Geology and Ore Deposits of the Nova Lima and Rio Acima Quadrangles Minas Gerais, Brazil

GEOLOGICAL SURVEY PROFESSIONAL PAPER 341-A

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

U.S. DEPARTMENT OF THE INTERIOR

March 3, 1849

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By JACOB E. GAIR

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1962

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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

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GEOLOGY AND ORE DEPOSITS OF THE NOVA LIMA AND RIO ACIMA QUADRANGLES, MINAS GERAIS, BRAZIL

By Jacob E. Gair

ABSTRACT

The Nova Lima and Rio Acima quadrangles lie in the north-central part of the Quadrilátero Ferrífero—the so-called iron quadrangle of central Minas Gerais, Brazil. The mapping of these quadrangles has been part of a joint project of topographic and geologic mapping of the iron region of central Minas Gerais, done jointly by the U.S. Geological Survey and the Brazilian Departamento Nacional da Produção Mineral. The area is part of the Precambrian shield of Brazil and, except for superficial deposits of Tertiary or Quaternary age, is underlain entirely by rocks of Precambrian age.

In the Nova Lima and Rio Acima quadrangles, the rocks of Precambrian age occur in two series, the older Rio das Velhas series and the younger Minas series, separated by a major unconformity. Most of the area of the two quadrangles is underlain by rocks of the Rio das Velhas series; the Minas series occurs only in the northwestern part of the Nova Lima quadrangle where it forms a northeastward-trending belt.

The major structural feature in the two quadrangles is the Rio das Velhas uplift, which occupies much of the area. The Minas series in the northwestern part of the Nova Lima quadrangle lies on one flank of the uplift, dips generally southeastward, and is overturned to the northwest. Another important structural feature in the area is a north-northwestward-trending syncline located mainly in the eastern part of the Rio Acima quadrangle and downfolded in the central part of the Rio das Velhas uplift. This structure is here called the Vargem do Lima syncline. It appears to converge on, and to be truncated by, rocks of the Minas series, some 20 to 25 kilometers southeast of the southeast corner of the Rio Acima quadrangle. The Vargem do Lima syncline therefore antedates the deposition of the Minas series.

Rocks of the Rio das Velhas series are complexly folded in the northwestern part of the Rio Acima quadrangle and in the adjoining southwestern part of the Nova Lima quadrangle, as shown principally by thin, mappable beds of iron-formation. The regional trend of this iron-formation is about northward from the Rio Acima quadrangle into the southwestern part of the Nova Lima quadrangle, then northwestward from the Nova Lima quadrangle into the Belo Horizonte quadrangle to the west, although eastward-trending folds and eastward-plunging fold axes, lying across this trend, are common.

Folding of the Rio das Velhas series prior to Minas time is indicated both by the truncation of the pre-Minas iron-formation by the Minas series in quadrangles to the east and west, and by the truncation of the Vargem do Lima syncline by the Minas series southeast of the present area. The eastward-trending folds in the area of complexly folded pre-Minas iron-formation, however, are here interpreted to be post-Minas cross-folds developed as a result of north- to northwest-directed movements that accompanied formation of the Rio das Velhas uplift. These movements also caused the northwestward overturning of the Minas series in the northwestern part of the Nova Lima quadrangle.

Rocks of the Rio das Velhas series have been divided into two groups, named in earlier reports by members of the U.S. Geological Survey. The older of the two groups, and the oldest known sequence of layered rocks in the Quadrilátero Ferrífero, is the Nova Lima group, and the younger is the Maquiné group.

The Nova Lima group consists of metasedimentary and metavolcanic schists and phyllites, with an estimated minimum thickness of 4,200 meters.

Iron-formation and associated cherty and graphitic quartzite, graywacke, quartz-dolomite-ankerite rock (lapa sêca), sericitic quartzite, and a locally developed schistose conglomerate are interlayered with the schist and phyllite of the Nova Lima group. These rocks are mapped separately in the present study, but are not given formal formation names.

At the surface, the iron-formation is weathered and consists of alternating laminae of quartz and magnetite-hematite-goethite. The fresh, unweathered, iron-formation, known only from underground workings and drill cores, consists mainly of alternating laminae of quartz and sideritic carbonate or magnetite-sideritic carbonate. The rock is similar to carbonate-facies iron-formation of the Lake Superior district. This rock was the host rock for gold-sulfide mineralization at the Raposos mines in the Nova Lima quadrangle.

The quartz-dolomite-ankerite rock (lapa sêca) is a recrystallized quartz-carbonate sediment. It is best known in the Morro Velho gold mine at Nova Lima, and in several abandoned mines, 3 to 8 kilometers south of Nova Lima, where it was the host rock for gold-sulfide mineralization.

The Maquiné group overlies the Nova Lima group, probably unconformably, and occupies the core of the Vargem do Lima syncline. The Maquiné has been divided into two formations. The lower formation is called the Palmital, ranges in thickness from 600 to 1,400 meters, and consists largely of schist and phyllite with lenses of quartzite. The upper formation of the Maquiné group is here named the Casa Forte, and is estimated to be from 250 to 400 meters thick. It contains schistose and massive sericitic quartzite, massive chloritic quartzite, quartzose conglomerate, and interlayered schist and phyllite. The convergence and apparent closure of beds of conglomerate in the Casa Forte formation in the northeastern part of the Rio Acima quandrangle constitutes the principal field evidence for the existence of the Vargem do Lima syncline.

The Minas series overlies the rocks of the Rio das Velhas series with great unconformity. The unconformity is known

in adjoining quadrangles but is not clearly evident in the area of the present report. In this area, the Minas series is developed only along the Serra do Curral in the northwestern part of the Nova Lima quadrangle. The Minas of the Quadrilátero Ferrífero has been divided into three groups, all of which are represented here. From the base upward, these groups are the Caraça, the Itabira, and the Piracicaba.

The thickness of the Caraça of the Nova Lima quadrangle is estimated to range from about 80 to 320 meters. Except for a small area of conglomerate near the west edge of the quadrangle, the group consists of schist and phyllite, in places interlayered with thin beds of white friable quartzite. Although the conglomerate, quartzite, and schist and phyllite have been mapped separately, the Caraça group is not here formally divided into formations.

The Itabira group contains the iron-formation, itabirite, in which the major iron-ore bodies of the Quadrilátero Ferrífero occur. In the Itabira group, in many parts of the Quadrilátero Ferrífero, itabirite is overlain by dolomite. In the Nova Lima quadrangle, however, the Itabira group consists of itabirite overlain in places by a weathered, ocherous itabirite that may be lithologically intermediate between itabirite and dolomite. The itabirite and overlying ocherous itabirite of the Nova Lima quadrangle are correlated with the Cauê itabirite of the Itabira district to the northeast. The outcrop belt of the the Cauê itabirite of the Nova Lima quadrangle has an average width of about 300 meters, and the average thickness of the formation is estimated to be 125 meters.

The Piracicaba group consists of two formations: the older is the Cercadinho formation, and the younger is here named the Sabará formation. The Cercadinho formation consists of alternating beds of ferruginous quartzite and of schist and phyllite, and is about 300 meters thick along most of its extent. Lenses of dolomite are found locally in the formation. Individual beds of ferruginous quartzite or of schist and phyllite are generally less than 50 meters thick. The Cercandinho formation is generally conformable with the underlying Cauê formation, but in places ferruginous grit and conglomerate along the base of the former indicate that consolidation and some erosion of the Cauê took place prior to deposition of the Cercadinho. A characteristic silver-gray phyllite is interlayered with the quartzitic rock in the upper part of the Cercadinho formation.

The Sabará formation consists mainly of quartz-sericite-chlorite schist, graywacke, subgraywacke, and staurolite-garnet schist. The formation ranges from about 1,850 meters to 3,400 meters in thickness. Thin beds of graywacke and subgraywacke are confined almost entirely to the schist of the lower half of the formation. The graywacke is not readily traceable and has not been mapped separately from the enclosing schist. Two thin beds of white cherty quartzite occur near the uppermost known part of the formation in the area. The top of the formation is not known in the area because the formation is in contact with intrusive granitic rock. This contact is generally parallel to the trend of the Sabará, and thermal metamorphism resulting from intrusion has produced a zone of staurolite-garnet schist in the upper part of the formation. This metamorphic aureole trends parallel to the intrusive contact and roughly parallel to beds of the Sabará formation.

Surficial deposits of Quaternary or Tertiary age occur in a few places in the area. These materials include clay beds, mudstone, canga, and stream gravels.

Rocks of intrusive origin in the area are serpentinite and associated metagabbro and talc schist, metadiabase, and granitic and pegmatitic rocks. Gneissic rock associated with the granitic and pegmatitic rocks is probably partly or possibly entirely intrusive in origin.

Most of the serpentinite is derived from dunite. The serpentinite is intruded into schist and phyllite of the Nova Lima group in the southwestern part of the Rio Acima quadrangle, and is probably pre-Minas in age. Metagabbro borders part of the serpentinite and the talc schist occurs mainly along a narrow belt that cuts across the serpentinite and partly across a body of metagabbro.

The gneissic, granitic, and pegmatitic rocks are confined almost entirely to the northwestern part of the Nova Lima quadrangle, northwest of the Minas series. Most of these rocks are of granodioritic composition. The relatively high grade metamorphic zone in the Sabará formation indicates that the intrusion of granitic rocks was of post-Minas age.

Metadiabase dikes occur in the Rio das Velhas and Minas series, and in the granitic rocks.

In the Nova Lima and Rio Acima quadrangles, there is petrographic evidence of only one period of progressive regional metamorphism, affecting both pre-Minas and Minas rocks. The evidence of folding of the Rio das Velhas series prior to deposition of the Minas series, however, suggests some degree of metamorphism in pre-Minas time.

The area of this report is an important producer of gold. There were two active mines in the area in 1956, the Morro Velho mine at Nova Lima and the Raposos group near Raposos in the south-central part of the Nova Lima quadrangle. Some silver and arsenic are produced as byproducts. In the Morro Velho mine, gold is associated with sulfides and is localized in bedded quartz-ankerite-dolomite rock (lapa sêca). In the Raposos mines, gold and sulfides are localized in sideritic carbonate iron-formation. Mineralization was by the hydrothermal replacement of lapa sêca or of carbonate iron-formation, and was accompanied by the formation of veinlets of quartz and carbonate. Ore deposits appear to be associated with eastward-plunging folds in lapa sêca or carbonate iron-formation, although they are not necessarily confined to the noses of such folds. These eastward-plunging folds appear to be cross-folds developed during post-Mínas folding and this suggests a post-Minas age for the mineralization. The mineralization may therefore be related to the post-Minas intrusion of granitic rocks.

There are no known workable deposits of high-grade iron ore within the Nova Lima and Rio Acima quadrangles. Several small areas along the belt of the Cauê itabirite contain hard blue hematite, and some strip mining in the largest of these areas, a short distance southwest of Sabará in the north-central part of the Nova Lima quadrangle, has been carried on within the past 15 years. The small areas of hard blue hematite may indicate underlying bodies of hard ore, but drilling or tunneling is needed to determine this. The prospect of finding sizable bodies of iron ore either in Minas or pre-Minas iron-formation of the two quadrangles seems unlikely in the foreseeable future. The only other geologic materials of economic note in the two quadrangles are clay, which is used in two large brickmaking and tilemaking plants at the outskirts of Rio Acima, and yellow ochre pigment from the ocherous itabirite, which supports a small paint factory about 750 meters northwest of the Triangulo in the west-central part of the Nova Lima quadrangle.

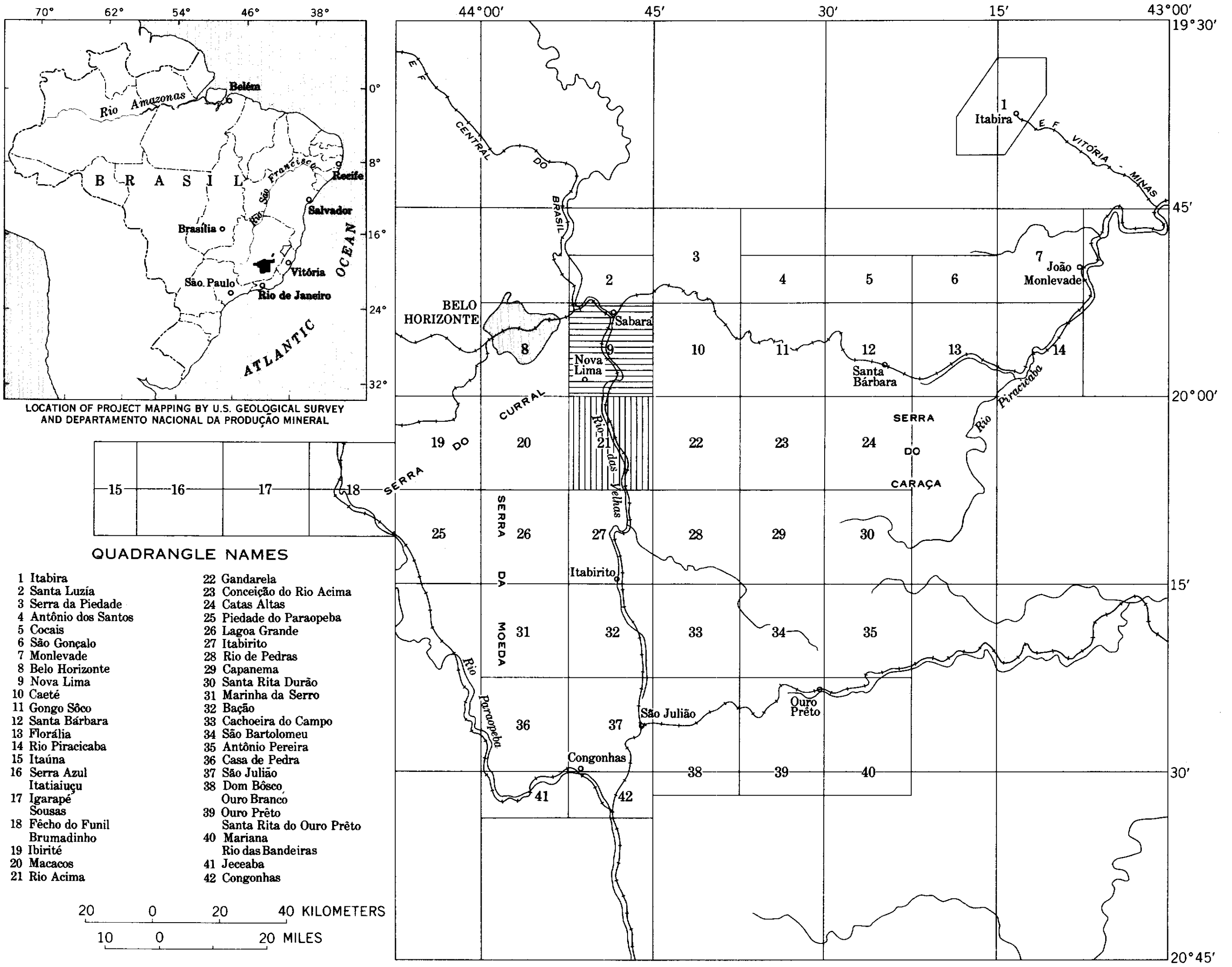

FIGURE 1.—Index map showing location of Nova Lima and Rio Acima quadrangles, Minas Gerais, Brazil.

INTRODUCTION

The Nova Lima and Rio Acima quadrangles have been mapped (pls. 1, 2) as part of a cooperative project of topographic and geologic mapping in the Quadrilátero Ferrífero—the iron quadrangle of central Minas Gerais, Brazil, conducted by the U.S. Geological Survey and the Departamento Nacional da Produção Mineral of Brazil (fig. 1). The project has been a part of the technical assistance program of the United States and has been financially supported, since its inception in 1946, by the U.S. Department of State as well as by the Brazilian Government.

LOCATION

The Nova Lima and Rio Acima quadrangles lie in the northwestern part of the Quadrilátero Ferrífero and occupy an area of about 360 square kilometers (140 square miles). The quadrangles lie between latitudes 19°52′30″ S. and 20°07′30″ S. and between longitudes 43°45′ W. and 43°52′30″ W.; they are separated along the 20th parallel of latitude, with the Rio Acima quadrangle to the south and the Nova Lima quadrangle to the north. The quadrangles are named from the towns of Nova Lima in the southwestern part of Nova Lima quadrangle and Rio Acima in the southeastern part of the Rio Acima quadrangle.

CLIMATE, DRAINAGE, AND TOPOGRAPHY

The Quadrilátero Ferrífero has a subtropical climate. Temperatures generally range from about 0°C on the coldest nights to about 35°C on the warmest days, with daytime average temperatures of about 18°C during the winter months and about 22°C during the summer months. Rainfall averages about 1.5 meters per year, with the greater part of the precipitation occurring between December and March (Brazilian Ministry of Foreign Affairs, 1944).

Drainage in the Nova Lima and Rio Acima quadrangles is controlled by the Rio das Velhas and its tributaries. The Rio das Velhas flows generally northward across the central part of both quadrangles. It joins the Rio São Francisco, 1 of the 3 major rivers of Brazil, about 300 kilometers north-northwest of the area.

The valley bottom of the Rio das Velhas drops in elevation from about 740 meters at the south edge of the Rio Acima quadrangle to a little less than 700 meters at the northern edge of the Nova Lima quadrangle.

The most important tributaries entering the Rio das Velhas from the west within the area are Rio do Peixe, Ribeirão dos Macacos, Ribeirão Água Suja, and Ribeirão Arrudas. The two major tributaries enter the Rio das Velhas from the east. They are Ribeirão da Prata and Ribeirão Sabará. Several smaller streams east of the Rio das Velhas form conspicuous valleys. They are Ribeirão dos Machados, Córrego da Casa Forte, Córrego Vargem do Lima, Córrego Cambimbe, and Córrego Brumado.

The topography of the area is moderately rugged. The major topographic features are the valley of the Rio das Velhas and the uplands bordering both sides of the valley. Several individual peaks and ridges form prominent landmarks. These include Morro do Pires (1,380 meters) in the northwestern part of the Rio Acima quadrangle, Morro dos Cristais (1,182 meters), near the southwest corner of the Nova Lima quadrangle, the part of the northeast-trending Serra do Curral that lies across the northwestern part of the Nova Lima quadrangle (highest point, 1,188.7 meters), and Morro do Enforcado (1,106 meters), about 3 kilometers southwest of Rio Acima.

The maximum difference in elevation in the area is slightly more than 680 meters, between the top of Morro do Pires and the Rio das Velhas at General Carneiro, near the northwest corner of the Nova Lima quadrangle.

CULTURE AND ACCESSIBILITY

The principal settlements in the area are the towns of Nova Lima in the southwestern part, and Sabará in the north-central part, of the Nova Lima quadrangle, and Rio Acima in the southeastern part of the Rio Acima quadrangle. Nova Lima is located 10 kilometers southeast of the city of Belo Horizonte, the capital of the state of Minas Gerais. Other smaller settlements are at Raposos in the south-central part, and at Marzagão and General Carneiro, near the northwest corner, of the Nova Lima quadrangle, and at Honorio Bicalho and Santa Rita in the north-central part, and at Cocho d'Agua in the southeastern part, of the Rio Acima quadrangle. There are also many isolated or small groups of habitations widely distributed through the area.

There are no paved highways in the area (as of 1956). A two-lane all-weather dirt-gravel road connects Rio Acima, Nova Lima, and Sabará. Eleven kilometers north of Nova Lima this road branches at the Triangulo, north and west across the Serra do Curral to Belo Horizonte, and northeastward toward Sabará. A shorter route directly westward from Nova Lima to Belo Horizonte was opened to automobiles in 1955, but was not suitable for heavy trucks and busses at that time.

Much of the area is unforested, crossed by trails, and accessible only on foot. Some parts of the area are accessible along regos, manmade water courses that approximate the contour of the land. Forested valley bottoms and ridges are virtually impenetrable and unless opened along trails are practically inaccessible for close geologic study.

MINES AND MINERAL EXPLORATIONS

The area is an important producer of gold. Many old gold washings dating from the colonial period of Brazil are found along the Rio das Velhas in both quadrangles. Currently (1956), the only operating gold mines in Brazil are located in the Nova Lima quadrangle: the Morro Velho mine at Nova Lima and the Raposos mine, near Raposos. The Morro Velho mine is world famous because of its large total production, nearly continuous operation for more than a century, and because at one time it was the deepest operating mine in the world (2,454 meters or 8,051 feet below the entrance adit).

There are many small abandoned gold mines and explorations dating from the early 1900's, and the second half of the last century or earlier, in both the Nova Lima and the Rio Acima quadrangles. Records of the smaller of these operations were either never kept or have been lost. Those about which something is known are the Morro das Bicas mine a short distance south of Raposos, the Bella Fama mine about 2 kilometers southeast of Nova Lima, the Gaia, Faria, and Gabirobas mines west-southwest of Honorio Bicalho, the Bicalho mine at Honorio Bicalho, and the Urubu mine about 3 kilometers south-southeast of Honorio Bicalho. These mines have been owned by the St. John del Rey Mining Co., Ltd., during the entire or greater part of their histories. The St. John del Rey Mining Co. has also made explorations for gold at Morro da Gloria, 1 kilometer west of Santa Rita, and along the Ribeirão da Prata southeast of Raposos.

FIELD AND LABORATORY WORK

Fieldwork in the Nova Lima quadrangle was done by Burton E. Ashley during 1953 and part of 1954, and by the author early in 1956, and in the Rio Acima quadrangle, by the author during 1955 and early in 1956. Three levels in the Morro Velho mine were studied and brief visits to the Raposos mines were made by the author during February and March, 1956.

Geologic mapping was done on aerial photographs of approximate scale of 1:10,000 and 1:25,000, generally with the aid of a single prism stereoscope. Field data were transferred from aerial photographs and notebooks to topographic maps of 1:10,000 or 1:20,000 scale. Final compilation is at a scale of 1:25,000. Aerial photographs and the topographic maps used for compilation were prepared by Serviços Aerofotogrametricos Cruzeiro do Sul, S.A., of Rio de Janeiro, in accordance with specifications of the U.S. Geological Survey.

Mapping of structures on three levels in the Morro Velho gold mine was done on maps of the levels prepared at a scale of 1:2,000 by the St. John del Rey Mining Co., Ltd.

Petrographic descriptions in this report are based on the study of approximately 475 thin sections, 425 of which were prepared by the Departamento Nacional da Produção Mineral of Brazil. Forty-seven thin sections were prepared in the petrographic laboratory of the University of São Paulo. Eight polished sections of iron-formation of pre-Minas age were prepared by the U.S. Geological Survey as well as four complete chemical analyses of iron-formation and dolomite.

Grain sizes are here arbitrarily designated as fine, if less than 0.1 mm, as medium, if between 0.1 and 2.0 mm, and coarse, if greater than 2.0 mm.

In most thin sections, percentages of minerals were determined by visual estimation, but a point counter was used where the percentage of minerals such as feldspar was critical in naming the rock.

COORDINATE SYSTEM FOR LOCATIONS

In the present report, many specific locations are indicated by coordinates measured in meters north and meters east of the southwest corner of each quadrangle. Thus the notation "Nova Lima N. 1,000, E. 500", locates a point 1,000 meters north and 500 meters east of the southwest corner of the Nova Lima quadrangle. If, from the context, it is already clear which quadrangle is under discussion, coordinates are generally given without additional reference to the name of the quadrangle.

ACKNOWLEDGMENTS

Burton E. Ashley of the U.S. Geological Survey mapped most of the Nova Lima quadrangle and calculated the tonnages of canga and itabirite given in the section on ore deposits (p. A62–A63).

Dr. Avelino de Oliveira, director of the Departamento Nacional da Produção Mineral (DNPM) extended the full available resources of his organization in support of the work. Dr. José Alves of the Belo Horizonte district office of the DNPM was most helpful in providing helper-guides and a diamond drill, and in arranging for the making of thin sections.

The St. John del Rey Mining Co., Ltd., offered their full cooperation in permitting access to company properties, providing mine maps and ready access to company reports and drill core, and providing living accommodations during most of the fieldwork. Special thanks are due Mr. G. Wigle and Mr. M. L. Yarnell, general managers during the early part of the work, and to Mr. H. C. Watson, general manager in Brazil during the latter part of the work. Mr. Charles Archibald, mine engineer, and Mr. Donald Kochersperger, mine superintendent, provided information and maps. Others of the technical staff who were particularly helpful were Mr. Allan Thomas, Sr. Dante Bernardi, Mr. A. F. Matheson, Mr. Oswald McCulloch, Mr. Peter Loubser, Mr. J. F. Fenton, and Mr. Eric Dempster. Mr. G. F. Senior, Mr. G. M. Pearson, Sr. Aldo Zanini, and Mr. Ronald Duncan arranged living accommodations in Nova Lima, and in a company field camp on the Rio do Peixe, and Mr. G. F. Senior made available old reports of the company.

Joel B. Pomerene of the U.S. Geological Survey mapped the Gaia tunnel of the St. John Del Rey Mining Co. at Honorio Bicalho in the north-central and northwestern parts of the Rio Acima quadrangle in 1951, and assisted in mapping a section along the Rio das Velhas northwest of Sabará early in 1956.

Edward C. T. Chao of the U.S. Geological Survey identified the iron minerals in a number of samples of pre-Minas iron-formation, and also identified chloritoid in some quartzites of pre-Minas age.

Mr. Ralph Arnold of the Geophysical Laboratory, Carnegie Institution of Washington, determined the minimum temperature of crystallization of ore minerals at the Morro Velho gold mine from a sample of Morro Velho ore, using the pyrrhotite-pyrite geothermometer.

Sr. José Rosa Ribeiro of Rio Acima, Sr. Geraldo Monteiro de Barros of Belo Horizonte, and Sr. José Roberto da Silva of Itabira served faithfully and uncomplainingly as helpers and guides during the fieldwork. Sr. José Santa Fé of Nova Lima acted as guide in the Morro Velho mine.

GEOLOGIC SETTING

The Quadrilátero Ferrífero occupies a part of the Brazilian shield and is underlain almost entirely by rocks of Precambrian age. The region is crossed by the southern end of the Serra do Espinhaço, the so-called backbone range of Brazil, that extends northward some 1,500 kilometers from the Quadrilátero Ferrífero. Surficial deposits and irregularly distributed small patches of bog or lake sediments of probable Tertiary age, rest on the Precambrian basement rocks of the region.

Within the Nova Lima and Rio Acima quadrangles all rocks are of Precambrian age, except for several types of surficial deposit, and one small area of rock of possible Tertiary age. (See table 1.) Most of the Precambrian rocks of the area are layered rocks and these are divided into two series separated by a profound unconformity. Rocks forming the older of the two series underlie all of the Rio Acima quadrangle, except for scattered areas of surficial material, and underlie nearly seven-eighths of the Nova Lima quadrangle. These rocks consist mainly of schists and phyllites, with lesser amounts of iron-formation, quartzite, conglomerate, graywacke, and a gray carbonate rock.

Rocks of the younger series form a northeastward-trending belt that crosses the northwestern part of the Nova Lima quadrangle. These rocks consist of quartzite, ferruginous quartzite, itabirite (see definition in section on Cauê itabirite, p. A–35), schists and phyllites, graywacke, and possible metavolcanic rock. The important iron deposits of the Quadrilátero Ferrífero occur in the itabirite of this younger series.

Serpentinite and metagabbro are intrusive into the older series of layered rocks in the southwestern part of the Rio Acima quadrangle, and granitic rock and pegmatite are intrusive into the younger series near the northwest corner of the Nova Lima quadrangle. Dikes of metadiabase occur in places in both series and vein quartz is found throughout the area.

PREVIOUS INVESTIGATIONS

Much has been written about the geology of Minas Gerais. (See bibliography in von Freyberg, 1932, with 976 titles.) However, few studies have been made of the Quadrilátero Ferrífero as a whole. No regional study had been based on detailed, large-scale geologic mapping until the joint Brazilian–United States program began in 1946.

The stratigraphic concepts developed during the present program are summarized and compared with major earlier concepts in table 1.

Von Eschwege (1817) divided the rocks of the Quadrilátero Ferrífero into two series—the older, a primary series or basement rock, and a younger secondary series consisting, in upward sequence, of argillaceous schists or slate, iron-formation, carbonate rock, and sandstone (table 1). Subsequent workers in the nineteenth century in general followed von Eschwege's twofold division of the rocks. Derby (1881) recognized a discordance within the equivalent of von Eschwege's secondary series, which separated a more highly metamorphosed sequence of quartzite, iron-formation, and dolomitic limestone below from a less metamorphosed, pebble-bearing sandstone above. The lower sequence of quartzite, iron-formation, and dolomitic limestone was named the Minas series by Derby (1906). This Minas series rests unconformably on gneiss and mica schist (equivalent to von Eschwege's primary series). Derby considered the Minas series as probably equivalent to rocks of so-called Huronian age of the Lake Superior region of North America, and the older gneiss and mica schist, on which the Minas series rests, as probably equivalent to rocks of Laurentian age.

Although Derby studied the rocks in the southern part of the Nova Lima quadrangle sufficiently to describe the country rock of the Morro Velho mine at Nova Lima as a calc-phyllite,[1] it is not entirely clear that he ever came to a conclusion as to whether the calc-phyllites belong to the Minas series or to the rocks older than the Minas.

Harder and Chamberlin (1915) accepted the twofold division of Precambrian rocks within the Quadrilátero Ferrífero and considered the Minas series to be of probable Algonkian age and to rest on gneiss, granite, and schist of probable Archean age. They divided the Minas series from bottom to top into Caraça quartzite, Batatal schist, Itabira iron-formation, Piracicaba schist and quartzite, and Itacolumi quartzite (table 1). They broadened the "Minas series" to include the Itacolumi quartzite, the pebbly "sandstone" that Derby had found was discordantly above his Minas series.

Although most workers in or adjacent to the Quadrilátero Ferrífero seem to have recognized the existence of an older group of rocks unconformably beneath the Minas series, prior to the time of the present Brazilian–United States joint mapping program, the locations of such rocks and of their contacts with younger rocks were in considerable doubt in most places. This had been largely a result of inadequate base maps and insufficient research efforts. Granite, gneiss, and schist of greater age than the Minas series generally were not separated from one another during earlier studies. Furthermore, schist and phyllite of the Minas series commonly have been confused with older schists in many places. As noted above, Derby evidently was unable to date his calc-phyllites of the Nova Lima area, and Harder and Chamberlin (1915, p. 347) showed the

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[1] In two private-letter reports to the St. John del Rey Mining Co., dated 1901 and 1904.

entire area of the Nova Lima and Rio Acima quadrangles underlain by Caraça quartzite of early Minas age. In the Nova Lima and Rio Acima quadrangles, this probably signifies much "quartzite schist" and "schistose quartzite", which Harder and Chamberlin included in their Caraça quartzite.

Guimarães (1931) and von Freyberg (1932, p. 4) followed Derby in recognizing a threefold division of the rocks as a crystalline basement complex overlain discordantly by the Minas series, discordantly overlain in turn by the Itacolumí series (named by Guimarães). Von Freyberg (p. 85–93) subdivided the Minas series into a lower group of thick schists with some quartzite beds, a middle group of itabirite and quartzite, and an upper group of schists (table 1). According to von Freyberg, the upper group of schists is developed mainly near Ouro Preto in the southeastern part of the Quadrilátero Ferrífero. Although von Freyberg did not describe specifically the area of the Nova Lima and Rio Acima quadrangles, it is evident from his general text (p. 238), maps (following p. 270, 304), and cross sections (following p. 4, 62) that he considered most of this area to be underlain by his lower group of schists of the Minas series, with the middle group found only in the Serra do Curral, in the northwestern part of the Nova Lima quadrangle.

Guimarães (1935, p. 1) divided the Minas series in the vicinity of Nova Lima into a lower part mainly of phyllites and schists, with interbedded dolomite, itabirite, and quartzite, and an upper part of phyllites and schists. He evidently placed all or most of the rocks that occur south and southeast of Serra do Curral in the two quadrangles in the upper part of the Minas series. The Minas series is exposed across the Serra do Curral with the top of the series to the northwest, suggesting that the rocks along the Rio das Velhas and in the vicinity of Nova Lima, southeast of Serra do Curral, are older than the Minas series. Guimarães (1951, p. 42–45), however, postulated a graben along the Rio das Velhas south and southeast of the Serra do Curral, thereby explaining, by downfaulting, the presence of rocks of presumed late Minas age near Nova Lima and along the Rio das Velhas to the south.

