Geology and Ore Deposits of the Cachoeira do Campo Dom Bosco, and Ouro Branco Quadrangles Minas Gerais, Brazil

GEOLOGICAL SURVEY PROFESSIONAL PAPER 341-B

Prepared in cooperation with the Departamento Nacional da Produção Mineral of Brazil under the auspices of the International Cooperation Administration of the United States Department of State

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By ROBERT F. JOHNSON

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1962

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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By Robert F. Johnson

ABSTRACT

The Cachoeira do Campo, Dom Bosco, and Ouro Branco quadrangles are on the southern margin of the Quadrilátero Ferrífero, in central Minas Gerais, one of the great iron-bearing areas of the world. Large iron-ore bodies have not been found in the mapped area; but manganese deposits have been mined in the past, and dolomite is now being quarried.

The mapped area is underlain by Precambrian metamorphosed sedimentary rocks of low to medium metamorphic grade intruded by granitic and mafic rocks. The most important rocks, economically, belong to the Minas series that underlies most of the Dom Bosco quadrangle. The oldest part of Minas series consists of a basal quartzite of variable thickness overlain by a thin discontinuous phyllite. These units constitute the Caraça group. Above the phyllite or resting directly on the quartzite or older rocks is the Cauê itabirite, a thin-banded rock composed of hematite or magnetite and recrystallized chert. Dolomite may be in the chert bands or may take the place of chert in the upper parts of the iron-formation. The Cauê is overlain by the Gandarela formation, composed of dolomite lenses and iron-formation with interbedded phyllite. These two formations belong to the Itabira group. The youngest rocks of the Minas series, the Piracicaba group, consist of ferruginous quartzite, phyllite, quartzite, graphitic schist, and dolomite. The Minas series unconformably overlies green schist and phyllite of the Rio das Velhas series, which crops out both north and south of the Minas series.

A gneiss batholith underlies most of the Cachoeira do Campo quadrangle and extends south into the Dom Bosco quadrangle. Both paragneiss and orthogneiss are represented. At least part of the gneiss is post-Minas in age, as granitic rock is found intruding the Minas along the southwestern margin of the gneiss west of the mapped area, and post-Minas intrusion or doming has arched the overlying sediments. A contact metamorphic aureole has developed around the gneiss. This contact metamorphism is confined to rocks of the Rio das Velhas series in the mapped area; the Minas series seems to be unaffected.

Structural features in the area trend eastward except in the northeast corner of the Cachoeira do Campo quadrangle where the schists strike northwest, parallel to the margin of the gneiss. The Minas series in the northern half of the Dom Bosco quadrangle is folded into a complex canoe-shaped syncline. The beds on the southern flank of the syncline are probably overturned, and the fold is cut off on the south by a thrust fault that has thrust rocks of the Rio das Velhas series and the lower part of the Minas over phyllites of the Piracicaba group. Thrust faults with the overriding block on the south or east sides of the fault are common. A syncline occurs north of the Serra do Ouro Branco, and an anticline occurs east of Morro do Gabriel. The tight folds and numerous thrust faults are evidence of strong compressive forces probably acting from the south or southeast, as shown by the relations along the thrust faults. The rocks of the Minas series may have been squeezed between the more massive blocks of the basal quartzite of the Minas(?) Serra do Ouro Branco and the gneiss of the batholith.

Landforms in the area to be described are determined by the resistance of the different rock types to erosion and by structural features. The larger streams are antecedent but the smaller are subsequent. The area has been uplifted, and remnants of old erosion surfaces are found in the northern half of the mapped area.

The iron-formation in the mapped area is relatively thin, only locally reaching 100 meters in thickness. The principal belts have been prospected on a small scale, and small shipments of ore have been made. The iron-formation consists of hard and soft itabirite; hard massive hematite of export quality has not been found. Some of the deposits may be exploitable in the future because of their proximity to rail transportation.

Manganese production has been economically important in the past, but the mines are now inactive. Over 1 million tons of ore with a grade of about 50 percent manganese was produced from the Burnier deposit at São Julião. The manganese is in a bed 2 to 4 meters thick, in the iron-formation and on the contact with dolomite. Large reserves of low-grade material are said to be available.

Many other small manganese deposits are found scattered throughout the Dom Bosco quadrangle, either associated with manganiferous dolomite or occurring in clastic rocks. The deposits are formed by surficial concentrations of manganese oxides. Ore found in similar deposits in adjacent areas ranges in grade from 30 to 50 percent manganese. Production ranges from a few hundred kilograms in most of the occurrences to a few tons from the larger deposits.

Dolomite quarries have been opened in dolomite lenses both in the Gandarela formation of the Itabira group and in the Piracicaba group. The largest quarry in operation in 1956 was at Cumbe, north of Dom Bosco, where building stone is the principal product. Lump dolomite for metallurgical use or for mosaics is quarried south of Hargreaves. Analyses of the dolomites show carbonate ranging from nearly pure dolomite to dolomitic limestone.

Clay, placer gold, imperial topaz, and quartz crystal have

been mined on a small scale. Cinnabar has been found near Dom Bosco, and sphalerite with various sulfosalts of lead occurs near Morro do Bule. Both occurrences are very small.

INTRODUCTION

The Quadrilátero Ferrífero in central Minas Gerais has long been known to contain some of the largest deposits of high-grade iron ore (more than 65 percent iron) in the world, as well as vast amounts of lower grade material. Geological studies of the ore deposits have been carried on intermittently since the pioneer work of Derby in the early 1900's. In 1947 the Departamento Nacional da Produção Mineral, in cooperation with the U.S. Geological Survey, undertook a long-range program to determine the size and structural relations of the ore bodies and to work out the regional stratigraphy and structure. The work plan was to map the entire area topographically and geologically with the maps to be published in 7½ minute quadrangle sheets on a scale of 1 : 25,000.

The regional stratigraphy had been determined by the time work began on the quadrangles to be described in this report; so emphasis will be on local lithology and structure. The iron-bearing formations are relatively thin in the area, and no high-grade ore bodies are known; hence, interest in the area is more of a geologic than an economic nature. Deposits of manganese, dolomite, clay, topaz, and gold have been worked on a small to moderate scale.

LOCATION AND ACCESS

The quadrangles are in the south-central part of the Quadrilátero as shown in figure 1.

The town of Cachoeira do Campo is 80 kilometers by road from Belo Horizonte, the state capital, and 25 kilometers from Ouro Preto.

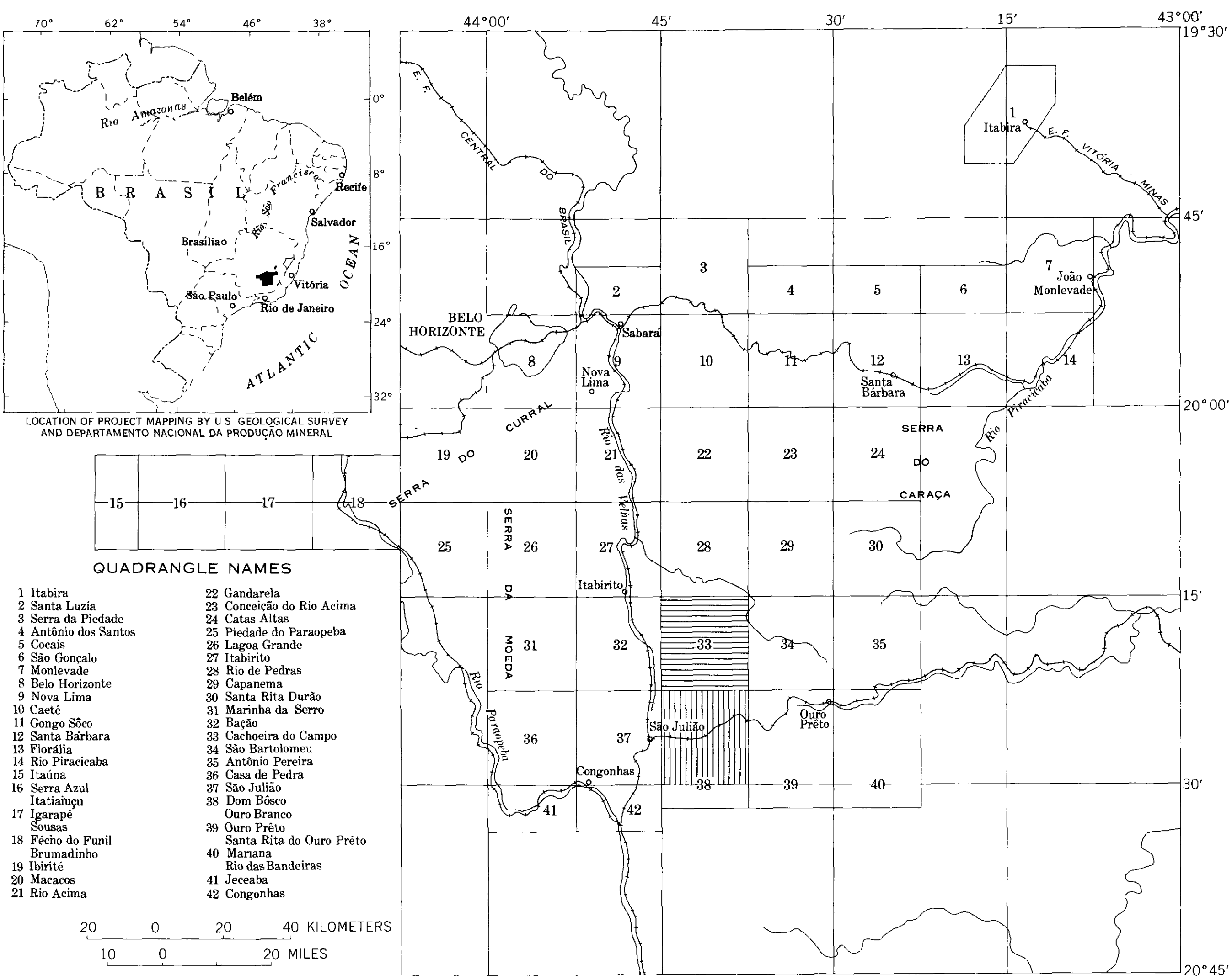

Figure 1.—Index map of the Quadrilátero Ferrífero showing the location of all quadrangles to be mapped in the Brazilian iron project. The shaded area is described in this report.

The principal roads are the Belo Horizonte–Ouro Preto highway that passes through Cachoeira do Campo, and the old Belo Horizonte–Rio de Janeiro highway that lies a few kilometers west of the quadrangle. Secondary roads provide access between the two highways and outlying villages, and private roads lead to dolomite quarries and hydroelectric powerplants. Except for the Belo Horizonte–Ouro Preto highway, the roads are not hard surfaced, but the main roads are maintained, and all roads are passable throughout the year except for short periods after heavy rains.

A railroad parallels the Belo Horizonte–Rio de Janeiro highway, and a branch line from São Julião[1] to Ouro Preto nearly bisects the Dom Bosco quadrangle.

Both railroads are narrow gage (1 meter). The main line has a third rail as far north as Itabirito increasing the gage to 1.60 meters. The branch line has a third rail only from São Julião to Hargreaves.

TOPOGRAPHY AND RELIEF

The topography ranges from gently rolling surfaces to steep slopes, depending largely on the underlying rock types. In areas underlain by gneiss, as in much of the Cachoeira do Campo quadrangle (pl. 1), the hills are low and gently rolling except for a few steep ravines. Relief in the gneiss area is low, generally 100 to 150 meters, but it reaches 200 meters in the valley of Ribeirão Mango (Mango River). Moderate to steep topography is characteristic of the area underlain by bedded rocks. Relief increases southward in the Dom Bosco quadrangle (pl. 2), and slopes become steeper. The quadrangle is crossed by three subparallel ridges that rise from an altitude of 1,300 meters on the northern ridge to 1,570 meters on the Serra do Ouro Branco.

[1] São Julião is shown on some maps as Miguel Burnier, and the two names are used interchangeably by the residents. São Julião is the official name.

The northern ridge is discontinuous, being cut by three streams. The ridge is not named, but the higher parts of it are given names such as Alto do Catete and Alto do Monumento.

The central ridge is higher and is only interrupted by one stream, Ribeirão Mango, which cuts through it in a steep ravine over 200 meters deep. The eastern half of the ridge is part of the watershed of the Rio São Francisco, one of the larger rivers in Brazil, and is called the Serra Geral in this region. The higher parts of the ridge also have local names (pl. 2).

The southern ridge is known as the Serra do Ouro Branco. Viewed from the south it is an imposing sight (fig. 2) that contrasts markedly with the prevailing rolling topography developed on areas underlain by gneiss or schist. The scarp is 200 to 400 meters high, and there is a total relief of 600 meters between the highest peak and the valley at the base of the range. High discontinuous ridges cut by steep valleys lie between the Serra do Ouro Branco and the central ridge of the Dom Bosco quadrangle.

Low rolling hills are found south of the Serra do Ouro Branco. Steeper topography and greater relief are found near the east edge of the Ouro Branco quadrangle (pl. 2).

DRAINAGE

Streams in the area flow into three major river systems; the Rio das Velhas, the Rio Paraopeba, and the Rio Doce. The Rio das Velhas and the Rio Paraopeba are northward-flowing rivers, tributary to the Rio São Francisco, and the Rio Doce flows eastward to the Atlantic. The Rio das Velhas cuts the northeast corner of the Cachoeira do Campo quadrangle, and its tributaries drain the entire area north of the drainage divide followed in the central part of the Dom Bosco quadrangle by the São Julião–Ouro Preto railroad. The Ribeirão Mango drains the west side of the area, and

FIGURE 2.—The Serra do Ouro Branco as seen from the southwest. The scarp has developed in quartzite.

the Ribeirão Maracujá drains the central part; the east side is drained by the Ribeirão Tabuões and Córrego Casa Branca. South of the divide, the principal streams are the Ribeirão da Colónia and Ribeirão do Ouro Branco, which drain into the Paraopeba system, and the Córrego da Cachoeira, which is part of the Rio Doce system.

Small hydroelectric plants are located on many of the larger streams. The power is used locally in the small towns of the area.

CLIMATE AND VEGETATION

A mild climate with markedly seasonal rainfall is charateristic of the area; November to May are the rainy months. Recent records are not available, but von Freyberg (1934, p. 25) gives the average annual rainfall for Cachoeira do Campo, for the period 1915–21, as 1,550 mm. Ouro Preto in the same period had an average annual rainfall of 2,100 mm.

June, July, and August are the coldest months. Freezing temperatures are unknown over most of the area, but may occur in the higher sheltered valleys.

Timber is found only along the streams and on the lower slopes of the hills. The higher ridges support a growth of shrubs and grass. Nearly all the forest has been cut for charcoal at least once, and cutting is repeated as soon as the trees reach a suitable size. Eucalyptus has been introduced and is also used for charcoal. The eucalyptus trees are first cut about 5 to 7 years after planting. After the initial cutting, a new growth sprouts from the old stump, and these in turn can be cut about every 5 years. The production of charcoal is an important local industry as most of the iron and steel plants in Minas Gerais use charcoal for fuel.

ACKNOWLEDGMENTS

This report was made possible through the cooperation of the author's colleagues in the Departamento Nacional da Produção Mineral and in the U.S. Geological Survey. They furnished a basic preliminary orientation to the work and helped discuss geologic problems that arose in the course of the mapping.

Dr. José Alves, head of the Departamento Nacional da Produção Mineral office in Belo Horizonte, was most helpful in arranging for the use of D. N. P. M. facilities and in furnishing the personnel for the preparation of maps and thin sections. Most of the chemical analyses given in this report were made at the D. N. P. M. laboratories by Drs. Cássio Pinto and José Doche. Dr. Alves assigned Sr. Geraldo Monteiro de Barros as field assistant for the project. Sr. Monteiro proved a most willing assistant and a pleasant companion during the course of the work.

Thanks are also due Dr. Amaro Guatimosim, of the Companhia de Mineração de Usina Wigg, at São Julião, who provided a house for the author's use during part of the fieldwork.

The operators of the marble quarry at Cumbe kindly allowed access to their properties and were helpful in many ways.

The work was done under the supervision of J. V. N. Dorr II, chief of the U.S. Geological Survey party in Minas Gerais and W. D. Johnston, Jr., Washington, D.C. The entire program was carried out under the terms of an agreement between the Departamento Nacional da Produção Mineral do Ministério da Agricultura of Brazil and the International Cooperation Administration of the U.S. Department of State.

PREVIOUS GEOLOGIC WORK

An extensive bibliography of the Quadrilátero Ferrífero has accumulated over the past 120 years. Most of the earlier papers dealt with features of individual deposits, but regional studies of the geology were published by Derby (1906), Harder and Chamberlin (1915), and von Freyberg (1932). The report by von Freyberg contains a bibliography of 976 titles. A more recent paper on the regional geology is by Guimarães (1951). The reports of Dorr (1963) and Guild (1957) discuss many regional geological problems connected with the iron deposits.

Reports that deal specifically with the mapped area are concerned primarily with individual mineral deposits, except for a paper by O. Barbosa (1949), who describes structural features on the west-margin of the Dom Bosco quadrangle. Manganese deposits near São Julião and along the railroad to Ouro Preto are described by Scott (1900) and discussed by Guimarães (1935), von Freyberg (1934, p. 141–145), and Guild (1957). The base-metal mineral locality at Morro do Bule has attracted considerable interest and was the subject of a report by Guimarães and Coelho (1946a), who also described the cinnabar occurrences near Dom Bosco (1946b). Gorceix (1881), Derby (1901), and Boa Nova (1929) have written about the topaz deposits.

PRESENT INVESTIGATION

The fieldwork on which this report is based was done in 1955 and early 1956. The primary purpose of the mapping was to determine the distribution and structural features of the rocks in the Minas series, the host rocks for the iron deposits. Field mapping was done on aerial photographs, on a scale of 1:25,000, and the data were transferred to a topographic base.

Because the Dom Bosco quadrangle contains nearly all the exposures of rocks of the Minas series, it was mapped in considerable detail. Most of the trails in the Cachoeira do Campo quadrangle were followed, and all areas of outcrop of gneiss that were found were plotted on the map. A detailed study of each outcrop to determine the internal structure of the gneiss and to delineate the different types of gneiss was not attempted as it was felt to be outside the scope of the present study. Little work was done south of the Serra do Ouro Branco because the exposures were too poor to give a clear understanding of the rock distribution.

GEOLOGY

STRATIGRAPHY

The Cachoeira do Campo, Dom Bosco, and Ouro Branco quadrangles are underlain by regionally metamorphosed Precambrian sedimentary and intrusive rocks of phyllite, low- to medium-grade schist, quartzite, dolomitic carbonate rock, iron-formation or itabirite,[2] mafic intrusive rocks, and granodiorite gneiss. The Precambrian age is assumed, as unmetamorphosed sedimentary rocks of Silurian (?) age rest on the metamorphosed and deformed older rocks north of the Quadrilátero Ferrífero (Oliveira and Leonardos, 1943, p. 261).

All sedimentary rocks of the area were included in the Minas series as originally defined (Derby, 1906, p. 396). As a result of more detailed work by Guimarães (1931, p. 8), Barbosa (1954), Oliveira (1956), and Dorr and others (1957), the original Minas series was divided into three series with the name Minas series retained for the middle series (table 1). The oldest rocks form the Rio das Velhas series, named and described by Dorr and others (1957), and the youngest were called the Itacolumí series by Guimarães (1931). Barbosa (1954, p. 21) suggested that the rocks now called the Rio das Velhas series may correlate with his Barbacena series. Evidence for an unconformity at the base of the restricted Minas series was presented by Rynearson and others (1954).

RIO DAS VELHAS SERIES

The Rio das Velhas series is divided into two groups of rocks; the Nova Lima group at the base, consisting of phyllite and green schist with minor amounts of quartzite and iron-formation; and the Maquiné group, composed largely of quartzite and conglomerate with some schist and phyllite. Dorr and others (1957, p. 21–22) give a minimum thickness of 4,200 meters for the Nova Lima group and 850–1,800 meters for the Maquiné group. No rocks definitely of the Maquiné group were found in the mapped area although the possibility that the quartzite of the Serra do Ouro Branco is part of the Maquiné group could not be disproved.

