Geology and Ore Deposits of the Alegria District, Minas Gerais, Brazil

GEOLOGICAL SURVEY PROFESSIONAL PAPER 341-J

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

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By CHARLES H. MAXWELL

GEOLOGY AND MINERAL RESOURCES OF PARTS OF MINAS GERAIS, BRAZIL

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GEOLOGY AND ORE DEPOSITS OF THE ALEGRIA DISTRICT, MINAS GERAIS, BRAZIL

By Charles H. Maxwell

ABSTRACT

A thick sequence of metamorphosed Precambrian sedimentary iron-formations containing local concentrations of high-grade hematite occurs in the Quadrilátero Ferrífero (Iron Quadrilateral) of central Minas Gerais, Brazil, within an area of about 7,000 square kilometers. The iron-formations form parts of three sedimentary series, separated by angular unconformities. The oldest is the Rio das Velhas Series, divided into three groups, from oldest to youngest: Nova Lima Group, composed of schist, phyllite, graywacke, quartzite, and iron-formation; Maquiné Group, composed predominantly of quartzite and subgraywacke; Tamanduá Group, composed of the massive crossbedded Cambotas Quartzite and a younger sequence of phyllite and iron-formation. The middle series, the Minas Series, also comprises three groups: Caraça Group, composed of sericitic quartzite and graphitic schist; Itabira Group, which contains most of the economic iron-ore deposits in the region, composed of oxide-facies iron-formation and dolomite; Piracicaba Group, containing interbedded phyllite and quartzite, with subordinate iron-formation, dolomite, graywacke, and volcanic rocks. The youngest series, the Itacolomi Series, is composed of a basal sequence of lenticular and rapidly changing conglomerates, quartzites, phyllites, and ferruginous beds, overlain by thick massive crossbedded quartzite.

Some of the metasedimentary rocks are intruded by and (or) interlayered with a thick sequence of greenstones, now altered mostly to chlorite, talc, and serpentine. These rocks have been intruded by peridotites and mafic dikes, and metamorphosed, deformed, and faulted and so altered that their equivalent age or correlation with other rocks is open to question.

The metasedimentary rocks were deformed by at least three major orogenies and intruded by granite, granodiorite, and mafic and ultramafic rocks during all three. A fourth orogeny did not involve large-scale intrusions.

The metamorphic rocks are in general in the greenschist facies, biotite isograd. The grade of metamorphism increases toward the east to the amphibolite facies. Locally, higher grade may be due to contact thermal metamorphism, which has produced rocks containing garnet, staurolite, andalusite, tourmaline, kyanite, and amphiboles. The arenaceous rocks—quartzite and quartz-rich phyllites—have a cataclastic texture. The argillaceous rocks are mainly medium- to coarse-grained quartz-sericite-chlorite phyllite or schist. The carbonate rocks are dolomite, with quartz, chlorite, muscovite, talc, hematite, and magnetite. The ferruginous sediments have been metamorphosed to itabirite and allied types.

An extensive peneplain was formed over the region in Mesozoic or early Cenozoic time. Uplift and erosion virtually destroyed the old peneplain, to produce the present topographic features. The major streams and some tributaries are antecedent; most tributaries are subsequent and consequent. Remnants of several old levels of erosion and terraces show that uplift has been intermittent.

Deep weathering has altered most of the surface rocks to a considerable depth, producing saprolite and laterite and locally canga (limonite-cemented detritus). In some areas, alumina-, iron-, and manganese-rich concentrations were formed. Alluvial deposits occur along most streams and on a few perched terraces. Most of them have been worked for gold.

Economic or potentially economic mineral deposits in the Alegria district are iron ores, manganese ores, and bauxite.

The iron ores are of three major types: (1) Itabirite, in many places weathered, hydrated, and softened to a depth of 20 meters or more; easily concentrated to ore grade, (2) hematite ores composed of hard and compact to soft pulverulent nearly pure iron oxide, and (3) canga, surficial deposits of iron-ore fragments cemented by limonite. With minor exceptions all the iron ore is associated with the Itabira Group of the Minas Series.

The itabirite formation ranges in thickness from 10 meters to more than 1,200 meters. The average grade is estimated to be about 45 percent iron in the unweathered rock and 50–60 percent iron in the weathered zone. The minerals are hematite, specularite, and quartz, with subordinate magnetite, hydrous oxides of iron, dolomite, and amphiboles.

High-grade (66–70 percent iron) hematite masses range from a few tons to many millions of tons and occur as replacement deposits in the itabirite. The hematite deposits range from a hard dense generally fine grained massive hematite to coarse- or fine-grained pulverulent specularite.

Canga deposits were formed by the mechanical concentration of chapinha (little plates) from the itabirite and from rubble ores from the hematite, cemented into a coherent rock by limonite. Canga was also formed by the leaching of gangue minerals from the rock and replacement and cementation by limonite.

Reserves and potential reserves of iron ore in the Alegria district are tremendous. Reserves of itabirite are inferred to be more than 100 billion tons; of enriched itabirite and canga, more than 30 billion tons; and of hematite, more than 70 million tons. Proved and indicated reserves of hematite containing more than 66 percent iron are about 50 million tons. Thus far, only a few thousand tons has been produced.

Manganese deposits are widespread and occur in many different types of rock. The large economic deposits are restricted to layers within the iron-formation. The principal deposits are concentrations of pyrolusite with minor manganite, in favorable zones in the Itabira Group. Areas explored sufficiently to give a third dimension have shown the layers to be concordant. The layers range in thickness from about 1 meter to more than 6 meters and are composed both of syngenetic and secondary manganese oxides. Total production from the one operating mine in the district has been about 25,000 tons.

Proved reserves of manganese are more than 1 million tons, indicated reserves are about 3 million tons, and inferred reserves are more than 20 million tons; average grade is about 40 percent manganese. More deposits are likely to be discovered in other areas as exploration continues.

Many deposits of bauxite have been found, and more are likely to be discovered. Most deposits are near-surface concentrations in laterite overlying dolomitic rocks and covered by canga or ferruginous laterite. Only two areas have been explored; bauxite from one is being used as flux for the steel mills. Total production has been only a few thousand tons having an average grade of more than 40 percent available alumina. Proved reserves at the Frazendão deposit are 100,000 tons; inferred reserves are about 500,000 tons. Total inferred reserves for the district are 1 million tons, but the potential may be several times this figure.

A small amount of placer gold is still being extracted along major streams, although most deposits have apparently been exhausted. Reserves of gold-bearing rock are large, but the grade is variable and ore bodies are intermittent and discontinuous. The gold is found in the iron-formation and in the pre-Minas quartzites and phyllites, generally in small stringers and veins of quartz and sulfides. The grade ranges from a few grams to about 16 grams per ton.

Other mineral commodities that have been produced include quartz crystal, amethyst, dolomite, talc, soapstone, asbestos, and ocher.

INTRODUCTION

The principal iron deposits of Brazil occur within an area of about 7,000 sq km (square kilometers) in south-central Minas Gerais, near the southern end of the Serra do Espinhaço (Backbone Range), in the central highlands of Brazil. The Serra do Espinhaço is a complex system of individual mountain ranges more than 1,000 km (kilometers) long which divides the drainage of the Rio Doce and other rivers flowing eastward directly to the Atlantic Ocean from the Rio São Francisco drainage, which flows northward for some 1,200 km before breaching the Serra do Espinhaço and turning eastward to the ocean. The Quadrilátero Ferrífero (Iron quadrilateral) lies near the headwaters of the Rio São Francisco and the Rio Doce, at altitudes ranging from 600 to 2,100 meters (1,900–6,300 ft). The area described in this report comprises three quadrangles, the Capanema, Santa Rita Durão, and Catas Altas, at the eastern edge of the Quadrilátero Ferrífero (fig. 1). The name "Alegria district" will be used to designate the area enclosed by the three quadrangles.

Several published works (Harder and Chamberlin, 1915; Harder, 1914a, b; and others) have described the "Alegria iron deposits" near Fazenda Alegria (fig. 1) as one of the world's major deposits of iron ore. They contain more than 50 billion tons of iron ore with a tenor of more than 40 percent all above topographic base level.

LOCATION AND ACCESSIBILITY

The Capanema, Santa Rita Durão, and Catas Altas quadrangles lie in the eastern part of the Quadrilátero Ferrífero, about 350 km north of Rio de Janeiro (fig. 1). The Capanema quadrangle (pl. 1), the most westerly, is approximately 40 km southeast of Belo Horizonte, the capital of Minas Gerais; the Santa Rita Durão quadrangle (pl. 2) joins the Capanema quadrangle on the east; and the Catas Altas quadrangle (pl. 3) joins the Santa Rita Durão quadrangle on the north. All three meet at lat 20°7′30″ S., long 43°30′ W. They occupy an area of approximately 540 sq km (210 sq mi).

The three quadrangles were accessible in 1961 only by dry-season one-lane roads and by several mule trails. The western part of the Capanema quadrangle may be reached from the all-weather Itabirito-Ouro Preto Highway by a narrow dry-weather road that runs northeast from a point 6 km southeast of Itabirito. This road forks near the western edge of the Capanema quadrangle; one branch ends at Fazenda Capanema, the other at Fazenda Ajuda, in the southwest corner of the quadrangle. Cia. Siderúrgica Belgo-Mineira, which owns most of the land in the vicinity of Fazenda Alegria, has built an access road from near Fazenda Ajuda across the Serra Geral to the manganese and iron mines at Conta História and to Fazenda Alegria. This road connects with other roads to the villages of Santa Rita Durão and Catas Altas.

The southeast corner of the Capanema quadrangle and most of the Santa Rita Durão and Catas Altas quadrangles are accessible by truck trails extending from a dry-season road between Mariana and Santa Bárbara. A new all-weather highway has been constructed from Santa Bárbara to Ponte Nova. The high mountains in the southwestern part of the Catas Altas quadrangle are accessible by a dry-season road from Barão de Cocais to the Colégio do Caraça. With the rapid expansion and development of the district and the consequent improvement of access and transporta-

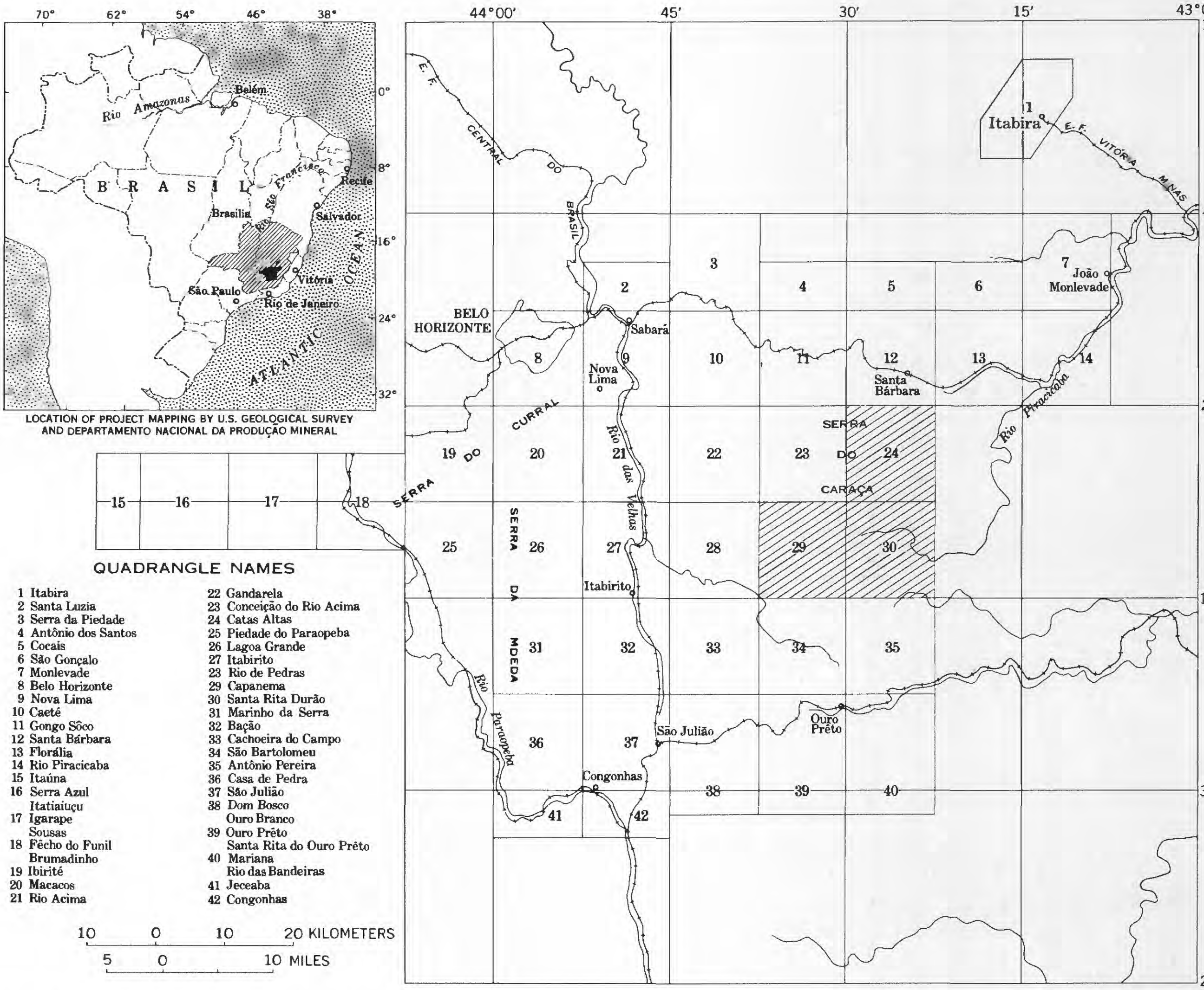

Figure 1.—The Quadrilátero Ferrífero showing 7½-minute quadrangles and the Alegria district (crosshatched quadrangles 24, 29, and 30), and inset map showing Minas Gerais (crosshatched area) and location of the Quadrillátero Ferrífero (black area).

tion, the area will undoubtedly be accessible by a network of all-weather roads within a few years.

A new railroad has been built across the area since fieldwork was completed, crossing the southeast corner of the Capanema quadrangle, through the Santa Rita Durão quadrangle along Córregos do Germano and dos Marcos to Rio Piracicaba, past Morro da Mina and Fazendão, then northeastward across the Catas Altas quadrangle.

CULTURE

The villages within the district are: Santa Rita Durão, population of about 270; Bento Rodrigues, population about 120; Água Quente, population about 100; and Catas Altas, population about 450. There are three large fazendas or ranches, in the area: Capanema, Ajuda, and Alegria, which is near the center of the common boundary between the Capanema and Santa Rita Durão quadrangles.

The gold deposits at Catas Altas (which means "high diggings") were discovered in 1702, and the villages and fazendas were founded shortly thereafter. Fazenda Alegria was established in 1730, probably first as a gold-mining center but later as an iron producer. There are several ruins of Catalan forges in the vicinity, and many small gold workings. The gold mines at Pitangui (fig. 37; p. J57) were at their peak in 1790–1800 but most were soon abandoned. The entire area became economically dormant and remained so for more than 100 years, until the present cycle of exploration and development.

Other than mining, the principal occupation in the area at the present time is the manufacture of charcoal for the steel mills; virtually the entire population is directly or indirectly supported by that occupation.

Most of the Santa Rita Durão quadrangle is covered by a forest of second-growth trees, which is cut for charcoal every 15–20 years, or when the trees are large enough. Many eucalyptus plantations are now being established by the steel companies. Eucalyptus trees grow to 20–25 cm (centimeters) in diameter in about 8 years. After that they are cut for charcoal, and the stumps allowed to send up new trees. These in turn are cut again in about 6 years, and then again in another 5 years. Thus, three crops of charcoal are obtained in 20 years, several times as much as is harvested from natural growth of native trees.

One hectare (2.47 acres) of virgin forest produces about 100 cu m (cubic meters) of charcoal. One hectare of eucalyptus forest produces about 125 cu m of charcoal; second-growth natural forest produces only about 60 cu m. Reduction of 1 ton of iron ore requires 3–4 cu m of charcoal (Struach, 1956). In 1960, the steel industry in Brazil used about 2½ million cu m of charcoal, or about 25,000 hectares of forest, part natural and part from eucalyptus plantations. There is approximately 150 sq km (15,000 hectares) of forest and eucalyptus plantation in the Alegria district. In 1960, about 180,000 cu m of charcoal was produced.

With improved transportation, farming and ranching are becoming more important. Catas Altas is well known locally for its vineyards and wineries, which produce several types of excellent wine and brandy. The Colégio do Caraça (fig. 2), in the center of the Serra do Caraça, is a boarding school and seminary. Established in 1744, it cites among its distinctions as having provided the primary and secondary education of seven of the heads of state of Brazil. Its setting is spectacular, a beautiful gothic cathedral surrounded by large stone buildings and courtyards, set in the middle of an isolated and almost inaccessible range of mountains (fig. 2). The fathers produce most of their own food and several varieties of excellent wine and brandy.

Figure 2.—Colégio do Caraça, view looking east. In the background is the Serra do Caraça. The relatively level top is considered to be an early Tertiary peneplain. The rounded peak to the left is Pico do Sol, altitude 2,072 meters; the Colégio is at an altitude of 1,280 meters. The forest-covered areas are mostly underlain by mafic intrusives, the rest of the area by quartzite.

CLIMATE

The Quadrilátero Ferrífero has a subtropical to temperate climate. Temperatures range from about 0°C (32°F) on the coldest nights to about 35°C (95°F) on the hottest days. The average daytime temperature is about 18°C (65°F) during the winter months and 22°C (72°F) during the summer months. Temperature range from day to night is greater than from summer to winter.

A marked cycle of wet and dry seasons corresponds in general to the solar seasons. The rainy season begins in early October (spring), with intermittent rains and thunder showers that continue until mid-December, when the heavy rains begin. Heavy and almost constant rains continue until February or March, then slack off to occasional light showers. The very dry season begins in May or June and lasts through September.

Rainfall averages about 150 cm (60 in.) per year. There are, however, noticeable local variations. Average annual rainfall for several localities in the Quadrilátero Ferrífero is as follows:

Locality	*Average rainfall (cm)*
Belo Horizonte [1]	166
Nova Lima [2]	160
Cachoeira do Campo [3]	155
Itabira [4]	158
Monlevade [5]	180
Alegria [5]	320
Ouro Preto [3]	210

[1] Instituto Brasileiro de Geographia e Estatistica, 1959.
[2] Pomerene, 1964.
[3] Johnson, 1962.
[4] Dorr and Barbosa, 1963.
[5] James Büchi, oral commun., 1960.

VEGETATION

The Serra do Espinhaço and Serra Geral form the approximate boundary between two major zones of vegetation types, the grassland (Zona do Campo) to the west and the forest (Zona do Mato) to the east. The actual boundary is much more complex. The river valleys along the boundary and even for considerable distances to the west have a more humid climate and more fog and dew; therefore, forest has grown along the river margins. Grasslands are common along the tops of high ridges extending eastward into the Zona do Mato.

The two major vegetation zones probably arise from differences in climate between the west and east sides of the divide. The divide acts as a partial barrier to moisture-laden air coming from the southeast and east. During parts of the spring and fall, the western side is in a rain shadow. During the rest of the year, except for part of the driest months, the dew, ground fog, low clouds, and light showers are much heavier east of the divide than west. The high precipitation rates for Ouro Preto and Alegria are indications of this difference.

The Zona do Campo is, in general, savannah. "Campo Cerrado" is a region of grasslands thickly to sparsely covered by small tortuous trees more or less widely spaced and with low brush (1–2 meters high). These grasslands provide good forage country for cattle. This type of vegetation is typical of the southwest corner of the Capanema quadrangle. The higher parts of the Campo do Rocha around Fazenda Capanema also have this type of vegetation.

At altitudes above 900–1,000 meters, a different type of vegetation appears, mostly grass and low brush, but with thick groups of trees along the watercourses; it is called "Campo Limpo" ("clean grasslands"). In areas above 1,800 meters the vegetation is reminiscent of alpine vegetation. Many dwarf plants grow very close to the ground, rarely more than 30 cm (1 ft) high, and sphagnum blanket bogs form in moist low areas. All the higher areas of the Alegria district have this type of vegetation.

The Zona do Mato is designated by type of vegetation as tropical forest or selva or even tropical rain forest locally; it is characterized by large trees, mostly deciduous, with many epiphytes, aerophytes, and vines and almost no surface vegetation—grass and bushes.

This type of forest once covered most of the Santa Rita Durão quadrangle and the eastern and northern part of the Catas Altas quadrangle. Descriptions of this area, written soon after the first colonization in the early 18th century, indicate that most, if not all of it, was dense forest. A few patches of virgin forest are preserved in inaccessible places on the south side of the Serra do Caraça, but timbering and charcoal manufacture have seriously depleted much of the forest cover over most of the area. The inhabitants customarily burn the brush and grasslands annually, with the result that second growth forest has not spread over much of the area.

The low rolling hills of the granitic terrane east of the Serra do Caraça are now a mottled patchwork of grasslands, thick low brush, forest, and occasional patches of cultivated land.

TOPOGRAPHY

The Alegria district lies on the east side of the Serra Geral at the headwaters of the Rio Piracicaba drainage. Only the southwest corner of the Capanema quadrangle, south and west of the Serra Geral (fig. 3), drains into the Rio das Velhas, a major tributary of the Rio São Francisco. The northern part of the quadrangle drains generally northward into Rio da Conceição, a tributary of the Rio Santa Bárbara, which is, in turn, a major tributary of the Rio Piracicaba. The remainder of the Capanema quadrangle and all but the northern border of the Santa Rita Durão quadrangle are drained by the headwaters of the Rio Piracicaba and the Rio Gualaxo, major tributaries of the Rio Doce. All streams of the Catas Altas quadrangle drain northward into the Rio da Conceição and the Rio Santa Bárbara and eastward into the Rio Piracicaba.

The Capanema, Santa Rita Durão, and Catas Altas quadrangles are centered around the highest mountain range of the Quadrilátero Ferrífero, the Serra do Caraça. The maximum relief in the Alegria district is 1,422 meters (4,262 ft)—from 651 meters (2,112 ft) altitude near the southeast corner of the Santa Rita Durão quadrangle to 2,072 meters (6,734 ft) at Pico do Sol in the Serra do Caraça, in the southwestern part of the Catas Altas quadrangle. In the north-central part of the Santa Rita Durão quadrangle, the relief is more than 1,200 meters within a horizontal distance of 1,000 meters.

The Alegria district is sharply divided into several types of terrain controlled largely by the lithology of the underlying rocks. The eastern part of the district is underlain by granitic rocks and consists of low rolling hills with an average relief of only about 60 meters. Hill and ridgetops are generally flat and have a thick lateritic soil cover. The river valleys are relatively broad and flat with large incised meanders, and serpentine meanders inside the large ones.

Rising abruptly out of this lowland is a spectacular mass of quartzite, the Serra do Caraça. The relief along the scarp ranges from 800 to 1,200 meters. The mountain is flattened on top and to the west descends abruptly about 500 meters to the Caraça basin. This basin is a fairly level bowl-shaped hanging valley in the center of the quartzite mountains (fig. 2). The ridges and peaks to the west of the basin rise more gradually to a summit level of about 1,800 meters altitude. Between these peaks and ridges and the Serra Geral, to the west, is a deeply incised basin, the Campo do Rocha, at about the same level as the Caraça basin. The Campo do Rocha area is underlain by quartzite, phyllite, and schist. West of the Serra Geral the land surface again descends abruptly, then gradually, on quartzite and phyllite to about 1,100 meters, where it changes abruptly into rolling hills and sharply dissected valleys, cut into schist and phyllite.

North and south of the Serra do Caraça, and still west of the granitic terrain, are areas of moderate to steep topography in bedded rocks: schist, phyllite, quartzite, and itabirite. A narrow band of hogbacks, which would be a conspicuous part of the topography but for the overshadowing bulk of the Serra do Caraça, follows closely around the eastern base of the Serra. The hogbacks consist of itabirite and quartzite, and are separated from the Serra do Caraça by a belt of greenstone. On the south side of the Serra do Caraça and along the east side of the Serra Geral are steeply rounded but locally deeply dissected hills of itabirite (figs. 28, 30).

GEOMORPHOLOGY

The erosional history of the area is complex; several stages of rejuvenation are recorded by ancient erosion surfaces. The age proposed by various authors for the primary peneplanation ranges from Precambrian through Paleozoic and Mesozoic to Cenozoic. Figure 3 shows the approximate extent of the recognizable erosion surfaces in the Alegria district. The oldest recognizable surface in the Quadrilátero Ferrífero is preserved only on the top of the Serra do Caraça. It may also be present along the crest of the Serra do Cipo to the north of the Quadrilátero Ferrífero. This old surface is at about 1,900 meters altitude and may represent a Mesozoic peneplanation, or monadnocks on a lower surface. This surface is not shown in figure 3 but is found between the easternmost areas of surface I.

Erosion surface I is evident at an altitude of 1,800 meters. Many of the ridges of the Serra do Caraça at about this altitude are flat topped and covered with thick pockets of soil, thick gravel beds, and many dislocated blocks of rock. The Serra do Batatal is a good example of this surface (fig. 5).

The most prominent of the old erosion surfaces occurs between altitudes of 1,350 and 1,550 meters. (fig. 3, II). This surface is undulating and slopes away from the Serra do Caraça in all directions. It is well formed over most of the higher mountains in the Quadrilátero Ferrífero. The present basic drainage pattern was probably imposed on this surface, without later significant changes. Many of the rivers follow deeply incised meanders, which in places are completely independent of the structure and lithology of the underlying rocks.

This old surface is well preserved in the Caraça basin, at Campo do Rocha, Alto do Conta História (fig. 39), and on "shoulders" along the southwest flank of the Serra Geral (fig. 3). The tops of some of the flat-topped ridges in the Campo do Rocha area are covered by thick layers of rounded and subrounded gravel and coarse sand interlayered with clay; some ridges have been excavated and washed for gold. Also in the Campo do Rocha area, stream meanders are incised to depths of 200–300 meters, with no apparent structural or lithological control. At Capanema (Capanema quad., N. 300, E. 350) a ridgetop is covered with coarse angular rubble of quartzite, similar to talus. Coarse angular gravels occur on the tops of many of the ridges in the Caraça basin. The Alto do Conta História (fig. 39) is capped by a thick relatively level layer of canga which is at approximately the same level as the gravel beds. Canga is a Brazilian term for a breccia or conglomerate composed largely of fragments of hematite or iron-formation cemented by limonite or hematite. See discussion on page J28.

At several localities along the river valleys, terraces have formed at an altitude of about 1,000–1,100 meters (fig. 3, III). South of Fazenda Alegria a dissected plateau slopes gradually from 1,100 meters near the mountains to 1,000 meters near Santa Rita Durão. There is no good evidence of old soil or gravel deposits at this level, but it seems likely that this represents an interruption in the erosion cycle.

East and north of Santa Rita Durão is an extensive canga-capped mesa at about 900 meters (fig. 3, IV). This mesa is the remnant of an extensive Tertiary basin of deposition. The caprock varies from canga and canga rica (more than 66 percent Fe) near the mountains, where it overlies the iron-formation, to canga on the western part of the mesa, to limonite-cemented conglomerate near the eastern boundary of the quadrangle, to indurated laterite near Fonseca (fig. 13). The rocks underlying all but the westernmost part of the mesa are poorly indurated coarse- to fine-grained silty sandstone, siltstone, and mudstone, with some thin beds of lignite and sublignite. These rocks have been named the Fonseca Formation. (See p. J27.) They represent an extensive period of Pliocene-age deposition in an area otherwise marked by a long history of erosion. Several terraces at the same level in the Santa Rita Durão and Catas Altas quadrangles are probably related to this interruption in the cycle of erosion. The lower level south of Santa Rita Durão is a dissected mesa with thinner canga and conglomerate, but probably represents a remnant of the same Tertiary rocks.

Many terraces are at about 750 meters altitude along the streams in the southeast corner of the Santa Rita Durão quadrangle. The terrace gravels have been worked for gold. Near Catas Altas this old level is extensive and well formed (fig. 3, V) and is perched from 20 to 40 meters above the present stream profiles.

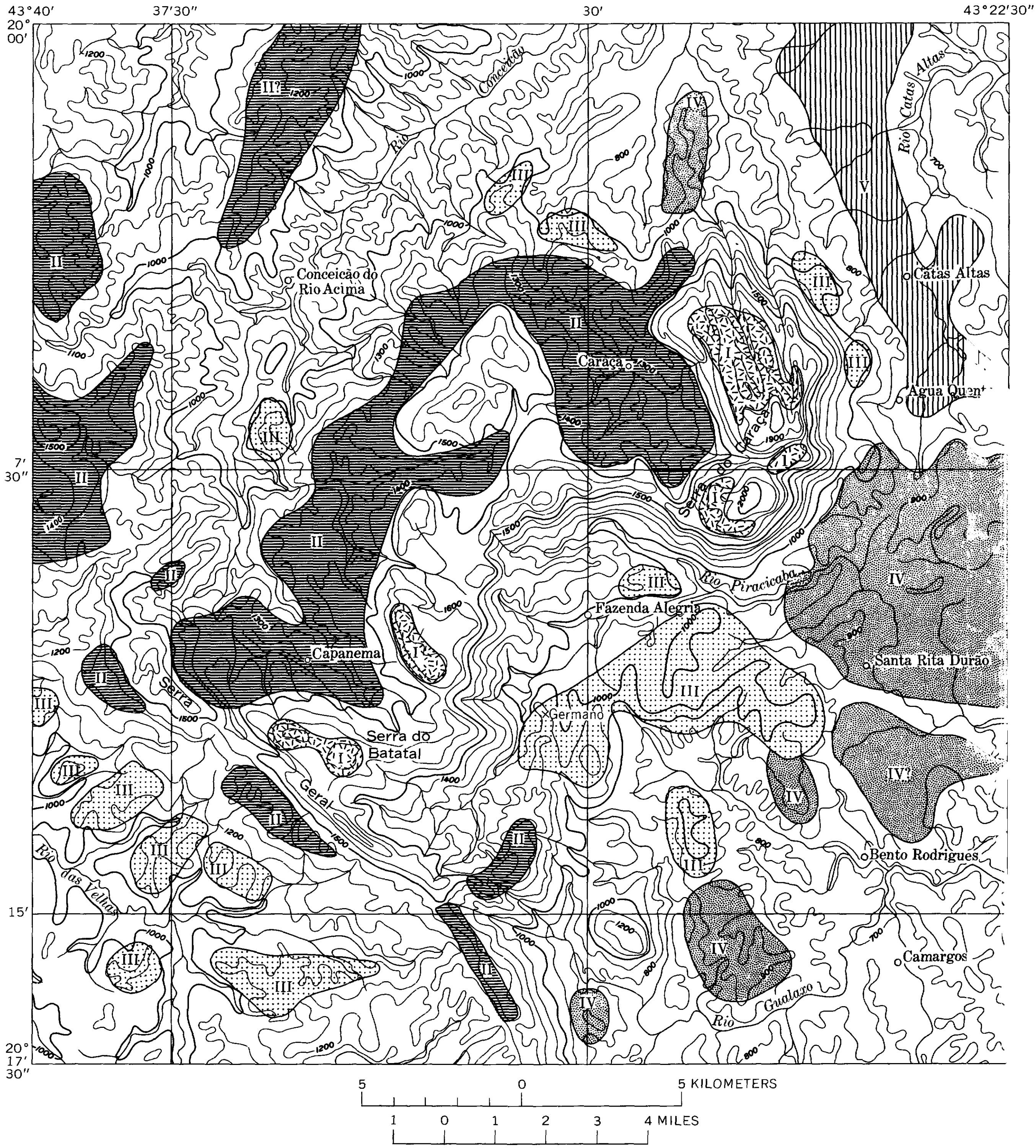

FIGURE 3.—Geomorphological map of the Alegria district and environs. Roman numerals indicate approximate extent of recognizable erosion surfaces in the Alegria district.

PREVIOUS GEOLOGIC INVESTIGATIONS

The geology of the iron region of Minas Gerais has been studied for many years. One of the first reports was by von Eschwege (1833). Some geologic descriptions were included in the many geographic reports published in the next 50 years. In the 1880's, O. A. Derby began publishing a series of modern geologic reports. At about the same time, Henri Gorceix also published a paper on the geology of Minas Gerais. In 1900 and 1902, H. K. Scott reported on the iron and manganese of Minas Gerais. In 1911, and for several years afterward, a group of geologists, including E. C. Harder, R. T. Chamberlin, and C. K. Leith, actively investigated the mineral deposits and regional geology of Minas Gerais, and especially of the Quadrilátero Ferrífero (Harder, 1914a, b; Harder and Chamberlin, 1915; Leith and Harder, 1911). Since the 1920's, many Brazilian geologists have published maps and reports on the Quadrilátero Ferrífero, among them: Andrade (1926), Guimarães (1931, 1935, 1951, 1958), Moraes Rego (1933), Lacourt (1936, 1938a, b), Oliveira and Leonardos (1943), Barbosa (1949, 1954), and Oliveira (1956).

The most comprehensive reports on the general geology and mineral resources of the Quadrilátero Ferrífero were by Harder and Chamberlin (1915) and von Freyberg (1927, 1932, 1934). A more modern review was prepared for the 12th Annual Congress of the Sociedade Brasileira de Geologia by members of the joint U.S. Geological Survey-Departamento Nacional da Produção Mineral team in 1958 (Departamento Nacional da Produção Mineral, 1960).

Published references on the geology of the Alegria district are few, generally brief, and mostly restricted to mineral deposits or to specific properties. Information specifically on the Alegria district appears in reports by Harder and Chamberlin (1915), Lacourt (1938a, b, structure and stratigraphy in the southern part of the district), Moraes Rego (1933, general geology and iron ore), Oliveira (1945, hematite and gold deposits), Büchi (1961, an excellent report on the geology and ore deposits of part of the district). Several private reports have contributed useful information to the project, including reports from the files of the Brazilian Iron and Steel Co., the J. C. Hammond Co., and Cia Siderúrgica Belgo-Mineira.

This paper is one of a series covering the geology of the Quadrilátero Ferrífero. The published studies (Guild, 1957; Gair, 1962; Johnson, 1962; Dorr and Barbosa, 1963; Pomerene, 1964; Wallace, 1965, Simmons, 1968; Moore, 1969) and the unpublished maps and manuscripts have provided a background for the present investigation.

PRESENT INVESTIGATIONS

Fieldwork in the Alegria district began in September 1956 and continued through August 1960. Three 7½-minute quadrangles were mapped on aerial photographs in the field and compiled at a scale of 1:20,000 for publication at 1:25,000. The data were transferred to topographic base maps compiled from the same photographs by the multiplex method. The photographs and topographic base maps were prepared by Servicos Aerofogrametricos Cruzeiro do Sul S. A. The location of the three quadrangles making up the Alegria district is shown in figure 1. Geologic maps of the quadrangles are plates 1–3; cross sections and fence diagrams are plates 4–6.

A coordinate grid system of 1,000-meter interval is used in all quadrangles for locating specific localities that are not named on the maps. The zero point is at the southwest corner of each quadrangle; small tick marks at 1,000-meter intervals extend east along the north and south boundaries and north along the east and west boundaries.

This work is part of a program of topographic and geologic mapping that was undertaken through a cooperative agreement between the United States of Brazil and the United States of America. The program was implemented by the Brazilian Ministério da Agricultura, succeeded by the Ministério de Energia e Minas, and the U.S. Department of State, through the Agency for International Development and predecessor organizations. The work has been carried out by the Brazilian Departamento Nacional de Produção Mineral (DNPM), Divisão do Fomento da Produção Mineral (DFPM), and the U.S. Geological Survey, Department of the Interior.

ACKNOWLEDGMENTS

Acknowledgment must be made first to Dr. Avelino Ignacio de Oliveira, director of the Departamento Nacional da Produção Mineral during the time fieldwork was in progress, for his complete support and great assistance to this program. Dr. José Alves, then director of the Belo Horizonte offices of the Departamento Nacional da Produção Mineral was equally helpful. The thin and polished sections and many of the chemical analyses used in this report were made in the Departamento Nacional da Produção Mineral laboratories in Belo Horizonte and Rio de Janeiro. The writer's field assistant, José Roberto da Silva, assigned by the Departamento Nacional da Produção Mineral in Belo Horizonte, is due many thanks for his unfailing cooperation and assistance in the field.

Special appreciation is due Prof. Francisco José Pinto de Sousa and Dr. James Büchi of the Cia. Siderúrgica Belgo-Mineira for their hospitality, professional stimulation, and inestimable assistance. They, along with others on the staff of Cia. Siderúrgica Belgo-Mineira arranged for the author to use much of the company's data on the Alegria district, and arranged for living accommodations and pack animals at Fazenda Alegria and other properties of the company. Much of the survey data, base maps (pl. 7), and chemical analyses presented in this report came from their files.

Other data in this report, made available by C. K. Leith, came from the files of the Brazilian Iron and Steel Co., mostly as unpublished reports by E. C. Harder, R. T. Chamberlin, Hugh Roberts, and others. and a report by Arthur Houle and William Jones for the J. C. Hammond Co.

A report of this type involves the help of many people who have assisted in fieldwork, contributed to interpretations of the geology, and have given freely of their time and knowledge; the writer wishes to acknowledge many such contributions from many colleagues, among them: A. L. de M. Barbosa, John Van N. Dorr 2d, Norman Herz, S. L. Moore, Joel B. Pomerene, Garn A. Rynearson, George C. Simmons, and Amos M. White.

REGIONAL SETTING

STRATIGRAPHY

The metasedimentary rocks of the Quadrilátero Ferrífero have been divided into three series, each separated from the other by a major unconformity. Many subdivisions and correlations of these rocks have been made; representative divisions are listed in figure 4, where they are correlated with the divisions used in this report.

The oldest metasedimentary rocks in the Quadrilátero Ferrífero have been named the Rio das Velhas Series (Dorr and others, 1957, p. 15–22). The series has been divided into three groups: the Nova Lima, the Maquiné, and the Tamanduá.