Moraes and Barbosa (1939) gave petrographic descriptions of gold-bearing rocks from the vicinity of Nova Lima, and included the rocks in the Minas series without specifying their stratigraphic position. By 1950, Barbosa (1954) had concluded that the rocks in the vicinity of Nova Lima are older than the Minas series and equivalent to his "Barbacena series",[2] a name he proposed for a sequence of schists located between Lafaiete, Barbacena, and St. João del Rey in south-central Minas Gerais. Barbosa's Barbacena series is older than the Minas series and younger than a group of granites and gneisses—his Mantiqueira series—that occur between southern Minas Gerais and the Atlantic coast. Barbosa, however, included in his Barbacena, rocks now known to be of post-Minas age, and included in the Minas series rocks now known to be of pre-Minas age. The suggested correlation of the schists and phyllites near Nova Lima with the Barbacena series evidently was based mainly on similarities of lithology.

Rynearson and others (1954) confirmed Barbosa's suggestion that the schists near Nova Lima, and also those southward along the Rio das Velhas to beyond the south edge of the Rio Acima quadrangle as well, are older than the Minas series. They did not imply, however, a correlation between these schists of pre-Minas age and Barbosa's Barbacena series. Rynearson and his colleagues cited evidence from 10 localities to prove both a sedimentary break and a structural unconformity between Caraça quartzite at the base of the Minas series and underlying schists that had previously been included in the Minas series. Eight of the localities cited are along a south-trending belt located a short distance west and southwest of the Nova Lima and Rio Acima quadrangles. The schists unconformably beneath the Caraça quartzite, pass from these localities without interruption into the Nova Lima and Rio Acima quadrangles.

Several private geological reports have been prepared for the St. John del Rey Mining Co. Files of the company as of 1956 contained geological or partly geological reports by O. A. Derby, 1901, 1904; by A. G. N. Chalmers; by L. C. Graton and G. N. Bjorge (with collaboration from A. B. Yates), 1929 and 1931; by A. M. McKilligin; and by A. F. Matheson. These reports were mainly concerned with the mineralogy and configuration of the Morro Velho "lode" and its immediately adjacent rocks, and generally did not deal with questions of regional stratigraphy. Matheson (1956), geologist with the St. John del Rey Mining Co. from 1951 to 1954, was acquainted with some of the findings of the geologists of the U.S. Geological Survey in the Quadrilátero Ferrífero. He made a broad geological reconnaissance of the extensive company properties, including those in the Nova Lima and Rio Acima quadrangles and in general followed interpretations of regional stratigraphy and structure developed by the present Brazilian–United States mapping program.

During the present Brazilian–United States mapping program, the stratigraphy and structure of the Quadrilátero Ferrífero have been much clarified, both in local

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[2] "Barbacena series" was first proposed and discussed by Octavio Barbosa at the Fourth Geological Congress of the Sociedade Brasileira de Geologia, at Ouro Preto in 1950.

areas and regionally. Rocks of pre-Minas age, rocks of the Minas series, and rocks younger than the Minas series have been distinguished in much of the area. Individual rock units of pre-Minas age, Minas age, and post-Minas age have been traced in detail across long distances. Subdivision of the Minas series has, in general, followed the concepts of Harder and Chamberlin (1915), although in treating the Itacolumi rocks as a series younger than, and unconformably above, the Minas series, the ideas of Derby (1906), Guimarães (1931), von Freyberg (1932), and Barbosa (1951) have been corroborated.

STRATIGRAPHY

Dorr and others (1957) have recognized that all pre-Minas rocks of the Quadrilátero Ferrífero, with the exception of gneisses west of the Serra do Moeda, belong to one series. These rocks have been designated the Rio das Velhas series because they are best exposed along the valley and bordering uplands of the Rio das Velhas.

In the Rio Acima quadrangle the Rio das Velhas series can be divided into two groups, the older of which is named the Nova Lima group (Dorr and others, 1957). This older group consists mainly of schists and phyllites, thin-bedded iron-formation, dolomite-ankerite rock, graywacke, and sericitic quartzite. Schists and phyllites, iron-formation, and dolomite-ankerite rock of this group are typically developed near the city of Nova Lima. The younger group of the Rio das Velhas series unconformably overlies the Nova Lima group and has been correlated with the Maquiné group of O'Rourke (written communication, 1956), a name first published by Dorr and colleagues (1957). The Maquiné rocks consist mainly of quartzite, schist, and conglomerate.

Rocks of the Minas series within the area of the present report occur in the northwestern part of the Nova Lima quadrangle. There the Minas series can be divided into three groups, which can be followed into and correlated with groups to the southwest in the Belo Horizonte quadrangle (J. B. Pomerene, written communication, 1958). These groups are, in upward succession, the Caraça group, the Itabira group, and the Piracicaba group (Dorr and others, 1957).

The Caraça group contains conglomerate, white quartzite (with minor subgraywacke), and schist-phyllite. The Itabira group contains dominant itabirite and subordinate laminated iron-formation of quartz, magnetite, and ocherous material probably derived from carbonate with or without iron silicate. In the Nova Lima quadrangle, the Piracicaba group comprises two formations: an older formation mainly of ferruginous quartzite and interbedded micaceous schist and phyllite, and a younger formation consisting mainly of quartzose chloritic and micaceous schists interlayered with graywacke and subgraywacke. The ferruginous quartzite and interbedded schist and phyllite have been called the Cercadinho formation in the Belo Horizonte quadrangle by Pomerene (1958a), and the younger sequence of rocks in the Piracicaba group has been named the Sabará formation by Gair (1958a).

STRUCTURE

The rocks of pre-Minas age that occupy all of the Rio Acima quadrangle and most of the Nova Lima quadrangle are part of a large area of pre-Minas rocks that extends generally beyond the limits of the two quadrangles, and is bordered by belts of rocks of the Minas series. One of the bordering belts of Minas rocks crosses the northwestern part of the Nova Lima quadrangle. An understanding of much of the regional structure in the north-central part of the Quadrilátero Ferrífero has been gained during the present program by tracing the belts of Minas rocks around this area of pre-Minas rocks.

The pre-Minas rocks of the area occupy the core of an anticlinorium-like structure here named the Rio das Velhas uplift. The location and outline of the uplift are represented by the area underlain by the Rio das Velhas series in plate 3.

The principal structural features within the Nova Lima and Rio Acima quadrangles are:

1. The Rio das Velhas uplift, best shown where the northeastward-trending rocks of the Minas series on the northwestern flank of the uplift cross the northwestern part of the Nova Lima quadrangle.
2. The rather tight syncline extending into southeastern part of the Rio Acima quadrangle from the adjacent Gandarela quadrangle and extending northwestward to north into the southeastern part of the Nova Lima quadrangle where the syncline ends by closure. This structure is named the Vargem do Lima syncline in the present report. It appears to be a large downfold in the central part of the Rio das Velhas uplift, but probably predated the formation of the uplift.
3. The area of tight complex folding in the northwestern part of the Rio Acima quadrangle and adjacent parts of the Nova Lima quadrangle, and near Raposos in the Nova Lima quadrangle. Folding is defined by thin beds of iron-formation, and in the Morro Velho mine, by one or more beds of a carbonate rock (lapa sêca).
4. The inferred fault along the Rio das Velhas near Honorio Bicalho in the north-central part of the Rio Acima quadrangle.
5. The inferred fault crossing Morro do Pires, in the northwestern part of the Rio Acima quadrangle.
6. The east-trending fault in the Minas series near the west edge of the Nova Lima quadrangle.

IGNEOUS ROCKS

Rocks of igneous origin in the area include volcanic rocks, and possibly sills, interbedded with metasedimentary rocks to form the Nova Lima group; a stocklike body of serpentinite with bordering small masses of metagabbro and talc schist; granitic and gneissic rocks and pegmatite; and scattered dikes of metadiabase.

The serpentinite, metagabbro, and talc schist represent intrusions into rocks of pre-Minas age in the southwestern part of the Rio Acima quadrangle. Granitic rock and pegmatite are intrusive into Minas rocks near the northwestern corner of the Nova Lima quadrangle and evidently are part of a large area of granitic rock and gneiss that extends far north, northwest, and northeast of the Nova Lima quadrangle. Granitic rock, exposed only across a few meters of outcrop, is found in lit-par-lit relationship with schist in one place in the southwestern part of the Nova Lima quadrangle, and is believed to represent small dikes. Small bodies of metadiabase and deeply weathered rock that probably was metadiabase occur throughout the area. Most of these bodies are probably dikes. They are best known in and near the Raposos mines and in the valley bottom of the Rio dos Macacos, 1.5 kilometers southwest of Honorio Bicalho, in rocks of pre-Minas age, and in rocks of the Minas series along the Rio das Velhas northwest of Sabará.

The granitic and gneissic rocks, pegmatite, and at least some of the metadiabase of the area are of post-Minas age. The serpentinite, metagabbro, and talc schist are probably of pre-Minas age.

REGIONAL DEFORMATION AND METAMORPHISM

At least two major periods of deformation and several minor disturbances are recorded in the rocks of the area. The Rio das Velhas series was strongly folded and subjected to erosion at least once prior to deposition of the Minas series. Following deposition of the Minas series another major deformation took place, and brought the rocks of the area approximately to their present attitudes.

Minor and probably only local disturbances occurred in Rio das Velhas time, after deposition of the Nova Lima group and before deposition of the Maquiné, and in Minas time, following deposition of the Cauê itabirite and before deposition of the Cercadinho formation. The Itacolumí series, lying unconformably above the Minas series in other parts of the Quadrilátero Ferrífero, evidently has been little disturbed, tectonically.

Most of the rocks of the Rio das Velhas and Minas series in the area of the present report are metamorphosed in the chlorite zone of regional metamorphism—the muscovite chlorite subfacies of the greenschist facies (Turner, 1948, p. 96). Biotite is distributed sporadically and is not common in most of the area. Some of it may be related to thermal effects from small bodies of intrusive rock.

Present regional metamorphic effects are obviously of post-Minas age. No petrographic evidence of regional metamorphism antedating the Minas has been found during the present study. Inasmuch as there is no necessary relationship between folding and regional metamorphism, the pre-Minas deformation suggests only a possibility of corresponding regional metamorphism. This statement assumes that postdepositional changes relating to compaction and diagenesis are not classified as metamorphic changes. It seems likely to the author, however, that at least low-grade regional metamorphism did accompany pre-Minas deformation, and that evidence of the metamorphism was obscured or destroyed by post-Minas deformation and metamorphism.

Granitic rock was intruded into the upper part of the Minas series in the northwestern part of the Nova Lima quadrangle in post-Minas time. The intrusive contact and a related thermal metamorphic aureole in the Minas adjacent to the contact rather closely parallel the trend of the Minas series. The thermal aureole is characterized by the presence of garnet and staurolite. The post-Minas intrusion of granitic rock may have accompanied post-Minas deformation and regional metamorphism, and thus the thermal metamorphism of the upper part of the Minas may be closely related to the regional metamorphism in time and ultimate cause.

RIO DAS VALHAS SERIES

NOVA LIMA GROUP

SCHISTS AND PHYLLITES

Interbedded metasedimentary and metavolcanic schists and phyllites form the bulk of the Nova Lima group. Fresh rocks are mainly green or gray-green, but at the surface the schists and phyllites commonly are pinkish, red, maroon, or buff owing to weathering. Secondary concentrations of hydrated iron oxides at or near the surface have modified the rock to a dense brownish ferruginous schist in places. Natural exposures are generally small. Graphitic phyllite is widespread but not abundant. Except for graphitic phyllite, the weathered rocks generally cannot be related to specific unweathered schists and phyllites, making it difficult or impossible to map varieties of schist or phyllite. Although different types of schist and phyllite have been identified at individual locations, they have been mapped together as a single stratigraphic unit.

DISTRIBUTION AND THICKNESS

Schists and phyllites of the Nova Lima group underlie much of the Nova Lima and Rio Acima quadrangles.

Highly weathered schists and phyllites are exposed in trails and road cuts throughout the area, in railroad cuts of the Central do Brasil along the Rio das Velhas, and in two areas of locally intense erosion ("washouts") in the Rio Acima quadrangle, located approximately at N. 5,340, E. 60, and at N. 5,700, E. 1,000. Fresh to slightly weathered schists and phyllites in natural exposures are best known along the Rio do Peixe eastward from near the southwest corner of the Rio Acima quadrangle to the vicinity of N. 1,200, E. 3,000. They are also found in the valley of the Rio dos Macacos (Rio Acima, vicinity N. 8,840, E. 1,460), along the Rio dos Machados (Rio Acima, vicinity N. 1,100, E. 10,000), near Morro do Enforcado, about 3 kilometers southwest of the town of Rio Acima, and along Rio das Velhas, north of Raposos (particularly, Nova Lima, vicinity N. 5,700, E. 5,900).

The only samples of completely fresh schist and phyllite in the area have come from the Morro Velho mine at Nova Lima, the Raposos mines, the dump of the Bicalho mine at Honorio Bicalho, from the Gaia tunnel, which extends west-southwestward about 2½ kilometers from Honorio Bicalho and from drill core obtained by the Departamento Nacional da Produção Mineral, about 1.4 kilometers south of Rio Acima (N. 2,960, E. 8,600).

Graphitic phyllite is best exposed in the western half of the Rio Acima quadrangle where it is widely distributed as thin layers in the more abundant quartz-sericite and chlorite-bearing schists. It forms a relatively large part of the schists and phyllites only in one zone about 400 meters wide in the Rio Acima quadrangle, extending north-northeastward approximately from the vicinity of N. 4,540, E. 2,600 to the vicinity of N. 6,240, E. 3,000. It is there abundantly interlayered with pink and purple weathered schists. Weathered graphitic phyllite is also commonly interlayered with pink-purple schists in the northwestern part of the Rio Acima quadrangle. In the Gaia tunnel in the same part of the area, fresh graphitic rock is closely associated with iron-formation. (See pl. 4.) The beds of graphitic phyllite in the northwestern part of the Rio Acima quadrangle are generally not more than 3 meters thick, and commonly are less than 1 meter thick.

Ferruginous schist typically forms small areas of blocky rubble along the crests of sloping ridges, on the side slopes, or near the ends of ridges. The ferruginous material is conspicuously formed only in the southwest quarter of the Rio Acima quadrangle. The most prominent locations of such material center approximately at the following points:

1. N. 1,260, E. 3,280
2. N. 1,760, E. 3,560
3. N. 3,380, E. 3,780
4. N. 3,720, E. 4,060
5. N. 3,920, E. 2,660
6. N. 4,420, E. 3,480
7. N. 4,740, E. 2,960
8. N. 4,940, E. 740
9. N. 5,000, E. 3,200
10. N. 5,320, E. 400
11. N. 5,400, E. 3,040
12. N. 5,540, E. 540
13. N. 5,640, E. 2,480
14. N. 5,840, E. 500
15. N. 6,240, E. 140
16. N. 6,660, E. 1,260
17. N. 6,700, E. 2,500

Most of the areas of rubbly ferruginous schist are less than 100 meters across in greatest dimension, but a few, notably those located at nos. 11, 14, and 15, are about 200 meters across. Gullies and test trenches show that the thickness of the rubbly ferruginous schist is generally less than 1 meter.

Fresh metavolcanic schists are identified with certainty only in thin section. Samples of such rock have come from the Gaia tunnel and from the drill core obtained by the Departamento Nacional da Produção Mineral, 1.4 kilometers south of Rio Acima. Coarser grained mafic igneous rock has also been found in the same drill core and may have been injected parallel with the schistosity of the country rock.

Much of the weathered schist of the Nova Lima group may be metavolcanic rock, but this could be established only by an extensive drilling program.

The drilling south of Rio Acima and the mapping of the Gaia tunnel by J. B. Pomerene (pl. 4) both indicate that metavolcanic schist alternates with metasedimentary schist. Moreover, the work in the Gaia tunnel shows that metavolcanic rock is interbedded with metasedimentary schists and ankeritic to sideritic carbonate-magnetite-quartz iron-formation.

No reasonably accurate estimate of the proportion of metavolcanic to metasedimentary schists in the Nova Lima group can be made at present.

The schists and phyllites of the Nova Lima group are the oldest known rocks in the region, and are separated from overlying rocks by an unconformity. Because of this, because of a lack of marker beds throughout much of the area of schists and phyllites, and because of the probability that unrecognized folds exist, an accurate measurement of thickness cannot be made. The estimated minimum thickness of the schists and phyllites is 4,200 meters in the Rio Acima quadrangle, measured along lines passing from N. 8,560, E. 9,900 to N. 7,300, E. 5,880; from N. 9,020, E. 5,340 to N. 9,200, E. 4,220; and from N. 9,020, E. 4,120 to N. 9,400, E. 3,840.

FIGURE 2.—Photomicrograph of metasedimentary quartz-carbonate-sericite schist, Nova Lima group. Drill core, drilled 1.4 km south of Rio Acima (N. 2,960, E. 8,600). Strongly foliated. Lenses and streaky zones of sericite-fuchsite (sf), quartz (q), and carbonate (c). Traces of rutile (r) as small rods in sericite-fuchsite, and of sulfide (s), mainly in areas of quartz-carbonate. Dark fine-grained unidentified dusty matter (d) along shear seams may be graphite. Plane polarized light.

PETROGRAPHY

Petrographic data for schists and phyllites of the Nova Lima group are listed in table 2. The metasedimentary varieties consist predominantly of quartz, sericite-fuchsite, chlorite, and carbonate in varying proportions. (See fig. 2.) Talc schist has been identified megascopically in several places within 500 meters south-southeast of the northwest corner of the Rio Acima quadrangle, but no thin sections of it have been made. The index of refraction of the ordinary ray and the corresponding composition of carbonates in schists, phyllites, and other rocks of the area are listed in table 3.

Feldspar or graphite is abundant locally in the schists or phyllites. Where feldspar is abundant, the schists have the composition of graywacke or arkose depending on the amount of sericite-chlorite forming the matrix. There are gradations from one type of schist to another; therefore, the designations in table 2 are arbitrary. The ferruginous schists listed in table 2 are a product of weathering and redeposition of iron, and prior to weathering may have corresponded to any of the other rocks listed in the table. Although most of the schists are altered at the surface by weathering, the ferruginous schists distinguished here are those in which weathering and redeposition of iron has been so extensive that the rock has a nearly completely ferruginous matrix and forms a hard blocky brownish rubble on the surface. Judging by the relative abundance of quartz, most or all of the ferruginous schists were probably metasedimentary in origin. The origin of this ferriginous material is not certain. However, the location of many of the areas of rubbly ferruginous schist, between 930 meters and 970 meters in elevation, suggests a relationship between them and an erosional base level or stillstand of ponded waters at the beginning of the present erosion cycle.

TABLE 2.—*Petrographic data for schists and phyllites of the Nova Lima group*

[Some minerals fall into more than 1 of the 3 percentage columns. Minerals preceded by an asterisk (*) are in the given percentage range in only a few thin sections]

METASEDIMENTARY SCHISTS

Quartz-sericite schists and phyllites

[Data based on 29 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz Sericite *Muscovite *Fuchsite *Yellow-brown iron oxide	Carbonate–calcite, dolomite, or ankerite Yellow-brown iron oxide *Chlorite *Quartz *Biotite	Chlorite Rutile Leucoxene Ilmenite Magnetite? *Sodic plagioclase *Carbonate *Pyrite *Yellow-brown iron oxide *Zircon *Epidote *Talc?

NOTE.—Grain sizes mainly less than 0.1 mm. Quartz in some samples, 0.1–2 mm. Carbonate generally 0.1–2 mm. Moderately to strongly foliated. Sericite or muscovite well alined. Quartz equant or elongated and alined. Sericite in irregular layers, lines, or streaky lenses alternating with layers of quartz. Isolated alined flakes of sericite widely distributed in quartzose areas. In some schists quartz forms lensoid mosaics in mica matrix. Sericite intergrown with chlorite or fuchsite in places. In few samples in which sericite only dominant mineral, foliation surfaces crinkled and crossed by fracture cleavage. Subordinate carbonate common in fresh schists as equant crystals, stringers, or lenses, alined parallel to foliation. Well-defined "spots" (some of which are rhomb-shaped), stringers, and lenses of yellow-brown iron oxide common in weathered schists and probably derived from oxidation of carbonate.

Quartz-chlorite and quartz-chlorite-sericite schists and phyllites

[Data based on 29 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz Chlorite *Sericite *Biotite or stilpnomelane	Sericite Carbonate *Quartz *Sulfide	Leucoxene Yellow-brown iron oxide Magnetite? *Sericite *Feldspar *Graphite *Rutile *Carbonate *Epidote *Biotite *Tourmaline *Sulfide

NOTE.—Grain sizes mainly less than 0.1 mm. Quartz "eyes," 0.1–2 mm. Carbonate from less than 0.1 to 2 mm. Carbonate and quartz, in veinlets, from 0.1 to more than 2 mm. Moderately to strongly foliated. Chlorite and sericite generally well alined. Schists commonly with alternating poorly defined quartz-rich and chlorite-rich layers or lenses. Quartz subordinate in phyllites. Quartzose layers commonly have isolated scattered chlorite flakes; chloritic layers generally have very little quartz. Quartzose layers commonly have some intergrown carbonate, and chloritic layers have some intergrown sericite. Biotite or stilpnomelane evenly spread through chlorite in a few samples. In places, quartz, chlorite, sericite evenly intermixed. Quartz-carbonate veinlets common, and in places carry sulfides.

TABLE 2.—*Petrographic data for schists and phyllites of the Nova Lima group*—Continued

METASEDIMENTARY SCHISTS—continued

Carbonate-rich schists

[Data based on 19 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz Carbonate Sericite *Fuchsite *Chlorite *Biotite *Muscovite	Chlorite *Fuchsite *Quartz *Sericite	Rutile Dusty opaque material Leucoxene Sulfide *Graphite *Chlorite *Yellow-brown iron oxide *Feldspar *Tourmaline *Epidote *Magnetite *Apatite?

NOTE.—Grain sizes mainly less than 0.1 mm. Some quartz and carbonate grains, 0.1–2 mm. Weakly to strongly foliated. Irregular layers of quartz-carbonate generally alternate with layers of finer quartz-sericite-chlorite. Generally strong alinement and foliation in micaceous layers and poor to moderate foliation in quartz-carbonate layers. In places seams or poorly defined lenses of sericite-quartz or sericite-chlorite-rutile alternate very irregularly with patchy areas of quartz-carbonate. Quartz-carbonate grains commonly somewhat elongated and intergrown in mosaic texture. Carbonate or carbonate-quartz may occur in lenticular pods. In places carbonate occurs in isolated scattered crystals, greatly elongated and alined parallel to foliation. Commonly, pods of quartz-carbonate and elongated carbonate crystals are sharply bounded by shear surfaces or seams of alined sericite. In places shear seams bend around quartz-carbonate pods. Rutile and graphite may be widely distributed through sericite, or concentrated into shear seams. In places aggregates of rutile partly altered to leucoxene.

Quartz-biotite (or stilpnomelane) schists and phyllites

[Data based on 7 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz Biotite (not readily distinguishable from stilpnomelane in several samples) *Chlorite *Yellow-brown or red-brown iron oxide	Yellow-brown iron oxide.	Sericite Magnetite Leucoxene Dusty opaque material *Sodic plagioclase *Chlorite *Red, yellow-brown, and red-brown iron oxides *Epidote

NOTE.—Grain sizes mainly less than 0.1 mm. Plagioclase 0.1–2 mm. Moderately schistose. Matrix of rock a mixture of quartz-biotite-sericite in which somewhat larger clastic quartz and feldspar are scattered. Mica flakes well alined between individual quartz grains. Biotite also concentrated and alined in streaks and in irregular poorly defined layers. Biotite considerably oxidized in places. Yellow-brown or red-brown iron oxide in dusty aggregates along shear seams and also widely distributed in isolated sharply defined "spots." Some scattered yellow brown iron oxide is rhomb-shaped and probably pseudomorphic after carbonate.

TABLE 2.—*Petrographic data for schists and phyllites of the Nova Lima group*—Continued

METASEDIMENTARY SCHISTS—continued

Quartzose and feldspathic schists

[Data based on 15 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz *Sericite *Feldspar	Feldspar—most, and perhaps all, is sodic plagioclase. Sericite *Chlorite *Carbonate	Carbonate Chlorite Rutile Leucoxene *Ilmenite? *Feldspar *Epidote *Biotite? *Graphite? *Red and yellow-brown iron oxides *Zircon

NOTE. Matrix grains, less than 0.1 mm. Larger clastic quartz and feldspar, 0.1–2 mm. Includes poorly to moderately schistose subgraywacke, graywacke, and arkosic schists. Foliation generally in form of discontinuous shear seams traversing fine-grained matrix. Generally distinctly larger quartz and feldspar set in matrix of wormy mosaic quartz and sericite. In places, continuous seams of sericite-chlorite pass between and isolate many quartz, feldspar, and carbonate grains. In some samples, layers with mosaic quartz alternate with layers of well-alined sericite in which are studded some crystals of feldspar and (or) carbonate. Feldspar in some samples largely altered to sericite.

Graphitic phyllites

[Data based on 5 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz	*Graphite	Yellow-brown iron oxide
Graphite Sericite	*Sericite *Carbonate	Sulfide—most or all is pyrrhotite *Carbonate

NOTE.—Grains mainly less than 0.1 mm; some quartz and carbonate that are probably of hydrothermal origin are 0.1–2 mm. Fresh rock commonly of slaty aspect. Graphite generally rather evenly distributed between individual quartz grains. In places graphite more highly concentrated into poorly defined layers. Some of rock sheared into closely spaced lenses (0.3–0.5 mm by 0.02–0.1 mm) of quartz-sericite with graphite along shear surfaces. Some of quartz cherty and in poorly defined layers parallel to foliation. Some of rock is phyllite with strongly alined graphite and with alined lenticular aggregates and lensoid crystals of quartz and carbonate, generally of two sizes (0.05 mm and 0.08–0.16 mm). Coarser grains probably a result of hydrothermal activity. Sulfide stringers are common parallel to foliation.

Ferruginous schists

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz Yellow-brown and red-brown iron oxide—most is probably goethite *Sericite *Kaolinite?	Sericite	Chlorite Magnetite *Quartz

NOTE.—Grain sizes from less than 0.1 to 2 mm. All schists highly weathered. Rock slightly to moderately schistose. Quartz grains commonly in matrix of iron oxide. In places quartz and iron oxide have even-grained granular to mosaic textures. In some rocks, distinct concentration of quartz and iron oxide into separate thin layers. No evidence of iron oxide replacing quartz. Fresh rocks probably similar to types listed above in this table, with present iron oxide a weathering product, possibly of chlorite, sericite, biotite, carbonate, or sulfide, or any combination of these minerals.

TABLE 2.—*Petrographic data for schists and phyllites of the Nova Lima group*—Continued

METASEDIMENTARY SCHISTS—continued

Metavolcanic schists

[Data based on 29 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Chlorite Epidote-clinozoisite Pale green hornblende—probably tremolitic to actinolitic *Sodic plagioclase *Zoisite *Quartz *Sericite *Carbonate *Biotite *Magnetite	Sodic plagioclase Quartz *Sericite *Epidote-clinozoisite *Carbonate *Leucoxene *Ilmenite *Magnetite	Leucoxene Ilmenite Sulfide *Sodic plagioclase *Carbonate *Epidote-clinozoisite *Fuchsite *Chlorite *Biotite *Quartz *Iron oxides *Tourmaline

NOTE.—Grain sizes mainly less than 0.1 mm. Plagioclase and carbonate from less than 0.1 to 2 mm. Most original minerals probably 0.1–2 mm; probable quartzose amygdules, 0.1–2 mm. Includes following assemblages with which ilmenite-leucoxene generally occur: chlorite-quartz-plagioclase-carbonate, chlorite-quartz-sericite, chlorite-quartz-biotite-carbonate, chlorite-epidote-clinozoisite, chlorite-amphibole-carbonate, plagioclase-clinozoisite-amphibole-sericite, plagioclase-epidote-sericite-carbonate, amphibole-zoisite, amphibole-clinozoisite, amphibole-sericite, sericite-epidote-carbonate, sericite-quartz-plagioclase, and sericite-quartz-magnetite. Slightly to moderately schistose. Original textures destroyed by metamorphism in most samples. Some samples have relict volcanic or diabasic textures, mainly in form of criss-crossing relicts of twinned plagioclase. Epidote-clinozoisite commonly in blocky aggregates pseudomorphic after plagioclase. In places sericite and chlorite also in blocky aggregates pseudomorphic after earlier minerals. Some quartz in scattered grains or irregular aggregates; some quartz in well-defined blebs or lenses—probably stretched amygdules. Some samples have very fine grained, even-grained assemblages—probably devitrified volcanic glass.

Schistosity is the dominant structure of the schists and phyllites of the Nova Lima group; bedding generally can be identified with certainty only where it is found crossing schistosity. In places there is an alternation of very thin micaceous and quartzose seams or lenses parallel to foliation of the rock. Where these seams are readily visible owing to color variations, bedding has been interpreted as parallel to schistosity. Typically there is nothing to indicate possible bedding, and whether or not it parallels schistosity is conjectural. The beds generally seen in these rocks are thin (0.1–2.0 cm), dark-purple, reddish, or black (graphitic?) layers interbedded with much thicker light-purple or pink layers, and noted only where schistosity crosses bedding at a large angle.

