance to the gneiss of Santa Bárbara have a metasomatic relation to the Minas Series in nearby areas (Maxwell, written commun., 1962).

PETÍ PHASE OF THE BORRACHUDOS GRANITE

A rock similar to the Borrachudos Granite of the Itabira district is found in the Santa Bárbara (pl. 1) and Florália quadrangles. Herz (written commun., 1961) considered it a comagnetic phase of the Borrachudos Granite on the basis of its characteristics in the Florália

[4] Petrographic description partly based on unpublished data of Norman Herz (written commun., 1961).

TABLE 5.—*Chemical analysis of gneiss of Santa Bárbara compared with average chemical analyses of gneissic granitic rocks of Group II and Group III, in percent*

	Group II [1]	Gneiss [2] of Santa Bárbara	Group III [1]
SiO_2	67.8	72.4	74.2
Al_2O_3	14.6	14.2	13.6
Fe_2O_3	1.1	.7	.7
FeO	2.6	1.3	1.1
MgO	1.5	.32	.43
CaO	2.6	1.4	.93
Na_2O	3.8	4.3	3.2
K_2O	3.8	3.9	4.8
H_2O	.72	.50	.66
TiO_2	.57	.19	.25
P_2O_5	.25	.06	.07
MnO	.09	.08	.05
CO_2	.09	.38	.17
F	.07	.04	.04
Sum	99.6	99.8	100.2

[1] Herz and Dutra (1961, p. 87).
[2] Analyzed by P. L. D. Elmore, S. D. Botts, I. H. Barlow, M. D. Mack, H. W. Thomas, and Gillison Chloe; F by S. M. Berthold, U.S. Geol. Survey.

TABLE 6.—*Normative minerals in gneiss of Santa Bárbara and Petí phase of Borrachudos Granite, in percent*

[From Norman Herz, unpub. data. Catanorms calculated by the method of Barth (1955)]

	Gneiss of Santa Bárbara	Petí phase Borrachudos Granite
Quartz	26.8	36.9
Orthoclase	23.4	24.7
Plagioclase	[1] 39.2	[2] 33.4
Anorthite	6.6	3.6
Corundum or wollastonite	.6	.1
Enstatite	.9	.0
Ferrosilite or hematite	1.4	1.2
Magnetite	.7	.4
Ilmenite	.3	.1
Apatite	.1	.0

[1] $Ab_{85.9}$.
[2] $Ab_{90.0}$.

quadrangle. He called it the Petí phase, after good exposures at the Petí Dam on the Rio Santa Bárbara, a few hundred meters east of the Santa Bárbara quadrangle.

The Petí phase of the Borrachudos Granite is assigned to Herz' Group III. Two potassium-argon age determinations from biotite at Petí yielded ages of 463 and 473 million years (Herz and others, 1961, table 1, sample 10). These are among the youngest ages obtained for granitic rocks in the Quadrilátero Ferrífero. A rubidium-strontium age determination from feldspar, on the other hand, yielded an age of 1,230 million years (Norman Herz, unpub. data).

Granite of the Petí phase underlies 8 square kilometers in the northeast part of the Santa Bárbara quadrangle (pl. 1). The granite is only in contact with the Nova Lima Group in the Santa Bárbara quadrangle; its extent and relationships to the east in the Florália quadrangle are unknown. Unlike most granitic rocks in the Quadrilátero Ferrífero, this rock crops out in bold bluffs and is well exposed.

The Petí phase of the Borrachudos Granite is a light-gray coarse-grained granite that has a weak linear structure. The rock contains quartz, orthoclase, microcline, plagioclase, biotite, and fluorite, accessory muscovite, and traces of chlorite. The rock is composed mostly of round and pod-shaped masses of quartz and blocky perthitic orthoclase and microcline. Quartz and small amounts of feldspar are present as fine-grained interstitial material between quartz and feldspar aggregates. Orthoclase is also present as large clear crystals. All plagioclase is albite (Ab_{97-100}) in large clear untwinned crystals and in many places is difficult to distinguish from orthoclase. Biotite occurs in elongated aggregates which impart the linear structure to the granite. In places fluorite makes up more than 2 percent of the rock; it occurs as fine grains in the interstitial quartz and along the borders of quartz and feldspar aggregates. A modal analysis is listed in table 3, and normative minerals are listed in table 6.

The low calcium, iron, and magnesium contents and the high fluorine content of the rock indicate that it crystallized at low temperatures; this is confirmed by the absence of contact metamorphic effects in the phyllites and schists of the intruded Nova Lima Group. Not only a low content of anorthite molecule in plagioclase but a fluorine content sufficiently high to produce a rock containing 2 percent fluorite suggest crystallization at temperatures more similar to those of a pegmatite than to those of a normal granitic magma. The similarity of the granite at Petí Dam and the Borrachudos Granite is evident from their chemical composition (tables 7, 8).

Based on field relations, the age of the Petí phase granite can be given only as post-Nova Lima Group, but the rock is unfoliated and therefore probably younger than the last deformation or post-Minas Series. Its texture also indicates that it is younger than the gneisses of Cocais and Santa Bárbara. Dorr and Barbosa (1963, p. 44–45) also concluded that the Borrachudos Granite is younger than the latest metamorphism in the Itabira district, 20 kilometers northeast of the granite at Petí.

MAFIC ROCKS

CHLORITE-TALC-ANTIGORITE SCHIST

Chlorite-talc-antigorite schist occurs in a northeast-trending belt 12 kilometers long and 200–500 meters wide in the southeast part of the Santa Bárbara quadrangle (pl. 1). The rock extends for an unknown

TABLE 7.—*Chemical analyses comparing the Petí phase of the Borrachudos Granite and the Borrachudos Granite, in percent*

[From Norman Herz, unpub. data. Analyses by P. L. D. Elmore, S. D. Botts, I. H. Barlow, M. D. Mack, H. W. Thomas, and Gillison Chloe; F by S. M. Berthold, U.S. Geol. Survey]

	Petí phase of Borrachudos Granite	Borrachudos Granite
SiO_2	77.8	74.2
Al_2O_3	11.7	12.7
Fe_2O_3	.4	1.0
FeO	1.0	1.1
MgO	0	.02
CaO	.71	.80
Na_2O	3.6	3.5
K_2O	4.1	5.1
H_2O	.52	.36
TiO_2	.08	.14
P_2O_5	.00	.02
MnO	.04	.04
CO_2	.06	.13
F	.52	.37
Sum	100.5	99.5

TABLE 8.—*Trace-element analyses comparing the Petí phase of the Borrachudos Granite and the Borrachudos Granite, in parts per million*

[From Norman Herz, unpub. data. Analyses by C. V. Dutra, Instituto de Tecnologia Industrial; n.d., not detected, below the limits of sensitivity]

	Petí phase of Borrachudos Granite	Borrachudos Granite
Ba	13	450
Co	n.d.	n.d.
Cr	n.d.	.8
Cu	2.0	4.4
Ga	24	24
La	120	230
Nb	112	57
Ni	4.0	2.7
Pb	23	33
Sn	77	17
Sr	14	42
Sc	n.d.	n.d.
V	n.d.	8.1
Y	200	320
Zr	270	410

distance to the northeast in the Florália quadrangle and forms a wider band to the southwest in the Catas Altas quadrangle (Maxwell, written commun., 1961). The schist lies between the Nova Lima Group and gneiss of Santa Bárbara, but its relation to these rocks is unknown.

At most places the weathered schist is dark-brownish-red to light-brown clay. The freshest known outcrop of this rock is in a railroad cut near Santa Bárbara (pl. 1, N. 4,300, E. 8,000); there the rock is dark grayish green and consists of chlorite, talc, and antigorite. Talc is the most abundant mineral at another exposure 2 kilometers to the northeast (pl. 1, N. 5,800, E. 9,000). At all but one exposure, which is adjacent to the gneiss of Santa Bárbara (pl. 1, N. 4,900, E. 8,900), the schist has a strong foliation parallel to the foliation in the Nova Lima Group. Small weathered dikes of chlorite, talc, and antigorite occur in the Nova Lima Group in the Barão de Cocais area; the best exposure is of a chlorite-talc dike several centimeters thick that crosscuts phyllite and iron-formation in and near the portal of the São Bento mine (pls. 1, 3).

Although the foliation of the schist in the northeast-trending belt is concordant with that of the Nova Lima Group, the belt diverges at an angle of 30° from the trend of the iron-formation in the Nova Lima Group 3 kilometers northeast of Santa Bárbara (pl. 1, N. 6,900, E. 10,600), and this divergence suggests that the rock is intrusive. The fact that similar rocks intrude the Rio das Velhas Series elsewhere in the Quadrilátero Ferrífero (Guild, 1957, p. 25–26; Gair, 1962, p. 44–46; Johnson, 1962, p. 23–24) also supports this conclusion.

CHLORITE SCHIST

Weathered mafic intrusives that are altered to chlorite schist are sparsely distributed in the gneiss of Santa Bárbara in the Minas Series, and possibly in the Nova Lima Group. They are medium to light reddish brown and are composed of chlorite and minor quantities of sericite and quartz. Dikes in the gneiss of Santa Bárbara are exposed in railroad cuts along the Central do Brasil Railroad southeast of Santa Bárbara. The best exposure in the Minas Series is in a railroad cut 1 kilometer north of Barão de Cocais (pl. 1, N. 8,700, E. 700), where a chlorite schist sill 3.3 meters thick separates the Gandarela and Cercadinho Formations.

GABBRO

Plugs, dikes, and sills of gabbro and gabbro porphyry are widely distributed in the gneiss of Cocais and Cambotas Quartzite. The largest body is a stock about 4 kilometers long and 1 kilometer wide that intrudes both gneiss and quartzite near the northwest corner of the Santa Bárbara quadrangle (pl. 1). Numerous sills and dikes extend from this stock into the Cambotas Quartzite; one such dike extends northward into the Cocais quadrangle (pl. 2) and thence northwestward into the adjoining Antônio dos Santos quadrangle. This dike lies between quartzite in the Serra das Cambotas to the west and gneiss of Cocais to the east. Another dike, 3 kilometers long, extends from the Cambotas Quartzite at the east end of the Serra do Tamanduá northward into gneiss of Cocais (pl. 2).

The gabbro is dark green and medium grained and contains plagioclase, pyroxene, and accessory magnetite; with one exception, it is not foliated, although in a few dikes plagioclase laths are alined along contacts. In thin section the rock is seen to contain plagioclase (andesine and labradorite), pale-brown pigeonite, blue-green uralite, biotite, magnetite, ilmenite, and leucoxene. The uralite rims the pigeonite, and at least some of the biotite was derived from the uralite.