The Nova Lima Group is composed of metasedimentary and metavolcanic schists and phyllites with locally interlayered iron-formation, conglomerate, schistose quartzite, and carbonate rock (Gair, 1962; Dorr and others, 1957, p. 15). It is unconformably overlain by the Maquiné Group. The Maquiné Group is divided into two formations: the Palmital Formation (O'Rourke, written commun., 1958), composed of quartz-sericite schist or phyllite with some interbedded sericitic quartzite, and the Casa Forte Formation (Gair, 1962), made up of conglomerate, massive quartzite, and sericitic and chloritic quartzite with some interbedded schist and phyllite.

The Tamanduá Group (Simmons and Maxwell, 1961) unconformably overlies both the Nova Lima Group and the Maquiné Group. It is composed principally of coarse arkose, conglomerate, and quartzite, with minor amounts of phyllite, schist, and dolomitic iron-formation.

A major orogeny and an extensive erosion period followed deposition of the Rio das Velhas Series. This produced an angular unconformity between it and the overlying Minas Series in many areas (Rynearson and others, 1954).

The Minas Series is divided into three groups: Caraça, Itabira, and Piracicaba. The Caraça Group (Dorr and others, 1957, p. 24) is composed of conglomerate, grit, quartzite, phyllitic quartzite, phyllite, and argillite. It includes some of the rocks that Harder and Chamberlin (1915) called Caraçã Quartzite and also their Batatal Schist, now called the Batatal Formation (Maxwell, 1958, p. 60). The coarser clastic rocks are now called the Moeda Formation (Wallace, 1958, p. 59).

The Itabira Group (Dorr and others, 1957) consists of iron-formation and dolomitic and calcareous marble and is divided into the Cauê Itabirite and the Gandarela Formation.

The Piracicaba Group (Departamento Nacional Produção Mineral, 1960) is composed of a thick series of quartzites, ferruginous quartzites, phyllites, graphitic phyllites, marble, and iron-formation. It has been divided into five formations: Cercadinho, Fêcho do Funil, Taboões, Barreiro, and Sabará.

Unconformably overlying the Minas Series is the Itacolomi Series, composed of quartzites, conglomerates, grits, and phyllites. In this report the Itacolomi Series is divided into the Santo Antônio Formation, below, and undivided Itacolomi quartzites, dolomites, and conglomerates, above.

The bedrock of the Quadrilátero Ferrífero is entirely Precambrian. The only younger materials are surficial deposits and Tertiary fresh-water sediments, which occur in two small areas; the Gandarela basin (Oliveira, 1956) and the Fonseca basin, most of which is east of the Quadrilátero Ferrífero. (See p. J27.)

Granitic rocks of two types occur in the Quadrilátero Ferrífero: (1) Granodiorite intrusive into the Nova Lima Group and (2) rocks ranging from granite through quartz monzonite, generally gneissic in texture, which are intrusive into the Minas Series. In many places they have altered or replaced parts of the metasedimentary rocks that were amenable to granitization.

Mafic and ultramafic dikes and stocks have intruded all the metamorphic rocks in the Quadrilátero Ferrífero except those of the Itacolomi Series. These intrusives probably ranged from dunite through gabbro and diabase; they have been altered to serpentine, talc, soapstone, and chlorite.

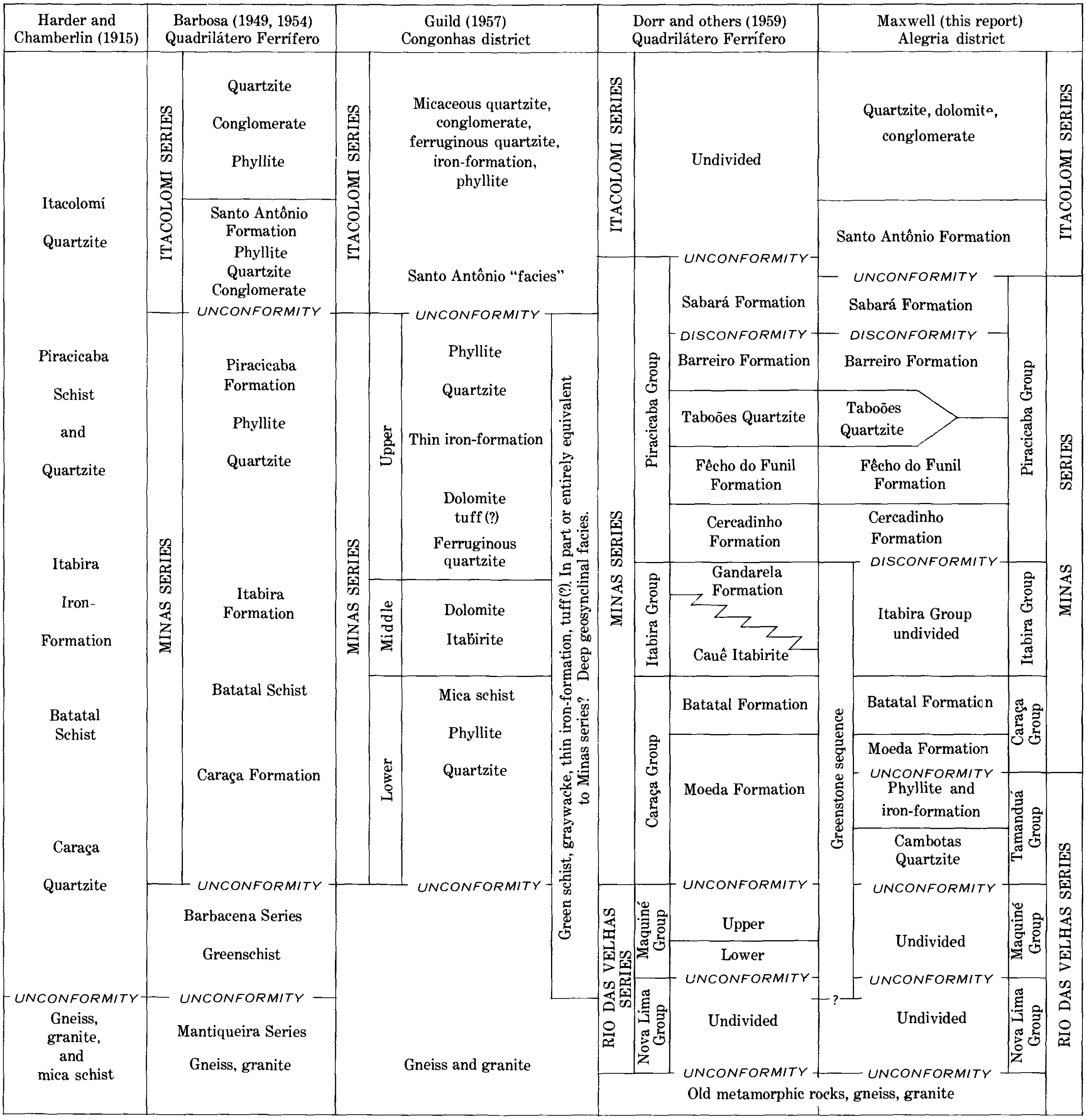

FIGURE 4.—Summary of stratigraphic nomenclature and divisions proposed for the Precambrian metasedimentary rocks of the Quadrilátero Ferrífero.

Quartz, quartz-kyanite, and pegmatite veins are common throughout the Quadrilátero Ferrífero.

The metamorphic rocks of the Quadrilátero Ferrífero belong, in general, to the greenschist facies. Locally, contact thermal metamorphism and hydrothermal alteration have produced rocks containing garnet, staurolite, andalusite, tourmaline, kyanite, and amphiboles. The grade of metamorphism increases toward the east, to the amphibolite facies, but this may also result partly from contact thermal metamorphism.

STRUCTURE

The rocks of the Quadrilátero Ferrífero are severely deformed, in a pattern of increasing deformation and metamorphic grade from west to east. The deformation has resulted in a complex system of crossing folds and faults, generally isoclinal and overturned toward the north and west. Some of the folds pass into reverse or thrust faults. The present outcrop pattern of the Minas Series shows sinuous synclines arranged in a roughly polygonal pattern, deeply eroded so that only the troughs are left, and with parts of the limbs obscured either by thrusting or by granite intrusion. The Alegria district is on the central-eastern edge of the polygon. Severe deformation, lack of exposures in critical areas, and lack of marker beds in some stratigraphic units have made deciphering of the structure difficult and subject to uncertainty.

PRECAMBRIAN METAMORPHIC ROCKS

RIO DAS VELHAS SERIES

NOVA LIMA GROUP

The Nova Lima Group in the Alegria District consists predominantly of metasedimentary and metavolcanic phyllite and schist, with minor amounts of graywacke, quartzite, dolomite, and iron-formation.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

Rocks of the Nova Lima Group crop out in the northwest corner of the Catas Altas quadrangle and in the west-central part and northwest and southwest corners of the Capanema quadrangle. Some rocks of Nova Lima lithology crop out in the southeastern part of the Santa Rita Durão quadrangle and as small lenses in injection gneiss and within quartzites tentatively correlated with the Maquiné Group. Because of their small areal extent they were mapped with the gneiss and the Maquiné Group.

The northwestern part of the Catas Altas quadrangle is part of a large area of structurally controlled northeast-trending valleys and ridges underlain by the Nova Lima Group. The group also forms part of the foothills of the Serra do Caraça. The ridges are for the most part covered with a thick growth of brush and trees and thick soil, there are few outcrops. In the alluvium-filled valley bottoms, areas of auriferous gravels were mined during colonial time.

At the Campo do Rocha, in the west-central part of the Capanema quadrangle, the Nova Lima Group underlies a small plain, which is fairly level but deeply dissected by the Córrego (brook) Grande and some tributaries. Its meanders and general course indicate that the Córrego Grande was little influenced by the lithology or structure of the Nova Lima Group. Instead, it appears to have followed meanders which were established when it was near base level. In the southwest corner of the Capanema quadrangle, the Nova Lima forms the lower part of the long slope from the Serra Geral to the Rio das Velhas. This slope is deeply incised by obsequent streams normal to the structural trend.

THICKNESS

The true thickness of the Nova Lima Group cannot be measured in the Alegria district, or for that matter, anywhere in the Quadrilátero Ferrífero, because the base of the group has not been definitely identified. In the southwest part of the Capanema quadrangle, a thickness of at least 2,500 meters is indicated; however, here, and in other areas, isoclinal folding and faulting may duplicate many beds.

CONTACT RELATIONSHIPS

The nature of the contact between the "true basement rocks" and the Nova Lima Group is unknown. In the Alegria district, the Nova Lima Group is in contact with the overlying Maquiné and Tamanduá Groups and with the Moeda Formation of the Minas Series.

In the southwestern corner of the Capenema quadrangle, the contact of the Nova Lima Group with the Maquiné Group is apparently concordant.

North of Campo do Rocha (Campanema quad. N. 11,000, E. 3,000), there is an angular discordance between the attitudes of the Nova Lima Group and the Maquiné Group to the east. The quartzose phyllites of the Nova Lima here strike east-northeast and northeast and dip 50° SE.; the Maquiné quartzites strike north-northwest and dip about 40° E. The contact between the Nova Lima and Maquiné Groups here may be either a fault or an angular unconformity. The rocks are sheared and complexly folded; their schistosity and fracture cleavage have obliterated the bedding in much of the area (fig. 21). A fault (not mapped) is present along part of the contact, but relative movement cannot be determined. Bedding-plane slippage (faulting) is very common and especially noticeable where adjacent beds differ in composition or texture.

In the west-central part of the Catas Altas quadrangle, the angular unconformity between the Nova Lima Group and the Maquiné is evinced by the difference in basic structure, although the contact is not well exposed (pl. 3). The quartzites of the Maquiné strike generally northwest and the phyllites and iron-formations of the Nova Lima strike generally northeast. About 1 km west of the Catas Altas quadrangle in the Conceição do Rio Acima quadrangle, the contact is exposed in a roadcut on the road to the Colégio do Caraça.

The Nova Lima is intruded by a diabasic dike-stock system along the southern and eastern limits of outcrop in the Catas Altas quadrangle (pl. 3). Thick brush and soil and lack of outcrops prevent determining the exact relationship of these intrusive contacts.

LITHOLOGY

The rocks of the Nova Lima Group almost everywhere form a surficial layer of light-yellow-buff to brick-red lateritic soil that blankets a deeply weathered saprolite. Outcrops are commonly found in roadcuts or gulleys and consist of soft, friable, tan, pink, red, or purple saprolite phyllites. Graphitic phyllite, quartzites, and iron-formation crop out in the northwestern corner of the Catas Altas quadrangle and in the Campo do Rocha area (Capanema quad.). As few fresh rocks are exposed, the original composition is not known with certainty. However, quartz-sericite schist, quartz-chlorite schist, and chlorite phyllite apparently predominate in the Alegria district. Nova Lima rocks in other localities have been identified as metavolcanics (Gair, 1962, p. 4–9), but lack of fresh outcrops prevents this identification in the Alegria district. At least some of the chlorite phyllite was probably of volcanic origin.

IRON-FORMATION

In the northwestern part of the Catas Altas quadrangle, the Nova Lima Group includes a series of thin lenticular beds of iron-formation, irregularly distributed along an iron-rich zone about 20 meters wide. The iron-formations range from a well-banded rock similar to itabirite to a rock with an indistinct banding of crystallized chert, limonite, and phyllitic material. The dominant type of rock in the lenses of iron-formation consists of layers of a mixture of iron oxides and limonite, or limonite alone, interbanded with thicker layers of quartz. The itabirite consists of layers of friable magnetite or hematite, and some fine quartz grains, alternating with thicker layers of fine-grained friable quartz. Many lenses change within a few meters along strike to alternating limonite with magnetite and fine-grained powdery quartz, or to limonite alternately quartz rich and magnetite rich. The layers range from 1 mm to 1 cm in thickness. The lenses of iron-formation range from about 10 cm to 10 meters in thickness, and make up about 20 or 30 percent of the iron-rich zone; the remainder is phyllite and quartzite.

All the outcrops of iron-formation and associated rocks are deeply weathered, and the lithologies described above reflect this. Some, if not all of the iron-formation was probably in the carbonate facies, as it is in the western part of the Quadrilátero Ferrífero (Gair, 1962).

The iron-formation of the Nova Lima Group has no commercial value in the Catas Altas quadrangle, although it contains a few small deposits of hematite. The main interest in this rock is its distinctive lithology, which permits the tracing of structural features that would otherwise be obscured by the regional foliation and schistosity.

MAQUINÉ GROUP

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

Rocks of the Maquiné Group crop out in the southwest, central, and north-central parts of the Capanema quadrangle (pl. 1), and in the west-central part of the Catas Altas quadrangle (pl. 3).

A large area of quartzites and phyllites in the southeastern part of the Santa Rita Durão quadrangle (pl. 2) was correlated with the Maquiné on the basis of lithologic similarity and structural position in a deformed syncline below the unconformity at the base of the Minas Series.

In the southwest part of the Capanema quadrangle, the Maquiné forms most of the crest of the Serra Geral and the upper more prominent part of the long slope from the Serra Geral down to the Rio das Velhas. The rocks here are deeply incised by obsequent streams, and only minor tributaries are consequent to the structure. The more resistant beds in the Maquiné form prominent ridges and hogbacks, many with vertical or overhanging cliffs, and the softer rocks form gentle grassy slopes (figs. 5, 6).

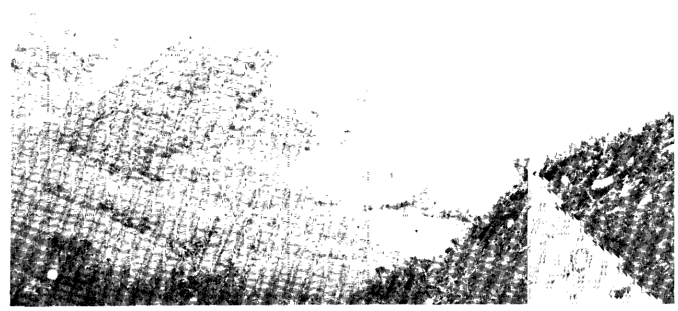

FIGURE 5.—Rocks of the Maquiné Group along the Serra Geral, Capanema quadrangle, looking southeast. The rounded hill at center left is Serra do Batatal.

THICKNESS

Complex faulting and shearing parallel to bedding and fold axes (pl. 1) preclude exact determination of the stratigraphic thickness of the Maquiné Group in the Capanema quadrangle. The exposed apparent thickness is 2,800 meters; the true stratigraphic thickness may be in the order of 1,400 meters.

FIGURE 6.—Outcrop of slabby-weathering quartzite of the Maquiné Group.

CONTACT RELATIONSHIPS

The contact of the Maquiné Group with the overlying Cambotas Quartzite of the Tamanduá Group is well exposed in the Capanema quadrangle (N. 13,600, E. 8,300), where the clean grits and orthoquartzites of the Cambotas Quartzite show a marked lithologic change from the subgraywackes and density-current conglomerates of the Maquiné. The attitudes of the bedding here are also slightly discordant.

About 9 km to the south in the southeast part of the Campo do Rocha area (Capanema quad., N. 5,400, E. 6,600), the contact between the Maquiné Group and Cambotas Quartzite is an angular unconformity of about 60°. The Maquiné strikes N. 10° E. and dips 50° E.; the Cambotas Quartzite strikes N. 80° W. and dips 40° S.

In the Catas Altas quadrangle the contact is completely obscured by soil and forest cover. Its position was determined by a combination of topographic expression and lithology. West of the quadrangle, on and near the road to the Colégio do Caraça, in several outcrops, the Cambotas and Maquiné are separated by a conglomerate that may have been either a regolith or a fault breccia. Most of the angular fragments are composed of subgraywacke, and the matrix is a mixture of quartz, mica, and chlorite (Moore, 1969).

In the Santa Rita Durão quadrangle the contact of the Maquiné Group with the gneiss was arbitrarily placed, within a wide transition zone, where weathering characteristics of the rock changed from the deep saprolite typical of the gneiss to surface outcrops of gneissic quartzite.

LITHOLOGY

The Maquiné in the western part of the Capanema quadrangle consists of a massively layered sequence of conglomerate, quartzite, schistose quartzite, schist, phyllite, and cataclasites composed of quartz, sericite, chlorite, and chloritoid. Sericite generally makes up less than 15 percent of the rock; chloritoid may be as high as 20 percent but is generally only 2 or 3 percent. Chlorite makes up only a small fraction of the rock.

The Maquiné weathers to white and buff sandy soil; weathered outcrops are dark gray, rounded, and tabular. On fresh surfaces the rock is gray, streaked gray, and gray brown, or a dense shiny brown.

The base of the Maquiné Group consists of thinly layered fine-grained quartz-sericite schist and quartzite interlayered with sericite-quartz schist. This unit is about 50 meters thick near the western boundary of the Capanema quadrangle and gradually pinches out to the southeast. It is in part the lateral equivalent of the Palmital Formation of O'Rourke (Dorr and others, 1957) but was not mapped separately in this report, both because of its limited extent and difficulty in delineating the contact within a wide gradational zone. The unit grades upward into coarse sericitic quartzite and conglomerate and locally into a cataclasite. This upper unit corresponds to the Casa Forte Formation (Gair, 1962, p. 31).

The conglomerate occurs as scattered lenses within sericitic quartzite. The pebbles are all stretched, and have axial ratios of 10 to 1 or greater. The rock in some areas is a cataclasite of small augen of shattered quartz in a matrix of quartz-sericite phyllite (fig. 7). These areas probably represent shear zones or fault zones. In the less sheared zones the conglomerate is composed of stretched pebbles and cobbles of quartzite and vein quartz in a matrix of well-sorted quartz, sericite, and chlorite. The pebbles and cobbles range from 10 to

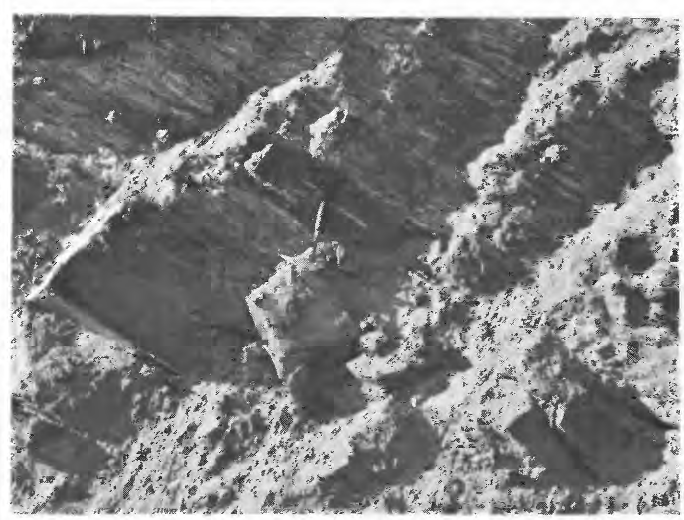

FIGURE 7.—Conglomerate of the Maquiné Group shattered to a cataclasite. The light streaks in the rock above the hammer are flattened and smeared pebbles of quartz in a quartz-sericite-chlorite matrix.

80 mm in diameter; the sand matrix, from 0.1 to 1.0 mm. Intermediate particle sizes seem to be lacking.

The quartzites are generally coarse grained but poorly sorted, and are composed of quartz, chlorite, and sericite. Grain diameters range generally from 0.5 to 2.0 mm; interstitial grains range from 0.1 to 0.5 mm in diameter (fig. 8).

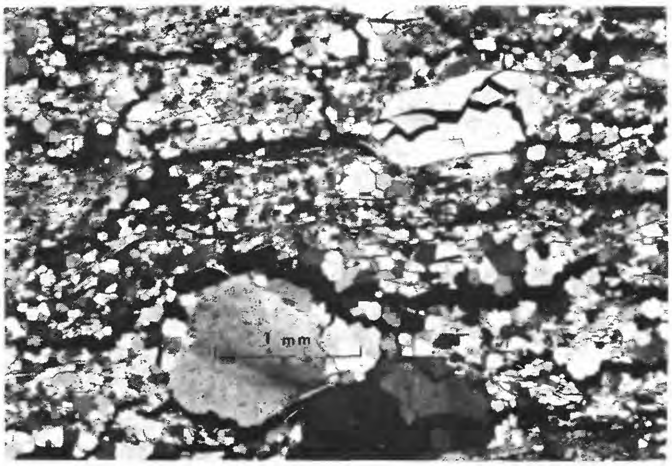

FIGURE 8.—Photomicrograph of quartzite of the Maquiné Group. Relict grains of quartz have strong undulatory extinction in a groundmass of crushed and recrystallized quartz, with thin layers and scattered grains of muscovite, sericite, and chlorite. Crossed nicols. (Capanema quad., N. 1,950, E. 3,150.

The coarse quartzite and conglomerate zone grades upward into a rock of generally similar lithology that contains chloritoid ranging from a few scattered grains to as much as 20 percent of the rock. The rocks of this unit crop out mostly in the northeastern third or half of the band of Maquiné in the southwest part of the Capanema quadrangle. The rocks of this zone are quartz-sericite-chloritoid phyllite with minor chlorite. They show strong cataclastic and augen structure. The quartz is almost all recrystallized in bands about 2 mm thick, separated by bands of sericite about 0.1 mm thick, and is generally xenoblastic, although a few grains are idioblastic. The few remaining original grains are shattered and show a strong undulatory extinction.

The chloritoid occurs in ragged plates and small clusters showing sieve structure with inclusions of quartz and sericite (fig. 9).

The quartz ranges from 0.1 to 0.8 mm in diameter, the chloritoid from 0.6 to 20 mm in length and from 0.2 to 3 mm in width.

Rocks of the Maquiné Group in the central and eastern parts of the Capanema quadrangle have a lithology slightly different from those west of the Serra Geral; they are correlated on the basis of general stratigraphic position and gross similarity. The contact between the Nova Lima and the Maquiné is obscured by forest and soil cover in this part of the area. It was placed at a topographic break above predominantly schistose rocks and below quartzitic rocks. The lowest rocks of the Maquiné Group that crop out in this area are subgraywackes composed of fine-grained quartz, chlorite, and sericite with small amounts of feldspar; these are overlain by schistose chlorite-sericite quartzite, and in the northern part of the Capanema quadrangle by a thick sequence of massive quartzite that becomes more chloritic and schistose to the south. The upper half of the exposed Maquiné in the Capanema quadrangle is composed of chlorite quartzite, subgraywacke, and biotite quartzite and sporadic conglomeratic zones. These zones differ markedly from the conglomerates in the Maquiné west of the Serra Geral; most are composed of very well rounded cobbles and boulders sparsely scattered through a fine- to coarse-grained matrix.

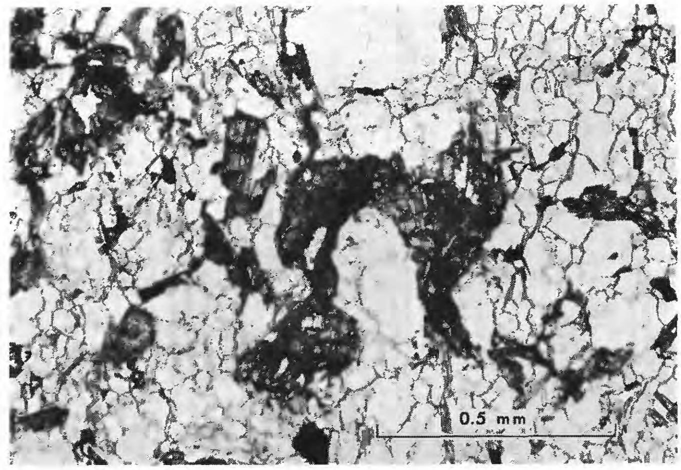

FIGURE 9.—Photomicrograph of chloritoid-rich quartzite of the Maquiné Group. The dark ragged grains are chloritoid with small inclusions of quartz and sericite. Plane light. (Capanema quad., N. 1,700, E. 4,000.)

In one outcrop of conglomerate (Capanema quad., N. 13,450, E. 6,600), well-rounded pebbles and cobbles 50–60 mm in diameter are sparsely scattered through a chlorite- and sericite-rich medium- to coarse-grained quartzite. The pebbles are fairly evenly distributed ½–1 meter apart in the quartzite. A similar quartzite, in about the same stratigraphic position, crops out (Capanema quad., N. 6,500, E. 8,300) just below the contact with the Cambotas Quartzite. The pebbles are somewhat larger and sparser but not as well rounded (fig. 10).

In other outcrops, large isolated cobbles or boulders several meters apart are set in a fine- to medium-grained biotite-chlorite quartzite. The groundmass commonly shows a mortar texture, particularly in outcrops near the contact with the overlying Cambotas Quartzite.

Many quartzite beds have conspicuous crossbedding at angles of about 20°; others show a complex series of convoluted planes that were interpreted to be submarine slump structures. The conglomerates were probably produced by turbidity or density currents.

FIGURE 10.—Turbidity-current conglomerate of the Maquiné group. The trace of the bedding is nearly horizontal and dips away from the observer. The foliation angles from the upper right toward the lower left and also dips away. Above and to the right of the pencil are several clear quartz crystals growing in a small fracture.

Outcrops of the Maquiné Group in the southeastern part of the Santa Rita Durão quadrangle are similar in lithology but have more interlayered schist than in other areas. Some of the quartzite and much of the schist have been altered to gneissic rock or migmatite in large areas within the unit and in a wide transition zone along the contact with gneiss.

TAMANDUÁ GROUP

Unconformably overlying the Maquiné Group is a thick section of quartzite and minor lenses of phyllite and iron-formation that was named the Tamanduá Group of the Rio das Velhas Series by Simmons and Maxwell (1961). These rocks were included in the Minas Series by some previous workers and in the Itacolomi Series by others.

Harder and Chamberlin (1915, p. 351) included the quartzite in their "Caraça Quartzite" and also included the Maquiné Group and what is now called the Moeda Formation of the Minas series in the unit. Moraes Rego (1933, p. 13) included the same rocks and, in addition, part of the Nova Lima Group in his Caraça Group. Rynearson, Pomerene, and Dorr (1954) described an angular unconformity between the Rio das Velhas Series and the Minas Series. Oliveira (1956) restricted the Minas Series to rocks above the unconformity. In 1957, Dorr, Gair, Pomerene, and Rynearson (1957, p. 24), in a revision of the stratigraphy of the Quadrilátero Ferrífero, differentiated the Maquiné Group from the overlying quartzites and phyllites. The younger rocks were designated the Caraça Group of the Minas Series, which included the overlying Batatal Schist of Harder and Chamberlin (1915, p. 356). The basal Minas quartzite was later named the Moeda Formation (Wallace, 1958, p. 59).

Later work indicated that the massive quartzites of the Serra Tamanduá and Serra do Caraça, the type area of the Caraça Quartzite, occupied a stratigraphic position between the Rio das Velhas Series and the Minas Series (Simmons and Maxwell, 1961). The group was included in the Rio das Velhas Series, although future work may indicate it should be raised to series rank or should be included with the Minas Series.

The Tamanduá Group is composed of quartzites, phyllites, quartzose and phyllitic schists, and phyllitic and dolomitic iron-formation. The group was divided into the Cambotas Quartzite and three unnamed overlying formations (Simmons and Maxwell, 1961). The three upper formations were later consolidated into a single unnamed formation (Simmons, 1968, p. H9).

CAMBOTAS QUARTZITE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Cambotas Quartzite crops out in the southwestern part of the Catas Altas quadrangle, the northern part of the Santa Rita Durão quadrangle, and the eastern part of the Capanema quadrangle, to form most of the spectacular Serra do Caraça, part of the Serra Geral, and the connecting ridges (pls. 1–3).

This quartzite unit is the most resistant formation in the Quadrilátero Ferrífero. It forms the highest peaks and ridges in the area. The Serra do Caraça has a maximum altitude of 2,072 meters and rises 1,200 meters above the granitic terrane to the east (fig. 11).

THICKNESS

The thickness of the Cambotas Quartzite is variable and nowhere is known for certain. The top of the unit had in most places been truncated by erosion before the overlying Minas Series was deposited; the only locality in the Alegria district where younger pre-Minas rocks overlie the Cambotas Quartzite (Catas Altas quad., N. 7,500, E. 5,000) is in a zone of complex faulting, so complex that measurement of the thickness is impossible. There are no definitive marker beds in the quartzite. A composite section of Cambotas Quartzite in the northeastern corner of the Capanema quadrangle gives a thickness of approximately 790 meters, divisible into four units. The basal unit, about 40 meters thick, consists of conglomerate and very coarse grained quartzite, and is overlain by about 70 meters of fine-grained sericitic quartzite. The thickest unit is composed of about 580 meters of crossbedded coarse- to fine-grained quartzite and sericitic quartize. The top unit is a very coarse grained quartzite about 100 meters thick.

CONTACT RELATIONSHIPS

The contact of the Cambotas Quartzite with the Maquiné Group has been previously discussed. The

FIGURE 11.—Panoramic view of the Serra do Caraça, looking west and northwest. The low hill on the extreme left is Morro da Mina; on the extreme right is Morro São Luiz. Relief from the center peaks to the valley below is 1,200 meters. The foreground is a canga-covered plain. The valleys between the hogback peaks and the serra are cut into greenstone or into the Caraça Group. The hogbacks are iron-formation.

Cambotas may be in unconformable contact with the underlying Nova Lima Group in the Catas Altas quadrangle, near Córrego do Tanque Prêto, but the nature of the contact is uncertain. Indications of an extensive thrust fault around the northern end of the Serra do Caraça suggest that the contact may be a fault.

The Cambotas Quartzite is in fault contact with the younger rocks of the Tamanduá Group at the type locality (Simmons and Maxwell, 1961). The only locality in the Alegria district where the younger units are present is also in a strongly sheared and faulted zone and the nature of the contact could not be determined. Where the younger formations are not present, the Cambotas Quartzite is unconformably overlain by the Minas Series.

In most individual outcrops immediately adjacent to the contact, the apparent layering of the Cambotas and the overlying rocks are virtually parallel. This layering gives an impression of concordance; however, the Cambotas Quartzite a few meters away from the contact may show widely discordant attitudes. The apparent concordance may be due in part to reworking of Cambotas sediments during deposition of the Minas Series, and in part to deformation and shearing along the contact.

Lithology

The Cambotas Quartzite has a relatively simple and consistent lithology in the Alegria district: pebble conglomerates, grit, coarse- to fine-grained quartzite, some of which is crossbedded, and minor quartzose sericite phyllite. Most specimens show considerable shearing. Thin sections show a range from a strong mortar texture in the least deformed specimens to a mylonite in the most deformed; cataclasites and protomylonites are predominant. The rock is composed of quartz, and only minor amounts of sericite-muscovite, chlorite, clinozoisite and kyanite. The kyanite is present only in zones of intense deformation.

In spite of the cataclastic nature of most of the formation, primary structural features such as stratification, crossbedding, and ripple marks are preserved in many localities (Simmons and Maxwell, 1961, p. 17).

A sequence of rocks overlying the Cambotas Quartzite and underlying the Minas Series occurs along the south and east sides of the Serra do Caraça. These rocks were mapped as Tamanduá Group undivided, corresponding in general to the unnamed younger formations in the Serra do Tamanduá and to parts of the Cambotas Quartzite. At the type locality (Simmons and Maxwell, 1961), the younger rocks comprise three units (in ascending order): phyllitic and quartzitic schist 211 meters thick, phyllitic and dolomitic itabirite 41 meters thick, and phyllitic schist 34 meters thick. In the Alegria district, these rocks consist predominantly of quartz-chlorite schist and minor amounts of limonitic quartz-chlorite schist and quartzose phyllite in the few exposures where they could be seen. Most of the area underlain by these rocks is covered by thick soil and forest or by canga. These younger rocks are absent in much of the Alegria district and the Cambotas Quartzite is overlain by Minas Series rocks.

CORRELATION

Three tenable correlations for the Tamanduá Group are: An upper group of the Rio das Velhas Series, a separate Tamanduá Series, or a lower group of the Minas Series. These rocks were designated by Simmons and Maxwell (1961) as the Tamanduá Group of the Rio das Velhas Series; this report follows that designation. Others consider the group to be a part of the Minas Series (Dorr, 1969), or of the Itacolomi Series (Hirson, 1967).

The discordance measurable in individual outcrop areas is apparently greater between the older groups of the Rio das Velhas series and the Cambotas Quartzite than it is between the Cambotas and the Minas Series. The regional outcrop pattern, however, shows that the greatest and most abrupt variations are in older formations below the Minas Series. The Minas Series throughout the Quadrilátero Ferrífero is a widespread sequence of rocks relatively consistent in both thickness and lithology; the Moeda and Batatal Formations and the Itabira Group have only minor lithologic variations wherever they occur. The rocks underlying the Minas Series vary greatly from one locality to another, and include metavolcanics, schist, phyllite, iron-formation, graywacke, quartzite, gneiss, and migmatite. In relatively short distances, the Minas Series overlies successively the Nova Lima Group, the Maquiné Group, and the Tamanduá Group.

Wherever it occurs in the Quadrilátero Ferrífero, the Tamanduá Group is present on only one side of synclines in Minas Series rocks, never on the opposite side.

Outcrops are distinctive in appearance, lithology, and distribution; they are widely separated and occur in the Serras das Cambotas and do Tamanduá in the northeastern part of the Quadrilátero Ferrífero, in the Serra do Caraça in the east-central part, and in the Serra do Ouro Branco in the south-central part. They are composed almost entirely of the Cambotas Quartzite, the nonresistant upper unnamed formation is only locally present. In all three areas the Cambotas Quartzite forms large spectacular mountains, composed of medium- and coarse-grained remarkably clean quartzite with some grit and conglomerate; all areas have fairly large zones of cataclasite; all have torrential and festoon crossbedding and very long foreset beds at shallow angles; all have complex plastic folding and complex systems of joints and fractures; all are intruded by prominent diabasic dikes; and all have conglomerates containing angular to rounded fragments of iron-formation, quartzite, and vein quartz. Some of these characteristics are displayed by the basal Minas rocks but are anomalous local features. Many faults, shear zones, diabasic dikes, and folds terminate at the contact with the overlying Minas Series, and most outcrops show a much higher degree of deformation in the Cambotas Quartzite than in the overlying Moeda quartzite.

The Moeda quartzite thins and changes toward a sericite schist in proximity to the Cambotas Quartzite, or wedges out completely; the argillites of the Batatal Formation become thinner and more silty or quartzose near the Cambotas.

Several theories of origin and environments of deposition of the Tamanduá Group are compatible with available field data. The writer believes that the rocks are erosional remnants of a once-widespread sequence of quartzite, schist, phyllite, and iron-formation, now partially preserved in synclines that predate deposition of the Minas Series. According to two other theories, the group originated as (1) an elongate wedge or series of wedges of coarse clastic sediments that were deposited at the edge of tectonically uplifted and faulted granitic rocks and later subsided and were reworked or eroded, after which the Minas Series was deposited, (2) littoral or offshore bars in association with deltaic material built up to the requisite thickness before deposition of the Minas Series in the same basin (Dorr, 1969, p. A33). The very clean nature of the thick quartzite sequence restricts many other possibilities.

Whatever origin is ascribed to the Tamanduá Group, it must have been subjected to deformation and erosion prior to the deposition of the Minas Series. The thinning of the Moeda Formation and the more clastic nature of the Batatal Formation near the outcrops of Cambotas Quartzite indicate that the Cambotas occupied an erosional high during deposition of the Minas Series.

For the reasons outlined in the foregoing paragraphs, Simmons and Maxwell (1961) considered the Tamanduá Group to be significantly older than the Minas Series and placed it in the Rio das Velhas Series. The writer has followed that designation here but tends to favor the hypothesis of a separate series separated from both the Rio das Velhas Series and the Minas Series by unconformities that represent periods of deformation and erosion. Future detailed mapping in the region north of the Quadrilátero Ferrífero, where these rocks are prominent but little known, may clarify the stratigraphic relationships of the units.

MINAS SERIES

Derby (1906, p. 396) described the Minas Series as including all the metamorphic rocks above the "gneiss and schist basement." Harder and Chamberlin (1915, p. 345) established the basis for the present usage when they divided the Minas Series into five units: Caraça Quartzite, Batatal Schist, Itabira iron-formation, Piracicaba Schist and Quartzite, and Itacolomi Quartzite. Guimarães (1931, p. 8) defined the Itacolomi, and on the basis of an unconformity gave it series rank. Moraes Rego (1933, p. 12) divided the Minas Series into three groups, Caraça, Itabira, and Ribeirão do Carmo. Lacourt (1936) used the terms lower, middle, and upper groups but included pre-Minas rocks in his lower group. Oliveira (1956) restricted the Minas Series to rocks above a regional unconformity described by Rynearson, Pomerene, and Dorr in 1954. Later workers used the designation lower, middle, and upper groups, but with restricted boundaries for the series (Dorr, Horen, and Coelho, 1956, p. 286; Guild, 1957, p. 8). Dorr and colleagues (1957, p. 13) reestablished the group names Caraça and Itabira, and renamed the upper group the Piracicaba Group, after the Piracicaba Schist of Harder and Chamberlin (1915).