The schist and phyllite of the Rio das Velhas series are similar in appearance to rocks in the Minas series; so the basal quartzite of the Caraça group in the Minas series is important in distinguishing the two series in the field. Unfortunately the quartzite is missing in part of the Dom Bosco quadrangle, and the distinction cannot always be made confidently.

DISTRIBUTION

Schists definitely of the Rio das Velhas series have been mapped across the northern part of the Dom Bosco quadrangle and in the southeast corner of the Cachoeira do Campo quadrangle, where they underlie the Caraça quartzite and have been intruded by granodirite of the Itabirito batholith. The contact between the schist and the gneissic rocks of the batholith swings to the north in the São Bartolomeu quadrangle east of Cachoeira do Campo (fig. 1) and reenters the Cachoeira do Campo quadrangle east of Glaura (pl. 1). The schist east of the contact is a continuation of the rocks mapped by O'Rourke (written communication). The isolated areas of schist found within the region underlain by the batholith are also mapped as Rio das Velhas series although no direct evidence was found for their correlation other than lithologic similarity and contact relations with the gneiss.

A band of schist and phyllite, mapped as part of the Rio das Velhas series, extends westward from near Dom Bosco to the edge of the mapped area (pl. 2).

Green schist intruded by granitic rock is found both north and south of the Serra do Ouro Branco. That south of the Serra is the eastward extension of the green-schist and granodiorite complex mapped as Minas equivalent (?) by Guild (1957, pl. 2). Exposures in the Dom Bosco and Ouro Branco quadrangles show that this schist underlies the quartzite of the Serra do Ouro Branco with slight to moderate unconformity. If the quartzite of the Serra is part of the Caraça group as proposed in this report, and as suggested by Guild (1957, p. 13), then the underlying schist should belong to the Rio das Velhas series.

The stratigraphic position of the wedge of green schist and granodiorite north of the Serra and east of the Fazenda Quindim (pl. 2) is uncertain. The rocks are identical in appearance with those south of the Serra and are mapped as Rio das Velhas series repeated by faulting. Their position in the section remains open to question because of the possibility that

[2] Iron-formation will be used in this report as a general term for banded iron-rich sedimentary rock. The iron-bearing minerals may be hermatite, magnetite, goethite, or limonite. The iron-rich layers alternate with light-colored minerals. Itabirite is metamorphosed oxide facies iron-formation with alternate laminae of iron-rich material and recrystallized chert. If dolomite is found in the chert layers, or in place of the chert, the rock is called dolomitic itabirite.

TABLE 1.—*Comparative stratigraphic chart of the Precambrian rocks of the Quadrilátero Ferrífero*

1915 Harder and Chamberlin

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

1954 O. Barbosa

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

1956 A. I. de Oliveira

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

1956 U.S. Geological Survey–Departamento Nacional da Produção Mineral

Itacolumí series		Quartzite, phyllite, and conglomerate.
		—Large unconformity—
Minas series	Piracicaba group 4–6 formations	Chlorite schist and graywacke with metavolcanic rocks.
Minas series	Piracicaba group 4–6 formations	Graphite schist.
Minas series	Piracicaba group 4–6 formations	Quartzite.
Minas series	Piracicaba group 4–6 formations	Quartz schist and ferruginous schist.
Minas series	Piracicaba group 4–6 formations	Ferruginous quartzite, phyllite, conglomerate, and dolomite.
		—Local unconformity—
Minas series	Itabira group	Gandarela formation; dolomite, phyllite, itabirite, and dolomitic itabirite.
Minas series	Itabira group	Cauê itabirite; itabirite (oxide facie iron-formation).
Minas series	Caraça group	Batatal formation; phyllite and graphitic phyllite.
Minas series	Caraça group	Quartzitic phyllite, quartzite, and conglomerate.
		—Large unconformity—
Rio das Velhas series	Maquiné group	Upper part; quartzite, conglomerate, and quartz schist.
Rio das Velhas series	Maquiné group	Lower part; quartzite, graywacke, quartz schist, and phyllite.
		—Unconformity—
Rio das Velhas series	Nova Lima group	Phyllite and green schist (metasediments and metavolcanic rocks), iron formation (carbonate), quartzite, dolomite, and graywacke
		—Large unconformity—
? [5]		Gneiss and granitic rock.

[1] Includes the Batatal of Harder and Chamberlin.
[2] Includes rocks classified in the U.S. Geological Survey–Departmento Nacional da Produção Mineral classification as Maquiné group.
[3] Includes part of the Rio das Velhas series in the U.S. Geological Survey–Departmento Nacional da Produção Mineral classification.
[4] Includes some known post-Minas rocks.
[5] The oldest gneisses and granitic rocks in the Quadrilátero Ferrífero do not have the same appearance as those of the type locality of the Mantiqueira series of O. Barbosa. Post-Minas gneiss is common.

they are rocks in the upper part of the Minas series that have been intruded by granitic material which raised the grade of metamorphism to a higher degree than that commonly found in the upper part of the Minas.

LITHOLOGY

Because very few outcrops of fresh rock were found in areas underlain by schist of the Rio das Velhas series, the rock descriptions will be those of weathered material or saprolite.[3]

Reddish-brown to dark-red weathered schist is the most common rock type found in representative outcrops of the Rio das Velhas series. The rock may be

[3] Saprolite is a general term for earthy material or clay that has formed in place from the parent material. Although the structure and texture of the parent rock are preserved, the mineralogy, owing to weathering, has radically changed.

phyllitic and may show a woody texture not found in the Minas series. Bleached micaceous material and quartz are generally the only recognizable minerals; they are enclosed in red clay. The micaceous material may be bleached chlorite or mica; individual flakes have a refractive index of 1.58 and show a negative, nearly uniaxial figure.

Fresh phyllite was found along the Ribeirão Mango, 200 meters northeast of Lagoa Sêca in the northern part of the Dom Bosco quadrangle. The rock is fine grained and gray with a silvery sheen on the schistosity surfaces. As seen in thin section, the principal minerals are quartz and sericite with about 10 percent magnetite. Chlorite and tourmaline are common accessory minerals. Porphyroblasts of garnet as much as 0.3 millimeter in diameter are probably due to contact metamorphism, as the outcrop is near the margin of the Itabirito batholith; garnets are common in the red schist near the contact. Sericite aggregates, pseudomorphous after a tabular mineral, possibly staurolite, are also seen in thin section.

Black graphitic schist is found in the belt of Rio das Velhas series rocks near the center of the Dom Bosco quadrangle, where it underlies red schist. Dark-gray schist is also found in the bed of the Rio das Velhas in the northeast corner of the Cachoeira do Campo quadrangle. The graphitic schist is dark gray to black and may have a reddish sheen on slip surfaces. The weathered rock is soft and enough graphite may be present to mark the fingers; some beds are hard and splintery. The schist is finely laminated, commonly with corrugations developed on the laminae. Slight color banding and a few red or brown beds show that most schistosity is close or parallel to bedding.

Coarse clastic rock is rare in the pre-Minas rocks in the mapped area. A quartzite with abundant detrital tourmaline occurs in a patch of schist north of Amarantina in the Cachoeira do Campo quadrangle. A thin conglomerate crops out on the ridge crest at coordinates N. 8,580, E. 360[4] in the Dom Bosco quadrangle and can be traced to the southeast for several hundred meters. The conglomerate is about 3 meters thick and is on the contact between red and black schist. Granules and rounded pebbles as much as 1 centimeter in length occur in a sandy matrix. Chlorite was found to be an abundant constituent. As seen in thin section, the chlorite flakes are found between the quartz grains and in braided aggregates closely intergrown with biotite. Sericite and magnetite are accessory minerals.

[4] Owing to the scarcity of named places in the quadrangles, a coordinate system will be used for location when needed. The coordinate numbers represent the distance in meters from the south and west borders of each quadrangle. The guide marks plotted along the margins of the maps at 2,500-m intervals will aid in location.

THICKNESS AND CONTACT RELATIONS

Rocks of the Maquiné group are absent in the mapped area, unless the quartzites of the Serra do Ouro Branco prove to be Maquiné in age. An unknown thickness of the Nova Lima group was removed before deposition of the Minas series; the base of the Nova Lima group is not exposed. A section along the ridge at N. 8,600, E. 360 that is about 650 meters thick and is bounded by faults above and below was the only section found that could be measured directly. Estimates of thickness based on the map width of the belts of pre-Minas rocks would be meaningless, as the internal structure of the belts is unknown. The rocks of the Minas series are tighlty folded, and there is no reason to suppose that the pre-Minas rocks of similar lithology would be less folded, particularly as they have undergone at least one additional period of deformation.

The schists of the Rio das Velhas series underlie the quartzite or iron-formation of the Minas series with slight to moderate unconformity. The contact in the northern part of the Dom Bosco quadrangle is nearly conformable except where it was crossed by Córrego Holanda. Here, a 40° difference in strike was found between the schist and the overlying quartzite. Part of the difference may have been due to hill creep, as the contact is on a steep hillside and not exposed. Elsewhere, the strike of the beds on either side of the contact is nearly the same, but the dip may differ 10° to 15°. The contact is well exposed north of the Ouro Preto highway in the southeast corner of the Cachoeira do Campo quadrangle, where channeling is evident on the surface of the pre-Minas schist. Bedding is nearly conformable in this area.

A strong angular unconformity between schist of the Rio das Velhas series and the overlying iron-bearing Cauê itabirite can be seen on the ridge northeast of Alemão in the Dom Bosco quadrangle (N. 8,540, E. 4,780). The contact itself is covered, but beds in the schist 40 meters from the contact strike into it at a high angle and dip in the opposite direction; there is no evidence of faulting. Schist of the Batatal formation normally lies beneath the iron-formation (table 1), but the rocks in question are not believed to be Batatal for two reasons: several hundred meters of schist are exposed in this area, while the known Batatal formation, only 4 kilometers to the north, ranges from 5 to 10 meters in thickness, or may be absent entirely; the contact with the Cauê itabirite is unconformable, at least in part, whereas elsewhere in the Quadrilátero Ferrífero, the contact between the Cauê itabirite and Batatal formation is conformable. The absence of the quartzite, found beneath the Batatal formation in the normal sequence, could also be due to nondeposition, as the quartzite is very thin in the northern section.

The contact at the base of the Ouro Branco scarp is exposed at the west end of the range (fig. 3) and

FIGURE 5.—Contact between quartzite and the underlying schist at the west end of the Serra do Ouro Branco.

along the Ouro Branco–Ouro Preto road. The strike of the schistosity in the schist and quartzite at the west end of the range differs about 20°. Bedding and schistosity are about the same in the quartzite, but their relationship could not be determined in the schist. The schist and quartzite are apparently conformable at the contact exposed along the road.

MINAS SERIES

The Minas series has been divided into three groups and many formations (Dorr and others, 1957, p. 22–29, and table 1). At the base is the Caraça group, which consists of clastic rocks, largely quartzite, quartz-rich schist, and conglomerate, with some phyllite near the top. These rocks are overlain by the Itabira group, principally sedimentary rocks of chemical origin, which includes the Cauê itabirite at the base and carbonate rock of the Gandarela formation above. The separation within the Itabira group is not complete; itabirite is found interbedded with carbonate rock, and part of the itabirite is dolomitic. The Piracicaba group overlies the Itabira group with local disconformity; the group consists of clastic rocks with some dolomite.

This sequence, widely exposed elsewhere in the Quadrilátero Ferrífero, can be found only in the northern part of the Dom Bosco quadrangle, and even there the Caraça group and the Cauê itabirite are thin and locally wedge out. Farther south the section is incomplete, and the location of contacts is arbitrary because the low-grade schists and phyllites of the different series are commonly indistinguishable in the field.

The Gandarela formation in the mapped area contains much more clastic rock than it does elsewhere in the Quadrilátero Ferrífero. Rocks of the Piracicaba group underlie a large area, but while all the rock types shown in table 1 are represented, it was not found possible to map them separately as formations owing to poor exposures or thinning of the lithologic types.

The section of the Minas series in the Dom Bosco quadrangle is in sharp contrast to that normally found in the Quadrilátero Ferrífero. The formations in the Dom Bosco quadrangle contain more clastic material and are not found as continuous units. The area may have been marginal to the basin in which the sediments of the Minas series were deposited. This could explain both the relative abundance of clastic rocks and the thinning and cutting out of the beds. A land area may have extended southeastward from the Itabirito batholith in the area where rocks of the Caraça and Itabira groups are missing.

CARAÇA GROUP

The thick and widespread quartzite at the base of the Minas series was named "Caraça quartzite" by Harder and Chamberlin (1915, p. 351), and the overlying schist and phyllite were named "Batatal formation" by the same authors. Since then, the quartzite was found to be divisible into three formations in parts of the Quadrilátero Ferrífero (G. A. Rynearson, oral communication), and these, together with the Batatal formation have been renamed "Caraça group" by Dorr and others (1957, p. 24–25). In the area described in this report, the quartzite cannot be divided, and the overlying schist and phyllite is not thick; so only the group was mapped during the present investigation.

The quartzite of the Serra do Ouro Branco, described in this part of the report, cannot be correlated with certainty to the quartzite of the Caraça group.

DISTRIBUTION

The Dom Bosco quadrangle contains most of the exposures of quartzite of the Caraça group. A thin band of quartzite extends eastward from the Cidreira dolomite quarry in the northern part of the quadrangle and continues to the Serra Siqueira in the southeast corner of the Cachoeira do Campo quadrangle. The quartzite is not continuous west of the quarry but reappears in the São Julião quadrangle and thickens to the northwest.

Many of the other quartzite occurrences in the mapped area cannot be dated with certainty. The great mass of quartzite of the Serra do Ouro Branco is mapped as Caraça(?). The large quartzite area east of Morro do Gabriel is also mapped as Caraça(?) because the rocks closely resemble those of the Serra do Ouro Branco.

LITHOLOGY

The sericitic quartzite, sericitic conglomerate, and quartz-sericite schist mapped as the Caraça group are light colored. Weathered surfaces are light to medium gray, and the fresh rock may be white to light gray. Greenish-gray rocks are not uncommon, and some exposures are moderate orange pink (Rock Color Chart, Natl. Research Council, 1948), owing to the staining of the sericite by iron.

Weathered surfaces have a rough texture caused by the presence of abundant coarse grains of quartz found in most quartzite beds. These grains range from 1 to 3 millimeters in diameter and generally make up more than 10 percent of the rock; most of the beds could thus be classified as conglomerate (Pettijohn, 1949). However, as they range from coarse quartzite to conglomerate, they will be called quartzite in this report to distinguish them from strongly contrasting beds of conglomerate made up of coarser material.

Bedding in the quartzite is nearly everywhere obscured by shearing and could not be determined at many outcrops. The sheared rock is composed of layers of granular quartz 1 to 2 mm in thickness separated by partings of sericite 1 mm or less in thickness. The sericite is braided; it splits and joins along strike, separating the quartz layers into lenses. The shearing may be parallel to bedding, but is often at a high angle to it

FIGURE 4.—Schistosity developed in quartzite on the Serra do Ouro Branco. Bedding is nearly at right angles to the schistosity.

(fig. 4). Where it can be seen, bedding is shown by variations of grain size in adjacent beds or by color banding. In the Serra do Ouro Branco, the bedding is usually parallel to the trend of the range, but the shearing strikes north to northwest. The range in thickness of individual beds is not well known, owing to the difficulty in determining the bedding. Beds 5 to 10 centimeters thick are known to exist, and a conglomerate on the north flank of the range is more than 5 meters thick with no definite break.

Quartz and sericite in varying proportions are the dominant minerals in the quartzite of the Caraça group. The quartz shows strain shadows in thin section, and the larger grains have crushed borders even though the grains are rounded. The small grains are angular and poorly sorted. This could be due to crushing during shearing rather than to original depositional differences. The larger grains are either individual quartz grains or aggregates of small grains that could originally have been quartzite or chert. Sericite occurs as tiny plates concentrated in thin laminae and also scattered through the quartz bands. Some of the quartzite is massive and fine grained rather than schistose, and the sericite is oriented poorly and scattered throughout the rock. This massive quartzite is common in the rocks of the Caraça group in the northern part of the Dom Bosco quadrangle but is rare elsewhere. Specular hematite and magnetite are common accessory minerals; zircon was found in some thin sections, and plagioclase was seen in one thin section from the Serra do Ouro Branco. Not enough petrographic work was done to determine the abundance or distribution of plagioclase.

Conglomerate crops out in the Serra do Ouro Branco and in the quartzite east of Morro do Gabriel. It is interbedded with quartzite at several places in the Serra do Ouro Branco, but a basal conglomerate was not found. The conglomerate is composed of rounded pebbles of quartz and quartzite or recrystallized chert as much as 10 centimeters in length in a groundmass of sand-size quartz and sericite; the pebbles make up 50 to 70 percent of the rock. Magnetite is abundant in the groundmass of some conglomerate. Ferruginous quartzite and phyllite pebbles were found at one locality near the north border of the Ouro Branco quartzite (N. 800, E. 9,650) in the Dom Bosco quadrangle. The pebbles are flattened and alined parallel to the schistosity. Conglomerate is rare in the other quartzite areas mapped as Caraça. A fine-grained pebble conglomerate crops out in the quartzite mass east of Morro do Gabriel (N. 5,720, E. 9,080). The pebbles are 3 to 4 millimeters long and are composed of vein quartz and quartzite or recrystallized chert.

The Batatal formation, not mapped separately in this study, consists of argillaceous schist and phyllite and is found between the quartzite of the Caraça group and the Cauê itabirite. Because the rocks are dominantly clastic in origin, they have closer affinities to the Caraça group than to the chemical sediments of the Itabira group. They have therefore been included in the Caraça group in the present stratigraphic classification.

The sericitic schist and phyllite of the Batatal formation can only be recognized where the complete lower section of the Minas series is exposed, as the rocks are indistinguishable from similar rocks in other units of the stratigraphic section. Exposures in road cuts in the northern part of the Dom Bosco quadrangle show from 5 to 10 meters of brown- and red-weathering schist that lies between the quartzite and the iron-formation. This schist is not continuous, as elsewhere along the same stratigraphic horizon the iron-formation lies directly on the quartzite (N. 12,930, E. 8,130). Because the Batatal formation weathers readily and no fresh rock was found, the reader is referred to reports on adjacent areas for a description of the formation.

THICKNESS AND CONTACT RELATIONS

The stratigraphic position of the quartzite of the Caraça group near the north boundary of the Dom Bosco quadrangle is well defined. All units of the Minas series are present, with the Caraça at the base disconformably overlying the schist of the Nova Lima group. The quartzite is not continuous, but where present, its thickness ranges from 1 to 75 meters. Thicker sections are limited in extent and may represent channels cut into the pre-Minas surface. The quartzite is overlain with apparent conformity by either schist of the Batatal formation or itabirite of the Cauê itabirite.

The stratigraphy is not as well defined in the central part of the Dom Bosco quadrangle. The northern contact of the quartzite body east of Morro do Gabriel is faulted from Morro do Gabriel to Dores da Belavista. East of Belavista the quartzite is overlain by schist and phyllite interbedded with thin quartzite. No iron-formation or carbonate rocks are found near the contact, and therefore the overlying rocks could not be correlated; they could be the equivalent of both the Cauê itabirite and Gandarela formation, or they could belong to the Piracicaba group with the lower formations not represented. The southern contact of this quartzite body is not well exposed owing to its location near the base of a moderately steep ridge. Iron-formation 10 to 15 meters in thickness is found along the contact north of Fazenda Lavrinha from E. 9,400 to E. 10,700, but seems to be absent both to the east and to the west. Bedding in the quartzite could be determined at only one locality (N. 4,340, E. 9,760) where the quartzite dips under the adjacent rocks, but it could not be determined if the contact was conformable. The overlying rocks south of the quartzite are more schistose than those to the north and are interbedded with lenses of thick, massive quartzite. This lack of correlation suggests that the main body of quartzite is not exposed in a simple anticline, although the rocks on either side belong to the Minas series.