The rock readily weathers to dark-brownish-red argillaceous saprolite and soil, and natural exposures of fresh gabbro are uncommon. Most fresh rock is found in cliffs and stream bottoms on the east flank of the Serra das Cambotas. Despite the sparsity of exposures, the gabbro is easily located because of the contrast of its weathering products with those of quartzite and gneiss.

The gabbro dikes, which are much less resistant to weathering than the quartzite are generally marked by distinct linear depressed areas covered with red soil and can be traced without difficulty. A similar pattern exists in the Serra do Caraça, where Maxwell (written commun., 1961) was able to map a network of mafic dikes largely on the basis of soil and topography. The gabbro is somewhat more resistant to weathering than gneiss of Cocais, and in that terrane it weathers to form subdued hills. Because of the lack of sharp topographic differences, however, gabbro-gneiss contacts mapped on the basis of soil differences are not as accurately located as similarly mapped gabbro-quartzite contacts.

The structural relations of a dike and sill at the east end of the Serra do Tamanduá (pl. 2) merit discussion. The dike strikes north and is 3 kilometers long; for most of its length the dike intrudes gneiss of Cocais, but at its south end it intrudes Cambotas Quartzite. Although its contacts with the quartzite are covered, the dike seems to be offset by faults. Strong joint sets in the quartzite parallel the inferred structures, which on the basis of topography must be normal faults.

A sheared sill of gabbro, largely altered to chlorite schist, extends southwest from the south end of the dike. Unaltered remnants of gabbro occur in spo adic lenses as much as 10 cm in length. Differential movement between the overlying and underlying Cambotas Quartzite undoubtedly produced the shear.

The inferred faults and sheared sill suggest tectonic movement following gabbroic intrusion and, if correctly interpreted, indicate the most recent deformation known in the Quadrilátero Ferrífero. The possibility remains that the sill may be older than the dike and related to rocks intrusive into the Minas or Rio das Velhas Series and gneiss of Santa Bárbara. If this is true, the Serra do Tamanduá occurrence would confirm the original gabbroic composition of some of those older intrusives.

AGES OF MAFIC INTRUSIONS

Ultramafic and associated mafic rocks intrude rocks of pre-Minas age throughout the Quadrilátero Ferrífero, as noted by Dorr and confirmed in the Nova Lima and Rio Acima quadrangles by Gair (1962, p. 44) and in the Dom Bosco and Rio Acima quadrangles by Johnson (1962, p. 23). These authors found that serpentinite and associated metagabbro and talc schist occur only in the Nova Lima Group, and, hence, these rocks represent the oldest period of mafic intrusion. This author considers the chlorite-talc-antigorite dikes in the Barão de Cocais area to be related to these post-Nova Lima Group and pre-Minas Series intrusions.

Plugs, dikes, and sills of gabbroic and diabasic rocks are considered to represent the youngest period of intrusion and may be of post-Precambrian age. These rocks intrude the Minas Series and gneissic rocks in the Nova Lima quadrangle (Gair, 1962, p. 46–47), the Minas Series in the Ibirité, Macacos, and Belo Horizonte quadrangles (Pomerene, 1964, p. 35), and the Borrachudos Granite and Rio das Velhas Series in the Itabira quadrangle (Dorr and Barbosa, 1963, p. 46–47). The similarity of gabbro intrusions in the Barão de Cocais area to those in other parts of the Quadrilãtero Ferrífero indicates that such intrusions in the report area are also younger than the Minas Series. The lack of foliation in the gabbro and the fact that it intrudes the Borachudos Granite, the only other unfoliated rock in the iron region, indicate that the gabbro is the youngest rock, canga excepted, in the Quadrilátero Ferrífero.

Mafic dikes and sills that are altered to chlorite schist are apparently intermediate in age between the chlorite-talc-antigorite schist and gabbro. The chlorite schist can be differentiated from the oldest period of mafic intrusives because it occurs in the Minas Series and it is not associated with ultramafic rocks. The presence of the chlorite schist in the Minas Series indicates that the original mafic rock was intruded prior to the conclusion of the last regional metamorphism and hence is older than the unfoliated Borrachudos Granite and the unfoliated gabbro which intrudes the granite. This substantiates the conclusions of Dorr and Barbosa (1963, p. 45) in regard to the age of similar schists in the Itabira district.

STRUCTURE

Parts of six major structural features occur in the Barão de Cocais area: the Cocais gneiss dome, the Cambotas homocline, the Santa Bárbara gneiss dome, a group of northeast trending isoclinal folds, the Gandarela syncline, and the Fundão thrust fault. A seventh feature, a thrust fault, is postulated to be present between the Cocais dome and the Cambotas homocline.

COCAIS GNEISS DOME

The Cocais gneiss dome is a large structure bounded on the south by the Gandarela syncline and on the east by a gabbro dike that separates it from the Cambotas homocline. Only the southwest part of the dome lies in the mapped area. Gneiss of Cocais is the only recognized gneiss in the dome. In better known gneiss domes in the Itabirito district (Herz and others, 1961, p. 1113) and in the western Serra do Curral region (Simmons, 1968), gneisses of Herz' Groups III and IV occur on the fringes of the domes and envelop older granitic rocks in the central parts of the domes. If the structure of the Cocais dome is analogous to that of the better known gneiss domes, then older granitic rocks should occupy the central part of the dome, but this has not yet been ascertained.

Foliation in the Cocais dome, outside of contact zones, generally strikes about north-northwest and dips 30°–60° E. Limited observations at the south margin of the dome near the Gandarela syncline indicate somewhat irregular attitudes of foliation, and the rocks generally strike parallel to the edge of the dome and dip southward somewhat more steeply than the rocks in the syncline. Foliation in the dome near the dike separating it from the Cambotas homocline is indeterminable; however, the regional foliation in the dome is approximately parallel to the attitude of the homocline.

The regional foliation in the Cocais dome strikes at 90° to the trend of the Gandarela syncline. This discordance in orientation suggests that the foliation and the syncline resulted from different forces during different tectonic periods. If this is true, the foliation in the gneiss dome is probably older because the Gandarela syncline formed during the last major orogeny in the Quadrilátero Ferrífero (Dorr, in Departmento Nacional da Produção Mineral, 1959, p. 96–97).

CAMBOTAS HOMOCLINE

Only a small part of the Cambotas homocline is in the Barão de Cocais area. The following description is to a large extent based on reconnaissance north of the Quadrilátero Ferrífero and in the António dos Santos and Gongo Sôco quadrangles mapped by S. L. Moore (written commun., 1962).

The Cambotas homocline is a complex structure trending north-northwest and dipping eastward, but it deforms only the Cambotas Quartzite. The structure is bounded on the west by the complex at Caeté, which is a gneiss dome; to the east it is separated from the Cocais dome by a gabbro dike. The homocline is flexed to the southwest at its south extremity, where it forms a structural nose around the southeast part of the complex at Caeté; the north boundary is unknown.

The homocline is about 5 kilometers wide at its south end near the west boundary of the Barão de Cocais area. From its south end the homocline extends northward for about 6 kilometers to a place near the north boundary of the Quadrilátero Ferrífero in the António dos Santos quadrangle. There, for a distance of 1 kilometer, the homocline has been eroded, and the underlying gneiss in the complex at Caeté is exposed. Farther north the homocline continues again for more than 8 kilometers. Thus, the structure, although discontinuous, is more than 16 kilometers long.

Structures in the Cambotas homocline are not readily apparent because of the homogeneity of the quartzite. The dominant feature is the east dip. Near the contact with the complex at Caeté the dip is nearly horizontal, but eastward from the contact the dip gradually increases to 30°–60° E. Open folds trending northeast parallel to the Gandarela syncline are superposed on the south end and perhaps other parts of the homocline. Abrupt local changes in dip along some low-angle fractures suggest that thrust faulting occurred, as does the presence of part of a network of gabbro dikes, which are similar to dikes that intrude in the Serra do Caraça (C. H. Maxwell, written commun., 1961).

POSTULATED THRUST FAULT

If the Cambotas Quartzite in the Cambotas homocline had a normal relation to both the Caeté complex and the Cocais dome, it would occupy a syncline between them. However, the homocline dips into, rather than off of, the Cocais dome, and this indicates a major structural discontinuity. This discontinuity is here interpreted as a thrust or high-angle reverse fault dipping to the east between Cambotas Quartzite in the lower block and gneiss of Cocais in the upper.

Gabbro was intruded along much if not all of this discontinuity and indicates the extension of the fault for at least 16 kilometers. Because of this intrusion, the pregabbro relation between the Cambotas Quartzite and gneiss of Cocais cannot be observed.

The proximity of the complex at Caeté to the Cocais dome and the similarity of gneiss of Cocais to some of the gneiss in the complex at Caeté suggest that the two structures may be protuberances of a single larger body of gneiss. In the area where the Cambotas homocline is completely eroded, gneisses in the two domes are close but are deeply weathered and covered by soil. During reconnaissance of this area the author was unable to confirm either the continuity of the two gneiss bodies or the presence of gabbro which would indicate that the two domes are separated by the postulated thrust fault. In regard to this area Dorr (written commun., 1965) stated that the gneisses of Cocais and Caeté are continuous—not separated by either lithologic or structural breaks.

The postulated fault evidently formed before intrusion of the gabbro. The length and attitude of the fault imply a major compressive force from the east-northeast, which also could account for the foliation in the Cocais dome. Conversely, the northeast-trending Gandarela syncline and the Fundão thrust fault apparently formed perpendicular to an axis of southeast compression. Because the gabbro dike terminates at the Gandarela syncline, the fault along which it occurs apparently was associated with an orogeny older than that of the Gandarela syncline and Fundão fault. As noted above, the nonfoliated gabbro is considered to be younger than the foliated rocks in the Gandarela syncline. Apparently, near the end of, or after, the last orogeny, gabbro was intruded along the earlier formed fault.

GANDARELA SYNCLINE

The Gandarela syncline is a closed fold, is overturned to the northwest, and is 44 kilometers long. Fifteen kilometers of the east part of the syncline lie in the Barão de Cocais area. The central and southwest parts of the syncline have been mapped by J. E. O'Rourke (written commun., 1957), S. L. Moore (written commun., 1962), and Benedito Alves (written commun., 1962). In the Baráo de Cocais area the syncline strikes N. 60° E. and plunges gently to the southwest. The syncline is bounded on the north by the Cocais dome and on the south by a belt of isoclinally folded rocks assigned to the Nova Lima Group. The fold involves all the rocks of the Minas Series in the Barão de Cocais area.