CARAÇA GROUP

The basal Minas quartzite was first named the Caraça Quartzite by Harder and Chamberlin (1915, p. 357). This was later elevated to group status by Moraes Rego (1933, p. 13); however, the bulk of both these units comprised rocks older than the Minas Series. Guild (1957, p. 8) called the basal clastic sequence (now the Moeda and Batatal Formations) of the Minas Series the lower group. Dorr, Gair, Pomerene, and Rynearson (1957, p. 24), unaware of Moraes Rego's previous usage, reestablished the name Caraça Group to include the Batatal Schist (Harder and Chamberlin, 1915, p. 356) as well as the basal Minas quartzite. Because of some doubt as to the age of the main body of the quartzite in the Serra do Caraça, Dorr and colleagues described the Caraça Group as it appears in the Serra do Moeda. The basal Minas quartzite was named the Moeda Formation (Wallace, 1958, p. 59), with the type section in the Serra do Moeda in the western part of the Quadrilátero Ferrífero, but was correlated with the "Caraça Quartzite" of Harder and Chamberlin, which was later found to be an older unit unconformably overlain by the Moeda Formation. The Batatal Schist was redescribed and named the Batatal Formation (Maxwell, 1958, p. 60).

MOEDA FORMATION

Distribution and Topographic Expression

The Moeda Formation in the western part of the Alegria district is extremely variable in lithology and thickness, and its exact contacts are difficult to locate. It is present, however, along both sides of the Serra do Ouro Fino syncline on the western border of the Capanema quadrangle, and in an intermittent layer in the valleys between the Serra do Caraça and the ridges of Minas iron-formations, beginning at Serra do Batatal in the Capanema quadrangle and continuing through the northern part of the Santa Rita Durão quadrangle and into the Catas Altas quadrangle.

The Moeda Formation forms prominent outcrops and cliffs around most of the Ouro Fino syncline and a conspicuous hogback along the eastern edge of the Serra do Caraça, in the Catas Altas quadrangle. In the rest of the district, however, the formation is thin and inconspicuous, and crops out only in a few localities.

Thickness and Contact Relationships

The Moeda Formation ranges in maximum thickness from about 300 meters in the eastern part of the Alegria district to about 200 meters in the western part. In most of the central part of the district the thickness ranges from 0 to 20 meters.

Lithologic similarities between the Cambotas Quartzite and the Moeda Formation and the relative homogeneity of both mask any discordance and, locally, even make it difficult to find the contact between the two. However, when one or the other is traced out, an angular discordance becomes evident. The upper member of the Tamanduá Group, stratigraphically between the Cambotas and the Moeda, is absent in some areas and has an apparent thickness of several hundred meters in other areas. The Moeda Formation is not underlain everywhere by Cambotas Quartzite. For instance, along the eastern edge of the Serra do Caraça a syncline of Minas Series rocks is bordered on one side by a tremendous thickness of Cambotas Quartzite, whereas none is present on the opposite side of the syncline.

The Moeda Formation thins radically and becomes more sericitic and generally somewhat finer grained where it directly overlies the Cambotas Quartzite or the upper Tamanduá rocks. The Moeda is thicker and coarser where it is underlain by pre-Tamanduá rocks.

The upper contact with the Batatal Formation is gradational. In many places a fine-grained quartzite or quartzose phyllite at the top of the Moeda Formation contains a layer 5–10 cm thick which is composed of fragments and small chips of black fissile argillite arranged either in random orientation or shingled up in rows and enclosed in matrix of the underlying rock. There is commonly a thin transition zone between the two formations.

Lithology

The Moeda Formation in the Alegria district is composed largely of a clean white fine-grained quartzite and minor amounts of sericite phyllite. Locally it contains a thin basal conglomerate.

In the Catas Altas quadrangle east of the Serra do Caraça, the base of the Moeda Formation is composed of lenticular beds of coarse grit or conglomerate ranging from a few centimeters to 1 meter or more in thickness. In several localities graded bedding is visible within the 1-meter unit, in many combinations of coarse to fine pebbles, coarse to fine grit, coarse to medium sand.

Discontinuous lenses of cobble and pebble conglomerate composed of quartzite or vein quartz, are exposed in the Catas Altas quadrangle (N. 1,200, E. 9,400, and N. 12,000, E. 5,400).

In the western part of the district many thick beds of coarse quartzite are composed of well-rounded quartz grains (median diameter 1.7 mm) enclosed in a matrix of fine-grained quartz and sericite. The quartz in the matrix ranges in diameter from 0.1 to 0.2 mm. The sericite has an average thickness of about 0.01 mm and an average diameter of 0.1 mm. The coarse quartzites are lenticular and variable in size, and are generally enclosed in fine-grained sugary quartzite, which contains thin sporadic lenses of green quartzose sericite schist or phyllite. The fine-grained quartzite is equigranular. The quartz is strained and has sutured boundaries. The sericite, only a small percentage of the rock, is randomly dispersed and oriented in the matrix; grains are generally about 0.005 mm thick and 0.02 mm in diameter. Where the fine-grained quartzite is phyllitic and sericitic, the sericite is concentrated in thin irregular bands and occurs in larger crystals, about 0.01 mm thick and 0.04 mm in diameter. The sericite schist has thin irregular bands of very fine quartz in a matrix of sericite and chlorite.

Most thin sections show a cataclastic texture. The larger grains show undulatory extinction and many are surrounded by borders of finely crushed quartz, some of which are recrystallized to a homogenous rim. Some have overgrowths of clear quartz. The sericite grains are generally oriented parallel to bedding planes but wrap around the larger quartz grains or around lenses of the quartzite in a reticulate pattern.

Kyanite occurs as sparsely disseminated minute grains in the cataclastic quartzite and in conspicuous zones associated with shearing and faulting in the western part of the Capanema quadrangle. These zones may be several meters wide and several tens of meters long. The kyanite occurs in aggregates of gray or colorless crystals, each 1–3 mm wide and 5–15 mm long, randomly oriented in a matrix of very fine grained cataclastic quartz, or rarely in long bluish-green crystals as much as 1 cm wide, 1 mm thick, and 6 cm long.

In some localities (as at Capanema quad., N. 8,200, E. 1,300), the kyanite occurs as acicular crystals in an overlapping tangle of unoriented sheaf-shaped aggregates, apparently pseudomorphous after sillimanite. As much as 50 percent of the sheaves may consist of quartz inclusions and intergrowths. Some of the inclusions are severely strained quartz grains with a rim of finely crushed quartz; others are fine grained and have a mosaic texture with deeply sutured boundaries; others are colorless quartz with parallel extinction over large areas. Pyrophyllite replaces in varying amounts some of the kyanite, around the edges of grains and along cleavages in aggregates of very small flakes (Herz and Dutra, 1964).

An emerald-green mica, probably a variety of fuchsite, is common in exposures of the Moeda Formation east of the Serra do Caraça, mostly in coarse quartzite or conglomerate near the contact with the granitic rocks. Tourmaline is common in the same area, generally in zones parallel to the contact. It occurs as slender yellow and colorless needles from a few hundredths to a few tenths of a millimeter in diameter and as much as 2 mm long, disseminated through the quartzite. Several concentrations of larger crystals were found. In the Catas Altas quadrangle at (N. 2,600, E. 8,260), very dark green to black tourmaline crystals as much as 3 cm long and 5 mm in diameter occur in sericite-rich, very fine grained cataclasite.

BATATAL FORMATION

Distribution and Topographic Expression

The Batatal Formation crops out in few localities in the Alegria district. It is mapped in the intervening space between outcrops of Moeda Formation and the overlying iron-formation. It occurs on both sides of the Ouro Fino syncline in the western part of the Capanema quadrangle (pl. 1). The type locality of the Batatal Formation is in the area of the headwaters of the Rio Piracicaba, east of the Serra do Batatal and near the center of the Capanema quadrangle (Harder and Chamberlin, 1915; Maxwell, 1958).

The formation crops out from Serra do Batatal down the valley of the Rio Piracicaba, bends north along the valley of the Córrego do Palmital, then east along the Córrego das Almas. It skirts the base of the Serra do Caraça and is faulted out near Água Quente in the southern part of the Catas Altas quadrangle. On the east limb of the Santa Rita syncline the Batatal Formation extends south from Quebra Osso to within 2 km of Bento Rodrigues (pls. 2, 3).

The Batatal Formation is soft and easily weathered and forms valleys and saddles between the more resistant quartzite and iron-formation on either side. It generally forms deep soil with few outcrops but is relatively easy to trace because it normally supports only grass and low brush.

Thickness and Contact Relationships

The Batatal Formation is variable in apparent thickness in the Alegria district, but much of the variation is probably due to faulting. The argillaceous and graphitic nature of the formation would provide excellent lubricated gliding surfaces for the faults. The thickest section is in the type area, about 30 meters, where it is apparently near the true thickness of the unit (Maxwell, 1958). It thins rapidly to the east to a thickness of less than 1 meter.

Both lower and upper contacts of the Batatal Formations are conformable and gradational. The contact between the Batatal and the overlying iron-formation is gradational through a thickness ranging from 1 to 4 meters. The contact with the underlying Moeda is gradational over a thickness of a few centimeters.

The upper contact is arbitrarily chosen in the gradational zone between a banded phyllite-quartz-hematite rock and a banded hematite-quartz rock.

Lithology

The Batatal Formation is a homogenous dark-gray fissile graphitic argillite throughout most of the Alegria district. At the base, beds a few centimeters thick are commonly arenaceous, but may constitute half the thickness of the unit where it is thinnest. In several localities the Batatal is characterized by the presence of small lenticular concretionlike bodies which weather out and form a layer on the surface of the soil. They appear to have been pyrite crystals or clusters that were deformed and altered to iron oxides. Toward the top of the formation, recrystallized chert beds, ferruginous chert, and iron-formation interbedded with the argillite become increasingly abundant.

ITABIRA GROUP

The Minas iron-formation was first separated from the rest of the Minas Series and named the Itabira iron-formation by Harder and Chamberlin (1915, p. 359). The type area was near Pico de Itabira, near the town of Itabirito (formerly Itabira do Campo). Moraes Rego (1933, p. 16) gave these rocks group status but did not name any formations.

Dorr and colleaues (1957, p. 26), unaware of Moraes Rego's use of the term Itabira Group, renamed the section of dominantly chemical sediments in the middle zone of the Minas Series the Itabira Group, in order to preserve Harder and Chamberlin's widely known and used name for much of this part of the Minas Series. Dorr (1958, p. 61–63) then divided the Itabira Group into two formations, the Cauê Itabirite and the Gandarela Formation.

The Cauê Itabirite, with the type section on Cauê Peak near Itabira (Dorr 1958), is described as a laminated oxide facies iron-formation composed of alternate layers of quartz and hematite. Sporadically and locally there may be thin subordinate lenses of dolomitic itabirite, amphibolitic itabirite, dolomite, phyllite, and quartzite. The Gandarela Formation is dolomite or strongly dolomitic, and contains subordinate amounts of itabirite and phyllite.

The contact between the Cauê Itabirite and the Gandarela Formation is placed where "normal" itabirite becomes subordinate to dolomitic itabirite or dolomite (Door, 1958, p. 62). In many parts of the Quadrilátero Ferrífero, the two formations are easily divisible, such as in the Gandarela syncline, but in many other places differentiation is difficult, especially where exposures are poor and where there is an extensive canga cap on the formation. For this reason the group will be described in this report as Itabira Group undivided.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Itabira Group, or the canga cap over it, crops out along the Serra do Ouro Fino and forms the top of the serra. Beginning at Serra do Batatal, the itabirite forms part of the valley and the ridges along the Rio Piracicaba, bends northward at Conta História and parallels the flank of the Serra do Caraça around to the east and again to the north, in the Serra da Boa Vista, west of Catas Altas. In all places it forms a subsidiary ridge, parallel to the Serra do Caraça and separated from it by valleys cut into the Batatal Formation or into a greenstone sequence. South of Santa Rita Durão the Itabira Group crops out between Fazendas Ouro Fino and Fábrica Nova and on Morro da Fraga, where it also forms the ridgetops.

THICKNESS

The Itabira Group in the Alegria district is structurally complex and has extreme variations in apparent thickness. Near Fazenda Alegria the apparent stratigraphic thickness is about 1,200 meters; 6 km east, the apparent thickness is only 80 meters. This variation is probably due largely to plastic flow during an early deformation or possibly to submarine slumping during deposition, but some is repetition due to later folding and faulting. Outcrops and individual beds or units are so discontinuous that a determination of the original thickness is virtually impossible. The original thickness was probably in the order of 50–200 meters.

CONTACT RELATIONSHIPS

The contact of the Itabira Group with the underlying Batatal Formation is gradational conformable, as previously discussed.

The contact with the overlying Cercadinho Formation is everywhere an erosional unconformity, possibly angular in places. The unconformity may be the result of a long period of widespread erosion, accompanied by epeirogenic movement; locally, apparent angularity may be the result of sedimentation on a karst topography or of cavern collapse and slumping following deposition of the Cercadinho Formation. In a few places the apparent angularity is due to faulting.

The rock types at the upper contact vary greatly. A red or variegated red and purple fine-grained lenticular rock, probably an ancient regolith, occurs locally.

LITHOLOGY

Most of the rocks of the Itabira Group were derived from chemical precipitates. They are composed almost entirely of iron oxides, recrystallized chert, and dolomite in varying mixtures and proportions. Minor thin clay beds and thicker sequences of weathered tuffaceous(?) dolomite are common in the upper part of the section; lenticular beds of greenstone, chlorite, and talc schist occur throughout the section but are more common in the basal part. Minor amounts of amphibole occur locally. All gradations occur between the two major rock types, dolomite and itabirite.

The name "itabirite" was first proposed for the banded iron-formation by von Eschwege in 1822 (Derby, 1909, p. 1258), after Itabira do Campo, later renamed Itabirito, Itabirite, from an aboriginal word meaning whetstone (certain types make excellent sharpening stones, Guild, 1957, p. 14), is currently applied to a laminated metamorphosed oxide-facies iron-formation in which the original chert or jasper bands have been recrystallized into granular quartz and in which the iron is present as hematite, magnetite, or martite (Dorr and Barbosa, 1963). The term is further restricted to material containing between 25 and 66 percent iron. Rock containing less than 25 percent iron is termed "metamorphosed ferruginous chert"; rock with more than 66 percent iron is termed "high-grade hematite." Figure 12 shows an intensely folded low-grade or quartz-rich soft itabirite.

Typical itabirite consists of alternate layers, each about 5–10 mm thick, of (1) white fine-grained quartz and a small amount of disseminated iron oxide and (2) black iron oxide, usually hematite, with a small amount of disseminated quartz. The contact between layers is gradational over a fraction of a millimeter. Although the thickness of layers varies widely, the appearance of even bedding is striking. In "normal" itabirate, the white layers consist almost entirely of quartz, with only minor amounts of other material. The black layers are mostly iron oxide and may vary greatly from compact nearly pure hematite, to specular hematite, to

FIGURE 12.—Thin-bedded quartz-rich itabirite, intensely folded. Light bands are quartz; dark bands are quartz and hematite. Quartz in the wider bands is recrystallized to euhedral and subhedral grains.

limonite, to red ocher (hematite). Other minerals, such as magnetite, martite, amphibole, talc, and dolomite, are locally common and, in some rocks, even predominant. Where minerals such as limonite, soft red hematite, or amphibole are abundant, the color of the rock changes to red, yellow, brown, or some combination of these, and layering may disappear as well.

Variations in the lithology of itabirite are described with modifying adjectives, such as dolomitic or amphibolitic. Amphibolitic itabirite consists of alternate layers of iron oxide and felted layers of limonite. The limonite is arranged in acicular, often radiating, pseudomorphs after a mineral with amphibole morphology. No unweathered rocks of this type have been found in the Alegria district.

Dolomitic itabirite generally consists of layers of limonite, magnetite, hematite, and martite in varying mixtures alternating with layers of quartz and dolomite in varying proportions. The dolomite is generally weathered and dissolved from the rock to a considerable depth, which leaves the lighter bands stained red or yellow.

Another type of itabirite difficult to classify with certainty is manganiferous and displays a rhythmic alternation of bands of light-colored minerals, iron oxides, and manganese oxides. The light and dark bands are roughly the same thickness as in the "normal" itabirite, 3–10 mm, with the manganese oxide bands generally about 1 mm thick at the top, or more commonly, at the bottom of the dark band. Because of the mobility of manganese and the deep weathering and hydration in the itabirite, it is not known whether those bands represent a secondary deposition or syngenetic layers in the iron-formation.

Although thick mappable dolomite units occur in other parts of the Quadrilátero Ferrífero (Guild, 1957; Gair, 1962; Johnson, 1962; Pomerene, 1964; Wallace, 1965; Moore, 1969; O'Rourke, written commun. 1954), none have been found in the Alegria district. There are, however, many thin discontinuous lenses of dolomite and siliceous dolomite scattered throughout the Itabira Group; these are more conspicuous near the top. These lenses are gradational laterally, and commonly vertically as well, into all of the types of iron-formation found in the district.

Chlorite schist, chlorite-sericite schist, and talc schist, generally in thin discontinuous and lenticular beds, are common in the basal section of the Itabira Group, less common in the upper section. Most of these beds are only a few centimeters thick, but some attain a thickness of 1 or 2 meters. These beds are most common in Córrego das Almas and near Fazenda Alegria. In part, they may represent sills associated with the mafic dikes in the area. They are similar in lithology, being mostly chlorite.

Dense hard goethite that breaks with a flinty conchoidal fracture is common in the upper part of the section, especially around Alto do Conta História. The rock may have formed entirely by replacement. In the manganese mines at Conta História it replaces schist or phyllite beds; elsewhere, it replaces the iron-formation in some fault zones.

A dark-red massive semi-indurated rock that supports little or no vegetation occurs at or near the top of the Itabira Group throughout the Quadrilátero Ferrífero. Exposures near the base of the unit commonly have small lenses containing pebbles or disoriented angular fragments of itabirite, phyllite, quartz, and limonite or wad nodules. This material has been called a weathering product of dolomite (Guild, 1957, p. 43) or a Tertiary mudstone (Gair, 1962, p. 42; Johnson, 1962, p. 24; Pomerene, 1964, p. 31; Dorr, 1969, p. 69).

An identical material occurs in several localities in the Alegria district. One large outcrop near Santa Rita Durão (N.9, 850, E. 8, 850) crosses under the bed of the deeply incised Rio Piracicaba. It is about 80 meters stratigraphically below the contact between the Itabira Group and the Cercadinho Formation. Several small lenticular zones in the rock contain scattered pebbles of quartz, itabirite, and phyllite, or small randomly oriented fragments of itabirite and phyllite. The lenticular zones are concordant with the bedding of the underlying and overlying rocks. Thin sections show that the rock is composed of corroded angular grains and prismatic and curved slivers of quartz and scattered grains or crystals of specularite, magnetite, and numerous unidentified minerals of very high relief (index of refraction more than 1.78) in a matrix of very finely disseminated iron oxide in clay. The quartz grains range from 0.001 to 1.5 mm in diameter. Most of the minerals of high relief are about 0.001–0.01 mm in diameter; some are equidimensional and some rod shaped.

These rocks are so deeply weathered that identification of the original rock type is very difficult. The gross appearance of the rocks, their occurrence at approximately the same stratigraphic position throughout the Quadrilátero Ferrífero, and the numerous minerals of high relief suggest to the writer that they are water-laid tuffs deposited within the Itabira Group, rather than mudflows or residual weathering products. Samples of residual soils, weathered dolomite and itabirite, and many other rocks were examined for similar quartz grains and minerals of high relief; none were found. Dorr (1969, p. 69) reports that analyses of similar material from other areas show an abnormally high content of TiO_2, locally more than 5 percent, which also suggests a volcanic source.

PIRACICABA GROUP

The group of rocks, predominantly clastic, which overlie the Itabira Group were first differentiated and named the Piracicaba Schist and Quartzite by Harder and Chamberlin (1915, p. 362). The type area was in the northern part of the Santa Rita Durão quadrangle, along the Rio Piracicaba between Santa Rita Durão and Fazenda Alegria. Moraes Rego (1933) named the same sequence the Ribeirão do Carmo Group, with the type area near Ouro Preto, but did not subdivide it. Lacourt (1936, p. 19) and Guild (1957, p. 18) designated the sequence as the Upper Group. Dorr, Gair, Pomerene, and Rynearson (1957, p. 28) elevated the rocks of Harder and Chamberlin's Piracicaba Schist and Quartzite to group status in order to set off the predominantly clastic upper sequence of the Minas Series from the predominantly chemical middle sequence. It was then known that the clastic upper sequence could be subdivided in most of the Quadrilátero Ferrífero into five units, from the youngest to oldest: Sabará Formation, Barreiro Formation, Taboões Quartzite, Fêcho do Funil Formation, and Cercadinho Formation. All but the Taboões Quartzite have been identified in the Alegria district.

CERCADINHO FORMATION

The Cercadinho Formation (Pomerene, 1958, p. 64) crops out on the western limb of the Santa Rita syncline, along the eastern edge of the Capanema quadrangle, across the northern part of the Santa Rita Durão quadrangle and a short distance into the southern part of the Catas Altas quadrangle, parallel to the exposures of the Itabira Group. On the eastern limb, the formation is complexly deformed and follows an intermittent and sinuous pattern from near Santa Rita Durão south to the limits of the quadrangle.

In the Alegria district, in contrast to much of the rest of the Quadrilátero Ferrífero, the Cercadinho Formation is generally deeply weathered and eroded, produces few outcrops and, with the rest of the Piracicaba Group, forms valleys and areas of negative relief between the resistant Itabira Group on one side and the iron-rich quartzites of the Itacolomi Series on the other side.

The thickness of the Cercadinho Formation is highly variable. Individual beds cannot be traced for any great distance; their lenticular nature makes any detailed correlation from section to section difficult. Correlation and measurement are further complicated in the Alegria district by lack of exposures and by thick soil and forest cover. Only by measuring across projected contacts can even a rough estimate of thickness be obtained. The least deformed area, in which exposures are best, is in the overturned limb of the Santa Rita syncline near Bento Rodrigues (pl. 2), where the thickness is apparently about 210 meters. Near Fazenda Alegria, on the western border of the Santa Rita Durão quadrangle, the thickness is about 225 meters. The formation at the type section is 317 meters thick, and at a distance of 3 km is 80 meters thick (Pomerene, 1958, p. 64).

The Cercadinho Formation is separated from the underlying Itabira Group by an erosional disconformity or unconformity. The upper contact with the Fêcho do Funil Formation is gradational over a thickness of a few centimeters to about 4 meters. The contact is so placed that the rocks characteristic of the Cercadinho Formation—quartzite, ferruginous quartzite, and shiny aluminum- or silver-colored phyllite—are excluded from the Fêcho do Funil Formation (Pomerene, 1964, p. 20).

Lithology

The characteristic features of the Cercadinho Formation are: A basal granule to cobble conglomerate containing angular to subrounded fragments of rock derived from the weathering of the underlying rocks, ferruginous quartzite beds, and a sericite phyllite with a definite metallic luster and the color of aluminum or silver (Pomerene, 1964, p. 24). Light- and dark-gray to black graphitic phyllite and phyllites that weather to red and tan are common in the formation, especially in the upper part. The bulk of the formation is quartzite and ferruginous quartzite.

The basal conglomerate is lenticular and discontinuous, and its lithology is extremely varied. The matrix varies from white to gray and brown fine- to coarse-grained quartzite; in places, it contains considerable amounts of chlorite or mica. The fragments range in size from granules to cobbles; the smaller sizes are predominant. The fragments generally consist of hematite, itabirite, or quartzite; small fragments of gray phyllite are less common. The basal conglomerate ranges from 0 to as much as 10 meters in thickness. It is overlain in most places by a sequence of equigranular medium-grained quartzite, commonly nonferruginous, which is white, light gray green or light gray and is composed mainly of well-rounded quartz grains and lesser amounts of chlorite, sericite, pyrite, graphite(?), and hematite. The quartz grains range from 0.01 to 1.0 mm in diameter; most are about 0.2 mm in diameter. The chlorite, sericite, and graphite(?) grains are all about 0.15 mm in size and constitute about 5 percent of the rock. Pyrite and hematite occur only locally.

Much of the Cercadinho Formation consists of ferruginous quartzite, composed predominantly of rounded quartz grains and flaky specular hematite. The color ranges from light to dark gray, depending on the percentage of hematite. Uncommonly, some beds may contain appreciable amounts of sericite-muscovite or chlorite. The ferruginous quartzite may be equigranular and well sorted. Generally, however, it is poorly sorted and medium to coarse grained; it contains some very fine grains and some very coarse grains and commonly shows graded bedding. The amount of hematite varies greatly, from one bed to another and along strike on any bed. Many of the ferruginous quartzite beds show crossbedding, generally at a very low angle to the true bedding; however, scour-and-fill structures occur locally. Beds may be as much as 3 meters thick but generally range from 20 to 50 cm in thickness and are commonly separated by thin beds of sericite phyllite or graphite phyllite.

Beds of silver- or aluminum-colored phyllite, though thin, are easily recognized in the section; they form a characteristic soil rich in tiny flakes of muscovite, and their outcrops have a distinctive metallic appearance. Most of the phyllite in the formation is soft and weathers readily to a tan, gray, or red phyllite saprolite, outcrops of which are sparse. In roadcut exposures, it rapidly breaks down to mud, which obscures any bedding or structure. Some phyllite is light gray and has a silvery luster but is not as metallic appearing as the aluminum-colored phyllite; it is composed of very fine grained quartz and specular hematite.

Manganiferous zones in a spongy yellow and brown-black phyllite, which appears to be the weathering product of an impure dolomite interbedded with the yellow and gray phyllite, occur at several localities in the uppermost part of the Cercadinho Formation. These zones are very similar in appearance to rocks in the overlying Fêcho do Funil Formation but are separated from them by beds of ferruginous quartzite and sericite phyllite. They probably represent a gradation between the two formations. The contact is arbitrarily placed at the top of the highest quartzite or aluminum-colored phyllite.

FÊCHO DO FUNIL FORMATION

The Fêcho do Funil Formation (Simmons, 1958) has the same pattern of distribution in the Alegria district as the Cercadinho Formation. Locally, rocks of the Fêcho do Funil Formation were apparently eroded away before deposition of the Itacolomi Series.

There are very few outcrops of the Fêcho do Funil Formation in the Alegria district. The formation is highly susceptible to weathering and erosion; thus, valleys and low areas of slight relief form on it and where roads cross it there is no need for deep cuts. Only one roadcut exposure is known, on the road to Conta História (Santa Rita Durão quad., N. 8,000, E. 200), where a small exposure of deeply weathered dolomitic phyllite is present.

At the type locality, the Fêcho do Funil Formation is about 300 meters thick. Complicated structure and almost complete lack of exposures in the Alegria district preclude accurate measurement of thickness. Calculations based on known and inferred contacts and dip and strike indicate a thickness of about 175 meters.

The contact of the Fêcho do Funil Formation with the underlying Cercadinho Formation is gradational. The upper contact, with the Barreiro Formation, has not been seen in outcrop, but is probably comformable and may be gradational over a fraction of a meter. In one series of exposures, in the drainage ditch of a road (Santa Rita Durão quad., N. 8,950, E. 1,550), the two formations have the same attitude within 1 meter of each other. All other exposures are complicated by faulting.

LITHOLOGY

Only two outcrops of unweathered rock in the Alegria district are mapped as the Fêcho do Funil Formation (Santa Rita Durão quad., N. 8,500, E. 6,400; N. 8,800, E. 6,000). In these exposures, thin-bedded quartzite and phyllitic dolomite units about 150 meters thick are bounded on both sides by deeply weathered dolomitic phyllite. The dolomite contains many thin lenticular discontinuous layers of specularite and may contain disseminated crystals and grains of hematite. Under the microscope, thin sections of this rock show a mosaic of anhedral generally equidimensional grains of a carbonate mineral, apparently dolomite, with diameters ranging from 0.03 to 0.2 mm and averaging about 0.1 mm. The dolomite encloses scattered subhedral grains of quartz with diameters of 0.1–0.2 mm. One thin section showed a mosaic of quartz, of about the same size ranges, with enclosed anhedral grains of a carbonate mineral, also in the same size range. Numerous lenticular agglomerations of quartz, 0.5–2 mm in length and 0.2–1 mm in width, are composed of grains about 0.1 mm in diameter.

Thin sections also reveal irregular patches, several millimeters across, of a carbonate mineral recrystallized almost entirely to euhedral rhombohedrons of what appear to be calcite. Muscovite is present in all thin sections, generally as crystals 0.1–0.2 mm across; some occur as randomly oriented flakes in the carbonate. In one slide, chlorite flakes 0.1–0.6 mm long and 0.01–0.02 mm wide are arranged subparallel to the layering. Hematite crystals are common and often form "beds" of about equal amounts of quartz or carbonate and hematite. The hematite is in euhedral or subhedral crystals; randomly scattered crystals have an average diameter of about 0.02 mm. Crystals concentrated in layers range from 0.01 to 0.1 mm in diameter; most have diameters of about 0.03 mm. The quartz content ranges from 10 to 50 percent; the carbonate, from 50 to 90 percent. The accessory minerals generally make up about 1–2 percent, rarely as much as 5 percent. In certain beds, thin irregular seams of hematite may constitute 20–90 percent of the rock.

Two samples were analyzed by Cia. Siderúrgica Belgo-Mineira, with the following results:

	RI [1]	R_2O_3 [2]	CaO	MgO	Loss on ignition
Bluish gray dolomite	11.98	4.60	26.88	17.06	39.78
White dolomite	2.26	3.00	30.17	19.38	44.84

[1] RI indicates alkalies, sulfates, silica, and others.
[2] R_2O_3 indicates alumina, titania, Fe_2O_3.

Most of the formation was mapped on the basis of either (1) very limited exposures of deeply weathered rock, or (2) soil type. Exposures generally show a buff-yellow, yellow-brown, or pink, very fine grained or clayey saprolite, thin bedded to fissile, commonly with thin discontinuous lenses of specular hematite or nodular limonite. One common type is a light-buff-yellow to light-brown saprolite with uneven layers of limonite concretions spaced 2–6 cm apart. The layers of concretions are concordant and may represent bedding. The concretions are generally almond shaped, 2–5 cm in greatest dimension but commonly coalescing to form uneven elongate masses as much as 10 cm long. Locally, the smallest dimensions of the concretions, 3–15 mm, are all oriented in the same general direction; elsewhere, they are randomly oriented. The two greater dimensions are parallel to the bedding.

In many places the formation was mapped on the basis of a characteristic aluminous laterite soil composed of small rounded concretions of bauxite in a matrix of red laterite. In several localities this soil grades into thick commercially valuable bauxite deposits. The producing bauxite deposits north of Santa Rita Rurão (N. 10,600, E. 8,800) overlie the Fêcho do Funil Formation (See p. J65). Generally wherever the Fêcho do Funil Formation occurs on a hill or other well-drained area of positive relief, it is capped by a bauxite deposit. These deposits do not normally extend over the Cercadinho Formation or over the Barreiro Formation.

BARREIRO FORMATION

The Barreiro Formation (Pomerene, 1958, p. 67) occurs intermittently in the same general pattern as the two underlying formations. It is very soft and easily weathered and, because of thick soil and forest cover in the outcrop belt, the presence of most of the formation is only inferred in much of the area where it was mapped. The only mappable exposures of the Barreiro Formation occur near Fazenda Alegria and about 1½ km southwest of Santa Rita Durão (Santa Rita Durão quad., N. 8,800, E. 1,500; N. 7,000, E. 7,000; and in the Capanema quad., N. 6,500, E. 12,500).

The Barreiro Formation at the type locality has a thickness of about 124 meters. Where present in the Alegria district the formation has an estimated thickness of about 170 meters. In several localities (pl. 2), the Barreiro was apparently removed by erosion before deposition of the Itacolomi Series.

The Barreiro Formation consists of a black or dark gray graphitic phyllite or argillite in almost all known exposures in the Alegria district. A few very small lenses of white very fine grained quartz, which were probably nodules of chert, are scattered intermittently in the phyllite. A few thin beds of reddish or purplish phyllite also occur. No exposures of the contact of the Barreiro with the overlying Sabará Formation were seen in the Alegria district, but structures in exposures near the contacts indicate that the relationship is concordant.

SABARÁ FORMATION

The Sabará Formation (Gair, 1958) is present in the central and south-central parts of the Santa Rita Durão quadrangle. Most of the area underlain by the Sabará Formation has a thick soil and dense forest cover. Exposures of deeply weathered rock occur in roadcuts near Fazenda Fundão and on the southern border of the quadrangle. New charcoal truck trails have produced a few exposures. Because of lack of outcrops many of the contacts shown on the map (pl. 2) are inferred on the basis of topographic expression and projection of known contacts. The Sabarã Formation generally weathers to low rounded hills.

The thickness of the Sabará Formation, estimated from the inferred contacts and structure, ranges from 800 to 1,700 meters and averages about 1,000 meters.

The contact of the Sabará Formation with the underlying Barreiro Formation appears to be concordant in most outcrops. The contact with the overlying Itacolomi Series was not seen, but a slight angular unconformity is suggested by the divergence of dips and strikes in some areas. The areal distribution of the rocks, along with the absence of the Sabará Formation in many localities, also indicates the possibility of an unconformity, although locally the absence could be due to faulting.

The Sabará Formation in the Santa Rita Durão quadrangle is composed of phyllites, schists, graywackes, subgraywackes, quartzite, and metamorphosed tuffs. A fine-grained chlorite schist containing scattered granules and pebbles is commonly the predominant type. Many of the subgraywackes contain scattered generally well rounded cobbles and boulders of quartzite, granite, and gneiss.

ITACOLOMI SERIES

The Itacolomi Series was originally included in the Minas Series and was first called the Itacolomi Quartzite by von Eschwege (Derby, 1898, p. 187) and later by Gorceix (1883) and Derby (1906). It was first formally designated as a formation by Harder and Chamberlin (1915, p. 364). Guimarães (1931, p. 9, 27) recognized the unconformity between the Minas Series and the Itacolomi Quartzite and therefore raised the Itacolomi to series rank. Moraes Rego (1933, p. 27) named the same sequence of rocks the Espinhaço Series but included in addition some schists and conglomerates in the basal part that had been considered by others as part of the Piracicaba Schist and Quartzite of Harder and Chamberlin (1915). Lacourt (1936, p. 24) divided the Itacolomi Series into lower, middle, and upper groups, including the basal schists and conglomerates and apparently some of the underlying Piracicaba Schist and Quartzite. Barbosa (1949, p. 7) named the basal sequence of phyllite, schist, quartzite, and conglomerate the Santo Antônio Formation but indicated that they were part of the Minas Series. In a later report (1954, p. 26), he indicated that the Santo Antônio Formation should be in the Itacolomi Series but posed many questions as to what constitutes the Itacolomi Series.

Guild, who studied the type area of the Santo Antônio Formation (1957, p. 25), and Dorr (1969, p. A59) refer to this unit as the Santo Antônio facies of the Itacolomi Series. Barbosa (oral commun., 1960), as well as many other geologists familiar with the area, now consider it to be a basal unit of the Itacolomi Series.

The Santo Antônio Formation and the Itacolomi quartzite may be facies of the same unit, as defined by Dorr (1969, p. A62) but they appear to comprise three distinct units in the Alegria district and in some exposures south of the district. The three units the Santo Antônio Formation, an overlying quartzite and sericite-phyllite unit, and an overlying massive cross bedded quartzite, are variable in thickness and are intergradational but are present in many exposures in an orderly sequence. The writer has mapped the lower unit as the Santo Antônio Formation, and the two upper units as Itacolomi Series undivided.

SANTO ANTÔNIO FORMATION

DISTRIBUTION

In the Alegria district, the Santo Antônio Formation occurs only in the south half of the extreme eastern edge of the Capanema quadrangle and in the western part of the Santa Rita Durão quadrangle. The best exposures are along the road from Fazenda Alegria to Conta História and along the eastern edge of the Serra da Boa Vista in the southwest part of the Santa Rita Durão quadrangle. The formation, along with the overlying units, forms ridges and hills above the more easily weathered Piracicaba Group.

THICKNESS AND CONTACT RELATIONSHIPS

The Santo Antônio Formation almost everywhere in the Alegria district includes a basal conglomerate composed of fragments of all the older rocks. The basal conglomerate is in contact at various places with all the formations of the Piracicaba Group. Although the contact may locally be a fault, in most exposures it is apparently an angular unconformity.

The upper contact of the Santo Antônio Formation was arbitrarily placed at the top of the highest conglomerate lenses that contained fragments of the underlying formations, then projected along strike where the conglomerate was absent. The highest such conglomerate coincided roughly with a gradational change from the varied lithology below to an upper unit composed predominantly of crossbedded quartzite, with minor lenses of quartz-pebble conglomerate and sericitic phyllite.

The thickness of the Santo Antônio Formation varies greatly. The molasse character of the rocks indicates the possibility of extreme variations in thickness as well as lithology. Field evidence tends to confirm this, although a complete section could not be measured in the Alegria district. The basal conglomerate ranges from a few centimeters to more than 100 meters in thickness. The entire formation may be as much as 800 meters thick in the environs of the Alegria district.

LITHOLOGY

The Santo Antônio Formation comprises a highly diverse assemblage of lithologic types. The most abundant rock is fine-grained chlorite-sericite-quartz schist. A conglomerate occurs almost everywhere at the base of the formation. The clasts range in size from boulders to small (1 mm–1 cm) rock fragments in a fine-grained sand matrix. The fragments consist of vein quartz and rocks from all the underlying formations. Itabirite is the most easily identified of these rocks, but ferruginous quartzite, graphitic schist, phyllite, and quartzite are readily identified in the larger fragments. Similar conglomerates occur throughout the formation, interbedded with sericitic quartzite, quartz-sericite schist, chlorite-sericite phyllite and schist, argillite, dolomitic phyllite, ferruginous quartzite, itabirite, and graywacke. These rocks form a succession of rapidly alternating rock types with short and irregular lateral extensions. In some areas, outcrops of the chlorite-sericite phyllite appears identical to similar rocks in the Sabará Formation and could easily be confused with them in the absence of rocks diagnostic of the Santo Antônio Formation.