Most of the metavolcanic schists are mafic. They differ from the metasedimentary schists by having assemblages typically resulting from the regional metamorphism of mafic volcanic rocks, particularly chlorite and plagioclase, chlorite and epidote or clinozoisite,

TABLE 3.—*Carbonates from rocks in the Nova Lima and Rio Acima quadrangles*

[Determinations from Winchell (1933, p. 70, 74, 75)]

Sample No.	Rock type	Location	Index of refraction of ordinary ray	Mineral	Approximate percentage of dominant carbonate molecule (where known or appropriate)
JG-131-56	Quartz-carbonate rock (lapa sêca).	Dump, Honorio Bicalho mine	1. 685	Magnesiodolomite	Dolomite 90
18-56	Quartz-sericite-carbonate schist	Drill core, 1.4 km south of Rio Acima.	1. 689-1. 693	do	Dolomite 85-88
20-56	Quartz-sericite-chlorite-carbonate schist	do	1. 694	do	Dolomite 84
36-56	Sericite-chlorite-carbonate schist	do	1. 709	Ankerite	
39-56	Graywacke with carbonate	do	1. 654	Calcite	
45-56	Quartz-sericite-carbonate schist	do	1. 702	Ankerite	
115-56	Quartz-carbonate rock (lapa sêca).	13-X stope, Morro Velho mine	1. 693	Magnesiodolomite	Dolomite 85
116A-56	do	do	1. 698	do	Dolomite 80
118-56	do	8 level, Morro Velho mine	Most 1. 694	do	Dolomite 84
			Few 1. 703	Ankerite	
120-56	Quartz-sericite-carbonate schist	12 level, Morro Velho mine	1. 690	Magnesiodolomite	Dolomite 85
127-56	Quartz-carbonate rock	8 level, Morro Velho mine	1. 685	do	Dolomite 90
129-56	Quartz (cherty)-carbonate rock (lapa sêca).	do	Most 1. 685; few well above	do	Do.
			1. 689	Ankerite	
131-56	Quartz-carbonate-feldspar rock (lapa sêca).	do	1. 685	Magnesiodolomite	Dolomite 90
134-56	Quartz-chlorite-carbonate schist	do	1. 694	do	Dolomite 84
135-56	Quartz-carbonate-feldspar rock (thin-bedded lapa sêca).	do	1. 698	do	Dolomite 80
136-56	Sericite phyllite replaced by quartz-carbonate (veins?).	do	1. 693	do	Dolomite 85
137-56	Gray-green carbonate rock replaced by quartz-carbonate.	900-ft level, Raposos mines	Approximately 1. 740	Ankerite-ferrodolomite	
138-56	Quartzose banded iron-formation; no magnetite.	do	Approximately 1. 745	Ferrodolomite	
139-56	do	do	1. 735	Ankerite	
140-56	Fine-grained quartzite with carbonate lenses.	do	1. 657	Calcite	
144-56	Banded iron-formation with probable graphite.	DDH R-32, Raposos mines	Most 1. 820	Sideritic carbonate	Siderite 50-70
			Some approximately 1. 809	do	Siderite 40-60
145-56	Banded iron-formation; no magnetite	do	Most approximately 1. 790-1. 800.	do	Do.
			Some 1.838	do	Siderite 60-80
146-56	Fuchsite schist	do	1.687	Magnesiodolomite	Dolomite 90
147-56	do	DDH R-34, Raposos mines	1.693	do	Dolomite 85
148-56	Poorly banded quartzose iron-formation.	do	1.701	Ankerite	
154A-56	Banded iron-formation with magnetite.	1500-ft level, Raposos mines	Most 1.830	Sideritic carbonate	Siderite 65-67
			Some much less than 1.810	Probably ankerite or magnesiodolomite.	
154B-56	do	do	1.851	Sideritic carbonate	Siderite 85-95
154C-56	do	do	1.839	do	Siderite 70-80
156A-56	do	900-ft level, Raposos mines	Most 1.731-1.733	Ankerite	
			Some >1.810	Sideritic carbonate	

156B-56	Banded iron-formation with magnetite (3 carbonates).	do	Beds with yellow-brown surface alteration 1.838.	do	Siderite 70–80
			Dark-gray beds; most approximately 1.733–1.740.	Ankerite-ferrodolomite	
			White vein; 1.660–1.690	Calcite-magnesiodolomite	
157-56	Banded iron-formation cut by carbonate veins; no magnetite.	do	Gray beds, approximately 1.790–1.831.	Sideritic carbonate	
			White veins; 1.658	Calcite	
160-56	Banded iron-formation; no magnetite.	200-ft level (41 adit level), Raposos mines.	Most 1.839	Sideritic carbonate	Siderite 70–80
			Some 1.730–1.735	Ankerite	
			Little 1.848	Sideritic carbonate	Siderite 80–85
160A-56	do	do	1.843–1.847	do	Siderite 75–85
160C-56	do	do	1.839	do	Siderite 70–80
160E-56	do	do	Most 1.850–1.851; some possibly to 1.857.	do	Siderite 85–95
160G-56	Banded iron-formation with magnetite(?).	do	Most 1.836	do	Siderite 65–78
			Some 1.848	do	Siderite 75–84
161-56	Banded iron-formation; no magnetite.	900-ft level, Raposos mines	Most 1.840	do	Siderite 70–80
			Some approximately 1.847	do	Siderite 75–85
162A-56	do	do	Most 1.845–1.848–1.853	do	Siderite 73–95
			Some approximately 1.734	Ankerite	
163-56	Quartz-carbonate (lapa sêca)	20 level, Morro Velho mine	Most 1.683	Magnesiodolomite	Dolomite 95
			Some 1.689	do	Dolomite 80
165-56	Carbonate rock	Large lens in ferruginous quartzite, 1,300 meters N. 73° W. of Triangulo.	1.674–1.676	Magnesiodolomite (probably slightly calcitic).	
Ga-803.3	Banded iron-formation; no magnetite.	Gaia Tunnel	1.702	Ankerite	
838	Fuchsite carbonate schist	do	1.659–1.660	Calcite	
995	Banded iron-formation with magnetite.	do	Most 1.842	Sideritic carbonate	Siderite 70–82
			Some approximately 1.832	do	Siderite 63–75
1340.4	do	do	Most approximately 1.730–1.740.	Ankerite	
			Some 1.831	Sideritic carbonate	Siderite 62–74

chlorite and amphibole, or epidote and amphibole. Quartz generally is not abundant. The amphibole is nearly colorless and nonpleochroic to slightly pleochroic in thin section. A quartz-sericite-plagioclase assemblage and a quartz-sericite-magnetite assemblage, each represented by one thin section, are thought to be silicic metavolcanic rock because of their small amount of ferromagnesium minerals and because some of the quartz of both samples is larger than surrounding grains and is somewhat embayed in the manner typical of volcanic quartz phenocrysts. Relicts of intergrown and crisscrossing plagioclase laths and possible stretched quartzose amygdules in some of these rocks are the only direct evidence of volcanic origin found.

IRON-FORMATION AND ASSOCIATED QUARTZITIC ROCKS

The pre-Minas iron-formation of the Nova Lima and Rio Acima quadrangles was not studied systematically prior to the present work, and individual beds had not been mapped at the surface. Weathered iron-formation of pre-Minas age is superficially similar to some itabirite, and was generally thought to be of Minas age.

Iron-formation and associated quartzitic rocks of the Nova Lima group occur mainly in two belts or zones, in which one to six beds of iron-formation are interlayered with schist or phyllite. Fresh unweathered iron-formation has not been found at the surface, but is known from mine samples and drill cores to be in beds composed of thin alternating quartzose layers and layers rich in sideritic carbonate or sideritic carbonate and magnetite. Beds of weathered iron-formation contain alternating quartzose laminae and brownish ferruginous laminae. In places iron-formation grades along strike into cherty quartzitic rock or graphitic phyllite, or is interbedded with lenses of cherty graphitic quartzite.

Individual beds of weathered iron-formation have been mapped during the present work (pls. 1, 2). They crop out typically as narrow ridges, locally coming almost to a knife edge. Narrow trains of boulders and blocks of iron-formation are thought to represent slumped outcrops in many places. Such trains have been used with considerable confidence in mapping individual beds, especially where the trains do not cross slopes parallel to the dip direction, where they pass into outcrops in both directions or downhill, and where they are approximately parallel to the trend of local structure as shown by adjacent outcropping beds of iron-formation.

DISTRIBUTION AND THICKNESS

The pre-Minas iron-formation of the area is best formed and most conspicuous in two zones, one in the northwestern part of the Rio Acima quadrangle and the adjoining southwestern part of the Nova Lima quadrangle, and the other in the vicinity of Raposos in the south-central part of the Nova Lima quadrangle. Beds of iron-formation in the first zone pass westward from the Nova Lima quadrangle into the Belo Horizonte quadrangle, and lens out southward across the western part of the Rio Acima quadrangle. The most conspicuous occurrences of iron-formation in this zone are (1) at Morro do Pires in the northwestern part of the Rio Acima quadrangle, and along the ridge extending northeastward to a point about 2 kilometers from the top of Morro do Pires, (2) at Morro dos Cristais in the southwestern part of the Nova Lima quadrangle, and (3) in the vicinity of Morro da Cachaça (Rio Acima, N. 10,100, E. 4,540).

Dark (graphitic?) cherty quartzite and graphitic phyllite grade into, or are interbedded with iron-formation, in the northwestern part of the Rio Acima quadrangle, in the vicinity of N. 10,200, E. 2,800; N. 9,600, E. 1,000, and in the Gaia tunnel (pl. 4). A white cherty quartzite facies of the iron-formation is exposed at N. 12,480, E. 2,340.

Individual beds of iron-formation are commonly 5 to 10 meters thick, but range in thickness from about 1 to 50 meters. Complex folding and lensing out of beds make it difficult to determine the number of beds of iron-formation in the stratigraphic section in any one part of this zone. However, there are probably no more than six such beds of iron-formation along any one traverse of the section, and the maximum total thickness of such beds is estimated to be 150 meters.

A single lenticular and discontinuous bed (or two closely spaced beds) of iron-formation is found in the southwestern part of the Rio Acima quadrangle, and may be at about the same stratigraphic level as the zone of iron-formation in the northwestern part of the Rio Acima quadrangle. Judging by topography, the horizon of this bed of iron-formation extends southwestward to the south edge of the quadrangle, 1,500 meters east of the southwest corner, although the iron-formation itself has lensed out northeast of this place. Evidently the horizon is folded a short distance to the south inasmuch as iron-formation occurs again in the quadrangle about 720 meters east of the southwest corner. The iron-formation extends northward to N. 3,580, E. 1,180, and from that place, as ferruginous silty quartzite to the vicinity of N. 4,040, E. 1,420. The horizon of this iron-formation and ferruginous quartzitic rock may extend from N. 4,040, E. 1,420 to the outcrops of iron-formation in the vicinity of N. 5,080, E. 400 and N. 5,000, E. 240, from where it appears to pass westward into the Macacos quadrangle, about 5,080 meters north of the southwest corner of the Rio Acima quadrangle. The southwesternmost bed of iron-formation in the Rio Acima quadrangle is rich in stilpnomelane where crossed by the Rio do Peixe at about N. 180, E. 700.

The zone of iron-formation near Raposos contains 1 to 3 beds of iron-formation which are estimated to have a maximum total thickness of 100 meters. The iron-formation lenses out 1 kilometer south-southeast of Raposos, and northwest of Raposos approximately between N. 4,280, E. 5,100 and N. 4,840, E. 4,740 it grades into locally banded (with iron minerals) and locally graphitic cherty quartzite, which extends northward and eastward to the Rio das Velhas. There it strikes northeastward, is 1 meter thick, and evidently lenses out completely a short distance to the northeast.

A small isolated lens of iron-formation, far from other occurrences, and probably not more than 20 meters thick, crops out in the Rio Acima quadrangle in the vicinity of N. 10,040, E. 8,460. It may be at the same horizon as the iron-formation that lenses out 1 kilometer south-southeast of Raposos.

PETROGRAPHY AND ORIGIN

Petrographic data for the iron-formation and associated quartzitic rocks of the Nova Lima group are listed in the following table:

Petrographic data for iron-formation and associated quartzitic rocks of the Nova Lima group

[Some minerals fall into more than 1 of the 3 percentage columns. Minerals preceded by an asterisk (*) are in the given percentage range in only a few thin sections]

Unweathered iron-formation

[Data based on 35 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz Carbonate *Magnetite	Magnetite *Carbonate *Chlorite—iron-rich with N*m* about 1.66 *Sericite *Biotite *Feldspar *Yellow-brown iron oxide	Graphite? Magnetite Sulfide *Chlorite—iron-rich with N*m* about 1.66 *Sericite *Biotite *Feldspar *Yellow-brown iron oxide

NOTE.—Grain sizes mainly less than 0.1 mm, but up to 0.15 mm in some samples. Grains of secondary carbonate and quartz (mainly in veinlets) 0.1–2 mm. Quartz and carbonate mostly with fine-, even-grained mosaic texture. Poorly to distinctly layered. Typically has alternating layers of quartz and carbonate. Quartzose layers generally with 20–30 percent scattered isolated carbonate crystsls. Layers vary greatly in thickness from less than 0.1 mm to 3 cm, mostly 0.2–5.0 mm thick. Layers generally rather continuous. Most carbonate is sideritic. (See table 3.) Magnetite dominant in a few samples, subordinate in some, minor in some, and absent in many. Most magnetite aggregated into layers, stringers, or blebs within carbonate layers. Chlorite in scattered patches and blades generally in contact with magnetite crystals. Relatively little magnetite scattered in isolated crystals in the quartzose layers. Fine dusty graphite(?) confined largely to some carbonate layers. A few feldspar porphyroblasts in one thin section. Biotite in seams and cracks in carbonate layers in two thin sections. Sulfide crystals, blebs, and stringers confined almost entirely to carbonate layers, to contacts between carbonate and quartz layers, and to cracks crossing both carbonate and quartzose layers. Sulfides believed to be secondary. Coarser secondary quartz and carbonate—in places with sulfide—form blebs and veinlets parallel to and crossing bedding.

Petrographic data for iron-formation and associated quartzitic rocks of the Nova Lima group—Continued

Weathered iron-formation

[Data based on 38 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz Yellow-brown to red-brown iron oxide—probably goethite	*Magnetite *Quartz *Brownish iron oxide	*Brownish iron oxide *Magnetite *Quartz *Sericite *Graphite?

NOTE.—Grain sizes mainly less than 0.1 mm. Some magnetite grains, 0.1–2 mm. Quartz forms even-grained mosaic texture, commonly with evenly dispersed and intergrown grains of magnetite and yellow-brown, red-brown, and red iron oxide. Much of magnetite, brownish iron oxide, and hematite aggregated into layers that alternate with quartz-rich layers. In iron-rich layers brownish iron oxide commonly forms matrix for magnetite. In some polished sections hematite rims and partly replaces magnetite. In few samples some brownish iron oxide has bladed and rosette forms, and may be oxidized iron amphibole. In places some isolated scattered granules of brownish iron oxide in quartzose layers appear to be rhomb-shaped. Partly weathered iron-formation in shallow workings of the Raposos mine is strictly analogous to quartz-carbonate iron-formation except that carbonate granules have been altered to a light yellow-brown. Most of brownish iron oxide thought to represent oxidized sideritic to ankeritic carbonates. Some, and possibly all, hematite from oxidation of magnetite. In places stringers of sulfide extend along layers of brownish iron oxide.

Quartzites—iron-poor varieties of iron-formation or stratigraphically within few meters of iron-formation

[Data based on 25 thin sections]

Quartz *Yellow-brown iron oxide *Fuchsite?	Opaque dusty material—most is probably magnetite or graphite *Yellow-brown iron oxide	Yellow-brown iron oxide *Chlorite *Sericite *Feldspar *Leucoxene *Sulfide

NOTE.—Grain sizes mainly less than 0.1 mm; some quartz grains, 0.1–2 mm. White to dark gray, structureless, massive to thin-bedded, somewhat slaty, commonly friable rock. Fine-, even-grained quartz mosaics generally with rather evenly interspersed small grains of yellow-brown iron oxide, with magnetite, and (or) graphite. Layering generally poorly defined to non-existent. However, in places layers of fine-grained cherty quartz (<0.05 mm) alternate with layers or lenses of coarser quartz (up to 0.25 mm). In places, dusty opaque matter or yellow-brown iron oxide somewhat concentrated into poorly defined layers. Layers generally 0.1–1.0 mm thick. Dusty opaque matter and yellow-brown iron oxide generally confined to areas of finer-grained cherty quartz. Coarser quartz probably in large part vein material with silica derived from finer-grained cherty quartz. Graphite commonly forms seams or single-flake sheaths between individual quartz grains. Some of these rocks contain abundant small solution cavities coated with drusy or fibrous quartz.

The iron-formation is weathered in all natural exposures and generally forms a laminated rock in which thin brownish ferruginous layers alternate with light-colored quartzose layers (fig. 3). Magnetite is common in nearly all samples, so possibly the parts of the iron-formation that were resistant enough to weathering to form outcrops were mainly those originally rich in magnetite.

Unweathered iron-formation is gray, dark gray, or light gray green and typically contains dominant quartz and iron-rich carbonate. (See figs. 4 and 5, and table 3.) In some places in the Raposos mines the unweathered iron-formation has abundant magnetite (fig. 6). The quartzose layers are white or light-colored, but the rock derives its dominant color from the carbonate or carbonate and magnetite. The carbonate is

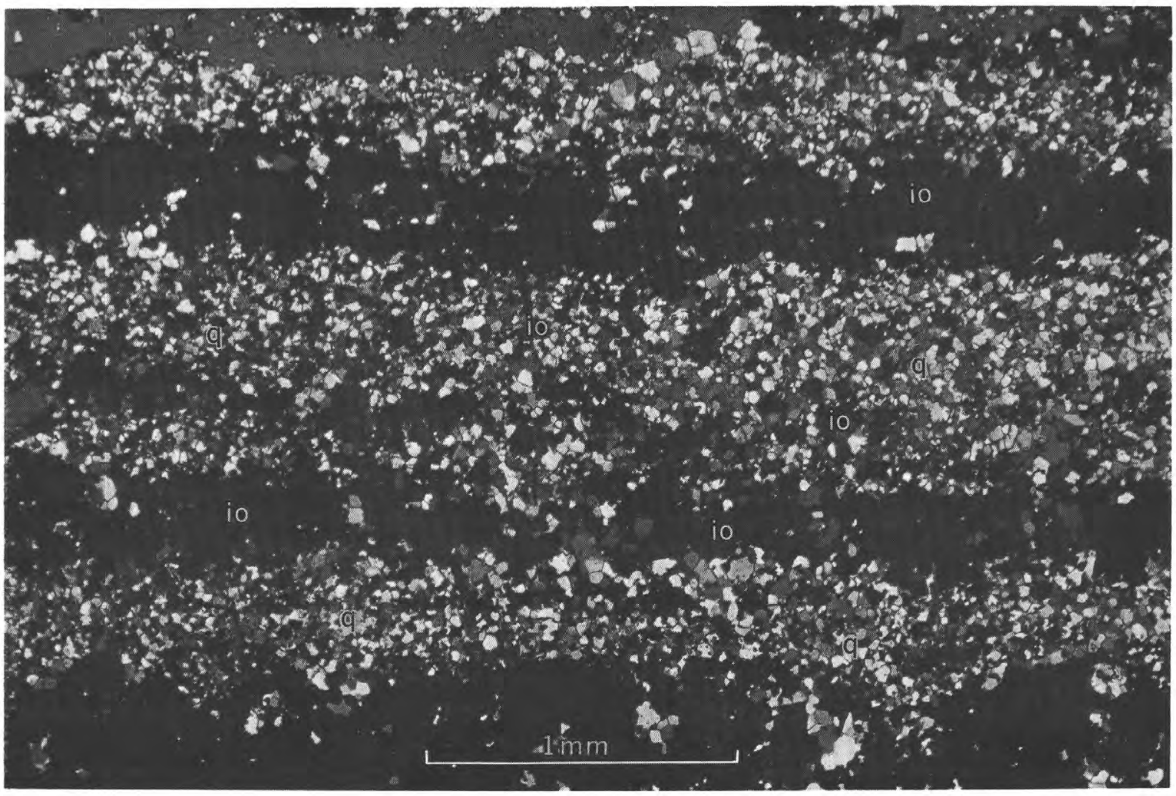

Figure 3.—Photomicrograph of weathered iron-formation, Nova Lima group. Rio Acima quadrangle (N. 12,680, E. 1,270). Alternating laminae of iron oxides (io) and quartz (q). Iron oxides consist of grains of magnetite partly replaced by hematite, and partly altered to and rimmed by goethite formed in weathering (relationships of iron oxides not shown in photomicrograph). Quartzose laminae have scattered grains of iron oxide. Crossed nicols.

generally sideritic, but in places it is ankerite or ferrodolomite. (See table 3.) Indices in the range approximately 1.81 to 1.85 in table 3 could indicate carbonate minerals rich in the manganese carbonate molecule, and relatively poor in the iron carbonate molecule. However, low Mn values in several analyses (see table 4), the gray green of the carbonate minerals in this range, and the fact that the weathering product of the carbonates in this range is almost always yellow-brown iron oxide, is the basis for assuming here that these carbonate minerals are rich in the iron carbonate molecule. The maximum range of percentage of the iron carbonate molecule for a given index of refraction is made with the assumption that manganese carbonate does not constitute more than half of the remaining carbonate molecules (carbonates of manganese, magnesium, and calcium are possible). Sample No. JG–156B–56 in table 3 is noteworthy in that layers with sideritic carbonate alternate with ankerite-ferrodolomite as well as with quartz. The sideritic carbonate is less stable than the ankerite-ferrodolomite under oxidizing conditions as indicated by a surface stain of yellow-brown iron oxide (oxidation having occurred since the opening of the mine tunnel) along the layers of sideritic carbonate of the hand specimen, and an absence of any indication of oxidation along the layers of ankerite-ferrodolomite. The fine-, even-grained mosaic texture common to the quartz and iron-rich carbonate suggests that the rock has been recrystallized from a fine-grained chert-carbonate material, probably a chemical sediment.

Sulfides occur in the unweathered iron-formation from both the Raposos mines and the Gaia tunnel (see fig. 7). Fresh sulfide is also common in weathered iron-formation 50 to 70 meters below the surface in the Raposos mines. The sulfides identified in oblique reflected light are pyrite and pyrrhotite. L. C. Graton and G. N. Bjorge (written communication to St. John del Rey Mining Co., 1929) also report very small or minor amounts of arsenopyrite and chalcopyrite from the ore (located in the iron-formation) of the Raposos mine. The sulfides are thought to be of later origin than the enclosing rock for the following reasons: (1) The gold deposits of the area are associated with the sulfides, and sulfides are known to be relatively abundant only in those parts of the iron-formation that carry substantial amounts of gold; (2) sulfide stringers alined parallel to bedding are almost entirely confined to layers of carbonate, and in places are best developed along the immediate contact between carbonate and quartz layers. Possibly, incoming H_2S reacted with the sideritic carbonate to produce much of the sulfide; (3) sulfide blebs and stringers or lines of sulfide grains are common in cracks crossing bedding; and (4) sulfide is commonly associated with patches and veinlets of coarser quartz-carbonate.

One complete chemical analysis and four partial chemical analyses of unweathered iron-formation from the Raposos mines and the Gaia tunnel have been prepared (table 4). The proportions of FeO, Fe_2O_3, MgO, MnO, and CaO show that the carbonate is rich in the $FeCO_3$ molecule and poor in the molecules of $MnCO_3$, $MgCO_3$, and $CaCO_3$. These analyses therefore corroborate and go beyond the optical data in table 3 in demonstrating that the carbonate of the iron-formation is predominantly sideritic.

TABLE 4.—*Complete and partial chemical analyses, in percent, of iron-formation from the Nova Lima group*

[Analysts: Nos. 1–3 Joseph I. Dinnin, U.S. Geological Survey; Nos. 4–7 Cassio M. Pinto, DNPM]

	1	2	3	4	5	6	7
SiO_2	38.9	67.8	38.0	49.3	60.4	38.1	56.9
Al_2O_3	.55	.31	.49	<.05	<.05	<.05	<.05
Fe_2O_3	9.7	24.6	58.6	1.4	3.1	4.1	10.4
FeO	27.6	6.0	1.3	21.8	15.3	29.8	16.6
MgO	.8	.07	.07	.9	1.0	1.0	.5
CaO	3.1	<.05	<.05	6.8	4.0	4.7	4.4
Na_2O	.22	.07	.11				
K_2O	<.01	<.01	<.01				
TIO_2	<.01	<.01	<.01				
P_2O_5	.08	.07	.12				
MnO	<.01	<.01	<.01	.92	.95	.93	.02
H_2O	.1	.7	1.5				
CO_2	17.9	.1	.1				
S	.53	<.005	<.005	.2	1.9	11.1	.3
Loss on ignition				15.9	12.8	13.7	10.7
Total	99	99	100	100.3	99.5	[1] 103.4	99.8

[1] Some S also included with "loss on ignition," accounting for high sum.

1. Unweathered carbonate iron-formation, 1,500-ft level, Mina Grande lode, Raposos mines. Rapid methods.
2. Weathered iron-formation, A Peixe road (Rio Acima, N. 10,360, E. 3,930). Rapid methods.
3. Weathered iron-formation, Santa Rita (Rio Acima, N. 9,610, E. 5,470). Rapid methods.
4. Unweathered carbonate iron-formation, 1,500-ft level, Mina Grande lode, Raposos mines. Partial analysis.
5. Unweathered carbonate iron-formation, about 200 ft below surface, Espirito Santo lode, Raposos mines, partial analysis.
6. Unweathered carbonate iron-formation, 900-ft level, Espirito West lode, Raposos mines, partial analysis.
7. Unweathered carbonate iron-formation, Gaia tunnel, 1340.7 meters from portal, partial analysis.

Unweathered iron-formation in the Raposos mines has long been called "caco," and also "banded silica," "banded silica and iron," or "banded silica and magnetite" by geologists and mining engineers of the St. John del Rey Mining Co. There has been considerable speculation as to the origin of the "caco," centering mainly on the question of whether the "caco" is a bedded sedimentary rock, or a replacement rock resulting from the hydrothermal alteration (with accompanying metasomatism) of an earlier rock. Graton and Bjorge thought that the "caco" might have formed by

FIGURE 4.—Photomicrograph of unweathered carbonate-facies iron-fomation, Nova Lima group, 41 adit level, about 60 meters below surface, Raposos mines (Espirito Santo). Alternating laminae of mosaic-textured sideritic carbonate (c) and quartz (q). Laminae rich in quartz also contain considerable carbonate in isolated grains. Traces of sulfide (s). Quartz veinlet (qv) cuts one layer of carbonate. Crossed nicols.

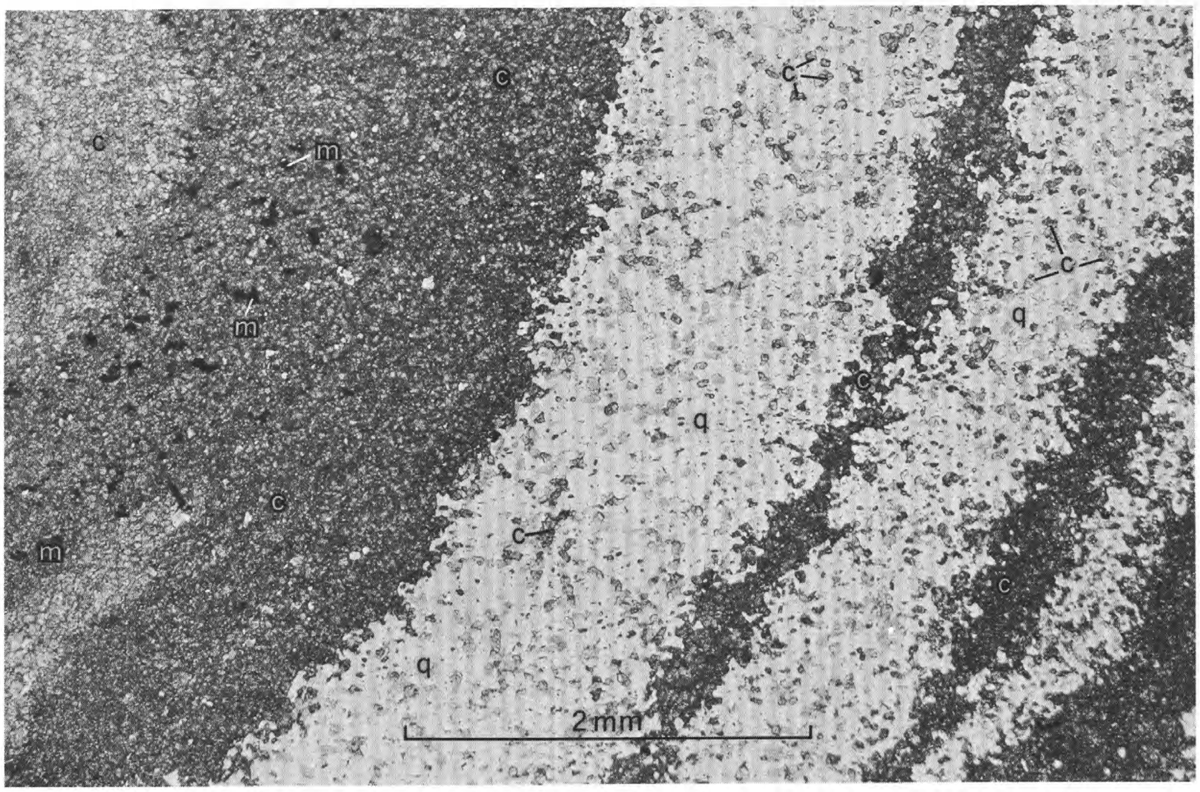

FIGURE 5.—Photomicrograph of unweathered carbonate-facies iron-formation, Nova Lima group. 1,500-foot level, Raposos mines (Mina Grande). Alternating laminae of sideritic carbonate (c) and quartz (q). Quartzose layers have scattered grains of carbonate. Small grains of magnetite (m) in one layer of carbonate. Small fold, left side of picture. Plane polarized light.

the replacement of a sheared diabasic rock by hydrothermal solutions prior to or early in the period of mineralization. Matheson (1956), geologist with the St. John del Rey Mining Co. from 1951 to 1954, considered the "caco" to be bedded sedimentary iron-formation interlayered with schists and phyllites. Surface mapping in the vicinity of the Raposos mines during the present study shows that eastward-plunging folds in the bedded weathered iron-formation are related to eastward-plunging folds in the unweathered iron-formation or "caco" underground. In some of the shallower workings at the west end of the mines, between 50 and 70 meters below the surface, greenish unweathered iron-formation ("caco") can be seen grading into brownish thoroughly weathered iron-formation. Beds mapped on the surface at the Raposos mines have been traced more than 2 kilometers southeastward and 2 kilometers northward. The map pattern made by these beds indicates that they are in general structural conformity with folded beds of iron-formation immediately southwest of Nova Lima. The unweathered iron-formation ("caco") of the Raposos mines is lithologically similar to unweathered iron-formation in the Gaia tunnel, some of which in turn can be projected upward to specific beds of weathered iron-formation that have been mapped for several kilometers on the surface, and which clearly are bedded sedimentary rocks.

There is no petrographic evidence that the unweathered iron-formation in the Raposos mines is a replacement rock. The layers of quartz and iron carbonate are regular and generally persistent. Mosaic textures both in quartz layers and in carbonate layers are notably even grained. The rock is similar to carbonate facies iron-formation of the Lake Superior region of North America.

Small, irregularly shaped whitish or light-colored patches, lenses, and stringers of medium-grained quartz and carbonate lie along or cut across layers of fine-grained quartz and carbonate in many places in the iron-formation (fig. 4). The areas of coarser quartz-carbonate may or may not have associated sulfide. These coarser grained areas within the iron-formation are believed to be a result of hydrothermal activity that followed recrystallization of the rock during regional

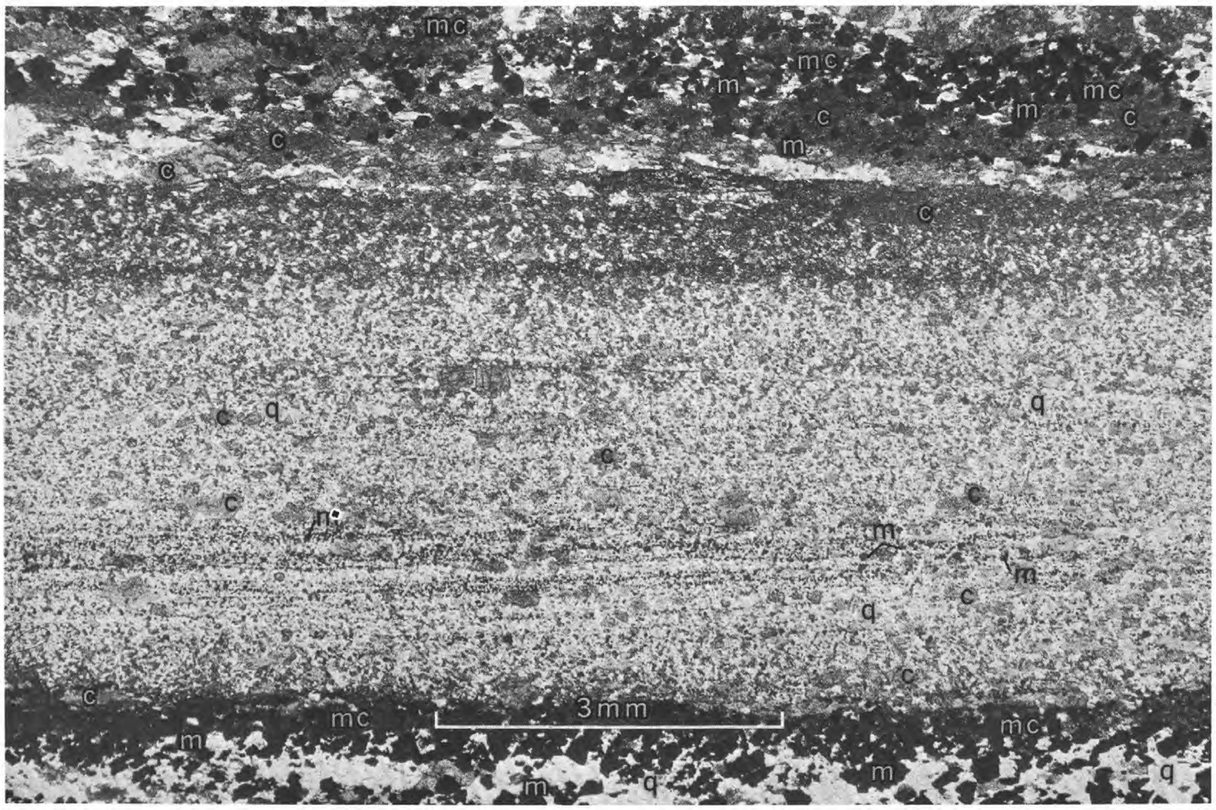

FIGURE 6.—Photomicrograph of unweathered carbonate-magnetite iron-formation, Nova Lima group. Raposos mines. Alternating laminae rich in quartz (q), sideritic carbonate (c), and magnetite-sideritic carbonate (mc). Magnetite (m) confined mainly to layers richer in carbonate. Quartzose layers contain considerable sideritic carbonate in isolated grains. Crossed nicols.

metamorphism. The hydrothermal activity was probably related to the gold mineralization. Carbonate from a light-colored veinlet in one sample of iron-formation has been identified and found to range from calcite to magnesiodolomite (table 3, JG–156B–56). Possibly, hydrothermal solutions brought calcium and magnesium into the rock, thereby making at least some of the replacement carbonates richer in these elements and correspondingly poorer in iron than the carbonate of the original sediment.