The thickness in this area could not be determined because the rock is too highly sheared to determine either bedding or structure. Minor crumpling of the shear planes is common, and the section could well be thickened by both folding and faulting.

The small area of quartzite north of Morro do Bule appears similar to the quartzite found to the northeast and has probably been thrust into its present position.

An apparent thickness of more than 1,400 meters of quartzite and sericitic quartzite is found in the Serra do Ouro Branco between the lower contact at the base of the scarp and the mafic dike on the north flank of the range. The dike has been intruded along a fault, and therefore, the quartzite to the north could be repeated; if not, an additional 500 meters is represented. There is evidence of imbricate structure within the range, and the true thickness may be less. Isoclinal folding, as postulated by O. Barbosa (1949, p. 10), would greatly reduce the true thickness, but in the absence of marker beds, the presence of such folding could not be determined. O. Barbosa gives a maximum thickness of 500 meters for this unit, which he refers to as the Santo Antonio formation.

THE PROBLEM OF THE QUARTZITE OF THE SERRA DO OURO BRANCO

A problem concerning the stratigraphic position of the quartzite of Serra do Ouro Branco became evident at an early date in the USGS–DNPM investigations. Harder and Chamberlin (1915, p. 353) and Guimarães (1951, p. 65) believed that the quartzite is post-Minas in age and correlates with the Itacolumí quartzite found to the east. O. Barbosa (1949, p. 7) made it part of his Santo Antonio formation in the upper part of the Minas series, but in a later paper (O. Barbosa, 1954, p. 26) he correlated it with the Itacolumí series. Guild (1957, p. 13) found evidence at the west end of the Serra that led him to map the quartzite as Lower Minas(?) or Caraça quartzite. The writer favors a correlation with rocks of the Caraça group or possibly even older, but no evidence was found that would definitely rule out correlation with quartzite of the Itacolumí series. As this is one of the chief stratigraphic problems remaining in the Quadrilátero, the geologic setting of the Serra will be summarized and the problem discussed.

The quartzite and minor conglomerate that make up the Serra do Ouro Branco crop out as a lens-shaped mass with its greatest thickness in the Dom Bosco quadrangle, where the outcrop width is more than 2.5 kilometers. The quartzite disappears in the São Julião quadrangle to the west, where it thins greatly before it is faulted. The lens also thins eastward in the Sta. Rita quadrangle and seems to wedge out. A. L. M. Barbosa (oral communication) found quartzite layers north of the eastern end of the lens that may be faulted segments of it, but he was unable to follow the segments to the east or to connect them with the thick quartzite found to the north and east that he correlates with the Itacolumí series. This lenslike shape could be interpreted, in the absence of other evidence, as being due to deposition in a small basin with thinning on the margins of the basin, or as a canoe-shaped isoclinal fold, either a syncline or an anticline. Little evidence could be found within the quartzite area to prove the presence of a plunging fold. The curving change in schistosity and bedding found locally is probably due to thrusting rather than folding, as the beds do not make the complete reversal in strike that is found around the nose of a fold. The changes are thought to mark the position of faults where the quartzite has been thrust westward forming imbricate structure. Except for these local variations the beds strike parallel to the long axis of the lens and dip northward 30° to 60°.

Lithologically the quartzite and conglomerate of the Serra cannot be distinguished in the field from quartzite elsewhere in the Quadrilátero Ferrífero that has been assigned to the Caraça group, Itacolumí series, or even Maquiné group. A study of the conglomerate pebbles proved unsuccessful as nearly all are quartz or quartzite. A gneiss pebble found in the conglomerate by Dorr (oral communication) was of little value for dating because it could be either pre-Minas or post-Minas gneiss, or it could be a gneiss pebble reworked from an older conglomerate. No itabirite pebbles were found by the writer although some iron-rich material and phyllite pebbles were found near the northern margin of the quartzite (N. 800, E. 9,650). Iron-formation is known to occur in the Rio das Velhas series (Gair, written communication); therefore, iron-formation pebbles in conglomerate would not be conclusive evidence for a post-Itabira age.

South of the Serra a slight to moderate unconformity separates the quartzite body from a green-schist and granodiorite complex, which dips north beneath the quartzite. A similar complex but with possibly less granodiorite is found north of the Serra and east of Alto do Quindim. These rocks also dip northward but are essentially conformable with the quartzite. Minas series rocks are found in contact with the quartzite north of the Serra and west of the green schist. This contact is definitely a fault at Alto da Pedra do Sabão where the dolomitic iron-formation can be seen striking nearly at right angles to the contact. The fault is assumed to continue to the west along the valley of the Ribeirão da Colónia.

From the foregoing summary it can be seen that the only rocks that can be correlated with certainty are those of the Itabira group north of the Serra, and they are in fault contact with the quartzite. The age of either the quartzite or the other rocks must be assumed in order to explain their relations.

A correlation of the quartzite with the Itacolumí series would imply that the structure is an isoclinal syncline, because it is generally agreed that the quartzite of the Itacolumí series belongs to the youngest sequence of sedimentary rock in the area. The adjacent rocks, other than those of the Itabira group, would then belong to the Piracicaba group, for it is very unlikely that the entire Minas series would be missing and that the quartzite of the Itacolumí series would be deposited on the Rio das Velhas series. The difficulty with this interpretation is that the green schist and granodiorite complex shows little resemblance to rocks of the Piracicaba group. The quartzite, ferruginous quartzite, and dolomite found in the Piracicaba group are not present south of the Serra do Ouro Branco even though a thick section is represented. On the other hand, the thick green-schist section could be easily correlated with the Nova Lima group in the Rio das Velhas series where thick sections of schist are known to occur. The itabirite and dolomite of the Itabira group would also be expected south of the Serra, but they have not been found.

Another possibility would be that the quartzite is part of the Maquiné group of the Rio das Velhas series. J. E. Gair (written communication) found a thick section of quartzite, conglomerate, and quartz-sericite schist at the top of the Maquiné group in the Rio Acima quadrangle. However, he also mentions graywacke and phyllite beneath the quartzite; these rocks are not found in the Serra do Ouro Branco area. Because the quartzite of the Maquiné was removed by erosion over most of the Quadrilátero Ferrífero before deposition of the Minas series, it seems unlikely that the quartzite in the Serra represents a thick isolated section of the Maquiné.

The interpretation of the geology shown on the maps and sections (pl. 2) of this report is based on the assumption that the green schist granodiorite complex is part of the Rio das Velhas series. The quartzite rests with slight to moderate unconformity on the schist in a relation similar to that found at the base of the Caraça group elsewhere in the Quadrilátero Ferrífero (Rynearson and others, 1954). A normal fault has dropped the rocks of the Gandarela formation against the quartzite on the north side of the Serra.

The main difficulty with the interpretation shown on the map is the relation between the quartzite and the green-schist and granodiorite complex found north of and near the east end of the Serra. The schist can be almost certainly correlated with that south of the Serra, therefore, its present position must be explained by folding or faulting. If the quartzites are folded into an isoclinal syncline, then the schist would be in its expected position on the overturned limb of the fold, but the relation between the quartzite and the Gandarela formation north of the Serra could then be explained only by a very complex series of events. Thrusting from the east is common in this part of the Quadrilátero Ferrífero (Guild, 1957, pl. 2) and is the solution preferred by the writer, although evidence of a thrust fault along the contact of the schist and the quartzite north of the Serra is admittedly weak.

The physiography of the area can also be used as supporting evidence for assigning the quartzite to the Caraça group. The rocks of the Minas and Itacolumí series occupy the highlands of the Quadrilátero Ferrífero and are bordered by steep slopes or scarps formed on quartzite of the Caraça group or Cauê itabirite. The Serra do Ouro Branco scarp may be one of these, and it is in good alinement with the edge of the known Minas series mapped by Guild (1957, pl. 2). The analogy breaks down to the east however, where a similar scarp is found cut in rocks mapped as Itacolumí quartzite by A. L. M. Barbosa (oral communication).

The solution of this problem will have to await a detailed study of the Serra to show its internal structure coupled with a regional study of the quartzites to determine if they can be separated. Heavy-mineral suites or trace-element studies may afford a means of correlation.

ITABIRA GROUP

The Itabira group as defined by Dorr and others (1957) is composed of the Cauê itabirite, named by Dorr (written communication), and the Gandarela formation, named by Dorr (written communication). The Cauê itabirite is composed of oxide facies iron-formation, largely itabirite, with minor amounts of clastic sedimentary rock and dolomite whereas the overlying Gandarela formation contains dolomite, dolomitic itabirite, itabirite, and iterbedded schist and phyllite.

The rocks of the Itabira group are economically the most important in the Quadrilátero Ferrífero because they contain all the commercial iron deposits and most of the dolomite and manganese. No iron deposits have been mined on a large scale in the area described in this report; but dolomite is being quarried, and manganese deposits have been commercially important in the past.

The dolomite and associated rocks now called part of the Gandarela formation were assigned to the base of the overlying Piracicaba group by Harder and Chamberlin (1915, p. 362), but recent work has shown that there is a gradational change from itabirite to dolomitic itabirite and dolomite (Guild, 1957; Dorr, written communication), and a disconformity between the dolomite and the overlying rocks (J. B. Pomerene, written communication). The group boundary was therefore placed at the top of the dolomitic Gandarela formation.

CAUÊ ITABIRITE

The Cauê itabirite in the mapped area differs from the type section in the Itabira district described by Dorr (written communication), in that clastic rocks seem to be absent. The formation is thinner here than in most parts of the Quadrilátero Ferrífero and may be absent locally. Conditions were not favorable for the formation of massive hematite bodies.

Distribution

The Cauê itabirite overlies the Caraça group in the northern part of the Dom Bosco quadrangle and in the southeast corner of the Cachoeira do Campo quadrangle. The formation could not be traced west of the Cidreira quarry (southwest of Catete), but itabirite reappears west of Sítio Lagoa Sêca and can be traced for several hundred meters. Another outcrop belt extends from near Alemão east to a point 1 kilometer south of Dom Bosco. The lower part of this unit is itabirite and is believed to belong to the Cauê itabirite; the upper part seems to be dolomitic itabirite of the Gandarela formation. A parallel lens east of Morro Mandachuva is also made up of the Cauê and Gandarela. The largest area underlain by itabirite is found west of Hargreaves and south of the railroad, where a thick plate of Cauê itabirite has been thrust over younger phyllite (pl. 2 and fig. 5).

FIGURE 5.—Itabirite of the Cauê itabirite capping hills southwest of Hargreaves, Dom Bosco quadrangle, and thrust over phyllite of the Gandarela formation.

Itabirite that crops out north of Fazenda Lavrinha, on the contact with quartzite, was mapped as Cauê itabirite, because the quartzite is believed to belong to the Caraça group.

Lithology

Itabirite of the Cauê itabirite ranges from well-banded rock, with a good separation of iron minerals and quartz, to rock with inconspicuous banding and considerable intermixing of minerals. The bands range from 1 to 5 mm in thickness. No systematic variation in thickness of the bands was found either with respect to position in the section or to location in the mapped area. Individual bands are continuous for several meters in areas not affected by small scale crumpling; such crumpling is common and very irregular.

The iron minerals in the itabirite are specularite and magnetite. Specularite is believed to be the dominant oxide in the Cauê formation, with magnetite more abundant in the itabirite associated with dolomite (Guild, 1953, p. 645). The iron mineral in the northernmost exposures of Cauê itabirite was found to be magnetic but a chemical analysis (table 4, No. 1) shows that only a small amount of the iron occurs as FeO, so magnetite may be only a thin surficial coating on the mineral grains. (See p. B–31.) Micaceous specularite occurs in the itabirite in a railroad cut west of Dom Bosco but is not common elsewhere in the Cauê itabirite of the mapped area.

The grain size of the itabirite, according to the Wentworth classification, ranges from fine to very fine sand. Measurements of individual grains made on three samples of Cauê itabirite show a range in grain size of the quartz grains of from 0.05 to 0.40 mm with sample averages of 0.10, 0.14, and 0.16 mm. The finest grained material is from the micaceous specularite-bearing itabirite west of Dom Bosco. Magnetite grains average about 0.05 mm in diameter, and the specularite flakes range from 0.01 to 0.05 mm in thickness and from 0.08 to 0.25 mm in length.

Fresh itabirite was not found in outcrop or in the limited workings in the area. The iron minerals are altered to limonite in many exposures, but most banding remains visible. The quartz grains may be removed by weathering, which leaves the iron-rich bands projecting as thin ribs. Sericite or talc and amphibole, possibly cummingtonite, are the only other minerals seen in hand specimens of the itabirite; no material was found suitable for thin section. Sericite or talc flakes are at the margin of some recrystallized chert bands, and cummingtonite(?) was in the quartz layers in one locality west of Hargreaves (N. 6,270, E. 2,100).

Thickness and contact relations

The true stratigraphic thickness of the Cauê itabirite could not be determined owing to the widespread crumpling of the beds and consequent thickening of the section. The northern belt of itabirite is about 50 meters thick where cut by the Cachoeira do Campo–Dom Bosco road and seems to thicken eastward. The exposures south of Dom Bosco show an outcrop width of over 200 meters, and a similar thickness is indicated in the folded mass of itabirite west of Hargreaves.

The Cauê itabirite appears to lie conformably on either the Batatal formation or the quartzite of the Caraça group in the normal stratigraphic section exposed in the northern part of the Dom Bosco quadrangle. No evidence was found to show that the Batatal formation was eroded prior to deposition of the itabirite, or was never deposited. The change from phyllite or quartzite to iron-formation is abrupt and may perhaps be best explained by gentle uplift followed by a new invasion of the sea with a change in physical and chemical conditions. However, no basal conglomerate or material from the underlying formations was found in the iron-formation; therefore, deposition may well have been continuous.

The upper contact with the Gandarela formation is conformable and is placed at the first appearance of dolomitic itabirite or of rocks other than itabirite. The highway between Cachoeira do Campo and Ouro Preto crosses the contact in the southeast corner of the Cachoeira do Campo quadrangle, where dolomite lies on ferruginous quartzite at the top of the iron-formation. Farther west, splash rock [5] is found above the itabirite, and near the Cidreira quarry the itabirite is overlain by schist and phyllite.

Contact relations of the Cauê itabirite are obscure elsewhere in the Dom Bosco quadrangle. The itabirite along the railroad lies unconformably on pre-Minas rocks in its western part, and is thrust over the Piracicaba group near its eastern end. The upper contact with dolomitic itabirite is well exposed along the railroad but could not be found elsewhere. The lens of iron-formation east of Morro Mandachuva is flanked by manganiferous dolomite of the Gandarela formation along its south margin. Manganese deposits, probably derived from the Gandarela formation, extend around each end of the lens but are not found on the north side, where phyllite of the Piracicaba group is in contact with the iron-formation. The Cauê itabirite west of Hargreaves has been thrust over rocks of the Piracicaba group and is probably also in fault contact with the overlying dolomite that cuts off the iron-formation at Hargreaves.

[5] Splash rock is an informal name given to a yellow-ochre or black alteration product of dolomite (Guild, 1957, p. 42).

GANDARELA FORMATION

The Gandarela formation was named by Dorr (written communication) from exposures in the Gandarela quadrangle (fig. 1). In the type section the formation is described as composed of massive dolomitic limestone with thin lentils of iron-formation and slate. The lower contact is said to be concordant and gradational with the Cauê itabirite, and the upper contact is said to be disconformable with ferruginous quartzite of the Piracicaba group. The rocks that lie within these limits in the Dom Bosco quadrangle contain a much larger percentage of phyllite and schist than those in the type locality, but the same rock types are represented.

Distribution

The Gandarela formation is exposed in a belt that extends across the northern part of the Dom Bosco quadrangle. West of the Cidreira dolomite quarry, the contacts become indistinct and the absence of dolomite further complicates the location of the Gandarela formation. The quartzite mapped as the upper limit of the formation south of Lagoa Sêca is not highly ferruginous, but must be near the base of the Piracicaba group.

Dolomite is abundant near Fazenda Papacobra in the west-central part of the quadrangle, where it is found associated with itabirite. Because the itabirite is interbedded with dolomite, the entire sequence is mapped as Gandarela formation.

A large area underlain by dolomite is found south of Hargreaves, and dolomite lenses are common in the schist and phyllite mapped as Gandarela formation north of the Serra do Ouro Branco and west of Morro do Bule. Part of the band of iron-formation west of Dom Bosco is dolomitic and is mapped as Gandarela formation. Dolomite of the Gandarela formation also occurs on the south edge of the itabirite lens east of Morro Mandachuva.

Lithology

Dolomite, dolomitic itabirite, itabirite, phyllite, and schist make up the Gandarela formation. Quartzite is not common. Outcrops of green schist of possible volcanic origin were found at two localities, N. 4,800, E. 1,140, and N. 4,980, E. 2,500 in the Dom Bosco quadrangle.

The dolomite ranges in composition from nearly pure carbonate rock, suitable for metallurgical use, to highly siliceous and ferruginous varieties. Chemical analyses of some of the varieties are given in table 2.

With the exception of the large area of dolomite south of Hargreaves, the dolomite is commonly lenticular in outcrop. The lenses range from a few tens of meters to more than a kilometer in length and are as much as 300 meters thick. They appear to be individual lenses in phyllite rather than unaltered remnants of a continuous dolomite bed. Alteration products of dolomite are often found as a thin shell around massive dolomite, but schist can be seen around the nose of a dolomite lens near Morais, in the southeast corner of the Cachoeira do Campo quadrangle, and also near Alemão. Traverses across the strike beyond the ends of other dolomite lenses show nothing but phyllite and no sign of alteration products of dolomite. Only the massive dolomite has been mapped separately on the quadrangle maps except in the Fazenda Papacobra area, where detailed mapping by J. B. Pomerene showed the presence of continuous bands of dolomite or its alteration products. This is one of the areas where he could prove that "splash rock" is an alteration product of dolomite.

TABLE 2.—*Dolomite analyses, Dom Bosco quadrangle, Minas Gerais*

[Analysis 329 by Cassio Pinto; remainder by José Doche both of the Departmento Nacional da Produção Mineral, Belo Horizonte. Analyzed September 1956]

	286	329	568	581	631	733	Theoretical dolomite
SiO_2	1.9	24.5	20.0	2.0	7.9	5.4	----------
Fe_2O_3	1.2	17.3	3.4	5.3	9.5	2.8	----------
Al_2O_3	.7	.3	.6	.3	1.0	.3	----------
CaO	29.6	19.2	23.1	32.7	27.2	28.3	30.4
MgO	20.4	8.4	16.8	15.3	8.6	19.6	21.7
MnO	.26	3.1	.06	.70	10.9	.5	----------
Loss on ignition	45.7	26.9	36.0	44.0	34.2	43.3	47.9
Total	99.76	99.7	99.96	100.3	99.3	100.2	100.0

Description:
286. White dolomite of the Piracicaba group from the quarry at Cumbe.
329. Dark-gray dolomite from N. 6,680, E. 8,460. Possible source rock for manganese found in this area.
568. Gray dolomite from N. 4,060, E. 4,320.
581. Red dolomite from quarry at N. 5,860, E. 5,480.
631. Nearly black dolomite near contact with itabirite at Hargreaves.
733. Dolomite from quarry at N. 4,800, E. 240.

Massive dolomite in beds of different thicknesses and compositions is interbedded with some dolomitic itabirite in a large body south of Hargreaves. Much of the surface is covered by black soil, but enough can be seen to show that dolomite is the predominant rock.

O'Rourke (written communication) was able to make a stratigraphic separation of the dolomites in his area based largely on color differences. He found white dolomite predominant in the lower part of the section, gray dolomite in the middle, and red dolomite in the upper part. These three colors are present in the mapped area, but they are not separable; red dolomite, for example, is found near the base of the section at Morais and in the middle and upper parts of the dolomite near Hargreaves. It is nowhere a dominant type but is found interbedded with older color varieties.