Layers or beds of specular hematite are common. They are generally thin but in some places are thick and pure enough to constitute an economic deposit. Two such layers form the Germano deposit (Santa Rita Durão quad., N. 6,500, E. 0 and 500, pls., 1, 2). Table 10 (p. J54) lists several analyses of this rock. In parts of the lenses the rock is clearly of clastic origin, with hematite flakes interstitial to larger well-rounded quartz grains and disposed in layers that commonly show crossbedding. In other parts of the lenses the rock looks like itabirite and shows little evidence of a clastic origin.

QUARTZITES

The quartzites overlying the Santo Antônio Formation are mapped as Itacolomi Series undivided. They occur in the southwestern corner of the Santa Rita Durão quadrangle, where they are gradational and conformable with the underlying rocks. The lower part of the unit is composed of coarse- to medium-grained sericitic quartzite, commonly crossbedded, and generally thick to massively bedded. Kyanite is a common constituent, both as disseminated grains and in small quartz-kyanite veins. Small quartz veins are common and widespread in the unit; some contain clear euhedral quartz crystals, and many contain euhedral hematite crystals that range from about 1 cm to as much as 15 cm in diameter. The quartzite contains small lenses of conglomerate composed of well-rounded pebbles and cobbles of quartzite and vein quartz in a quartz-sericite matrix. Lenticular and discontinuous thin lenses and layers of sericite-quartz phyllite or phyllonite are common as bedding-plane partings in the rock. Dolomite and ferruginous quartzite occur sparsely in the lower part of the unit. The upper part of the unit comprises a thick section of very massive, medium- to coarse-grained cross-bedded quartzite and grit that contains varying quantities of sericite and only minor amounts of other constituents. It comprises the bulk of the series south of the Alegria district. The only exposure in the Alegria district is at Pico do Frazão, the crest of which is 800 meters south of the Santa Rita Durão quadrangle (E. 1,250).

TERTIARY AND QUATERNARY DEPOSITS

Tertiary and Quaternary deposits in the Quadrilátero Ferrífero consist of canga, alluvium, residual gravels, residual clay, bauxite, laterite deposits, and lacustrine sediments of the Fonseca Formation.

Most of the area mapped in the Alegria district is covered by a veneer of soil, alluvium, laterite, or canga, but these deposits are shown on the geologic maps only where they have economic, geologic, or physiographic significance. In addition, many perched gravel deposits have been mapped.

FONSECA FORMATION

The Fonseca basin (Gorceix, 1884, p. 95) is an area of about 35 sq km underlain by Tertiary lacustrine and fluviatile sediments with an average thickness of about 85 meters. These sediments lie largely east of the Quadrilátero Ferrífero (fig. 13), but extend short distances westward into the northeastern part of the Santa Rita Durão quadrangle and the southeastern part of the Catas Altas quadrangle. In the Alegria district, the sediments are about 70 meters thick, and are composed predominantly of sandy siltstone and sandstone with a few lenses of coarse sandstone and conglomerate. Thin seams of lignite in the siltstone contain plant fossils of probable Pliocene age (Dolianiti, 1949). The deposits are only slightly indurated and form a deep soil that generally supports a thick growth of brush and trees. The deposits are commonly capped by 1–3 meters of hard canga or indurated ferruginous laterite. These sedimentary deposits are here designated the Fonseca Formation.

About 5 km east of the eastern boundary of the Santa Rita Durão quadrangle, near the town of Fonseca, recent erosion has exposed most of these Tertiary deposits. Table 1 shows the type section measured in that area.

TABLE 1.—*Stratigraphic section of Tertiary lacustrine and fluvatile deposits of the Fonseca Formation*

	Thickness (meters)	Cumulative thickness (meters)
Canga cap: fragments of itabirite, quartzite, and phyllite cemented by limonite. Probably not part of Fonseca basin sedimentation	1.0	1.0
Covered: rock fragments in soil mostly platy siltstone	10.0	11.0
Mostly covered: some massive clay, nodular concretions, thin siltstone and sandstone layers	20.0	31.0
Buff and white sandstone interbedded with massive claystone	12.0	43.0
Massive yellow claystone with thin- to medium-bedded yellow-buff siltstone and sandy claystone	17.0	60.0
Platy thin-bedded white, gray, and dark-gray siltstone and claystone. Minor buff claystone and white-buff sandy siltstone. Near middle of sequence are several thin lignite seams, 2–80 cm in thickness	8.5	68.5
Covered	3.0	71.5
Yellow, red, and purple thick-bedded claystone	7.0	78.5
White argillaceous sandstone	.7	79.2
Boulder and cobble conglomerate at base to pebble conglomerate near top. Sandy clay matrix with fragments of deeply weathered gneiss, phyllite, and quartzite. Weathered gneiss below the conglomerate	7.0	86.2

The original extent of the Fonseca basin cannot be determined because erosion has removed much of the sediments deposited in it. The laterite and gravel beds shown in the east-central part on plate 2 and in figure 13 could be remnants of the Tertiary deposits, presumably along the border of the basin. The thickest Tertiary deposits follow an axis that curves from near the southern boundary of the Catas Altas quadrangle. The axis crosses into the Santa Rita Durão quadrangle and then out near the northeast corner; in a south-southeasterly direction, it passes just north of the village of Fonseca. The inferred possible extent of the original basin is shown in figure 13.

The Fonseca Formation is present under most, if not all, of the canga of Espigão do Canga, northeast of Santa Rita Durão, but is so thin and poorly exposed that it was included with the canga (pl. 2). The canga grades imperceptibly toward the east into a ferruginous laterite hardpan. In areas of recent gully erosion, the laterite exhibits a distinct horizontal layering that merges with the layering in the underlying Fonseca Formation. In some of the exposures along the south side of the Espigão do Canga, layered ferruginous laterite is in contact with gneiss saprolite; in others, thin beds of Fonseca Formation occur between the laterite and the gneiss.

SURFICIAL DEPOSITS

CANGA

The term "canga," as used in this report, refers to a surficial but well-indurated resistant ferruginous rock ranging in composition from a breccia conglomerate of hard hematite fragments cemented by a minimum of hydrated iron oxide to a laterite hardpan of clay and ferruginous soil cemented by limonite. The most common type of canga is composed of itabirite fragments cemented by limonite. Canga is gradational into all types of surficial deposits—soil, gravel, conglomerate, laterite, bauxite—and into itabirite and hematite. The word "canga," as applied to this rock, is apparently a contraction of an Indian word, Tapanhoacanga, meaning negro's head, in allusion to the rounded black forms commonly seen on the surface (Derby, 1909, p. 1258). In the Alegria district, canga occurs on most of the prominent ridges formed by the Itabira Group, on the slopes of the ridges, and in many places it extends out over nonferruginous formations, including gneiss and granite. Canga overlies the Tertiary sediments of the Fonseca basin and may overlie other small areas of Tertiary and Quaternary sediments.

The thickness of the canga sheet ranges from a few centimeters to 50 meters or more, and averages 1–2 meters. Locally, where talus accumulations have been cemented into canga, the deposit may attain a considerable thickness. The canga in an exploratory adit on the east side of Serra do Ouro Fino, near Capanema, is 35 meters thick. In adit 33, Alegria deposit (Capanema quad., N. 10,500, E. 12,000), the canga is 30 meters thick.

Canga has been divided by Pomerene (1964, p. 30) into three general types:

1. Canga rica—a breccia-conglomerate of hard hematite cemented by a minimum of hydrated iron oxide. It occurs in the vicinity of hematite deposits in the Cauê Itabirite. Canga rica contains more than 66 percent iron.
2. Ordinary canga—a breccia-conglomerate of hematite chips and itabirite fragments cemented by hydrated iron oxide, mostly limonite and goethite. It is the most common and widespread type of canga in the district. Ordinary canga varies widely in grade, but generally ranges from 50 to 60 percent iron.
3. Chemical canga—mostly limonite, cements clay and ferruginous soil, grades laterally into indurated laterite. This type of canga is common outside areas of iron-formation and overlies generally nonferruginous formations.

A fourth type, referred to as structure canga, is a subdivision of ordinary canga. An in situ weathering product of itabirite, it forms when limonite, produced by

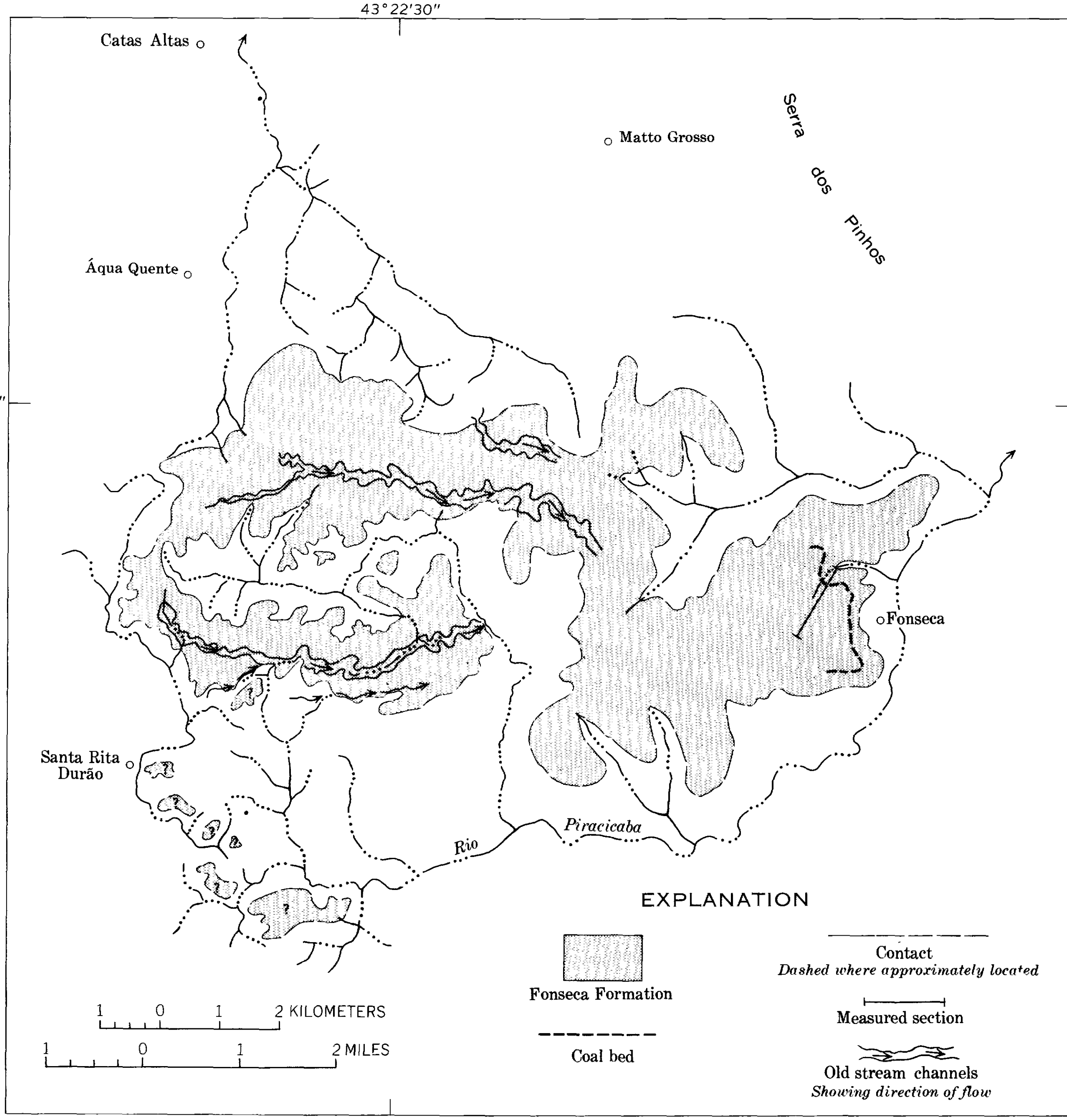

FIGURE 13.—Map of the Fonseca basin showing approximate extent of the Tertiary lacustrine and fluvatile deposits of the Fonseca Formation. See table 1 for measured section.

hydration of hematite, leaches and replaces quartz. The resulting hardpan or canga cap shows vestiges of the original layering and structure. The grade of the canga is generally considerably higher than that of the soft and weathered itabirite underlying it.

Table 2 lists partial analyses of several types of canga in the Alegria district.

The origin of canga has been discussed by many authors, among them: Guild (1957), Simmons (1960), Dorr and Barbosa (1963), and Pomerene (1964). Pomerene and Simmons concluded that canga is formed near the surface under a ferruginous soil cover and is

TABLE 2.—*Partial analyses, in weight percent, of several types of canga in the Alegria district*

[Analysts: Cia. Siderúrgica Belgo-Mineira staff. N.d., not determined]

	1	2	3	4	5	6
Fe	55.92	59.72	63.11	65.80	47.10	42.35
SiO_2	1.50	2.74	1.70	.55	5.90	3.00
Al_2O_3	5.84	4.00	.83	.21	14.40	21.10
P	.26	.30	.39	.24	N.d.	N.d.
Mn	N.d.	N.d.	.13	.05	N.d.	N.d.
Loss on ignition	12.00	N.d.	5.10	3.60	12.40	14.20

1. Canga from top of Alto do Conta História.
2. Canga, mouth of adit 33, Alegria deposit.
3, 4. Structure canga, Córrego do Meio, Conta História.
5. "Chemical canga" above bauxite deposits at Fazendão.
6. Indurated laterite, surface, shaft 21, Fazendão.

related to either an erosion surface, an old peneplanation (as on the concordant summits of the iron-formation), or a slope outwash from the ridges of iron-formation. According to this hypothesis, meteoric waters dissolve organic matter and become acidic; they then dissolve iron from the soil and carry it laterally and downward to a new environment, where the iron precipitates as limonite around detrital fragments to form canga (Simmons, 1960, p. 43–50).

One of the areas studied by Simmons was at Fazenda Alegria (Santa Rita Durão quad., N. 8,400, E. 100). His report (1960, p. 48) included analyses of samples from that locality. They are reproduced, in part, below:

[Analyst: C. M. Pinto, chemist, Dept. Nac. da Produção Mineral]

Sample	Depth from surface (cm)		Chemical analyses (percent)		
	Top	Base	Fe	Si	Al
1	0	10	15. 1	22. 3	7. 9
2	25	35	23. 3	17. 7	7. 1
3	65	75	20. 6	19. 9	11. 4
4	95	105	20. 8	21. 4	7. 4
5 (canga)	105	115	37. 3	4. 3	10. 8

The author and others (Pomerene, 1964, p. 30, and Simmons, 1960, p. 45) have observed that wherever canga is protected by a soil cover, however thin, or where it has been only recently exposed, it exhibits a smooth botryoidal surface that changes progressively away from the cover and shows an increased breakdown of the botryoidal structure. Every bare canga surface shows a characteristic rough, hackly surface.

From this evidence it might be inferred that all the canga was once covered by soil and vegetation, although most of it is relatively bare now. The iron-formation is covered by thick soil and dense vegetation in some places. In a few of these areas, test pits or trenches have exposed a thick layer of canga, with a botryoidal surface, below the soil. In some places the boundary between bare canga and soil-and-forest-covered canga follows a property boundary or other artificial line rather than a topographic or geologic "boundary line." Because most of the canga and iron-formation occur in areas of high relief and the soil cover over the canga is generally relatively thin, cutting the forest cover and burning the grass and brush allow rapid erosion of the soil during the next rainy season. Once the soil is removed the canga weathers, hardens, and forms a hard cap that inhibits additional erosions.

LATERITE

Most of the residual soils in the Quadrilátero Ferrífero are pedalfers and, except where they are underlain by quartzite, are ferruginous and (or) aluminous laterites.

In areas of low relief, a mantle of laterite overlies a deep layer of saprolite. The laterite generally ranges in thickness from about 50 cm to 10 meters and probably averages 1 or 2 meters. The saprolite is commonly as much as 60 meters thick, and is so widespread in the areas underlain by granitic and schistose rocks that outcrops of relatively fresh rock are very sparse. Schist and gneiss in the Quadrilátero Ferrífero have generally been mapped on the basis of the lithology and structure of the saprolite.

Laterite formed on hills where soil drainage is good is a hard indurated type, easily broken when moist but hardening on exposure to air. It is extensively used in road construction.

Throughout the Alegria district, the laterite on the tops of hills or well-drained mesas has been altered to aluminous laterite or bauxite, and in low marshy areas the laterite has been altered to kaolin, in many places virtually pure. This alteration seems to be a direct function of the drainage: kaolin forms only near or below the water table, bauxite only on the tops of well-drained mesas, and aluminous laterite in intervening areas.

The bauxite generally occurs as a thin layer on the laterite, and is underlain by a thick transition zone to clay and saprolite.

Table 3 lists analyses of clay and laterite from the Santa Rita Durão quadrangle. Analyses of bauxite and laterite from the Fazendão deposits are shown on pages J65, J66.

TABLE 3.—*Analyses, in weight percent, of clay and laterite samples from the Alegria district*

[Analysts: Siderúrgica Belgo-Mineiro staff]

	1	2	3	4
SiO_2	13. 20	44. 00	16. 60	15. 40
Fe_2O_3	40. 36	7. 12	32. 44	37. 18
Al_2O_3	25. 57	36. 18	32. 17	28. 83
Loss on ignition	18. 90	13. 00	18. 80	19. 00

1. Chemical canga, hardpan, Espigão do Canga.
2. Clay bed below hardpan in low area.
3, 4. Laterite, Espigão do Canga.

ALLUVIUM

Small deposits of sand, gravel, and transported silt and clay occur along the major streams and many small tributaries and at many spots on the hills and ridges where they have not been removed by rejuvenated streams.

Many of the thick alluvial deposits, especially on the smaller streams, have been formed in the last 200 years and are composed of tailings from placer gold mining. Only a few of the large alluvial deposits, and a few of the perched gravels, are shown on the maps.

The alluvium consists for the most part of silt and clay with interbedded lenses of gravel and coarse sand made up mostly of vein quartz, quartzite, and hematite. In some places, considerable fine black sand is admixed in layers and lenses in the gravel. The gravels are auriferous, and most have been worked for their gold content.

Deposits of residual soil and gravel occur on many small terraces and hilltops in the Alegria district. Small pockets of gravel in a residual soil were found on top of the Serra Caraça and Serra Batatal and on ridges in the Capanema area. They are described in the section on "Geomorphology" (p. J6). Gravel and laterite in several areas south and east of Santa Rita Durão are probably remnants of more extensive deposits. Other gravel deposits occur on terraces near Catas Altas. The gravels near Capanema and Catas Altas have been worked for placer gold.

PRECAMBRIAN IGNEOUS ROCKS

Three types of igneous rocks occur in the Alegria district: (1) granite-granodiorite gneiss (shown on the geologic maps as gneiss and granite undifferentiated), (2) a mafic and ultramafic suite of intrusive and extrusive rocks now altered to serpentine, soapstone and talc, and chlorite schists, and (3) diabasic and porphyritic dike rocks now mostly altered to chlorite schist. The gneisses are in contact with rocks of pre-Minas and Minas age in the eastern part of the area and show a border or transition zone of migmatite. The mafic and ultramafic suite occurs only in a band from the north-central part of the Catas Altas quadrangle to the northeastern part of the Santa Rita Durão quadrangle between the Tamanduá and Nova Lima Groups and the Minas Series. The diabasic rocks are most abundant in rocks of pre-Minas age, but also intrude rocks of the Minas Series in a few places.

Small pegmatite veins of simple mineralogy occur in both the gneissic rocks and the metamorphic rocks. Quartz-tourmaline veins also occur in both gneissic and schistose rocks in the eastern part of the district, near the gneiss contacts. Quartz-kyanite veins occur in the Maquiné Group, in the Cercadinho Formation, and in the Itacolomi Series. Milky quartz veins occur in all formations in the district. Many of them contain vugs of clear quartz crystals, which have been mined for optical or piezoelectric quartz.

GRANITE-GRANODIORITE GNEISS

Most of the rocks mapped as gneiss on plates 2 and 3 are deeply weathered to saprolite and covered by a thick layer of soil. The saprolite exhibits all the textures and structures of the parent rock. The few exposures of fresh rock are light- to medium-gray fine- to medium-grained granite or granodiorite gneiss, with dark-gray or greenish-gray poorly defined layers or contorted lenses of fine-grained quartz-biotite gneiss or quartz-amphibolite gneiss.

Exposures of the contact or contact zone of the granitic rocks with the metamorphic rocks are rare in the district. The contact with the greenstone sequence at the northern edge of the Catas Altas quadrangle was placed at a change in soil type near exposures of chlorite schist.

The contact of the gneiss with the quartzite over most of its length across the Catas Altas quadrangle shows an interlayering, and tongues of gneiss intrude the quartzite in many places. The contact was placed at the point where the proportion of feldspar to quartz was high enough to radically change the weathering characteristics of the rock.

South of a cross fault in the Catas Altas quadrangle at (N. 12,300, E. 5,350), the Moeda Formation, although recognizable, is altered to a gneissic-appearing rock composed of rounded quartz grains with quartz overgrowths, biotite, and orthoclase feldspar. At its outer edge, Moeda quartzite to the south at or near the contact with the granitic rocks has the same general composition. Outcrops (Catas Altas quad., N. 10,200, E. 5,800) show a transition from quartzite with scattered small grains of biotite and orthoclase to a gneiss with quartz, orthoclase, microcline, biotite, and albite, with calcite and muscovite(?) associated with the albite, possibly alteration products from a more calcic plagioclase. The transition zone generally ranges from about 1 to 20 meters in width.

Many small bodies of migmatite occur along the contact in the Catas Altas and Santa Rita Durão quadrangles; most were too small to map separately. They are composed generally of deeply weathered schists in layers ranging from a few millimeters to several centimeters in thickness alternating with layers of granitic gneiss ranging from 1 to about 20 cm in thickness. Similar migmatites in larger areas of mixed gneissic and metamorphic rocks contain many lenses of schist and phyllite and layers of gneiss or very fine grained quartz-microcline pegmatite. The gneiss in most of the migmatites is very similar to but slightly finer grained than the adjacent gneiss body. The schists and phyllites are for the most part identical in general appearance with those in the Nova Lima Group. Schists near the contact with gneissic rock (Santa Rita Durão quad. N. 3,100, E. 8,800) contains shattered and deformed garnet crystals as much as 2 cm in diameter, indicating post-metamorphic deformation. The entire area is in the biotite zone of regional metamorphism, with no indication of a contact-metamorphic aureole around the gneiss (Herz, 1970).

The gneiss is composed of quartz, microcline, microperthite, plagioclase, biotite, sericite, and muscovite with accessory garnet, zircon, clinozoisite, allanite, and xenotime. Some specimens show calcite and sericite in albite grains, apparently derived by alteration of more calcic plagioclase. Most specimens are generally felsic and equigranular. Many show a mortar structure. The plagioclase generally shows a wormy alteration to sericite. The biotite alters to a green biotite and to chlorite (fig. 14).

The range of modes of the gneiss, specimens mostly from the Catas Altas quadrangle, were: potassium feldspar 20–35 percent, plagioclase (predominantly oligoclase) 25–40 percent, quartz 20–40 percent, biotite 6–14 percent, white mica 0–6 percent, chlorite 0–4 percent.

Analyses of two samples of gneiss from near Santa Bárbara, about 3 km north of the Catas Altas quadrangle, are as follows:

	A	*B*		*A*	*B*
SiO_2	74.68	72.4	K_2O	4.45	3.9
Al_2O_3	13.49	14.2	H_2O^+	.66	-------
Fe_2O_3	.65	.7	H_2O^-	.07	.50
FeO	.84	1.3	TiO_2	.17	.19
MgO	.71	.32	P_2O_5	.01	.06
CaO	.52	1.4	MnO	.05	.08
Na_2O	3.70	4.3	CO_2	.05	.38

A. Analysis by Moraes (1939, p. 171).
B. Analyses by P. Elmore and others (Herz, 1970, table 12).

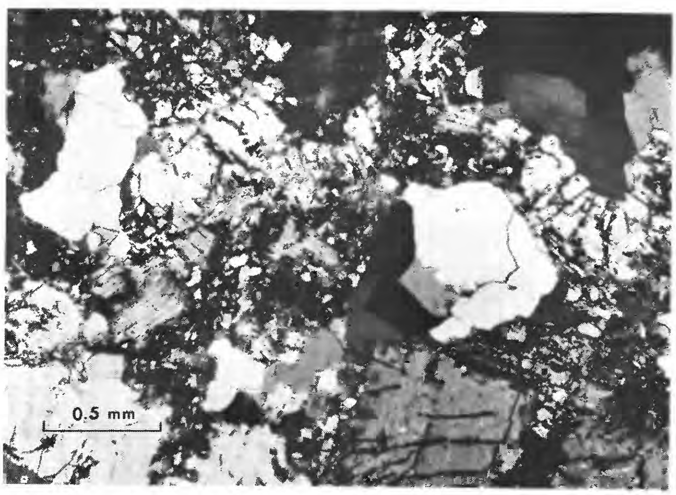

FIGURE 14.—Photomicrograph of granite gneiss. Crossed nicols. (Catas Altas quad., N. 4,750, E. 12,650.)

MAFIC AND ULTRAMAFIC ROCKS

The mafic and ultramafic rocks of the Alegria district are grouped in a single unit shown on plates 2 and 3 under the general field term "greenstone sequence." The rocks are all altered and so deeply weathered and poorly exposed that separation was impractical. They probably include metasedimentary rocks, mafic and ultramafic intrusive and extrusive rocks, and mafic dike rocks similar to those mapped separately in the adjacent Cambotas Quartzite. The greenstone is composed mostly of chlorite, serpentine, talc, and tremolite-actinolite, with accessory magnetite, pyrite, apatite, and tourmaline. Relicts of albite are common in some specimens.

The chlorite consists mostly of clinochlore, but prochlorite is predominant in a few layers. Some specimens show a large percentage of penninite, both as clots of tiny crystals and as euhedral crystals enclosed in other chlorite or in talc (fig. 15). Cronstedite, an iron chlorite, has been tentatively identified in some specimens (Norman Herz, oral commun. 1960).

FIGURE 15.—Photomicrograph of altered mafic rock. p, penninite; t, talc; c, chlorite. Most of the dark groundmass is antigorite(?). Crossed nicols. (Catas Altas quad., N. 10,400, E. 4,050.)

The serpentine is largely chloritelike antigorite, but massive serpentine with included veins of chrysotile is common in certain bands. The chrysotile occurs both as the silky cross-fiber type and as lenses and pods of the coarse slip-fiber type, with fibers as much as 8 cm in length.

The talc occurs as massive soapstone, foliated talc schists, and crystals and replacement bodies in the chlorite and serpentine rocks.

Magnetite is the most abundant of the accessory minerals and, in one specimen, the most spectacular. The chlorite schist (Catas Altas quad., N. 11,200, E. 5,300) contains huge nearly perfect octahedra of magnetite as much as 7 cm (2.8 in.) in axial dimensions. Most of the crystals there are 3–5 cm in size. Figure 16 shows of the largest and most perfect crystals. Elsewhere in the quadrangle, the average axial dimension of magnetite crystals is 1 cm, and the largest are about 3 cm.

Most of the magnetite crystals occur in a relatively narrow zone adjacent to the Moeda and Batatal Formations extending from near the northern border of the Catas Altas quadrangle south to the vicinity of Pitangui. Only a few scattered occurrences of small crystals were noted elsewhere in the chlorite schist.

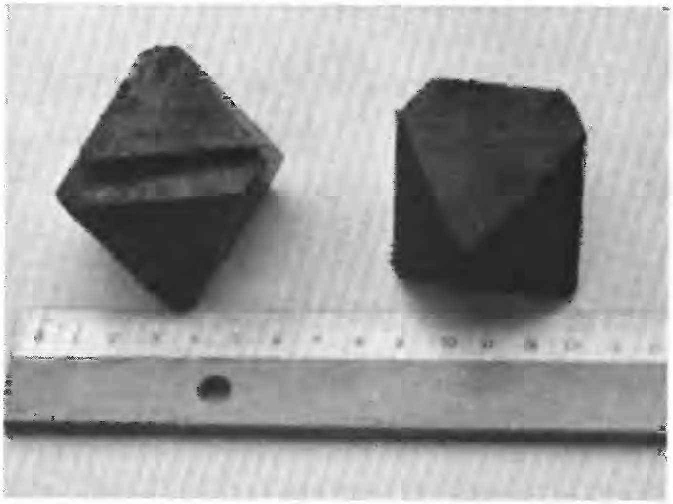

FIGURE 16.—Magnetite crystals from the Catas Altas quadrangle. Scale in centimeters.

FIGURE 17.—Photomicrograph of magnetite-chlorite schist. The opaque material is magnetite; the large crystal contains inclusions and embayments of apatite, which is also present in the chlorite groundmass. Plane light. (Catas Altas quad., N. 11,200, E. 5,150.)

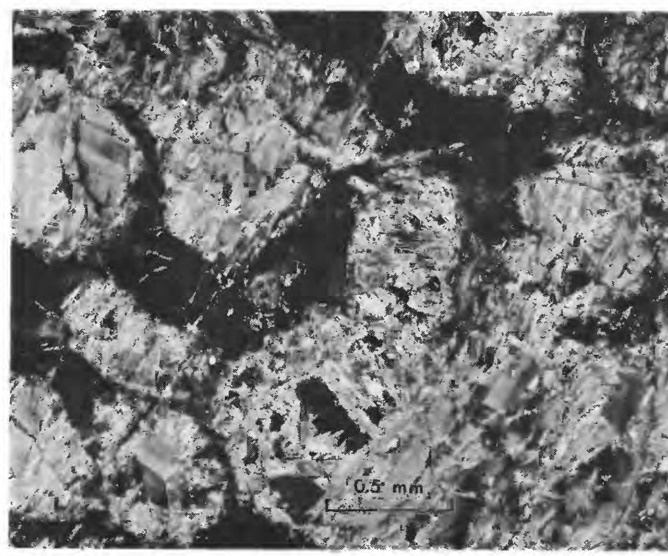

FIGURE 18.—Photomicrograph of altered peridotite, now composed of rounded aggregates of talc and chlorite in a groundmass of antigorite(?). Crossed nicols. (Catas Altas quad., N. 7,700, E. 2,400.)

Thin sections of chlorite schist from one locality show a fine-grained matrix of chlorite with small clusters of apatite in the chlorite and in some grains of magnetite (fig. 17). Apatite is absent from some sections. In other sections, magnetite occurs as crystals about 0.01 mm in diameter. Chlorite schists from other localities (Santa Rita Durão quad., N. 8,100, E. 6,800[1]; N. 10,800, E. 7,000; Catas Altas quad., N. 2,000, E. 8,700; N. 10,000, E. 4,500) appear identical in hand specimens and thin section but lack magnetite. The chlorite schist in a discontinuous zone roughly parallel to and just west of the magnetite zone, contains euhedral pyrite crystals ranging in size from 2 mm to 6 cm, now mostly altered to goethite. In one place (Catas Altas quad., N. 11,000, E. 4,850) goethite pseudomorphs were found which apparently were originally pyrite. They are all consistently deformed in the same manner to striated crystals exhibiting an apparent triclinic symmetry. The well-developed faces, however, are those of a striated cube modified by either a diploid or a pyritohedron, with the longest axis of the distorted cube inclined 10°–15°.

An antigorite schist with small inclusions of talc and penninite crops out in the Catas Altas quadrangle (N. 7,700, E. 2,400). Thin sections show a peridotite texture with small rounded clots or aggregates of small unoriented plates of talc and small equidimensional clots of dark-green fine-grained chlorite in a groundmass of antigorite(?) (fig. 18).

The contact between the Nova Lima Group and the greenstone sequence in the northern part of the Catas Altas quadrangle is inferred. It is placed between exposures of fine-grained friable quartz-chlorite-sericite schist that weathers reddish and yellowish and exposures of massive green medium- to coarse-grained chlorite schist and associated gray-green talc schist. The contact with the Tamanduá Group north of Córrego do Tanque Prêto (Catas Altas quad., N. 8,800, E. 4,200) appears to be erosional. The rock at the contact is composed of small fragments of quartzose phyllite in a matrix of quartz and chlorite, which grades into the chlorite schist on one side and into quartzose phyllite of the Tamanduá on the other. A tongue of chlorite schist (Catas Altas quad., N. 8,700, E. 4,000) appears to be gradational into a layer of iron-formation and into phyllites; exposures at the contact are very poor. The chlorite schist is identical with the main body to the north and weathers to the same thin yellowish-red soil;

[1] Sabará Formation.

similar bands or layers in the quartzite to the south weather to a deep red lateritic soil and are apparently related to the diabasic dikes. Thin sections from samples collected across a 3-meter contact zone in the Catas Altas quadrangle N. 6,500, E. 6,400, show a progressive alteration from a sericitic quartzite to a chlorite-sericite quartzite to a quartzose chlorite schist to a chlorite schist with many small grains of a carbonate mineral.

Near the center of the Catas Altas quadrangle, the Itabira Group is interlayered with the greenstone. Thin fingers of chlorite schist several meters long extend into the iron-formation and thin beds of iron-formation into the chlorite schist. The same features were observed to the north, between the greenstone and the Batatal Formation. Wherever the contact of the greenstone sequence with the Minas Series was exposed south of Pitangui (fig. 27) it appeared to be in sedimentary contact with the Moeda Formation, as at Morro da Mina (Capanema quad.).

DIKE ROCKS

The most common dike rocks in the Alegria district are those shown on the geologic maps as diabase dikes. They occur mostly in a swarm and intrude fault planes in the Serra do Caraça, both in the Cambotas quartzite and in the overlying and underlying schists and quartzites (pls. 1–3). The dikes in the Serra do Caraça are deeply weathered and commonly eroded below the level of the surrounding quartzite; they form a thick dark-red soil that supports luxuriant vegetation. A hard ferruginous laterite has formed in some areas where the dikes cross hills and ridges. Exposures of the dike rock are rare and generally deeply weathered. No fresh rock was found.

A thin section of one deeply weathered but coherent specimen showed ophitic texture, elongate coarse plates of muscovite randomly oriented with interstices filled with a yellow and green pleochroic chlorite, small irregular aggregates of quartz grains, and a few grains of an opaque mineral, apparently mostly magnetite. This specimen was from a dike intruding a fault in the Maquiné Group (Capanema quad., N. 13,650, E. 7,800).

A dike in the Nova Lima Group (Catas Altas quad., N. 11,050, E. 1,700) is composed of large crystals of actinolite and smaller crystals of clinozoisite-epidote and serpentine. The groundmass consists mostly of oligoclase-andesine (An_{30}) with scattered chlorite flakes and possibly quartz. Much of the feldspar is in clear untwinned grains very difficult to distinguish from quartz. There are a few small grains of carbonate, apparently calcite, and several large grains of leucoxene. The rock was probably altered from a pyroxenite.

A dike of porphyritic diabase in the Catas Altas quadrangle (N. 7,650, E. 2,550) intrudes the Cambotas Quartzite in the same manner and orientation as the diabasic dikes, but mapped separately on plate 3. It is a dark-green fine-grained rock with phenocrysts of plagioclase as much as 3 cm in length (fig. 19), that have been largely saussuritized to a mixture of pure albite and clinozoisite, with wavy albite twinning and many inclusions, mostly of a pleochroic green ripidolite chlorite (N_m 1.633) (Herz, 1970, p. B41). The groundmass is composed of green chlorite, quartz, biotite, large muscovite clots, calcite, epidote, K-feldspar, and opaque minerals rimmed by leucoxene (fig. 20). A complete analysis of this rock is given by Herz (1970, table 13, p. B41).

Several small granitic dikes intrude schists and quartzite near the contact with the large gneiss body on

FIGURE 19.—Porphyritic diabase dike. The light-colored polygonal spots under the water and the small bumps on the right and at the end of the hammer handle are phenocrysts of albite.

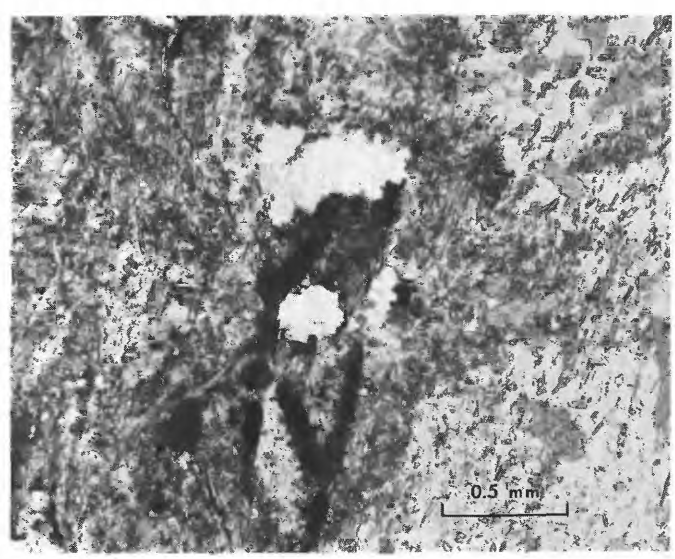

FIGURE 20.—Photomicrograph of porphyritic diabase. The right half of the picture shows part of a phenocryst of albite (Ab_{100}) with many inclusions of chlorite (ripidolite?), epidote, muscovite, and calcite. The opaque laths are rimmed with leucoxene. The left half of the picture shows small plagioclase laths, calcite, biotite, chlorite, and quartz. × 40, plane light (Catas Altas quad., N. 7,700, E. 2,600.)

the eastern side of the district. They have approximately the same composition as the gneiss. Because of the very poor exposures they were not mapped separately but were included with the surrounding rock. They probably largely represent a metasomatic granitization in sheared or shattered zones. The Santa Rita fault was intruded by granitic rock in many places but most conspicuously in the southern half of the Santa Rita Durão quadrangle.

QUARTZ VEINS

Quartz veins are abundant in all rocks in the district, particularly in quartzite. They may be divided into several types according to their occurrence and mineralogy.