On the basis of composition, thin regular alternating layers of quartz and iron-rich carbonate, and even-grained texture, this rock is classified as carbonate-facies iron-formation (James, 1954, p. 251–256). The association of magnetite, finely disseminated graphite(?), and small amounts of iron-rich chlorite with iron-rich carbonate suggests that the rock originated in a restricted or closed marine basin (or basins) as a chemical sediment under conditions ranging from reducing to mildly oxidizing (Huber and Garrels, 1953; James, 1954, p. 272–273).

The fine-, even-grained quartzitic rocks associated with the iron-formation in some parts of the area probably represent local environments with a scarcity of iron where chert was precipitated without intervening precipitations of iron-rich minerals. The lensing out of iron-formation into thin graphitic phyllite, as was noted by Matheson (oral communication to J. B. Pomerene, U.S. Geological Survey) in several places in the Raposos mines, probably represents local environmental changes during deposition under reducing conditions, from environments rich in iron to those lacking iron.

Mafic metavolcanic rocks comprise part of the schists of the Nova Lima group and in the Gaia tunnel are known to be stratigraphically near carbonate-magnetite iron-formation. (See pl. 4.) The association of mafic metavolcanic rock with iron-formation in the Gaia tunnel, as well as the presence of both types of rock in other parts of the Nova Lima group may explain the origin of some of the iron of the iron-formation. Changes from iron-rich to iron-poor environments within a basin of deposition as noted above, might be accounted for by fluctuations in volcanic activity during chemical sedimentation. Contemporaneous volcanism is not necessary nor can it account for most iron-rich environments (Grout, 1919; Gruner, 1922, 1924; James, 1954). However, because of the close association of volcanic rocks and iron-formation in the Nova Lima and Rio Acima quadrangles, volcanic activity may have provided some of the iron for the pre-Minas iron-formation of the area.

GRAYWACKE

DISTRIBUTION AND THICKNESS

Thin lenticular beds of slightly to moderately schistose medium-grained graywacke are interlayered with schists and phyllites of the Nova Lima group and are exposed in the southeastern part of the Rio Acima quadrangle. The graywacke is most conspicuous for 1,200 meters southeastward from Rio Acima, where it has been mapped as a single bed although it may actually be in several beds separated by thin layers of rock less resistant to weathering than the outcropping graywacke. This bed is well exposed in the quarry and in the nearby waterfall at Rio Acima near N. 4,400, E. 9,060 as well as in several outcrops to the southeast. Isolated beds of graywacke, 200 to 800 meters in strike-length, are found within 1,200 to 1,400 meters north and northeast from Rio Acima. Some of these beds may be repeated by undetected local folds or faults. The estimated maximum thickness of individual beds or lenses is 50 meters, although they are generally considerably thinner than this. The estimated maximum total thickness of graywacke in the southeastern part of the Rio Acima quadrangle is 180 meters.

Fine-grained graywacke schist may be widely distributed in the Nova Lima group, but it cannot be mapped readily at the surface. Fresh fine-grained schist with the composition of graywacke is interbedded with other schists and with phyllites in the drill hole located 1.4 kilometers south of Rio Acima. Schist rich in quartz, feldspar, carbonate, and sericite-chlorite has been drilled in the Morro Velho mine at Nova Lima.

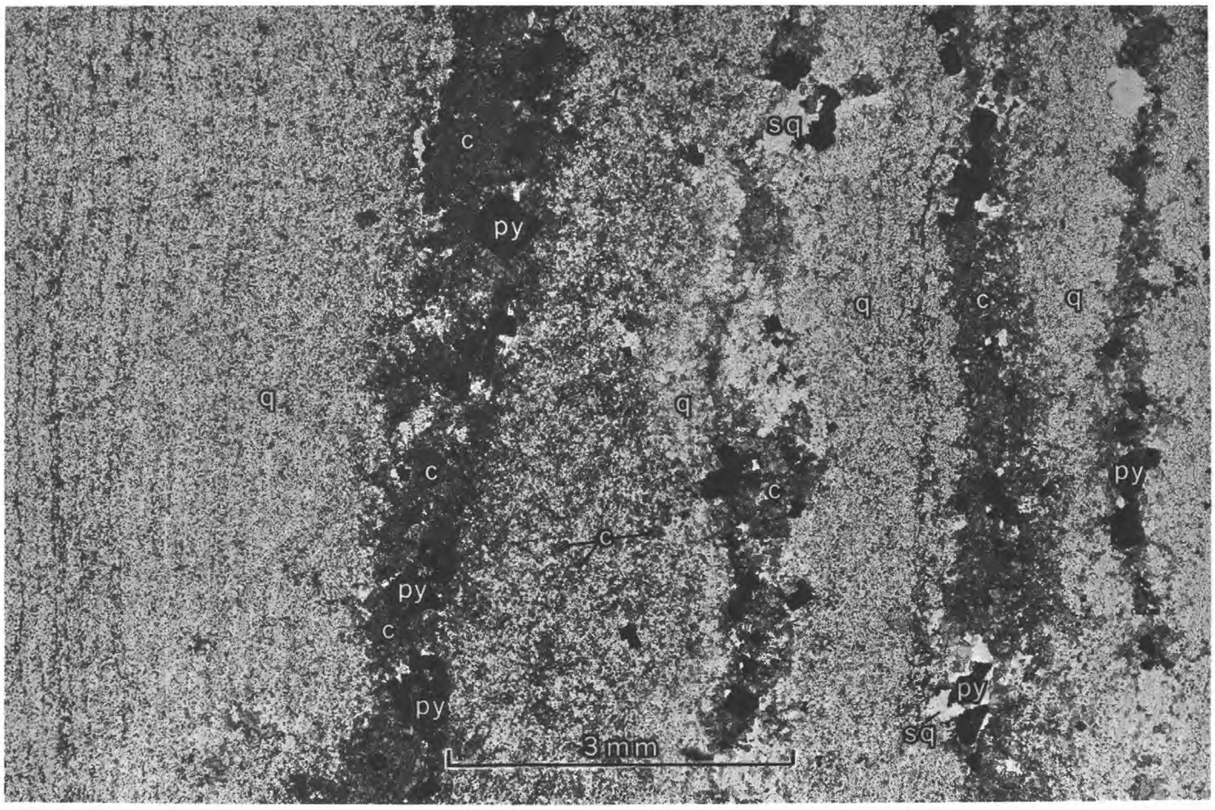

FIGURE 7.—Photomicrograph of unweathered carbonate-facies iron-formation, with sulfide mineralization, Nova Lima group. 41 adit level, about 60 meters below surface, Raposos mines (Espirito Santo). Alternating laminae rich in quartz (q) and sideritic carbonate (c). Pyrite (py) confined almost entirely to layers rich in carbonate. Quartzose layers contain considerable carbonate in isolated grains. Quartz (sq) of larger grain size than in most of rock, and of probable secondary origin, is adjacent to some pyrite crystals. This quartz was probably introduced during mineralization. Plane polarized light.

PETROGRAPHY

Petrographic data for graywackes of the Nova Lima group are listed in the following table. Fresh rock exposed in the quarry at Rio Acima is gray green to dark green. Weathered graywacke in natural exposures is gray green, brownish green or yellow brown.

Petrographic data for graywackes of the Nova Lima group

[Analyses made from examination of 18 thin sections. Some minerals fall into more than 1 of 3 percentage columns. Mineral names preceded by an asterisk (*) indicate that the named mineral is in the given percentage range in only a few thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz Sodic plagioclase *Carbonate	Sericite Chlorite Carbonate *Fuchsite *Amphibole *Epidote *Fragments of volcanic rock? Yellow-brown iron oxide	Epidoteclinozoisite Carbonate Leucoxene *Chlorite *Sericite *Amphibole *Yellow-brown iron oxide *Sulfide *Zircon *Rutile *Fragments of quartzite?

NOTE.—Grain sizes in matrix less than 0.1 mm; larger detrital quartz and feldspar 0.1–2 mm. Some of these rocks cannot be distinguished with certainty from crystal tuffs. Matrix of granular mosaic-textured quartz, some of which is cherty, with scattered epidote-clinozoisite and rather evenly distributed sericite and chlorite. Larger detrital fragments of quartz and sodic plagioclase studded through matrix. Rock grades to subgraywacke in at least one place. Rock poorly to moderately foliated, generally with strong alinement of platy minerals and slight or no alinement of matrix quartz. Larger crystals generally more or less equant. Alined sericite and chlorite in places bend around larger clastic quartz and feldspar to produce augen structure. Sericite and chlorite both scattered through matrix and aggregated in thin shear seams parallel to foliation. Plagioclase generally studded with flakes of sericite. Carbonate commonly has slight elongation and alinement parallel to foliation. Yellow-brown iron oxide result of weathering of chlorite and (or) carbonate. Leucoxene in small granules and aggregates of granules. Fragments of volcanic rock (tuff?) in one sample have fine-grained groundmass that encloses feldspar fragments.

The classification of graywacke used here closely follows that given by Pettijohn (1949, p. 227, 243–255). The important features are abundant detrital quartz and feldspar set in a "clay paste" matrix represented in the metamorphosed rock by fine-grained chlorite, sericite, and cherty quartz. Rock fragments are common in graywackes, but are rare in the graywackes from the vicinity of Rio Acima. By reduction in the amount of feldspar and a corresponding reduction in average grain size, the graywacke grades into subgraywacke schist. A classification of subgraywacke is made here if the rock has less than 15 percent feldspar, whereas Pettijohn (1949) placed the division at 10 percent feldspar.

Some of these rocks are not distinguishable with certainty from crystal tuffs mainly because the larger fragmental quartz and feldspar grains are not clearly either of detrital or volcanic origin. Fibrous amphibole in the matrix of some of these rocks is of metamorphic origin, and quite possibly was derived from admixtures of volcanic material in the original sediment.

QUARTZ-DOLOMITE AND QUARTZ-ANKERITE ROCK (LAPA SÊCA)

Lenticular discontinuous beds of a gray massive quartz-carbonate rock that resemble dolomite lie at one or more horizons within the Nova Lima group. The rock is best known in the Morro Velho mine at Nova Lima, where it forms the host rock for sulfides and gold and where it has long been called lapa sêca, or "dry stone," to distinguish it from the gold ore. The lapa sêca is associated with schist of somewhat similar composition and probably grades into this schist both across and along the strike of bedding. In places, small amounts of quartzitic rock are also associated with lapa sêca.

In the mineralized zone in the Morro Velho mine, lenses and stringers of white vein quartz or of quartz-carbonate of coarser grain and lighter color than the lapa sêca, lie parallel to the bedding of the lapa sêca. Tabular and wedge-shaped veinlets and irregularly shaped bodies of similar vein quartz or quartz-carbonate also commonly cut across the bedding of the lapa sêca.

DISTRIBUTION AND THICKNESS

The quartz-carbonate rock (lapa sêca) that forms the host rock for the gold in the Morro Velho mine can be extended about 2 kilometers northwest of the mine on the basis of rubble at N. 3,400, E. 1,760, and an outcrop at N. 3,980, E. 1,000. Within the mine there is one main bed of lapa sêca, but in places at least one other thinner bed of quartz-carbonate rock appears to be in stratigraphic sequence with the main bed. It may be merely a part of the main bed repeated by folding or faulting. Lapa sêca extends southeastward from the Morro Velho mine toward the Bicalho mine. Outcrops are few and widely separated. Southeast of the mine in the Nova Lima quadrangle, lapa sêca has been reported on maps of the St. John del Rey Mining Co. in a large exploration pit in the Nova Lima quadrangle at N. 2,580, E. 3,220. Lapa sêca also crops out in the vicinity of N. 1,460, E. 4,440 and has been found with gray carbonate-rich schist on the dump of the abandoned Bella Fama mine at N. 240, E. 4,160. Massive quartz-carbonate schist here correlated with lapa sêca, is exposed near the north edge of the Rio Acima quadrangle at N. 13,680, E. 5,380. Although the rock may extend continuously betwen the Morro Velho and Bicalho mines, it cannot be mapped as a continuous unit without relying unduly on the interpretation of aerial photographs of the areas between outcrops. It seems likely, however, that the lapa sêca between the two mines is located at virtually one horizon.

The dump of the Bicalho mine at Honorio Bicalho contains abundant rubble of lapa sêca and gray carbonate-rich schist. The schist is similar to that associated with lapa sêca in the Morro Velho mine. Massive quartz-carbonate rock, in places somewhat schistose, extends southward 4 kilometers from Honorio Bicalho along the steep-sided ridge on the east side of the Rio das Velhas. Good exposures of the quartz-carbonate rock are found along the ridge south of Honorio Bicalho at N. 10,040, E. 5,880, N. 9,640, E. 6,080, and in a quarry at N. 9,320, E. 6,160. Along this stretch, the formation is the host rock for gold deposits at the abandoned Urubu mine near N. 9,340, E. 6,280. The massive quartz-carbonate rock cannot be traced farther to the south or southeast. However, carbonate-bearing schists similar to those associated with lapa sêca in the Morro Velho, Bella Fama, and Bicalho mines, are exposed in the Rio Acima quadrangle near N. 6,480, E. 9,560 and N. 4,980, E. 10,660. A distinct topographic break that in places forms a conspicuous escarpment extends between N. 8,440, E. 6,920 and N. 6,480 and E. 9,560 and may represent a continuation of the carbonate-bearing schist or a fault that has displaced the schist between these two places. Weathered schist, probably derived from carbonate-rich schist similar to that associated with lapa sêca, is exposed along the Rio Acima-Gandarela road at N. 3,320, E. 11,260. The horizon along which the lapa sêca occurs farther north appears to pass beneath unconformably overlying quartzite and schist of the Maquiné group near this place.

The estimated maximum thickness of the quartz-dolomite-ankerite rock is 190 meters, along the east side of the Rio das Velhas, 2 kilometers south of Honorio Bicalho. In most places, however, the thickness is probably much less than this.

PETROGRAPHY AND ORIGIN

Petrographic data for the quartz-dolomite and quartz-ankerite rocks (lapa sêca) and closely associated rocks of the Nova Lima group are listed in the following two tables:

Petrographic data for quartz-carbonate rocks (lapa sêca) of the Nova Lima group

[Data obtained from examination of 35 thin sections. Some minerals fall into more than 1 of the 3 percentage ranges. Mineral names preceded by an asterisk (*) indicate that the mineral is in the given percentage range in only a few thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Carbonate—mainly dolomite or ankerite Quartz *Sodic plagioclase	*Quartz *Sericite *Chlorite *Sodic plagioclase *Sulfide	Sodic plagioclase Leucoxene Sulfide *Quartz *Chlorite *Sericite *Epidote *Magnetite *Rutile *Graphite?

NOTE.—Grain sizes from less than 0.1 to 2 mm. Intergrown carbonate and quartz, commonly with mosaic texture. Parts of rock fine, even grained; parts uneven grained. In many samples small irregular patches of mosaic-textured quartz irregularly distributed through the mosaic-textured carbonate. Layering generally poorly defined or not evident in thin sections. Faint layering in some samples caused by lenses or streaky layers of fine-grained cherty quartz enclosed in areas of larger fine-grained quartz or quartz-carbonate. Rock generally nonfoliated or crossed by relatively few widely spaced discontinuous shear seams. Quartz and carbonate generally not elongated. Isolated larger crystals (0.3–2.0 mm) and clusters of larger crystals of carbonate are common throughout areas of finer-grained carbonate. In places clusters of larger carbonate grains elongated parallel to bedding; in other places clusters have grown across bedding. Some coarser carbonate distributed along cracks or shears crossing bedding. In places medium-size rhombs of carbonate grow across matrix quartz. Locally, lenses or veinlets of medium-grained quartz follow or cut across bedding. Coarser carbonate and quartz probably a result of hydrothermal activity. Plagioclase in isolated crystals (up to 0.3 mm) intergrown with carbonate-quartz matrix grains, or in considerably larger (0.4–1.0 mm) blocky and lath-shaped crystals commonly associated in irregular-shaped patches or in veinlets with medium-grained quartz or carbonate. Abundant fine- medium-grained plagioclase in one sample is in clear simply twinned lath-like grains, commonly intergrown with carbonate, and is probably hydrothermal. Some definitely fragmental plagioclase found (multiple albite twinning at large angle to long axis of elongate angular grains). Most of coarser plagioclase probably of hydrothermal origin. Dusty opaque matter, possibly graphite, in much of the carbonate. Sericite and chlorite generally along shear seams or very thinly scattered through carbonate-quartz. Two thin sections have amber-colored chlorite in thin tabular patches parallel with bedding or in irregular and angular patches. Latter in one thin section probably replacements, either of quartz-carbonate, or of earlier ferromagnesian mineral. Sulfide (pyrite and pyrrhotite identified in oblique reflected light) in isolated crystals and irregularly shaped patchy aggregates. Much of aggregated sulfide associated with patches or veinlets of medium-grained carbonate-quartz. In one sample, sulfide is along a box work pattern of thin cracks in mosaic-textured carbonate.

Petrographic data for schists and quartzitic rocks associated with lapa sêca of the Nova Lima group

[Data obtained from the examination of 16 thin sections. Mineral names preceded by an asterisk (*) indicate that the mineral is in the given percentage range in only a few thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz Sericite—some probably is fuchsite *Carbonate *Sodic plagioclase *Biotite *Chlorite	Carbonate Chlorite *Sericite *Graphite?	Yellow-brown iron oxide Dusty opaque material, possibly graphite Leucoxene Pyrite *Sericite *Chlorite *Feldspar *Rutile *Quartz *Carbonate

NOTE.—Grain sizes mainly less than 0.1 mm. Carbonate grains from less than 0.1 to 2 mm. Rocks moderately to strongly schistose. Commonly lenses of quartz and carbonate with mosaic texture alternate with seams, folia, and lenses of fine-grained sericite-chlorite or quartz-sericite-chlorite. In quartzitic rocks larger fine-grained detrital quartz set in matrix of smaller quartz-sericite, or quartz-sericite-chlorite. Platy minerals of matrix generally well alined. These rocks generally have subordinate medium-grained carbonate that is somewhat elongated and alined parallel to alinement of platy matrix minerals. Minor amounts of feldspar in schists commonly are in clear simple twins, and may be hydrothermal . In one sample where foliation cuts rock at an angle of 35° to alternating layers rich in sericite or quartz, or rich in quartz-carbonate, carbonate crystals in carbonate-rich layers are elongated parallel to foliation. Shear seams in places coated by graphite(?). Dusty graphite(?) spread through some micaceous layers. One sample of schist with dominant sericite and minor quartz has sharply defined blebs of chlorite, possibly amygdules. This rock may be metavolcanic. One sample is megascopically similar to lapa sêca and comes from the belt of lapa sêca and associated rocks extending southward from Honorio Bicalho, but has relatively abundant plagioclase (20 percent) and less carbonate (16 percent). This rock is properly classified as a feldspathic micaceous quartzite. In places in schists, secondary quartz-carbonate wedges in a long foliation and is locally crosscutting.

The quartz-carbonate rock and associated schists commonly are a rather even battleship gray. However, A. F. Matheson (written communication to St. John del Rey Mining Co., 1954) has recognized the following six varieties of lapa sêca in the Morro Velho mine, mainly from drill core obtained in the mine: Light-colored hard massive, very siliceous rock; white fragmental type—rock similar to light-colored siliceous rock above with lighter colored siliceous fragments; black fragmental type—dark gray with darker lenticular and alined fragments; gray rock with both light-colored and dark fragments; finely banded fairly soft gray rock; and dark-gray finely banded siliceous rock.

The lapa sêca, as seen in thin section, typically is a mosaic-textured intergrowth of quartz and carbonate with minor plagioclase, chlorite, and graphite, and in some samples, with traces of epidote (fig. 8). In places, shearing has largely destroyed the integrity of bedding (fig. 9). As seen in figure 9, graphite is commonly disposed along shears or along bedding.

Bedding, where distinguishable in mine openings and in hand specimens, typically consists of thin layers of even thickness, or streaky layers of a darker gray than the bulk of the rock, or of light-colored quartzose streaks or seams. The dark gray of some thin layers is probably caused by finely dispersed graphite or magnetite, or by varying proportions in the mixture, quartz-carbonate (fig. 10). Bedding is emphasized and most easily seen where lenses and seams of relatively large grained secondary quartz and carbonate (in places with sodic plagioclase) are alined parallel to bedding.

Owing to several factors, the origin of the lapa sêca has not been well understood in the past by geologists who have studied the rock in the Morro Velho mine. When L. C. Graton and G. N. Bjorge studied the mine in 1928, ore bodies and enclosing lapa sêca south of the main lode had not been discovered and the lapa sêca was known only as a narrow east-trending ribbonlike body, standing edgewise and extending diagonally downward from the surface. Results of this and a later study are in two private reports submitted to the St. John del Rey Mining Co. in 1929 and 1931. (See also Lindgren, 1933, p. 676, section written by L. C. Graton.) This ribbonlike body of lapa sêca with its enclosed ore appeared to trend across bedding (actually schistosity) of the schists of the Nova Lima group and therefore was thought to be a replacement of some type of dike rock, possibly diabase. Graton and Bjorge attributed the east-trending color banding that represents bedding in the lapa sêca of the main lode to replacement along east-trending shear surfaces of the original dike rock.

The metamorphic recrystallized texture of the lapa

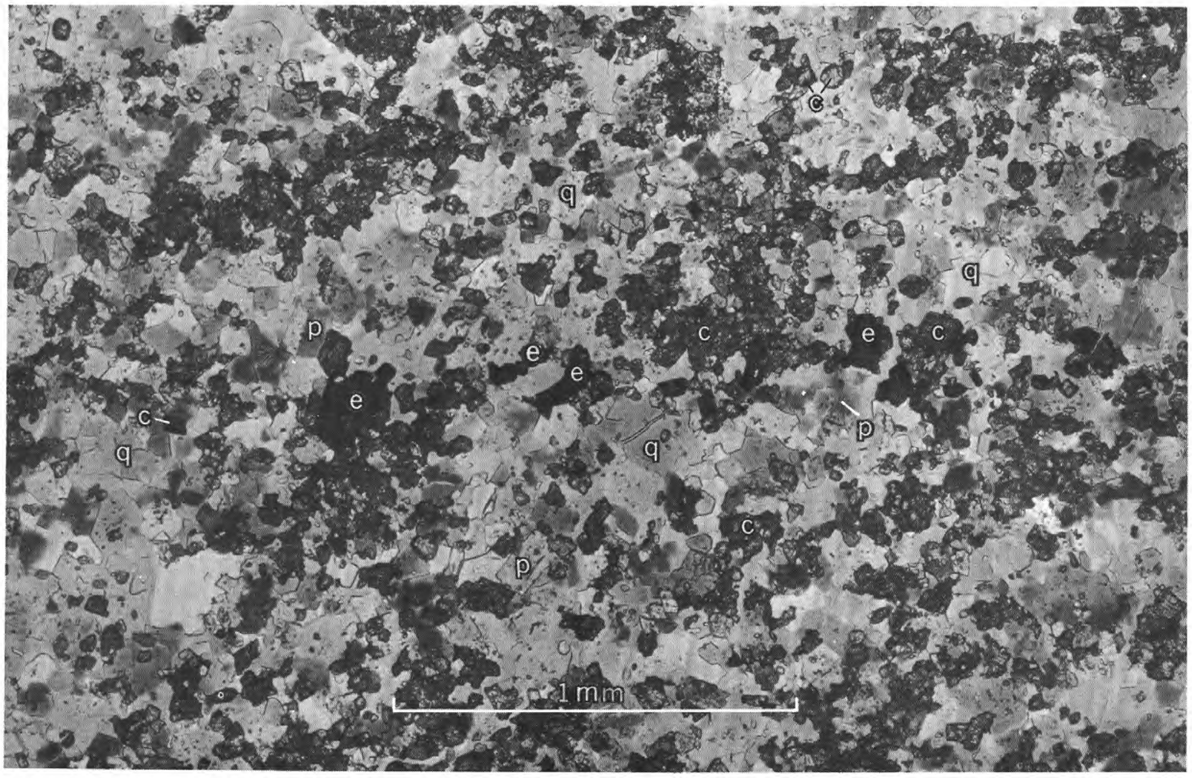

FIGURE 8.—Photomicrograph of quartz-carbonate rock (gray thin-layered lapa sêca), Nova Lima group. Eight level, Morro Velho mine. Mosaic-textured quartz (q) and carbonate (c). Rock has small scattered laths of plagioclase (p) and some epidote (e). Nicols partly crossed.

sêca does not provide strong direct evidence of either a sedimentary or a replacement origin, although in its composition and texture, the rock is much more analogous to metamorphosed feldspar-bearing quartzose limestone or dolomite than to altered, replaced mafic dike rock. The fragmental brecciallike structures in the lapa sêca noted by Matheson, the sparse fragmental feldspar, the lenses of cherty quartz, and the association of graphite(?) with carbonate, constitute petrographic evidence that the lapa sêca originated as a sediment.

Lenses, stringers, veinlets, and irregular shaped areas of quartz, carbonate, and in places, plagioclase that are coarser grained than the bulk of the lapa sêca are probably replacement features, and evidently were used by Graton and Bjorge as evidence of the influence of hydrothermal solutions in forming lapa sêca. However, these features are clearly of later origin than the bulk of the rock, although they may contain only material that was derived from the lapa sêca, mobilized (during mineralization?), and recrystallized within the source rock. These secondary features in themselves are not satisfactory evidence with which to deduce a replacement origin for the lapa sêca.

The discovery (1930 and later) of ore bodies south of the main lode in the Morro Velho mine, the extension of this ore into the main lode, and the configuration of the ore bodies south of the main lode (see section on the geologic setting of the Morro Velho mine, p. A55–A56). strongly suggest that the lapa sêca is a folded bed. This conclusion is strengthened by the continuation of the lapa sêca well to the south of Nova Lima. Furthermore, the map pattern indicates that lapa sêca was folded conformably with beds of iron-formation lying southwest and northeast of Nova Lima, and therefore is part of a sequence of bedded (sedimentary) rocks.

SERICITIC QUARTZITE AND SCHISTOSE CONGLOMERATE

Sericitic quartzite and schistose conglomerate form discontinuous, poorly defined beds and wedgelike masses in the Nova Lima group. In one place in the south-central part of the Nova Lima quadrangle, a lens of

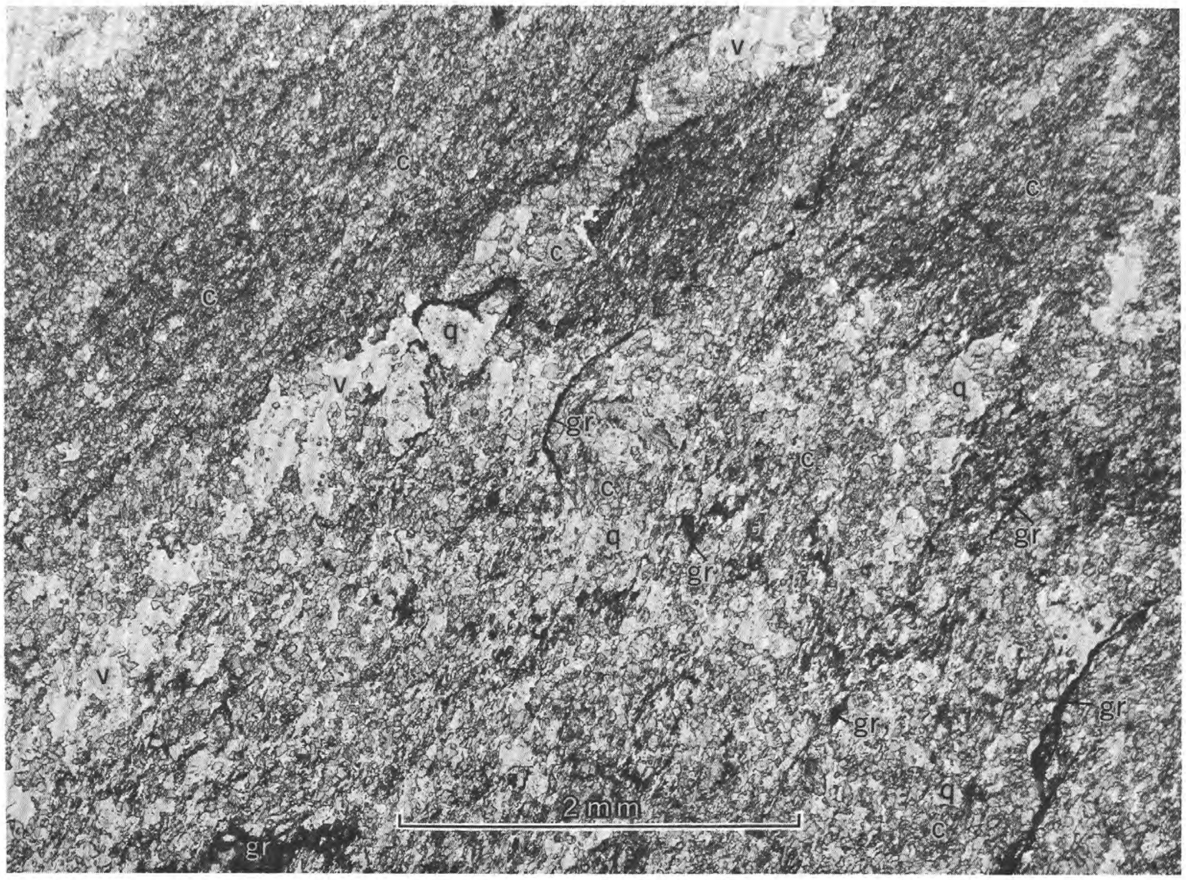

FIGURE 9.—Photomicrograph of quartz-carbonate rock (lapa sêca), Nova Lima group. Near bottom of Rampa 13–3 (between 13 and 14 levels), Morro Velho mine. Rock rather strongly foliated (sheared) from lower left to upper right part of photomicrograph. Faintly discernible sheared bedding crosses photomicrograph from right to left, bending toward parallelism with foliation on left side. Even-grained mosaic-textured quartz (q) and carbonate (c). Some shear surfaces, and bedding surfaces that have been sheared into zigzag pattern (resemble stylolites), are coated with graphite (gr). One veinlet (v) of larger grained quartz and carbonate parallels foliation. Plane-polarized light.