The syncline is more complex than its general outline indicates (pls. 1, 2). Both limbs are undulatory. In general, the normal limb dips more steeply in the west than in the east, and the overturned limb dips more steeply in the east than in the west, but there are many local exceptions. Subsidiary folds, parallel to the strike of the syncline, are common in the Cercadinho and Gandarela Formations, but most are too small to be mapped. The two largest folds, an overturned syncline and its complementary overturned anticline, occur on the normal limb of the main syncline about 1 kilometer north of Barão de Cocais (pl. 1); they were traced for about 3 kilometers. The strike and direction of overturning of the Gandarela syncline and subsidiary folds indicate that the folds are the result of compression from the southeast.

Numerous minor folds with axes transverse to the principal fold axis occur throughout the Gandarela syncline; they are particularly prominent in itabirite. The plunge of these folds is variable between east and south at 20°–45°.

The Morro Grande anticline and the Dois Irmãos syncline, located 3 kilometers north of Barão de Cocais (pl. 1), differ from other folds in the syncline by being gentle open folds that strike N. 70° W. The anticline is continuous with the line of maximum width across the gabbro stock to the west; a remnant of Cambotas Quartzite overlying the gabbro along this line clearly indicates that uplift was associated with the gabbro intrusion. As a result of the shape of the stock and of the fact that the gabbro of the stock erodes more rapidly than the adjacent metasedimentary rocks on the northwest limb of the Gandarela syncline, the metasedimentary rocks are exposed in an S-shaped trend along the crest of the Serra do Tamanduá. This pattern superficially resembles that produced by the tight medium-size folds on the norhtwest limb of the principal syncline in the Itabira district (Dorr and Barbosa, 1963, p. 49, pl. 1); though similar in appearance, the patterns differ in origin.

Normal faults are rare in the Gandarela syncline (pl. 2). All those mapped offset rocks in the Tamanduá Group and may extend into rocks in the lower part of the Minas Series, though this possibility was indeterminable because of overlying canga.

FUNDÃO FAULT

The Fundão fault is a thrust and high-angle reverse fault more than 50 kilometers long. It crosses the Barão de Cocais area from southwest to northeast for 15 kilometers, extending subparallel to the southeast limb of the Gandarela syncline and intersecting that limb in three places (pls. 1, 2). The fault is not exposed within the area, and its trace was mapped from gross rock relations, from topography, and from a sheared zone in the Nova Lima Group a few hundred meters east of the boundary of the area. The Fundão fault was named by J. E. O'Rourke (written commun., 1957), and he and S. L. Moore (written commun., 1962) mapped parts of it southwest of the Barão de Cocais area.

The offset on the Fundão fault is about 500 meters both horizontally and vertically. From its approximate trace across the topography the fault appears to have an average dip of 55° to the southeast.

The northwest offset of the southeast limb of the Gandarela syncline along the Fundão fault, and the northeast strike and the southeast dip of the fault indicate compression from the southeast, so the Fundão fault and the Gandarela syncline are considered coevally as well as spatially associated. Undoubtedly they formed during the last orogeny in the Quadrilátero Ferrífero. This orogeny also produced similarly oriented structures of comparable size, such as overturned folds in the Itabira district (Dorr and Barbosa, 1963, pl. 1) and the Monlevade district (Reeves, 1966, pls. 1, 2), and thrust faults in the Congonhas district (Guild, 1957, pl. 1).

NOVA LIMA BELT OF ISOCLINAL FOLDS

The Nova Lima belt of isoclinal folds lies southeast of, and parallel to, the Gandarela syncline and is at least 25 kilometers long. Fifteen kilometers of this distance is in the Barão de Cocais area, where the belt is 6–7 kilometers wide. The Nova Lima isoclinal belt is bounded to the southeast by chlorite-talc-antigorite schist, which separates it from the Santa Bárbara gneiss dome.

Foliation is prominent in the Nova Lima isoclinal belt. It strikes N. 35° E. in the west part of the Barão de Cocais area and gradually changes to N. 70° E. in the east, and it has a fairly constant dip of 55° SE. Bedding, determined almost exclusively from iron-formations, is approximately parallel to the foliation.

Although large-scale isoclinal folding is inferred from small isoclinal folds, the magnitude of the folding was determined from one extensive bed of iron-formation. This bed crops out in the Santa Bárbara quadrangle (pl. 1) and was also mapped in the Catas Altas and the Conceição do Rio Acima quadrangles by C. H. Maxwell and by S. L. Moore, respectively (written communs. 1962). The iron-formation extends 10 kilometers southwest from the São Bento mine to the south boundary of the Santa Bárbara quadrangle, across the northwest corner of the Catas Altas quadrangle, and into the Conceição do Rio Acima quadrangle, where, from an abrupt fold, it extends for 7 kilometers back into the Santa Bárbara quadrangle. The two limbs of this fold are 2 kilometers apart in the Santa Bárbara quadrangle.

A few normal faults occur in the isoclinal belt. These are vertical or nearly vertical faults striking perpendicular to the trend of the belt. Most have a displacement of not more than a few tens of meters; near the southwest corner of the Santa Bárbara quadrangle (pl. 1, N. 1,500, E. 2,900), however, one such fault has a vertical displacement of approximately 150 meters. Two normal faults extend from the belt of isoclinal folds across the chlorite-talc-antigorite dike into the gneiss of Santa Bárbara.

SANTA BÁRBARA GNEISS DOME

The Santa Bárbara gneiss dome is a large structure, the northwest edge of which lies in the Barão de Cocais area. The west boundary of the dome lies to the south in the Catas Altas and Santa Rita Durão quadrangles, where the dome adjoins folded pre-Minas and Minas rocks for a distance of 26 kilometers (C. H. Maxwell, written commun., 1962). The structure of the dome to the east in the Florália and Rio Piracicaba quadrangles and to the southeast outside of the Quadrilátero Ferrífero is unknown. The only gneiss thus far mapped in the Santa Bárbara dome is gneiss of Santa Bárbara. However, the texture of some granitic saprolites indicates that other granitic rocks are present south of the report area.

Foliation in the Santa Bárbara dome was not observed at enough localities to determine its overall pattern. About half of the attitudes measured are approximately parallel to foliation in the Nova Lima belt of isoclinal folds, but the other attitudes have different orientations, so that the possible structural parallelism between rocks of the Nova Lima Group and the dome is obscured.

The chlorite-talc-antigorite dike separating the Santa Bárbara dome from the Nova Lima belt of isoclinal folds and the southeastward dip of bedding in the belt toward the Santa Bárbara dome suggest that the dike was intruded along a structural discontinuity. Similar structural relations exist between the Cocais dome and the Cambotas homocline.

METAMORPHISM

Two periods of regional metamorphism are recognized in the Quadrilátero Ferrífero. The first metamorphism is considered to have occurred after deposition of the Rio das Velhas Series and prior to deposition of the Minas Series; the second is considered to be later than the Minas Series (Herz and others, 1961, p. 1111–1112). The grade of regional metamorphism in both the Rio das Velhas and the Minas Series in the Barão de Cocais area is the greenschist facies, so the effects of the first metamorphism are uncertain.

REGIONAL METAMORPHISM

PELITIC ROCKS

The most abundant rocks in the Barão de Cocais area are phyllite and schist. They make up almost all the Nova Lima Group, the unnamed formation of the Tamanduá Group, the Batatal Formation, and a large part of the Moeda, Gandarela, and Cercadinho Formations. These rocks are composed of chlorite, white micas, and quartz and accessory iron oxides, carbonaceous material, and carbonate. All the minerals are generally fine-grained except the white micas. The mineral assemblages, and the fine-grained sizes indicate low-grade metamorphism.

QUARTZITES

Quartzite and quartz-rich rocks make up the bulk of the Cambotas Quartzite, Moeda Formation, and much of the Cercadinho Formation. These rocks contain quartz, white mica, and minor chlorite. Hematite is abundant in the Cercadinho Formation, less abundant in the Cambotas Quartzite, and rare in the Moeda Formation. Small kyanite blades were found in the Cambotas Quartzite at several places and in a quartzite bed in the upper part of the Tamanduá Group. Chloritoid rosettes were found in one thin section of Cambotas Quartzite. The association of quartz, white micas, and chlorite and the general absence of medium- and high-grade metamorphic minerals indicate low-grade metamorphism.

Kyanite occurs in the epidote-amphibolite metamorphic facies, and it is considered a typical guide mineral to the highest pressure parts of the amphibolite facies (Ramberg, 1958, p. 147, 151) and rarely occurs in the greenschist facies (Turner and Verhoogen, 1951, p. 468–469). Kyanite is rare in the Cambotas Quartzite, and Norman Herz (written commun., 1960) thought that it probably is hydrothermal in origin rather than metamorphic.

Evidence of dynamic metamorphism is abundant. Many quartz grains are strained, fractured, sheared, and crushed, and many pebbles in conglomerates of the Moeda and Cercadinho Formations are deformed and fractured.

ITABIRITE AND IRON-FORMATION

Itabirite and other iron-formation consisting of quartz and hematite are somewhat inert to chemical changes, but increasing temperatures of metamorphism produce increasing grain sizes (James, 1955, p. 1473–1480). Grains of quartz and hematite in the Barão de Cocais area rarely exceed 0.06 mm in maximum length; the quartz grains average 0.03 mm in length, and hematite grains average 0.04 mm. These sizes are similar to those in the chlorite zone of metamorphism of iron-formations in northern Michigan (James, 1955, p. 1462) and suggest that the iron-formation in the Barão de Cocais area has a similar metamorphic grade.

Many iron-formations, including some itabirite, contain magnetite and dolomite. Although a question exists in regard to the origin of the magnetite, the mineral assemblage and grain size indicate low-grade metamorphism.

As previously mentioned, weathered actinolitic(?) itabirite occurs at one place in the mapped area. Although limonite has replaced the amphibole mineral, the preserved radiating and acicular structure resembles that of actinolite and cummingtonite. These two minerals occur unweathered in the western Serra do Curral region (Simmons, 1968), and their presence is interpreted to be the result of metamorphism in the upper part of the greenschist facies.

MAFIC ROCKS

Mafic rocks also appear to have been metamorphosed to within the greenschist facies of regional metamorphism. Most of these rocks, now chlorite schist, contain no minerals indicating a higher metamorphic grade. The large body of mafic rock along the contact of the gneiss of Santa Bárbara and the Nova Lima Group may have been metamorphosed to a slightly higher grade; it contains chlorite, talc, and antigorite. Ramberg (1958, p. 145) noted that talc is unstable above 700° C and that serpentine is unstable above 500° C. However, both minerals are stable with chlorite at the temperatures of the greenschist facies, and because no higher temperature minerals are present, this body probably was not metamorphosed at temperatures approaching 500° C.