The nearly pure dolomite may be white, red, or gray and consists of interlocking grains of carbonate with rare quartz. Sericite or chlorite partings are common.

The color is due to minor impurities, and O'Rourke (written communication), found the red was due to fine, disseminated hematite. The analysis of red dolomite near Hargreaves shows a Fe_2O_3 content of 5.3 percent. This is a higher percentage of iron than in the white dolomite but less than in the dark type. Pyrite and fluorite were found in dolomite float south of Hargreaves and sphalerite together with various sulfosalts of lead were found near Morro do Bule, (Guimarães, and Coelho, 1946a). A 2-centimeter band of magnetite was found in creamy-colored dolomite in a quarry near Hargreaves (N. 6,220, E. 4,800). As seen in thin section of a sample from the contact zone, the magnetite was probably detrital; quartz grains were common in the magnetite band and also seemed to be detrital, as there was no evidence of veining. Carbonate grains were also common in the magnetite band.

Hand specimens of siliceous dolomite are banded or mottled and commonly have partings of sericite or chlorite; biotite was found in one specimen. Thin sections of this dolomite show that the banding is due to differences in grain size. Quartz and carbonate grains, or carbonate alone, 0.1 to 0.5 mm in diameter, are interlayered with grains 0.02 to 0.06 mm in diameter. The layers are crumpled and broken by small healed faults. Some of the quartz is found in tiny veinlets, but most seems to be an original constituent of the rock.

Ferruginous dolomite ranges from a dark-gray massive rock with disseminated magnetite to dolomitic itabirite in which the iron oxide may be magnetite and specularite. Dolomitic itabirite grades into normal itabirite and may contain some bands of recrystallized chert. Cummingtonite(?) is an abundant constituent of dolomitic itabirite in a band that extends eastward from the west edge of the Dom Bosco quadrangle along the Ribeirão da Colonia. The cummingtonite(?) occurs as needles oriented with their long axes parallel to the banding, and as larger individual needles as much as 3 mm long that have no preferred orientation. Coarse blades of actinolite about 1 centimeter in length were found in dolomitic itabirite near Hargreaves (N. 6,570, E. 3,620). The itabirite was unusually coarsely banded with individual bands about 1 centimeter thick. Some light bands were more than 80 percent quartz with the remainder carbonate and magnetite; carbonate was abundant in the iron-rich bands.

Phyllite from the Gandarela formation is indistinguishable from phyllite in the Piracicaba group. Fresh rock is rarely found; only two specimens suitable for sectioning were found in the northern band of Gandarela formation and one southeast of Fazenda Rodeio. In hand specimen these rocks are greenish-gray and schistose with a silvery sheen on plane surfaces. Sericite or chlorite is the principal mineral enclosing streaks and lenses of granular quartz. Fine-grained magnetite is widely distributed, and epidote occurs as individual crystals parallel to schistosity.

The weathered phyllite is red, brown, or gray and is characterized by a sheen on the schistosity planes that is due to sericite. Bedding in the weathered rock can often be distinguished by color banding, variation in quartz content, or variation in grain size. Bedding and schistosity are usually almost parallel, but may intersect at a high angle. The closely spaced schistosity surfaces may themselves be wrinkled into a series of closely spaced crenulations.

Green schist of possible volcanic origin occurs in the Gandarela formation north of Ribeirão da Colónia. The rock consists of a dense dark-green matrix enclosing magnetite crystals and biotite. In thin section, quartz is found to be an important constituent, forming 15 to 30 percent of the rock. Chlorite is the predominant mineral, as much as 80 percent of some bands in the rock. The chlorite is fine grained and consists of oriented intergrown flakes. The quartz occurs as individual angular grains less than 0.1 mm in diameter or as thin streaks or lenticular bodies in the chlorite matrix. Small oval-shaped bodies flattened parallel to schistosity and consisting of quartz and chlorite could be interpreted as amygdules. Magnetite crystals as much as 1 mm in size are common. Biotite is found as flakes adjacent to and oriented parallel to the faces of the magnetic grains, or oriented across the schistosity of the chlorite matrix. The random orientation suggests crystallization at a later date. The greenschist bands are only a few tens of centimeters thick and are of importance only in pointing out the possibility of volcanic activity during the time of deposition of the Gandarela.

Thickness and contact relations

The thickness of the Gandarela formation in the northern band is 200 to 250 meters. More than 400 meters of interbedded dolomite and phyllite are found north of the Ribeirão da Colónia, southwest of Fazenda Rodeio, with neither the top nor bottom exposed. This section does not seem to be duplicated by folding near the west edge of the quadrangle. The limits of the formation in other areas are too indefinite to be of use in estimating thickness.

The basal contact of the Gandarela formation is exposed along the Ouro Preto highway in the southeast corner of the Cachoeira do Campo quadrangle and in a railroad cut west of Dom Bosco (N. 8,280, E. 7,300) in the Dom Bosco quadrangle. Dolomite interbedded with ferruginous quartzite is found in contact with iron-formation at the highway exposure. The contact appears to be unconformable at this point, as shown by the intersection of dolomite bands with the itabirite (pl. 1), but this could be due to faulting, as bedding seems to be conformable in the two formations farther west.

A mafic intrusive body is found at the contact between dolomitic itabirite and itabirite west of Dom Bosco. The bedding is crumpled but seems to be nearly conformable on either side of the intrusive mass.

The dolomite south of Hargreaves is probably in fault contact with the underlying itabirite, as the itabirite wedges out rapidly on the north side of the dolomite (see pl. 2).

The upper contact of the Gandarela formation is not exposed in the mapped area. J. B. Pomerene (written communication) and J. E. Gair (written communication) found a disconformity between the Gandarela formation and Piracicaba group, marked by a conglomerate at the base of the Piracicaba group. This conglomerate could not be found in the Dom Bosco quadrangle, so the contact was placed at the lowermost bed of ferruginous quartzite. Owing to poor exposures and the lenticular nature of the quartzite, the contact in the northern point of the quadrangle could not be accurately located. Still less information was available in the southern half of the quadrangle, as the ferruginous quartzite becomes even more sporadic in its occurrence. The contact was mapped at the base of the massive quartzite lenses above the uppermost dolomite lens. Dolomite is absent east of Morro do Bule; therefore, the entire sequence above the quartzite of the Caraça(?) group was mapped as Piracicaba group. The section between the quartzite and the massive quartzite lenses in the Piracicaba group could well be the Gandarela formation.

PIRACICABA GROUP

The Piracicaba group is the uppermost group of rocks in the Minas series. The name Piracicaba formation was used by Harder and Chamberlin (1915, p. 362) for the rocks lying above the Itabira group and below the Itacolumí series. The dolomitic rocks at the base of the Piracicaba have been placed in the Itabira group, and J. B. Pomerene (written communication) has been able to separate the rocks overlying the dolomite into several formations; so the Piracicaba unit has been given group status by Dorr and others (1957), as shown in table 1.

No way was found to delineate the separate formations of the Piracicaba group in the mapped area. Rocks similar to the types described by Dorr and others (1957, p. 29) occur, but no clearly defined continuous lithologic units were found to differentiate the formations in the field. The Piracicaba group is thus shown as one unit on the geologic map, and some of the quartzite units are shown separately to indicate the structure. Dolomite outcrops of possible economic interest as well as one large area of siliceous dolomite are also shown on plate 2. In the quadrangles mapped, the rocks of the Piracicaba group are found only in the Dom Bosco quadrangle, where they underlie about 40 percent of the area.

LITHOLOGY

The predominant rock type in the Piracicaba group is phyllite, and the minor constituents are graphitic schist, quartzite, ferruginous quartzite, and dolomite. Unweathered rock is rare; the weathered phyllites are usually various shades of red but may be gray, silvery gray, yellow, ochre, or brown. The color is due to the oxidation of the iron in magnetite, chlorite, or chloritoid in the fresh phyllite. Octahedra of martite or magnetite 2 to 3 mm in diameter are abundant in some beds. The phyllite grades into metamorphosed siltstone with an increase in grain size, but both rocks are characterized by abundant oriented sericite that gives a sheen to the surface of schistosity planes. As the volume of micaceous minerals decreases, the rock becomes less fissile and breaks with a hackly fracture.

The schistosity planes are closely spaced, generally 0.2 mm or less apart. They are commonly parallel to, or lie within a few degrees of, the bedding planes but locally may cut the bedding at high angles. In many places the schistosity planes are crumpled by small subparallel wrinkles formed by cross folding or by fracture cleavage. The wrinkles are spaced about 1 mm apart and may be several centimeters long. Wrinkling produced by fracture cleavage is more regular than that produced by cross folding but is of the same order of magnitude.

The bedding is commonly masked by the schistosity but may be dominant, so that the weathered rock resembles shale. Bedding can be distinguished by color banding or by differences in grain size or lithology. Most phyllite is thin bedded, and individual beds are as much as 1 centimeter thick. This thin bedding may be masked in weathered material, but bedding may then be shown by color banding on a larger scale or by intercalation of other rock types.

The dominant minerals, as seen in the few thin sections of fresh phyllite and green schist studied, are quartz, sericite, and chlorite. The fresh rock is gray green to green depending on the amount of chlorite present. The ratio of quartz to micaceous minerals ranges from 1:1 to 1:5, with the minerals usually separated into quartz-rich bands and micaceous bands. The rocks are fine grained; the quartz grains are generally less than 0.1 mm in diameter in the phyllite and increasing to 0.2 mm in the green schist of higher metamorphic grade. Few sericite and chlorite flakes are more than 0.15 mm long. Chloritoid is a common accessory mineral and makes up about 40 percent of one thin section. It occurs as tabular porphyroblasts 0.2 to 0.5 mm in length and is not well oriented with respect to the schistosity. Epidote is not a common accessory mineral but may be locally abundant. Other accessory minerals are magnetite, apatite, sphene, tourmaline and zoisite(?). Sphene and tourmaline are more common in the green schist; the sphene may be recrystallized, but the tourmaline seems to be detrital. A mineral that was either biotite or stilpnomelane was found in one section of green schist.

Kyanite occurs locally in phyllite as radiating clusters of crystals on schistosity planes (fig. 6), but it is generally near quartz veins containing coarse kyanite of hydrothermal origin. The kyanite in the foliation planes of the phyllite is therefore believed to be related to this hydrothermal activity rather than to a high grade of metamorphism.

FIGURE 6.—Hand specimen of gray phyllite with radiating clusters of kyanite crystals on schistosity planes. Scale is in millimeters.

Graphite-bearing schist and phyllite are found throughout the Piracicaba group but are most abundant in the upper part of the section near Morro do Caxambú. The weathered rock is dark gray to black. Some varieties are very fine grained and shaly; others are more schistose. The schistose varieties may have a dark-reddish tinge on the surface of the schistosity planes.

Quartzite is common in the rocks of the Piracicaba group. The quartzite units seldom exceed 30 meters in thickness in the northern part of the Dom Bosco quadrangle, but in the southern half of the quadrangle lenses may be more than 100 meters thick and as much as 1 kilometer long. The quartzite is white to light gray and variable in both texture and composition. It ranges from fine to coarse grained. Many outcrops are composed of massive quartzite with no evidence of bedding, but others are well bedded and may be laminated with sericite partings. Sericite may be so abundant that the rock grades into a quartz-sericite schist similar to units of the Caraça group, but as a rule sericite is a minor constituent and is found as scattered flakes in the quartzite. Green chloritoid-bearing quartzite may be present on the margins of quartzite lenses or intertongued with white quartzite (fig. 7).

FIGURE 7.—Hand specimen of quartzite of the Piracicaba group showing green chloritoid-rich quartzite intertongued with white quartzite. Scale is in millimeters.

Thin sections of the chloritoid-rich quartzite or of chloritoid-quartz schist show the rock consists almost entirely of quartz and chloritoid. The chloritoid occurs as poorly oriented plates 1 millimeter in length. The chloritoid is weakly to strongly pleochroic and has strong dispersion and inclined extinction. Inclusions are abundant in the chloritoid, but the hour-glass arrangement of inclusions was not found. Tourmaline was an abundant accessory in one thin section of quartz-chloritoid rock.

Ferruginous quartzite is found as thin but continuous bands in the phyllites of the Piracicaba group and as thin beds in the quartzite lenses. A distinctive horizon of ferruginous quartzite with associated silver-colored phyllite could be traced nearly continuously from the Cachoeira do Campo-Dom Bosco road (N. 12,140, E. 9,420) westward for about 7 kilometers to the vicinity of Lagoa. Eastward, beyond a gap of about 1,200 meters, a similar band was found at about the same stratigraphic horizon and could be traced to the northeast corner of the quadrangle. A roughly parallel band that could also be at the same stratigraphic horizon was traced from the south flank of Morro do Caxambú eastward to the north flank of Serra do Rodrigo Silva.

Other bands found south and west of Lagoa may also be at the same horizon. Ferruginous quartzite borders the southern edge of the steeply dipping quartzite south of Fazenda Papacobra and the southern edge of the quartzite band that crops out along the railroad west of Hargreaves. The quartzite lenses in the southern half of the Dom Bosco quadrangle contain minor amounts of ferruginous quartzite but seldom enough to be shown on the map. The thickest exposures are near the east side of the quadrangle (N. 2,700, E. 12,560).

Ferruginous quartzite is silvery where the iron mineral is specularite and dark gray where magnetite is dominant. The rock is composed of clastic sediment with the iron minerals either disseminated through the quartzite or coarsely banded with iron-rich and iron-poor bands; the mineral separation is not as clean or the bands as thin as in itabirite. Abundant rounded granules of quartz, in a matrix of fine-grained ferruginous quartzite are found in the northern part of the Dom Bosco quadrangle, and similar material is found south of Fazenda Papacobra. The granule-bearing ferruginous quartzite seems too widespread to be of value in correlation.

Small lenses of dolomite are interbedded with phyllite in the area between Cumbe and Morro do Caxambú, and isolated lenses crop out at the following locations in the Dom Bosco quadrangle: N. 10,060, E. 240; N. 7,640, E. 5,240; N. 10,820, E. 3,940; and at Agua Fria and Pasto da Rosa near the east edge of the quadrangle. A large body of siliceous dolomite near Morro Mandachuva is also mapped as Piracicaba.

The dolomites are white, red, or gray depending on the amount and type of purity. Color banding is well marked at some exposures, as at Cumbe (Guild, 1957, p. 16, fig. 7), and on a smaller scale at Pasto da Rosa where 1- to 2-mm bands of alternating brown and white carbonate are found.

Partings of sericite are common in the dolomite, and quartz is a minor constituent of some lenses. A specimen from the Pasto da Rosa quarry contains scattered amphibole crystals in the brown carbonate layers. Some of the carbonate beds are nearly pure dolomite; an analysis of white carbonate rock from the Cumbe quarries given in table 2 shows a carbonate content of 96 percent with a CaO:MgO ratio nearly that of pure dolomite.

A siliceous dolomite lens was found on the south flank of Morro Mandachuva. The rock is dark gray with small-scale color banding that seems to be due to differences in grain size. As seen in thin section, the rock is made up of a quartz-carbonate aggregate with about 10 percent pale-brown mica, possibly phlogopite. Magnetite, pyrite, and sphene are accessory minerals. The grain size ranges from 0.05 to 0.1 mm. The lens is enclosed in phyllite and was mapped as part of the Piracicaba group.

Fresh graywacke that is probably part of the upper Piracicaba group crops out about 1,600 meters south of Cumbe (N. 8,590, E. 6,410) on the north flank of the high central ridge of the Dom Bosco quadrangle. The graywacke overlies a weathered fragmental rock consisting of phyllite and quartz fragments in a claylike matrix that in turn overlies graphitic phyllite. This same sequence was found in the Belo Horizonte quadrangle, where the graywacke was mapped as part of the Sabará formation (Gair, written communication). Only the one exposure was found in the Dom Bosco quadrangle.

The graywacke is a medium-gray slightly foliated rock speckled with numerous lenticular grains of white quartz and fragments of dark-gray phyllite. As seen in thin section, the rock is composed of about 50 percent quartz, 25 percent chlorite and sericite, 10 percent slightly altered plagioclase (albite-oligoclase), and 10 percent carbonate. Magnetite, zircon, tourmaline, and apatite are accessory minerals. The carbonate occurs both as anhedral grains and as euhedral crystals with limonite-stained borders.

Thickness and contact relations

A thickness of from 1,000 to 2,000 meters is indicated for the rocks of the Piracicaba group. The rocks are tightly folded, and faulting is probably more common than is shown on the map (pl. 1).

Discontinuity of rock types in the Piracicaba group gives rise to uncertainty in stratigraphic interpretation. For example, lenses at Agua Fria and Pasto da Rosa are mapped with the Piracicaba group because they are found in phyllites with no nearby iron-formation. These lenses are similar to other outcrops of dolomite found farther east and are believed to be in the Piracicaba group (A. L. M. Barbosa, oral communication). Inspection of the map (pl. 2), however, shows a bend in the structure that is marked by the change in direction of the ridge between Alto da Figueira and Serra do Rodrigo Silva and by the change in strike of the quartzite beds on the north flank of the ridge. The itabirite and dolomitic itabirite of the Cauê and Gandarela formations south of Dom Bosco could not be traced eastward to the Alto da Figueira, but the stratigraphic horizon may continue. If so, and if the bend in the structure is considered, the dolomite lenses at Agua Fria and Pasto da Rosa could be part of the Gandarela formation. A little float of iron-formation found near Agua Fria tends to support this interpretation; but no outcrop could be found, and the entire south side of the ridge is underlain by schist and phyllite.

The contact of the rocks of the Piracicaba group with older rocks is not well defined. The continuous band of ferruginous quartzite that crops out near the northern contact with the Gandarela formation is found at different distances from the contact, which suggests a disconformable relation. This is in accord with the findings of J. B. Pomerene (written communication) and Gair (written communication). East of Dores da Belavista, phyllite is found lying on quartzite that was mapped as the Caraça(?) group. Except for surficial deposits and intrusive rocks, the Piracicaba group is the youngest stratigraphic unit in the area.

INTRUSIVE ROCKS

Dikes and sills of felsic, mafic, and ultramafic igneous rocks have intruded the sedimentary sequence, and felsic rocks make up a large part of a batholith in the northern part of the mapped area. The mafic rocks have been metamorphosed to amphibolite and the ultramafic rocks to talc schist.

Fresh rock is not abundant; the mafic rocks are nearly everywhere completely altered to saprolite at the outcrop. The mafic rocks break down to a distinctive reddish-brown soil that is useful in showing the location of the rock between outcrops.

ITABIRITO BATHOLITH

The name "Itabirito batholith" will be used in this report as a descriptive term for the large mass of gneissic rock that underlies the greater part of the Cachoeira do Campo quadrangle and that extends into adjacent quadrangle on all sides. The name has been used as a field term for convenience but is not proposed as a formal name. Itabirito is a town near the northwestern edge of the batholith in the Itabirito quadrangle (fig. 1).

Nearly all rocks of the Itabirito batholith are gneiss and include both granitic orthogneiss and banded biotite-rich paragneiss that probably represents granitized sedimentary rock. Pegmatite dikes, mafic dikes, and lenses of biotite-garnet schist are found in the batholith; and pendants of low- to medium-grade schist, probably part of the Rio das Velhas series, cover small areas (pl. 1). The gneiss is deeply weathered over large areas, but the textures may be preserved in saprolite. A few outcrops of domelike masses of fresh rock may be as much as 400 meters in diameter. Deep gullies develop readily in the weathered gneiss and are useful in giving a three-dimensional picture of the structure. All outcrops of massive gneiss found in the course of field mapping, as well as the saprolite found in gullies, are shown by a distinctive pattern on the maps (pls. 1, 2).

Owing to the limited and widely scattered exposures of gneiss, it was not possible to make a detailed differentiation between the orthogneiss and paragneiss. Figure 8 shows the very generalized distribution of the two types, based on outcrops and soil color. The soil over granitic gneiss is lighter colored than that formed over biotite-rich gneiss.