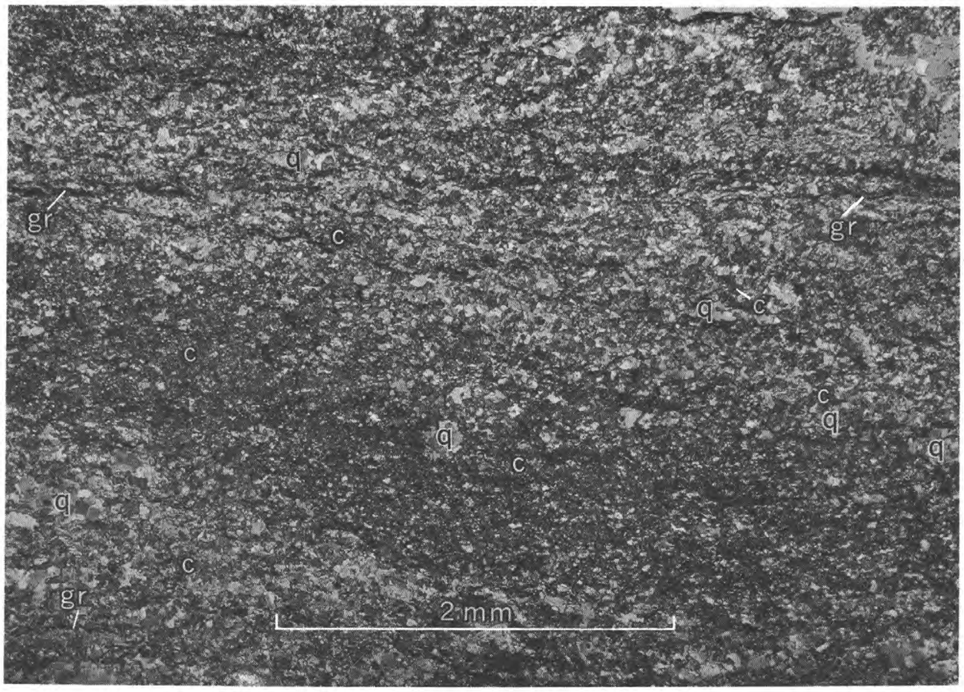

FIGURE 10.—Photomicrograph of quartz-carbonate rock (lapa sêca), Nova Lima group. Twelve level, Morro Velho mine. Vague layering—darker and lighter bands—from left to right across photomicrograph. Darker layers richer in carbonate (c). Lighter layers contain about 35 percent quartz (q) intergrown with carbonate. Probable graphite (gr) in small shear seams. Nicols partly crossed.

conglomerate is at about the same horizon as a lens of sericitic quartzite, and appears in the section near the place where the sericitic quartzite lenses out. The two types of rock otherwise appear to be at different horizons in the same general part of the stratigraphic section.

These rocks are not notably different from quartz-rich schists of the Nova Lima group and they probably grade into such schists. Exposures in the vicinity of contacts are few, and the locations of contacts with the enclosing schist are uncertain. The locations of such contacts on the map are based largely on photointerpretation.

DISTRIBUTION AND THICKNESS

Sericitic quartzite is located mainly in the south-central part of the Nova Lima quadrangle and near the southeast corner of the Rio Acima quadrangle. Schistose conglomerate occurs in several beds in the south-central part of the Nova Lima quadrangle, and in one bed in the west-central part of the Nova Lima quadrangle, extending northward about 500 meters from N. 5,220, E. 3,420.

The thickest bed of sericitic quartzite in the south-central part of the Nova Lima quadrangle has an estimated maximum thickness of about 200 meters, and that near the southeast corner of the Rio Acima quadrangle, about 285 meters. Other layers of this sericitic quartzite are probably not more than 75 meters thick. Beds of schistose conglomerate are probably not more than 10 or 15 meters thick.

PETROGRAPHY

The freshest sericitic quartzite seen is light greenish gray, but where it is more than slightly weathered it is generally light buff. The rock commonly has medium-grained detrital quartz set in a matrix of fine-grained quartz and sericite. Parts of the quartz matrix have the appearance of recrystallized chert. Sericite is generally in subordinate amounts, is well alined, and occurs both dispersed through the matrix and concentrated along shear seams. Fine-grained chloritoid, somewhat altered to yellow-brown limonitic material, is common in one bed of quartzite in the Nova Lima quadrangle, located at N. 400, E. 8,860 and at N. 4,700, E. 9,440. The chloritoid is in small blades and clumps of blades along shear seams and also is generally distributed throughout the matrix. Some blades of chloritoid appear to grow into quartz grains, but it is not clear whether the chloritoid actually has grown into the quartz, or whether the quartz grew partly around the chloritoid during regional metamorphism. The origin and possible significance of the chloritoid is therefore not understood.

The rock is generally moderately foliated and in places has small-scale augen structure where foliation surfaces pass around detrital quartz grains.

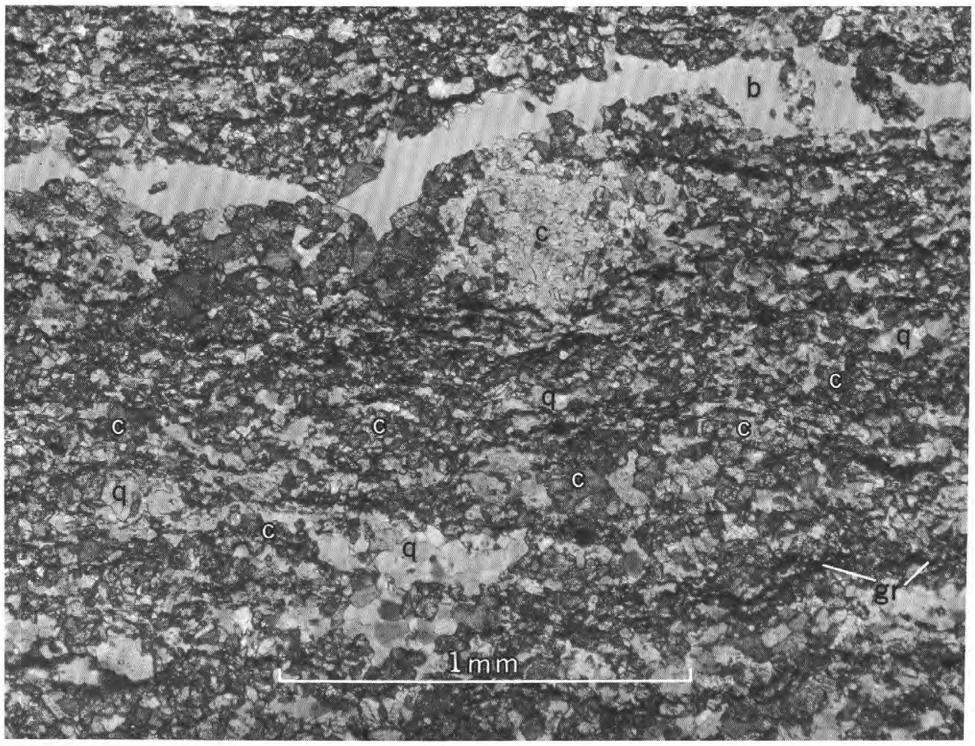

FIGURE 11.—Enlarged part of thin section shown in figure 10. Balsam (b) in crack across upper part of thin section. Nicols partly crossed.

Fresh schistose conglomerate has not been observed in the Nova Lima group although Matheson reports thin layers in the Morro Velho mine (written communication to St. John del Rey Mining Co., 1954). The weathered conglomerate is light buff. Its matrix is quartz-sericite schist, and probably comprises 75 to 85 percent of the rock. The pebbles include grayish and greenish schist, vein quartz, and cherty quartzite, and commonly are flattened and less than 1 cm in size; however, B. E. Ashley reports (written communication, 1954) that in some places flattened pebbles are as much as 9 cm long.

AGE RELATIONS OF ROCKS OF THE NOVA LIMA GROUP

The Nova Lima group contains the oldest rocks in the area of the present report and the oldest known schistose rocks of the Quadrilátero Ferrífero. Rocks older than the Nova Lima group are absent in the area under study, and the base of the group is therefore unknown.

The Maquiné group unconformably overlies the Nova Lima group in the southeastern part of the Nova Lima quadrangle and in the eastern part of the Rio Acima quadrangle. The Minas series unconformably overlies the Nova Lima group in the northwestern part of the Nova Lima quadrangle. Evidence that the Maquiné group and the Minas series are younger than the Nova Lima group is given in the sections on the age relations of these younger rocks (p. A33–A34).

Although the Nova Lima group is unconformably beneath the Maquiné group, the angle of unconformity is small except near the nose of the large fold in the southeastern part of the Nova Lima quadrangle, where beds of sericitic quartzite and iron-formation diverge from the Nova Lima-Maquiné contact. The trends of sericitic quartzite and iron-formation in the southeastern and south-central parts of the Nova-Lima quadrangle, and the attitudes of bedding in schist along the road east of Raposos indicate that, notwithstanding limited divergences from the trend of the Maquiné, these rocks are a part of the large fold that involves the Maquiné to the south and southeast. Evidence presented below indicates that the Maquiné stratigraphically overlies the Nova Lima and, therefore, that the large fold is a syncline. In passing westward along the boundary between the Nova Lima and Rio Acima quadrangles, one descends in the stratigraphic section. Near the southwest corner of the Nova Lima quadrangle a northeastward-trending anticlinal axis is crossed, and to the northwest one ascends in the section.

Within the Nova Lima group the apparent sequence of rocks from older to younger age, aside from schist and phyllite in which all the other rocks occur as lenticular beds, is iron-formation, graywacke, quartz-dolomite and quartz-ankerite rock (lapa sêca), schistose conglomerate, sericitic quartzite, iron-formation, and sericitic quartzite.

THE MAQUINÉ GROUP

The Maquiné group (J. E. O'Rourke, written communication, 1956) contains the youngest known rocks of pre-Minas age in the Quadrilátero Ferrífero (Dorr and others, 1957). During the present study, the Maquiné group has been found to occupy the core of a north-northwestward-trending syncline, named the Vargem do Lima syncline in this report. The Vargem do Lima syncline is discussed in more detail in the section on Structure, p. A49–A50.

O'Rourke recognized the Maquiné as unconformably overlying the schists and phyllites of the present Nova Lima group. From west to east across the western parts of the Gandarela and Rio de Pedras quadrangles, the Maquiné mapped by O'Rourke consists of: a unit of schist with some quartzite and beds of intraformational conglomerate; a unit of quartzite and conglomerate with some interbedded schist; and a unit of schist with some quartzite and intraformational conglomerate. East of the Maquiné rocks, between the Maquiné and the Minas series, O'Rourke mapped a unit of gray slate with interbedded conglomerate and iron-formation. Evidence in O'Rourke's area was inconclusive as to whether the sequence in the Maquiné, and the gray slate east of the Maquiné are continuously younger from west to east, or whether there is repetition of the sequence within the Maquiné by folding.

During the present study, strong evidence was found that the belt of Maquiné rocks appears to terminate by structural closure at the north end of the Vargem do Lima syncline in the southeastern part of the Nova Lima quadrangle. The southeastern part of Nova Lima quadrangle is immediately northwest of the area mapped by O'Rourke. (See fig. 1.)

According to the interpretation of a synclinal fold, the Maquiné and adjoining parts of the Nova Lima group are repeated between the Rio das Velhas in the Rio Acima quadrangle and the base of the Minas series in the Gandarela quadrangle. The formation of quartzite and conglomerate with some schist, described by O'Rourke, extends north-northwestward from the Gandarela quadrangle into the Rio Acima quadrangle and occupies the core of the Vargem do Lima syncline. This unit is folded back on itself. The lowermost formation of the type Maquiné—schist with some quartzite and intraformational conglomerate—is lithologically similar and stratigraphically equivalent to the formation lying immediately east of the quartzite and conglomerate that occupies the core of the syncline.

The lower unit of the Maquiné has been named the Palmital formation by O'Rourke (written communication, 1956). The upper unit is named the Casa Forte formation in the present report. The gray slate with its interbedded iron-formation and conglomerate that occurs east of the Maquiné in O'Rourke's area is stratigraphically equivalent to rocks of the Nova Lima group. The Maquiné group therefore consists of two formations, the Palmital formation of schist with some quartzite and intraformational conglomerate, overlain by the Casa Forte formation of quartzite and conglomerate with some schist.

The Maquiné of the Rio Acima and Nova Lima quadrangles differs from the type Maquiné of O'Rourke in not having intraformational conglomerate in the Palmital formation. The contact between the Palmital and the Casa Forte formations in the Rio Acima quadrangle is placed at the base of the lowermost intraformational conglomerate, thereby excluding conglomerate from the Palmital by definition. A thin discontinuous cobble-bearing bed of phyllite near the base of the Palmital generally has less than 10 percent of cobbles and therefore cannot be strictly defined as conglomerate. Furthermore, it is distinctly different from the conglomerate of the Casa Forte formation, which contains abundant closely packed pebbles and fragments.

Assuming a synclinal structure, the conglomerate at the base of the Casa Forte formation crosses the eastern boundary of the Rio Acima quadrangle at 2,690 meters and at 7,475 meters north of the southeast corner and projects into, or very close to, the contacts mapped by O'Rourke. The conglomerates are mapped separately on plate 1 of the present report, but they are mapped as members of the Casa Forte formation rather than as separate formations. Intraformational conglomerates mapped by O'Rourke in the lower part of the Palmital formation evidently are not developed in the Rio Acima or Nova Lima quadrangles.

PALMITAL FORMATION

DISTRIBUTION AND THICKNESS

The Palmital enters the southeastern part of the Rio Acima quadrangle between 1,600 and 2,600 meters north of the southeast corner of the quadrangle and trends north-northwestward almost to the north border of the quadrangle. In the northeastern part of the Rio Acima and the southeastern part of the Nova Lima quadrangles the formation bends eastward around the nose of the Vargem do Lima syncline.

The contact between the Palmital formation and schist and phyllite of the Nova Lima group is clearly defined in the southeastern and esat-central parts of the Rio Acima quadrangle by paired beds of basal sericitic quartzite and immediately adjacent cobble-bearing phyllite. The combination of light-colored sericitic quartzite and cobble-bearing phyllite has been found in the vicinity of the following places in the Rio Acima quadrangle, with the cobble-bearing phyllite stratigraphically above the quartzite: N. 2,160, E. 12,190; N. 2,300, E. 12,150; N. 3,430, E. 11,330; N. 6,240, E. 10,890; and N. 7,240, E. 10,350. Between several exposures of sericitic quartzite and adjacent cobble-bearing phyllite, the contact has been located by light-colored quartzitic rock that occurs without adjacent cobble-bearing phyllite. This quartzitic rock occurs in the vicinity of: N. 3,670, E. 10,890; N. 4,840, E. 10,950; and N. 6,840, E. 10,330.

An isolated mass of such light-colored quartzitic rock, centering at about N. 7,140, E. 10,010, lies well west of the projected contact between the Maquiné and Nova Lima groups and is here interpreted as a west-faulted part of the basal quartzitic rock of the Palmital formation.

North-northwestward from the vicinity of this inferred fault, the contact between the Maquiné and Nova Lima groups has been mapped along a line of rather sudden change from fine-grained schist and phyllite on the west to fine- and medium-grained schistose sericitic quartzite on the east. This lithologic change is represented by a topographic break along the crests of most of the west-trending ridges in this part of the area. The contact has been projected between ridge crests by interpretation of aerial photographs.

The contact is extended from near the north edge of the Rio Acima quadrangle northward into the Nova Lima quadrangle and then eastward almost entirely by photointerpretation. The general trend of the contact in the southeastern part of the Nova Lima quadrangle is suggested by strike readings of bedding in the Maquiné and Nova Lima groups, and by the lithologic change from quartz-rich rocks to quartz-poor, micaceous, in part chloritic rocks approximately along the line of contact. The pattern made by beds of conglomerate in the Casa Forte formation also has served as a general guide in locating the eastward-trending part of the contact of the Maquiné group and the Nova Lima group.

Lenticular beds of quartzitic rock are widely distributed through the Palmital formation. Typically they crop out as riblike ridges. The most conspicuous occurrences of massive or schistose quartzitic beds in the Palmital formation, other than those adjacent to the contact with the Nova Lima group, occur in the Rio Acima quadrangle, between

N. 2,480, E. 12,770 and N. 3,160, E. 12,550; N. 4,200, E. 11,310 and N. 4,800, E. 11,290; N. 4,540, E. 11,590 and N. 4,920, E. 11,510; N. 6,740, E. 10,850 and N. 7,140, E. 10,750; N. 6,840, E. 10,950 and N. 7,020, E. 10,920; N. 8,440, E. 10,670 and N. 9,340, E. 10,450; N. 9,380, E. 10,530 and N. 9,500, E. 10,650; N. 9,580, E. 10,230 and N. 9,660, E. 10,430; N. 8,400, E. 10,270 and N. 9,560, E. 10,050; N. 11,540, E. 9,170 and N. 12,050, E. 8,890; N. 13,290, E. 9,450 and N. 13,390, E. 9,790.

Quartzitic rocks of the Palmital formation also occur abundantly in the northeastern part of the Rio Acima quadrangle, within 1,900 meters south and 2,200 meters west of the northeast corner of the quadrangle, and in the Nova Lima quadrangle, within 1,200 meters north and 3,900 meters west of the southeast corner. One lenticular "quartzite" bed has proved to be graywacke and close sampling with accompanying microscopic study might indicate considerably more graywacke in the formation than is now known. The quartzitic beds range in thickness from a few meters to about 75 meters, but most are probably between 10 and 30 meters thick. Most beds of quartzitic rock are probably between a few tens of meters and 1.5 kilometers in strike length. The light-colored quartzite rock at the base of the formation in the southeastern and east-central parts of the Rio Acima quadrangle ranges from about 5 to 20 meters in thickness. The cobble-bearing phyllite adjacent to this quartzite is probably not more than 10 meters thick.

The thickness of the Palmital formation is estimated to range from 600 to 1,400 meters.

PETROGRAPHY

Petrographic data for the Palmital formation of the Maquinê group are given in the following table. Schist and phyllite comprise perhaps two-thirds of the formation. Phyllites are rich in sericite (or fuchsite?). In some places the phyllite has thin graphitic layers. The fresher phyllites are gray or greenish. The more weathered phyllites typically are buff or tan; they may also be pinkish or nearly white. Schists of the Palmital are largely or entirely of quartz-sericite (or fuchsite). The freshest schists are medium to light gray, and the more weathered are buff, yellow brown, reddish brown, or very light gray.

Petrographic data for the Palmital formation, Maquiné group

[Some minerals fall into more than 1 of the 3 percentage columns. Minerals preceded by an asterisk (*) are in the given percentage range in only a few thin sections]

Schist and phyllite

[Data based on 5 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Sericite (or fuchsite?). Quartz *Dusty opaque material (aggregated into small spots throughout one thin section).	*Quartz	Leucoxene Rutile *Yellow-brown iron oxide.

NOTE.—Schists generally strongly foliated mixture of fine-grained sericite and quartz (0.01–0.05 mm) with larger quartz grains or "eyes" (0.1–0.2 mm) evenly distributed through the matrix. In places "lines" of fine-grained quartz parallel traces of foliation and probably represent bedding that is parallel to foliation. Grain sizes in phyllites less than 0.1 mm and rock is mainly well-alined sericite (or fuchsite?) with thin lenses and stringers of quartz parallel to foliation. Foliation probably parallel to bedding in most places.

Graywacke

[Data based on 1 thin section]

*Quartz *Sodic plagioclase	*Sericite *Chlorite	*Leucoxene *Yellow-brown iron oxide

NOTE.—Matrix grains less than 0.1 mm; nonmatrix detrital quartz and feldspar, 0.1–2 mm. Matrix of fine-grained recrystallized quartz, sericite, and chlorite surrounds medium-grained detrital quartz and feldspar. Most of quartz is in matrix. Sericite and chlorite strongly alined throughout matrix to give rock pronounced foliation. Folia of sericite-chlorite bend around medium-grained quartz and feldspar. Some of the larger feldspar elongate and alined parallel to foliation. Plagioclase speckled with sericite (or paragonite?). Leucoxene widely distributed. Yellow-brown iron oxide along shear seams.

Quartzite

[Data based on 7 thin sections]

Quartz *Sericite *Chloritoid	Sericite *Chlorite *Sodic plagioclase *Yellow-brown iron oxide	Chlorite Chloritoid Yellow-brown iron oxide *Feldspar *Leucoxene *Rutile *Epidote *Biotite *Carbonate *Sericite *Sphene

NOTE.—Most of these rocks have medium-grained detrital quartz (0.2–0.8 mm) set in fine-grained matrix (grains <0.1 mm) of quartz-sericite, or quartz-sericite-chlorite. Sericite and chlorite that are scattered through the matrix generally well alined. Rocks slightly to moderately foliated with shear surfaces lined by sericite, chlorite, and iron oxide. In one sample, shear surfaces also have aggregates of fine rutile needles. Sparse small pebbles of quartzite scattered through some of these rocks. Chloritoid in isolated blades and clumps of a few blades, and commonly is partly replaced by yellow-brown iron oxide.

Lenses of quartzite with sericite or sericite and chlorite are interbedded in the schist and phyllite. Chloritoid is a minor or subordinate mineral in some of the quartzite. The more sericitic of the quartzites are gray to nearly white and distinctly schistose, whereas those that are relatively rich in chlorite are greenish. Individual beds of chloritic quartzite are compact, dense, poorly foliated or nonfoliated, and range in thickness from about 6 to 30 cm.

The sericitic quartzite along the base of the Palmital in the southeastern and east-central parts of the Rio Acima quadrangle is tan to nearly white, and is overlain by gray, buff, or pink phyllite containing cobbles of vein quartz and white friable cherty quartzite. Cobbles are as much as 15 cm in diameter but probably constitute less than 10 percent of the rock in most places. Some of the cherty quartzite cobbles have faint banding emphasized in some cobbles by yellow-brown iron-oxide that has worked in along the layers from the outer surfaces of the cobbles. Banding lies either parallel to or across bedding(?)-foliation of the phyllite.

CASA FORTE FORMATION

The Casa Forte formation is here named from Corrego da Casa Forte along which the formation is very well exposed in the east-central part of the Rio Acima quadrangle.

DISTRIBUTION AND THICKNESS

The Casa Forte formation is folded back onto itself in the core of the Vargem do Lima syncline. The fold axis trends north-northwestward and extends across the eastern edge of the Rio Acima quadrangle about 5,280 meters north of the southeast corner of the quadrangle. As the formation extends north-northwestward from the east edge of the Rio Acima quadrangle, its outcrop belt gradually narrows, and ends by closure near N. 12,690, E. 10,250.

One to three beds of conglomerate occur in about the lower half of the formation in the Rio Acima quadrangle. They are lenticular and discontinuous and appear generally to be bounded by schist. At the base of the formation conglomerate is interbedded with quartzite in places and, along the strike, may give way rather abruptly to quartzite.

Conglomerate cropping out along a low ridge at N. 9,020, E. 12,310 in the Rio Acima quadrangle grades north-northwestward into quartzite along the same low ridge. This quartzite in turn grades north-northwestward into schist cropping out along a small riblike extension of the same ridge. The low rib of outcropping schist rises to near the top of the knob at N. 9,520, E. 11,910. The rib of schist probably is at the same horizon as the conglomerate to the south-southeast. Conglomerate extending northward from the vicinity of N. 7,740, E. 11,950 lenses out a short distance south of the top of the same knob. Judging by the apparent convergence of the horizon of the conglomerate beds and by the shape of the knob near N. 9,520, E. 11,910, the axis of the Vargem do Lima syncline passes through the knob.

In the knob the horizon of the conglomerate beds is some 3.5 kilometers map distance from the base of the formation at the fold axis. One to two kilometers to the south-southeast, or to the south, of the knob at N. 9,520, E. 11,910, respectively, on the flanks of the fold, beds of conglomerate at the same horizon as in the knob are some 300 to 500 meters map distance from the base of the formation. The separation of the horizon of the upper conglomerate from the base of the formation in the axial region of the Vargem do Lima syncline is believed to be a result of flowage of schist from the flanks into the axial region of the fold during deformation.

In the Rio Acima quadrangle, quartzite of the Casa Forte formation is most conspicuous between N. 4,200, E. 12,750 and N. 7,940, E. 12,550 and between N. 7,940, E. 11,650, N. 8,940, E. 11,110, and N. 9,800, E. 11,450. The quartzite forms massive lenses as much as several hundred meters in thickness.

The conglomerate beds are generally 2 to 10 meters thick and from several hundred meters to about 4 kilometers in length in the Rio Acima quadrangle.

The thickness of the Casa Forte formation, measured some 7,000 meters north of the south edge of the Rio Acima quadrangle, and well away from the thickening of the axial region of the fold, is estimated to be from 250 to 400 meters.

PETROGRAPHY

Petrographic data for the Casa Forte formation are given in the following table. The formation is characterized by conglomerate, schistose and massive sericitic quartzite, and massive chloritic quartzite, with interbeds of schist or phyllite.

Schist-phyllite is deeply weathered, poorly exposed, and commonly represented by smooth grassy slopes. The weathered schist and phyllite is generally light buff or light gray to brown. No schist or phyllites from this formation suitable for making thin sections were obtained during the present work.

Petrographic data for the Casa Forte formation, Maquiné group

[Some minerals fall into more than 1 of the 3 percentage columns. Minerals preceded by an asterisk (*) are in the given percentage range in only a few thin sections]

Quartzite

[Data based on 7 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz	Sericite-fuchsite Chlorite *Chloritoid	Chloritoid Yellow-brown iron oxide *Sericite *Magnetite

NOTE: —Matrix grains less than 0.1 mm; nonmatrix detrital quartz, 0.1 to more than 2 mm; chloritoid grains, from less than 0.1 to 2 mm. Inequigranular texture common, with medium- to coarse-grained detrital quartz studded through finer grained matrix of mosaic-textured recrystallized quartz and scattered alined sericite-fuchsite and chlorite. Rock moderately schistose. In places foliation surfaces bend around detrital quartz grains to form a microaugen structure. Medium- and coarse-grained quartz may have strain shadows and commonly has sutured borders against matrix quartz. Chloritoid mainly in blades, small clumps, and vague rosettes. Some chloritoid blades alined parallel to foliation, some alined across foliation, and some extend into the matrix from foliation surfaces. In some places chloritoid is molded partly around detrital quartz grains. Chloritoid rather extensively altered to yellow-brown material, probably iron oxide.

Conglomerate

[Data based on 4 thin sections]

Quartz		Red and yellow-brown iron oxide Chloritoid *Sulfide *Leucoxene

NOTE.—Matrix grains mainly less than 0.1 mm; some quartz grains, 0.1–2 mm; pebbles and fragments, generally 4–6 cm. Pebbles and brecciallike fragments of cherty quartzite and iron-formation (with grains <0.05 mm) and medium-grained detrital quartz in poorly sorted fine-grained matrix of granular to mosaic-textured quartzite. Iron oxides mainly in scattered "spots" within fragments of cherty quartzite. One fragment of iron-formation seen in thin section has alternating layers of fine- even-grained quartz and aggregated magnetite-brownish iron oxide. Chloritoid generally distributed along irregularly oriented cracks in the rock.

The conglomerate is generally a dark rusty brown on the surface, and mottled brownish and white on fresh fractures. It is characterized by closely packed fragments and rounded pebbles of vein quartz and cherty quartzite, and by platy fragments of iron-formation in a quartzitic or ferruginous quartzitic matrix. Pyrite and chloritoid occur along cracks in some places in the conglomerate, particularly near Vianna waterfall, about 4 kilometers east of Rio Acima. The conglomerate typically weathers to a deeply pitted clinkerlike surface.

The quartzites of the Casa Forte formation are schistose to compact and massive. Scattered quartz pebbles as much as 3 cm in diameter occur in the quartzite near interbedded conglomerate in several places in the Rio Acima quadrangle near N. 7,440, E. 11,790. Quartzites richer in chlorite have poorer alinement of the platy minerals and generally are more compact than those richer in sericite. The sericitic quartzites are medium to light gray, and weathering appears to lighten their color. Quartzites with considerable chlorite as well as sericite are dark gray or greenish gray, but commonly are dark brown or reddish brown on weathered surfaces. Oxidized chloritoid also locally contributes to the brownish color of the weathered quartzitic rocks.

AGE RELATIONS

The Maquiné group is considered to be younger than the Nova Lima group, and the fold, along the core of which occurs the Maquiné group, is interpreted to be a syncline for the following reasons:

1. Most of the conglomerate mapped in the Maquiné group along the west limb of the fold occurs at or near the contact between a schist and quartzite sequence to the west and massive quartzite with less abundant schist to the east. If the rocks east of the conglomerate are considered to be younger than those to the west, and if the fold is assumed to be a syncline, the conglomerate succeeds a sequence of fine-grained rocks and lies at or near the base of massive quartzite. It is more consistent with generally accepted theories of sedimentation to have conglomeratic beds near the top of a preceding sequence of fine-grained rocks and near the base of a sequence of relatively coarse grained rocks.
2. The cobble- and pebble-bearing bed of phyllite in the southeastern and east-central parts of the Rio Acima quadrangle is close to the contact between a sequence of schists and phyllites to the west and schist, phyllite, and quartzite to the east. As in 1, if younger rocks are assumed to lie east of the cobble- and pebble-bed, and if the fold is assumed to be a syncline, the position of the conglomeratic bed at the base of a coarser grained sequence of rocks and above a finer grained sequence is consistent with theories of sedimentation.
3. The conglomerates mapped in the upper formation of the Maquiné contain fragments of iron-formation similar in appearance to weathered iron-formation of the Nova Lima group. Many of the cobbles in the phyllite near the contact between the Maquiné and Nova Lima groups resemble cherty quartzite associated with the iron-formation of the Nova Lima group. These fragments or cobbles of iron-formation or cherty quartzite therefore suggest that the Maquiné group is younger than the Nova Lima group, and support the interpretation of a syncline.

There is some structural evidence in the Rio Acima and Nova Lima quadrangles that the Maquiné group unconformably overlies the Nova Lima group. The horizon of the quartz-dolomite-ankerite rock (lapa sêca) appears, on very scant evidence, to extend southeastward across the Rio Acima quadrangle from a short distance east of Santa Rita, to converge on the contact between rocks of the Nova Lima and Maquiné groups, and to be truncated by that contact. Schistose quartzite and iron-formation of the Nova Lima group trend toward the Maquiné–Nova Lima contact in the southeastern part of the Nova Lima quadrangle and rocks of the Nova Lima group in this area are more complexly folded than those of the Maquiné. Thrust faulting out of the core of the syncline might increase the apparent degree of truncation of the Nova Lima group by the Maquiné group, or be the sole cause of truncation, thereby heightening the unconformity or producing the illusion of an unconformity where none actually exists. The weight of evidence indicates the existence of an unconformity, but the evidence is not conclusive.

Available items showing evidence of age relations, although separately not very strong, all suggest that the Maquiné is younger than the Nova Lima group, and therefore collectively are believed to indicate the relative ages of the Maquiné and Nova Lima rocks.

MINAS SERIES

CARAÇA GROUP

The Caraça group is the lowermost group of rocks in the Minas series. Harder and Chamberlin (1915, p. 351–356) originally used the name "Caraça" to designate the basal Minas formation of quartzite and associated conglomerate and quartzose schist. Dorr and colleagues (1957; Maxwell, 1958; Wallace, 1958) broadened the use of the term by applying it to all the rocks beneath the laminated iron-formation (itabirite) in the Minas series, thereby including in their Caraça group the rocks both of Harder and Chamberlin's "Caraça formation" and "Batatal schist" (1915, p. 356).

The Caraça group has not been divided into formations in the Nova Lima quadrangle as it has been in many other parts of the Quadrilátero Ferrífero (Dorr and others, 1957; Maxwell, 1958; Wallace, 1958). In the Nova Lima quadrangle the Caraça group is relatively thin. Its thickness is estimated to range from about 80 to 320 meters. Except for a small area of conglomerate near the west edge of the quadrangle, the group in this area consists of one or two beds of quartzite interlayered with schist and phyllite along only part of the belt of Minas rocks, and elsewhere only of schist and phyllite. Quartz veins are common in the quartzite beds.

CONGLOMERATE

A small area of poorly exposed conglomerate occurs near the west edge of the Nova Lima quadrangle in the vicinity of N. 6,600, E. 260. The conglomerate consists of rounded cobble-size and smaller fragments of quartzite and vein quartz in a quartzitic matrix. This conglomerate occurs between itabirite of the Minas series to the west and northwest, and schists of pre-Minas age to the east and southeast. Its similarity to conglomerate at the base of the Minas series to the southwest in the Belo Horizonte quadrangle (J. B. Pomerene, written communication, 1958), and its location indicate that it should be assigned to the base of the Caraça group.