CONTACT METAMORPHISM

QUARTZITE

Contact metamorphosed quartzite occurs intermittently along the contact of the Cambotas Quartzite and the gneiss of Cocais in zones as much as several tens of meters thick on the north side of the Serra do Tamanduá and as inclusions in the gneiss. Some metasomatism has occurred; at places three gradational subzones are discernible. In the outer subzone the quartzite is sheared along some bedding planes, and secondary quartz has crystallized in the shears. White mica is abundant in this subzone. In the middle subzone, large discordant potassium feldspars that disrupt the bedding occur on sheared bedding planes. White mica in this subzone has a slightly larger grain size than that in the outer subzone. In the inner subzone plagioclase (Ab_{87-97}), biotite, and epidote are present; one specimen from this zone also contained chlorite, ilmenite, and tourmaline. Bedding in the quartzite is difficult to recognize in the inner subzone.

Inclusions of quartzite, quartzite schist, and hybrid quartzite gneiss in the gneiss of Cocais resemble quartzite in the inner subzone above, but most inclusions also contain kyanite. The source of the inclusions is unknown; they may be Cambotas Quartzite or relicts of other rocks.

IRON-FORMATION

Contact metamorphosed iron-formation of the Tamanduá Group occurs at one place in the Serra do Tamanduá (pl. 1, N. 13,500, E. 5,000). There, for a distance of several hundred meters, the Cambotas Quartzite is absent, and the upper part of the Tamanduá Group is in contact with gneiss of Cocais. Although no contact effects were observed in weathered phyllite of the Tamanduá Group, a few hematite flakes in the iron-formation are as long as 4 mm, and a few magnetite crystals are as much as 1 cm in diameter (fig. 7). As this is the only place where iron-formation is close to gneiss and where iron minerals are so coarse grained, the coarse grain sizes probably resulted from the higher temperatures which prevailed near the gneiss.

ANDALUSITE SCHIST

A roof pendant or inclusion of andalusite schist, also containing biotite, chlorite, quartz, ilmenite, and leucoxene, crops out about 5 kilometers northwest of Cocais (pl. 2, N. 4,100, E. 900). The andalusite schist represents the highest metamorphic grade recognized in the Quadrilátero Ferrífero. Andalusite is generally considered to form near the boundary of the amphibolite and granulite metamorphic facies (Ramberg, 1958, p. 48). The andalusite schist undoubtedly resulted from the original rock being metamorphosed deep within the gneiss of Cocais.

MINERAL DEPOSITS

"Minas Gerais has a heart of gold and a chest of iron." Thus, an old Brazilian adage describes the people and resources of Minas Gerais. Gold lured explorers into the State as early as the 17th century, but the rich deposits have been long exhausted, and iron holds the economic key to the future. The earliest mining activities in Minas Gerais consisted of placer and placer-type operations in alluvium, colluvium, and "jacutinga" (incoherent specular hematite derived by weathering of itabirite). Large quantities of gold were sent to the coffers of Portugal. Gold-lode mining, which did not begin until the 19th century, has continued on a limited scale to the present time.

Iron deposits were found not long after central Minas Gerais was settled, and many small Catalan forges were built early in the 19th century to produce iron for domestic uses. Iron deposits were often recorded in the early geologic literature of Brazil, but not until Derby (1910) reported their presence to the International Geological Congress in Stockholm were they brought to international attention. Since then the iron region has been the subject of numerous investigations during which this part of Brazil has been found to contain not only iron deposits but also manganese and aluminum deposits, all of which are currently being mined.

Gold has been the only mineral produced in quantity in the Barão de Cocais area. Antônio Bueno explored northward from Catas Altas along the margins of the Rio Santa Bárbara and discovered gold. This discovery attracted settlers to the present site of Santa Bárbara in 1704 (Instituto Brasileiro de Geografia e Estatística, 1959, p. 116). Shortly afterwards, in 1713, gold was found at the present site of Barão de Cocais (Instituto Brasileiro de Geografia e Estatística, 1958, p. 132). Remains of ancient diggings occur at many places but are most extensive along the Rio Santa Bárbara between the two towns mentioned above. Gold-lode mining was carried on intermittently at the São Bento mine and Santa Quitéria near Barra Feliz and at Brumal between the middle 1860's and the middle 1920's; since that period little gold has been mined.

All other mineral deposits have been of minor economic importance. Manganese was produced from one group of deposits during World War I, and from two other deposits during World War II. A small iron mine near Barão de Cocais has been operative since 1925, and it produces 2,000 tons of ore a year for the smelter in that town. Gneiss is intermittently quarried near Santa Bárbara for riprap on the Central do Brasil Railroad. A vein of quartz crystals near the west end of the Serra do Tamanduá was prospected for oscillator-quality material, but there was little or no production. A few small diamonds are said to have been found in streams draining the Serra das Cambotas.

GOLD

SANTA QUITÉRIA

At Santa Quitéria, gold was found both in the sulfide replacement and quartz vein deposits in the Nova Lima Group and in alluvial and colluvial deposits. These deposits cover an area of about 4 square kilometers near Barra Feliz (pls. 1, 3). The deposits are close to the railroad station at São Bento and to the Barão de Cocais–Santa Bárbara road, but the old workings have been abandoned and are generally inaccessible. Much of what is known of the lode mining here was recorded by Moraes and Barbosa (1939, p. 142–146). Sr. Antônio Guerra of the São Bento Mining Co. kindly gave permission to use a map prepared by Emilio Alves Teixeira of the Departamento Nacional de Produção Mineral showing locations of some of the workings at Santa Quitéria and São Bento; the map has been modified to make plate 3.

The lode deposits are sulfide replacements in iron-formation of the Nova Lima Group and pod-shaped sulfide concentrations in quartz veins that cut rocks of the Nova Lima Group. The gold is intimately associated with pirite and arsenopyrite in both occurrences. Most of the gold was mined from veins as much as 1.5 meters thick, but much sulfide-bearing quartz occurs in veinlets a few millimeters to a few centimeters thick; many of these veinlets parallel the structure of the phyllite and schist in which they occur. Replacements in iron-formation are thin tabular bodies, mostly less than 10 cm thick, in which sulfides are disseminated throughout and are locally concentrated in kernels as much as 1 cm in maximum diameter. Much of the original sulfide has weathered to limonite at the depths opened by mining.

Underground workings at Santa Quitéria may exceed 1,000 meters of drifts, but most are inaccessible. Some drifts were opened under the direction of Moraes and Barbosa in 1934. They studied what are known as the No. 7 drift, the João Peba mine or No. 2 drift, No. 3 drift, No. 4 drift, José Tapa mine or No. 5 drift, and Minas de Jambeiro. The first four drifts are within a few hundred meters of each other and comprise the central part of the underground workings. The João Peba mine, No. 3 drift, and No. 4 drift, are about 1,500 meters N. 60° E. of the São Bento train depot; the first two are indicated on plate 3. The No. 7 drift (pl. 3), José Tapa mine, and Minas de Jambeiro are 300 meters southwest, 1,500 meters north, and 2,000 meters east, respectively, of the central part of the workings.

The following description of the Santa Quitéria workings is based on the description given by Moraes and Barbosa (1939, p. 142–146) and on one day of field observations by the author.

The principal drift of the João Peba mine strikes N. 70° W. and is open for 116 meters, beyond which further workings are obstructed. Most rocks in the drift are weathered dark-gray carbonaceous, red, and yellow phyllite and schist. A few thin beds of iron-formation, as much as 1 m thick, crop out near the portal. The rocks have a general northeast strike and moderate to steep southeast dips. The mineralized quartz vein that was mined for gold is 1 meter thick and is exposed at the obstructed end of the drift. Drift No. 1 is parallel to the João Peba mine and is 7 meters below and 40 meters south of it. The drift is caved 35 meters from the portal and apparently did not reach the quartz vein but, in 1934, served to drain the João Peba drift.

The No. 3 drift is 45 meters long and strikes N. 55° W. The drift is in weathered red, yellow, and gray carbonaceous phyllite and schist. A weathered iron-formation is exposed in the face of the drift, and within the iron-formation is a mineralized zone 60–80 cm thick. In 1934 this zone was being mined by two men and a boy who daily removed 12 cartloads (60–80 kilograms) of ore, which, after being washed in wooden troughs, yielded 2.5–3 grams of gold (Moraes and Barbosa, 1939, p. 144).

The No. 4 drift is 36 meters long and strikes N. 70° W., parallel to the João Peba mine and No. 1 drift. Like the No. 1 drift it did not extend far enough to reach the mineralized quartz vein. The drift is chiefly in red phyllite and schist.

The José Tapa mine is in a mineralized zone of quartz lenses and interbedded ferruginous phyllite 1.2–1.5 meters thick. Few individual quartz lenses exceed 15 cm in width. The entry drift strikes S. 25° E. for the first 10 meters and then S. 35° W. for 66 meters. This latter section of the drift lies parallel to and along the mineralized zone and the bedding of the phyllite, which dip 45° SE. Most of the ore was mined from two stopes above the drift; one 17 meters from the portal and 11 meters long, and the other 30 meters from the portal and 12 meters long. Both stopes connect with other workings.

The ore in Minas de Jambeiro is weathered sulfide replacements in an iron-formaion 1.5 meters thick. The limited workings consist of several shallow pits and a drift 10 meters long.

In one deposit in the main group of workings, according to Gorceix (1889, p. 71) (translated from Portuguese): "The gold is encountered in a limonite vein derived from the decomposition of pyrite * * *. Samples from the top of this vein yield 1.5 grams of gold per ton, which tenor is raised to 45 grams by ferruginous concretions. This vein is accompanied by arenaceous quartzite, of ocherous sands, with limonite and hematite concretions, which have samples yielding 260 grams of gold per ton."

Moraes and Barbosa (1939, p. 142) reported that 30 kilograms of gold was extracted from one pocket in the main group of workings about 1917.

Extensive sampling was carried out at Santa Quitéria in 1934, particularly in the No. 7 drift. In regard to this sampling Moraes and Barbosa said (1939, p. 142; translated from Portuguese):

"The sampling results for gold on the hundreds of samples collected here were discouraging, revealing an absence or small quantity of this precious metal."

SÃO BENTO

The São Bento gold deposits are sulfide replacements in iron-formation of the Nova Lima Group and are on the southeast side of Córrego São Bento about 1 kilometer southwest of the confluence of that creek with the Rio Socorro (pls. 1, 3). The deposits are owned by the São Bento Mining Co. and are linked by a spur road with the São Bento station on the Central do Brasil Railroad and the Barão de Cocais–Santa Bárbara road.