PETROGRAPHY

The orthogneiss is a medium-grained granitic rock with a low percentage of biotite. The biotite flakes may be unoriented, but most show some alinement. Quartz, plagioclase, and microcline are the main constituents of this rock. Porphyritic gneiss, with microcline or orthoclase crystals as much as 1.5 centimeters in length, is found but does not seem to be abundant. Outcrops of this porphyritic gneiss were found at N. 5,140, E. 2,350; N. 3,270, E. 12,500; and N. 1,480, E. 11,920 in the Cachoeira do Campo quadrangle, and N. 13,480, E. 2,620 in the Dom Bosco quadrangle.

The modes of three specimens of granodiorite gneiss are shown in table 3 together with two modes, numbers 4 and 5, published by Guild (1957, p. 27, No. 5; p. 10, No. 2). Number 4 is from the Itabirito batholith, and number 5 is from the "basement complex" farther south. Mode 2 has a relatively high biotite content, but has a granitic aspect; the biotite occurs as scattered unoriented flakes. The rocks of the Itabirito batholith are very similar in mode to gneissic granodiorites from the Scandinavian area listed in Johannsen's tables (1932, v. 2, table 173, p. 337–339).

TABLE 3.—*Modes of granodiorite gneiss and banded gneiss from the Itabirito batholith and the basement complex*

[Percentages, except for numbers 4 and 5, are based on 700–800 point counts in each thin section. x indicates presence of mineral]

	1	2	3	4	5	6	7	8
Quartz	34.0	26.0	31.0	25.1	30	21.4	26.4	13.7
Microcline	9.4	6.1	25.7	11.7	31	10.0	10.3	11.6
Oligoclase	50.0	56.0	33.8	53.5	36	54.2	46.8	37.4
Biotite	5.6	11.5	6.7	5.8	1.5	10.3	10.1	25.8
Muscovite	x	------	2.8	3.9	1	1.0	3.3	3.5
Clinozoisite	x	x	x	------	------	x	x	------
Epidote	x	x	x	------	------	------	3.0	x
Apatite	------	x	------	------	------	x	x	x
Zircon	x	x	x	------	------	x	------	x
Tourmaline	x	------	------	------	------	------	------	------
Sphene	------	------	------	------	------	x	x	x
Garnet	------	------	x	------	------	------	------	------
Chlorite	------	------	------	------	------	------	x	------

Specimen locations:
1. N. 4,200, E. 7,460, Cachoeira do Campo quadrangle.
2. N. 2,560, E. 9,040, Cachoeira do Campo quadrangle.
3. N. 12,300, E. 3,410, Dom Bosco quadrangle.
4. Northeast corner, São Julião quadrangle, P. W. Guild (1957, p. 27, No. 5).
5. Basement complex, P. W. Guild (1957, p. 10, No. 2).
6. N. 5,920, E. 5,360, Cachoeira do Campo quadrangle.
7. N. 5,860, E. 5,950, Cachoeira do Campo quadrangle.
8. N. 1,060, E. 11,910, Cachoeira do Campo quadrangle.

As seen in thin section, the quartz and oligoclase grains are as much as 1.5 mm in diameter, and the biotite and microcline are as much as 0.5 millimeter. The quartz grains are rounded and embayed, and blebs of

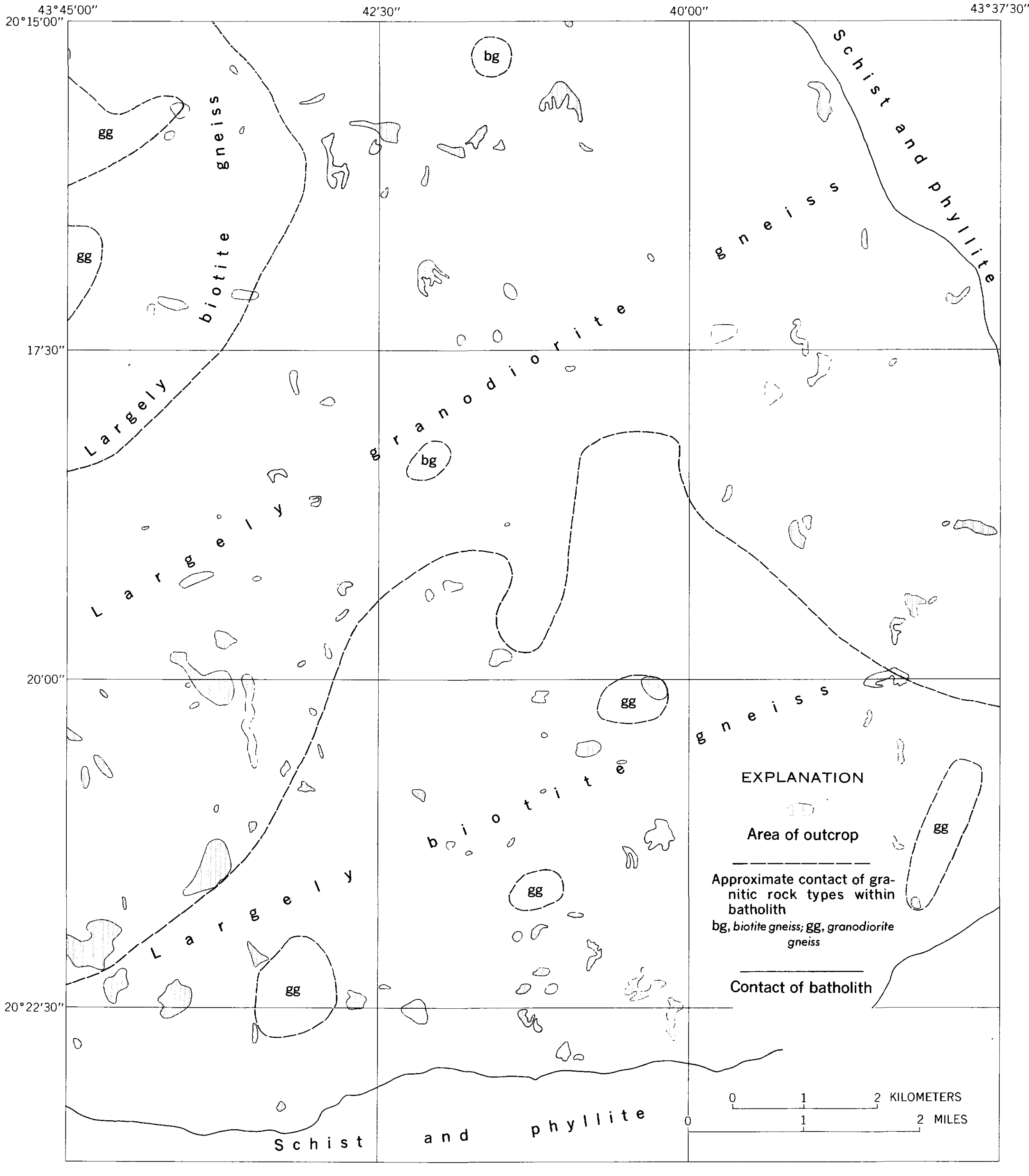

Figure 8.—Sketch map of a part of the Itabirito batholith showing the approximate distribution of orthogneiss and paragneiss.

quartz are found enclosed in feldspar (fig. 9). Oligoclase may show multiple twinning, but only of the albite type. Clinozoisite has begun to form in the plagioclase. Microcline is fresh and shows multiple twinning in two directions. It occurs interstitially between the larger grains of quartz and plagioclase. Biotite is brown, much of it with a greenish tinge, and is strongly pleochroic. The flakes are small, but most are well defined, although shreds and irregular patches of this mineral may be present. Accessory minerals are rare,

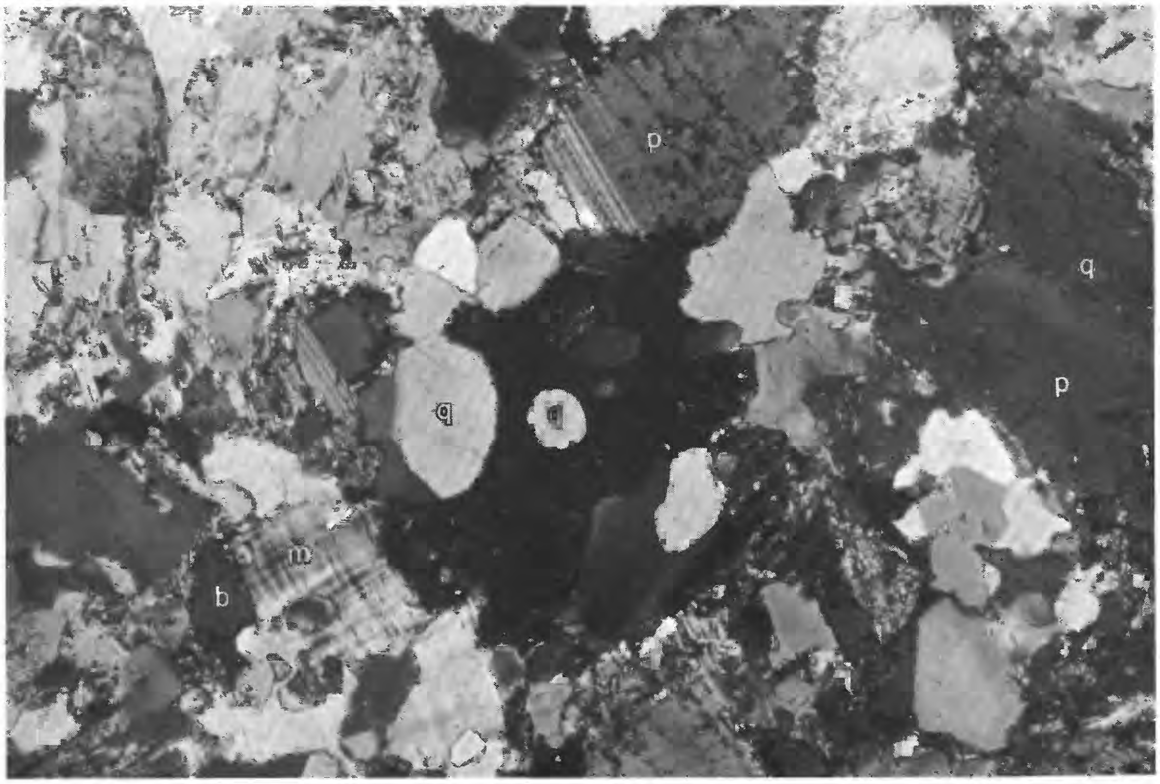

FIGURE 9.—Photomicrograph of granodiorite gneiss showing rounded quartz blebs in feldspar—b, biotite; m, microcline; p, plagioclase; q, quartz. Crossed nicols, × 50.

in the magnitude of less than 10 grains to a section. They include apatite, muscovite, zircon, tourmaline, sphene, and garnet. Minerals of secondary origin include the epidote group, chlorite, and at least part of the muscovite.

The banded gneiss contains a higher percentage of biotite and is marked by the segregation of the biotite and the light minerals into definite bands. A complete gradation exists between granodiorite gneiss and biotite-rich banded gneiss. The banded gneiss seems to grade into migmatites and granitized sediments. Crosscutting relations between the two types of gneiss and dikes of granodiorite cutting the schist bodies in the gneiss, show that at least part of the gneiss is intrusive.

The modes of two banded gneisses, numbers 7 and 8, and a gneiss with oriented biotite flakes, number 6, are included in table 3. A sample from the same locality as specimen 6 was analyzed in the Geological Survey laboratories by P. L. D. Elmore and S. D. Botts, using methods of rapid rock analysis similar to those described by Shapiro and Brannock in U.S. Geol. Survey Bulletin 1036–C. The results were as follows:

Constituent	*Percent*	*Constituent*	*Percent*
SiO_2	72.0	K_2O	2.8
Al_2O_3	15.6	TiO_2	.24
Fe_2O_3	.3	P_2O_5	.05
FeO	1.3	MnO	.04
MgO	.56	H_2O	.42
CaO	2.1	CO_2	.21
Na_2O	4.6		

Modes 6 and 7 have a slightly higher biotite content than most of the granodiorite gneiss, but no higher than mode 2, a rock with a typical granitic texture. Mode 7 is a distinctly banded rock with good separation of the biotite into zones 1 mm in thickness separated by 2 to 3 mm of biotite-poor material. Mode 8 is probably representative of the biotite-rich gneiss. The quartz-feldspar grains in this specimen are crushed, and the foliation is more irregular than in the other paragneiss.

Lenses of garnet-bearing biotite-amphibole schist occur in two areas within the Itabirito batholith, one about 1,500 meters northeast of Cachoeira do Campo and the other about 1,600 meters west of the town. A thin section of a specimen from the first locality is made up of aggregates of quartz and andesine separated by biotite-cummingtonite(?) layers and contains garnet porphyroblasts. The rock is coarse grained—the quartz and andesine grains about 1 mm in diameter and the biotite and cummingtonite(?) 2 to 3 mm in longest dimension. The garnet grains are as much as 2 centimeters in diameter; they have a sieve texture and include fragments of the other minerals. Apatite, magnetite, and sphene are accessory minerals. Larger garnet grains, which are up to 7 centimeters in diameter and contain abundant inclusions, are found in the schist lens west of Cachoeira do Campo.

The lenses described in the preceding paragraph are coarser grained than the schists that border the batholith on the east, but their mineralogy is the same; therefore, they may represent engulfed masses of pre-Minas rocks that were maintained at a very high temperature for a longer period of time.

AGE AND CONTACT RELATIONS

The relative ages of the various granitic gneiss masses in the Quadrilátero Ferrífero are of fundamental importance in deciphering the geologic history of the region. Granodiorite of the Itabirito batholith is known to intrude rocks of the Minas series in the São Julião quadrangle (Guild, 1957, p. 27), but only rocks of the Rio das Velhas series have been intruded and metamorphosed by the rocks of the batholith in the area described in this report.

Mention has been made of the thin but continuous belt of pre-Minas schist along the southern margin of the batholith. Garnet and staurolite(?) formed in the schist, owing to contact metamorphism, but the schist of the Batatal formation at an equal distance from the contact with the batholith shows no contact effects. That the garnet was formed by contact metamorphism and not by regional metamorphism of the Rio das Velhas series is indicated along the east border of the batholith where zones of amphibolite and garnet-amphibole schist are found parallel and close to the contact, with low-grade schist found farther away.

A migmatite zone as much as 30 meters in width occurs between the gneiss and schist along the southern margin of the batholith. The migmatite is composed of 2- to 3-mm layers of schist interlayered with thin streaks of granitic material. The layers are not highly crumpled along the contact, in contrast to contorted migmatite found within the batholith. The migmatite fades out into the gneiss but is in sharp contact with the schist; the contact shown on the map is that between migmatite and schist. Pegmatite dikes that contain coarse muscovite and black tourmaline are common along the contact both in the migmatite and in the schist. The biotite-rich banded gneiss that is widespread in the southern part of the batholith may well be granitized parts of the Nova Lima group.

The contact metamorphism of the pre-Minas rocks adjacent to the batholith is the strongest argument that at least part of the mass is intrusive. Supporting evidence is the presence of a granitic dike cutting a small schist pendant, probably part of the Rio das Velhas series, north of Amarantina (fig. 10).

FIGURE 10.—Granitic dikes cutting red-weathering schist of probable pre-Minas age north of Amarantina. Granite, gn; schist, sch.

Heavy minerals were separated by panning three samples of saprolite derived from granitic and banded gneiss in the Cachoeira do Campo quadrangle. Samples were taken from a granitic dike intruding an isolated mass of pre-Minas schist at N. 10,580, E. 3,580, and from granitic and banded gneiss at N. 4,200, E. 11,820. The work was done as a preliminary test to see if any differences could be found between the granitic rocks and to compare these samples with those taken in Belo Horizonte and from near Brumadinho.

Monazite was an abundant constituent of the heavy minerals from the dike that cut pre-Minas schist but was rare or absent in the samples from the Belo Horizonte gneiss. The monazite i the granitic dike consisted of small angular grains. Xenotime was found in the banded gneiss as coarse doubly terminated flattened pyramids. Rutile was found in the banded gneiss but not in the other samples from the batholith. Tiny laths of zircon(?), some with reddish-brown cores and white opaque borders, and others completely altered to the white material were found in most samples but in varying amounts. The sample from near Brumadinho was characterized by an almost complete lack of heavy minerals. The above minerals were all from weathered gneiss and so were unsuitable for age determinations.

Time did not permit a detailed study of heavy-mineral suites in the area, but the problem should be investigated further as significant differences were found in both varieties and forms of the heavy minerals.

DIKE ROCKS

GRANITIC DIKES

Granodiorite intrusive rocks, both dikes and small irregular bodies, are abundant in the green-schist and granodiorite complex in the Ouro Branco quadrangle and in the wedge of pre-Minas rocks in the southeast corner of the Dom Bosco quadrangle. Fresh rock was not found, but the dikes are probably similar to those described by Guild (1957, p. 27) found in the complex in his area.

Granitic dikes as much as 10 meters wide and a few hundred meters long occur in sericitic quartzite of the Caraça(?) group east of Morro do Gabriel in the Dom Bosco quadrangle at N. 6,280, E. 9,970; N. 6,200, E. 9,540; and N. 4,730, E. 9,740. The dike rock has weathered to saprolite and resembles saprolite derived from granodiorite gneiss of the Itabirito batholith.

Saprolite derived from granitic dikes or from fine-grained pegmatite dikes occurs in phyllite north of Morro do Bule (N. 4,500, E. 7,600). These dikes, together with a few outcrops of quartz-tourmaline rock found in the saddle west of Morro do Bule and in the valley and ridge to the east, are the only granitic or pegmatitic rocks found by the writer in the rocks of the Piracicaba group in the mapped area.

Fresh porphyritic rock crops out at N. 3,220, E. 10,020; and N. 5,120, E. 12,740 in the Dom Bosco quadrangle. The exposure at the first locality is irregular in outline, and the mass at the second locality is tabular. In thin section the porphyritic rock was seen to consist of porphyroblasts of perthite, up to 1 centimeter in length, in a groundmass of quartz, andesine (An_{30-40}), and muscovite. The perthite is tabular but anhedral with ragged borders, and it contains abundant inclusions of the other minerals. Part of the quartz and muscovite occurs as unaltered remnants of the original rock, a quartz-sericite schist. Quartz layers 1 to 2 mm thick are separated by sericite partings as much as 0.5 mm thick. In other parts of the thin section, the quartz is crushed, and the sericite partings are frayed and broken. Andesine is found in the crushed areas as twinned and zoned angular crystals that are also broken. The perthite porphyroblasts formed later and replaced or grew around the other minerals. Sericite layers can be seen extending through perthite crystals with no evidence of thinning or replacement by the sericite. Biotite was found in one thin section; some flakes were oriented parallel to the sericite, but most were of random orientation. The rocks may represent an example of alkali metasomatism in quartz-sericite schist (Turner and Verhoogen, 1951, p. 485), in which the alkali-bearing solutions followed crushed zones in the schist.

MAFIC AND ULTRAMAFIC INTRUSIVE ROCKS

Dikes, sills, and small irregular intrusive masses of mafic and ultramafic igneous rock are found throughout the area but are most abundant in the gneiss and in the rocks of the Rio das Velhas series. Ultramafic rock intrudes only rocks of the Rio das Velhas series in the mapped area. The rocks range in composition from talc schist derived from ultramafic rock to amphibolite probably derived from gabbroic rock (Guild, 1957, p. 28).

Ultramafic rock crops out in the Ouro Branco quadrangle, where two exposures were found; one on the road about 5 kilometers west of Ouro Branco (N. 2,400, E. 1,380), and the other in the southeast corner of the quadrangle (N. 320, E. 12,530). The rock in each outcrop is massive talc. The fresh talc is greenish brown, weathers nearly white, and consists of a compact aggregate of small micaceous flakes. Both outcrops have been prospected superficially but are too small to be of commercial interest. The talc appears similar to some of the talc being processed for industrial use in a mill near Ouro Branco.