QUARTZITE

Two thin beds of white friable fine- to medium-grained quartzite occur near the base of the Minas series, low along the southeast flank of the northeast-trending ridge that is upheld by Minas iron-formation. These beds of quartzite extend discontinuously from near the west edge of the Nova Lima quadrangle to about 3 kilometers southwest of Sabará near N. 9,960, E. 4,800. To the northeast a single bed of quartzite extends from about 2 kilometers southwest of Sabará to the south limits of Sabará. These beds are generally less than 10 meters thick and in many places are covered by talus of itabirite.

The quartzite of the Caraça group generally consists of dominant quartz with minor amounts of sericite, chlorite, magnetite, and other oxides of iron. Typically, medium-grained detrital quartz is set in a fine-grained matrix of mosaic-textured quartz and of minor minerals. Typically, boundaries between the larger quartz grains and the matrix are sutured, and the larger quartz grains are strained. In places medium-grained quartz comprises much of the rock with only thin selvages of finer grained quartz. Quite possibly such thin selvages of fine-grained quartz are recrystallized crush quartz broken from the detrital grains during folding and rock deformation.

In at least one place in the Nova Lima quadrangle, N. 9,400, E. 3,400, one bed of quartzite of the Caraça group gives way to subgraywacke. The subgraywacke contains dominant quartz, dominant biotite-chlorite-sericite-epidote, subordinate sodic plagioclase, and minor magnetite. The paragenesis of the present biotite-chlorite is not known. The amount and extent of this subgraywacke in the Caraça group probably are small.

SCHIST AND PHYLLITE

Schist and phyllite of the Caraça group is exposed in few places in the Nova Lima quadrangle. It generally forms grassy slopes. It is best exposed along the highway between the Triangulo and Belo Horizonte, within 100 meters of the Triangulo, near N. 8,760, E. 2,300 and along the railroad tracks of the Central do Brasil, about 100 meters southwest of the south end of the highway bridge across the Rio das Velhas at Sabará. From Sabará northeastward to the north edge of the quadrangle, the Caraça group appears to consist entirely of schist and phyllite.

The schist and phyllite is strongly weathered wherever exposed, and is buff to reddish. In appearance it is not unlike much of the weathered schist of pre-Minas age. Quartz, mica, and possibly chlorite are important constituents of the fresh rock. Southwest of Sabará, foliation appears to be conformable with bedding of the interlayered quartzite.

AGE RELATIONS

There is no direct evidence within rocks of the Caraça group in the Nova Lima quadrangle to indicate the direction of the tops of beds. There also is no indication within the quadrangle of an angular unconformity between rocks of the Caraça group and rocks of the Rio das Velhas series to the southeast. The position of the quartzite and schist and phyllite between itabirite of the Minas series and rocks of the Rio das Velhas series establishes the correlation of the quartzite and schist and phyllite with the Caraça group of adjoining areas. In other quadrangles studied during the present program, conglomerates at or near the contact between Caraça rocks and rocks of the Rio das Velhas series, or cross-bedding in the Caraça rocks indicate "top directions," and establish that the Caraça rocks underlie the Minas itabirite. In the Nova Lima quadrangle therefore, the "top direction" of bedding is to the northwest. The southeastward dips of Caraça and other Minas rocks is a result of northwestward overturning of the Minas series during formation of the Rio das Velhas uplift. The direct evidence indicating "top direction" and the normal order of stratigraphic succession was corroborated by Rynearson and colleagues (1954), who described a number of places in the north-central part of the Quadrilátero Ferrífero where bedding of rocks of the (later-named) Rio das Velhas series is truncated by bedding in rocks of the Caraça group. They thereby not only proved an unconformity, but also that Caraça rocks are younger than the Rio das Velhas series.

ITABIRA GROUP

Harder and Chamberlin (1915, p. 358) named the iron-formation of the Minas series, which contains the major iron ore deposits of the Quadrilátero Ferrífero, the "Itabira iron formation." Dorr and colleagues (1957) and Dorr (1958*a*, *b*) expanded the use of the term to include dolomitic rocks that overlie and grade into the iron-formation, and they named the iron-formation (itabirite) and dolomite sequence the "Itabira group." Dorr (1958*a*) named the iron-formation of the Itabira group, the "Cauê itabirite," and Dorr (1958*b*), following the suggestion of J. E. O'Rourke (written communication, 1956), called the dolomite formation of the Itabira group, the "Gandarela formation."

CAUÊ ITABIRITE

DISTRIBUTION AND THICKNESS

Itabirite is a widely used term that originated in Brazil and has had several meanings. It is now probably most widely understood to designate a type of metamorphosed (recrystallized) iron-formation characterized by alternating laminae of iron oxides and light-colored constituents. The dominant light-colored constituent is quartz; the quartz may be admixed with small amounts of other light-colored minerals, especially dolomite or calcite or both. J.V.N. Dorr 2d (oral communication) states that he considers that "itabirite" should be used only for metamorphosed laminated oxide-facies iron-formation containing between 20 and 66 percent iron, and that where dolomite or other light-colored minerals are dominant over quartz, the term "itabirite" should be modified by the name of the dominant light-colored mineral.

Only the Cauê itabirite of the Itabira group is definitely known in the Nova Lima quadrangle. The Cauê itabirite is marked along much of its extent across the northwestern part of the Nova Lima quadrangle by a prominent steep-sided ridge. The outcrop belt of the Cauê ranges from about 50 to 900 meters in width, and averages about 300 meters. However, a considerable part of this width of outcrop must be accounted for as dip slope. (See pl. 1.) The average thickness of the Cauê itabirite in the Nova Lima quadrangle is estimated to be 125 meters.

A zone of ocherous iron-formation in the upper part of the Cauê itabirite extends northeastward for some 3 kilometers from near the place where the highway between the Triangulo and Belo Horizonte crosses the formation. Where the highway crosses the Cauê itabirite the width of the zone of ocherous iron-formation comprises some 500 meters out of the total width of 600 meters for the entire formation. The zone of ocherous itabirite thins to 50 meters or less within 1 kilometer to the northeast. Ocherous magnetic iron-formation also occurs at the top of the Cauê itabirite northwest and north of Sabará.

Itabirite is well exposed for about 1.5 kilometers along the crest of the ridge west of the Triangulo, along the crest of the ridge between 1 and 3 kilometers southwest of Sabará, and in road and railroad cuts along the Rio das Velhas at the southwest edge of Sabará. The ocherous itabirite is well exposed along the highway between the Triangulo and Belo Horizonte, within some 800 meters of the Triangulo.

PETROGRAPHY

In the Nova Lima quadrangle the Cauê itabirite is strongly weathered, and consists of alternating laminae of quartz and bluish-black to reddish-brown iron oxides (fig. 12). Fresh unweathered itabirite is not known in the area. The principal effects of weathering appear to have been loosening by the dissolving action of ground water along grain boundaries, causing a softening of the rock and disaggregation of grains of quartz and iron oxide, and hydration of some of the iron oxides to goethite. Weathered earthy yellow-brown ocherous rock is not uncommon, particularly in the upper part of the formation. In some exposures the earthy ocherous material occurs as thin layers alternating irregularly with thin layers of reddish-brown to gray-black generally magnetic iron oxide, or of magnetic iron oxide and phyllitic oxidized yellowish platy silicate(?). The earthy ocherous material may occur in rather widely spaced laminae interlayered with itabirite, or it may form a nearly continuous sequence of thin laminae interlayered with rather widely spaced thin layers of dark-colored iron oxide. The earthy yellow-brown ocherous material absorbs water readily and if struck by a hammer when saturated with water, the rock may yield a "splash" of water. This characteristic of ocherous parts of the Minas iron-formation accounts for the local name "splash rock" applied to it by some geologists in the area.

Laminae in itabirite and ocherous itabirite range widely in thickness from about 0.1 to 10.0 mm, but commonly range from 0.5 to 2.0 mm. There is no apparent systematic distribution of laminae of a given order of thickness. Individual laminae are of variable thickness and in places are lenticular. Quartzose laminae generally carry scattered grains of iron oxide, and the laminae of iron oxide generally have small amounts of quartz in interstices between grains or aggregates of iron oxide.

Quartz grains generally range from 0.05 to 0.15 mm in mean diameter, and in any one sample form a rather even-grained mosaic texture. Iron oxide commonly is in aggregated grains so that the sizes of individual grains are difficult to measure and crystal forms are not evident. Isolated grains of iron oxide are as much as 0.3 mm in diameter. Some isolated grains, particularly in the ocherous itabirite, are octahedral.

The chemical analyses in table 5 indicate high percentages of quartz and ferric iron in the weathered itabirite, and very little alumina, manganese, titanium, phosphorus, and sulfur.

No polished sections of itabirite from the Nova Lima quadrangle have been made. Types of iron oxide have been determined by megascopic examination, in thin section by oblique reflected light, by the use of a hand magnet, and indirectly from the chemical analyses of the iron-formation.

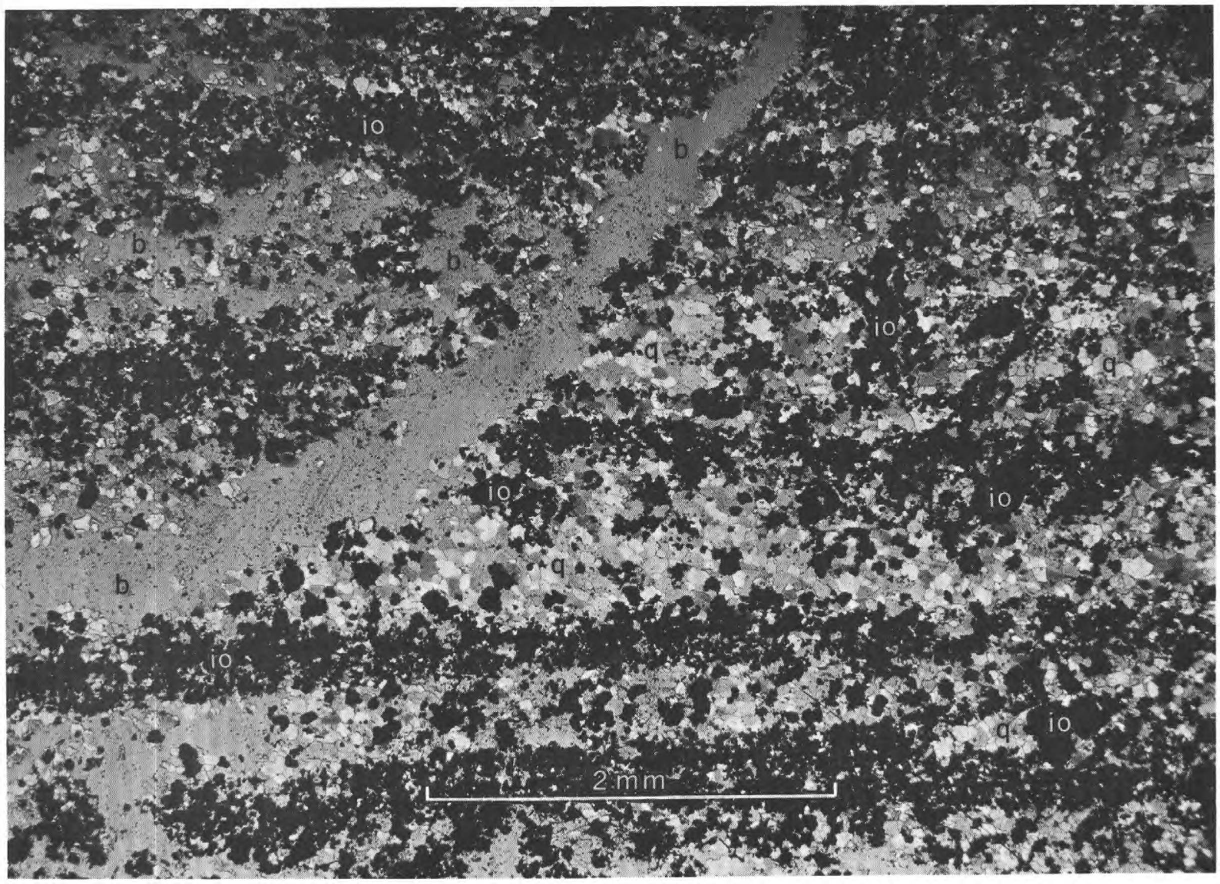

FIGURE 12.—Photomicrograph of weathered Cauê itabirite. Highway between the Triangulo and Belo Horizonte, Nova Lima quadrangle (N. 8,875, E. 2,325). Alternating laminae of iron oxide (io) and quartz (q). Many laminae not sharply defined because of intermixing. Iron oxides consist of hematite, small amounts of magnetite, and of goethite. Areas of balsam (b) within thin section and along crack illustrate difficulty of obtaining thin sections from weathered itabirite. Nicols partly crossed.

The principal iron oxide in the itabirite is hematite. Yellow-brown "limonitic" iron oxide is generally subordinate in amount and magnetic iron oxide is found in minor amounts or is absent. In ocherous itabirite, magnetic and yellow-brown iron oxides are generally dominant. Grains or small aggregates of gray-black magnetic iron oxide are commonly rimmed by or set in a matrix of yellow-brown iron oxide. The small proportions of FeO to Fe_2O_3 in analyses 2 and 3 of table 5, however, indicate very little magnetite in the ocherous itabirite. The apparently magnetic iron oxide may contain only a small proportion of magnetite intergrown with gray black nonmagnetic ferric oxide, or the iron mineral may be a magnetic ferric oxide. The yellow-brown iron oxide rimming gray-black iron oxide probably formed by the hydration of some of the latter during weathering.

AGE RELATIONS

The iron-formation in the northwestern part of the Nova Lima quadrangle extends continuously southwestward into similar rocks in the Belo Horizonte quadrangle. This iron-formation of the Nova Lima quadrangle cannot be traced northeastward to the type area of the Cauê itabirite in the Itabira district (J.V.N. Dorr 2d, written communication, 1954) because of intervening intrusive rocks. However, the similar lithologic character of the iron-formation in the northwestern part of the Nova Lima quadrangle with the type Cauê itabirite, and the similar stratigraphic position between rocks of the Caraça group and the overlying Cercadinho formation clearly mark the iron-formation as part of the Minas series and as equivalent to the Cauê itabirite of the Itabira district.

ORIGIN

The alternating laminae of quartz and hematite constituing bedding, the rather fine and even grain sizes, the mosaic recrystallized textures, and the absence of detrital grains, indicate that the Cauê itabirite was formed by the regional metamorphism of a chemical sediment. Other evidence of the chemical origin of itabirite has been presented by Tyler (1948), and Barbosa (1954). Guild (1953, p. 651) discusses the origin

TABLE 5.—*Chemical analyses of weathered Cauê itabirite and ocherous itabirite, Nova Lima quadrangle*

[Analysts: Nos. 1–3, Joseph I. Dinnin, U.S. Geological Survey; Nos. 4–10, Cassio M. Pinto, DNPM]

	1	2	3	4	5	6	7	8	9	10
SiO_2	47.9	44.5	42.1	17.7	39.0	40.0	54.2	23.7	24.7	49.8
Al_2O_3	.40	.22	.11	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Fe_2O_3	47.7	49.7	52.8	--------	--------	--------	--------	--------	--------	--------
FeO	1.4	<.1	.9	--------	--------	--------	--------	--------	--------	--------
Fe	--------	--------	--------	56.1	42.1	41.2	31.8	53.0	51.3	34.6
MgO	.03	.05	.07	--------	--------	--------	--------	--------	--------	--------
CaO	<.05	<.05	<.05	--------	--------	--------	--------	--------	--------	--------
Na_2O	.13	.11	.15	--------	--------	--------	--------	--------	--------	--------
K_2O	<.01	<.01	<.01	--------	--------	--------	--------	--------	--------	--------
TiO_2	<.01	<.01	<.01	--------	--------	--------	--------	--------	--------	--------
P_2O_5	.02	.33	.11	--------	--------	--------	--------	--------	--------	--------
P	--------	--------	--------	.02	.03	.02	.03	.03	.02	.02
MnO	<.01	.48	<.01	--------	--------	--------	--------	--------	--------	--------
Mn	--------	--------	--------	<.01	.09	.02	<.01	<.01	<.01	.02
H_2O	1.7	3.9	3.0	--------	--------	--------	--------	--------	--------	--------
CO_2	.2	<.1	<.1	--------	--------	--------	--------	--------	--------	--------
S	<.005	<.005	<.005	--------	<.02	--------	--------	--------	--------	--------
Loss on ignition	--------	--------	--------	1.9	.60	.90	.10	.3	1.9	.6
Sum [1]	100	99	99	99.8	99.8	99.8	99.7	99.7	99.9	99.8

[1] Sums of analyses 4–10, based on given percentages plus sufficient oxygen to compute all the Fe as Fe_2O_3.

1. Itabirite, N. 8,880 E. 2,300. Rapid methods.
2. Ocherous itabirite, N. 8,880 E. 2,000. Rapid methods.
3. Ocherous itabirite, N. 8,800, E. 1,620. Rapid methods.
4. Itabirite, N. 9,620, E. 2,700.
5. Itabirite, N. 9,740, E. 2,640.
6. Itabirite, N. 8,860, E. 2,320.
7. Itabirite, N. 10,840, E. 4,600.
8. Itabirite, N. 10,900, E. 4,640.
9. Itabirite, N. 11,720, E. 5,260.
10. Itabirite, N. 12,140, E. 6,000.

of itabirite and concludes that it "originated as chemical precipitates of iron compounds, silica, and in places carbonates of calcium and magnesium, with variable but generally minor quantities of alumina, phosphates, and other substances." Guild postulated the development of itabirite in bordering parts of a sea under conditions of restricted circulation. Under such conditions the pH at times fell below 7.8, and inhibited the deposition of carbonates, which ordinarily mask precipitates of iron and silica. Guild suggested that contemporaneous volcanism may have contributed to the lowering of the pH. In the Nova Lima and adjacent quadrangles, however, there is no evidence of volcanism contemporaneous with deposition of the Cauê itabirite. There is no known direct evidence indicating the primary premetamorphic mineralogy of the itabirite of the present area. The mineralogy and structure of the itabirite are similar to those of some banded iron-formation or ironstone of the Lake Superior area (Grout, 1919; Gruner, 1922, 1946; Gill, 1926, 1927, James, 1951, 1954), of Australia (Miles, 1941), of Urucum, Brazil (Dorr, 1945), of India (Spencer and Percival, 1952), of central Sweden (Geijer, 1938), and of the Transvaal (du Preez, 1945), in which laminae of primary iron oxide (hematite) alternate with laminae of cherty quartz. Like these other iron formations, itabirite is believed to be primary hematite-banded iron-formation of the oxide facies. (For description and definition of this facies see James, 1954, p. 259–260.)

The unweathered source rock for the magnetite-bearing ocherous itabirite has not been identified in the Nova Lima quadrangle. However, the general structural similarity of this laminated rock to itabirite, and the occurrence of isolated ocherous laminae in itabirite indicate a gradation during continuing chemical sedimentation from itabirite to the unweathered source rock of the ocherous itabirite.

Guild (1953, 1957) has described dolomitic itabirite from the southwestern part of the Quadrilátero Ferrífero, and has shown (1957) that ocherous rock ("splash rock") similar in appearance to the ocherous material in the Cauê itabirite is derived by the weathering of dolomite and dolomitic itabirite. A lack of fresh material has thus far prevented the determination of all types of carbonate from which "splash rock" may be derived. There is no direct evidence for the origin of the ocherous material in the Cauê itabirite of the Nova Lima quadrangle, although it may well represent original layers of dolomite. Small amounts of oxidized platy and bladed relicts of unidentified silicate minerals occur in places in the ocherous material. There is little or no evidence of primary silicate facies of iron-formation in the Cauê itabirite anywhere in the Quadrilátero Ferrífero; hence, the relict silicates are thought to have formed during regional metamorphism. The ocherous material probably represents mainly preweathering dolomite.

The upward change from itabirite (weathered oxide facies iron-formation) to ocherous itabirite may be equivalent to the upward change from itabirite of the Cauê to dolomite of the Gandarela in many other parts of the Quadrilátero Ferrífero. The Gandarela has been mapped by Pomerene (written communication, 1958) in the Belo Horizonte quadrangle and may extend a short distance into the western part of the Nova Lima quadrangle. Canga and weathering in that part of the quadrangle mask the Itabira group. The environmental conditions, in terms of available free oxygen and hydrogen ion concentration (pH), for the precipitation of the oxide facies of iron-formation have been discussed by Guild (1953) and James (1954), and for limestone or dolomite (marble), by Krumbein and Garrels (1952) and Dorr, Coelho, and Horen (1956). By analogy with conditions postulated by these workers, the lower part of the Cauê itabirite probably was precipitated in a shallow restricted sea, mainly in a slightly alkaline environment (pH, 7.0 to 7.8) containing free oxygen. By the time of deposition of the upper part of the Cauê, the sea probably had become deeper and less restricted, with little or no free oxygen and with a pH above 7.8.

PIRACICABA GROUP

The Piracicaba group is the uppermost group in the Minas series. Harder and Chamberlin (1915, p. 362–363) originally used the name "Piracicaba" to designate a formation consisting of argillaceous, ferruginous, quartzose, and talcose schists, ferruginous quartzite, and minor iron-formation and limestone.

Detailed mapping during the present Brazilian-United States program has divided the "Piracicaba formation" of Harder and Chamberlin into at least five formations. In the Ibirité and adjoining quadrangles, some 15 to 40 kilometers west-southwest of the Nova Lima guadrangle, the formation units are, in upward succession, quartzite (locally ferruginous and locally conglomeratic), phyllite, graphitic phyllite, fine-grained white quartzite, and chloritic quartzite-graywacke (Dorr and others, 1957; Pomerene, 1958*a*, *b*, *c*; Simmons, 1958). The formations extend east-northward along the northwestern foothills of the Serra do Curral from the Brumadinho quadrangle through the Ibirité quadrangle into the Belo Horizonte quadrangle. Of the five formations of the Piracicaba group known in the Brumadinho, Ibirité, and Belo Horizonte quadrangles, only the basal and uppermost formations, and possibly part of the next formation above the basal one, persist northeastward into the Nova Lima quadrangle. The lower (basal) unit of the Piracicaba group has been named the Cercadinho formation by Pomerene (1958*a*). It consists of ferruginous quartzite, schist, silver-gray phyllite, ferruginous conglomerate, iron-poor quartzite, and lenses of dolomite. The upper unit of the Piracicaba group in the Nova Lima quadrangle was named the Sabará formation by Gair (1958*a*). The type section is along the Rio das Velhas, between 1 and 3.5 kilometers northwest of Sabará.

In the Nova Lima quadrangle, the Cercadinho formation of the Piracicaba group overlies the Itabira group with erosional disconformity. The Sabará formation is conformable on the Cercadinho formation, and the upper part of the Sabará formation is in irregular contact with intrusive granitic and gneissic rocks near the northwest corner of the quadrangle.

CERCADINHO FORMATION

The Cercadinho formation consists mainly of beds of schist or silver-gray phyllite alternating with beds of ferruginous quartzite and related quartzose rocks. Several lenses of dolomite are also known in the formation, which suggests to the author the possibility that those parts of the Cercadinho formation as mapped in the Nova Lima quadrangle may have been forerunners of the dolomite-bearing Fecho do Funil formation (Simmons, 1958) that immediately overlies the Cercadinho along the Serra do Curral southwest of the Nova Lima quadrangle.

DISTRIBUTION AND THICKNESS

In the Nova Lima quadrangle the Cercadinho formation lies along, or close to, the crest of the Serra do Curral, northwest of and stratigraphically above the Itabira group. Along most of its extent in this area the Cercadinho formation is about 300 meters thick, but thins to about 100 meters where it crosses the western edge of the Nova Lima quadrangle. Individual beds of ferruginous quartzite or schist and phyllite are commonly less than 50 meters thick, but in places are as much as 90 meters thick. Beds of conglomerate or grit along the base of the formation are generally less than 50 meters thick.

The base of the formation is marked along much of its extent in the Nova Lima quadrangle by ferruginous conglomerate (at least 10 percent of grains larger than 4 mm), ferruginous grit (at least 10 percent of largest grains between 2 and 4 mm), or ferruginous to nonferruginous quartzite. Facies changes from conglomerate to grit to quartzite evidently are common. Conglomerate or grit has been found along the base of the formation at the following localities: N. 8,680, E. 360; N. 8,560, E. 700; N. 8,620, E. 880; N. 8,580, E. 1,100; N. 9,060, E. 1,760; N. 9,560, E. 2,300; N. 9,840, E. 2,920; N. 10,140, E. 3,620; N. 12,240, E. 5,890; N. 13,400, E. 6,820.

Beds of quartzose rocks in the formation commonly stand out as low narrow ridges whereas schist and phyllite underlie grassy shallow troughlike depressions between the beds of quartzose rock.

Lenses of dolomite occur in at least two areas along the belt of Minas rocks in the Nova Lima quadrangle. Several lenses and thin beds of dolomite are in the upper part of the Cercadinho formation near Sabará in the vicinity of N. 12,260, E. 5,700. A single lens in the western part of the quadrangle, near N. 8,800, E. 1,000, has been mapped in the lower part of the formation, but this mapping may require revision in the future. Evidence found in a new road cut, after completion of mapping by the author, suggests the possibility that this dolomite represents part of the Gandarela formation in the upper part of the Itabira group, brought to the surface by a local reversal of dip on a small fold (J. V. N. Dorr, 2d, written communication, 1957). Although Gandarela dolomite is in the section to the southwest in the Belo Horizonte quadrangle, no other evidence of its possible existence in the Nova Lima quadrangle is known. According to the interpretation presented on plate 1, the Gandarela is assumed to have lensed out west of the Nova Lima quadrangle. The thickest lens of dolomite near Sabará has a maximum thickness of about 40 meters, and the lens in the western part of the quadrangle, a maximum thickness of about 50 meters.

PETROGRAPHY

Petrographic data for the Cercadinho formation are listed in the following table. Schist and phyllite, which constitute more than half the formation, are poorly exposed and weather to material generally too soft or too fissile for thin sectioning. The description of these rocks therefore depends on megascopic examination. In the lower part of the formation fresher parts of the schist are light gray, and in the more weathered parts, buff or pink. Grain sizes are fine with quartz lying between seams of platy minerals. Fissile silver-gray sericite phyllite with greasy luster and feel is distinctive in approximately the upper half of the formation. Acicular crystals of kyanite are found in places in the schist near the top of the formation.

Petrographic data for the Cercadinho formation

[Some minerals fall into more than 1 of the 3 percentage columns. Minerals preceded by an asterisk (*) are in the given percentage range in only a few thin sections]

Schist

[Data based on two thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
*Sericite *Quartz *Biotite	*Chlorite *Sericite	*Hematite *Magnetite *Yellow-brown iron oxide *Quartz *Zircon

NOTE.—Grain sizes less than 0.1 mm. Schist and phyllite of this formation not adequately represented by thin sections because the rocks softened by weathering. Strong alinement of platy minerals. Quartz grains mainly equant. Hematite and magnetite (?) in small granules and dusty patches.

Quartzite

[Data based in three thin sections]

Quartz		Sericite Hematite Dusty opaque material

NOTE.—Grain sizes from less than 0.1 to 2 mm. Mostly fairly even grained, mosaic textured. Layering in one sample of fine-grained quartzite marked by evenly distributed dusty opaque matter. Scattered cracks subparallel with bedding. In one sample fine-grained quartz selvage between medium-sized detrital grains may be result of granulation and recrystallization.

Ferruginous quartzite

[Data based on six thin sections]

Quartz *Hematite *Magnetite *Sericite	Hematite *Sericite	Sericite

NOTE.—Grain sizes from less than 0.1 to 2 mm. Rounded and lensoid detrital grains mainly of quartz, but some of quartz-sericite schist or sericite phyllite, probably derived from the Caraça group. Quartz grains in most samples elongated and alined parallel with bedding. Matrix mainly hematite, with small amounts of sericite and fine-grained quartz. Matrix hematite both platy and granular. Platy hematite alined to give rock moderately strong foliation parallel with bedding. Matrix in some samples exists only as thin seams around detrital quartz. Anastomosing seams of matrix give rock a microaugen structure. At ends of some of larger lensoid quartz are patches of fine granular quartz splayed out into matrix. This quartz is probably recrystallized crush quartz. One sample has abundant magnetite.

Dolomite

[Data based on three thin sections]

Dolomite (See table 3)		Quartz Dusty hematite *Sericite

NOTE.—Grain sizes from less than 0.1 to 2 mm. Buff to purplish pink fairly even grained, mosaic textured in most of these rocks. In at least one place dolomite grains are elongated and well alined. Isolated fine grains of quartz widely scattered.

Ferruginous conglomerate and grit

[Data based on five thin sections]

Quartz *Sericite	Hematite	Sericite Yellow-brown iron oxide

NOTE.—Grain sizes from less than 0.1 to more than 10 cm. Coarse detrital grains of quartz and quartzite seen in thin section. Hand specimens show pebbles, platy fragments of vein quartz, schist, cherty quartzite, possible silicified carbonate, and itabirite in a ferruginous quartzitic matrix. Coarser grains in moderately foliated fine-grained matrix of sericite, hematite, and quartz. Some matrix quartz granular to mosaic textured. Largest fragment seen in hand specimen is 11 by 7 by 4 cm.

The ferruginous grits near the bottom of the formation, and the ferruginous quartzite are readily distinguished from itabirite of the underlying Itabira group by their abundant rounded detrital quartz grains of medium to coarse size, and by their lack of laminations (fig. 13).

Graded bedding was observed at Nova Lima, N. 12,200, E. 5,760, with the top direction to the northwest in overturned southeastward-dipping sericitic quartzite near the base of the formation.

AGE RELATIONS

Bedding of the Cercadinho formation appears to be conformable with that of the Cauê itabirite everywhere in the Nova Lima quadrangle, notwithstanding evidence of a limited erosion interval between them.

Beds of conglomerate at or near the contact with the Itabira group contain fragments of itabirite, and provide strong direct evidence that the Cercadinho formation is stratigraphically above the Itabira group. Other supporting evidence is the prevalence of coarser grained quartzose beds in parts of the Cercadinho formation nearer rocks of the Itabira group, and the graded bedding found in one place.

SABARÁ FORMATION

The Sabará formation is the uppermost formation of the Piracicaba group and of the Minas series. It is named from the city of Sabará, a short distance northwest of which occur the best known exposures of the formation (Gair, 1958*a*.) The type section along the Rio das Velhas is about 4,000 meters wide. Part of this section lies outside the Nova Lima quadrangle to the north. The part of the type section that occurs in the Nova Lima quadrangle is shown diagrammatically in plan in plate 5.

The Sabará formation is in conformable contact with the stratigraphically underlying Cercadinho formation toward the southeast, and in irregular contact with intrusive granitic and gneissic rocks to the northwest. From southeast to northwest across the formation, the metamorphic grade increases from a chlorite zone in the lower part of the formation through a biotite zone to a garnet-staurolite zone in the upper part of the formation.

DISTRIBUTION AND THICKNESS

The Sabará formation occupies a northeastward-trending belt along the northwest side and immediately northwest of the Serra do Curral. Beds of graywacke and subgraywacke are common in the lower half of the type section. Most of these beds are less than 15 meters thick and commonly only 1 to 3 meters thick. One bed of fine-grained graywacke in the section along the Rio das Velhas is 70 meters thick. Individual beds of graywacke evidently are not persistent along strike inasmuch as beds observed on the north or east sides of the Rio das Velhas have not been found on the south or west sides of the river. The graywackes are not well exposed and have not been traced along strike from the road and railroad cuts in which they have been observed along the Rio das Velhas. Graywackes comprise about 10 percent of the lower half of the formation.

Approximately the upper two-fifths of the formation is entirely schist except for two thin beds of quartzite, which extend northeastward some 2½ kilometers from the vicinity of Marzagão to near the north edge of the quadrangle about 1 kilometer east of General Carneiro. The quartzite can be projected a few hundred meters northward from its northernmost outcrops in the Nova Lima quadrangle near N. 13,620, E. 2,160 into a northeastward-trending ridge north of the quadrangle, along which poorly banded iron-formation crops out. This iron-formation is almost certainly a ferruginous variety of the quartzite.