The history of the São Bento mines has been summarized by Miles Flynn (in McCartney [5]) as follows:

The first quartz mining appears to have been done about 80 years ago by a Brazilian who discovered the Pinta Bem outcrop. Early records indicate that these Brazilians mined about 200,000 tons of oxidized ore from the São Bento–Pinta Bem vein. The ore ran about 8 DWTS [0.4 oz] of gold per ton of which about half

[5] McCartney, G. C., 1947, A report on São Bento mine and immediately adjacent properties: South America Gold Areas Co., unpubl. rept.

was recovered in the crude wooden stamp mills that were used at that time. The gold was recovered on blankets.

From 1898 to 1905 the property was operated by the São Bento Gold Estates, Limited, which was under the management of John Taylor & Sons, London, England. During this period the company mined 211,000 tons from which an extraction of 62,863 oz. of gold and 5,130 ozs. of silver was made; the value of the bullion as shown by Sales Certificates having been £266,744, 8s, 6d. This figures out at 0.30 ozs. per ton or $10.50 at the present value of gold. The extraction of gold during this period in the Cyanide mill was around 90 percent to 92 percent. The ore, therefore, averaged $11.55 per long ton.

By 1905 the oxidized ores which extended to a depth of around 600 to 800 feet were worked out. The lower levels entered the sulphide zone and the mill which was erected to handle the easily treated oxidized ores was not able to make an extraction of over 55 percent of the gold in the sulphide ores.

The company suspended operations in 1906 and nothing was done again until June 1923 when a new company, the South America Gold Areas Limited, acquired the title to the property. A new mill was installed which was planned to treat 150 tons per day using Oil Flotation and Cyanidation to recover the gold, and roasting of the concentrate to recover the arsenic, which at that time had a good market in Brazil.

When this new plant was started it was discovered that the Oil Flotation process which had been installed was not suitable for this ore. The mill was operated for about three months treating about 6,000 tons of ore during this time.

A bed of iron-formation, 10–30 meters thick, contains all the ore. This bed, locally known as the Formation, strikes N. 50° E. and dips 50° SE. Most of the gold is associated with arsenopyrite and, to a lesser extent, with pyrite and pyrrhotite. The sulfide minerals are concentrated in pods as much as several centimeters long, and these pods are disseminated in the iron-formation. Silver has been recovered from mill operations, but its mode of occurrence is unknown. The iron-formation is underlain by phyllite and schist, most of which is carbonaceous, and overlain by chlorite schist; however, it is not known if the rocks are in normal or overturned positions.

Four known mineralized zones occur parallel to the bedding of the Formation. From northwest to southeast (apparent stratigraphic bottom to top) these are: West Branch Lode, Middle Branch Lode, São Bento Lode, and Eastern Branch Lode. One or more of these lodes have been of sufficient thickness and grade to be mined at three places, which are, from northeast to southwest, the Number 1, Number 2, and Pinto Bem ore bodies.

In plan view the ore bodies are elongated lenses oriented with the strike of the iron-formation. The Number 1 and Number 2 ore bodies extend downdip for at least 400 meters, and the Pinta Bem extends for at least 250 meters. The reason for localization of ore is unknown. The oxidized zones of the three ore bodies, extending 200–240 meters below the surface, have been mined out, and only unoxidized sulfide ores remain.

The ore bodies are explored by numerous drifts and crosscuts. The longest, most recent, and deepest working is the 1100 drift (pl. 3), which extends for 1,270 meters along the Formation. Nine or 10 levels of older workings vertically spaced 20–30 meters apart occur on the hillside above the 1100 drift. Some of these can be entered by adits, but only a few were visited, and no attempt was made to measure their extent.

In the Number 1 ore body, ore has been mined from the West Branch Lode, Middle Branch Lode, and São Bento Lode. The Eastern Branch Lode does not occur above the lowest level (1100 drift) in this ore body and is not of commercial grade. However, 200 meters to the southwest, the Eastern Branch Lode widens abruptly to form the Number 2 ore body. This body has produced ore from the surface downdip to the 1100 drift, a distance of 370 meters.

The Pinta Bem body is not connected with the other two ore bodies by mine workings, but it is considered to be on an extension of the São Bento Lode. The Pinta Bem ore body was mined on seven upper levels, but the 1100 drift, which explores the Number 1 and Number 2 ore bodies, ends about 300 meters short of the downdip projection of the Pinta Bem ore body.

Wilfred Tansley made a study of the São Bento area for South America Gold Areas Co. in 1947. The study included core drilling to explore the depth of the Number 1 and Number 2 ore bodies. Near the end of this exploration program Dr. Tansley (in McCartney [6]) reported as follows:

> Although the underground drilling program * * * has not yet been completed, sufficient data have been completed to permit calculations of grade and tonnage for the No. 1 Orebody.
>
> Calculations * * * indicate that the No. 1 Orebody * * * may be expected to produce 144,000 short tons of ore having an average grade of $12.80 (at $35. gold) and with a width of 6.0 feet * * *. [This] would yield 420 tons per vertical foot.

Combined tonnage and values

Vein	Short tons	Average grade (dollars)	Average width (feet)	Tons×dollars	Tons ×feet
São Bento	39, 000	12. 35	6. 4	492, 700	255, 300
Middle Branch	45, 000	11. 10	4. 5	499, 500	202, 500
West Lode	59, 000	14. 50	7. 2	855, 500	424, 800
	143, 900			1, 847, 500	882, 600

Average grade 1, 847, 500÷143, 900=$12. 80
Average width 882, 600÷143, 900=6. 0 ft

Tons per vertical foot:	
São Bento	130
Middle Branch	140
West Lode	150
Total	420

[6] See footnote 5, p. H33.

G. C. McCartney [7] summarized the results of the development work as follows:

About 6,000 feet of drilling in a series of 16 holes have been completed. The holes serve to test the downward extension of the No. 1 and No. 2 ore bodies below the main adit level. The holes were drilled from underground stations in such a manner as to intersect the veins at a vertical depth of about 300 feet below the adit and make intercepts along the strike of the veins about 100 feet apart.

It is an arsenical ore and not more than 90% of the gold is recoverable. However, there is a market for arsenic oxide in Brazil and this partially offsets the poor recovery of gold.

On a basis of 420 tons per vertical foot and with levels spaced 125 feet vertically it is apparent the combination of the three veins, the São Bento, the Middle Branch, and the West Lode will provide sufficient ore for a 100–125 tons per day mill supposing one level mined each year.

It is the writer's opinion that in a replacement type of ore of only medium grade such as the São Bento that a considerably larger tonnage will have to be placed in sight before assurance can be given that the mine can be operated profitably.

McCartney recommended further exploration to determine if a larger tonnage of ore were present. This included detailed geologic mapping and drilling of the iron-formation to confirm the correlation between the iron-formation at São Bento and the iron-formation at Santa Quitéria (1 kilometer to the northeast), and testing the iron-formation at various places between different workings. If the findings were favorable it was also planned to extend the 1100 drift the 300 meters necessary to intersect the projection of the Pinta Bem ore body. However, South America Gold Areas Co. decided that the margin of profit was too low and that further exploration was unwarranted. The property was idle at the time of the present mapping and has passed into the hands of the São Bento Mining Co.

TAQUARÍL

The very fine grained native gold at Taquarîl, referred to as Cocaes (Cocais) in some of the older literature, occurs in weathered iron-formation on the north side of the Serra do Tamanduá, about 1.5 kilometers south of the village of Cocais (pl. 1, N. 13,500, E. 4,800). The east end of the abandoned workings is just below the crest of the serra where the Bãrao de Cocais–Cocais road passes over the range. From this point the workings extend 2 kilometers to the southwest.

Gold was mined from four beds of iron-formation, each about 10 meters thick (Moraes and Barbosa, 1939, p. 137–138). The iron-formations are interbedded with five phyllite beds totaling about 50 meters in thickness. Together the nine units form the entire upper part of the Tamanduá Group in this vicinity. The uppermost beds of phyllite and iron-formation are overlain by canga; the lowest phyllite bed overlies the Cambotas Quartzite throughout most of the length of the deposits. The Cambotas Quartzite, only several meters thick in this area, has a metasomatized contact with gneiss of Cocais. At the east end of the deposits the Cambotas Quartzite is missing, and units in the upper part of the Tamanduá Group are in contact with the gneiss.

The iron-formations consist of specular hematite, very fine grained quartz, magnetite, and minor amounts of chlorite and argillaceous material. Weathering has rendered the iron-formations somewhat friable, owing to solution of dolomite and probably some quartz.

The upper part of the Tamanduá Group strikes N. 70° E. and, although crenulated in detail, particularly the iron-formations, dips 3°–45° SE., and the dip averages 30°. Quartz veins from a few millimeters to several meters in thickness cut all units, some parallel to and others crossing the bedding. The larger veins transect the bedding and are more numerous in the lower iron-formations.

Iron-formation is strongly weathered to dark red adjacent to some quartz veins, and such zones, known as sangue de boi (ox's blood), reputedly contained the most gold.

The iron-formations were mined by longitudinal trenches along the strike, by inclined shafts, and by adits. The larger of the trenches are more than 10 meters deep and several hundred meters long. The inclined shafts were collared in iron-formation and appear to have been sunk down the dip of the bedding. All the adits started in the footwalls of iron-formation or in phyllite where the footwall of the iron-formations could be readily reached. Most of the underground workings are now caved (1960).

The Taquarîl deposits are famous for being the source of the Barão de Cocais gold fortune, but little is known of their operation and production. The incomplete record was summarized by Bensusan (1929, p. 21) from publications not available to the author; the citations from other reports and most of the information contained in the following history are derived from this reference.

The first recorded gold production at Taquarîl is that noted by Henwood (1872) for the year 1814, but mining may have started in the early part of the 18th century, about the time of the founding of the towns now known as Santa Bárbara and Barão de Cocais. Mining operations were described by Baron W. L. von Eschwege in 1833 as follows: [8]

The ore was brought in small broken pieces—all quartz, sand, and jacutinga—from the mine and placed into a sluice 200 ft. long, sloping down between the creeks in the valley, and it

[7] See footnote 5, p. H33.

[8] Quotation from "Pluto Braziliensis," translated from German and cited by Henwood (1872) in Bensusan, (1929, p. 21).

could be closed every 40 ft. by cross timbers where they could catch all heavy material. The heavy iron, sand, and concentrated gold was put through a rocker having riffles of wood; the tailings went over hairy skins and again through the rocker—the dirty water went over a blanket table 18 palmos × 1½ palmos (1 palmo = 8 in.) and inclined at 20° covered with ox skins which were beaten in the concentration box. After this there was another small rocker and two blanket tables, and any gold escaping was caught in four blanket tables in the canal with the greater inclination. Still much gold escaped to the fossickers (faiscadores) of the Rio Una, which flows to the Rio Sta. Bárbara. The gold retained by the rockers and that of the concentrates was washed in bateas and dried over a weak fire.