SIMPLE QUARTZ VEINS

Most quartz veins consist of cloudy white "bull" quartz, which may contain zones or vugs of clear crystalline quartz. Vugs are most conspicuous, though not necessarily most abundant, in quartzite of the Moeda Formation and in the Cambotas Quartzite. Many veins in the quartzite are pockmarked by thousands of holes that were dug by prospectors looking for clear untwinned crystals for use in the radio industry during World War II.

The veins range from microscopic stringers to masses 10 meters thick or more and several hundred meters long. Only the largest were mapped (pls. 1 and 3).

Where these veins crop out in schistose rocks they form small hills and ridges. In the quartzite and more resistant rocks, however, they are generally inconspicuous, except the larger veins of massive white bull quartz, which remain as walls as the less resistant quartzite weathers away. The veins commonly weather to a fine-grained sugary texture which is difficult to distinguish from cataclasite-quartzite in shear zones. The presence of many quartz veins is revealed only by a small amount of milky float or small clear quartz crystals. These veins are numerous in the neighborhood of Serra do Batatal (Capanema quad., N. 5,000, E. 5,000). There, as well as in many other localities in the Quadrilátero Ferrífero, the veins include vugs and masses of water-clear crystals ranging from a few millimeters to a meter or more in length. Many of the crystals are doubly terminated; some of the smaller crystals are perfectly formed.

Most of the quartz veins in the quartzites are parallel to, and commonly traceable into, shear zones, faults, or zones of cataclastic rock. They may have been formed in the late stages of the orogeny which produced the faults.

QUARTZ-KYANITE VEINS

Quartz-kyanite and quartz-kyanite-pyrophyllite veins are locally very common in some units, such as the Maquiné Group, Cercadinho Formation, and Itacolomi Series, and are rare or absent in the others.

Milky quartz veins with randomly oriented bright-blue or blue-green blades of kyanite occur in the Maquiné Group and in a few places in the Cambotas Quartzite. One representative locality is on the road to Capanema (N. 4,300, E. 1,650), where a lenticular vein of milky quartz containing kyanite blades that average about 3 cm by 7 mm by 1 mm in size crops out in the roadcut. Another representative locality is in the Serra do Caraça (Catas Altas quad., N. 2,100, E. 4,650) (pl. 3).

Extensive quartz-sericite-kyanite veins occur in and along faults and shears in many localities. Most of the specimens show a felted network of kyanite crystals, commonly slightly radiating. They are randomly oriented in two dimensions but are generally parallel to the schistose structure paralleling the faults. Small bodies of kyanite in completely random orientation are found in a few places along the faults.

Quartz-kyanite-pyrophyllite veins ranging in thickness from about 4 cm to about 1 meter are common in most exposures of the Cercadinho Formation in the Alegria district. The veins are zoned; a quartz core is bounded on both sides by selvages of kyanite ranging from about 5 mm to 10 cm in thickness. The kyanite with included pyrophyllite and muscovite is oriented at right angles to the outer edges of the vein. Where the outer boundary of the vein curves, the kyanite remains at right angles to the vein walls in a radiating arrangement. The contact of kyanite with the country rock is sharp; the kyanite-quartz core contact is irregular and hackly.

QUARTZ-HEMATITE VEINS

Quartz-hematite or quartz-specularite veins are relatively common in the Itabira and Piracicaba Groups and in the Itacolomi Series. They have not been found in the pre-Minas rocks in the Alegria district. The most common occurrence is in small crosscutting veins or rodlike pods in the Itabira Group. These veins are commonly small, with abundant flaky specularite in thin plates, which may be strongly curved.

Quartz veins with large single and multiple crystals of hematite as much as 10 cm in diameter and 3 cm thick are exposed in the Santa Rita Durão quadrangle (N. 4,300, E. 2,000; N. 400, E. 400). In many other localities crystals of hematite have been found as float. These veins are common in the Cercadinho and Santo Antônio Formations.

OTHER QUARTZ VEINS

Several other types of vein quartz have been found in the Alegria district. Veins of rutilated quartz are common in the manganiferous itabirite around Conta História. One, between adits 52 and 53, fills a northeast-trending fracture. The quartz has a fibrous appearance and a pseudocleavage. The fibers are in columns 2–4 mm in diameter that extend perpendicularly from wall to wall of the vein. The columns are separated by thin films of amorphous iron and manganese oxides. Some of the columns are round and have a central core of goethite; others are irregular, with grooves filled with goethite. The quartz is filled with tiny black and red-black hairlike acicular needles tentatively identified as rutile, all arranged generally parallel to the columns. Several small ones were immersed in oil on a slide and rotated on the microscope. The extinction of individual columns was invariably uniform and at an angle to the crosshairs; different columns showed different orientations but always at a small angle.

Small quartz-tourmaline and quartz-feldspar veins are locally common in the gneiss, migmatites, and metamorphic rocks near the gneiss contact.

METAMORPHISM

The metamorphic history of the Quadrilátero Ferrífero is complex, and involved five datable events: at about 2,700, 1,930, 1,350, 1,000 and 500 m.y. (million years). The four older events were related to intrusion of igneous rocks and the formation of gneiss, and the 500 m.y. event was largely thermal, accompanied by the formation of pegmatites (Herz, 1970, p. 48).

Three major periods of orogeny are involved in the history of the area. During the earliest orogeny, the rocks were apparently subjected to high temperature and high-pressure regional metamorphism and converted to the garnet-amphibolite facies (Herz, 1960, p. 99). The metamorphic effect of the next orogeny was apparently limited to contact or thermal metamorphism. In the last major orogeny, the rocks underwent a general low-grade chlorite-isograd metamorphism, but in places, granitization and contact metamorphism as high as the staurolite isograd took place (Herz, 1960, p. 102). The metamorphic grade increases to the east, apparently the result of more widespread granitic intrusion. The effects of retrograde metamorphism are locally evident.

The regional metamorphic grade in the Alegria district corresponds in general to the chlorite or biotite isograd. The arenaceous rocks, quartzite and quartz-rich phyllites, have cataclastic textures; strained or crushed quartz grains are surrounded by sericite, muscovite, chlorite, and fine-grained recrystallized quartz. The argillaceous rocks are mainly medium- to coarse-grained quartz-sericite-chlorite phyllite or schist. The carbonate rocks are composed of dolomite and quartz with chlorite, muscovite or phlogopite, talc, and in a few places tremolite. Inclusions of hematite and magnetite are locally common. The ferruginous sediments were metamorphosed to itabirite, or to dolomitic and amphobolitic itabirite. Chloritoid is a common constituent of many of the quartzites and subgraywackes.

Garnet occurs in several localities in the eastern part of the district in chlorite-sericite phyllites and schists. The garnets occur both as very small or microscopic crystals and as shattered and deformed crystals as much as 2 cm in diameter; their association and appearance suggest either almandite or andradite, but no determinations were made. Some of the garnets occur along the borders of the gneisses and undoubtedly represent local contact aureoles. Others are probably associated with the roof of a contact aureole. The distribution of garnets is not sufficiently consistent and widespread to indicate that they resulted from regional metamorphism.

The borders of the gneiss bodies generally show a transition zone of migmatite or granitized metamorphic rocks, some of which appear to be the result of pneumatolitic metamorphism. The metamorphic grade of the rocks adjacent to these transition zones is generally the same low grade as the regional chlorite zone.

Kyanite is commonly disseminated in the quartzite, quartz-sericite schist, and graywackes and is seemingly anomalous in view of the low grade of metamorphism of the surrounding rocks. It formed in the troughs of synclines in country rocks that were unusually high in Al_2O_3 (more than 20 percent) and SiO_2 and were metamorphosed at high pressures and moderate temperatures coexistent with the greenschist facies (Herz and Dutra, 1964).

Veins of kyanite, with associated quartz, muscovite, and pyrophyllite, are present in most formations in the district, but are most common in the pre-Minas quartzites and in the Cercadinho Formation. Some have a distinct quartz core and a kyanite-pyrophyllite muscovite border, but most are irregular replacement bodies in breccia and shear zones. The vein kyanite formed at lower pressures and perhaps higher temperatures than the disseminated kyanite and was apparently produced by hydrothermal or pneumatolytic solutions (Herz and Dutra, 1964).

Topaz has been reported by local residents from an area near Germano, apparently from the Cercadinho Formation in or near the large fault zone between Conta História and Germano. The writer found one small water-worn pebble of topaz in that area.

Rocks in several small areas in and adjacent to outcrops of the greenstone sequence in the Catas Altas quadrangle have a higher grade of metamorphism than rocks in the rest of the area. They contain garnet, staurolite, kyanite, huge magnetite and pyrite crystals, and many small quartz-tourmaline veins. These minerals may have formed as a result of contact metamorphism.

STRUCTURE

The Precambrian rocks in the Quadrilátero Ferrífero have been affected by at least three major periods of orogeny. The first resulted in the deformation and metamorphism of the oldest sedimentary rocks in the district, and the intrusion of granodiorite. The second was largely a palingenetic reactivation of the granodiorite domes with the consequent deformation, contact metamorphism, and emplacement of granite.

Structures that evolved during the first two periods of orogeny were largely obscured by the effects of the third orogeny, which is interpreted to have comprised four interrelated stages. The first was a general regional dynamo-thermal metamorphism to the chlorite grade. This was followed by renewed uplift of the granodiorite domes and folding, which produced north- and east-trending closed synclines and broad open domes and anticlinoriums. During the third stage, pressure and stress were relieved around the domes and subsidiary folds formed at various angles to the folds of the preceding stage. Thrust faults and fracture zones were formed, and granite was intruded in many areas. The margins of the granodiorite domes and some fracture zones were metasomatized and granitized. During the last stage, stresses oriented southeast to northwest folded and thrust the Minas Series and younger rocks around and over the domes.

These deformations produced a complex system of crossfolds and thrust and reverse faults. The folds are generally overturned toward the north and west, and many are isoclinal. Some pass into reverse or thrust faults. High- to low-angle reverse faults are common, thrust and normal faults are less common. Most of the faults have the same general trend as the folds. In many areas, notably in the Serra do Caraça, some of the faults are partly intruded by diabasic dikes.

The present outcrop pattern of the Minas Series shows sinuous synclines arranged in an approximately polygonal pattern, deeply eroded so that only the troughs are left and with part of the limbs obscured either by thrusting or by granite intrusion. The synclines are bent and folded around axes plunging southeast at moderate angles. Superimposed on these major structures are many subsidiary folds, pencil structures, and lineations that plunge moderately to steeply S. 70° E. to east.

STRUCTURAL ELEMENTS

PLANAR ELEMENTS

BEDDING

Bedding is commonly the most conspicuous single feature in most of the Minas and post-Minas rocks. In weathered outcrops of pre-Minas rocks, however, it is difficult or impossible to distinguish. The apparent bedding or layering in these rocks is the result of structural deformation. Most quartzite and dolomite beds are massive and show no clear bedding in outcrop but may show a diastrophic planar element. The only bedding clearly distinguishable in the Alegria district is in those outcrops which show a series of rocks differing markedly in composition and (or) texture, and bounded by relatively plane and parallel surfaces, or those rocks which have preserved such sedimentary features as crossbedding, graded bedding, and ripple marks.

Graded bedding was observed in many places in the Cambotas, Moeda, Cercadinho, and Itacolomi quartzites and was very useful in determining the attitude of bedding. Pseudoripple marks were seen in many places, but no clearly sedimentary ripple marks were observed.

Crossbedding of both the current and scour-and-fill types is locally common in the quartzites of the Cambotas and Cercadinho Formations. The long straight foreset beds in the Cambotas Quartzite generally make an angle of about 20° with the gross bedding. The foreset beds are as much as 20 meters long in gross bedding, 8–10 meters thick, and where recognizable are generally more than 4 meters long in beds 1–2 meters thick. Scour-and-fill crossbedding in overlapping spoon-shaped "lenses" 30–150 cm in diameter is the most common type. Many of these lenses have grit or pebbles at the bottom and become progressivley finer toward the top, or have curved wedge-shaped layers 0.5–2 cm thick showing graded bedding within the layers. These structures in any one outcrop show a wide variation in orientation. The outcrops in one area may show a slight preferential orientation in one direction, but no attempt was made to determine these directions for the district.

SCHISTOSITY AND FOLIATION

Most of the metamorphic rocks in the district contain platy minerals that are generally oriented in one plane and impart fissility or schistosity.

Schistosity is parallel or nearly parallel to the compositional layering or bedding in most of the rocks in the Minas Series, even around many folds. In the pre-Minas rocks, the schistosity is parallel to the bedding of Minas rocks close to contacts but follows a regional trend of north-south and northeast-southwest away from the contacts, and crosses the bedding where there is any variation in attitude of the pre-Minas formations. If the stratigraphic trends of the pre-Minas rocks happen to parallel the trends of the Minas rocks, then the bedding and schistosity are generally parallel, but if the pre-Minas bedding is at an angle to the Minas rocks, as it is in many localities (Rynearson and others, 1954), the schistosity is generally parallel to the Minas rocks and across the bedding of the pre-Minas rocks. This is in most cases an axial plane schistosity.

Locally, where a well-developed schistosity intersects what appears to be a nearly obliterated relict schistosity, a lineation can be seen at the intersection, even if the relict schistosity cannot be distinguished in hand specimen. A few combination symbols on the geologic maps show that in some outcrops there are intersections of bedding, one or more schistosities, and a slip or fracture cleavage.

In several areas in the Alegria district, rocks show only flow cleavage parallel to major shear zones or faults. In one such area, in the south-central part of the Capanema quadrangle, rocks of the Maquíne group consist mostly of cataclasites which have true compositional layering in only a few exposures. The plane of the flow cleavage is roughly parallel to the fault planes in that area. Flow cleavage in another area is in the mafic rocks along the east side of the Serra do Caraça. Here the schistosity and flow cleavage are generally indistinguishable but are generally parallel to extensive faults within the unit, and are presumed to be caused by solid movement of the rocks. Within the faults some lenses of rocks are composed mostly of coarse to very coarse grained chlorite, serpentine, and talc in random orientation; they are assumed to be the product of later recrystallization of the rock.

In the southwest of the Capanema quadrangle, the regional fabric of the Nova Lima Group, generally schistosity or foliation, is locally transverse to the bedding, masking it and in places obliterating it entirely. These relations are shown in an outcrop in the Campo do Rocha area (fig. 21). The original bedding is very difficult to see in this outcrop; the only evidence of it is the relative abundance of quartz in zones striking unevenly east-northeast. Two zones in this outcrop are absolutely free of quartz, and fragments ground between teeth have no gritty feeling. The other two zones contain much quartz. At right angles to this vague banding is an obvious color banding that superficially resembles compositional layering and could easily be mistaken for bedding. The schistosity is approximately parallel to this color banding. In other outcrops in the same general area, color banding and schistosity intersect at various angles.

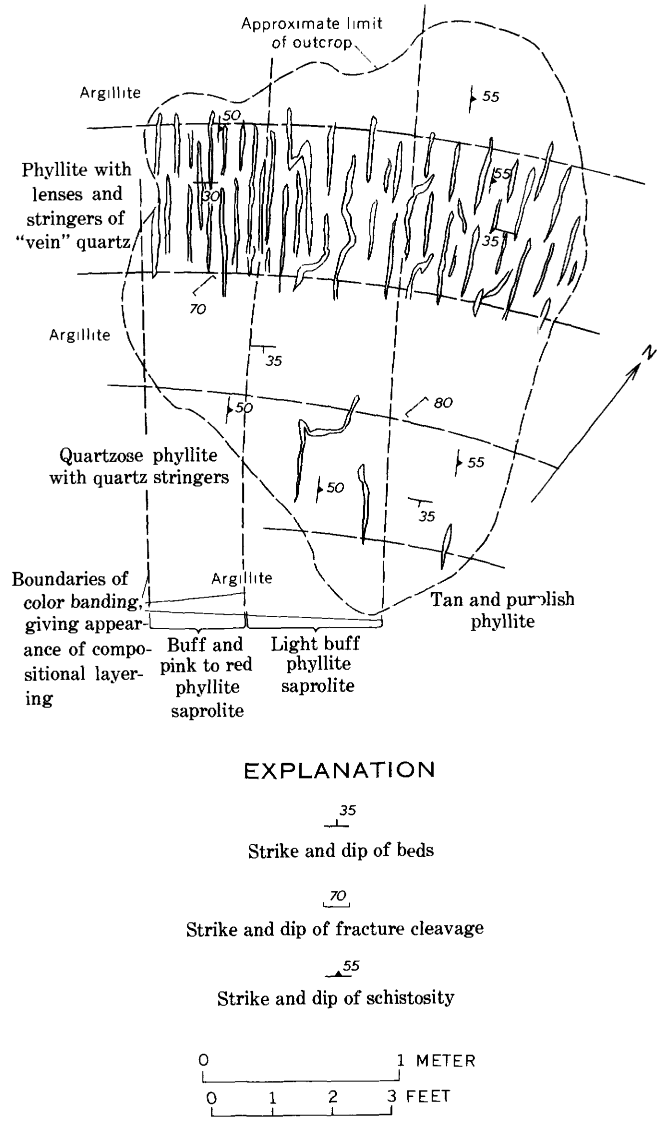

FIGURE 21.—Sketch of an outcrop of rocks of the Nova Lima Group in the Campo do Rocha area, illustrating the almost complete obliteration of original bedding by a color banding and superimposed schistosity.

This might indicate three ages of "layering": original bedding, an imposed schistosity that has color banding parallel to it, and a second schistosity superimposed over the other two. Many outcrops show two distinct lineations in the plane of the last schistosity, and two in the plane of the color banding. One of these limitations is consistent and is in the line of intersection of the schistosity with a N. 5°–10° E. fracture cleavage; the other is variable and is apparently the intersection of the two schistosities.

FRACTURE OR SLIP CLEAVAGE

A conspicuous feature in much of the schist and phyllite of the district is a corrugation or fracturing of the rock in closely spaced parallel planes. Some of the planes show a distinct movement; in others there is no apparent dislocation, only fracturing. Where movement can be recognized along these planes, the upward movement is almost invariably on the south or east side of the plane. Many specimens show no fracturing, only a corrugation in the plane of the schistosity which looks like miniature current ripple marks. In cross section, the corrugations resemble miniature drag folds, the tops of which moved upward toward the north or west. The trend of the fracture cleavage varies widely, but in general there are two major attitudes, north-south to N. 10° E. and east-west, both steeply dipping.

JOINTS

Joints are abundant in all the rocks in the district. Some outcrops may have three or four conspicuous sets and as many vague or poorly developed sets. Joints are particularly well developed in the hard quartzites (fig. 22), much less so in the softer rocks. Many joint sets seem to be closely associated with slip cleavage. In some areas, the joints are closely spaced, 10–15 cm apart; generally they are spaced from less than a meter to several meters apart.

Joints are responsible for some of the more spectacular topography in the district. On the Pico do Inficionado at the southeast end of the Serra do Caraça (Santa Rita Durão quad.) there are a great many deep straight-walled sink holes whose only outlets are narrow joints. These sinks are controlled by joints and were apparently formed by solution, disaggregation, and transportation along joint planes of the material from areas between joints. These sinks range from a few meters wide and several tens of meters long to as much as 30–40 meters wide and 250 meters long. Depths range from a few meters to more than 100 meters. They are formidable obstacles to travel. Most of the top of the Serra do Caraça is cut by such sinks and caverns. Some sinks are controlled by several sets of joints, as in the Pico do Inficionado, but most are controlled by faults.

Except in a few representative areas, joint symbols were not included on the geologic maps; those shown are only the most conspicuous sets.

LINEAR ELEMENTS

The linear elements in the Alegria district comprise several types of lineations that have several distinct trends. Lack of outcrops prevented determination of the lineation types (*a*, *b*, or *s*) or their correlation with the different periods of folding.

Linear elements were measured wherever possible and are shown on the geologic maps by symbols indicating which elements were affected to form the lineation. They are grouped into five divisions: (1) axes of small-scale folds, (2) axes of crenulations, (3) flow lines, mineral alinement, and stretching of pebbles, (4) intersections of bedding planes, schistosity and foliation, pencil structure, and (5) slickensides and striae on bedding planes, schistosity and faults.

FIGURE 22.—Rocks of the Maquiné Group in the Serra Geral (Capanema quad.) showing effect of jointing and slip cleavage on topographic expression.

Three general regional trends of lineations are particularly well developed in the pre-Minas rocks. One plunges moderately to steeply northward and is commonly in the form of a wrinkling or crenulation, or small folds. The second, and most uniform and consistent, plunges moderately to steeply eastward, and may be in the form of microfolds, flow lines, mineral alinement, stretching, or rarely intersection of planes. The third, generally a pencil structure or small fold but locally an intersection of planes or a mineral alinement, occurs in all the Precambrian rocks of the district. The plunge is usually low to moderate, 10°–20°, and trends are consistently east-southeastward.

Numerous other trends of lineation occur locally. Most are apparently associated with folds of one period that have been affected by a later folding. Most are intersections of planes or mineral alinements, but all the previously mentioned types may be represented.

The small-scale drag folds resemble the larger ones, but their amplitudes are measured in millimeters. Amplitudes rarely are as much as 1 cm, even on the long limbs. Many show no clear association with larger folds but, instead, appear to result from stress and differential movement along compositional layering.

The wrinkling and crenulations are generally similar in size and plunge to the small drag folds but display much greater size variations. Amplitudes range from about 1 mm to 5 cm, and wavelengths from 2 or 3 mm to 30 cm or more. The ratio between amplitude and wavelength also varies greatly. Most of the crenulations are open and symmetrical, with length-to-depth ratios of 3 or 4 to 1, rarely 1 to 1, commonly 6 to 1, and rarely as much as 20 to 1.

Mineral alinement generally results from elongation of mineral grains and aggregates of grains. Common examples are clusters of mica spread out along a line on the schistosity, or elongate patches of talc flakes in the chlorite schists and itabirites. Some rocks contain elongate, parallel-oriented crystals of kyanite, clinozoisite, or quartz.

Conglomerate pebbles of vein quartz or quartzite are commonly two or three times as long in one dimension as in the others; long axes are oriented approximately parallel to the regional or local lineation. The parameter ratio of the conglomerate pebbles is commonly as much as 10 to 1, and parameters of 20 to 1 have been observed.

Pencil structure generally results from intersection of bedding and cleavage. Rock displaying this structure commonly breaks up into elongate fragments. In unfractured rock, the linear direction is present as striations or corrugations in the plane of the schistosity or bedding. In a few places the pencil structure was formed by the flowage and separation of rods of quartz along the crests and troughs of small folds. These rods range from 1 to 6 cm in diameter and are as much as 50 cm long. They commonly show boudinage.

The intersection of planar elements may locally result in pencil structure, but generally produces only fine striations on the more conspicuous plane. Magnification reveals that the striations are alternate linear zones of quartz and mica or linear zones of mica whose orientation alternately parallels one plane and then the other. They have been observed as the intersection of bedding or compositional layering with schistosity or foliation; or bedding, schistosity, or foliation with slip cleavage.

Slickensides, though generally confined to fault planes, also occur in planes of slip cleavage and, rarely, in the planes of schistosity or bedding. Some are difficult to distinguish from lineation caused by the intersection of planar elements. In a few places, where both could be identified in the same rock, they were oriented differently. Slickensides were mapped only where they were clearly due to differential movement.

Most, if not all, of the hematite deposits in the Alegria district are elongate parallel to the east-southeast lineation trend and are apparently larger and have a higher tenor where the lineations change direction slightly or plunge more steeply, as at Córrego do Meio (pl. 7) and the Alegria and Morro da Mina deposits (pl. 2).

MAJOR STRUCTURAL FEATURES

FOLDS

FOLDS OF PRE-MINAS AGE

The attitudes of the band of Maquiné rocks in the southwestern part of the Capanema quadrangle suggest the presence of an isoclinal syncline. There is no direct evidence in the Alegria district for the presence or absence of such a fold. Gair (1962, p. 49–50) cited evidence for a synclinal closure at the northern end of the exposure of Maquiné rocks, in the Nova Lima quadrangle.

The band of Maquiné rocks east of the Campo do Rocha-Capanema area contains a fold which could be either an anticline or a syncline. Fracture, cleavages, drag folds, and any primary sedimentary features have been obliterated by the regional schistosity in the outcrops studied. Apparently, these rocks were folded primarily before deposition of the Minas Series and then modified by post-Minas folding, because the outcrop pattern and fold axes are divergent and apparently unrelated to trends of folding in the Minas Series.

The Nova Lima schist and phyllites in the Campo do Rocha area seem to be in angular contact with the Maquiné, but the degree of deformation and lack of exposures make any interpretation tenuous. These rocks are less deformed to the north and are easier to map.

Iron-formation and quartzite-iron formation interbedded with the schists are good marker units. They were mapped by Moore in the Conceição do Rio Acima quadrangle as closing in a fold about 2 km west of the Catas Altas quadrangle (Moore, 1969, pl. 3). This closure is tentative and cannot be distinguished as either an anticline or a syncline because of the masking effect of the regional schistosity. These folds probably predate the Minas Series.

The Cambotas Quartzite is complexly folded into two types of folds, one of which has no counterpart in the overlying Minas series, and another which may not have a counterpart but is associated with faults that are present in both pre-Minas and Minas rocks. The first type is a series of folds oriented in a radiating pattern, trending southeast at the southern end and west at the northern edge; open folds on the south becoming progressively tighter to the north. The second type is associated with the north-trending series of imbricate thrust and high-angle reverse faults, at least some of which continue southward into the Minas rocks. The folds are relatively small isoclinal and recumbent anticlines and synclines reminiscent of Alpine-type folds (fig. 23A). At one locality, near the one sketched in figure 23B, the fold has progressed to horizontal and on to a dip in the opposite direction, that is, one limb has been rotated about 190°. Tops of beds were determined by graded bedding and torrential crossbedding.

The structure in the quartzite around Bento Rodrigues and in the southeast corner of the Santa Rita Durão quadrangle is a possible pre-Minas fold reactivated by post-Minas folding. The nature of this fold could not be determined. Granite gneiss and migmatite form the central part and both flanks of this fold (pl. 2).

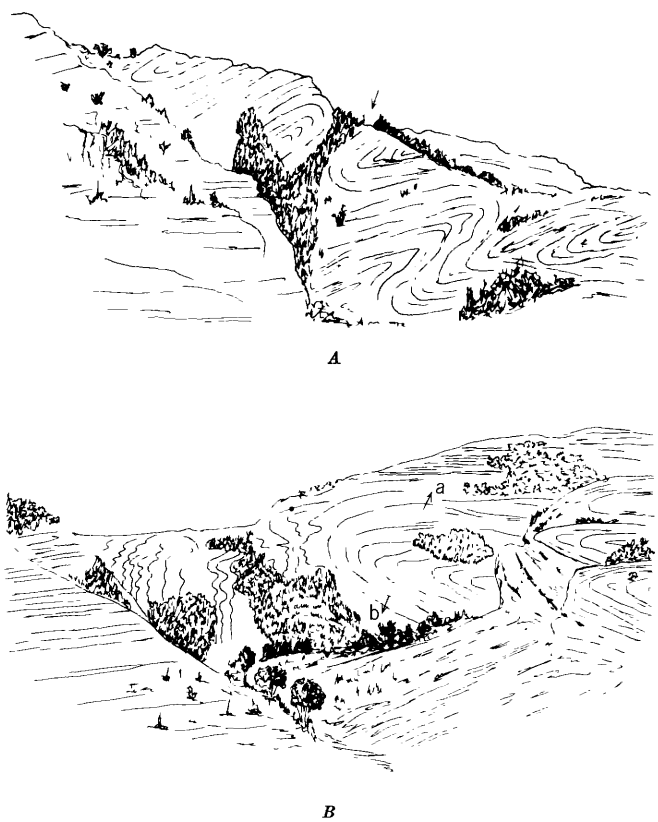

FIGURE 23.—Folds in the Cambotas quartzite, Serra do Caraça. *A*, Catas Altas quadrangle (N. 12,380, E. 4,000). View looking S. 20° W. *B*, Near the top of the serra looking N. 45° E. to arrow, same location as A. Axial plane dips 13° SE. Distance a–b is about 60 meters.

FOLDS OF MINAS AGE

The largest and most prominent fold in the Alegria district is the north-trending syncline in the south-central part of the district, referred to herein as the Santa Rita syncline. Itacolomi and Minas Series rocks form the core of the syncline; Cambotas Quartzite and Nova Lima-Maquiné rocks crop out on the west flank, and Maquiné(?) rocks and granite gneiss on the east flank. Figure 24 shows the configuration of this syncline. It is cut by a series of high-angle reverse faults that may be associated with the imbricate system in the Cambotas Quartzite to the north. The syncline and the faults were refolded by a southeast-plunging syncline. The Santa Rita synclinal axis bends sharply to the east and is faulted off, and the east limb of the syncline continues northward and disappears in the northern part of the Catas Altas quadrangle, apparently because of a combination of faulting, the southward plunge of the syncline, and intrusion by the granite gneiss and possibly by the ultramafic rocks. On the southern half of the syncline, the east limb is undulating and is cut by a fault along its east side. Figure 24 is schematic and simplified, but the shaded bands shown for the limbs are generally equivalent to the Itabira Group.

Numerous small isoclinal folds within the Santa Rita syncline are generally local in occurrence and may be restricted to only one or two of the formations. They generally parallel the axis of the Santa Rita syncline and (or) the faults shown in figure 24. The great thickness of the iron-formation near Fazenda Alegria is partly due to one or more of these folds. The complicated pattern of the formations near Santa Rita Durão is probably due to some extent to these small folds. Numerous folds have the same aspect in the Catas Altas quadrangle. Only a few of the more prominent folds are illustrated on the geologic map (pl. 1, N. 5,000, E. 9,500).

The Santa Rita syncline and associated faults have been folded into a series of open folds plunging moderately to steeply toward the southeast. The northernmost fold is an open anticline whose axis passes through the Serra do Caraça. The next fold to the southwest is a syncline in the Fazenda Alegria area. South of this syncline lies another open anticline and, at Conta História, a tight syncline which passes into a shear fold and thrust fault (fig. 24 and pl. 1). All these folds, except possibly the Conta História syncline, are superimposed upon the preexisting folds and faults. Associated with these major folds are a great number of small open folds, giant crenulations, which are particularly prominent on the dip slopes of the Cambotas Quartzite. Only a few of the many folds are shown on the geologic map (pl. 1, N. 8,000, E. 9,500).

The closed isoclinal syncline in Serra do Ouro Fino, on the western edge of the Capanema quadrangle, is overturned to the west and north. The forces that produced its present crescentic shape also created east-west trending cross folds that are horizontal to steeply east-plunging (J. E. O'Rourke, written commun., 1956), and transect the regional structural trends.

The Ouro Fino syncline may be a continuation of the Conta História syncline, with which it is associated, and may have become separated from it, and contorted, by thrust faulting directed toward the northwest. It may also be a continuation of the Gandarela syncline, separated by either a northeast-trending series of shear folds and faults, or northwestward thrusting, or a combination of the two. All the rocks of the Alegria district, as well as those to the north and northwest, show evidence of having been displaced a considerable distance toward the northwest along a series of thrust and shear faults.

FAULTS

Faults in the Alegria district, like the folds, belong to several periods of orogeny, but they are more difficult to correlate with any one period. Few faults can be traced for any distance because most areas are covered by soil and vegetation. Thus, most are projected long

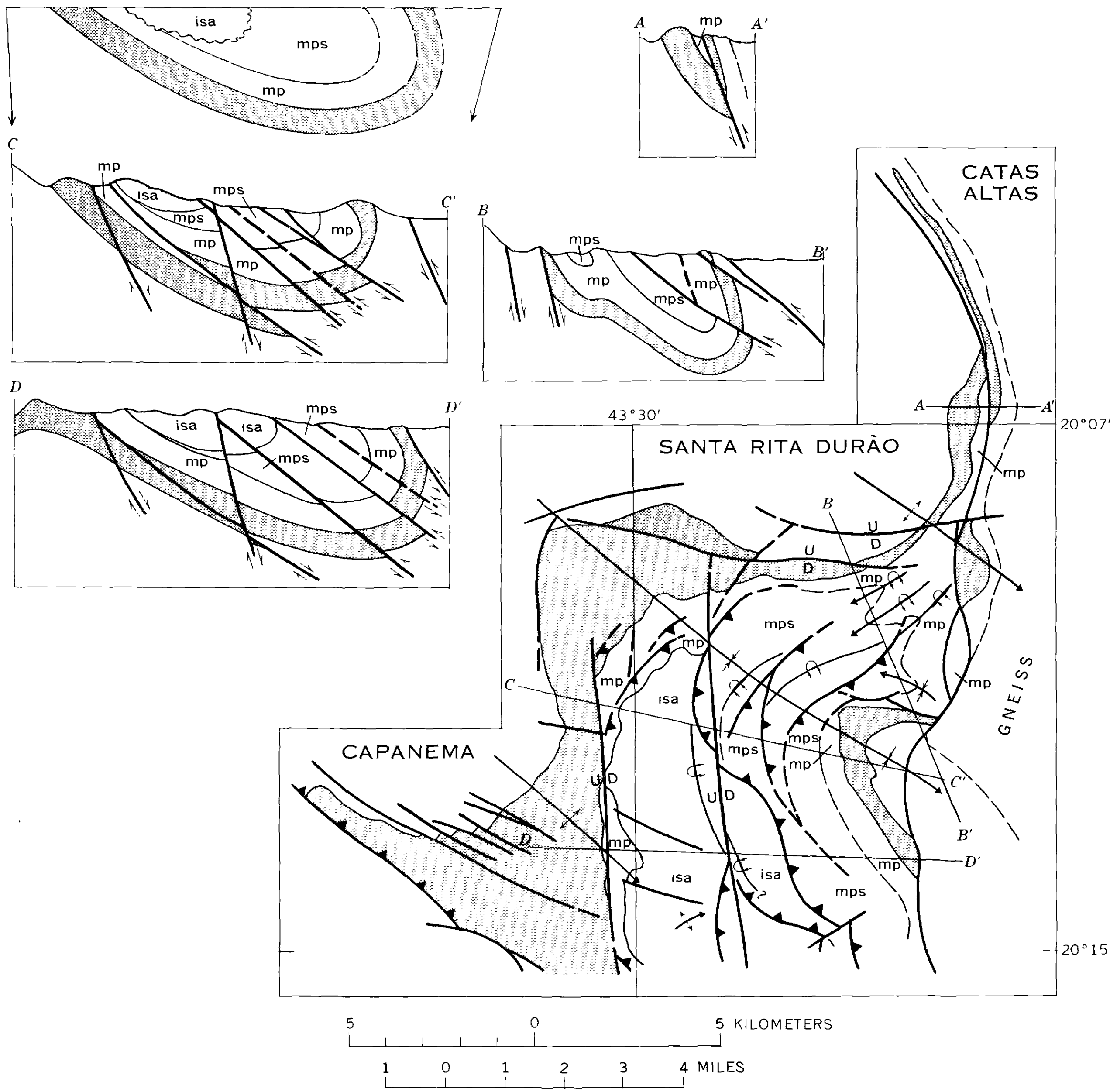

FIGURE 24.—Diagrammatic sketch map and sections of the Santa Rita syncline showing modifying relationships of faults and approximate trace of axis. Upper left section shows restoration of section $C–C^1$ before faulting. Shaded area designates the Itabira Group; other geologic units are mp, lower part of the Piracicaba Group undivided; mps, Sabará Formation; isa, Santo Antônio facies of the Itacolomi Series.

distances between exposures, or are inferred. Exceptions are the youngest faults, which are well exposed and easy to trace. Thrust or high-angle reverse faults are most common, with upward or overriding movement to the west or north. The youngest faults are post-tectonic. There are no later Tertiary or Holocene faults in the area.

FAULTS OF PRE-MINAS AGE

Pre-Minas faults are probably numerous in the district, but they are hard to find and trace because of the similarity of lithology and the uniformity of the superimposed schistosity. Several faults were found in the pre-Minas rocks, but no displacements could be found in the nearby Minas rocks along projections of the faults.

FAULTS IN THE SERRA DO CARAÇA

The massive Cambotas Quartzite in the Serra do Caraça is veined by a complex network of faults trending in several directions. Those faults that extend into the Minas rocks commonly have much smaller apparent displacements in the Minas rocks than in the Cambotas

Quartzite. They probably predate the Minas Series and were reactivated in post-Minas time.

Only the major and representative faults in the Cambotas Quartzite are shown on the geologic maps. The most conspicuous faults are imbricate thrust or reverse faults trending north-south and dipping 30°–50° E. (fig. 25) and trending northwest and dipping 40°–50° NE. These faults are extensively intruded by rocks with a diabasic texture.

Other faults, clearly post-Minas in age, trend west-northwest and west-southwest and are nearly vertical. One in the northeastern part of the Capanema quadrangle was intruded by a dike that has a maximum width of 300 meters and a projected length of more than 12 km. These faults do not appear to have been affected by the latest folding. They may have formed in response to stresses in the overriding block of the postulated northwest-directed thrust fault that produced the east-west trending folds in the Ouro Fino syncline.

FIGURE 25.—The Serra do Caraça, looking south, illustrating the topographic expression of imbricate faults. All the valleys on the mountain coincide with thrust faults or high-angle reverse faults.

Several curving "shear zones" occur in quartzite on the southeast flank of the Serra do Caraça, near Morro da Mina. The zones consist of mylonite or cataclasite in which kyanite crystals are locally abundant. Zones of serpentine and chrysotile in the chlorite schists can be traced into mylonites in the quartzite.

Several near-vertical east-trending breccia zones and faults occur in the itabirite north of Fazenda Alegria, but they cannot be traced any great distance. South of Fazenda Alegria, numerous north-trending faults and fault zones cut the Piracicaba and Itabira Groups, but they are also difficult to trace for any distance.

OTHER FAULTS OF POST-MINAS AGE

A series of northwest-southeast-trending faults occur in the southern part of Capanema quadrangle (pl. 1). The thrust faults and fault zones in the Maquiné Group and the large fault between the Maquiné and the Itabira Groups dip 35°–45° NE. The faults in the Maquiné appear to be older than the Minas Series or are at least very early faults that were reactivated during the post-Minas orogeny, then displaced by the fault between the Maquiné and Itabira Groups, here referred to as the Ouro Fino fault. The faults between Serra do Batatal and Conta História are nearly vertical; upward displacement has been on the northeast sides. They are probably contemporaneous with the folding; the thrust faults are probably later, perhaps contemporaneous with the large fault along the east side of the Santa Rita syncline, here referred to as the Água Quente fault.