The Sabará formation in the Rio das Velhas section has a thickness of approximately 3,400 meters, of which some 1,300 meters are the garnet-staurolite schists. The formation thins to the southwest and near the western edge of the Nova Lima quadrangle it is approximately 1,850 meters thick.

PETROGRAPHY

The Sabará formation consists mainly of mica-chlorite schists with thin interbedded graywacke, subgraywacke, and quartzite. Petrographic data are given in the following table:

Petrographic data for the Sabará formation

[Some minerals fall into more than 1 of the 3 percentage columns. Minerals preceded by an asterisk (*) are in the given percentage range in only a few thin sections]

Quartzite

[Includes associated ferruginous weakly laminated types. Data based on 7 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz *Magnetite *Epidote *Grunerite?	Muscovite-sericite Red-brown and yellow-brown iron oxides *Chlorite	Magnetite *Biotite

NOTE.—Grain sizes from less than 0.1 to 2 mm, but most grains are 0.1–2 mm. Slightly to moderately schistose. Quartz generally even grained, but slightly elongated parallel to foliation-bedding in few places. Muscovite-sericite evenly distributed between quartz grains or in streaky zones, generally well alined. Ferruginous types not exposed in Nova Lima quadrangle, but are described from occurrences north of the quadrangle, 1 to 2 km northeast of General Carneiro. Ferruginous rocks mainly mosaic-textured quartz with weak layered concentrations of magnetite and yellow-brown iron oxide. Two samples have medium-grained detrital quartz in weakly foliated matrix of epidote, chlorite, sericite, and magnetite. One sample is poorly banded quartzitic magnetite-grunerite(?) iron-formation. Most of the red-brown and yellow-brown iron-oxides from weathering of magnetite.

Petrographic data for the Sabará formation—Continued

Staurolite-garnet schist

[Data based on 10 thin sections]

Dominant minerals (>15 percent)	Subordinate minerals (5–15 percent)	Minor minerals (<5 percent)
Quartz Mica—muscovite and biotite *Chlorite *Tourmaline *Staurolite	Chlorite *Staurolite *Sodic plagioclase *Magnetite	Staurolite Garnet Magnetite Feldspar *Chlorite *Mica *Brownish iron oxide *Quartz

NOTE.—Grain sizes from less than 0.1 to 2 mm, but most grains are 0.1–2 mm. Lepidoblastic and porphyroblastic textures. Crinkling of foliation surfaces common. Folia generally represented by alined blades of mica and chlorite with seams of quartz between them. In some samples with microaugen structure, blades of mica anastomose around single quartz grains or small aggregates of quartz, and have preferred but not complete alinement parallel to foliation. Staurolite and garnet form medium- and coarse-grained porphyroblasts. Staurolite has prominent sieve structure. One sample of tourmaline-quartz schist from northeast bank of Rio das Velhas 500 m north of place where river leaves Nova Lima quadrangle. Some garnet partly or completely replaced by brownish iron oxide during weathering.

Subgraywacke and graywacke

[Data based on 13 thin sections]

Quartz *Feldspar—mainly or entirely sodic plagioclase *Sericite *Chlorite	Feldspar Biotite Chlorite Sericite (including some fuchsite?) *Epidote	Epidote Magnetite *Feldspar *Sericite *Biotite

NOTE.—Grain sizes from less than 0.1 to 2 mm. Medium sized equant grains of quartz or quartz and feldspar studded through finer grained matrix of quartz, mica, chlorite, epidote, and magnetite. Matrix of some samples moderately foliated; in other samples, not foliated, but with granulitic texture. Biotite in two samples forms porphyroblasts studded with inclusions of quartz, and in most samples biotite is in relatively large blades. Paragenesis of biotite-chlorite not clear in thin section. Magnetite in one sample has grown partly around quartz and detrital feldspar; therefore, it is postdepositional.

Quartz-sericite-chlorite schist

[Data based on 2 thin sections]

*Quartz *Sericite *Biotite	*Chlorite *Sericite	*Hematite *Magnetite? *Yellow-brown iron oxide *Quartz *Zircon

NOTE.—Grain sizes mainly less than 0.1 mm. Some blades of sericite are 0.1–2 mm. These schists inadequately represented by thin sections because of softening effects of weathering. Moderately strong foliation. One sample has thin layers composed of the three dominant minerals in different proportions. Within layers, texture is decussate with practically no foliation. Yellow-brown iron oxide mainly along shear seams and stains weathered sericite or chlorite.

In the section along the Rio das Velhas, approximately the lower half of the formation consists of interbedded quartz-chlorite-sericite schist, graywacke, subgraywacke, and chloritic quartzite. The schist forms about 90 percent of this rock assemblage and weathers to material from which it is difficult to obtain a thin section. Biotite is scarce in the schists of approximately the lower half of the Sabará formation, but is common (in subordinate amounts) in the interbedded graywackes and subgraywackes.

With approach to the intrusive granitic and gneissic rocks toward the northwest across the formation, grain size and metamorphic grade increase. Platy minerals change from fine-grained shreds and irregularly shaped flakes to distinct blades of fine or medium size. The upper half of the Sabará formation is composed largely of biotite-muscovite schist in which porphyroblasts of garnet and staurolite commonly occur in minor or subordinate amounts (fig. 14). Chlorite is common in some of the biotite-muscovite schist; some chlorite grades into biotite with similar shapes and sizes and is probably a result of retrograde metamorphism of biotite.

The quartzite in the upper part of the formation is a friable fine-even-grained white rock, probably recrystallized chert.

AGE RELATIONS

Bedding in the Sabará formation parallels bedding in the Cercadinho formation. The evidence cited above indicating that the top direction is to the northwest in the Cercadinho formation also indicates that the Sabará formation stratigraphically overlies the Cercadinho.

Although the contact of the Sabará formation with granitic and gneissic rocks is approximately parallel to the trend of the Sabará, the metamorphic aureole in the Sabará formation that is parallel with, and adjacent to, the contact shows that the granitic and gneissic rocks are younger than, and in intrusive contact with, the Sabará. The younger age of the granitic and gneissic rocks is also indicated by the presence of thin pegmatites in the Sabará formation along the Rio das Velhas a short distance north of the quadrangle. The southwestward-trending tongue of granitic and pegmatitic rock in the upper part of the Sabará formation, about 1 kilometer east and southeast of General Carneiro, is conclusive evidence that the granitic rocks are intrusive into the Sabará formation.

QUATERNARY(?) AND TERTIARY(?) ROCKS

CLAY BEDS

Rocks of probable Tertiary age are known in three places in the Nova Lima and Rio Acima quadrangles. These places are small, relatively flat areas, as much as 300 meters across, and probably represent former lake bottoms or river flats in the bends of meanders. They are located in the Nova Lima quadrangle, 2¾ kilometers southeast of Sabará, and in the Rio Acima quadrangle about 1 kilometer southeast and about 1 kilometer northwest of the center of Rio Acima.

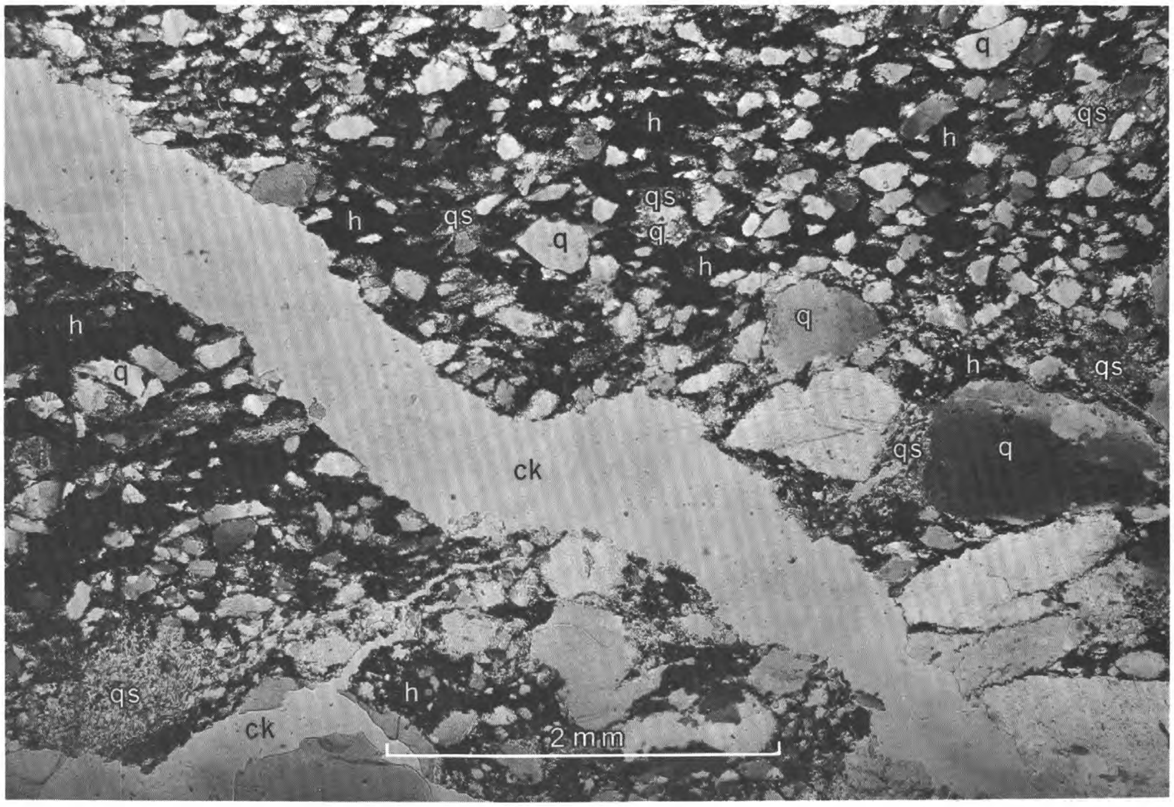

FIGURE 13.—Photomicrograph of ferruginous quartzite, Cercadinho formation, Piracicaba group. Highway between the Triangulo and Belo Horizonte, Nova Lima quadrangle (vicinity N. 9,125, E. 1,775). Angular and rounded quartz (q) grains in matrix of hematite (h), and finer quartz and sericite (qs). Several cracks (ck) in thin section. Nicols partly crossed.

Beds are flat lying and the material consists of clays of different colors, mainly light gray, light creamy yellow, and white. Pink and dark-gray clay are less common. The deposit of clay in the Nova Lima quadrangle contains unidentified fossil leaves and plant stems.

Harder and Chamberlin (1915, p. 374–375) described "irregular deposits of clay and sand containing lignite and fossil leaves," which, on the basis of the plant remains they referred to the middle or late Tertiary. The clay deposits described by them occur in the Gandarela area, east of the area of the present report, at the bottoms of some valleys that had been incised into a canga-capped plateau. On the basis of similarity of material, if not of exact similarity in geologic setting, the clay beds in the Nova Lima and Rio Acima quadrangles are tentatively considered of equivalent age to those described by Harder and Chamberlin.

MUDSTONE

Surficial deposits of dark-brown to reddish-brown structureless compact material are found in three places in the Nova Lima quadrangle, on or close to the contact between the Itabira and Piracicaba groups. The largest of these three deposits centers approximately at N. 9,260, E. 2,060, and is well exposed in cuts along the Belo Horizonte–Triangulo road. This deposit lies astride the contact between the Cauê itabirite and the Cercadinho formation, but is mainly in the area of the Cauê. The two smaller deposits are respectively about 500 meters and 1,000 meters east-northeast of the larger deposit and lie astride the Cauê itabirite.

The rock consists mainly of a brown matrix that resembles baked mud. Rounded medium-size quartz grains are randomly distributed through the rock, and probably form only a few percent of the material. Nodules of brown iron oxide are common. In places adjacent to the contact with the Cauê itabirite, the rock contains fragments of itabirite and ocherous material derived from the Cauê. Much of the "baked mud" matrix may have been derived by weathering and reworking of ocherous itabirite. The rock appears somewhat similar to known hardened mudflows and for this reason, as well as for lack of a better name, it is called "mudstone."

The age and origin of the mudstone are uncertain. The locations of the mudstone astride or close to the contact of the Cauê itabirite and Cercadinho formation, as well as the composition of the mudstone, indicate that it has been developed virtually in place. Evidently, material derived from ocherous itabirite, and at least in some places, from ferruginous quartzite, was required to form the mudstone, but controlling factors of weathering and(or) erosion are not yet understood. It is not known, for example, whether the mudstone developed on favorable rocks merely by subaerial weathering, or whether it formed as deposits of mud along stream courses or beneath shallow bodies of water ponded on a former peneplained surface. The mudstone evidently formed either during the present erosion cycle, or is a remnant of the surface formed during the preceding cycle. The mudstone, therefore, probably is not older than Tertiary.

CANGA

Canga is a Brazilian term for a surficial rock widely developed on or adjacent to iron-formation, and less commonly on other types of rock relatively rich in iron. It is typically composed of fragments of iron-formation (itabirite), and locally of hard blue hematite, strongly cemented by hard yellow-brown and red-brown iron oxides precipitated from ground-water solutions. Canga forms a hard surface capping that is very resistant to erosion. In the same area it may have developed during different erosion cycles and therefore may be of different ages.

There is only one canga plain of mappable size in the Nova Lima quadrangle near N. 8,360, E. 300 and a few very small patches of canga low on the southeast flank of Morro do Pires in the northwestern part of the Rio Acima quadrangle. The body of canga in the Nova Lima quadrangle overlies Cauê itabirite and forms a resistant cap on the highest part of the Serra do Curral in the quadrangle.

This canga probably formed on, and is a remnant of, an old Tertiary peneplain that has been dissected to produce the present topography. The canga, therefore, is tentatively dated as Tertiary in age.

RECENT DEPOSITS

The only deposits definitely known to be of Recent age in the area are blocks, cobbles, gravel, and sand along parts of the Rio das Velhas and a few of its tributaries. The main areas of such surficial deposits extend along the Rio das Velhas for 3 kilometers southwest of Sabará, and for 1.5 kilometers north and 2 kilometers south of Honorio Bicalho. This material

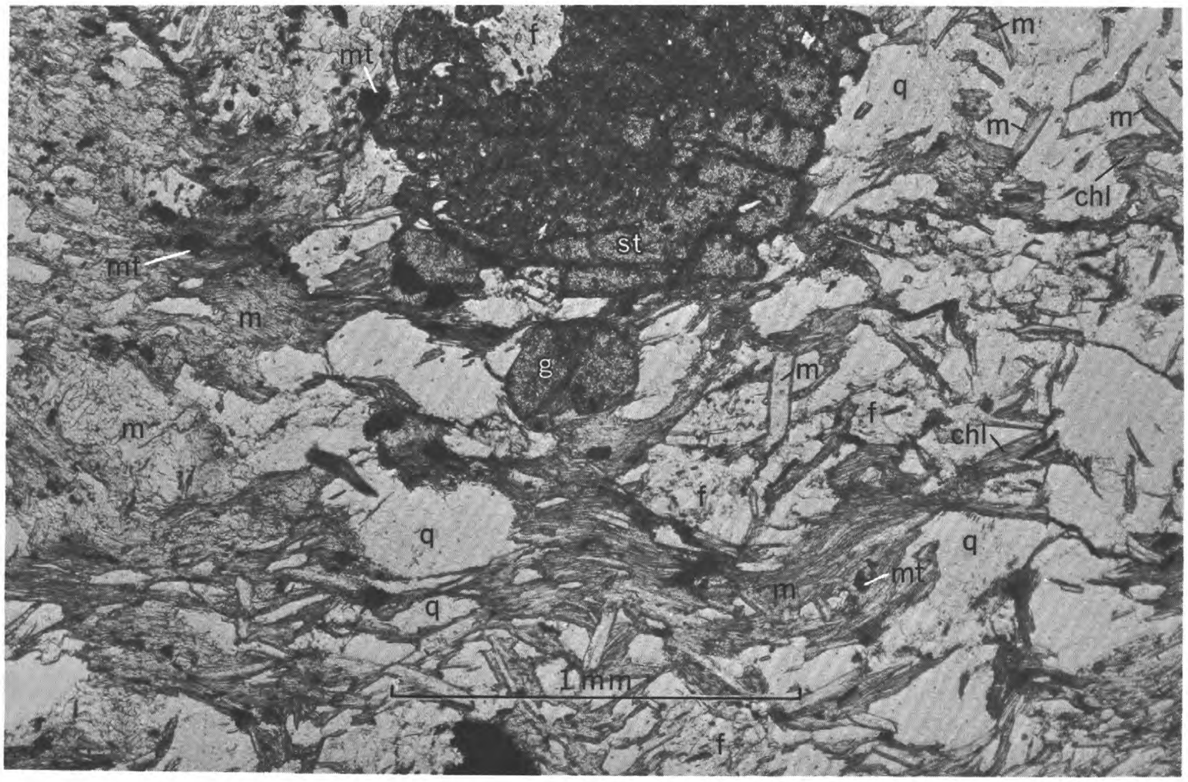

FIGURE 14.—Photomicrograph of staurolite-garnet schist, Sabará formation. Along northeast bank of Rio das Velhas, a few hundred meters north of north edge of Nova Lima quadrangle. Porphyroblasts of staurolite (st), garnet (g), and feldspar (f) in schistose groundmass of quartz (q), muscovite (m), chlorite (chl), and magnetite (mt). Feldspar typically has sieve structure. Chlorite probably retrogressive from biotite. Foliation surfaces somewhat crenulated. Plane polarized light.

has not been mapped during the present work.

Southwest of Sabará the Recent deposits consist mainly of boulders, cobbles, and gravels of schist, quartzite, itabirite, hard blue hematite, metadiabase and vein quartz. Near Honorio Bicalho, pebbles of vein quartz and cherty quartzite, and large slablike blocks of pre-Minas iron-formation are mixed with sand and silt.

INTRUSIVE ROCKS

METAMORPHOSED MAFIC AND ULTRAMAFIC ROCKS

SERPENTINITE

Serpentinite forms an elongate northward-trending body about 4 kilometers in length in the southwestern part of the Rio Acima quadrangle and in the adjoining part of the Macacos quadrangle to the west. (J. B. Pomerene, written communication, 1958).

The serpentinite is well exposed for about 1 kilometer south of the road that crosses the west edge of the quadrangle, 2,440 meters north of the southwest corner. Good exposures are also found within 400 meters of the west edge of the quadrangle, between 3,500 and 4,300 meters north of the south edge of the quadrangle.

The rock is found as small blocky and knoblike outcrops. Many outcrops are strongly jointed with narrow weathered-out gaps along joints. The spacing of joints commonly ranges from about 0.3 meter to 1 meter. Although no attempt was made during the present study to determine whther there is a preferred statistical orientation of these joints, the most prominent joints appear to strike between N. 20°E. an N. 55°E. Zones of foliated, fine-grained serpentinite, generally less than 5 meters in thickness and less than 25 meters in strike length, are widespread in the more massive serpentinite, apparently are irregular in orientation, and are interpreted here as representing local zones of shearing developed during emplacement of the rock.

Veinlets of asbestos occur in the serpentinite and are mined from the southern part of the serpentinite body, a short distance west of the Rio Acima quadrangle. (J. B. Pomerene, written communication, 1958).

PETROGRAPHY

The serpentinite varies from dark grass green to dull green and gray green. Weathered surfaces are green, greenish brown, yellow brown, or dark brown.

The principal mineral of the serpentinite is antigorite, in bladed and platy aggregates pseudomorphous after olivine. Although no olivine remains, its crystal forms are distinct in many places, and irregular fractures, such as commonly transect olivine grains in dunite, are well preserved. The original grains were medium and coarse, whereas most of the present antigorite is fine grained. Blades of antigorite may be well alined in one preferred direction within individual pseudomorphs, or they may form a cross-hatch structure as is typical of many serpentinites from other parts of the world. Seams and veinlets of a fibrous serpentine occur both along boundaries between, and in cracks transecting, original olivine crystals.

Small amounts of magnetite occur throughout the serpentinite, and talc and tremolitic amphibole are minor constituents of some of the serpentinite. The magnetite generally is in fine isolated grains or streaky zones, and less commonly in lenticular aggregates, or in isolated skeletal crystals. Talc is generally interleaved with antigorite, and tremolitic amphibole occurs in isolated relatively large blades.

Veinlets of talc or quartz are widespread, but are small and much less common than veinlets of fibrous serpentine.

AGE AND ORIGIN

The serpentinite is intruded into rocks of pre-Minas age. The present serpentinite was probably intruded as dunite or peridotite, and altered to its present composition either during or following the time of intrusion. The precursors of serpentinites and associated mafic rocks are not known to have intruded rocks of either the Minas series or younger age elsewhere in the Quadrilátero Ferrífero (J.V.N. Dorr, 2d, written communication, 1955). On this basis, the serpentinite is assigned a post-Nova Lima, pre-Minas age.

Although the serpentinite clearly has been derived from dunite or peridotite, no evidence has been obtained in the area of the present report of the process by which dunite or peridotite was altered. Residual or later aqueous solutions probably were responsible for the change of olivine or olivine and pyroxene to antigorite and talc (Bowen and Tuttle, 1949, p. 439–460; Turner, 1948, p. 130–133).

Bowen and Tuttle (1949, p. 453) have shown that serpentine and talc assemblages form during the cooling of a mass of forsterite and enstatite in the presence of excess water vapor. The antigorite-talc assemblages, as well as the minor tremolitic amphibole in some of the serpentinite of the present area, suggest that the original ultramafic rock contained pyroxene as well as olivine.

Local crosscutting of schist and phyllite of the Nova Lima group by serpentinite is indicated by the contact pattern of the two rocks. The general conformity of trend of the elongate serpentinite body with foliation of the schist and phyllite, however, suggests that to a large extent, foliation of the schist and phyllite controlled the intrusion of the original dunite or peridotite.

METAGABBRO

DISTRIBUTION

Metagabbro forms a small body in the west-central part of the Rio Acima quadrangle near N. 7,500, E. 2,460, and two bodies bordering the serpentinite in the southwestern part of the Rio Acima quadrangle. Metagabbro also occurs immediately west of the serpentinite, in the Macacos quadrangle to the west (J. B. Pomerene, written communication, 1958).

The metagabbro at the first-mentioned locality above is known only from abundant float of slightly weathered rock. Exposures of unweathered metagabbro are scarce and are found only along a stream between N. 830, E. 540, and N. 1,050, E. 500; in a cliff at N. 1,240, E. 600; and in an erosional "washout" near N. 2,440, E. 600. Exposures of strongly weathered metagabbro are found widely, particularly along the ridge top near N. 1,680, E. 620, in roadside banks and gullies, and where vegetation and thin topsoil have been worn away along trails. The metagabbro mapped near the north end of the serpentinite is known only from highly weathered material in gullies.

PETROGRAPHY

The unweathered metagabbro is a massive dull-green or a mottled green and white rock, most of which is unfoliated or slightly foliated. This rock commonly weathers to a compact mottled or spotted white and pink or white and yellow-brown fine-grained material, distinct from the known weathering products of other rocks in the area. In places the weathered metagabbro is soft and clayey; in other places it is relatively hard.

The unweathered metagabbro characteristically contains dominant tremolitic hornblende and zoisite or clinozoisite, with smaller amounts of sodic plagioclase, chlorite, and sericite, and with minor ilmenite-leucoxene. Bladed tremolitic hornblende commonly is surrounded by finely granular aggregates of clinozoisite. These aggregates of clinozoisite commonly have vague to distinct blocky or lath forms, pseudomorphous after plagioclase. In some of the metagabbro, needles of tremolitic hornblende, intergrown with flakes of chlorite, occupy angular patches between lathlike aggregates of clinozoisite. In places, remnants of sodic plagioclase are surrounded by or intergrown with, zoisite or clinozoisite. Premetamorphic textures were gabbroic, ophitic, and subdiabasic. Where sodic plagioclase is included within blocky or lathlike aggregates of clinozoisite, it seems likely that the sodic plagioclase developed from calcic plagioclase while most of the lime of the original feldspar was utilized in forming clinozoisite. The mineral assemblages demonstrate metamorphism in the chlorite zone or the lower part of the greenschist facies.

The highly weathered metagabbro consists principally of a chlorite mineral and yellow-brown to red iron oxides. The chlorite mineral has low birefringence, is nonpleochroic, and has a mean index of refraction of 1.570–1.573. It forms a matted fabric of fine- and even-grained clumps or books with decussate texture. Spotted through the mass of chlorite are areas containing concentrations of fine dust and granules of iron oxides. These areas are generally rather well defined and are believed to represent original ferromagnesian minerals.

AGE, ORIGIN, AND RELATIONSHIP TO SERPENTINITE

The metagabbro is intrusive into rocks of the pre-Minas Nova Lima group and is clearly associated spatially with the serpentinite. As noted in the section on the age and origin of the serpentinite, altered basic rocks associated with serpentinite are not known to be younger than pre-Minas age elsewhere in the Quadrilátero Ferrífero. The metagabbro is therefore tentatively assigned a post-Nova Lima–pre-Minas age.

No contacts between serpentinite and metagabbro have been seen and therefore the order of intrusion at the level of the present erosion surface is not known.

TALC SCHIST

DISTRIBUTION

Talc schist occurs in two narrow zones in the southwestern part of the Rio Acima quadrangle. One zone extends roughly eastward across the southern part of the serpentinite body to its east edge, thence north-northeastward along the eastern edge for 600 meters. The other zone extends north-northeastward across most of the larger of the two bodies of metagabbro. This zone lies virtually along the line of projected trend of the first-mentioned one. Although there are no outcrops in the narrow area between the two zones of talc schist, the soil there is typical of that overlying schist and phyllite of the Nova Lima group and the talc schist therefore probably does not extend continuously from one zone to the other. A possible cause of the alinement of the two zones is discussed in the section on the origin of the talc schist.

PETROGRAPHY

The talc schist is strongly weathered and therefore not readily studied in thin section. The weathered rock is generally light yellow brown or buff and moderately to strongly foliated. It typically forms narrow elongate slablike outcrops.

The rock consists mainly of fine-grained talc, generally well alined, but locally with decussate texture.

In addition to talc, the rock contains minor amounts of dusty yellow-brown iron oxide, magnetite, and chlorite in thin seam fillings that parallel foliation.

ORIGIN

One widely accepted mode of origin for talc is by the alteration of ultramafic igneous rock, either directly to talc-rich rock, or through an intermediate serpentine-rich stage (Hess, 1933*a*, 1933*b*; Turner, 1948, p. 132–133). The envisaged alterations involve the addition of silica and removal of some magnesia by hydrothermal solutions, or the addition of carbon dioxide and the accompanying formation of carbonate. The association of the talc schist of the present area with serpentinite and metagabbro is here considered strong evidence that the talc schist formed either by direct alteration of ultramafic and mafic rock in place, or that the talc was derived from the surrounding ultramafic and mafic rocks during their alteration, and was subsequently carried into place by hydrothermal solutions.

The alinement of the two zones of talc schist and the pronounced foliation of the schist parallel to the trend of the zones suggest that the schist was localized along a shear zone that extended across the serpentinite, the metagabbro, and the intervening schist and phyllite of the Nova Lima group. The talc schist occurs only where this inferred shear zone is in serpentinite and metagabbro and probably was produced in place by hydrothermal alteration of those rocks.

METADIABASE

DISTRIBUTION

Metadiabase and weathered rock that probably was metadiabase are widely distributed in the quadrangle. Exposures are small and relationships with the country rock generally can only be inferred. The diabase dikes can be followed along the strike for only very short distances and in most parts of the area have been projected only short distances from observed exposures in road cuts, railroad cuts, trails, or creeks. The three longest dikes shown in the southern half of the Nova Lima quadrangle (pl. 1) have been mapped by projecting between relatively numerous small exposures of weathered metadiabase found along the lines of the dikes.

Unweathered or little-weathered metadiabase is best known in the Nova Lima quadrangle from the Raposos mines, but is also found at the surface near the mines at N. 3,800, E. 5,200 and at N. 4,400, E. 5,100. Elsewhere in the quadrangle relatively fresh metadiabase is is found in pre-Minas rocks in the vicinity of N. 4,300, E. 8,120 and has been reported from the Morro Velho mine. Unweathered metadiabase is found in the Minas series northwest of Sabará, and in post-Minas granitic rocks near N. 12,060, E. 530. In the Rio Acima quadrangle such rock is known only from the bed of Ribeirão Macacos, 1,500 meters southwest of Honorio Bicalho.

PETROGRAPHY

Weathered metadiabase is typically mottled or patchy pink and white, pink and yellow brown, or red brown and yellow brown, with the areas of different color poorly defined. The fresher metadiabase is generally a dull green and fine- to medium-grained. Original textures are not evident except in thin section where the rock is seen to have relict diabasic texture, typically modified to some extent by shearing.

The principal minerals of the metadiabase are pale-green hornblende, chlorite, biotite, and clinozoisite. The rock also contains small amounts of plagioclase, ilmenite, leucoxene, magnetite(?), quartz, and in places, carbonate, epidote, apatite, and sericite.

Hornblende in isolated or small clusters of bladed crystals is commonly associated with chlorite. Some hornblende has been partly altered to biotite and chlorite and some rock has blocky-shaped aggregates of biotite, evidently pseudomorphous after hornblende or pyroxene.

Clinozoisite forms granular aggregates in which sodic plagioclase, chlorite, and quartz commonly are intergrown. Plagioclase in these aggregates occurs both in irregular and in lath-shaped grains. Individual aggregates in the present rock are generally clearly defined in thin section, in places are blocky or lath-shaped, and are thought to represent individual crystals of original calcic plagioclase. In some of the metadiabase the aggregates are somewhat lensoid and alined as a result of shearing of the rock.

Leucoxene forms granular aggregates or rims ilmenite.

AGE AND METAMORPHISM

The metadiabase, containing mineral assemblages typical of regionally metamorphosed mafic rock, can be dated only as younger than the country rock in which it occurs, and as older than the post-Minas regional metamorphism. Metadiabase in the granitic rocks in the northwestern part of the Nova Lima quadrangle indicates that post-Minas regional metamorphism continued until after the time of granitic intrusion.

Metadiabase in the Raposos mines contains biotite of secondary (metamorphic) origin, although the country rock in the mine is known to contain chlorite-sericite assemblages indicative of regional metamorphism of lower grade than the biotite zone. This may be explained by the fact that biotite can form in diabase before it does in sedimentary rock at a given level of metamorphism. On the other hand, unknown factors of composition or of date of intrusion in relation to regional metamorphism may have caused this apparent metamorphic anomaly.

GNEISSIC, GRANITIC, AND PEGMATITIC ROCKS

DISTRIBUTION

Gneissic, granitic, and pegmatitic rocks of the area of this report are confined mainly to the northwestern part of the Nova Lima quadrangle. Granitic or pegmatitic rocks, however, are known in or have been reported from three places in the southern half of the quadrangle. Thin lenses of granitic rock are in lit-par-lit relationship with Nova Lima schist in a small exposure only a few meters across in the southwestern part of the quadrangle near N. 240, E. 1,300. A small body of quartz monzonite has been reported from the Raposos mines (Graton and Bjorge, written communication to St. John del Rey Mining Co., 1929.) but was not seen by the present writer. A weathered pegmatitic dike crosses the Nova Lima–Raposos road at N. 4,830, E. 4,000.

The gneissic, granitic, and pegmatitic rocks in the northwestern part of the Nova Lima quadrangle have been mapped as one unit. They are rather intimately intermixed and do not appear to occupy distinct areas that would be practical to separate at the scale of the present mapping. Furthermore, the scarcity of good exposures probably would prevent their being mapped separately even at a larger scale.

PETROGRAPHY

The gneissic rocks are mainly light gray, but have dark-gray or greenish-gray layers, in places streaky and poorly defined, in other places, clearly defined. The granitic and pegmatitic rocks are typically a rather uniform light gray.

The gneissic rocks generally are fine grained to medium grained and moderately foliated, the granitic rocks are medium grained and slightly to moderately foliated, and the pegmatitic rocks are coarse grained and unfoliated.

The principal minerals in the gneissic rocks are quartz, feldspar, and micas, and in the granitic rocks, quartz and feldspars. Accessory minerals include epidote or zoisite, chlorite, and leucoxene, which in the gneissic rocks typically occur with micas along shear zones and seams and, in slightly foliated granitic rocks, are in small patchy areas interstitial to quartz and feldspar. The darker layers of the gneissic rocks are defined by concentrations of biotite. Veinlets of epidote cut the granitic rocks in places.