In 1833, José Feliciano Pinto Coelho da Cunha, later and better known as the Barão de Cocais (Baron of Cocais), joined a group of English investors headed by Lord Oxenford to form the successful National Brazilian Mining Association. The company explored the Taquaríl deposits, which were part of the Baron's extensive land holdings, and, according to Henwood, the company extracted 557,000 pounds troy of gold between 1833 and 1846. The deposits were visited during this period by Gardner (in Bensusan, 1929), who noted that the workings included a shaft 50 fathoms (300 feet) deep and that 30 English miners, 30 hired free Brazilians, and about 300 slaves were employed.

Mining apparently stopped in 1851. Burton (in Bensusan, 1929) indicated that mining costs exceeded ore value in 1850. Walker found the mine unmanageable because of water during this year, and in 1851 the principal underground workings caved and were flooded.

SÃO JORGE MINE

The São Jorge mine is near the community of Brumal (pl. 1, N. 100, E. 4,600). The principal workings consist of a large excavation about 100 meters long, 50 meters wide, and 30 meters deep in rocks of the Nova Lima Group. The pit is connected to the old mill site by a tunnel 140 meters long. Most of the rock in the pit is concealed by slumped overburden; production apparently came from a ferruginous quartzite and a quartz vein, both of which contained pyrite, pyrrhotite, arsenopyrite, and probably very fine grained native gold. Some quartzose schist containing these minerals also was mined from the tunnel. An old man had been mining the property for a number of years when the property was acquired by Sr. Amable Peres of Barão de Cocais, the present owner, in 1948. Since 1948 there has been no production.

BRUCUTÚ

Apparently, gold was mined from the Cauê Itabirite at two places on the south limb of the Gandarela syncline (pl. 1, N. 13,400, E. 9,450 and N. 13,300, E. 11,200). The properties, 11 and 13 kilometers from Barão de Cocais, respectively, are accessible by a poor dirt road that provides access to a power line from the Petí hydroelectric plant. The east property belongs to Sr. Antonio Soares of Barão de Cocais and is designated "Brucutú 21." The west property belongs to Companhia Brasileira de Usinas Metallurgicas in Barão de Cocais. The author did not determine on which Brucutú lot the west property is located, and it is designated simply "Brucutú."

The Cauê Itabirite at these two places is so weathered that it readily crumbles to a powder of specularite and very fine granular quartz. The itabirite was mined from surface excavations, and at Brucutú 21 it was also mined from two shafts, which were not located during the present study. Tailings indicate that the itabirite was carried to nearby streams where it could be washed. Neither property owner had records pertaining to mining on these properties, nor were references to the properties found in the literature. The type of workings and the architectural style of an old stone structure near Brucutú indicate that the deposits were mined by slaves.

IRON

Iron, the most economically important ore in the Quadrilátero Ferrífero, is mined on a very small scale in the Barão de Cocais area. All production has come from the Cabeça de Ferro mine, which is in a small replacement deposit of high-grade compact hematite in itabirite. The Cabeça de Ferro mine and nearby deposits of rolado and canga in the Gongo Sôco quadrangle supply all the ore for the smelter of the Companhia Brasileira de Usinas Metallurgicas in Barão de Cocais. The only other deposits in the report area are two small undeveloped low-grade rolado deposits near the village of Cocais.[9] The Barão de Cocais area contains considerable potential iron resources of soft itabirite, canga, and enriched itabirite, but little likelihood of their development exists until the higher grade deposits of the area and the low-grade potential resources that are closer to large smelters are mined out.

DEPOSITS AND ORES

The source of all iron ores in the Quadrilátero Ferrífero is itabirite. Fresh itabirite contains about 60 percent hematite and averages between 40 and 45 percent iron. Several billion tons of itabirite occur in the Barão de Cocais area, but so many higher grade sources exist in Brazil that fresh itabirite has no foreseeable economic importance.

Iron has been concentrated in itabirite by hydrothermal and weathering processes. These concentrations may be geologically classified according to origin as replacement, detrital, and residual deposits, which

[9] Subsurface exploration accomplished after this report was prepared indicates a considerable body of hematite ore in the Serra da Tamandua near Brucutú (pl. 1).

closely correspond to, respectively, the economic classifications of high-grade deposts, low-grade deposits, and potential-resource deposits. Replacement deposits include nearly pure hard compact hematite, soft hematite derived by weathering of compact hematite in place, and varieties of hematite that are intermediate between hard and soft. Only one small replacement deposit, the Cabeça de Ferro, occurs in the Barão de Cocais area. The compact hematite ore in this deposit, described under a subsequent heading, is not generally representative of high-grade deposits in the iron region, and for discussions of the environment and origin of the ores, the reader is referred to earlier papers in this series of publications: Guild (1957); Dorr and Barbosa (1963); Pomerene (1964).

DETRITAL DEPOSITS AND ORES

Detrital deposits are colluvium containing compact hematite, itabirite, and iron-formation. They form surficial blankets several centimeters to several meters thick, that extend as much as several kilometers downslope from their principal source, the Cauê Itabirite. At one place or another, detrital deposits overlie every stratified rock unit in the Barão de Cocais area. Where these colluvial deposits are unconsolidated they are called rolado, and where cemented by limonite, canga.

The iron content of detrital deposits is partly dependent upon the amount of compact hematite they contain, and some deposits in the Quadrilátero Ferrífero contain as much as 68 percent iron. Throughout the iron region canga ore averages between 62 and 64 percent iron. Canga in the Barão de Cocais area has an estimated iron content of 45–65 percent and averages 55 percent iron. Most canga contains more itabirite than compact hematite, and although no lower iron-content limit is established separating ore from subore, 60 percent is the lower limit usually mined. Iron percentages reported for rolado deposits are based on ore from which fines and earthy material have been discarded. As a result of the varying quantities discarded, recovery factors of 1.5–3.0 tons per cubic meter are used in calculating rolado ore reserves. Recovery factors of 2.5–3.0 are used for canga.

RESIDUAL DEPOSITS AND ORES AND POTENTIAL ORES

Three gradational types of potential ores result from the chemical weathering of itabirite in place: structure canga, enriched itabirite, and soft itabirite. All are currently mined in the Quadrilátero Ferrífero under certain circumstances, and although present in the Barão de Cocais area, they are not mined there.

Structure canga is itabirite from which most of the quartz has been leached, in which most hematite has beem hydrated to limonite, and which is enriched by limonite. Structure canga preserves the original itabirite bedding, but at many places it is indistinguishable from canga containing detrital itabirite. Both have the same range in grade and recovery factors, and the two rocks are identical from an economic point of view.

Enriched itabirite is transitional between structure canga and soft itabirite. It is itabirite from which much quartz has been leached but in which the hydration of hematite and enrichment of limonite has not been sufficient to consolidate the weathered itabirite into structure canga.

Enriched itabirite overlies most of the Cauê Itabirite in the Serra do Tamanduá. Only the most resistant itabirites and those which have recently been mechanically eroded have no covering of enriched itabirite. Much enriched itabirite covered by structure canga is exposed along eroded canga rims. Its observed thickness range is from a few centimeters to 10 meters and its estimated average thickness is 1 meter.

Enriched itabirite in the Barão de Cocais area is estimated to contain 10 percent more iron than unweathered itabirite, or about 55 percent iron. This figure is similar to the 55 percent plus figure used by P. W. Guild in calculating the enriched itabirite reserves of the Congonhas district (1957, p. 67–69). Enriched itabirite is only mined at a few places in the Quadrilátero Ferrífero where it can be handled in the same manner as the overlying canga. As canga is not mined in the Barão de Cocais area, enriched itabirite is not considered an ore there, but large tonnages are present which are potential ore.

Soft itabirite is itabirite which has been softened by the leaching of quartz; it is a potential source of more iron than all other ores in the Quadrilátero Ferrífero. Most itabirite has been softened to a depth of more than 50 meters and would be easy to mine. Thicknesses of more than 50 meters are exposed on the sides of steep drainage heads at several places in the Serra do Tamanduá. Guild (1957, p. 45) reported weathered itabirite at a depth of 220 meters below the surface, and softening probably occurs from the surface to the water table. Dorr (in Departamento Nacional da Produção Mineral, 1959, p. 105) stated, "Such large tonnages of soft itabirite exist, and the rock is so easy to mine and concentrate that it inevitably will be used commercially within a relatively short period."

Some disagreement exists as to the exact process of softening. Dorr and Barbosa (1963, p. 27) believed that much of the hard itabirite exposed at the surface is the rock from which soft itabirite is formed. Pomerene (1964, p. 44) considered that soft itabirite results from leaching of a different itabirite, one that has a different combination of carbonate content, grain size, and distribution of hematite and quartz. According to Dorr (in Departmento Nacional da Produção Mineral, 1959, p. 106), soft itabirite ranges in tenor from about 35 to 65 percent iron and may average between 45 and 50 percent. Soft itabirite in the Barão de Cocais area is estimated to average 45 percent iron.

RESERVES

Total iron resources of the Barão de Cocais area include 1.1 billion tons of potential resources but only minor reserves of high-grade and low-grade ores. The potential resources include 60 million tons of canga estimated to contain 55 percent iron, 20 million tons of enriched itabirite estimated to contain 55 percent iron, and 1.02 billion tons of soft itabirite estimated to contain 45 percent iron (table 9).

TABLE 9.—*Potential iron resources of the Barão de Cocais area*

Type	Area (millions of square meters)	Average thickness (meters)	Volume (millions of cubic meters)	Recovery factor (tons per meter)	Metric tons (millions)	Grade (percent)
Canga	22	1	22	2.8	60	55
Enriched itabirite	6.8	1	6.8	3.2	20	55
Soft itabirite	6.8	50	340	3.0	1,020	45
Total tonnage					1,100	

Canga containing 60–64 percent iron is regarded as low-grade ore, and some areas of canga within the Barão de Cocais area undoubtedly have enough iron to be so classified, but most canga in this area has a much lower iron content. As the detailed sampling necessary to outline low-grade canga ore bodies was beyond the scope of this work and the interest of mining companies, all canga in the Barão de Cocais area is classified as potential resources.

Potential resources of canga, 60 million metric tons, were calculated by measuring the canga-covered areas of 22 million square meters on plates 1 and 2 with a planimeter. Although thickness is variable, it is estimated to average 1 meter; thus, the canga has a calculated volume of 22 million cubic meters. Multiplication of the volume by the recovery factor of 2.8 tons per cubic meter yields the tonnage figure of 60 million tons.