The Água Quente fault is the most conspicuous of the faults, as well as the most persistent. It trends north-south and dips 40°–50° E. This fault has thrust pre-Minas rocks and gneiss up over the Minas Series in the southern part of the area. To the north, along the east side of the Serra do Caraça, it has thrust the eastern limb of the Santa Rita syncline up over the western limb and over the pre-Minas rocks of the Serra do Caraça.

LINEAMENTS

Uniform, persistent lineaments have topographic expression throughout the Quadrilátero Ferrífero. They are commonly conspicuous on aerial photographs and are most noticeable in the granitic and pre-Minas metamorphic rocks. In the Minas Series, zones of jointing and warping give rise to less pronounced lineaments.

Some of the lineaments are more than 100 km long and almost straight; others appear to be only a few kilometers long. In the Alegria district most lineaments trend east to N. 80° E., or north to N. 10° E.

Lineaments in the granitic rocks reflect a strong mortar texture and augen gneiss in zones 10–50 meters wide. In the phyllites, mostly in the Nova Lima Group, there is an imposed schistosity. In the Minas Series, lineaments can generally be traced as a series of closely spaced joints and fractures over a zone 30–200 meters wide, or as a shear fold and a deflection in the outcrop pattern.

These lineaments are probably the surface expressions of deep-seated vertical faults or zones of weakness. If they are fault zones at depth, they fan out near the surface to form wide zones lacking true fault planes.

MINERAL DEPOSITS

The Alegria district contains economically important deposits of iron, manganese, and bauxite. Deposits of gold, asbestos, quartz crystal, and talc are of little economic interest at present.

IRON ORE

Iron ore is the most important commodity of the district. Most of it occurs within the metamorphosed Precambrian iron-formation of the Itabira Group; only two deposits are in older or younger formations. The three major ore types are high-grade hematite, softened or enriched itabirite, and surficial iron deposits.

High-grade hematite is ore containing more than 66 percent iron. It ranges from extremely hard and dense to fine-grained and pulverulent; the color is a medium neutral gray, although it often appears to have a blue tinge. This ore consists of almost pure hematite, with minor amounts of magnetite and quartz and with only traces of other minerals such as talc or kaolinite, or of argillaceous material. A complete analysis (Guild, 1957, p. 51) gave 99.34 percent iron oxides; the remainder consisted of silica, alumina, magnesia, oxides of manganese, chromium, and phosphorous, and traces of sulfur. Other elements were looked for but not found.

Large bodies of massive hard high-grade hematite are uncommon in the Alegria district but small irregular generally crosscutting lenses mixed with schistose or pulverulent specularite are widespread. Concordant lenses and layers of hard hematite interlayered with itabirite are locally common. The most common types of hematite ore in the district are (1) hard to soft medium- to coarse-grained schistose specularite in aggregations of flat crystals formed into flat plates, and (2) soft pulverulent rock composed of tiny flat single crystals of specularite. The schistose hematite can be both concordant and crosscutting, and is generally clearly associated with zones of faulting, shearing, or intense folding. The pulverulent hematite occurs within and surrounding hard or schistose hematite, or interlayered with the itabirite.

The hard hematite has a uniform mosaic texture; grains and pores generally range from about 0.02 to 0.04 mm in diameter. Pore spaces make up at most only a fraction of a percent in some layers and several percent in others. The layering visible on weathered surfaces is probably a function of the amount of pore space. The schistose hematite is composed of euhedral and anhedral grains oriented in generally the same directions, and ranging from less than 0.01 to 1 mm or more in size. The pulverulent hematite grains range from less than 0.01 to about 0.1 mm in diameter.

The term "itabirite" has been restricted to rock containing between 25 and 66 percent iron (Dorr and Barbosa, 1963, p. 19). Rock containing less than 25 percent iron is considered a metamorphosed ferruginous chert; with more than 66 percent it is high-grade hematite. The types grade into each other and are difficult to delineate without extensive analyses. Lenses and beds of ferruginous metachert are common in some areas of iron-formation, sparse in others. Most itabirite contains at least 35 percent iron; the average iron content is between 40 and 45 percent (Guild, 1957, p. 44). Weathering tends to soften and enrich itabirite by leaching or eluviation of the silica and carbonate, and addition or redistribution of iron. Weathered itabirite generally contains 50–65 percent iron, and is a potential ore because it can be mined without drilling and blasting, and can usually be easily concentrated into material containing more than 65 percent iron. It commonly breaks up into small resistant plates (chapinha) of hematite and soft granular quartz.

Most exposures of itabirite are chapinha or soft itabirite, outcrops of hard itabirite are rare. Most exposures are in underground workings of opencuts, mixed with soft itabirite or chapinha, and in gullys and washes, where it crops out as pinnacles and small ridges. The hard itabirite is not necessarily fresh and unweathered but is more likely material less susceptible to weathering than the surrounding material (Pomerene, 1964, p. 44), or was not subjected in the same degree to the agents responsible for the weathering.

Beds of hard itabirite occur in soft itabirite and occupy similar or identical physiographic positions, and were therefore subjected to the same agents and processes. Alternate thin beds of hard and soft itabirite occur in many localities, especially in underground workings. There is no apparent structural or textural difference in adjacent beds of hard and soft itabirite. Under these conditions it is difficult to see why some beds of itabirite should remain hard whereas others became soft if all the itabirite was originally homogenous. Carbonate minerals are a common constituent of the iron-formation; leaching of a small percentage of carbonate minerals in a part of the rock could cause disaggregation of that part of the rock.

Dorr and Barbosa (1963, p. 26) believe that the soft itabirite probably never contained carbonate, that disaggregation was caused by leaching of quartz over a very long period of time, and that texture, structure, and physiographic position, as well as time, were primary controls. Guild (1957, p. 50) and Pomerene (1964, p. 44) believe that the soft itabirite once contained a small amount of carbonate in addition to quartz and hematite. Meteoric water dissolved the carbonate, thus became alkaline, and was able to dissolve quartz more easily and further disaggregate the itabirite. The process of disaggregation of the itabirite probably involved all the conditions described above, variable from one locality to another, and may include other factors as well, for example, the action of organic material introduced into the ground water, such as silica dissolving agents derived from the many types of silica-fixing plants known to grow in the region. In any case, the origin of the soft itabirite is of economic and scientific interest and therefore merits future study.

In most areas itabirite is weathered to a depth of 20–40 meters, less commonly to as much as 100 meters. Weathered itabirite comprises two general types: soft itabirite, in which both the quartz-rich layers and the hematite-rich layers disaggregate into small fragments; and chapinha, in which only the quartz-rich layers disaggregate and the hematite-rich layers break up into plates. Chapinha is an important potential ore because much of it can be concentrated to more than 65 percent iron by a simple screening process.

In contrast to these in situ, eluvial deposits are (1) layers of coherent iron-rich material formed near the surface by meteoric waters, and (2) alluvial and colluvial deposits. The surficial alluvial and colluvial iron deposits comprise three major types: canga, rolado (alluvium composed of boulders, cobbles, and pebbles of hematite in soil and rubble), and gravel deposits which are composed largely of hematite fragments. Canga, a conglomerate or hardpan formed by the cementation of rock fragments by limonite, is the most widespread and important of the three. It forms a cap over much of the iron-formation and may extend for considerable distances downslope over adjoining formations. The texture and composition of this material vary greatly. (See p. J28.) Iron-rich, ore-grade canga is composed chiefly of fragments of hematite and chapinha cemented by limonite, or consists entirely of fragments that have been altered to or replaced by limonite, so that the rock is virtually pure limonite. Most canga is relatively rich in phosphorous (fig. 26).

The only deposit of rolado of any economic significance in the Alegria district is on the north slope of Pico Piçarra (Catas Altas quad., N. 6,500, E. 6,800). Other small deposits of talus and dump material occur in the vicinity of the iron-formation between Catas Altas and Água Quente.

The gravel ore deposits are generally too low grade and too small to have any commercial significance at the present time. They are amenable only to small-scale hand work. Large areas of valley alluvium contain appreciable amounts of hematite which could be dredged and concentrated.

MINING, HISTORY, AND PRODUCTION

Commercial manufacture of iron in the Alegria district began in 1803 (von Eschwege, 1833). By 1810 most large fazendas (ranches) had their own stone or brick furnaces, each with a production capacity of 1–16 pounds of iron per load of ore. Larger, Catalan-type forges were also in use at that time near Antônio Pereira, just south of the Alegria district. These forges were of the batch type, fueled with charcoal, and with the blast formed by water falling into a shaped chamber under the furnace. The crude iron was cleaned of slag and shaped under hammers powered by water wheels.

Records are incomplete but many Catalan forges were built throughout the Alegria district during the 1830's and 1840's. The foundations of many of these mills may yet be seen. At one, north of Santa Rita Durão (N. 10,100, E. 6,700), most of the machinery is still intact. The writer has noted more than 20 sites in the area, from Quebra Osso to Santa Rita Durão to Alegria, along the margins of the iron-formation. Derby (1909) stated that by 1864 there were about 120 direct-process forges in the Quadrilátero Ferrífero, each of which had 100 tons per day total capacity.

No records were found to indicate when the iron industry collapsed in the area. Older residents state that no iron was produced after the 1890's, and that most production stopped years earlier. This would indicate only about 50 years of industrial production.

From 1909 to 1913, the Alegria, Germano, and Fábrica Nova deposits were extensively explored by the Brazilian Iron and Steel Co. under the direction of E. C. Harder, R. T. Chamberlin, Hugh Roberts, H. K. Shearer, and Harmon Lewis. No development work was undertaken. The Brazilian Iron and Steel Co. kindly provided access to all records of their exploration when the U.S. Geological Survey began its regional study. Some of their data have been incorporated in this report. The Conta História iron deposits were explored in 1930 by the Bethlehem Steel Corp., but reports on that work were not available for this study. The iron deposits at Morro São Luiz were explored in 1911 by Arthur Houle and William Jones for the J. H. Hammond Co. Some data from their report, included among the material provided by BISCO, have also been incorporated in this report.

Almost all the iron-bearing regions of the Alegria district south of Morro São Luiz have become the property of Cia. Siderúrgica Belgo-Mineira and were first developed for charcoal. Exploration of the iron deposits in the Morro da Mina, Alegria, and Conta História areas was started by CSBM in 1960.

The iron deposits at Capanema (Serra do Ouro Fino) and between Morro São Luiz and Pico Piçarra are the only ones in the district not presently owned by CSBM. They were privately owned when fieldwork was in progress.

The only production of iron ore from 1900 to 1961 was a few thousand tons of handpicked talus and rubble hematite from the area near Catas Altas.

The average grade of the unweathered itabirite in the Alegria district is probably about 45 percent. The shafts and drill holes which presumably penetrated through the zone of surface hydration and enrichment date from the time that Harder and Chamberlain (1915) were exploring the area, and most of them are inaccessible now. Figure 26, adapted from data gathered by E. C. Harder, H. K. Shearer, Harmon Lewis, and others, shows the relationships between the approximate percentages of iron, phosphorus, and water of crystallization in itabirite from several exploratory shafts.

The first column shows selected analyses of enriched hydrated itabirite from shaft 1 of the Alegria deposit. The bottom of the major zone of hydration, about 23 meters below the surface, is reflected by a sharp increase in the amount of silica and a corresponding decrease in iron and water contents. The contents of water and phosphorus are closely parallel, although that of phosphorus is abnormally high at the surface and at the bottom of the zone of greatest hydration. These relationships typify normal itabirite.

Shaft 1 was started in structure canga (p. J28) less than half a meter thick. The first 19 meters is in thin-bedded moderately hard chapinha, relatively free of quartz; the color varies with the degree of hydration from yellow and red to gray or black. From 19 to 23 meters the rock remains unchanged, but the quartz content between chapinha layers increases. The last 6 meters is in slightly hydrated itabirite.

The analyses in the second column are similar to those of the first column. The upper 3 meters of shaft 4 is in canga; beneath this is 3 meters of deeply hydrated and partly cemented chapinha—almost structure canga. The next 15 meters is in hydrated chapinha mixed with thin layers of soft fine-grained specularite, of which the lower 7 meters shows an increasing amount of interbedded quartz. The remaining 11 meters is in relatively fresh-appearing itabirite.

The analyses in the third column (dolomitic itabirite and canga) are considerably different from those of the other columns. The upper 9 meters of shaft 2 is in hard dark red-brown canga. A thin layer of weathered fine-grained black hematite occurs at about 6½–7 meters. The hard red-brown canga grades gradually into a layer about 10 meters thick of soft yellow, ocherous material containing nodules of hard, red ocher and thinly dis-

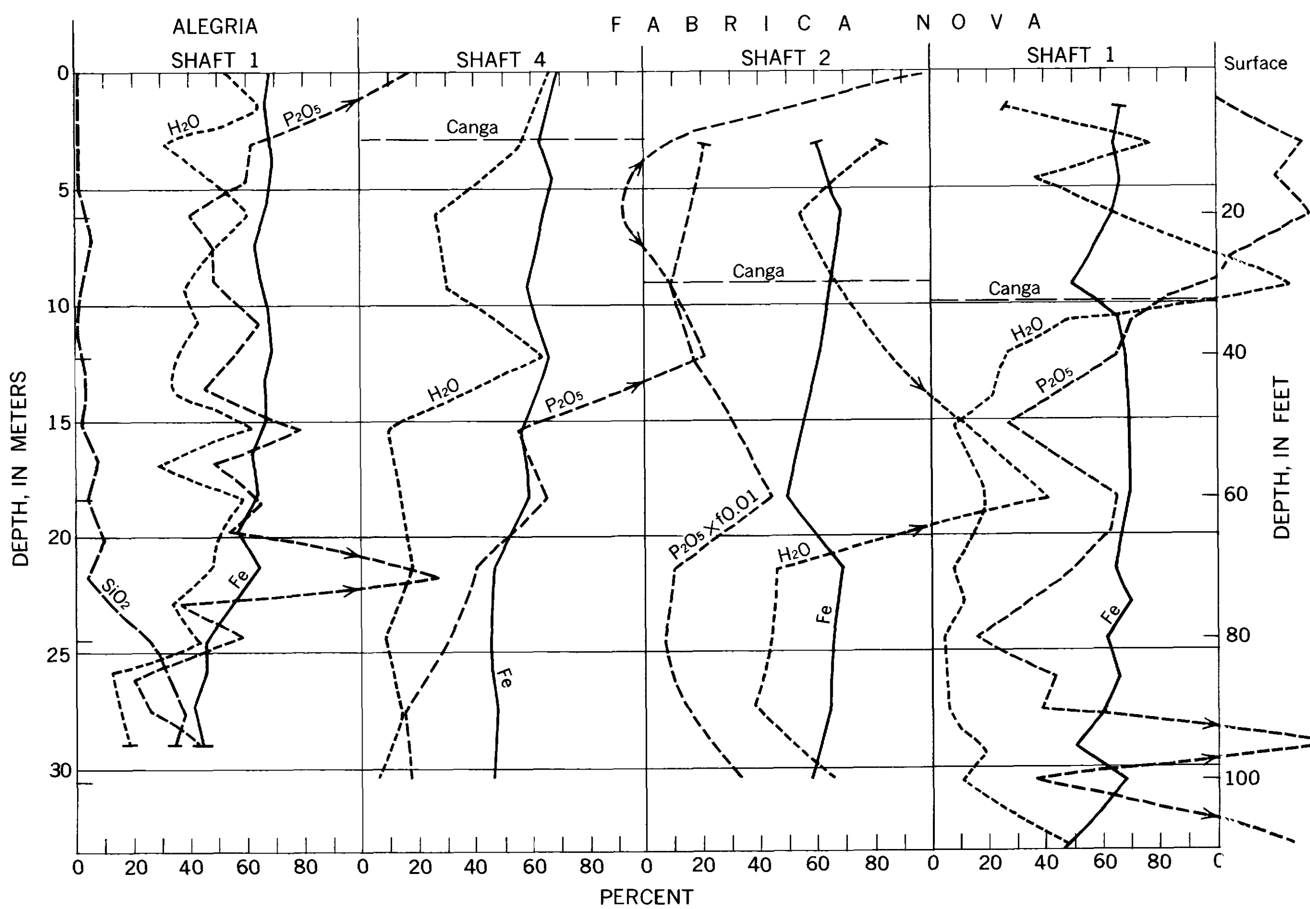

Figure 26.—Relationships among iron, phosphorous, and water of crystallization in itabirite from the Minas Series. Multiply the values in the graphs above by the factors: SiO_2, 1.0; Fe, 1.0; P_2O_5, 0.001; H_2O, 0.1.

seminated tiny magnetite octohedra. Within a space of about 2 meters, this material grades into a 3-meter layer of fine-grained hematite and specularite with many tiny magnetite crystals. The bottom 6 meters is in hematite and specularite interbedded with thin layers of ocherous clay and quartz, which become thicker and more numerous with depth.

The last column illustrates analyses from a combination of the rock types of the preceding three shafts. The upper 7 meters is in hard, red-brown canga with blocks of indurated fine-grained specularite, and is underlain by 3 meters of hard yellow, ocherous canga. Below this is about 17 meters of fine-grained hematite and specularite with sparse layers containing disseminated magnetite crystals, and interbedded toward the bottom with thin layers of quartz and schistose itabirite. Beneath this is about 2 meters of phyllite and 2 meters of fine-grained specularite and magnetite. The remainder of the shaft is in a mixture of phyllitic material interbedded with relatively fresh appearing itabirite.

RESERVES

In areal extent, the iron-formation of the Alegria district totals about 50 sq. km. Iron-formation, most of which is covered by canga, has been exposed in some 35 adits, shafts, and trenches, and along the cuts of two access roads. Additional exposures are afforded by numerous adits and trenches in the manganese mining area at Conta História (fig. 38 and pl. 7). The area tested by this exploration, however, is only a very small proportion of the total. For this reason, the writer has classified most of the reserves by tons per meter depth of indicated or inferred itabirite ore. No attempt was made to divide the iron-formation into areas of various grades, other than to delimit and classify known hematite deposits by tons per meter-depth. The tonnage of hematite deposits was projected to visible depth wherever possible. Surface observations suggest that the iron-formation is homogeneous enough to be classified as one unit; however, further exploration may indicate the presence of much dolomite and low-grade itabirite under the canga cover. On the basis of the data available, the iron-formation is assumed to contain 40–45 percent iron.

Data from the exploratory workings enabled further subdivision of the iron-formation into a second type of ore, hydrated and leached itabirite and chapinha, which has been projected to a depth of 20 meters over part of the iron-bearing area. This ore is inferred to average 55 percent iron. Much of the chapinha is even richer (fig. 26, table 7).

For comparative purposes, the total amount of iron-formation to the base of the formation or to topographic base level was also calculated.

Total inferred reserves for the entire Alegria district are summarized in table 4. In addition, the reserves of individual deposits are described in the next section. The canga reserves were calculated for most of the district on the basis of an average thickness of 1 meter; however, the thickness of canga varies greatly. In the Ouro Fino South area (fig. 27) for example, canga ranges from about 1 to 35 meters in thickness. Specific gravities used in calculating the reserves are: canga and chapinha, 3; itabirite, 3.5; soft hematite, 4; and hard hematite, 4.5.

MINES AND POTENTIAL MINES

OURO FINO

The Ouro Fino iron deposits lie generally on the summit and east slopes of the Serra do Ouro Fino-Serra Geral, in the western part of the Capanema quadrangle.

The iron-formation is mostly itabirite, locally quartz rich. Lenses of phyllitic and dolomitic material are common, particularly in the northern ridge, where the only ore is one lens of dark-red hard hematite about 3 meters thick and 20 meters long in outcrop. Outcrops of

TABLE 4.—*Summary of inferred reserves of iron ore in the Alegria district*

[Reserves in metric tons]

Deposit (fig. 27)	Canga		Itabirite				Hematite	
	Million cubic meters	Million tons	Area (sq km)	Million tons per meter depth	Million tons enriched to 20 meters depth	Million tons above topographic base level	Million tons per meter depth	Million tons, total projected
Ouro Fino North			1.8	63	1,260	500		
Ouro Fino South	9	27	2.3	80	1,600	600		
Conta História	23	69	23.0	800	16,000	76,700	0.55	2
Alegria	16	48	16.1	560	11,260	70,000		15
Morro da Mina	.8	2.4	1.0	3	60		.7	10
São Luiz	2	6	1.5	5	100	500	.6	20
Pitangui			.6	1.8	36	100		5
Fábrica Nova	4	12	2.5	8.7	174			10
Germano								2
Totals	54.8	164.4	48.8	1,521.5	30,490	148,400	1.85	77

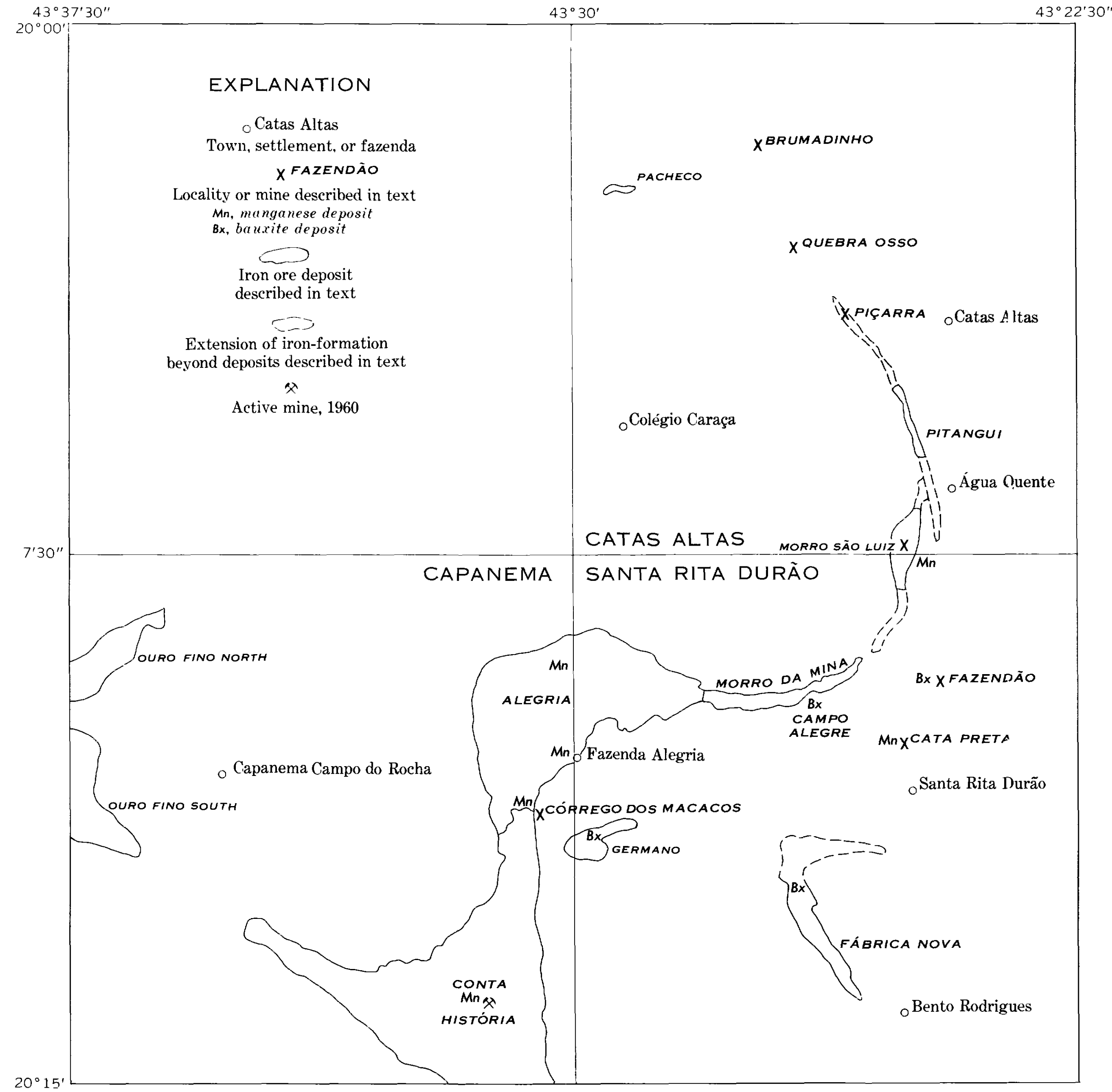

FIGURE 27.—Economic deposits and mineral occurrences described in text.

itabirite and chapinha are abundant along the northern ridge.

The southern ridge of Serra do Ouro Fino has many extensive layers of soft hematite and chapinha, but most are very thin. On the western slope, near the base of the iron-formation, several small opencuts and trenches are in sandy itabirite. One cut at N. 6,200, E. 1,000 shows about 10 meters of soft hematite and enriched itabirite.

Structure canga and chapinha crop out along the top of the southern ridge. Chapinha and a few lenses of soft hematite crop out in the washes near the bottom of the hill on the eastern side. The remainder of the area is covered with a thick layer of canga. An adit driven 100 meters into the ridge from a point near N. 7,600, E. 300 is in canga except for a few meters near the end, where soft chapinha and itabirite were found, 85 meters vertically below the surface of the ridge (E. C. Harder, written commun., 1912).

No outcrops of hard "blue" hematite were seen in this area. All of the richer iron ore is dark red or reddish brown. Most of it is apparently a surface enrichment of the itabirite. Table 5 lists some analyses of the iron-formation of Ouro Fino deposits (E. C. Harder, written commun., 1912).

TABLE 5.—*Analyses, in weight percent, of samples from the Itabira Group in the Ouro Fino deposits*

Location (pl. 1)	Sample	Fe	P	SiO_2	H_2O	Remarks
N. 11,100, E. 800.	1	69. 20	0. 03	0. 33	1. 21	Dark-red hard hematite.
Unknown---	2	60. 60	. 09	1. 41	11. 73	Limonite, grab sample.
N. 8,000, E. 0.	3	67. 30	. 06	. 54	3. 86	Chapinha.
N. 8,600, E. 100.	4	63. 30	. 03	7. 08	1. 91	Do.
N. 7,600, E. 300.	5	66. 95	. 06	. 75	5. 93	Chapinha at end of adit.
N. 8,600, E. 100.	6	67. 40	. 08	. 71	4. 75	Do.
N. 8,700, E. 0.	7	53. 10	. 21	1. 99	16. 32	Phyllitic material.[1]

[1] Apparently an amphibolitic material in which nonferrous material was largely replaced by limonite.

The northern section of the Ouro Fino deposits covers about 1.8 sq km and contains about 500 million tons of iron-formation above topographic base level. The average grade is probably about 40–45 percent iron. The southern section covers about 2.3 sq km and contains about 600 million tons of iron-formation above topographic base level. The southern section also contains about 9 million cu m of canga, or about 27 million tons, with a probable grade of about 60 percent iron. An additional 20 million tons of ore with a grade of more than 60 percent is inferred for enriched itabirite, soft hematite, and chapinha.

CONTA HISTÓRIA

As described herein, the Conta História iron deposits include all the iron-formation between Serra do Batatal and Alto do Conta História and extend north to the water gap formed by Rio Piracicaba, near the center of the eastern border of the Capanema quadrangle (pl. 1). This includes an area of about 23 sq km, the maximum relief of which is about 650 meters.

Most exposures of iron-formation within this area consist of itabirite and chapinha (fig. 28). A few outcrops of hard schistose hematite occur along the axial trough area of the Conta História syncline. The deposits of hard and soft hematite connected with these outcrops are shown on the geologic map (pl. 1). Canga derived from schistose hematite occurs at several other localities, among them: (Capanema quad., N. 5,000, E. 11,400; N. 1,400, E. 10,000). Very fine grained soft hematite is interbedded with the itabirite and manganese ore in the mines at Conta História and in exploratory workings in the vicinity. It probably occurs at many other localities, but because it erodes so rapidly no other exposures were seen. Much of the area is covered by canga, and the few outcrops are mostly of weathered itabirite and chapinha. Exposures along the access roads are predominantly low-grade soft itabirite, amphibolitic itabirite, and canga.

FIGURE 28.—Cliff outcrop of itabirite near Conta História. The ledges are generally higher in iron content than the slopes between them. About 1 meter of canga covers the dip slope in the center of the picture. The cliff near the left side is approximately 215 meters high. The peak in left background is composed of quartzite of the Itacolomi Series.

Deposits of hematite shown on plate 1 consist mostly of dark-red-brown fine-grained hematite and lenses and stringers of fine-grained specularite localized along crests or troughs of small isoclinal folds that plunge 15°–20° S. 55°–60° E., or along zones of intense small-scale folding and crenulation with the same plunge. The only hard "blue" ore in these bodies is in small layers and irregular masses surrounded by pulverulent specularite and dark-red-brown hematite.

The total observed area of the hematite in the Conta História deposit is about 123,000 sq m (square meters). The deposit is estimated to contain about 550,000 tons per meter depth of hard and soft hematite, in about equal proportions. Many of the outcrops have visible depths of 2–5 meters. The total projected hematite ore is estimated to be in excess of 2 million tons. Considerable hematite ore has been exposed in access roads and exploratory workings of the Conta História manganese deposits (p. J58; pl. 7) in layers and lenses in itabirite. Table 6 lists analyses of some of the iron-rich rocks associated with the manganese ore beds at Alto do Conta História. These deposits were not included in the hematite reserves because they are in relatively small bodies scattered through the itabirite. Similar small bodies of hematite ore are probably common in the itabirite throughout much of the area, and may in the future constitute an important reserve. As access is improved the hematite deposits will become better known and more important.

TABLE 6.—*Analyses, in weight percent, of iron-formation associated with the manganese ore beds at Conta História*

[Analyses courtesy of Cia. Siderúrgica Belgo-Mineira]

Sample	Location	Type	Fe	Mn	SiO_2	Al_2O_3	P	Loss on ignition
1	Cut above adit 55, cliff face, soft hematite and itabirite.	Channel	61. 48	0. 10	0. 55	6. 70	0. 27	4. 50
2	Cut above adit 55, cliff face, soft itabirite	do	53. 94	. 11	1. 10	10. 05	. 28	10. 45
3	Cut at adit 55, cliff face, soft hematite	do	66. 34	. 16	. 20	1. 25	. 16	1. 50
4	Top of cliff, left side, Córrego do Meio, chapinha	do	65. 80	. 05	. 55	. 21	. 24	3. 60
5	Base of cliff, left side, Córrego do Meio, chapinha	do	63. 11	. 13	1. 70	. 83	. 39	5. 10
6	Top of Alto do Conta História, canga	Grab	55. 92	--------	1. 50	5. 84	. 26	12. 00
7	Adit 56, composite of goethite in faults and capping manganese bed.	do	61. 15	. 50	. 96	. 68	. 25	10. 00
8	Adit 53 mouth. Goethite at base of manganese	do	55. 92	1. 84	3. 60	2. 74	. 15	9. 86

The itabirite in this area is leached and enriched to a depth of about 20 meters. The Conta História area is estimated to contain more than 16 billion tons of enriched or leached itabirite and chapinha, of which at least half is, or could be easily concentrated to, more than 65 percent iron. The canga is assumed to have an average thickness of about 1 meter over the area, for a reserve figure of more than 69 million tons. Iron-formation above the topographic base level of the present drainage system amounts to more than 70 billion tons.

ALEGRIA

Most of the early exploration in the Alegria district was in the iron deposits near Fazenda Alegria (pls. 1 and 2; fig. 30). Figure 29 shows the location of exploratory workings in the Alegria deposit. Adits 31–33 and 35 were made by Cia. Siderúrgica Belgo-Mineira. The other shafts, drill holes, and adits were made by the Brazilian Iron and Steel Co. in 1909–13. Figure 29 also shows the approximate outlines of the deposits of hematite or hematite mixed with itabirite.

The Alegria deposits cover an area of approximately 16.1 sq km. Most are within a shallow southeast-plunging syncline.

The iron-formation is composed of interlayered beds and lenses that vary widely in composition, from very quartzose or schistose itabirite to pure hematite. Surface alteration has increased the iron content and made the rock more amenable to mechanical concentration to a depth of 20 meters or more (fig. 26). Little is known of the physical properties or composition of the rock below this depth. The surface alteration includes hydration of the iron and leaching of other material, mainly silica.

Itabirite beds or layers of high silica content may be almost completely leached of silica at the surface, to form a type of canga. One example of this feature is well exposed in shaft 15 (fig. 29), where bedding planes can be followed down the side of the shaft. At the surface the rock consists almost entirely of hematite and limonite, at a depth of about 2 meters the layers become quartzose, passing into chapinha, which continues to the bottom of the shaft, about 9 meters.

The descriptive material in the following paragraphs was taken partly from data provided by the Brazilian Iron and Steel Co. and from observations in those workings which are still accessible.

Adit 2 (fig. 29) is about 25 meters long; all but the last 5 meters is in canga. Only a thin layer at the surface is dense and hard; the remainder of the first 10 meters is red, porous, and relatively soft, with angular chapinha fragments sparsely scattered through it. This material grades into a soft red and yellow claylike material that was probably a dolomitic iron-formation. The soft claylike material grades over several meters into soft itabirite. The itabirite in the last 5 meters is highly contorted but strikes roughly east and dips vertically. Small folds and pencil structures plunge about 35° S. 75° E.

Shaft 3 is apparently in canga to the bottom, a depth of about 10 meters. The shaft is filled with water. Dump material is all hard canga with fragments of chapinha and blue hematite.

Adit 8 is caved. Dump material is mostly canga but contains a few blue hematite fragments. The entire dump area is covered with very fine flakes of specularite, which may be an indication that soft hematite was found in the adit.

Shaft 9, only 2 meters deep, is entirely in hard canga with fragments of chapinha and blue hematite.

Shaft 14 is filled with water to within about 3 meters from the surface. All the material in the shaft above the water is hydrated and indurated chapinha; strike is roughly east, dip is vertical. The shaft is within a zone 300–500 meters wide and at least 2.5 km long of folds and faults that trends about N. 70° W. The zone contains many folds, crenulations, and pencil structures plunging 25°–35° S. 70°–75° E. The dump material of shaft 14 is all chapinha with some hard black hematite.

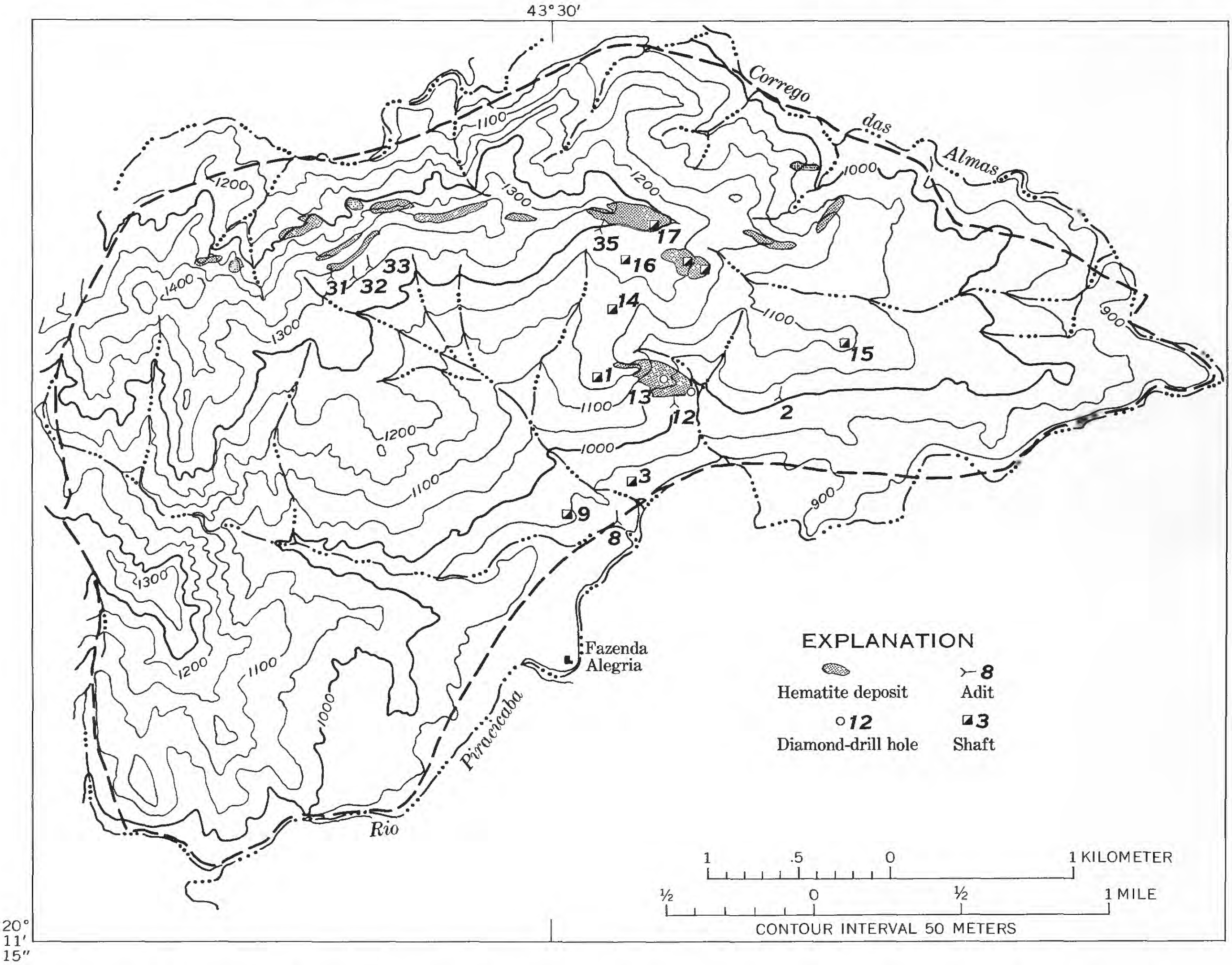

FIGURE 29.—Index map of the Alegria iron deposit, showing location of exploratory workings and the major hematite deposits.

Shaft 16 is filled with water. Surficial material around the shaft is structure canga that strikes roughly east and dips 50° S. Most of the dump material is fine-grained black hematite mixed with chapinha.