Amphibolite dikes consist of dense greenish-black rock where fresh and reddish-brown rock where weathered. Their mineralogy and appearance is remarkably uniform throughout the area. The amphibolite is too fine grained to show any megascopic texture, but a suggestion of diabasic texture could be seen under the microscope. Fresh rock was found in dikes cutting the Itabirito batholith, the adjacent schists of the Rio das Velhas series, and the green-schist and grandiorite complex south of the Serra do Ouro Branco. Dikes cutting the Minas rocks are completely altered to saprolite, and their original texture and mineralogy is unknown.

Bluish-green hornblende is the predominant mineral, making up from 50 to 70 percent of the amphibolite. Chlorite similar in color to the hornblende, but with very low birefringence, occurs as rims around hornblende grains and as interstitial material. Zoned plagioclase (An_{30-40}) is the next most abundant mineral and is commonly saussuritized. Leucoxene is a common accessory mineral and may be accompanied by sphene. Pyrite is usually present and makes up about 3 percent of one thin section. Other accessory minerals are quartz, apatite, and magnetite. A dike in gneiss near the pre-Minas contact southwest of Catete in the Dom Bosco quadrangle is composed of hornblende and quartz with about 10 percent garnet and 5 percent plagioclase (about An_{20}). This dike probably represents a mixed rock with some assimilation of gneiss.

Amphibolite dikes are common in the gneiss of the Itabirito batholith, particularly in the northern part of the Cachoeira do Campo quadrangle, where they crop out as lines of exfoliated boulders with weathered rims and fresh cores. Some dikes can be traced as much as a kilometer, but most are covered with soil and cannot be traced for more than a few tens of meters. Scattered outcrops of amphibolite connected by bands of reddish-brown soil were mapped as continuous dikes.

Few mafic intrusive rocks intrude the Minas series above the quartzite of the Caraça group, but they may be more abundant than shown on the map. Several dikes were found in railroad cuts; therefore, there is no reason to suppose they are not present below soil cover elsewhere. The dikes intruding the Minas series are now saprolite, but they are unfoliated and may well correlate with the post-Minas diabase described by Dorr (written communication).

Many mafic dikes intrude the quartzite east of Morro do Gabriel, and a conspicuous dike cuts the Ouro Branco massif. This dike can be clearly seen on aerial photographs and extends from near the Ribeirão da Colónia at the west end of the range nearly to the east edge of the Ouro Branco quadrangle. The dike is marked by a reddish-brown soil band 60 to 80 meters wide that fills a linear depression in the white quartzite. The depression contains trees near cross-cutting streams and gullies, in contrast to the quartzite which is only covered by brush.

Mafic dikes are common in the green schist south of the Serra do Ouro Branco. Many of them are alined with N. 60° W. strike. Larger gabbroic bodies appear about 1 kilometer south of the south boundary of the Ouro Branco quadrangle. Soil formed over these masses is more fertile than that formed over the adjoining schist and has been found particularly favorable for growing potatoes. The rough outlines of the intrusive bodies are indicated by the areas that have been cleared for planting. A dike just south of the mapped area is characterized by an abundance of large white plagioclase crystals in a greenish-black groundmass (fig. 11). The feldspar is almost completely altered to an aggregate of clinozoisite grains with interstitial albite. The groundmass consists of plagioclase, biotite and hornblende, partly altered to chlorite. The biotite forms a rim of small flakes around the large plagioclase crystals and is also scattered throughout the groundmass.

Pluglike mafic intrusive masses a few tens of meters in diameter crop out in the Dom Bosco quadrangle at N. 12,540, E. 4,000 and N. 6,420, E. 12,280. Fresh rock from the first locality is identical in appearance with the previously described dikes, and saprolite from the second locality has comparable amphibolite texture. A small mafic intrusive mass in the Cachoeira do Campo quadrangle (N. 5,830, E. 10,530) contains abundant talc and acicular amphibole and is derived from a more mafic parent rock.

SURFICIAL DEPOSITS

Talus, laterite, canga, and alluvium are the principal types of surficial material in the mapped area. Talus is abundant only along the base of the Ouro Branco scarp, where it forms a narrow apron and many talus cones. Reworked talus forms a broad belt that may extend as far as 1 kilometer from the scarp. Quartzite blocks in the talus and reworked material are as large as 6 meters in exposed diameter, but most blocks measure less than 1 meter across. The rock breaks down readily to quartz sand. Large blocks may be found, singly or in groups, at a distance of several hundred meters from the scarp; erratic bedding in the blocks helps to distinguish them from quartzite in place. The Ouro Branco quartzite is cut by several sets of joints that facilitate the spalling off of the blocks. Masses of quartzite of great size have apparently broken away from the cliff face because streams draining the face disappear partway down the cliff; they probably drain off through the talus cones into adjacent gullies.

Lateritic soil is widespread, but was not mapped separately. The largest continuous areas of lateritic soil are in the Ouro Branco quadrangle where the low, rolling topography is favorable for soil development. Lateritic soil is also well developed in the Cachoeira do Campo quadrangle; many gullies in the weathered gneiss show a thickness of 3 to 4 meters of red or brown lateritic soil lying on saprolite. Laterite in the valley bottoms and lower elevations is soft, but on ridge crests or benches marking old erosion surfaces it is hard and resistant to erosion.

Hardened or indurated laterite consisting of red clay with included quartz grains, and which may contain spots of white clay, has been given the field name of mudstone. The largest and best exposure of mudstone in the mapped area is crossed by the road to the Cumbe dolomite quarry and is northwest of Morro do Caxambú (pl. 2). This exposure has been described by Guild (1957 p. 43), who thought it was a probable alteration product of dolomite. The mudstone wedges out downward and also caps an adjacent ridge to the west. The contact with the enclosing phyllite is sharp and angular fragments of phyllite are found in the mudstone adjacent to the contact. It therefore appears to the writer to be transported material, possibly filling an old channel. A smaller area of mudstone south of Morro do Caxambú (N. 9,540, E. 8,580) is better exposed and

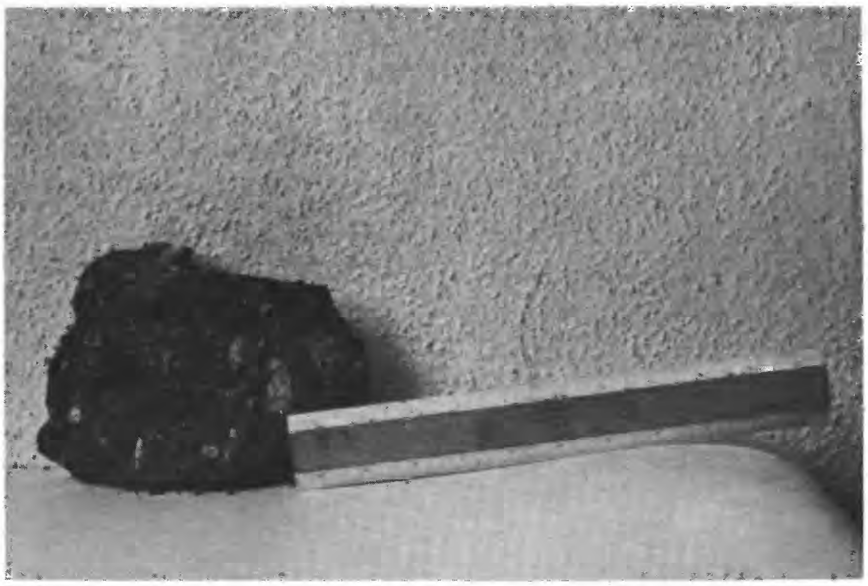

FIGURE 11.—Mafic dike rock with large altered plagioclase crystals.

also seems to be channel fill. Fresh dolomite crops out near the mudstone and some weathering product of the dolomite may have acted as a hardening agent, but it seems unlikely that the mudstone is a direct alteration product of dolomite in this area. The white clay in the mudstone forms worm-shaped growths and seems to be due to alteration of the red clay, as described by Guild (1957, p. 43).

Canga is the local name given to a hard surficial capping mostly on areas underlain by iron-formation, or downslope from iron-formation. Canga is composed of fragments of iron-formation cemented by hydrated iron oxides. Various types of canga have been described by Dorr (written communication). The classification is based on differences in source material (that is, hard ore or itabirite) and whether the material is residual or transported. Canga is poorly developed in the mapped area. It is widespread in some parts of the Quadrilátero Ferrífero and is an important source of ore in places.

Areas of canga large enough to show on the geologic map are along the central ridge in the Dom Bosco quadrangle west of Dom Bosco, south of the ridge at N. 8,000, E. 5,240, in the Fazenda Papacobra area, and in the valley at the west end of the itabirite lens east of Morro Mandachuva. The largest masses of canga occur on gentle slopes and over thick sections of itabirite. From this it is assumed that such a combination of source material and topography is necessary for optimum development of canga. Neither of these conditions is fulfilled in most parts of the Dom Bosco quadrangle and hence may explain the scarcity of canga in the area.

Alluvium and terrace gravels are found along the larger streams but are not shown on the maps. Gold-bearing gravels cemented by limonite occur along the Ribeirão da Colónia north of the Serra do Ouro Branco in the western part of the Dom Bosco quadrangle. The gravels were deposited behind a barrier formed by the quartzites at the western end of the range. The Serra is now breached by a narrow gorge, and the gravels are 10 to 20 meters above the present stream level. Terrace gravels south of the Serra along Ribeirão Ouro Branco and Ribeirão Agua Limpa have also been mined for gold. The remains of old placers along the Ribeirão Tabuões on the east edge of the Cachoeira do Campo quadrangle are in terrace gravels 10 to 20 meters above the level of the stream.

METAMORPHISM

Most mineral assemblages in the sedimentary rocks described in preceding parts of this report are characteristic of metamorphic rocks of the lower grades in the facies classification;[6] that is, the green schist and albite-epidote- amphibolite facies; this corresponds to the chlorite and biotite zones of regional metamorphism. The physical-chemical conditions of the amphibolite facies were reached in the contact aureole of the Itabirito batholith, and within the batholith.

With the exception of the dolomite and iron-formation, the sedimentary rocks of the mapped area are characterized by the ubiquitous quartz-sericite-chlorite mineral assemblage. This assemblage is found in the phyllite of the Piracicaba group in the northern part of the Dom Bosco quadrangle and in the green schist that

[6] The facies classification of metamorphic rocks proposed by Eskola (1920) and expanded by Turner (1948) will be followed in this report.

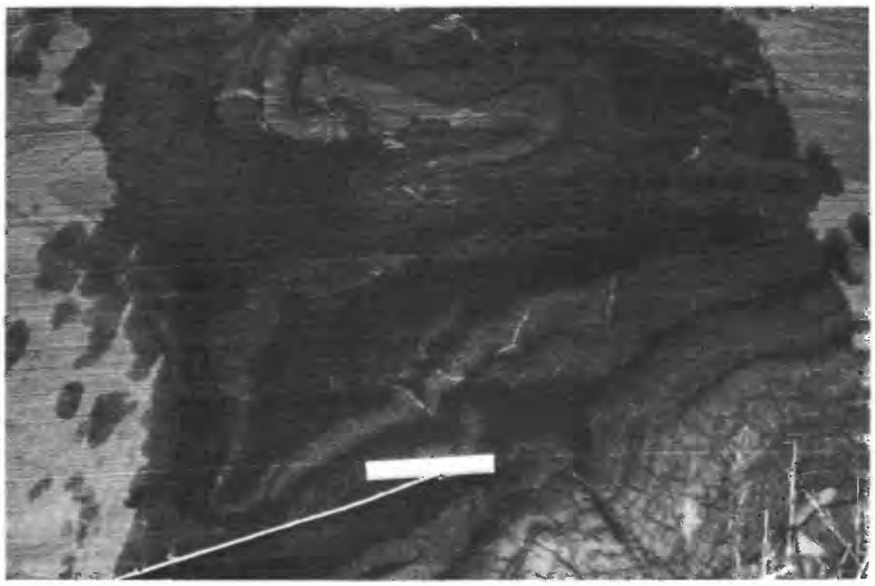

FIGURE 12.—Complex crumpling in dolomite at the Cumbe quarries.

crops out along the Córrego da Cachoeira in the southeast part of the quadrangle. The green schist has a slightly coarser grain size and may represent a slightly higher metamorphic grade, possibly reaching conditions found in the albite-epidote-amphibolite facies. The epidote and chloritoid in the phyllite is also indicative of low metamorphic grade. In the mapped area, no albite was found in phyllite and green schist, although in other parts of the world, that mineral is present in rocks of this facies. Kyanite found in phyllite north of Cumbe is thought to be of hydrothermal origin rather than representative of high-grade metamorphism. (See p. B–17.)

Carbonate-bearing rocks show little change under the metamorphic conditions found in the area (fig. 12). The association dolomite, quartz, and sericite is common and is stable in lower grade rocks (Turner and Verhoogen, 1951, p. 469). The mineral assemblage of dolomite, phlogopite, quartz, epidote, and chlorite in a calc-schist from the northeast corner of the Dom Bosco quadrangle (N. 12,080, E. 12,640) is a low-grade calc-schist assemblage (Williams, Turner, and Gilbert, 1954, p. 217). Tremolite also develops at low temperatures in carbonate rocks; so the association of dolomite, tremolite, quartz and magnetite in dolomitic itabirite north of the Ribeirão da Colónia does not represent a much higher metamorphic grade.

The iron-formation of the Quadrilátero Ferrífero is generally assumed to have been deposited as a chemical sediment composed of hydrous iron oxides and silica. The conversion of this material to itabirite involves both diagenetic changes during lithification and changes produced during metamorphism. Some of the changes may be indistinguishable as to which process was responsible (James, 1955, p. 1437). James further states that increase in grain size is an obvious effect of metamorphic activity, and may be the only effect. The recrystallized chert and crystalline hematite or magnetite in the itabirite are, therefore, the best evidence that the itabirite is metamorphosed. The itabirite is assumed to be mostly in the green-schist facies, the metamorphic grade of the enclosing rocks. The diopside-epidote-actinolite iron-formation along the Córrego da Cachoeira (N. 3,780, E. 12,620) is representative of higher grade conditions, possibly in the albite-epidote-amphibolite facies. This mineral assocation is supporting evidence for a higher grade metamorphism in the southeastern part of the area.

Rocks of the amphibolite facies are found in the contact aureole of the Itabirito batholith. The association quartz, andesine, cummingtonite(?), biotite, and garnet occurs in schist close to the contact with gneiss (fig. 13) and in schist xenoliths in the gneiss.

All gneiss in the batholith corresponds mineralogically and texturally to the quartz-feldspathic schist described by Williams and others (1954, p. 236) as belonging to the amphibolite facies. This is the highest metamorphic grade found in the mapped area.

The mafic dikes commonly appear to be of higher metamorphic grade than the enclosing rocks. Throughout the area they have a constant mineralogy of hornblende and plagioclase (An_{35-50}), with partial alteration of the hornblende to chlorite and of the plagioclase to minerals of the epidote group.

STRUCTURE

All workers in the Quadrilátero Ferrífero have commented on the intense deformation of the stratified

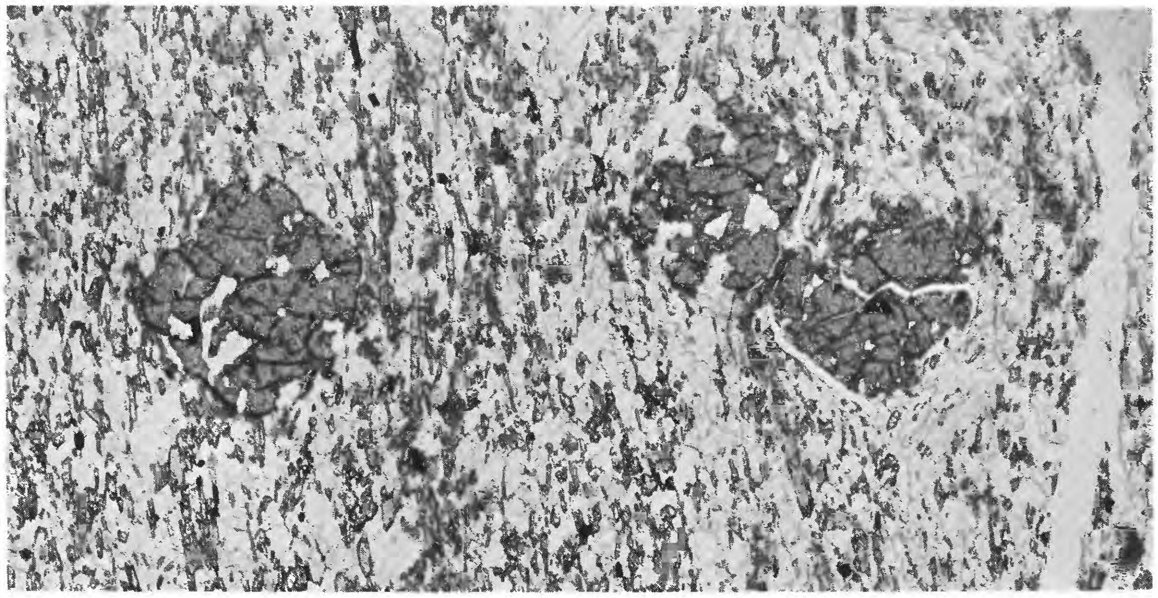

FIGURE 13.—Photomicrograph of schist from the contact aureole on the east side of the Itabirito batholith. Garnet porphyroblasts are found in a groundmass of quartz, andesine, cummingtonite(?), and biotite. Plane polarized light. × 25.

rocks. Tight folds, plastic flow of material from the flanks to the axial regions of folds, and thrust faults furnish evidence for strong compressive forces in the area described herein. The Dom Bosco and Ouro Branco quadrangles lie in a zone of east-trending structural features that extends from the São Julião quadrangle east through Ouro Preto (fig. 1). Structural features in the layered rocks of the Cachoeira do Campo quadrangle trend parallel to the contact of the Itabirito batholith.

Interpretation of the structure is largely dependent on knowledge of the stratigraphy, and as the stratigraphic column is incomplete in much of the area, the following structural interpretation is in part based on inconclusive evidence. The basic assumption made in the following descriptions is that isolated masses of itabirite belong either to the Cauê or Gandarela formations.

DEFINITION OF TERMS

Schistosity, foliation, and lineation are the only terms that may require an explanation as to usage in this report.

Schistosity refers to a planar structure in the metamorphosed rocks characterized by the preferred orientation of micaceous minerals and by the concentration, by recrystallization, of micaceous and granular minerals into subparallel laminae. The rocks tend to break parallel to the micaceous bands. Schistosity as used in this report includes the term "flow cleavage" used by Guild (1957, p. 30) to describe similar structures.

Foliation is poorly developed schistosity in the gneiss of the Itabirito batholith. The foliation is shown by alinement of dark minerals. Dark minerals locally occur in bands; where this condition exists the rock is somewhat fissile. The same map symbol is used for both schistosity and foliation.

Lineation refers to any linear element on the schistosity or bedding planes. The linear elements shown on the maps are either wrinkles on the schistosity planes produced by the intersection of fracture cleavage with the planes, or small folds, whose amplitude can usually be measured in centimeters. The smallest of these folds may give the rock a pencil structure and many of the larger crop out as cigar-shaped bodies elongated along the plunge of the fold.

CACHOEIRA DO CAMPO QUADRANGLE

The Cachoeira do Campo quadrangle is underlain by rocks of the Itabirito batholith except for a small area underlain by schist of the Rio das Velhas series in the northeast corner of the quadrangle, and another small area underlain by schist of the Rio das Velhas series, and iron-formation and dolomite of the Minas series in the southeast corner. The stratified rocks strike parallel to and dip away from the contact with the gneiss of the batholith in the mapped area, but the iron formation and dolomite do not follow the contact with the gneiss on the eastern side of the batholith. In the latter area they strike east and extend into the São Bartolomeu quadrangle. The arcuate pattern of the rocks adjacent to the contact could be attributed to either intrusion of the granodiorite or to later doming of the rocks in the batholith area.