Potential resources of enriched and soft itabirite, 20 million and 1.02 billion metric tons, respectively, were calculated from the areal distribution of the Cauê Itabirite. The Cauê Itabirite, extending for 16 kilometers on the north limb of the Gandarela syncline and having an average width of 300 meters, covers 4.8 million square meters. The formation extends for 9 kilometers on the south limb of the syncline, has an average width of 220 meters, and covers 2 million square meters. Although some fresh itabirite occurs in a few places, no areas of consequence are directly underlain by hard itabirite, and so no calculation was made for hard itabirite.

Volumes of 6.8 million cubic meters of enriched itabirite and 340 million cubic meters of soft itabirite were calculated by multiplying the surface area covered by each by estimated thicknesses of 1 meter and 50 meters, respectively. These estimated thicknesses are based on field observations. The tonnage figures were calculated by multiplying the volumes by recovery factors of 3.2 metric tons per cubic meter for enriched itabirite and 3.0 for soft itabirite.

CABEÇA DE FERRO MINE

The deposits at and near the Cabeça de Ferro mine consist of several small ore bodies of high-grade compact hematite on the north limb of the Gandarela syncline near the boundary between the Santa Bárbara and Gongo Sôco quadrangles. The largest of the bodies, at the Cabeça de Ferro mine itself, is on a hilltop about 2 kilometers north of Barão de Cocais (pl. 1, N. 8,600, E. 200). The other bodies are in the Gongo Sôco quadrangle about 500 meters southwest of the Cabeça de Ferro mine and have been studied by S. L. Moore (1968). The Cabeça de Ferro mine is owned and operated by Companhia Brasileira de Usinas Metallurgicas, and all ore is trucked 2 kilometers to the company mill in Barão de Cocais.

The deposit occurs in itabirite in the Gandarela Formation and occupies the trough of a syncline which plunges 29° SE. (fig. 12). The ore body and itabirite are topographically above the surrounding Cercadinho Formation; so, the Gandarela Formation probably owes its present position to movement along a high-angle reverse or thrust fault, but this could not be verified from the limited outcrops in the area.

The ore is compact hematite formed by the replacement of quartz in itabirite; remnants of original beds of itabirite are well preserved (fig. 13). As seen in polished section, the ore is made up of laminae of very fine size euhedral plates of hematite oriented parallel to bedding. A few of the laminae contain dense mattes of unoriented, interlocking anhedral hematite grains. Minute octahedra of magnetite are disseminated throughout and may make up as much as 2 percent of the ore. The ore has been slightly softened by weathering, and it fractures along bedding planes when struck with a hammer, but none is so friable that it would be classed as soft ore.

The Cabeça de Ferro ore body crops out as a cap on a hilltop. The ore is mined by hand; hematite blocks are pried loose and tumbled down to a loading bench. Hematite has been mined in this manner on both the northeast and southwest slopes, but in recent years

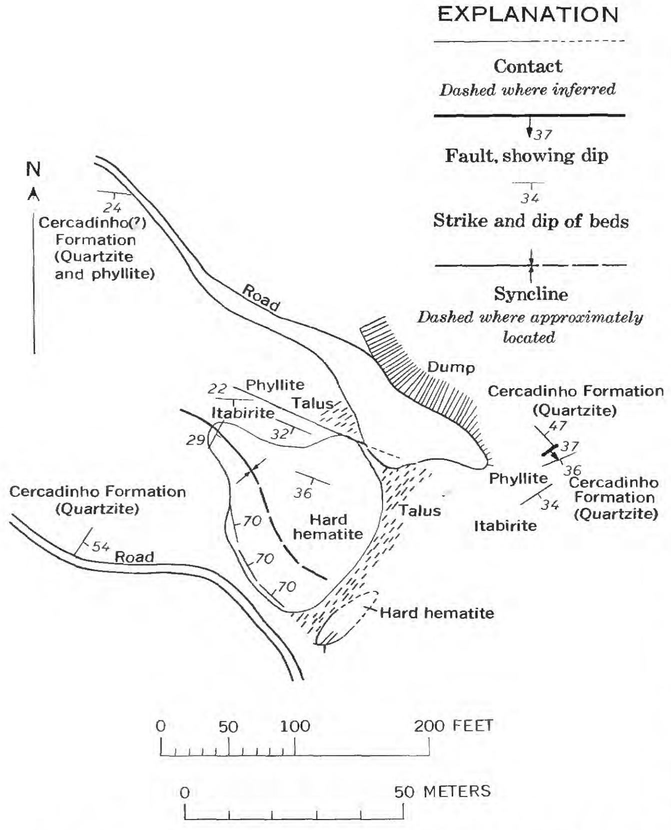

FIGURE 12.—Sketch map of the Cabeça de Ferro mine. (Pl. 1, N. 8,600 E. 200).

FIGURE 13.—Hematite ore at the Cabeça de Ferro mine showing preserved itabirite bedding.

(prior to 1960) mining has also been carried out on the northeast slope.

Some 1,200 square meters of ore are exposed, and calculations show 36,000 metric tons of indicated ore above the lowest exposure. The true horizontal limits of the ore body are probably only slightly more than the exposed limits, and projection of surface dips to their subsurface intersections suggests that little ore can be inferred below the 20 meters of present (1961) vertical exposure. Dips on the synclinal structure suggest that the ore body diminishes in size with depth. The volume, therefore, was calculated as one-third of a rectangular solid 1,200 square meters in area and 20 meters deep, or 8,000 cubic meters. The tonnage figure is calculated by using the common recovery factor, based on specific gravity, of 4.5 tons per cubic meter.

The Cabeça de Ferro mine has produced ore continuously since 1925; total production by 1960 was 70,000 tons, an average of 2,000 tons per year. More than 4,000 tons was mined in 1960. An average of analyses of the Cabeça de Ferro ore, supplied by the Companhia Brasileira de Usinas Metallurgicas, is (in percent): Fe, 67.77; P, 0.012; SiO_2, 0.62; Mn, 0.48.

COCAIS ROLADO

The Cocais deposits comprise two small undeveloped bodies of colluvial or rolado ore 2 kilometers southwest of the village of Cocais (pl. 2, N. 100, E. 2,900 and N. 200, E. 3,500). The deposits are 1 kilometer from the end of a poor dirt road which extends 1 kilometer from Cocais. The ore bodies are colluvial blankets overlying Cambotas Quartzite. Scattered iron-rich colluvium near the deposits indicates that the ore bodies are erosional remnants of a larger blanket which extended from the north slope of the Serra do Tamanduá.

The ore contains pebbles and cobbles of compact hematite, itabirite, and other iron-formation partly embedded in an earthy matrix. Some of the itabirite and other iron-formation were partially replaced by hematite prior to deposition as rolado and were enriched and softened by weathering after deposition. The ore is unique in that a large part of it was derived from iron-formations in the upper part of the Tamanduá Group; iron deposits derived from pre-Minas iron-formations are extremely rare. The derivation of the detritus from the iron-formations of the Tamanduá Group can be recognized by the high content and coarse grain size of magnetite, which are distinctive features in many outcrops on the flank of the Serra do Tamanduá 1,500 meters to the southeast.

The two deposits contain 35,000 metric tons of indicated ore estimated to average 64 percent iron. Minable parts of the deposits range from 0.5 to 2.5 meters in thickness and average 1 meter. The larger, west body of 10,000 square meters and the smaller, east body of 4,000 square meters have a combined volume of 14,000 cubic meters. A recovery factor of 2.5 tons per cubic meter used to calculate the reserve figure of 35,000 tons. Deposits of this size are too small for large mining operations but may be economically mined by small independent mine operators.

MANGANESE

Small amounts of manganese were mined in this area during the two World Wars, and reserves of several tens of thousands of tons remain. Of the 20,000–25,000 tons of ore produced, one-fifth came from high-grade alluvial and replacement deposits at Morro Grande which are now exhausted. Most of the ore, however, was produced at the Brucutú 54 mine, a low-grade epigenetic deposit, and several thousand tons of ore were mined at the Morro Dona Ana mine, a vein deposit. Reserves, most of which are at the Brucutú 54 mine, are low-grade ores. Unless the price of manganese rises, little likelihood exists that the mines will resume operations in the near future.

MORRO DONA ANA MINE

The Morro Dona Ana mine is in a vein deposit in argillaceous rock of the Nova Lima Group near the southwest corner of the Santa Bárbara quadrangle (pl. 1, N. 300, E. 200). The mine is reached by driving 6 kilometers southwest of Barra Feliz on the gravel road to the Colégio do Caraça. At this place a dirt road leads northwest for 1 kilometer to the Ferreira fazenda. The mine is north of the fazenda and is connected with it by a trail 2 kilometers long.

The manganese-bearing vein is in weathered yellowish-brown argillaceous material presumably derived from phyllite or schist. No structures in the host material were observed. The vein is exposed intermittently for a length of 100 meters in a largely grown-over and soil-covered trench on a steep hillside. In the best exposure of the vein at the upper end of the trench, the vein is 3 meters wide, strikes N. 39° E., and has a vertical dip.

The vein consists of pyrolusite and todorokite(?) in approximately equal abundance; no gangue minerals were seen, but the high aluminum content of an analyzed sample indicates some are present. The pyrolusite has a porous columnar structure, and some surfaces have reniform coatings. The todorokite(?) is a very soft black mineral which soils the hands and has a dark-brown streak. It occurs as banded aggregates of thin platy crystals as much as 10 cm long.

The todorokite(?) was tentatively identified from an X-ray analysis by M. E. Mrose, U.S. Geological Survey (written commun., 1963). The following is paraphrased from her report: The d-data obtained by cursory measurements with a 2θ ruler are close to, but not identical with, those in the literature for todorokite, ideally $Mn_2Mn_5O_{12}.3H_2O$. The film is related to patterns for todorokite from Tarantana, Cuba. The strong lines show close agreement with the lines for the Cuban todorokite, but lines beyond d=2.38 A differ markedly from those for the Cuban todorokite.

A sample weighing 0.5 kilogram was selected as being representative of exposed ore and was analyzed by J. B. de Araujo, Ministério das Minas e Energia, Belo Horizonte, and the following results were obtained, in percent: Mn, 41.0; Al, 12.9; SiO_2, 1.1; Fe, 0.8; P, 0.042; loss on ignition, 20.97.

From the size of the trench on the Morro Dona Ana vein, it is estimated that between 3,000 and 5,000 tons of ore was mined. The author was unable to contact the owner, Sr. Mario Campos Ferreira of Belo Horizonte, and production figures and analyses were not available. All ore was mined by hand and transported by burro to the road. Although the mine operated during World War II, it probably will not be reopened in the near future because of the size, grade, and location of the deposit.