Shaft 17 is also filled with water to within about 5 meters of the surface. The material at the surface consisted of hard, dense canga and fragments of blue and black hematite. The dump material is hydrated chapinha and hematite mixed with granular quartz and small flakes of specularite.

Drill holes 12 and 13 were both started in canga near outcrops of hard schistose hematite. A few core fragments of hard blue hematite were found in the vicinity; otherwise there is nothing to indicate the type of iron formation found in the holes.

The outcrops of hard specular hematite near drill hole 13 are highly contorted with numerous small crenulations and drag folds plunging 70° S. 55° E. The layering generally strikes east, and dips vertically to 80° N.

The adit between drill holes 12 and 13 is in soft itabirite, much of it very quartzose, composed of very thin layers (1 mm) of alternating specularite and quartz, interlayered with a few beds in which the layers are 1–3 cm thick, alternately quartz and a mixture of quartz and specularite.

Adits 31–33 and 35 were driven by CSBM to explore for continuations of the hard hematite outcrops near the crest of the ridge 100–150 meters above the adits. The type of iron-formation in these adits is shown in figure 31. The hematite outcrops project downdip to about the area of samples 6 and 7 in adits 31 and 32 and well beyond the end of adit 33. The hematite does not extend downdip as far as the adits. As in other parts of

FIGURE 30.—The Alegria iron deposit. Fazenda Alegria is near the left center margin, 5 km away. The mountains in the background are the Serra do Caraça. Along the left foreground is a dip slope of Cambotas Quartzite. The dark-gray, less ragged appearing topography is underlain by itabirite.

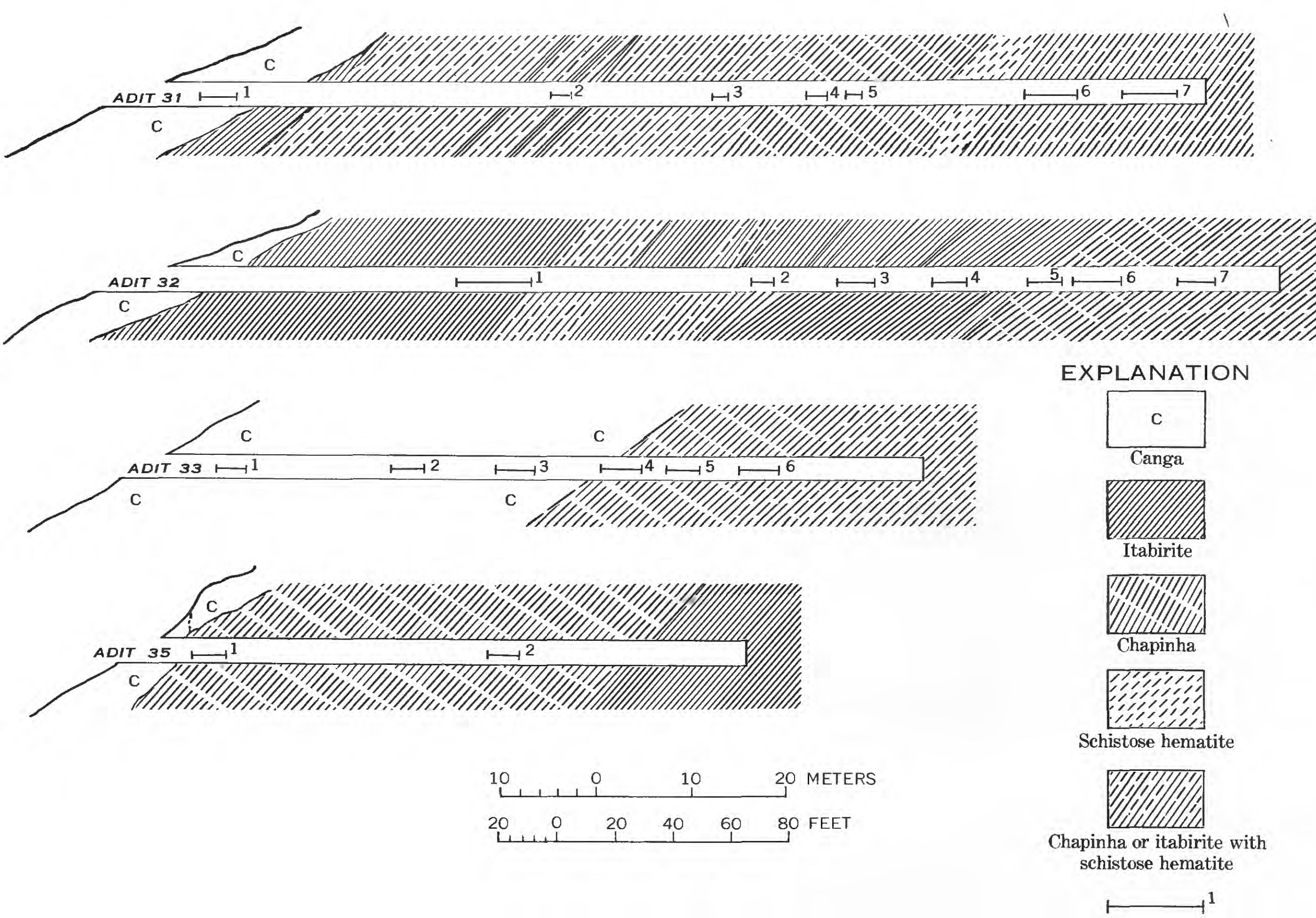

FIGURE 31.—Cross sections along four exploration adits in the iron-formation, Alegria iron deposits. Analyses of the channel samples are listed in table 7.

the area, the hematite body is probably elongate in the direction of the east-southeast lineation. Table 7 lists analyses of samples from the four adits.

TABLE 7.—*Analyses of samples, in weight percent, from exploration adits, Alegria iron deposits*

[Analyses courtesy of Cia. Siderúrgica Belgo-Mineira]

Sample [1]	Fe	SiO_2	Al_2O_3	P
Adit 31				
1 [2]	62.67	6.14	--------	0.13
2 [3]	60.24	12.41	0.88	.05
3 [4]	60.80	11.48	.88	.04
4	43.80	39.65	.52	.03
5	41.97	40.13	.92	.01
6	50.24	26.20	1.48	.03
7	47.79	30.89	.75	.01
Adit 32				
1	53.72	17.16	.93	.05
2	55.20	20.70	--------	.02
3	56.88	18.19	--------	.03
4	42.69	35.80	1.24	.02
5	61.73	8.50	1.80	.01
6	55.20	18.67	.47	.02
7	47.56	27.07	.80	.01
Adit 33				
1	59.72	2.47	4.00	.30
2	60.52	2.28	2.48	.31
3	60.47	6.32	1.81	.36
4	62.08	4.52	3.08	.18
5	59.87	7.35	1.40	.20
6	65.66	.72	.66	.17
Adit 35				
1	60.52	1.66	1.80	.17
2	68.04	1.00	.47	.03

[1] Sample locations shown in fig. 31.
[2] Also contains 0.07 percent sulfur.
[3] Also contains 0.13 percent manganese.
[4] Also contains 0.18 percent manganese.

MORRO DA MINA

The Morro da Mina deposits join the Alegria deposits on the east. The dividing line was placed at the water gap formed by Córrego das Almas (pl. 2). Figure 32 shows the approximate extent of the high-grade ore bodies and the location of exploratory workings and samples.

The high-grade ore is mostly a surficial layer enriched and hydrated by the action of surface waters. Below, this the ore is softer and lower grade. The narrow band of outcrop in the western ore body and most of the eastern ore body have abnormally high water and phosphorous contents (table 8). Hard blue hematite and schistose specularite occur in a few generally concordant layers in enriched itabirite or in a dense brownish-black hematite. The rest of the iron-formation and the canga are the same as described for the Alegria and Conta História deposits.

A thick fault gouge was found in exploratory adit 3 (fig. 32) at about 100 meters, water soaked and so heavy that normal timbering would not hold it. The adit was abandoned.

TABLE 8.—*Analyses, in weight percent, of iron ore from Morro da Mina*

[Tr., trace. Analysts: Cia. Siderúrgica Belgo-mineira staff]

Sample [1]	Description or location	Fe	SiO_2	Mn	Al_2O_3	P	Loss on ignition
1	Western ore body hematite	63.10	1.20	0.03	1.67	0.32	5.40
2	do	64.72	.80	.03	1.25	.27	3.90
3	Itabirite	45.84	32.50	.03	Tr.	.05	1.70
4	Eastern ore body, hematite	69.04	.30	.11	Tr.	.08	.50
5	do	65.80	.66	1.33	1.88	.05	1.20
6 [2]	Adit 2, 7–17 meters	63±	.50±	------	------	------	4±
7	Adit 2, 17–22 meters	66±	.40±	------	------	------	3.5±
8	Adit 2, 22–38 meters	64±	2.10±	------	------	------	5±
9	Adit 2, 38–41 meters	63±	6.0±	------	------	------	3±
10	Adit 2, 41–60 meters	58±	12.0±	------	------	------	3±
11 [3]	Adit 1, Range or average	65–67	1.0–	------	------	------	3–7
12	Adit 3, Range or average	60±	5–7	------	------	------	5–6

[1] Location of samples 1–5 shown in fig. 32.
[2] Analyses for numbers 6–10 were averaged to closest significant figure.
[3] Order of magnitude or range of analyses.

Inferred reserves are as follows: Western ore body, 20 million tons of enriched itabirite; eastern ore body, 40 million tons enriched itabirite; total hematite deposits, about 10 million tons.

GERMANO

The deposit at Germano, between the Capanema and Santa Rita Durão quadrangles (N. 6, 200–6, 800) is one of the few economic iron-ore deposits in the region that is not in the Itabira Group of the Minas Series. The Germano deposit consists of two lenses of medium- to fine-grained pulverulent specularite, separated by a ferruginous phyllite, in the Santo Antônio Formation of the Itacolomi Series. The iron appears to be mainly a mechanical concentration of hematite and magnetite fragments. A few specimens are indistinguishable from itabirite and may be iron-formation, but the bulk of the deposit is a Precambrian detrital concentration.

Tables 9 and 10 list analyses of ore from the eastern and western parts of the deposit. The Germano deposit generally contains only traces of phosphorus whereas the Itabira Group ore in the Alegria district rarely contains less than 0.05 percent phosphorus and may contain 0.2 percent or more.

Inferred reserves of ore containing more than 60 percent iron total about 5 million tons, about 2 million tons of which contains more than 66 percent iron.

TABLE 9.—*Analyses, in weight percent, of samples from the eastern part of the Germano deposit*

[R. T. Chamberlin, written commun., 1911. Analyst: H. K. Shearer]

Sample	Fe	P	H_2O	Mn	SiO_2
H–1	66.94	0.014	1.55	--------	0.58
H–2	63.49	.012	.97	--------	8.55
H–3	67.89	.014	1.33	--------	1.12
H–4 [1]	58.54	.024	.60	0.04	14.40
H–5	67.79	.014	1.22	--------	1.44
H–6	68.84	.010	1.16	--------	.67
H–7	68.10	.006	1.94	.04	.20

[1] From canga cap.

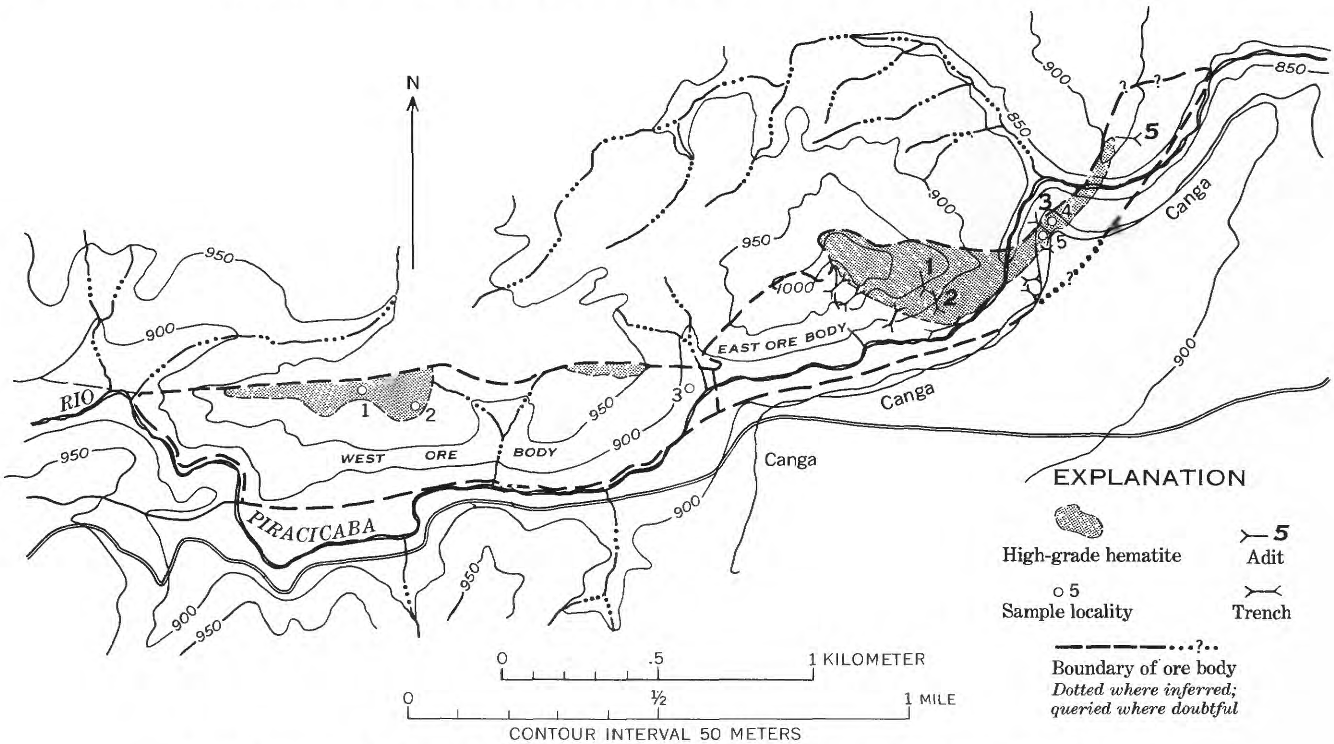

FIGURE 32.—Index map of the Morro da Mina iron deposit, showing the workings, samples, and hematite deposits.

TABLE 10.—*Analyses, in weight percent, of iron ore from the western part of the Germano deposit*

[Analyst: Cassio Pinto, DFPM]

Sample	Location (pl. 1)	Fe	SiO_2	Al_2O_3	Mn	P	Loss on ignition
1. Normal, soft specularite	N. 6,650, E. 13,050	58. 40	12. 30	7. 90	0. 015	Tr.	1. 20
2. Compact hematite	N. 6,450, E. 13,000	68. 50	. 90	. 80	. 017	Tr.	. 30
3. Rich, soft specularite	N. 6,450, E. 13,000	67. 30	2. 70	. 40	. 50	Tr.	. 80

FÁBRICA NOVA

The Fábrica Nova deposit is near the center of the Santa Rita Durão quadrangle, along Serra Lagoa Sêca and Morro da Fraga. Both the northern and southern ends of the iron-formation are faulted out by a major north-trending fault.

The Fábrica Nova iron deposit was prospected by H. K. Shearer and Harmon Lewis in 1911–12 (written commun., 1912); however, none of the workings were accessible in 1960. Data from their exploration (fig. 26, p. J46) indicate that the iron-formation is more dolomitic than the formation at Alegria and Conta História, and that it contains more soft hematite interbedded with the itabirite.

The iron-formation at Fábrica Nova covers an area of about 2.5 sq km but is overturned; it dips eastward and is relatively thin, so estimates of volume are tenuous. The deposit may contain more than 8 million tons of enriched itabirite per meter depth and a total of more than 170 million tons of itabirite. The total projected hematite is inferred to be about 10 million tons in small bodies interbedded with itabirite. High-grade canga, enriched itabirite, and surface exposures of hard hematite are inferred to total about 10 million tons.

MORRO SÃO LUIZ

Morro São Luiz is about 400 meters north of the southern boundary of the Catas Altas quadrangle (E. 8,400, pl. 3). The Morro São Luiz deposits extend about 1 km into the Santa Rita Durão quadrangle (pl. 2). They consist of several bodies of compact hematite that occur along the axes of northeast-trending folds in the itabirite.

The largest of the exposed hematite bodies is along the eastern side of the peak. It is 650 meters long and 200 meters wide, and it has an exposed thickness of about 20 meters and a projected thickness of at least 50 meters. Several samples from the east side of the deposit averaged more than 69 percent iron. The rubble ore west of the largest hematite body has an average iron content of more than 65 percent.

Figure 33 shows a large block of "rubble ore," mostly enriched itabirite, that fell from the cliffs above. The folding is similar to that in the axial zones of the folds. The recessed parts were quartz that has been replaced by limonite. The harder parts are composed of coarse-grained specularite and blue hematite in discrete layers interbedded with dense brownish-black hematite and limonite.

FIGURE 33.—Weathered surface of a block of hematite and enriched itabirite. The channels were formed by the weathering of limonite layers which replaced quartz layers. The folding is typical of the high-grade deposits.

Many small deposits of rich canga occur in the area. A few are remnants of old erosion surfaces. One, about 20 meters long, 4 meters thick, and 6–10 meters wide, rests on hematite and enriched itabirite. (fig. 34).

The following is an analysis, in weight percent, of one sample from the eastern side of the peak (Catas Altas quad., N. 700, E. 9,000).

SiO_2	0.97
Fe	69.21
Al_2O_3	.25
P_2O_5	.01
Mn	.07
Loss on ignition	.60

Reserves in the Morro São Luiz area are estimated as follows (in millions of tons).

Hematite (more than 66 percent iron):	
Indicated	7.5
Inferred	20
Itabirite (more than 50 percent iron):	
Inferred	500
Canga and rubble ore (more than 60 percent iron):	
Indicated	0.5
Inferred	3
Canga (more than 50 percent iron):	
Inferred	6

PITANGUI

The Pitangui mine, a large opencut about 2 km southwest of Catas Altas, was originally worked for gold. In figure 35, the lighter colored and rougher appearing rock on the wall of the cut, which extends across to the shadow of the massive outcrop, is hematite, clearly cutting across the bedding. The smooth planes in shadow are bedding planes. The massive material is mostly itabirite but has interbedded layers of hard hematite. The dump on the left is composed mostly of blocks and plates of hard hematite from these layers. Quartz-rich itabirite in the Pitangui area is shown in figure 36.

The many dumps and rubble piles around the mine are composed of hard hematite averaging more than 66 percent iron. The location of these dumps and the major natural deposits are shown in figure 37.

Reserves, in millions of tons, are as follows.

	Pitangui mine	*Pitangui area*
Hematite:		
Proved	0.4	
Indicated	1	2
Inferred	3	5
Itabirite:		
Inferred	50	100

FIGURE 34.—Perched canga remnant resting on hard hematite and enriched itabirite. The canga is about 4 meters thick. Location: Plate 3, N. 800, E. 8,600.

FIGURE 35.—Opencut at Pitangui mine. The spires in the upper left are hematite. The massive exposures in the center of the picture are composed of thin beds of hard hematite interbedded with itabirite. To the left is dolomitic quartzose itabirite, now weathered to a soft, sandy limonitic rock. The mine dump on the left is composed mostly of compact hematite.

FIGURE 36.—Itabirite from the Pitangui area. Note the almost isoclinal chevron type folds—the pencil point is on one axis. The light bands are quartz, the darker bands are hematite.

PIÇARRA

Pico Piçarra, about 2 km northwest of Catas Altas, is the site of a few high-grade hematite deposits interbedded with itabirite or in small crosscutting masses. The itabirite here is the northernmost of the outcrops of Itabira Group in the area (pl. 3). In this area, the Itabira Group appears to interfinger with parts of the greenstone sequence and may continue northward as small lenses within the greenstone. The area is within a zone of intense faulting and shearing and exposures are poor, so the exact relationship between the itabirite and the greenstone is not known.

Reserves are inferred at 25,000 tons of hematite rubble ore and 20,000 tons of hematite in the itabirite.

PACHECO

The Pacheco area is in the northwestern part of the Catas Altas quadrangle, near the western boundary (fig. 27). The deposits are in iron-formation of the Nova Lima Group and are the only potential ore of pre-Minas age in the district. They are composed of hematite and magnetite layers and lenses in a quartzose iron-formation. Reserves are estimated at 30,000 tons containing more than 60 percent iron.

MANGANESE ORE

Manganese deposits in the Alegria district are of two major types: (1) Beds of syngenetic sedimentary manganese and (or) secondary concentrations and (2) concretions and irregular replacement deposits. They all are apparently related to the present erosion surface; most are near the surface and those below the

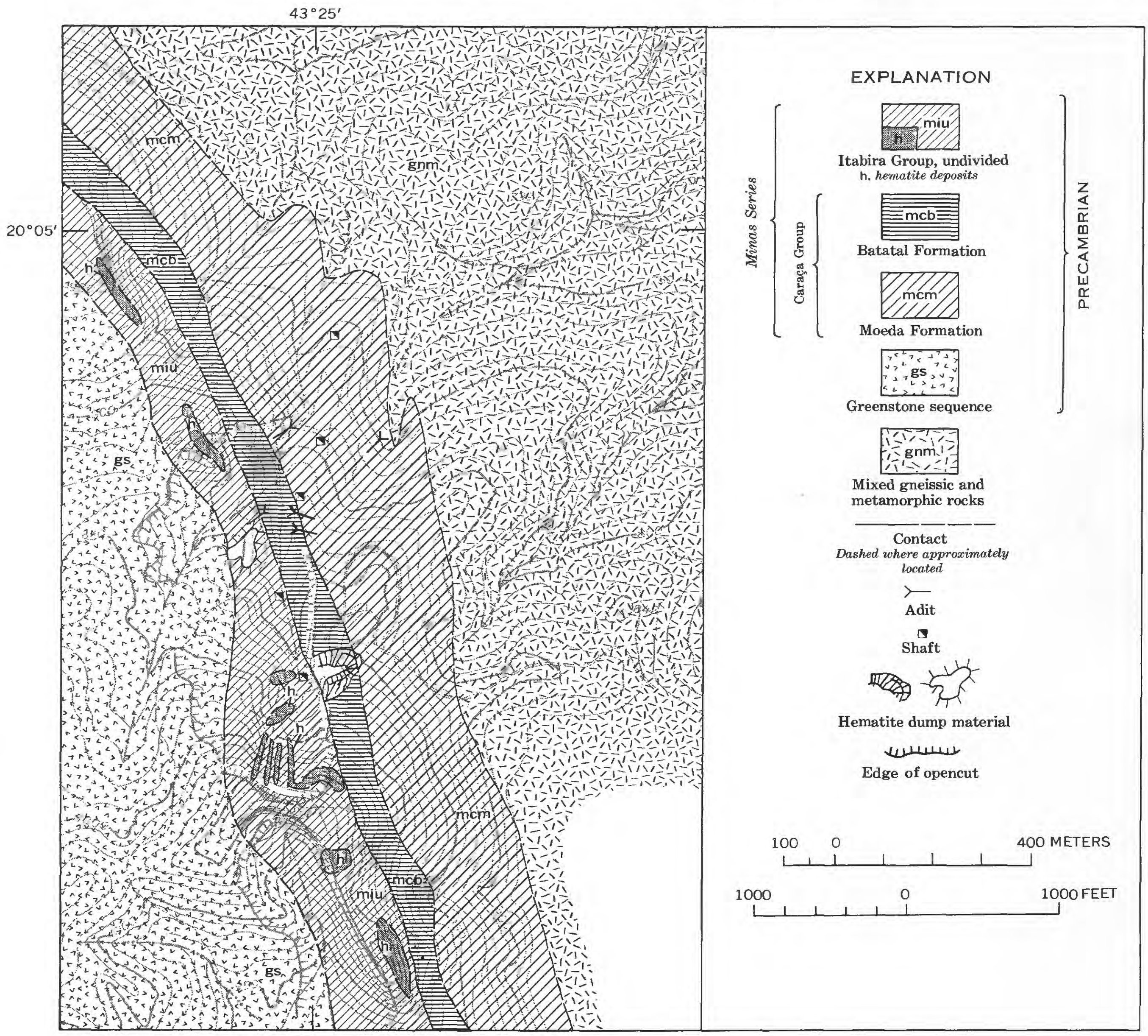

Figure 37.—Geologic map of the Pitangui mine area.

present soil zone, as at Conta História (pl. 7), decrease markedly in tenor with depth.

The two types of deposits are mineralogically similar. The most common manganese mineral is pyrolusite; psilomelane and manganite occur in very small quantities.

Manganese deposits associated with iron-formation and dolomite probably originated in much the same way as the iron and silica: the manganese was deposited as an oxide along with the iron-formation in syngenetic layers. The deposits at Conta História were probably derived partly from these syngenetic layers and partly by supergene enrichment, which concentrated manganese in favorable beds within the iron-formation. This type of deposit was called the "Lagoa Grande" type by Park, Dorr, Guild, and Barbosa (1951). The combined iron manganese content commonly totals about 60 percent; generally, the maximum manganese content is about 45 percent. A very few samples analyzed contained more than 45 percent manganese; none contained more than 50 percent.

The bedded deposits are of several different types. The most important are the concordant, partly syngenetic, but largely secondary concentrations in a bed or beds in the Itabira Group, notably at Conta História. A common but generally low-grade type occurs in dolomite or dolomitic phyllite, in discrete beds containing thin layers and lenses or nodules of manganese oxides. The beds range from a few centimeters to several meters in thickness. The thinner layers are generally interbedded with phyllite in a zone several meters thick; the thicker beds form a single unit. This type of bed is common but discontinous and lenticular in the upper part of the Itabira Group. Several extensive beds occur in the Fêcho do Funil Formation. One is near Córrego dos Macacos, exposed in the roadcut between Fazenda Alegria and Conta História; another is below the bauxite deposits near Santa Rita Durão, at Cata Preta; and another is near the southern boundary of the Santa Rita Durão quadrangle.

Concretionary deposits, mostly associated with dolomitic or ferruginous rocks, are widespread but relatively unimportant. They occur in veinlike crosscutting bodies and in the soil. A deposit in ferruginous laterite just south of the Santa Rita Durão quadrangle has yielded several tons of high-grade, hand sorted nodules. The nodules, in thin irregular bodies in the B soil zone, range from a few millimeters to about 10 cm in diameter and are generally irregular in shape. Those large enough to concentrate by hand sorting make up only about 2 percent of the volume of the soil.

The veinlike concretionary deposits are apparently controlled both by the type of gangue rock and by fracturing; nodules and veinlets fill fractures and cavities in the generally dolomitic country rock. The nodules consist of almost pure manganese oxides but are so widely scattered that a bulk sample would analyze only 15 or 20 percent manganese. One such deposit is about 300 meters northwest of Fazenda Alegria, another is on the margin of the Rio Piracicaba (Capanema quad. N. 7,650, E. 12,100). Nodules commonly show very fine rhythmic layering and have botyroidal forms. Few such deposits constitute ore, as they require hand sorting and the removal of much gangue.

A few alteration deposits in dolomite were recorded in the Alegria district, both in the Itabira Group and in the Fêcho do Funil Formation, but they are small and discontinuous. No production has been recorded.

Quartz veins in which thin fractures are filled with manganese oxides were prospected at several localities, but the manganese is sparse.

A small deposit of manganese fills fractures in phyllite in the northwestern corner of the Catas Altas quadrangle and extends northeastward into the Santa Bárbara quadrangle, where major deposits are located. It has been tentatively classified as a vein deposit, although the material at the surface is probably secondary. The manganese mineral was identified by X-ray as todorokite ($Mn_2Mn_5O_{12} \cdot 3H_2O$) (Simmons, 1968, p. 40).

Concentrations of manganese in canga occur in many localities. Some are surface expressions of the bedded deposits, but many others are apparently unrelated to the underlying rock. Some are associated with bauxite deposits; others are in indurated ferruginous laterite overlying the greenstones, gneiss, and the metamorphic rocks. Only a few have been prospected. One, tentatively correlated with this type, is in Canga overlying the Santo Antônio Formation (Santa Rita Durão quad., N. 5,300, E. 100).

MINING

The geology of the manganese deposits in Minas Gerais was first described by Derby (1899) and Scott, (1900), who mentioned some of the deposits in the Alegria district. Other reports mention these deposits (Guimaraes, 1935; Moraes, 1939; Dorr, Horen, and Coelho, 1956), but no study had been undertaken. Many small deposits in various parts of the district have been prospected from time to time, but all are small and uneconomic and do not merit much attention.

The deposits at Conta História were not discovered until 1951. The area had been mapped and explored for the iron ore by E. C. Harder and others in 1909–12 and by the Bethlehem Steel Co. in 1930. The only outcrops of manganese were on a sheer cliff. The area was prospected and explored by Cia. Siderúrgica Belgo-Mineira from 1951 until 1957, when production of manganese was started in conjunction with the exploration of the deposit. Production for export began in 1959.

The total quantity of manganese produced from the Alegria district is not known. A few hundred tons may have been produced from the many small prospects. At the close of fieldwork in 1960, the Conta História mine had produced about 25,000 tons of ferruginous manganese ore, of which about 17,000 tons was exported to Europe.

The average grade of the mine-run manganese ore is shown in table 11. The coarse fraction is lump ore 3–20 cm in diameter; the medium fraction is screened to a size range of 1–3 cm, and the fine fraction is less than 1 cm.

CONTA HISTÓRIA

The largest known deposits of ferruginous manganese ore in the Quadrilátero Ferrífero are those at Conta História. The manganese mines are on the top of Alto do Conta História and extend down the dip slope to the east (pl. 1; fig. 38). The main mine area is shown on plate 7, and the other producing mines and the area of plate 7 are shown in figure 38.

Alto do Conta História is in part the remnant of an old erosion surface (p. J6), a gently undulating plateau covered with canga (fig. 39), in places several meters thick. The manganese ore occurs in a generally discrete concordant layer interbedded with itabirite.

TABLE 11.—*Analyses, in weight percent, of shipped ore, Conta História mine*

[Data from production files of Cia. Siderúrgica Belgo-Mineira. Analysts: Cia. Siderúrgica Belgo-Mineira staff]

Sample	Description		Mn	Fe	SiO_2	Al_2O_3	P
1	Coarse fraction	Max	46.07	27.75	5.50	5.22	0.21
2	do	Min	30.80	15.21	.40	.41	.05
3	do	Avg	39.61	21.19	1.62	2.31	.12
4	Medium fraction	Max	44.65	38.71	7.80	4.22	2.70
5	do	Min	28.32	17.62	.10	.83	.08
6	do	Avg	37.50	23.15	2.71	2.04	.14
7	Fine fraction	Max	38.00	38.21	11.30	6.47	.28
8	do	Min	24.41	22.70	.60	1.04	.11
9	do	Avg	30.11	30.54	3.04	2.48	.17
10 [1]	Average of 2,000 tons exported		39.80	19.50	2.30	1.50	.11

[1] Büchi (1961, p. 142).

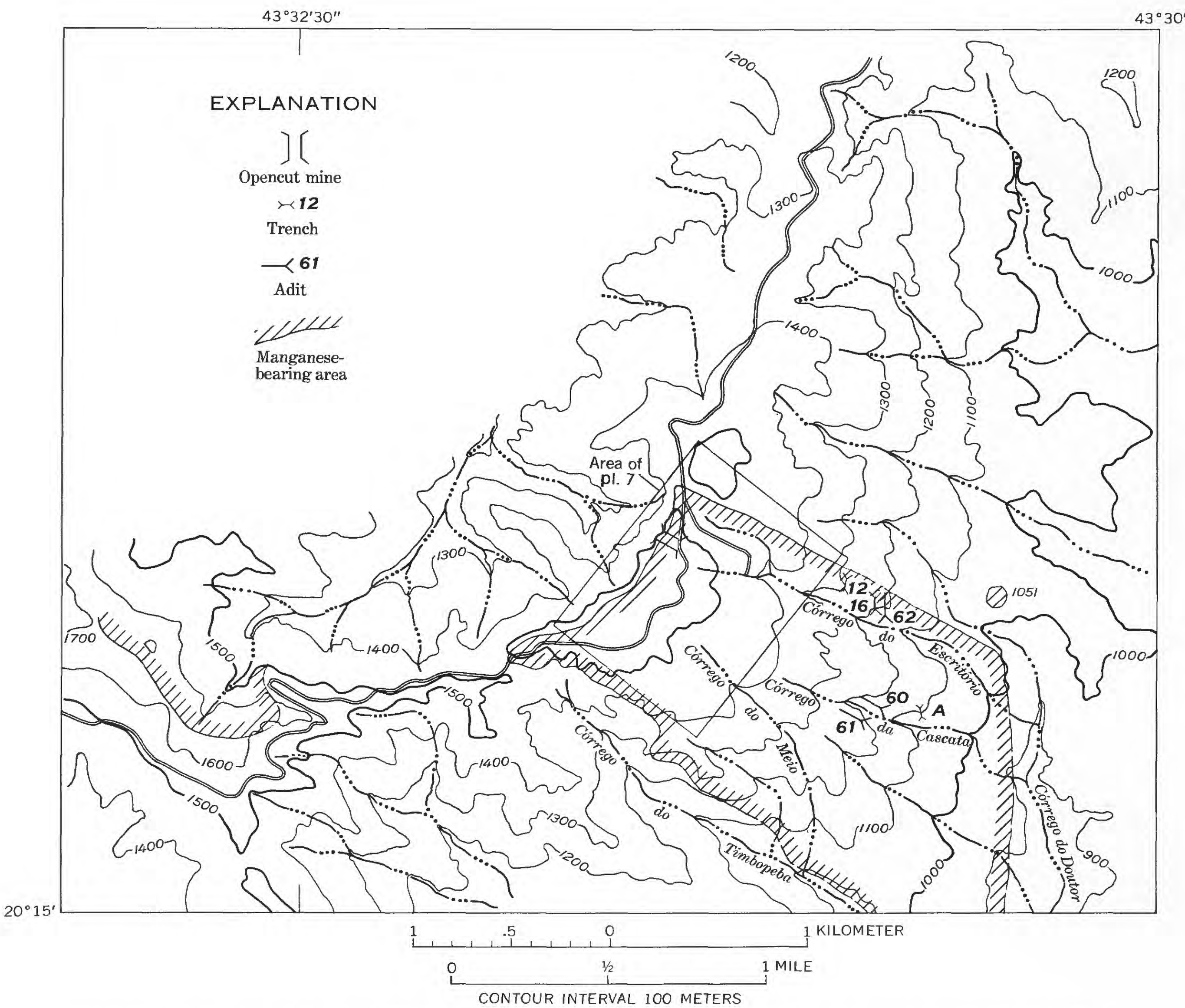

FIGURE 38.—Index map of the Conta História area. The shaded part is known or inferred to contain manganese deposits.

FIGURE 39.—Alto do Conta História, opencut of the manganese mines near the center of the picture. The cliffs below the road, extreme right background, are canga on the old erosion surface, underlain by the manganese beds.

The layer ranges from 2 to 7 meters in thickness and contains from 30 to 45 percent manganese. Where thickest, the layer is generally well stratified and breaks up into small plates. Manganese-rich and manganese-poor beds alternate and the general tenor is lower than in places where the layer is thinner. Where thinner, the layer is almost massive and consists of hard compact manganese ore. The manganese ore is interlayered in some areas with many thin beds of schist or clay ranging from 1 to 50 cm in thickness (fig. 40).

In most places where the manganese layer is thick and stratified, about 1 meter at the top and another at the bottom contain 40–45 percent manganese, and the layer between contains only 30–35 percent manganese, with a few small rich pockets or nodules scattered through it.

The manganese ore is richer near fault planes, probably because faults facilitated circulation of ore-bearing solutions. The manganese layer is cut by two sets of faults. The major set comprises many faults that trend about N. 70° W., are almost vertical, and have displacements ranging from a few meters to more than 60 meters (pls. 1, 7). The manganese layer has been faulted up and eroded off in some places (fig. 41).

FIGURE 40.—Cut and left drift of adit 57, Conta História. The conspicuous layer about 2 meters above the timbering is the goethite cap above the manganese ore; above the cap is itabirite. The white streaks in the manganese bed are interlayered clay and schist.

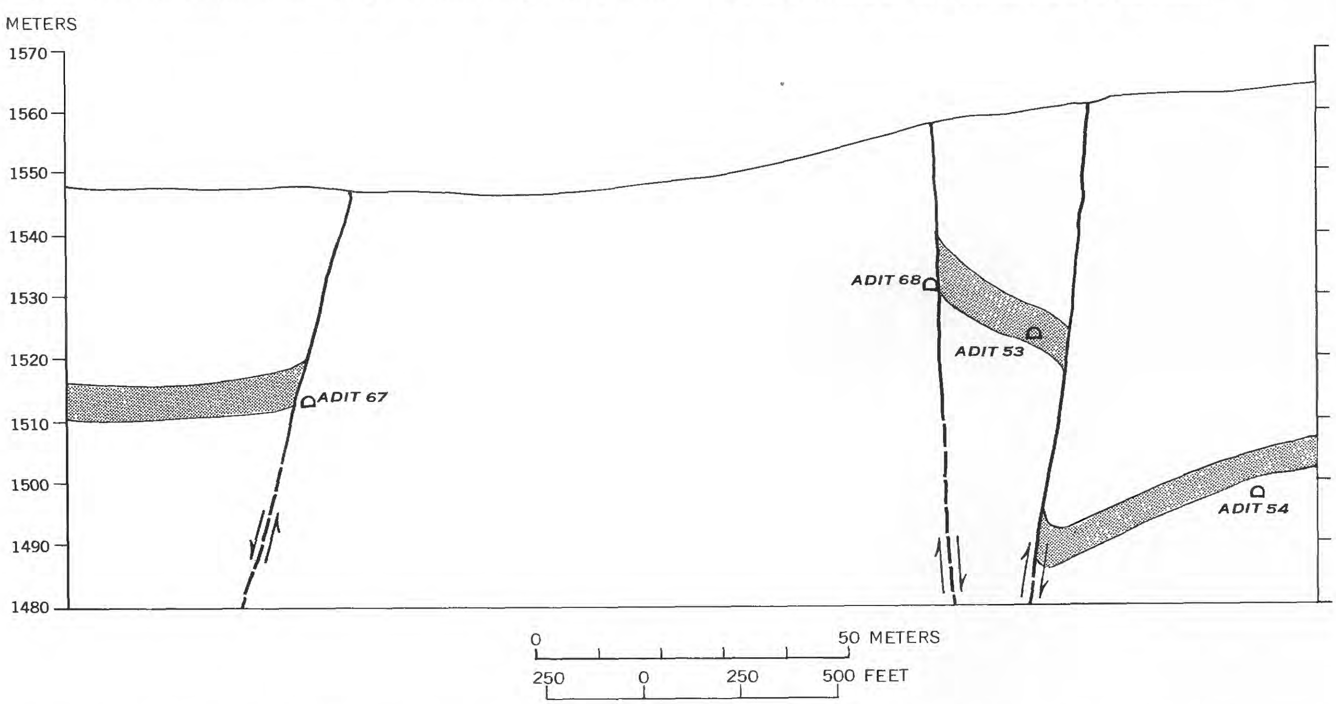

FIGURE 41.—Schematic cross section at the cliff face, Conta História. Manganese-bearing beds are shaded. Scale approximate. Adopted from Büchi, 1961, p. 147.