A striking feature of the outcrop pattern shown on plate 1 is the absence of the Minas series in the northeast corner of the quadrangle. Rocks of the Minas series crop out 400 meters from the contact with the batholith in the southeast corner of the quadrangle but are not exposed within 2,400 meters of the contact in the northeast corner, even though the dips are steeper in the latter area. The implications of this geographic distribution could not be determined in the limited area mapped.

Gneiss outcrops within the area of the batholith are too widely separated to allow any study of the internal structures of the batholith. The foliation in the gneiss is nearly parallel to the contact near the margin of the batholith but within a short distance turns to a predominant northwest trend. The trend of the foliation turns to the west and even a little south of west in the area south of Amarantina but beyond this point turns back to the northwest. Another turn to the west seems to be indicated in the northwest corner of the quadrangle.

No structural reason is apparent for the presence of the low-metamorphic grade schist pendants along the Ribeirão Maracujá north of Amarantina. Mapping by O'Rourke (written communication) in the adjacent Rio das Pedras quadrangle to the north shows that the roof of the batholith extends south close to the north boundary of the Cachoeira do Campo quadrangle. The small area of schist at the north edge of the quadrangle west of the river is probably part of the roof, and the other schist areas may be downwarped or faulted parts of the original cover of the batholith.

NORTHERN HALF OF THE DOM BOSCO QUADRANGLE

Gneiss of the Itabirito batholith underlies the northern part of the Dom Bosco quadrangle. The gneiss is bordered by a thin sequence of schist of the Rio das Velhas series overlain by the rocks of the Minas series. The rocks of the Caraça and Itabira groups of the Minas series are thin, but a thick section of rocks of the Piracicaba group is exposed. Most layered rocks strike eastward. From north to south the dominant structural features are the southern flank of the domed Itabirito batholith, a synclinorium in the rocks of the Piracicaba group, and a thrust block containing rocks of the Rio das Velhas and Minas series.

Foliation in the gneiss of the batholith is parallel to the contact with pre-Minas rocks, and the sedimentary rocks commonly dip south or southeast from the contact. North dips were found in an overturned section of lower Minas rocks near the Cidreira dolomite quarry. The reversal of dip, together with the disappearance of the iron-formation and Caraça quartzite in the same area, suggests that the beds may have been cut out by faulting, but exposures were too poor to permit determination of the structure.

Within the synclinorium, a ferruginous quartzite zone in the rocks of the Piracicaba group was continuous enough to be useful as a marker bed. The outcrop pattern of the ferruginous quartzite is shown on plate 2 and it can be seen that, although several gaps exist along the strike of the bed, the pattern suggests a complex plunging syncline. A small subsidiary syncline is well exposed south of Lagoa (N. 9,700, E. 2,800), and the thickening of beds in the keel of this syncline is evident. The long gap in the ferruginous quartzite south of Cumbe is difficult to explain. Graphite schist overlain by graywacke considered to be at the top of the Piracicaba group occurs south of Cumbe. The ferruginous quartzite may double back to the south and may be cut out by the thrust plate that caps the ridge.

The plunge of the synclinorium is to the east in the western part of the quadrangle but reverses in the eastern part, as shown by the near closure of the ferruginous quartzite north of the Serra do Rodrigo Silva. A. L. M. Barbosa (oral communication) found similar canoe-shaped folds on the eastward extension of this synclinorium.

Minor folds within the syncline could not be mapped except for those outlined by the outcrop pattern of the ferruginous quartzite. Additional folds are undoubtedly present, as small superposed folds are widespread. An example of small-scale crumpling in dolomite is shown in figure 12.

Small faults are common within the synclinorium, and larger faults may well be present but can only be inferred owing to the absence of marker beds. The quartzite beds north of Cumbe, for example, are cut off by a fault, but the offset part could not be located. Elsewhere, beds are offset, but adjacent beds show no effects of faulting. Similar effects seen on a small scale in hand specimens, seem due to plastic flow of material combined with slippage along bedding or schistosity planes.

South of the synclinorium, itabirite overlain by dolomitic iron-formation crops out along the crest and south flank of the central ridge from Alemão east to near Dom Bosco. The iron-formation unconformably overlies red-weathering schists believed to be pre-Minas in age. These schists are thrust northward over rocks of the Piracicaba group. Evidence for the thrust, consisting of abrupt changes in attitude or lithology, and a crushed zone of limonitized and manganese-bearing rock, could be seen east of Ribeirão Mango, but the fault could not be traced west of the river or east of the railroad at N. 8,440, E. 8,080. East of this latter point the fault was inferred to be at the base of the itabirite, but was not shown on the map east of Dom Bosco because the itabirite disappears. West of the Dom Bosco quadrangle, the thrust may swing back to the south and be cut off by the fault that limits the pre-Minas rocks on the south; this leaves only a small wedge of pre-Minas rocks in the São Julião quadrangle. The presence of pre-Minas rocks was not recognized at the time Guild did his field mapping in the São Julião quadrangle, so he made no separation of the pre-Minas and Upper Minas rocks on his map.

Rocks of the Piracicaba group crop out south of the central ridge, except in the Fazenda Papacobra area. The structure in the Fazenda Papacobra area is complex. Itabirite crops out in two parallel layers flanked on either side by dolomite or alteration products of dolomite; the area is the eastward extension of a large dolomite-bearing area mapped by Guild (1957, pl. 2). Each of the itabirite layers has a dolomite breccia on its south side. If the dolomite breccia is assumed to be one horizon as evidence elsewhere in the Quadrilátero Ferrífero suggests, then the two itabirite layers must be repeated by faulting rather than by folding. The fault could not be located but may lie close to the southern band of itabirite, as the quartzite and ferruginous quartzite between the bands is repeated south of the southern band. A small north-striking block of itabirite about 600 meters northwest of Fazenda Papacobra, with dolomite breccia on the east and massive dolomite on the west, is probably a rotated fault block. The rocks of the Gandarela formation in this area are faulted against rocks of the Rio das Velhas series on the north and rocks of the Piracicaba group on the east.

SOUTHERN HALF OF THE DOM BOSCO QUADRANGLE

The structural features in the southern half of the Dom Bosco quadrangle are the most complex that were found during the field mapping. In addition to east-trending folds, the rocks are cut by many thrust, normal, and tear faults. The Minas series underlies most of this area and is bounded on the south by the great north-dipping mass of quartzite of the Serra do Ouro Branco. The rocks north of the quartzite are folded and faulted into a very complex pattern. Lenticular outcrops with the consequent lack of marker beds add to the difficulty of structural determinations. The quartzite in the Serra do Ouro Branco and the area of quartzite and quartz-sericite schist south of Dores da Belavista in the northeastern part of this area appear similar and are both mapped as the same formation. The two quartzites differ in their resistance to erosion, the Ouro Branco mass forming a bold highland in contrast to the subdued and lower topography of the northern quartzite, but granule-size quartz grains in a sheared quartz-sericite matrix make up the bulk of the rock in each area. If this correlation is correct, then the rocks of the Minas between the two quartzites lie in a syncline as shown on section $B–B'$ (pl. 2).

The itabirite southwest of Hargreaves in the northwestern part of the area is mapped as a thrust plate, thrust westward over phyllites of the Piracicaba group (pl. 2, section $A–A'$). A large mass of graphitic schist of the Piracicaba group lies under the west end of the itabirite and above the thrust fault. It is believed to be a mass of the upper part of the group pushed ahead of the overriding sheet of iron-formation. The itabirite plunges to the east with its northern part overlain by a thick section of massive dolomite beds. The dolomite bends to the southeast at Hargreaves and is cut off on the south by an east-trending fault.

South of the east-trending fault is the northwest-trending syncline between the two large quartzite bodies previously described. The syncline can be traced only as far east as the Morro do Bule where the dolomitic iron-formation and the dolomite lenses disappear. The southern flank of the syncline is faulted against the quartzite of the Serra do Ouro Branco at Alto da Pedra do Sabão; and the northern flank is overriden by a small plate of quartzite, which appears similar to that of the Serra do Ouro Branco and which is thrust over phyllite and quartzite of the Piracicaba group north of Morro do Bule.

Schist and phyllite with lenses of quartzite and thin bands of iron-formation are the only rocks between the two major quartzite bodies east of Morro do Bule. The phyllites with interbedded quartzite and iron-formation are mapped as Piracicaba group. Farther east, green schist intruded by granodiorite crops out, and quartzite and iron-formation are absent; so the rocks were mapped as Rio das Velhas series (pl. 2). This stratigraphic interpretation results in a complex fault pattern in the area. The rocks of the Rio das Velhas series are assumed to be thrust westward over the rocks of the Piracicaba group. This necessitates a tear fault between the rocks of the Rio das Velhas series and the quartzite of the Serra do Ouro Branco. A normal fault passing through Fazenda Lavrinha cuts the thrust on its northeast flank and drops rocks of the Piracicaba group against the Rio das Velhas series.

The weakness of this interpretation is the scarcity of evidence of a fault contact between the schist of the Rio das Velhas series and the quartzite of the Serra. The movement may have been along the contact parallel to the bedding in the quartzite and may be related to the development of the imbricate structure in the quartzite described on page B–10.

The scarp along the south side of the Serra do Ouro Branco was thought by Guild (1957, p. 36) to be on the eastward extension of a complex fault zone in the São Julião quadrangle. No evidence of faulting was found along the base of the scarp at rock contacts exposed near the west side of the Dom Bosco quadrangle and along the Ouro Branco-Ouro Preto road in the Ouro Branco quadrangle. The scarp could be a faultline scarp with the fault lying an unknown distance to the south but could also be an erosional scarp due to differential weathering between the resistant quartzite and the softer green-schist and granodiorite complex. The fault zone described by Guild lines up very well with a fault zone on the north flank of the Serra now occupied by a thick mafic dike.

Younger rocks are found thrust over older rocks in the southern part of the Dom Bosco quadrangle. A possible explanation of this may be that east-plunging folds developed earlier than the thrusts. Thrusting essentially up the plunge of the fold could then result in the observed pattern.

OURO BRANCO QUADRANGLE

The Ouro Branco quadrangle is underlain by the green-schist and granodiorite complex, except for quartzite in the Serra do Ouro Branco, which is underlain by quartzite. The few attitudes obtained in the schist indicate north- to northwest-trending structural features. Schistosity is parallel to bedding near the contact with the Ouro Branco quartzite, and the contact seems nearly conformable.

Many bodies of mafic intrusive rock strike N. 60°–70° W., but the significance of this parallelism is not apparent. Some of the tabular intrusive masses are parallel to schistosity and may be sills, but the relationship of most of them is unknown.

INTERPRETATION

The dominant compressive forces in the Dom Bosco quadrangle acted from the north or south and resulted in the formation of the east-trending folds. This compression was accompanied, or closely followed, by forces acting from the southeast or east that formed the arcuate north- to northeast-trending thrust faults. The complex outcrop pattern in this area may also be due in part to the squeezing of the less competent rocks of the Minas series between the large competent block of quartzite of the Serra do Ouro Branco on the south and the Itabirito batholith on the north.

PHYSIOGRAPHY

The physiography of the mapped area was not studied in detail, so no attempt is made to describe the complete development of the topography. Only the salient features of the physiography are described.

Landforms in the three quadrangles are determined both by the resistance of the different rock types to erosion and by structural features. The larger streams flow north or south across the main east-trending folds, but tributary streams have followed the less resistant sedimentary rocks, resulting in the development of east- or southeast-trending valleys and ridges. The higher ridges are commonly underlain by quartzite or iron-formation, but phyllite underlies the high area east of Dom Bosco in the central part of the Dom Bosco quadrangle. Low, rolling topography has developed in the area underlain by the Itabirito batholith.

Remnants of old erosion surfaces can be found above the present stream levels in many parts of the area. Evidence for the existence of the old surfaces consists of concordant summits or rock-cut terraces.

A striking concordance of summit altitudes is found in the rolling area underlain by the Itabirito batholith. Altitudes slowly decrease northward from about 1,150 meters near the southern edge of the batholith to 1,000 meters at the north edge of the quadrangle. The Ribeirão Maracujá and its tributaries in the central part of the quadrangle have cut valleys about 100 meters deep into the old surface. To the west, the Ribeirão Mango with its greater flow of water has cut a valley 200 meters deep and may capture the upper drainage of the Córrego da Prata, a large tributary of the Maracujá, at Santo Antonio do Leite. A slight rise in the old surface is found at the contact with schist in the northeastern part of the Cachoeira do Campo quadrangle. The rise seems to continue to the northeast beyond the mapped area except where cut by the valley of the Rio das Velhas.

The ridge held up by the quartzite of the Caraça group and the iron-formation in the northern part of the Dom Bosco quadrangle probably extended above the general level of the old surface, traces of which can be seen culminating in a high area north of Dom Bosco and east of the Morro do Caxambú.

On the sides of the valley that drains westward from the Morro do Caxambú, more than one terrace level can be seen. One is between 1,150 and 1,200 meters altitude, and another is at about 1,100 meters.

Old surfaces have been largely destroyed in the southern half of the Dom Bosco quadrangle. Some concordant ridges at about 1,250 meters altitude are found in the quartzite area south of Dores da Belavista, but elsewhere erosion has destroyed any surfaces that may have been present. The canga on the ridge crest west of Dom Bosco may have developed on an old surface.

ORE DEPOSITS

The ore deposits of the mapped area, with the exception of the manganese deposit at São Julião, have only been mined on a small scale. No large high-grade hematite bodies such as those found in the Congonhas area to the west (Guild, 1957, p. 50) are known, and the iron-formation is relatively thin. Dolomite is being mined at several localities, and this, together with limited prospecting for iron, gold, and clay, were the only mining activities in 1955. Manganese, iron, dolomite, placer gold, clay, quartz crystal, and topaz have been produced in commercial quantities, and talc, cinnabar, sphalerite, chalcocite, and various sulfosalts of lead are known to occur, although not in commercial quantities.

IRON

Guild (1957, p. 44) has classified the iron ores of the Congonhas district into three major types: itabirite ores, hematite ores, and surficial ores. Itabirite ores can be further classified into hard and soft itabirite; the hematite ores, into hard and soft ore; and the surficial ores, into chapinha,[7] rubble ores (composed of cobbles and blocks of hard hematite), and canga. Itabirite ores and surficial ores are found in the area described in this report.

The Dom Bosco quadrangle contains all the iron-formation in the area described in this report with the exception of one band in the southeast corner of the Cachoeira do Campo quadrangle. Limited prospecting has been done in the past on most of the outcrop areas, and some ore has been shipped. Some of the itabirite, especially that close to the railroad, will probably be mined in the future when beneficiation of itabirite is undertaken.

The part of the northernmost band of itabirite of greatest economic interest lies east of Córrego Holanda (N. 12,740, E. 7,500). From the Córrego to the eastern end of the mapped area, a distance of about 6 kilometers, the itabirite is continuous and ranges from 20 to 70 meters in thickness. Several prospect pits and a short adit were dug along this band, and a few tons of itabirite was mined from a small open pit located where the itabirite is crossed by the Cachoeira do Campo–Dom Bosco road, 1.5 kilometers east of Córrego Holanda.

A channel sample taken across 5 meters of soft itabirite in the adit at N. 12,850, E. 8,300 (800 meters east of Córrego Holanda) was analyzed, and the results are shown in table 4 (sample 208). The itabirite is high in silica, but the iron minerals were found to be easily separable from the quartz by magnetic means. A chip sample taken across the entire band in a roadcut was separated with a small horseshoe magnet after being crushed. A magnetic fraction, 65 percent by weight, of the sample was obtained; 20 percent of the magnetic fraction was composed of quartz grains mechanically bound by the magnetic grains. The quartz fraction of the sample contained a few percent magnetic material after one separation but contained very little hematite.

TABLE 4.—*Chemical analyses of itabirite and dolomitic itabirite from the Cauê itabirite and Gandarela formation, Dom Bosco quadrangle*

[Cássio M. Pinto, analyst, Departamento Nacional da Produção Mineral, Belo Horizonte, September 1956]

	208	319	385	554	687–1	687–2	764
SiO_2	42.1	24.2	28.6	47.1	51.1	53.1	48.1
Fe_2O_3	55.3	73.5	67.1	49.3	32 2	45.2	28.3
FeO	2.1	Tr.	Tr.	1.3	-----	-----	-----
Fe	39.9	51.8	47.3	35.3	22.6	31.6	19.8
Al_2O_3	Tr.	Tr.	Tr.	Tr.	.6	Tr.	.2
CaO	-----	-----	-----	-----	9.3	.3	7.3
MgO	-----	-----	-----	-----	5.4	Tr.	4.7
MnO	.30	.50	2.70	1.30	-----	-----	.60
P	.03	.03	.03	.01	-----	-----	-----
Loss on ignition	.10	1.90	1.50	.75	1.5	1.0	11.0
Total	99.93	100.13	99.93	99.7	100.1	99.6	100.2

208. Cauê itabirite, soft itabirite from N. 12,850, E. 8,300.
319. Cauê itabirite, soft itabirite from N. 8,300, E. 7,520.
385. Cauê itabirite, soft itabirite from N. 6,830, E. 8,300.
554. Cauê itabirite, soft itabirite from N. 4,950, E. 3,160.
687–1. Hard diopside actinolite itabirite from N. 3,760, E. 12,600.
687–2. Weathered rock from the same locality as 687–1.
764. Hard dolomitic itabirite from N. 4,720, E. 5,920.

The magnetic material was thought to be magnetite, but as the chemical analysis showed only 2.1 percent FeO, additional material was collected for mineralogical study to see if the iron mineral could be maghemite. An X-ray examination by F. A. Hildebrand of the Geological Survey showed the minerals of the magnetic fraction to be magnetite, hematite, and traces of quartz and an unidentified iron-bearing mineral. No maghemite or jacobsite could be detected.

If concentration of this itabirite were economically feasible, there is 350,000 tons of itabirite per meter of depth in a block extending 1 kilometer east and 1 kilometer west of the Cachoeira do Campo–Dom Bosco road.

Little is known of the hardness of this itabirite, as no underground information is available. The itabirite adjacent to the road is hard in the Córrego Dom Bosco; the stream drops in a double waterfall over ribs formed by the itabirite and the underlying quartzite. The material in the road cut is moderately soft but with considerable chapinha. The adit from which sample 208 was taken was driven into soft itabirite but only attains a depth of about 10 meters.

A second belt of itabirite 4.5 kilometers south of the northern belt extends from 1 kilometer south of Dom Bosco westward for 5.5 kilometers nearly to Alemão (pl. 2). It ranges from 20 to 100 meters in thickness. This belt is of economic interest, owing to its location

[7] Chapinha (little plate) is the name given to surficial material consisting of platy fragments of the iron-rich bands of itabirite and quartz sand. A good grade of blast-furnace ore can be obtained by screening the material.

near the railroad branch line leading to Ouro Preto. Remnants of mine workings are found just south of the railroad about 2 kilometers west southwest of Dom Bosco. Much surface work was done, but deep gullies that cut the workings make quantitative estimates of past production impossible.

The analysis of a sample of itabirite taken from a railroad cut adjacent to the mine workings is shown in table 4 (sample 319). The recrystallized chert in the surficial material sampled had disaggregated into loose quartz sand. Some of this sand was lost during sampling, so the iron content is considered to be from 5 to 10 percent lower than shown by the analysis. The itabirite is of good grade and will undoubtedly be mined when ore concentration becomes practicable in the area. No adits were found along this belt; therefore nothing is known of its characteristics at depth.

A lenticular mass of itabirite crops out about 1 kilometer south of the belt described in the previous paragraph. The eastern end of the lens lies 2 kilometers south of Dom Bosco and extends 2.2 kilometers westward. The outcrop width of the lens ranges from 300 to 350 meters over 1.6 kilometers of its length; it tapers at each end and disappears. This lens is favorably located with respect to transportation; its west end lies 1 kilometer south of the railroad that leads to Ouro Preto and is 5 kilometers by road from the railroad station at Dom Bosco.