BRUCUTÚ 54 MINE[10]

The Brucutú 54 mine is in the Gandarela Formation on the north limb of the Gandarela syncline (pl. 1, N. 13,500, E. 7,300). The mine is owned by João Thibaut of Belo Horizonte. The mine is reached by driving 7 kilometers from Barão de Cocais on the Barão de Cocais–Cocais road, and then 3.5 kilometers eastward on a poor dirt road.

A mine pit at the end of a ridge exposes weathered rock that can be divided into three zones, the lowest of which contains the manganese (fig. 14). The zones are subparallel to the surface. The upper zone, 3–5 meters thick, is made up of kaolinite which contains many particles of free quartz and nodular concretions of bauxite as much as 10 cm long. The bauxite concretions make up about 5 percent of the zone. The middle zone, from less than 1 to 3 meters thick, is a canga layer chiefly made up of manganiferous limonite. The lowest zone has a maximum exposed thickness of 14 meters and is made up of black wad containing thin streaks of higher grade dark-gray manganese oxide. Analyses of samples from the different zones are given in table 10, and the sample localities are noted on the sketch map of the mine (fig. 21).

The principal mine working consists of a two-level pit. The lower level of the pit is 30 meters long, 15 meters wide, and 6–8 meters deep; it is entered by a 25-meter-long trench from the southeast; the upper level of the pit is entered by a 30-meter-long trench from the southwest and a 40-meter-long trench from the northeast.

A description of the Brucutú deposit based on information supplied by Francisco Pinto de Souza was

[10] Brucutú was the name of a large old fazenda covering 2,000 Alqueires (about 50 square kilometers). This fazenda was later divided into numbered lots. Mine workings and prospects on the old fazenda property are named for the fazenda and the number of the lot on which they occur.

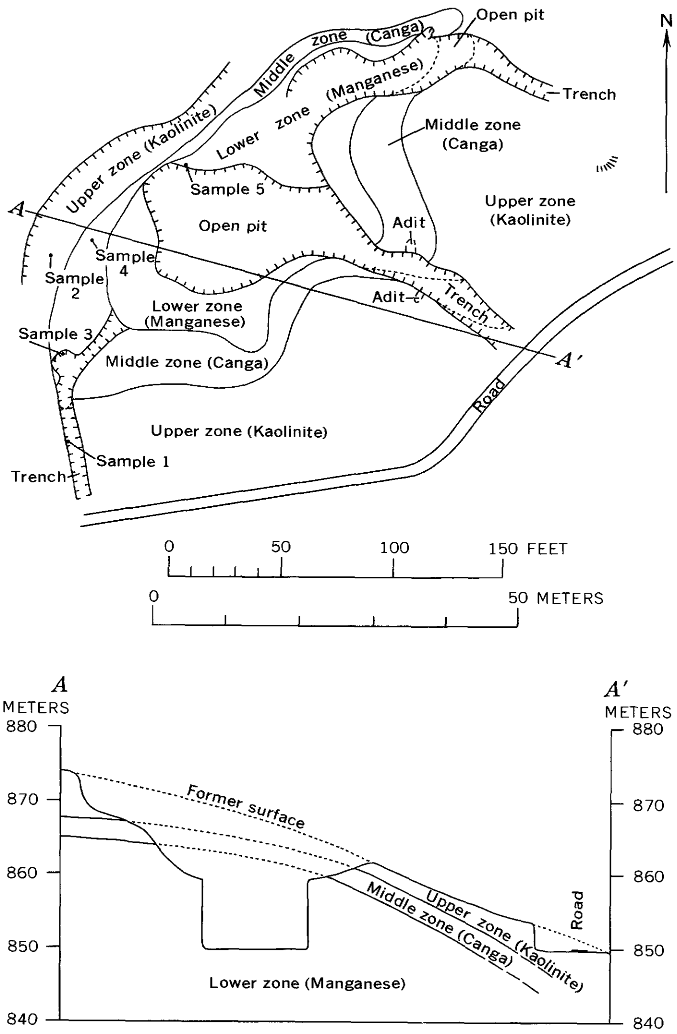

FIGURE 14.—Sketch map and section of the Brucutú 54 manganese mine. (Pl. 1, N 13,500, E. 7,300)

TABLE 10.—*Analyses of samples from the Brucutú 54 manganese mine, in percent*

[Analyst, Cassio Pinto, Departamento Nacional da Produção Mineral. n.d., not determined]

Sample	Zone	SiO_2	Fe	Al_2O_3	Mn	P
1	Upper	55.9	1.4	30.7	0.07	n.d.
2 [1]	do	14.9	.5	57.1	.08	n.d.
3	Middle	4.0	56.1	1.5	8.4	0.05
4	do	9.2	55.4	.5	5.5	.08
5	Lower	.61	38.6	.5	24.3	.03

[1] Bauxite nodule.

cited by Dorr, Coelho, and Horen (1956, p. 334-335); the following is quoted from their report:

On the surface were found a small quantity of cobbles and fragments of manganese ore with a grade of 40 to 45 percent Mn which occurred among blocks of compact hematite and canga. When this material was removed, a body of black friable manganese ore was found streaked by lenses of gray, very high-grade hard manganese ore and also' iensee of compact hematite. The black material without high-grade streaks varied between 20 and 35 percent manganese and the sum of the Mn plus Fe varied between 58 and 62 percent. The black ore in the ground contained between 8 and 15 percent moisture. During the rainy season the black ore when wet increased in moisture to between 40 and 50 percent, gradually decreasing when set out to dry. This material is probably in part wad.

* * * * *

About 15,000 tons were extracted [during World War II], but mining was stopped because extraction of only the high-grade ore was not economic and the pulverulent ore was too wet for successful use. At the time mining stopped, it was estimated that perhaps several tens of thousands of tons of ore were left in the deposit.

The Brucutú 54 deposit resembles many other small manganese deposits in the Quadrilátero Ferrífero which are considered genetically related to the weathering of manganiferous dolomite in the Gandarela Formation. The abundance of manganese in dolomite of the Gandarela Formation was noted by Dorr, Coelho, and Horen (1956, p. 303). The spatial relation of manganese oxide and dolomite in central Minas Gerais (p. 304) strongly indicates an epigenetic origin for many manganese deposits found in that formation, but no dolomite is exposed at Brucutú, and, therefore, other theories of origin may account for the deposit.

MORRO GRANDE

The abandoned Morro Grande manganese deposits include several small replacement bodies in the Gandarela Formation and alluvial deposits in an area of about 2 square kilometers which extends from the north outskirts of Barão de Cocais (pl. 1) westward into the Gongo Sôco quadrangle. Most of the replacement deposits are in the Gongo Sôco quadrangle, and the alluvial deposits occur along Córrego (creek) Morro Grande north of Barão de Cocais.

The Morro Grande deposits were mined during World War I, and the workings are now inaccessible. According to Conover [11] (1921, unpub. data).

The exact nature of * * * occurrence and distribution is obscure, since for the most part they have been worked out and the excavations subsequently covered by slumping and washing down on the soft schist. * * * However, a small party of men was extracting ore at [one place]. * * * Here, the ore was seen to be an irregular elongate bean-shaped mass * * * 2 or 3 meters in diameter and * * * mined along its length for about 3 meters. The ore consists of hard, dark blue-black manganese oxides, for the most part very finely crystalline, with a steely fracture which gives it an appearance similar to the hard blue iron ores. There are no visible impurities, and the shipments from the mine are reported to have contained consistently about 56 percent manganese and very little iron or phosphorus * * *.

From knowledge as to the amounts received by Sr. Moraes, who is working the property, and of average prices for the ore, we estimated that the workings * * * produced eight or ten thousand tons during the war. * * * Tvo shipments * * *

[11] Conover, J. D., 1921, Report on the manganese workings near Sao Joao de Morro Grande, Minas Geraes, Brazil: Brazilian Iron and Steel Co., unpub. report.

representing about 800 tons, showed the following analysis, and all the ore is said to have had a very even tenor:

Mn	56. 045
Fe	1. 805
Phos	. 135
SiO^2	2.
Al^2O^3	1. 215
Moisture	0. 485

With the fall in the manganese market, operations were stopped, and the schist had since slumped down over most of the workings. There is thus practically no ore in sight, and from what we can learn there was but little ore left actually showing when work was stopped * * *.

Along the river there are a large number of localities which during the war were worked in a small way for pebbles and boulders of manganese ore. Much of this material was of the same high grade, and the total production was probably a few thousand tons.

PROSPECTS

Several manganese prospects occur at scattered localities in the Gandarela Formation, and a few are in the Nova Lima Group. Most prospects in the Gandarela Formation are shallow pits located where small nodular pellets of manganese oxide are found at the surface, and some are short adits located where traces of manganese occur in weathered rock under canga rims. Prospecting in the Nova Lima Group was done by short adits driven in phyllite and schist at places where traces of manganese had been found. None of these openings indicated the presence of ore bodies.

DIAMONDS

Several small diamonds reportedly were found in streams which drain the Cambotas Quartzite, but the author was unable to verify these claims. Similar reports have come from near the Serra do Caraça, where the Cambotas Quartzite also is prominent (C. H. Maxwell, written commun., 1961). The Cambotas Quartzite extends northward from the Serra das Cambotas into the Serra Cipó. The quartzites in the Serra do Cipó have not been thoroughly studied as far north as the famous diamond region of Diamantina, where quartzite is a major source of diamonds. No reasons exist to suppose that an abundance of diamonds occurs in the Serra das Cambotas, for they probably would have been discovered long ago, but the reported finds are geologically possible.

QUARTZ CRYSTAL

A prospect for oscillator-quality quartz crystal is located 3 kilometers north of Barão de Cocais (pl. 1, N. 10,700, E. 1,200). The owner of the property and the production, if any, are unknown. The prospect is in a quartz vein in Cambotas Quartzite several meters north of a quartzite-gabbro contact. The prospect was developed by an undercut 6–7 meters wide and 1–2 meters high which enters the quartzite for about 2 meters. Numerous crystals were found on the dump, including several doubly terminated specimens 12–14 cm long, but few clear crystals remain in place in the vein.

GNEISS

Several quarries occur in the gneiss of Santa Bárbara in and near the town of Santa Bárbara. The one now active is on the southern outskirts of that town along the Central do Brasil Railroad. Gneiss is crushed at the quarry and used for riprap on the railroad.

CLAY

Impure clay derived from the weathering of phyllite and granite is excavated at several localities in the Barão de Cocais area, and it is used to make bricks and roof tiles for local consumption.

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