The other set consists of smaller more recent faults, having displacements ranging from 1 cm to 3 meters. They trend generally about N. 40° E., and dip steeply northwest; the northwest side is downthrown. The location and alinement of the scarp on the northwest side of the deposit is controlled by these faults. The faults appear to be slump blocks activated by the deep erosion below the scarp. Figure 42 shows the displacement of the manganese bed on one of these faults and the relationship of the scarp to the fault. Several representative faults and associated cross faults in the opencut are shown on plate 7. The entire area is cut by a close network of similar faults.

FIGURE 42.—Fault displacing the manganese ore bed in the opencut, Conta História. All the overlying itabirite was removed preparatory to mining the manganese ore. The fault plane is easily visible in the wall to the left of the cart; the arrow points to a continuation of the fault, visible on the scarp. The displacement is about 2.5 meters.

The N. 70° W.-trending faults apparently formed before the last period of deformation and metamorphism. In places they are completely healed in the overlying itabirite and cannot be traced, even on close inspection, regardless of the amount of apparent displacement of the manganese bed. The more recent faults, such as the one illustrated in figure 42, have sharp planes easily traced through the manganese and the iron-formation.

Most of the larger faults and some of the smaller ones have been filled by seams of goethite and limonite ranging from a few centimeters to several meters in width. The goethite fillings are commonly extremely variable in width, with long projections parallel to the bedding or layering extending into the county rock on either side of the fault (fig. 43).

The manganese layer terminates abruptly against these faults. Displacements range from a few centimeters on some to an unknown distance above the present erosion surface on others (fig. 41). The manganese bed is generally overlain by a bed of goethite and, in many places, is also underlain by one. Figure 44 is a cross section along a crosscut of adit 56 (pl. 7), showing the cap and base of goethite and the fault. In many places kaolinite is interbedded in the manganese. A kaolinite layer in adit 56 has been partly replaced by geothite (fig. 44).

Table 12 lists analyses of the goethite from several localities at Conta História.

Most of the goethite that fills faults and overlies the manganese-bearing layer is later than the manganese and replaces or encloses the manganese to some extent. In a few places, however, limonite and goethite have been replaced by the manganese. Several stages of deposition, precipitation, and replacement were involved in the formation of the deposits. Syngenetic and supergene minerals were affected, as well as material introduced from the fault planes.

Many samples of manganese ore from the various exploratory workings in the Conta História mine were analyzed by Cia. Siderúrgica Belgo-Mineira. Analyses of representative samples from several localities are given in table 13, and analyses of samples from one of the exploration adits (52) are given in table 14. Analyses of the cores recovered from the diamond drill holes shown on plate 7 are listed in table 15.

TABLE 12.—*Analyses, in weight percent, of limonite-goethite in faults and manganese layers at Conta História*

[Analysts: Cia. Siderúrgica Belgo-Mineira staff]

	1	2	3	4	5
Fe	61.15	59.03	55.92	59.68	60.88
Mn	.60	-------	1.84	.39	.23
SiO	.96	1.58	3.60	1.94	1.68
AlO	.68	-------	2.74	-------	1.00
P	.25	.24	.15	.30	.25
Loss on ignition	10.00	11.06	9.86	10.28	9.96

1. Composite sample of fault filling and cap over manganese layer, mouth of adit 56 (fig. 43*C*).
2. Cap over manganese bed. Adit 51 at 32–33 meters.
3. Layer at base of manganese layer, mouth of adit 53.
4. Layer at base of manganese layer, trench, upper Morro Norte (fig. 43*A*).
5. Layer at top of manganese layer, trench, upper Morro Norte (fig. 43*A*).

The location of samples of manganese ore from outside the area of plate 7 is shown in figure 38, and analyses of these samples are listed in table 16.

The reserves of manganese ore at Conta História are relatively well known because of the exploration and development work of Cia. Siderúrgica Belgo-Mineira. The following is a summary of their 1960 reserves, in millions of tons, of manganese ore for this deposit:

Proved	1.8
Indicated	5
Inferred	20

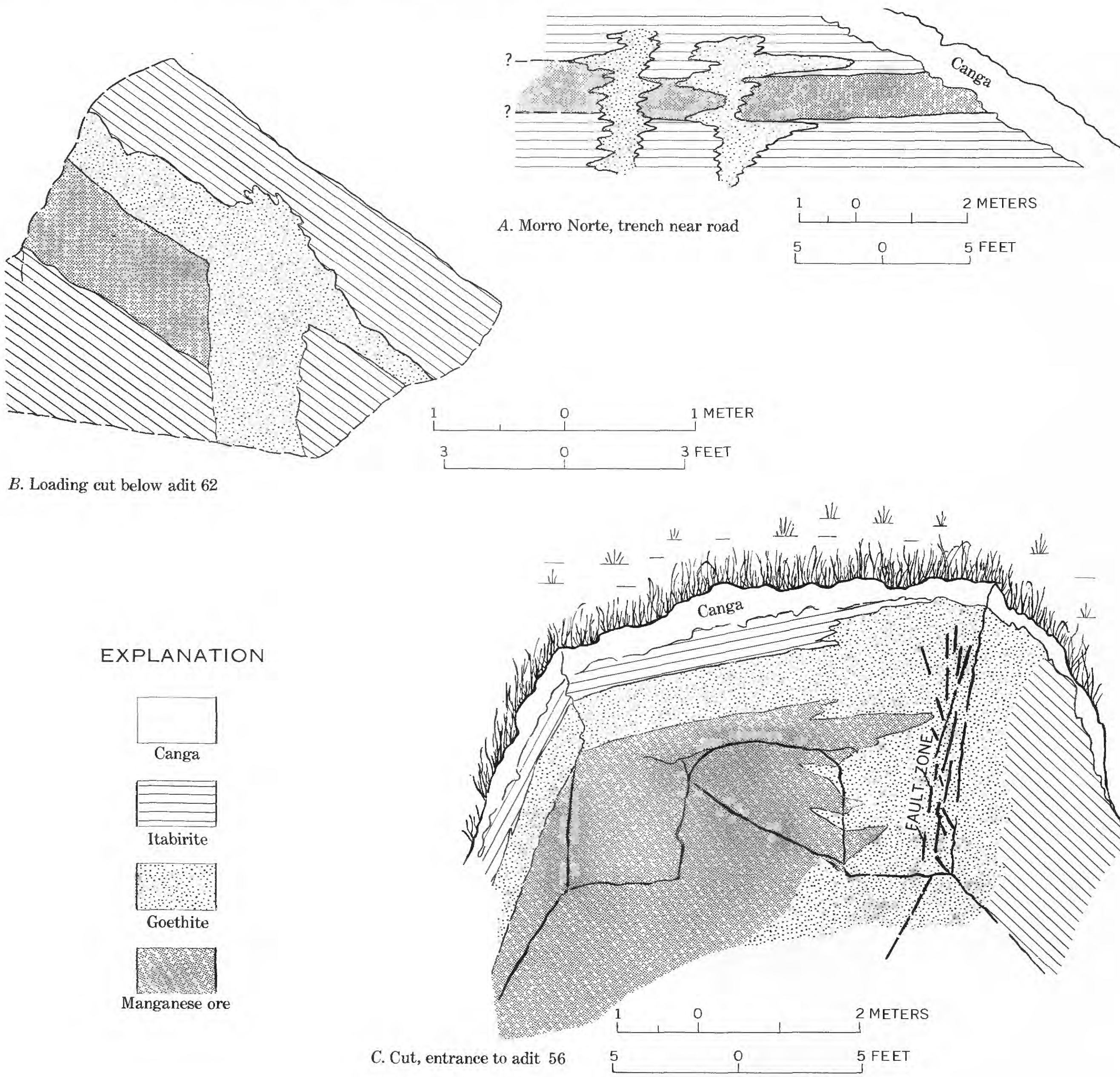

FIGURE 43.—Schematic diagrams illustrating relationship of goethite-filled faults to the manganese ore beds, Conta História. Scales approximate.

OTHER MANGANESE DEPOSITS

Córrego dos Macacos.—Several manganese deposits were prospected by Cia. Siderúrgica Belgo-Mineira in Córrego dos Macacos in the east-central part of the Capanema quadrangle; several were apparently transported boulders in the soil. One of the boulders was found in the roadcut (Capanema quad. N. 5,300, E. 12, 700) below a deposit in the canga on top of Serra Germano (Santa Rita Durão quad., N. 5,350, E. 75). The boulder may have fallen from an extension of the canga deposit, although exploration has not yet delineated such an extension.

A bedded deposit of manganese nodules in a weathered dolomite and dolomitic itabirite occurs in the Capanema quadrangle (N. 5,450, E. 12,700). The manganese is sporadic and relatively low grade.

Two adits and several prospect pits and trenches were dug in a similar deposit near the junction of Córrego dos Macacos and the Rio Piracicaba, in phyllitic and dolomitic itabirite and in fault gouge containing scattered nodules of manganese.

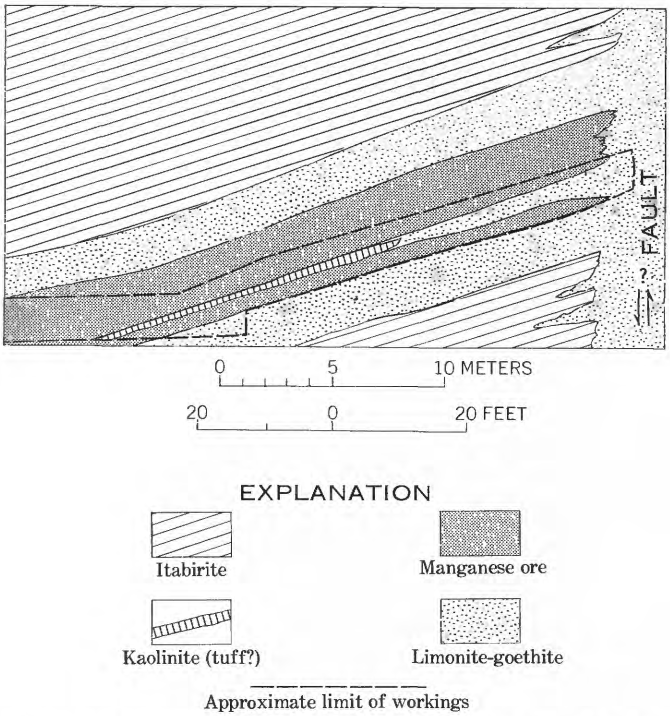

FIGURE 44.—Section along the first crosscut on the north side of adit 56, Conta História. Adapted from Büchi, 1961. p. 145.

TABLE 13.—*Analyses, in weight percent, of samples of manganese ore from exploration adits and trenches in the Conta História area*

[Analysts: Cia. Siderúrgica Belgo-Mineira staff]

Sample	Location	Mn	Fe	SiO_2
1	22–23m, adit 55	38.35	20.65	0.70
2	23–24m, adit 55	36.61	22.49	.70
3	24–25m, adit 55	47.45	12.78	.60
4	25–26m, adit 55	43.05	17.95	.56
5	26–27m, adit 55	45.76	16.47	.60
6	27–28m, adit 55	41.52	20.45	.60
7	28–29m, adit 55	41.10	21.58	.60
8	0–1m, drift 1	32.20	31.24	.70
9	1–2m, drift 1	27.79	30.44	.84
10	2–3m, drift 1	42.37	19.31	.80
11	3–4m, drift 1	33.89	29.76	.96
12	4–5m, drift 1	39.66	21.13	1.20
13 [1]	Adit 56	35.70	18.82	.70
14 [2]	do	42.68	27.50	2.00
15 [3]	do	39.96	21.10	.90
16	Scarp, mouth of adit 51	26.85	30.98	1.51
17	Scarp, mouth of adit 52	40.41	17.89	.84
18	Scarp, 0–20 meters southwest of adit 52	38.54	21.38	1.10
19	Scarp, 20–40 meters southwest of adit 52	38.84	18.94	1.00
20	Scarp, 40–60 meters southwest of adit 52	37.80	17.42	.86
21	Upper trench, Morro Norte	46.09	17.96	.82
22	Lower trench, Morro Norte	43.81	16.40	.84

[1] Lowest of eight samples.
[2] Highest of eight samples.
[3] Average of eight samples.

Alegria.—Only one, minor, manganese deposit, near Fazenda Alegria (fig. 27), has been prospected in the Alegria area. However, the stratigraphy and lithology of part of the area are identical with those of the Conta História area, and the canga and rubble on the north side of the iron-formation contain scattered fragments of manganese. A number of pieces of manganese were found in the rubble at the foot of the slope (Capanema quad., N. 11,150, E. 12,800) and several in the canga to the east. Ferruginous manganese beds should, therefore, occur in the Alegria area. Careful prospecting and exploration would be necessary to delineate them.

TABLE 14.—*Analyses, in weight percent, of samples of manganese ore from exploration adit 52, at Conta História*

[Analysts: Cia Siderúrgica Belgo-Mineira Staff]

Sample [1]	Location (meters)	Mn	Fe	SiO_2	Al_2O_3	P	Loss on ignition
1	1–3	44.79	14.62	1.02			
2	3–5	39.54	20.23	.77			
3	[2] 10	36.14	21.82	.63			
4	14–15	35.08	21.31	.72			
5	[3] 21	40.29	19.60	.82			
6	[4] 21	47.99	11.54	.58			
7	20–22	45.20	12.77	.50			
8	22–23	43.77	15.43	.68			
9	23–24	46.78	12.77	.54		0.11	13.86
10	24–25	44.40	12.98	.60		.11	12.50
11	25–26	42.55	14.68	.52		.15	13.30
12	26–27	44.57	14.11	.50		.11	13.64
13	[5] 27–28	47.43	12.46	.69	0.94	.11	14.18
14	[2] 28	47.35	13.22	.65	1.92	.07	12.08
15	[6] 27–28	44.56	16.09	.63	2.24	.07	12.04
16	28–29	48.10	11.10	.42	1.64	.11	13.82
17	29–30	43.56	15.14	.60		.13	12.70

[1] Samples are average of material removed except as noted.
[2] Vertical channel sample across bed.
[3] Vertical channel sample west side of fault.
[4] Vertical channel sample east side of fault.
[5] Horizontal channel sample top of bed.
[6] Horizontal channel sample bottom of bed.

TABLE 15.—*Analyses, in weight percent, of cores from diamond-drill holes at Conta História*

[Analysts: Cia. Siderúrgica Belgo-Mineria Staff]

Drill hole	Depth of ore bed (meters)	Mn	Fe	SiO_2	P
3	28.5–30.3	39.72	24.87	0.76	0.07
4	38.6–40	40.50	19.04	2.20	.11
6	33.0–35.2	48.25	13.80	.90	
7	34.47–36.87	42.71	17.52	1.16	
10	34.3–37.5	49.98	8.01	.94	
11	26.1–30.0	45.72	14.86	.52	

Cata Preta.—The old Cata Preta gold mine (pl. 2) was extensively explored by Cia. Siderúrgica Belgo-Mineira for the manganese minerals exposed in the old workings. The manganese is largely confined to a layer of manganiferous splash rock, but discontinuous discordant veins, as well as concordant replacement bodies and nodules, are locally common, and all the high-grade deposits are in or near the mineralized fault zone which carried the gold ore (p. J67). The country rock is dolomite and dolomitic phyllite. The deposits are not sufficiently well exposed or explored for a definition of type or for a determination of reserves. Reserves in the known deposits are said to be 10,000 tons indicated and 20,000 tons inferred, average grade 35 percent manganese. Table 17 lists analyses of samples from the Cata Preta deposits.

Morro São Luiz.—The manganese deposits in the Morro São Luiz area are similar to those at Cata Preta. They occur in dolomitic rocks in the same zone of faulting. One deposit is in the canga and underlying phyllite 100–300 meters south of the northern boundary of the

TABLE 16.—*Analyses, in weight percent, of manganese ore from areas east of the main mine at Conta História*

[Analysts: Cia. Siderúrgica Belgo-Mineira staff]

Sample	Location (fig. 38)	Mn	Fe	SiO_2	Al_2O_3	P_2O_5	Loss on ignition
	Córrego da Cascata						
1	Foot of waterfall	26. 85	31. 01	9. 71	1. 05	0. 15	2. 61
2	North side of waterfall	30. 98	25. 75	10. 39	. 62	. 12	3. 09
3	Block outcrop A	44. 20	15. 50	3. 82	. 62	. 78	3. 42
4	Trench at A	25. 20	30. 18	14. 80	. 56	. 07	1. 77
5	Adit 60, mouth	26. 85	33. 50	3. 85	1. 12	. 11	4. 39
6	Adit 60 at 35 meters	35. 94	23. 66	7. 00	. 63	---	1. 46
7	Adit 61, mouth	32. 00	27. 96	4. 70	1. 25	---	3. 11
	Córrego do Escritório						
8	Adit 62, mouth	42. 68	16. 22	4. 00	1. 13	---	---
9	Loading area cut, adit 62	38. 42	20. 77	1. 90	1. 67	---	---
10	Trench 12, average	47. 60	15. 67	. 54	. 62	---	---
11	Trench 16, average	33. 46	29. 79	2. 20	---	---	---
	Road to adit 62						
12	Near T 1051	24. 37	20. 21	31. 80	. 24	---	---

TABLE 17.—*Analyses, in weight percent, of manganese ore from the Cata Preta area, Santa Rita Durão quadrangle*

[Analysts: Cia. Siderúrgica Belgo-Mineira staff]

Sample	Location and description [1]	Mn	Fe	SiO_2	Loss on ignition
1	Adit 1, at heading, channel	36. 51	2. 17	1. 38	---
2	Adit 1, at 10 meters, channel	36. 86	17. 52	3. 18	15. 46
3	Adit 1, left side, channel	36. 70	17. 52	6. 16	13. 42
4	Adit 1, veins, grab	49. 74	7. 66	1. 36	22. 04
5	Adit 2, average of six samples	33. 60	22. 44	2. 88	14. 72
6	Adit 3, average of nine samples	36. 21	16. 42	3. 44	14. 06
7	Adit 5, average	33. 11	2. 22	5. 74	---
8	Adit 6, heading, channel	27. 51	1. 88	19. 04	---
9	Adit 6, rubble ore, grab	44. 15	1. 08	6. 30	---
10	Adit 6, veins in heading, channel	44. 62	1. 14	1. 64	---
11	Adit 9, heading, grab	46. 36	. 63	11. 60	---
12	Deposit 2, average	26. 32	1. 99	17. 46	---
13	Soft core, Benjamin deposit	47. 21	11. 39	3. 52	---
14	João Mohl. deposit, average	22. 23	18. 80	5. 24	---

[1] Samples 1–11 from N. 9,250, E. 8,650 (800 meters northwest of Santa Rita Durão). Sample 12 from N. 9,000, E. 8,600. Sample 13 from N. 9,800, E. 8,500. Sample 14 from N. 7,800, E. 8,000.

Santa Rita Durão quadrangle at E. 9,200. The manganese ore occurs as scattered nodules and fracture filling in the canga and phyllite. Another deposit is in manganiferous splash rock and phyllite (Catas Altas quad., N. 600, E. 9,300). Several adits and trenches were dug in the deposit, but all are now inaccessible. Because the overall grade is apparently very low, no reserves were calculated.

Fábrica Nova.—No manganese ore deposits as such are known in the Fábrica Nova iron deposit, but most exposures contain a small amount of manganese minerals, several have thin beds of ferruginous manganese, and the canga in several localities includes fragments of hard manganese ore. It therefore seems likely that the iron deposits at Fábrica Nova contain beds of manganese ore similar to those of the Conta História deposits, and constitute a potential economic deposit of manganese ore as well as of iron ore.

BAUXITE

The Alegria district contains many known bauxite deposits and an equal number of localities where bauxite might be found. Only a few have been prospected or explored enough to indicate size and extent, and bauxite ore was being mined at only one when mapping was in progress. Field observations and study of the trenches and test pits in the known deposits indicate that all deposits formed under similar conditions.

Remnants of old erosion surfaces with rapid subsurface drainage and an indurated cap of ferruginous laterite or canga almost invariably have deposits of bauxite immediately under the caprock. These deposits are thickest along the precipitous edges and thin toward the center. The size and thickness of the bauxite layers—that is, mineral localities versus economic deposits—also depend on the type of basement rock, the aluminum content of the source rock, and the weathering characteristics of the source rock or the basement rock.

Any perched erosion and (or) deposition surface may have bauxite deposits if source rocks and basement rocks are favorable and drainage is good. The caprock may be effect rather than cause, but it nevertheless protects the deposits from too rapid erosion.

The richest, thickest bauxite deposits have formed over dolomitic phyllites and dolomite and over ultramafic rocks; thinner deposits have formed over phyllites and other high-alumina rocks, and generally only very thin or minor deposits have formed over silicic rocks. Thickness ranges from a few tens of centimeters to more than 6 meters and varies proportionately with the excellence of the drainage, thickest near the edges of the "mesas" and thinning inward. Areal extent of the deposits ranges from a few tens of square meters to several square kilometers.

The richest deposits have formed below an indurated cap of ferruginous laterite on an old erosion surface of relatively high relief with rapid subsurface drainage. Under other conditions, smaller deposits form, or the available alumina content is lower.

Much of the bauxite is formed by the desilication of clays. The alumina-rich components of igneous rocks weather to clay more easily than the mica and chlorite of the phyllites. The magnesia-rich rocks such as dolomite, ultramafic, or mafic rocks may furnish a desilicating agent, in the form of magnesium bicarbonate. Deposits that have formed on old erosion surfaces over ultramafic rocks may lack a caprock, but all are well drained.

All the known bauxite deposits in the Alegria district are surface concentrations in laterite, ferruginous laterite, or saprolite derived from dolomitic and ultramafic rocks; most of them have a cap of canga or indurated ferruginous laterite, and most are associated with an old erosion surface (page J6).

MINES AND POTENTIAL PRODUCERS

FAZENDÃO

The only bauxite mine active in the district in 1960 was the Fazendão mine, about 3 km north of Santa Rita Durão. The mine is the most accessible and easily worked of several deposits in the area. The approximate locations of the deposits are indicated on plate 2, by the symbol Bx. Plate 8 shows a geologic map, cross sections, and analyses of samples from the mine area.

The bauxite deposit at the Fazendão mine is crescentic and thickest in the concave part, where it encircles the head of the drainage in a cliff 3–6 meters high (fig. 45). The thickness ranges from 6 meters in the center to a few centimeters along the convex side of the deposit. The bauxite is underlain by a ferruginous dolomitic schist or by laterite which is underlain by the schist. Canga overlies part of the bauxite. Near the cliff face almost all the canga has been eroded away.

Samples were taken both vertically and horizontally from cliff face toward the outer limits of the deposit and from top to bottom in the shafts; analyses of samples from one of the trenches are listed in table 18.

Other deposits in the Fazendão area were not developed, but some test pits were dug and sampled. Table 19 lists analyses of some of the samples.

Proved reserves at the Fazendão mine are 100,000 tons, and inferred reserves of the several Fazendão deposits are about 500,000 tons.

GERMANO

The bauxite deposits at Germano have not been explored, but several localities were sampled; analyses are listed in table 20. The deposits are similar to those at Fazendão, but the underlying rock is only slightly dolomitic. Much of the bauxite appears to have been formed from alluvial material rather than from laterite. The bauxite is capped by canga on an old and extensive erosion surface (fig. 3, area III). Indicated reserves are about 60,000 tons.

FIGURE 45.—Fazendão bauxite deposit. The scarp shows in the cut at the end of the mine. Serra do Caraça in the background.

TABLE 18.—*Analyses, in weight percent, of material from trench IV, Fazendão bauxite deposit*

[Analysts: Cia. Siderúrgica Belgo-Mineira]

Sample	Description [1]	SiO_2	Fe	Al_2O_3	TiO_2	Mn	P	Loss on ignition
1	Yellow coarse fraction	2.00	19.09	42.68	2.70	0.07	0.01	25.00
2	Red and yellow variegated coarse fraction	1.00	17.47	45.26	2.10	.07	.03	26.00
3	Red, coarse fraction	1.00	16.67	46.65	1.80	.07	.05	26.00
4	Mine run, coarse fraction	1.10	16.13	46.92	1.80	.07	.05	26.44
5	Mine run, fine fraction	3.18	25.26	38.30				21.82
6	Mine run, medium fraction	1.55	22.03	41.00	2.40			23.10
7	Concretions in fine ore	2.70	21.99	41.46				23.74
8	Mine run, fine ore	2.50	22.54	41.77				23.70
9	Yellow ore, average	1.10	21.44	43.35				24.85
10	Dark yellow-brown ore, average	1.30	18.15	46.66				26.00

[1] Samples 1–6 screened to less than 1 cm (fine fraction), 1–4 cm (medium fraction) and more than 4 cm (coarse fraction) in size.

TABLE 19.—*Analyses, in weight percent, of bauxite and laterite from the Fazendão area*

[Analyst: Cia. Siderúrgica Belgo-Mineira staff chemist]

Sample	Location	Al_2O_3	SiO_2	Fe_2O_3	Loss on ignition
1	New road west of Fazendão.	25.57	59.00	5.53	9.00
2	900 meters east of new road.	27.07	4.60	49.18	18.62
3	Bulk sample at telegraph pole 109.	20.89	21.00	44.31	13.60
4	Soil concretions at sample 3 site.	61.47	7.64	2.44	27.88
5	Shaft near road, Fazendão-Santa Rita Durão.	53.47	11.00	9.50	26.20
6	50 meters east of the above road.	26.48	5.60	47.48	20.50
7	Macaquinho	40.11	43.44	3.26	13.71
8	do	40.51	42.64	2.84	13.87
9	Road, Santa Rita Durão-Algeria.	49.26	27.02	2.03	21.73

TABLE 20.—*Analyses, in weight percent, of bauxite, and laterite samples from the Germano area*

[Analysts: Cia. Siderúrgica Belgo-Mineira]

Sample	Al_2O_3	SiO_2	Fe	Loss on ignition
1	49.00	5.00	14.50	25.00
2	51.76	3.56	12.90	26.00
3	34.10	10.08	25.52	17.20
4	36.31	32.92	8.59	17.95
5	40.84	14.08	14.24	24.00
6	40.90	2.30	22.10	25.00

FÁBRICA NOVA

Bauxite deposits in the Fábrica Nova area are widely scattered throughout most of the area covered by the canga. A few test pits were dug, and bauxite layers were found in all, from a few centimeters to more than 2 meters thick. The bauxite was not sampled by the author, and analyses were not available from the previous work. In appearance, the bauxite resembles that at Fazendão and is probably equivalent in grade. If all the favorable areas in which outcrops or pits show the occurrence of bauxite are underlain by half a meter of bauxite ore, potential reserves are about 500,000 tons.

GOLD

Gold is widespread throughout the Alegria district, but ore bodies are generally small and low grade. Placer gold occurs in all the major streams and in many of the perched terraces and gravel deposits. Most of the river deposits and terrace gravels were extensively worked during colonial time, and some of the gravel bars are still being worked (fig. 46), but only sporadically as a part-time occupation. The coarser gravel is scraped up into ridges with a crude hoe or rake, thereby allowing the current to wash away the fine light material from the channel thus formed; then the "concentrated" material is washed by hand in a shallow round wooden pan. Production is insignificant.

Some of the old alluvial workings are very extensive. The alluvium in the river valley in the northwest corner of the Catas Altas quadrangle is made up entirely of tailings from gold extraction in the 18th and 19th centuries. These tailings extend for many miles downstream. All the terrace gravels shown on the maps (pls. 2, 3) were worked for gold.

FIGURE 46.—Panning for gold in the Rio Piracicaba near Santa Rita Durão. Serra do Caraça, Pico Inficionado in the background.

Gold deposits in generally concordant layers within rocks of pre-Minas age are common and widespread in the Alegria district. One very extensive deposit occurs in the Nova Lima Group in the southwest corner of the Capanema quadrangle (pl. 1) and extends for at least 15 km to the northwest. No records of production or grade were available for this deposit.

Similar deposits occur around Bento Rodrigues in the south-central part of the Santa Rita Durão quadrangle. The gold is in thin lenses and stringers in quartzite, associated with pyrite and arsenopyrite. The caretaker and one-time mine manager reported to the author that channel samples across the working face contained as much as 16 grams of gold per ton in the richer parts and about 4 grams per ton over most of the gold-bearing area. The average is probably about 5 grams per ton. The "ore body" contains a maximum of about 50,000 tons of ore per meter depth. The maximum depth observed is about 20 meters for a total of about 1 million tons of ore, of which not more than half contains sporadic and discontinuous lenses of gold-bearing rock.

Other similar deposits occur in the Campo do Rocha area (Capanema quad.) but were not analyzed or studied.

Several other gold mines are located along the eastern side of the Serra do Caraça, along a zone of faulting, and associated with the Minas Series and the greenstone sequence. The gold occurs in many small reticulated stringers and veins trending generally north-south and dipping steeply to the east. The major mines, from south to north, are Cata Preta or Durão, Fazendão, Paracatu (Água Quente), Piçarra, Bananal, Pitanquí, Boa Vista, Quebra Osso, and Brumadinho.

Cata Preta mine.—The Cata Preta mine, within and north of Santa Rita Durão, is a confusing network of opencuts and adits along several different "veins." A deep opencut about 600 meters west of Santa Rita Durão has graphite schist on the footwall and a red tuffaceous-appearing rock on the hanging wall. No vein material was seen in the cut. Northward, along the road to Fazenda Alegria, several west-dipping quartz veins were explored along several drifts and opencuts. The veins range in thickness, generally from 25 to 100 cm, although in places they widen into a reticulated network as much as 4 or 5 meters across. They contain a small amount of weathered pyrite and brilliant green mica (fuchsite?). The major workings just east of these veins are visible only as a deep alluvium-filled opencut showing quartzite, ferruginous quartzite, and sericite schist on the footwall and highly contorted and intimately interlayered "splash rock," weathered dolomitic itabirite, and manganese-rich "splash rock" on the hanging wall. Nothing is known about the type or tenor of the gold ore here; some of the older residents in Santa Rita Durão said that it was "very rich." While fieldwork was in progress a 26-gram nugget was found in the stream just below the mine. At least 10 million cubic meters of weathered rock has been removed by the mining and subsequent erosion.

Fazendão mines.—The mines at Fazendão consist of a great number of adits, tunnels, and drifts, all but three of which are now inaccessible. The rock in the accessible workings is iron-formation with no visible veins or stringers of material other than iron-formation.

Paracatú mines.—The mines at Paracatú and Água Quente are mostly deep narrow trenches and shafts. The great volume of dump material near Água Quente indicates that the shafts must have been deep and the workings extensive. They are now water filled and inaccessible. The shafts just west of Água Quente are in itabirite and dolomitic itabirite. The only "vein material" on the dumps is chalcedony. About 1 km west of Água Quente a deep trench is cut into a large reticulated quartz vein in chlorite-sericite schist. The vein contains many weathered sulfide minerals and irregular pods and stringers filled with limonite. Many shafts and drifts were dug along the trench.

Pitangui mine.—The Pitangui mine, though now important as a high-grade iron ore deposit (p. J55), was originally worked as a gold mine. The mine was opened in the early 1700's and was worked until 1887, when water problems forced its closure. It consists of an opencut more than 400 meters long and several deep shafts and adits now inaccessible (figs. 35, 37). One adit is more than 300 meters long; numerous drifts and raises connect with other adits and shafts. Production records were kept only for about the last 15 years of operation. During that time, about 285 kg (kilograms) of gold was extracted. The ore was reported to have an average tenor of 15.6 grams per ton (Moraes, 1939, p. 136). In 1941–42 the Departamento Nacional da Produção Mineral made a systematic study of the mine, cleaning and mapping more than 1,330 meters of old adits and shafts (Oliveira, 1945, p. 100). They found the tenor to range from 2 to 7 grams per ton. The gold-bearing zone is mostly in the itabirite but in the lowest workings was also in the underlying schist.

The Boa Vista mine is about 1.5 km north of the Pitangui mine. The southeastern part is in itabirite, and the northwestern part is in chlorite-sericite schist. The chlorite-sericite schist contains thin quartz veins and thick zones of serpentine and talc along a major fault zone.

Quebra Osso mine.—The Quebra Osso mine is in the center of the Catas Altas quadrangle (pl. 3), in quartzite of the Moeda Formation that dips about 80° E. The gold-bearing veins occur in a zone about 20 meters wide and 100 meters long that trends about N. 50° W. The zone contains four major veins and many small reticulated veinlets. The veins consist of quartz with a high content of weathered sulfides, mostly pyrite, and a green chrome-mica (fuchsite?); rutile was also identified (Barbosa, 1939, p. 170). The rock in the mineralized zone is quartz cataclasite and sericite phyllite bordered on the east by conglomerate and quartzite and on the west by chlorite-sericite schist, chlorite schist, and serpentinite with antigorite and magnetite. Production figures were not available. About 80,000 tons of rock was removed from the mine.

Brumadinho mine.—The Brumadinho mine consists of many old workings, both surface and underground, along a zone of iron-formation and quartzite interbedded with chlorite schist and serpentinite. The zone is about 20 meters wide and 1 km long and trends about N. 15° W. Most of the workings are small and irregular surface or near-surface excavations, but some are apparently fairly deep inclined shafts. The zone contains six to eight "veins," each about 1 meter wide. They consist of deeply weathered and altered iron formation, with many tiny reticulated veins of quartz. Porous zones in the veins contain quartz crystals and pyrite altered to limonite, surrounded by thin layers of manganese. Moraes (1939, p. 140) quoted a figure of 8 grams of gold per ton for ore extracted but thought that this was only at about 50 percent recovery from ore that contained 16 grams per ton. Ore this rich probably came from thin stringers within the vein. The rock between the iron-formation and quartzite is a chlorite schist, locally containing radiating articular crystals of tremolite, commonly deformed, in a felted dark-green chlorite matrix (Barbosa, 1939, p. 169).

PLATINUM

Platinum and palladium, associated with xenotime, monazite, and zircon, have been reported from the mines near Bento Rodrigues, on Morro do Fraga (Hussak, 1906, p. 151). The author was unable to verify this occurrence.

Hussak (1906, p. 137) also indicated that platinum may have been found in the mines near Água Quente. The author panned some black sand from Córrego do Quebra Osso near Brumadinho and recovered several tiny rounded brownish-black very heavy fragments that were magnetic and malleable. The fragments, about ½ mm, in diameter, were tentatively identified as platinum similar to that described by Hussak (1906) from the region north of the Quadrilátero Ferrífero.

ASBESTOS

Massive serpentine and lenses, pods, and seams of chrysotile occur in several localities in the greenstone sequence near Quebra Osso. The occurrences are along a line corresponding to a projection of one of the north-trending shear zones on the east side of the Serra do Caraça.

The chrysotile is silky cross-fiber type in seams ranging from a fraction of a millimeter to as much as 2 cm in width, and coarse slip-fiber type, in fibers as much as 8 cm in length. Both types occur together in the same rock. The chrysotile generally constitutes only a few percent of the rocks, but in some specimens as much as 30 percent.

The occurrences had not been explored. They do not crop out and are exposed only in the roadcut (Catas Atlas quad., N. 8, 350, E. 6,000) and in a few washes and old gold workings. Because of the lack of exposures and deep weathering, potential reserves could not be estimated.

QUARTZ CRYSTAL

The Alegria district has been extensively prospected for optical and radio-quality quartz crystal. Most of the quartzite in the area is pockmarked by prospect pits in the several thousand quartz crystal deposits. These deposits are generally small lenticular bodies of recrystallized quartz. Crystals have also been obtained from veins of milky quartz in the quartzite and subgraywacke, and in other rocks as well. The lenses and veins were formed along shear zones and joints. A few representative veins and prospect pits are shown on the geologic maps (pls. 1–3).

Amethyst was reported in quartz veins near the eastern boundary of the district, near Fonseca, but the author was unable to verify the report or to find the deposit. However, a few rounded pebbles of pale amethyst were found in gravel in several streams along the eastern side of the district, in the Santa Rita Durão quadrangle.

OTHER MINERALS

Dolomite was quarried in at least one deposit in the district (Santa Rita Durão quad., N. 8,700, E. 6,500). The deposit is poor grade and of little potential. (See analyses, p. J25).

Soapstone in the greenstone sequence was mined at several localities for use in carvings and utensils for the churches, but none has been mined for many years. Several colors and grades of soapstone occur in the Catas Altas quadrangle, ranging from a dense fine-grained dark-green rock and an alabaster-like white fine-grained rock to a coarse-grained rock rich in chlorite or dark mica. Some of the soapstone is massive and unfoliated, but most has a well developed schistosity which limits its usage.

Small bodies of coarsely crystalline talc occur in the soapstone at some localities. It is light green and can be purified easily. Although the known deposits are of little interest economically, future demand and exploration might stimulate production.

Kyanite is locally plentiful in quartzite and subgraywacke associated with shear zones. Some layers or deposits contain 20–80 percent kyanite, in blocks representing at least several tens of thousands of tons of rock. The gangue minerals are quartz, chlorite, muscovite, and pyrophyllite intimately intermixed with the kyanite. Better deposits elsewhere in Brazil make these unimportant.

Small deposits of red and yellow ocher, scattered through the Alegria district, have been mined for local use as paint pigments. The deposits are small, erratic, and sporadic and of little economic interest; except for local use. Only a few tons have been produced.

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