This lens has been prospected by many adits, most of which are now caved. Prospecting was being carried on in 1956 by Sr. Serifim Gomes, of Dom Bosco, who was sinking pits through a canga capping near the west end of the lens in a search for hard hematite ore. Little hard ore was found; but the canga from the pits was hand sorted, and a few tons of the richer material was shipped.

A channel sample of soft itabirite from the lens was taken from an adit at N. 6,830, E. 8,300, Dom Bosco quadrangle. The results of analysis of this sample are given in table 4 (sample 385). The itabirite is of good grade and will probably be of economic interest in the future.

Soft itabirite predominates in this lens, at least in near-surface material. A gully at N. 6,840, E. 8,300 cuts 60 meters into soft itabirite without exposing hard itabirite.

The largest mass of itabirite in the mapped area underlies the higher ground west and southwest of Hargreaves, a railroad station in the west-central part of the Dom Bosco quadrangle. It also forms a ridge extending about 2 kilometers west from a point 800 meters southwest of Fazenda Rodeio, a farm that lies 1.2 kilometers south of Hargreaves.

Little prospecting has been done in this area. A few tons of siliceous material was mined from itabirite that is crossed by the road southwest of Fazenda Rodeio; the material was shipped to the Esperança furnace near Itabirito. An adit about 25 meters long extends into the ridge adjacent to the opencut; sample 554, table 4, was obtained from near the face of this working. The sample proved to be relatively low in iron and high in silica.

Most itabirite in this area seems hard because it crops out as cliffs or along the ridge crests (fig. 5), but whether the hardness is due to surficial "case hardening" or is characteristic of the itabirite could not be determined. The itabirite in the adit mentioned above is soft except for the first few meters near the portal. The itabirite of this body crops out over an area of about 1.5 square kilometers, and the material is favorably located near the railroad; therefore, it will be of interest when the ores can be economically concentrated.

Relatively inaccessible masses of itabirite and dolomitic itabirite are shown on plate 2 in the several kilometers east and southeast of Fazenda Rodeio. Most of them have been prospected and considerable work has been done on the body 1 kilometer east of Fazenda Rodeio, where fragments of micaceous specularite up to several kilograms in weight occur in the soil. This itabirite is soft at the surface. The other bodies are hard siliceous or dolomitic itabirite; they crop out as conspicuous ridges or form waterfalls in the streams that cross them. Itabirite 2.4 kilometers east-southeast of Fazenda Rodeio is dolomitic (table 4, sample 764).

Table 5 shows the inferred reserves of itabirite per meter depth in the outcrop areas of the iron-formation in the Dom Bosco quadrangle. The tonnages per meter depth were compiled by estimating the areas of outcrop, in meters, and multiplying this by 3.5, the estimated specific gravity of itabirite. The grade of the itabirite indicated in table 5 is based on one sample from each outcrop area; areas for which grade is not shown were not sampled. The foregoing text indicates the amount of information available on each area with respect to number and size of exposures and the extent of knowledge on the relative hardness or softness of the itabirite resources of the mapped area.

Rubble ore was recovered from a small area 1 kilometer northwest of Hargreaves. Cobbles of hard hematite occur in the soil adjacent to and downslope from the itabirite belt. The production is not known; small piles of cobbles at the end of an abandoned road indicate that some ore was recovered.

Itabirite along the Córrego da Cachoeira, near the east margin of the quadrangle, contains diopside and

TABLE 5.—*Reserves of itabirite in the Dom Bosco quadrangle, given as tons per meter depth*

Outcrop area	Type of itabirite	Dimensions of outcrop		Inferred reserve (thousands of tons)	Grade (percent) [1]
		Length (kilometers)	Average width (meters)		
Northern belt	Hard and soft	7.4	60	1,500	40
Belt extending from 1 km south of Dom Bosco station west to Alemão.	Not known	5.8	100	2,000	50
West of Alemão, north belt.	Soft near surface	2.2	100	800	--------
West of Alemão, south belt.	Hard and soft	3.6	40	500	--------
Belt extending east from Morro Mandachuva.	Soft near surface	2.2	250	2,000	45
Mass west and southwest of Hargreaves.	Not known	3.5 sq km		11,500	35
Belt along Ribeirão da Colónia, west edge of quadrangle.	Hard	2.5	50	400	--------
Belt extending east from 1 km south of Hargreaves.	Soft	2.5	100	900	--------
Belts north and south of Morro do Vieira.	Hard, dolomitic	4.2	80	1,200	20
Alto da Pedra do Sabão	Hard, dolomitic	1.6	250	1,400	--------
Total				22,200	--------

[1] Grade is based on analyses made of samples collected during this investigation. Areas for which no grade is shown were not sampled.

actinolite (table 4, samples 687–1 and 687–2). The samples were analyzed to determine what chemical changes took place during weathering. The results show a 9 percent increase in iron with a loss of nearly all the calcium and magnesium. The latter elements were contained in the diopside and actinolite that were completely broken down during weathering.

MANGANESE

The manganese deposits of the Dom Bosco quadrangle are of two types; (a) supergene concentration of manganese from manganese-bearing beds interbedded with itabirite and dolomite, or from manganiferous carbonate; and (b) small surficial deposits formed by supergene concentration of manganese derived from clastic rocks.

The Burnier mine at São Julião is the best known deposit of the first type. Small deposits along the strike of the iron-formation or in areas underlain by dolomite are probably also of this type. Most of the other manganese occurrences are of the second type; they are found throughout the quadrangle in areas underlain by rocks of the Gandarela formation and the Piracicaba group. They are absent in areas underlain by gneiss or by quartzite.

More than 50 small manganese prospects were seen in the Dom Bosco quadrangle. Most consist of a shallow pit or trench with a small pile of ore near the working. The pile of ore at each prospect probably represents the total amount of material mined, and ranges from a few kilograms to possibly 300 kilograms. None of the material was analyzed as it seemed of little economic importance, but similar material in other parts of the Quadrilátero Ferrífero ranges from 30 to 60 percent manganese. Nothing could be seen at most prospects to explain the concentration of manganese oxides or to indicate future possibilities for production. Some prospects are along faults or joints.

The mineralogy of the manganese ores was not studied but is probably similar to that in adjacent areas. Cryptomelane, pyrolusite, manganite, polianite, psilomelane, and wad are reported from ores of these types (Dorr and others, 1957). All ore has been derived from weathered material; so the mineralogy of the protore is not known; Guimarães (1935) believes that the Burnier deposit consists largely of syngenetic manganese oxides, whereas Scott (1900) thought that the ore was derived from leaching of manganiferous dolomite.

The Burnier deposit at São Julião consists of an east-trending manganese-bearing zone about 8 kilometers in length, the eastern 1.5 kilometers of which extend into the Dom Bosco quadrangle. The east end of the deposit is near Fazenda Papacobra; extensive workings cover the hill west southwest of the Fazenda (N. 7,460, E. 920). The mine is not operating and the workings are largely inaccessible.

The most complete description of the deposit is that by Scott (1900), who studied the mine during its greatest activity. Production at that time was more than 63,000 tons of ore per year, with a manganese content of about 55 percent. Later production figures are not avaliable, but Guild (1957, p. 81) states that substantial production was maintained until the 1920's, and operations continued until about 1940. Total production is estimated to have been about 1 million tons of ore. Guild (1957, p. 82) has summarized the geology of the mine area.

Scott (1900) describes the ore as a bedded deposit about 3 meters thick, in itabirite but on the contact with dolomite. The bed seems to thin eastward and probably lenses out south of Fazenda Papacobra. The bed was not found in the parallel band of itabirite to the north. The northern itabirite was thought by Scott to be the north limb of an anticline, but the presence of a similar appearing dolomite breccia on the south side of each itabirite belt suggests that the repetition is due to faulting. (See p. B–29.)

Manganese reserves are said to be large at the São Julião deposit (A. Guatamosim, oral communication), but a decrease in grade and a high water content of the material make it uneconomical to mine at this writing. The hard high-grade ore has been largely mined out.

The other manganese prospects associated with itabirite and dolomite of the Itabira group occur in various parts of the quadrangle. Manganese prospects are above and close to the iron-formation in the northern part of the Dom Bosco quadrangle (N. 12,760, E. 5,320; N. 12,650, E. 5,820). Lump manganese ore was recovered from shallow workings at each locality, and a few hundred kilograms of ore were stockpiled. It was not possible to determine whether the manganese was derived from the itabirite of the Cauê formation or from the overlying Gandarela formation.

Another group of prospects is along the southern edge of the itabirite lens east of Morro Mandachuva, and a considerable tonnage of ore was apparently mined from the east end of the lens. No figures are available, but large opencuts and adits on several levels are evidence of former activity. Dark-gray to black dolomite that crops out at N. 6,680, E. 8,460 contains 3.1 percent manganese oxide (table 2, sample 329) and may well be the protore of the deposits. Concretions of manganese oxides as well as lumps 6 to 10 centimeters in diameter are abundant in this area.

At least some of the manganese deposits near Fazenda Rodeio are derived from weathering of dolomite. Manganese oxides fill open spaces in schist and phyllite beneath terrace gravels near the quartzite contact south of Ribeirão da Colónia (N. 3,940, E. 3,180). Alteration products derived from dolomite are abundant in the area. Farther east, at N. 3,960, E. 4,480, manganese oxide nodules and rock with abundant manganese stain cover a small hill underlain by dolomite. Analysis of one of the dolomite beds, however, showed only 0.06 percent manganese oxide (table 2, sample 568).

Dolomite from the north margin of the large dolomite lens near Hargreaves is also manganese-bearing; an analysis (sample 631, table 2) showed 10.9 percent manganese oxide. Guild (1957, p. 60) reports a 30-centimeter vein of pyrolusite in dolomite north of Fazenda Rodeio.

Manganese deposits in rocks of the Piracicaba group are derived from dolomite as well as from clastic rocks. Some occurrences closely follow dolomite beds, as in the vicinity of N. 10,900, E. 3,940, but many others are far from any known dolomite. There are several prospects along the thrust fault in the central part of the Dom Bosco quadrangle, and others are along faults or joints. The deposits in clastic rocks are more numerous in the mapped area than deposits derived from dolomite, but are small and of no present economic significance. Individual deposits do not warrant detailed description.

DOLOMITE

The Dom Bosco quadrangle contains all the exposures of dolomite in the mapped area with the exception of two lenses that extend from the Dom Bosco quadrangle into the southeast corner of the Cachoeira do Campo quadrangle. The more readily accessible dolomite exposures have been opened by quarries. Few of the quarries are active at present, but their size shows that most have produced several thousand tons of dolomite each. Both dimension stone and lump dolomite for metallurgical use have been quarried.

The largest operation at present is in the north-central part of the Dom Bosco quadrangle at the quarries at Cumbe, which are owned and operated by the Cia. Mármora Aurora. In addition to the Cumbe quarries, the company owns the Cidreira quarry near Catete, 3.4 kilometers northwest of Cumbe, the quarry at Moreira in the southeast corner of the Cachoeira do Campo quadrangle, and the quarries at Pasto da Rosa, 3.2 kilometers east of Dom Bosco station.

Dimension stone is the principal product from the Cumbe quarries, and lump material is produced as a byproduct. The dolomite is quarried in blocks up to 1 meter in cross section and about 1.5 meters long. These blocks are either shipped without further processing or sawed into slabs and then shipped. About 30 gangsaws were in use; each saw consists of a series of parallel steel bands about 3 centimeters apart. Quartz sand is the cutting agent and the time needed to slab a block is about 30 days.

Lump dolomite is recovered from the quarries in the large dolomite mass south of Hargreaves. Sr. Serafim Gomes, of Dom Bosco. the only mine operator extracting dolomite in this area in 1956, obtained red dolomite from quarries in a dolomite mass north of Morro do Bule and from the dolomite mass southeast of Hargreaves. Sr. Gomes also mined white dolomite from other areas near Hargreaves. These operations are on a small intermittent scale with a daily production of 4 to 5 tons.

Another producing area is along the dolomite band near Ribeirão da Colónia, 3.2 kilometers southwest of Hargreaves. The largest quarries are west of the Dom Bosco quadrangle, but some work has been done along the entire band. Lump dolomite is quarried and trucked to São Julião for rail shipment to the steel plant at Volta Redonda.

Almost unlimited dolomite resources are available in the Dom Bosco quadrangle, although much of the dolomite is blanketed by weathering products. No attempt was made to calculate reserve figures, but the size and number of dolomite outcrops shown on plate 2 indicate that supplies are adequate for many years. The analyses given in table 2 show that the composition of the dolomites ranges from nearly pure dolomite to dolomitic limestone and that some varieties are high in silica.

TOPAZ

Yellow and orange topaz of the variety known as imperial topaz is found at a few localities in the Dom Bosco quadrangle. The topaz is most abundant along a narrow band extending east from Morro do Caxambú, in the north-central part of the quadrangle and closely following the belt of ferruginous quartzite shown on plate 2. Boa Nova (1929) describes a topaz-bearing area near Morro do Gabriel, 2.4 kilometers east southeast of Hargreaves, but little can currently be seen at this locality. Systematic mining for topaz is not carried on at present in the Dom Bosco quadrangle. Tiny crystals of no commerical value are common in residual soil adjacent to the ferruginous quartzite.

Gorceix (1881) and Derby (1901) studied the topaz deposits at a time when some mining was in progress. Topaz and euclase, a rare beryllium-aluminium silicate mineral, occur in siliceous nodules in clay. Only singly terminated crystals were found; this indicates that the crystals grew into drusy cavities. Derby described the topaz-bearing schist as containing abundant clay and believed the rock to be intrusive in origin, possibly syenite or nepheline syenite. Gorceix mentions an association between quartz and topaz that could indicate a pegmatitic origin for the topaz. Boa Nova (1929) thought the clay and the topaz near Morro do Gabriel were derived from pegmatites. Large quartz crystals up to 20 centimeters in cross section occur along the topaz-bearing zone, and quartz veins are abundant in the ferruginous quartzite and adjacent phyllite. The location of the topaz-bearing material in a narrow stratigraphic horizon is difficult to explain if the topaz occurs in pegmatites, but the pegmatites could have been localized in one bed, owing to a difference in competence of the rocks during folding and shearing.

The principal production of imperial topaz is from the adjacent Ouro Preto quadrangle, but a few crystals of gem quality are also found near Dom Bosco every year by searching the gullies after heavy rains. One man was seen washing and hand screening the weathered schist in a search for topaz.

CLAY

Clay has been mined from two pits in the Dom Bosco quadrangle. The largest pit is north of the railroad at N. 8,090, E. 6,260. This pit is 40 meters long and reaches a depth of from 5 to 6 meters. The clay is white but contains many iron-stained bands and is free from quartz grains. Itabirite underlies this deposit; so the clay must have been transported to its present position rather than being residual. The clay mineral was not identified but was assumed to belong to the kaolin group as kaolin is a common end product in lateritic weathering, which is so common in this region.

The second pit is at N. 5,220, E. 6,210 south of Morro do Gabriel. Here the clay is at least in part residual. White clay is common and seems to have formed by the leaching out of red clay. Laterite containing small spots of white clay caps the hill above the deposit.

Information was not obtained on the use of the clay from these pits, but it was probably used for tile and ceramics manufacturing in one of the plants in the larger towns along the railroad.

Impure clay with abundant detrital quartz grains is commonly present along many of the streams in the area, particularly those draining the area underlain by gneiss in the Cachoeira do Campo quadrangle. A bed of iron-stained clay from 40 to 60 centimeters in thickness and 40 meters in exposed length crops out in a road cut near the Córrego Cambraia in the northern part of the Cachoeira do Campo quadrangle, N. 10,700, E. 1,520. The clay was underlain by stream gravels.

PLACER GOLD

The remains of old workings for placer gold can be seen along the streams that flank the Serra do Ouro Branco in the Dom Bosco and Ouro Branco quadrangles and along the Riberão Tabuões in the Cachoeira do Campo quadrangle. The most extensive workings are south of the Serra do Ouro Branco. In several areas as large as 200 by 400 meters in extent, piles of quartzite cobbles and boulders are common where the soil has been stripped away, and the remains of old sluiceways can be found. The gold in these placers was probably in part concentrated from the conglomerates and quartzites of the Serra, and in part derived from the granodiorite intrusions.

The placers along the Ribeirão Tabuões are on old river terraces 10 to 20 meters above the river and are marked by boulder piles. The source of the gold is unknown. Some may have come from the quartzites of the Caraça group because the river cuts through the lower part of the Minas series, but the quartzites are thin in this area. Another possible source could have been gold-bearing veins in the vicinity of Ouro Preto, for the river drains a large area west of that town.

QUARTZ CRYSTAL

The only known area prospected for quartz crystal is 400 meters northeast of Hargreaves. A series of trenches cut one or more northeast-trending quartz veins that are characterized by abundant badly flawed crystals and fragments of clear quartz. The dumps of the trenches contain fragments of large crystals of milky quartz.

Quartz veins are common throughout the mapped area, and small crystals are abundant, but material suitable for piezoelectric use was not found and is not reported.

CINNABAR

Cinnabar occurs at two localities near Dom Bosco, and specimens from the area can be seen in mineral collections at Ouro Preto and Rio de Janeiro. The deposits were described and sampled by Guimarães and Coelho (1946a). No cinnabar was seen in a superficial examination of the localities during the present fieldwork. Most of the following information is summarized from the cited report.

Both cinnabar occurrences are in areas underlain by iron-formation belonging to the Itabira group. One locality is described as being near the railroad west of Dom Bosco at kilometer 512+800 meters, and the other is 400 meters southeast of Dom Bosco.

A few hundred kilograms of cinnabar is said to have been recovered from the locality near the railroad. The entire deposit must have been removed, as only traces of mercury were found in analyses of the samples collected by Guimarães and Coelho. A few kilograms of cinnabar was found during the course of prospecting in the area southeast of Dom Bosco, but the sampling by Guimarães and Coelho showed very little mercury in the area. The highest grade sample assayed 40 pounds of mercury per ton, but only one other sample contained as much as 2 pounds per ton, and most showed only traces. As the authors state in their conclusion, the occurrence is a specimen locality rather than a commercial deposit.

BASE METALS

The following information on the sulfide mineral occurrence at Morro do Bule is taken from the reports of Guimarães (1934) and Boa Nova (1929). The workings were filled with water, and nothing could be seen at the time of the present investigation except thin seams of sphalerite in joint cracks in the adjacent dolomite of the Gandarela formation.

The deposit is near the northern edge of a dolomite lens about 680 meters northwest of the summit of Morro do Bule and about 4 kilometers southeast of Hargreaves.

The sulfide minerals were in a lenticular vein in dolomite that was as much as 70 centimeters in thickness. An earthy, antimony-bearing capping was overlying the deposit. An inclined shaft sunk to a depth of 7 meters showed the vein to pinch out at that depth. A crosscut adit about 30 meters long was driven into the dolomite and crossed the vein projection near the shaft; the vein was not found in the crosscut. Subsequent prospecting along the southeast projection of the vein disclosed a thin stringer containing sphalerite but no ore (Guimarães and Coelho, 1946b).

The vein was composed of massive sulfide minerals and quartz. Stibnite was altered to bindheimite, valentinite, and stibiconite, but the sphalerite was unaltered. The bindheimite is thought to have formed before the deposition of sphalerite (Guimarães, 1934).

An altered zone as much as 20 centimeters wide was found between the vein material and fresh dolomite. Within the zone, the dolomite was recrystallized, and calcite and aragonite deposited. Some carbonate minerals were colored yellow by bindheimite inclusions, and limonite was abundant in the zone. Druses containing aragonite crystals as much as 10 centimeters in length were adjacent to the massive sulfide minerals.

Guimarães (1934) identified the following minerals in the vein and the altered zone and listed them from oldest to youngest: stibnite, tetrahedrite, quartz, dolomite, pyrite, aragonite, bindheimite, valentinite, stibiconite, jamesonite, sphalerite, and pyrite.

A few tons of ore taken from the shaft as well as 4 tons of the earthy material that capped the deposit are said to have been shipped. The deposit holds little promise for further production.

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U. S. GOVERNMENT PRINTING OFFICE : 1962 O - 639646