The gneissic rocks are granodioritic in composition, but typically have less feldspar and more quartz, biotite, epidote, and possibly chlorite than the granitic rocks of the area. Locally, through distances of 1 or 2 centimeters in thin section, feldspar is scarce and the rock fabric resembles that of fine- and even-grained quartz-mica schist. In such parts of the rock the scarce feldspar (mainly sodic plagioclase) commonly is medium grained, equant, and strikingly larger than the elongated and alined grains of quartz and micas of the groundmass.

A fine- to medium-grained garnet-bearing amphibolite has been found at one place in the northwestern part of the Nova Lima quadrangle near N. 12,160, E. 160, and is considered to be part of the gneiss. The amphibolite has a granoblastic fabric and consists mainly of pale-green hornblende, quartz, garnet, and aggregates of fine-grained sericite, epidote, feldspar, and quartz. Minor minerals are titanite, apatite, and ilmenite partly altered to leucoxene.

The granitic rocks are mainly of granodioritic composition, with abundant sodic plagioclase and small amounts of either microcline or orthoclase or both. Some granitic rocks have compositions of quartz monzonite and of tonalite. Sodic plagioclase in the granitic rocks is mainly oligoclase with a little albite. The potassium feldspar of these rocks is almost entirely microcline. Oligoclase is typically speckled with fine-grained flakes of sericite (locally also with chlorite), whereas albite and microcline are almost invariably much fresher looking. The possible significance of this difference in the feldspars is discussed in the following section on the age and origin of these rocks.

The feldspar of the pegmatitic rocks is mainly microcline. Quartz is both interstitial to and forms graphic intergrowths with microcline. Sodic plagioclase occurs in small amounts in the pegmatitic rocks, commonly as inclusions within much larger crystals of microcline. Micas are minor accessory minerals.

AGE AND ORIGIN

Relationships betwen the gneissic, granitic, and pegmatitic rocks are not well known. Granitic rocks have not been observed in contact with gneissic rocks. In cuts for a new road along the north bank of the Rio das Velhas north of the Nova Lima quadrangle, about 600 meters north and 2,200 to 2,800 meters east of the northwest corner of the Nova Lima quadrangle small pegmatitic dikes and tongues cut gneissic rocks.

The granitic and pegmatitic rocks are intrusive into and younger than the Sabará formation. This is indicated by the large tongue of such rock extending southwestward from the north edge of the Nova Lima quadrangle into the upper part of the Sabará formation, by the intrusive relations between granitic rock and the Sabará near General Carneiro, and by the thermal aureole of staurolite and garnet schist adjacent to the contact between the Sabará and the area of gneissic, granitic, and pegmatitic rock.

Sericitized sodic plagioclase and fresh potassium feldspar in the granitic rocks probably represent two generations of feldspar, with the potassium feldspar the younger. These feldspars may represent early and late crystallizations during one period of magmatic intrusion, or they may represent an introduction of potassium feldspar into an existing plagioclase-rich rock.

It is not definitely known whether the gneissic rock is a banded granitic rock of intrusive origin or an original sedimentary rock that has been feldspathized and recrystallized in place. The well-defined layering and the abundance of quartz and mica with concomitant scarcity of feldspar in some layers, suggest that the gneiss originally was a quartz-mica sedimentary rock. Small percentages of relatively large blocky feldspar isolated in such quartzose, micaceous layers possibly constitute evidence of feldspathization. Much of the feldspar in the present gneiss probably grew during the post-Sabará intrusion of granitic and pegmatitic rock.

Whether the sediments that were probably reconstituted into gneiss in the northern part of the Nova Lima quadrangle were of Minas or pre-Minas age is unknown. The area of gneissic, granitic, and pegmatitic rocks extends northeastward (probably continuously) to the Itabira district. Dorr and Barbosa (written communication, 1955) have shown that at least some of the gneiss of the Itabira district formed by the feldspathization of sediments of pre-Minas age, and their mapping also indicates truncation of the Minas series by gneissic-granitic rocks. Consequently, possible sedimentary parent rocks of the gneiss may have been of more than one age.

QUARTZ VEINS

Quartz veins are ubiquitous in the area, but are seen in place in relatively few localities. The quartz is mainly white "bull" quartz, but a glassy gray quartz occurs in places. Vein quartz is especially abundant throughout the area of schist-phyllite of the Nova Lima group. The quartz is generally seen as spotty areas of pebbly and blocky rubble along ridge tops. In the few localities where seen in place, the quartz typically forms thin veinlets, less than a meter in thickness, and parallel or subparallel to the foliation of the enclosing schist and phyllite. The areas of vein quartz have not not been mapped seperately during the present investigation.

STRUCTURE

The principal structural features of the area are listed on page A–8, and include (1) the Rio das Velhas uplift; (2) the Vargem do Lima syncline; (3) the complexly folded iron-formation in the northwestern part of the Rio Acima quadrangle and the southwestern part of the Nova Lima quadrangle; (4) the inferred fault located mainly along the Rio das Velhas in the north-central part of the Rio Acima quadrangle; (5) the inferred fault crossing Morro do Pires; and (6) the eastward-trending fault in the Minas series near the west edge of the Nova Lima quadrangle.

BEDDING

Bedding is the dominant structure element in the pre-Minas and Minas iron-formations, in most of the other rocks of the Minas series, in graywacke and quartz-carbonate rock (lapa sêca) of the Nova Lima group, and in the conglomerate of the Casa Forte in the upper part of the Maquiné group. Bedding in the schists and phyllites of the Nova Lima group evidently is largely destroyed or masked by schistosity and has been observed in relatively few places.

SCHISTOSITY

The dominant structure element in pre-Minas rocks other than iron-formation and the Casa Forte formation is schistosity (foliation). Schistosity mainly strikes northeastward and dips southeastward. It is developed not only in the schists and phyllites of the Nova Lima group, and in schists of the Maquiné group, but also in all but the purer quartzites of the area, in graywacke, in some of the quartz-carbonate rock (lapa sêca) of the Nova Lima group, and in some of the conglomerate in the upper part of the Maquiné group. The shearing that produced this regional schistosity evidently did not penetrate the beds of iron-formation.

LINEATIONS

Lineation generally is not common in the area. "Lines" representing the traces of schistosity rather than an actual linear structure element are seen on nondescript rock surfaces throughout the area of pre-Minas schist and phyllite. The only lineation of significance is in the form of wrinkles or small rolls of bedding in tightly folded parts of the pre-Minas iron-formation. These lineations are alined parallel to local fold axes. Similar lineations have been observed in lapa sêca in a few places in the Morro Velho mine. Elongated pebbles lying in the plane of schistosity are found in places in the schistose conglomerate of the Nova Lima group, but only a few reliable measurements of their orientations have been made. In places, schistosity surfaces in the garnet and staurolite schists of the Sabará formation have been wrinkled with the attendant development of actual or incipient fracture cleavage. The axes of the wrinkles are at the intersections of schistosity with fracture cleavage surfaces, and form a prominent local lineation. The significance of this lineation is not definitely understood, although it may be related to deformation accompanying the intrusion of granitic rocks near the northwestern corner of the Nova Lima quadrangle.

FOLDS

RIO DAS VELHAS UPLIFT

The central part of the Rio das Velhas uplift lies partly in the Rio Acima and Nova Lima quadrangles. Aside from the area along the belt of Minas rocks in the northwestern part of the Nova Lima quadrangle, the flanks of the uplift lie outside these quadrangles, in the Belo Horizonte, Macacos, Itabirito, Gandarela, and Caeté quadrangles (fig. 1 and pl. 3). The core of the uplift trends from northwest to north to northeast across the Rio Acima and Nova Lima quadrangles, although this is apparent only on a regional map (pl. 3) showing the trends of contacts between the pre-Minas and the overlying flanking rocks of the Minas series.

Judging by the dips of rocks of the Minas series on the flanks of the uplift, the uplift is overturned to the southwest across much of the Rio Acima quadrangle, to the west in the northern part of the Rio Acima and the southern part of the Nova Lima quadrangles, and to the northwest in the northern part of the Nova Lima quadrangle. Although the pre-Minas rocks in general appear to follow the regional trend of the uplift, commonly bedding in these rocks is locally not parallel with the contact between pre-Minas and Minas rocks (Rynearson and others, 1954). In places, the pre-Minas rocks are complexly folded and cross the general trend of the uplift at wide angles. This is particularly evident in the northwestern part of the Rio Acima quadrangle and the southwestern part of the Nova Lima quadrangle.

It is difficult to date the folding of the pre-Minas rocks. The fact that in places the contact between rocks of Minas and Rio das Velhas age truncates beds of the latter series indicates that folding occurred prior to Minas time. However, the post-Minas forces that produced the Rio das Velhas uplift probably caused some additional folding of the pre-Minas rocks. It is not well understood to what extent the tight folds in the northwestern part of the Rio Acima and the southwestern and south-central parts of the Nova Lima quadrangles orignated during pre-Minas, and to what extent, during post-Minas deformation. The belt of iron-formation in the northwestern part of the Rio Acima quadrangle and the southwestern part of the Nova Lima quadrangle has a general northward to northwestward trend and is evidently truncated by the belt of Minas rocks in the Belo Horizonte quadrangle a short distance northwest of Nova Lima. This general trend of the belt of pre-Minas iron-formation therefore probably was established in pre-Minas time. Possibly the tight eastward-trending and eastward-plunging folds, which lie across the general trend, formed in post-Minas time, as a result of the same north- to northwest-directed movements that are presumed to have caused the overturning of the Minas series in the northwestern part of the Nova Lima quadrangle (Gair, 1958b).

Southward across the east-central part of the Rio Acima quadrangle, quartz-dolomite-ankerite rock and associated rocks appear to trend gradually toward the contact between the Nova Lima and Maquiné groups. Following deposition of the Nova Lima group and prior to deposition of the Maquiné group there evidently was slight uplift, and some erosion of pre-Maquiné rocks.

VARGEM DO LIMA SYNCLINE

The Vargem do Lima syncline trends north-northwestward across the eastern part of the Rio Acima quadrangle and ends by closure in the southeastern part of the Nova Lima quadrangle. The Vargem do Lima syncline is truncated by the Minas series about 20 to 25 kilometers southeast of the southeast corner of the Rio Acima quadrangle (Dorr, J. V. N., 2d, written communication). The structure is named after Corrego Vargem do Lima, an important tributary of the Rio das Velhas in the northeastern part of the Rio Acima quadrangle. The syncline involves mainly rocks of the Maquiné group, with the upper part of that group occupying the core of the structure.

Rocks of the Nova Lima group underlie the Maquiné apparently with slight unconformity along the west limb of the syncline in the central part of the Rio Acima quadrangle. Folds that adjoin the syncline, on the west in the Nova Lima group, limit the west limb of the syncline approximately to the area east of the Rio das Velhas.

The recognition of the Vargem do Lima fold is based on the following features:

1. The pattern made by the conglomerate beds in the Casa Forte formation indicates a structural closure in the northeastern part of the Rio Acima quadrangle. Plate 2 carries virtually an outcrop map of this conglomerate. Evidence of closure is strongest at the following places: (a) In the vicinity

of N. 11,800, E. 10,260, where beds of conglomerate from both limbs of the fold come close together (the conglomerate cannot actually be traced continuously from one limb to the other); (b) In nearly continuous outcrop between N. 9,040, E. 12,280 and the knob at N. 9,520, E. 11,860, conglomerate grades into quartzite, which in turn grades into schist. Conglomerate extending northward from near N. 7,740, E. 11,950 lenses out 200 meters south of the top of the same knob. The horizon along which the conglomerate occurs clearly forms a closure on this knob; (c) The evidence of closure at location (b) is corroborated by the trend of the conglomerate and by the topography on the twin knobs located about 1 kilometer north of the knob at N. 9,520, E. 11,860.

2. Prevailing eastward or nearly eastward strikes of bedding in the southeastern part of the Nova Lima quadrangle near N. 300, E. 10,900 and along the road east of Raposos. Aerial photographs of this part of the area also show prevailing east-west trends of bedding, which compared with the prevailing northward trends farther to the south, indicate a closure.

3. The failure of prominent quartzite beds to extend north of the extreme southeastern part of the Nova Lima quadrangle, combined with the map pattern made by the beds of conglomerate and with the east-west trends, as mentioned above, also indicates a structural closure.

4. General lithologic similarities east and west of the core of the fold. The Palmital formation contains discontinuous lenticular beds of quartzite interbedded with dominant schist, both east and west of the core of the fold. The core contains more abundant massive, and continuous quartzite rocks of the Casa Forte formation. Rocks immediately east of the lower part of the Maquiné on the east limb of the fold in the Gandarela quadrangle are dominantly phyllites with some interbedded iron-formation, and are lithologically similar to some of the schists and iron-formation of the Nova Lima group west of the lower part of the Maquiné on the west limb of the fold.

The conclusion that the Vargem do Lima fold is a syncline is also based on the consideration (p. A–33) that the Maquiné group (at the core of the fold) is younger than the Nova Lima group (on the flanks of the fold).

The truncation of the Vargem do Lima syncline by the Minas series southeast of the present area indicates that the Vargem do Lima syncline was formed prior to the deposition of the Minas series.

FOLDS IN THE SANTA RITA–NOVA LIMA–RAPOSOS AREA

Between Santa Rita in the north-central part of the Rio Acima quadrangle, Nova Lima, and Raposos, the Nova Lima group is deformed into several eastward-trending, eastward-plunging folds, lying across the regional northward to northwestward trend of the pre-Minas rocks in that part of the area. The folding is indicated by the trends and by crumpling of individual beds of iron-formation at the surface and in the Raposos mines, and of lapa sêca in the Morro Velho mine and vicinity.

The discontinuous lenticular nature of the iron-formation combined with the effects of local small-scale folding and probable offsets along small faults tend to obscure and confuse the overall fold pattern. Fold axes in the iron-formation plunge northeastward, eastward, and southeastward (pls. 1 and 4).

Folds in lapa sêca in the Morro Velho mine are shown by the attitudes of bedding mapped on three levels of the mine (pl. 6). The folds are also emphasized by the plans of the stopes which closely follow lapa sêca, the host rock for the gold.

Fold axes mapped in the lapa sêca in the mine have orientations similar to those of fold axes in the iron-formation to the south and southwest, and to the northeast.

The folds in the lapa sêca of the mine appear to be drag folds on the north limb of the large fold extending at least from 1 kilometer southwest of Nova Lima to 1 kilometer west of Raposos. The surface projection of the axis of this fold probably passes northeastward from about N. 1,680, E. 1,800 to N. 2,640, E. 3,200, thence more nearly eastward to N. 2,800, E. 4,600, and from there northeastward to N. 4,340, E. 5,860. This fold is indicated southwest of the mine in the Nova Lima quadrangle by the change in the trend of iron-formation from northward to westward near N. 1,680, E. 1,800.

INFERRED FOLD IN SOUTHWESTERN PART OF RIO ACIMA QUADRANGLE

A thin discontinuous bed of iron-formation extends south-southwestward in the Rio Acima quadrangle from the vicinity of N. 3,200, E. 3,160. Although the iron-formation lenses out north of the Rio do Peixe, small boulders of iron-formation along the south-south-westward-trending ridge at N. 400, E. 1,680 indicate that the same horizon (with local lenses of iron-formation) follows this ridge to the south edge of the quadrangle, and probably beyond. The convergence of this ridge with the southward-trending bed or belt of iron-formation that crosses the south edge of the Rio Acima quadrangle about 700 meters east of the southwest corner suggests a closure of the horizon of the iron-formation a short distance south of the Rio Acima quadrangle. The trend of this inferred fold is at a large angle to nearby northwestward-trending rocks of the Minas series immediately outside the Rio Acima quadrangle to the southwest (pl. 3). This indicates that the inferred fold developed prior to deposition of the Minas series.

FAULTS

The existence or locations of most of the faults shown on plate 1 are inferred. Faulting is known with certainty in the northwestern part of the Rio Acima quadrangle near N. 10,140, E. 1,560 and in the east-central part of the Rio Acima quadrangle near N. 7,040, E. 9,960. In the latter place an isolated mass of quartzitic rock from the lower part of the Maquiné group occurs well west of similar quartzitic rock to the north and south. The nature of the faulting, however, and the orientation of the fault or faults must be inferred. Lower Minas rocks are cut off by a north-trending fault near the middle of the west edge of the Nova Lima quadrangle. Probable fault breccia occurs along this fault near the west edge of the Nova Lima quadrangle. A northwestward-trending fault causes small offsets in beds of ferruginous quartzite northwest of the Triangulo in the west-central part of the Nova Lima quadrangle. Small offsets of beds of itabirite and ferruginous quartzite in the Minas series at Sabará, and the offsetting of itabirite and ferruginous quartzite immediately north of Sabará are almost certainly results of faulting.

The major inferred fault of the area occurs mainly along the Rio das Velhas in the north-central part of the Rio Acima quadrangle. This fault is deduced from an apparent difference in deformation east and west of the Rio das Velhas. The rather thick massive quartz-dolomite-ankerite rock east of the Rio das Velhas and a short distance south of Honorio Bicalho trends northward with only small changes in strike. Immediately west of the Rio das Velhas in the same vicinity, iron-formation is rather tightly folded with common westward to northwestward trends. Some type of shear surface or zone between the crumpled schist and iron-formation and the uncrumpled quartz-dolomite-ankerite rock must exist approximately along the valley bottom of the Rio das Velhas.

The fault probably developed because of the great difference in rigidity between the sequence of thin-bedded iron-formation and the thick massive-bedded quartz-dolomite-ankerite rock, which facilitated the cross-folding of the former and not the latter.

The fault evidently dies out to the north and south where the quartz-dolomite-ankerite rock lenses out or thins sufficiently to be folded conformably with the more ferruginous parts of the Nova Lima group.

It is at present impossible to know whether beds of conglomerate in the upper part of the Maquiné group, and of iron-formation in the Nova Lima group, that in many places apparently are offset from similar beds, have actually been offset along faults, or merely are lenses. The fortuitous lensing in and lensing out of beds of iron-formation near one another, but at different horizons, for example, could produce apparent offsets. An interpretation of faulting has generally been made during the present work, however, in the interest of showing such possible separate lenses at a minimum number of horizons.

Most of the inferred faults in the zones of iron-formation of the Nova Lima group are small and evidently have helped to relieve local tensions or pressures developed during folding. Faulting in two places appears to have caused notable thickening of the iron-formation or overlap of the stratigraphic section: at Morro do Pires, and in the southwestern part of the Rio Acima quadrangle near N. 3,300, E. 1,500.

Beds of Minas rocks have been cut off and offset by faults near Sabará and near the place where rocks of the Itabira group cross the western edge of the quadrangle. The northeastern part of the main segment of the Minas series in the north-central part of the Nova Lima quadrangle appears to have moved a short distance northeastward stratigraphically over other Minas rocks lying to the northeast, whereas the southwestern part of the same segment appears to have sustained relative displacement southwestward stratigraphically over Minas rocks to the southwest. One kilometer west of Sabará the Minas series has been offset about 1 kilometer. The two beds of white friable quartzite in the upper part of the Sabará formation are cut off by a fault that trends nearly parallel to the Serra do Curral and the Minas rocks.

During northwestward overturning in the northwestern part of the Nova Lima quadrangle, accompanying the formation of the Rio das Velhas uplift, there was probably shearing along the contact between Minas and pre-Minas rocks as well as between individual beds within the Minas series. The shearing presumably was mainly dip-slip movements similar to those occurring along bedding during the formation of flexure folds. The faults trending subparallel to bedding or cutting bedding at a small angle in the Minas series are believed by the writer to be related to such movements. It seems likely that one of three possible types of movement was mainly responsible for the observed offsets. Displacement may have been caused by strike slip, possibly related to larger scale dip-slip movements; by dip-slip movements that produced overlaps of the ends of the faulted segments at the present erosion surface; or, by movements trending between the directions of strike and dip.

METAMORPHISM

Most of the area of the Nova Lima and Rio Acima quadrangles is characterized by low-grade regional metamorphism of post-Minas age. (See p. A-9.) Mineral assemblages of quartz, sericite, chlorite, and carbonate, or of tremolite amphibole, clinozoisite, and chlorite are typical. Grain sizes of less than 0.1 mm are normal in these rocks. There is little or no evidence in the schist and phyllite of the Nova Lima group of retrogression from a higher level of metamorphism. Chlorite is flaky and shredlike and does not suggest pseudomorphous development from blades of biotite.

Biotite occurs in metasedimentary schist in a few places in the southwestern part of the Rio Acima quadrangle, and in metavolcanic schist (or schistose metadiabase?) from a drill hole 1.4 kilometers south of Rio Acima. Biotite has also been found in 2 samples of iron-formation and in 1 sample of quartz-mica schist in the northwestern part of the Rio Acima quadrangle. The association of quartz, chlorite, sericite, and biotite has generally been considered unstable and representative of an absence of equilibrium during or after metamorphism (Turner, 1948; James, 1955). The spotty occurrences of biotite, therefore, are apparently anomalous. They may be accounted for by incomplete reaction in chlorite-sericite-quartz assemblages because of a thermal peak of short duration during regional metamorphism, by small undetected bodies of mafic rock intruded late in the period of post-Minas regional metamorphism, or by variations in available water during metamorphism. (See Yoder, 1955.) Without more knowledge of the systematic distribution of the metamorphic mineral assemblages in areas adjacent to the Rio Acima and Nova Lima quadrangles, attempts to explain the presence of biotite will probably remain largely conjectural.

In the northwestern part of the Nova Lima quadrangle, the Sabará formation is intruded by granitic rocks. The contact between granitic rock and the Minas series strikes northeastward, roughly parallel to the trend of the Minas series. Within the limits of the Sabará formation the metamorphic grade rises from the chlorite zone in the lower (southeastern) part of the formation to the staurolite zone in the upper (northwestern) part of the formation with approach to the granitic contact. Metamorphic isograds are generally parallel with the trend of the formation and with the contact between granitic rock and the Sabará formation.

Biotite is sparsely found in apparently anomalous association with chlorite and sericite in some of the schists in the lower half of the Sabará formation. The biotite there typically forms large porphyroblasts in contrast to the finer grained more shredlike chlorite and sericite, suggesting that the reaction by which biotite replaced sericite and chlorite was never completed.

The schists of the staurolite zone are typified by larger grain sizes and more pronounced foliation than the Sabará schists in the chlorite zone, and by porphyroblasts of garnet and staurolite. The porphyroblasts are set in a groundmass of strongly alined, and in places, chevron-folded biotite, muscovite, and chlorite. Similarities of size and clearly defined bladelike forms for biotite and chlorite indicate that the chlorite has formed pseudomorphously from biotite by retrograde metamorphism. Retrograde metamorphism has also produced a small amount of chlorite from garnet.

The conformability and proximity of the zone of staurolite-garnet schist to the contact of schist with intrusive granitic rock indicates that the high metamorphic grade of the schist is a result of thermal (contact) metamorphism.

GEOLOGIC HISTORY

The rocks and structures in the Nova Lima and Rio Acima quadrangles suggest the following events in the geologic history of the area:

1. Formation of the Nova Lima group: Sedimentation of mixtures of muds and fine silts, and locally of muds and coarser grained quartz-feldspar sand. Intermittent vulcanism, with emplacement mainly of basic or intermediate flows and (or) tuffs. Contemporaneous local chemical deposition of ferruginous carbonate, silica, and magnetite in basins with limited access to the open sea.
2. Slight uplift and erosion.
3. Deposition of the lower formation of the Maquiné group: Fluctuations of base level to give sedimentation, alternately rich in mud and in quartz-rich clastic sediments.
4. Deposition of the upper formation of the Maquiné group: Stronger uplift and active erosion of iron-formation and quartzitic rock of the Nova Lima group. Fluctuations of base level and alternating deposition of fine gravel, coarser grained clastic sediments, and of muds.
5. Local intrusions of ultramafic and mafic rocks.
6. Deformation (folding) of the Rio das Velhas series, formation of the Vargem do Lima syncline, possibly regional metamorphism, uplift, erosion leading to peneplanation.
7. Deposition of the Caraça group: Erosion of pre-Minas rocks with some fluctuations in base level resulted in the alternating deposition of clastic quartz-rich sediments and of muds.

8. Deposition of the Itabira group: Slight subsidence followed by a period of relative crustal stability. Alternating chemical precipitation of iron oxide (or iron hydroxide) and silica in environment of a generally well aerated sea bottom (probably a coastal shelf, but probably not in the immediate environs of a shore). Locally, circulation of sea water somewhat restricted, aeration limited, and slight chemically reducing environment produced. Alternating chemical precipitation of some magnesian carbonate muds, silica, and iron oxides. Toward end of time of deposition of the Itabira group, reducing conditions on sea bottom became more widespread, probably because continuing subsidence and warping of the sea bottom extended area of limited circulation of sea water.

9. Consolidation of sediments of Itabira group. Uplift and local erosion.

10. Deposition of the Cercadinho formation of the Piracicaba group: Continuing uplift with relatively frequent fluctuations in base level, resulting in alternate deposition of clastic sediments and of muds, including ferruginous mud from reworking of underlying itabirite. Gradual lowering and stabilization of base level. Possibly long interval with relatively little deposition during which formations between Cercadinho and Sabará formations were deposited west of the Nova Lima quadrangle.

11. Deposition of the Sabará formation: Laying down of thick deposits of mud under conditions of gentle subsidence. Local and brief reversals (uplifts) resulted in local deposition of clastic quartz-feldspar sands that gave rise to the present graywackes and subgraywackes.

12. Doming and orogenic deformation of most of the area of the two quadrangles with accompanying intrusions of granitic rock. Granitic intrusions possibly one cause of the doming. Some migmatization occurred, contributing to development of gneissic rocks. Probably time of gold-sulfide mineralization, and possibly, time of development of hard blue hematite in itabirite. Intrusion of diabase dikes. With continued doming and locally strong deformation, overturning of the Minas series occurred on the northwest flank of the uplift. This deformation attended by regional metamorphism to the level of the chlorite zone, although close to contacts with intrusive granitic rock, the country rocks were thermally metamorphosed to the staurolite zone.

13. Long period of crustal stability and erosion to regional base level (probably continued until Cretaceous time, based on considerations outside Nova Lima and Rio Acima quadrangles). Possible formation of canga on peneplain.

14. Gradual uplift, and erosion to local base levels. Formation of local clay deposits in areas of ponding. Mudstone may have formed during this stage.

15. Renewed uplift and active erosion, to present time. Formation of canga in place on ridge tops and slopes, by cementing action of circulating ground water.

ORE DEPOSITS

GOLD

There are remains of small gold prospects throughout the area, and old placer washings are common along the Rio das Velhas. Placer washings are particularly common a few kilometers south of Honorio Bicalho and near Sabará. Records of these ventures are not known to the writer and probably few were ever prepared. The story of these operations is now lost.

The St. John del Rey Mining Co. is the only important producer of gold in the area and in recent years has produced approximately 250 to 300 kilograms of gold per month from the Morro Velho mine at Nova Lima and the Raposos mines near Raposos. Although most of the prospecting and all mining in this area has been ostensibly for gold, the gold recovered almost invariably carries some silver. Silver represents about one-fifth of the production by weight at the Morro Velho mine. Production of gold is given in ounces troy. The St. John del Rey Mining Co. produces about 100 tons per month of As_2O_3 as a byproduct of its gold mining operations. The arsenic compound is derived from arsenopyrite. Silver and arsenic are not treated separately in this report.

MORRO VELHO MINE

Much of the historical information and data about chemical composition, mineralogy, and textures of the ores presented here have been taken from Annual Reports of the Directors of the St. John del Rey Mining Company and from private reports to the company by Prof. L. C. Graton and G. N. Bjorge, and by A. F. Matheson. The mine was studied early in 1928 by Bjorge and briefly by Graton, and many polished sections of the ore were prepared and studied by Graton and by A. B. Yates. Reports by Graton and Bjorge were transmitted to the company in 1929 and 1931. Matheson was company geologist from 1951 to 1954. Geology was mapped on three levels by the author (pl. 6).

HISTORY

The Morro Velho mine at Nova Lima has been operated by the St. John del Rey Mining Co. since 1834. The property had been worked before that for possibly 50 years. Mining began as an open pit operation. By 1867 the lode, which in its upper part plunges about 45° eastward, had been followed downward to a depth of about 1,100 feet. The pit was some 275 meters (900 feet) long in an eastward direction and 4.5 to 13.5 meters (15 to 45 feet) wide. The walls of the stope were supported by timbers. In 1867 fire destroyed an important part of the mine. Between 1868 and 1873 production dropped to between one-third and one-fifth of what it had been in the years immediately preceding the fire. Production figures are given in the following table:

Production at the Morro Velho mine

[Values are approximate]

Year	Gold (In thousands of ounces)	Ore milled (In thousands of tons)	Year	Gold (In thousands of ounces)	Ore milled (In thousands of tons)	Year	Gold (In thousands of ounces)	Ore milled (In thousands of tons)	Year	Gold (In thousands of ounces)	Ore milled (In thousands of tons)
1834	2	--------	1864	30	61. 5	1898	87	93. 5	1927	90	151
1835	2	--------	1865	60	58. 5	1899	95. 6	122. 5	1928	99	158
1836	3	--------	1866	62. 5	62. 5	1900	99. 5	142	1929	111. 5	166. 5
1837	4	9	1867	37. 5	65. 5	1901	86	155	1930	123	202. 5
1838	6	14	1868	12. 5	59	1902	81	147. 7	1931	116. 5	220. 5
1839	7	17. 4	1869	12. 5	52	1903	86. 5	145. 5	1932	110	238
1840	7. 5	20	1870	12	45. 5	1904	87. 3	145	1933	105	232
1841	7. 5	21	1871	12. 6	52. 4	1905	87. 5	147. 6	1934	95. 5	241. 2
1842	11	23	1872	2	17	1906	80	140. 5	1935	94	242
1843	13	25	1873	7. 5	8. 5	1907	97. 5	152. 8	1936	99	235
1844	13. 5	30	1874	38. 5	38. 5	1908	101	172. 5	1937	94. 5	242. 5
1845	13. 7	32. 5	1875	70	63. 5	1909	104	183	1938	95	258
1846	17	34. 5	1876	51. 5	61. 5	1910	98	190	1939	90	247
1847	21. 5	43	1877	54. 7	66. 5	1911	103	192	1940	83. 5	240
1848	28	60	1878	47. 5	67. 4	1912	93. 3	173	1941	78	226. 5
1849	32	67	1879	41	57. 5	1913	97. 5	145. 7	1942	83	222. 5
1850	34	67	1880	29. 7	48. 5	1914	107. 5	191	1943	95	212
1851	38	80	1881	33. 5	60	1915	109	193	1944	104	216. 4
1852	40	79. 5	1882	27	68. 5	1916	111	186. 5	1945	108. 5	217
1853	42	85	1883	23	63	1917	108	177. 5	1946	95	211. 5
1854	42	86. 5	1884	25. 6	59. 2	1918	100. 8	166	1947	95. 5	219
1855	40	85. 5	1885	27. 5	57	1919	105	166. 6	1948	91	211. 5
1856	34	86		Mine fell in		1920	99	147	1949	83	221. 5
1857	30	85	1892	20	3. 5	1921	120	168	1950	84	231. 5
1858	32. 5	87	1893	8. 5	12. 5	1922	113	158. 5	1951	87. 5	246
1859	42. 4	81. 5	1894	9. 6	20	1923	105. 8	158. 5	1952	91	236. 5
1860	52	73. 5	1895	38	56	1924	90	139	1953	78. 4	197. 8
1861	61. 5	70	1896	42. 5	74	1925	72	116	1954	83	207. 7
1862	62	66. 4	1897	52	84	1926	89	141. 5	1955	74. 8	194. 2
1863	52. 5	64									

Total tons milled 1834–1955	13, 840, 000
Total ounces of gold	7, 319, 400

During the years, 1868 to 1873, two vertical shafts were sunk southeast of the open pit (*A* and *B* shafts). One shaft cut ore at 318 meters (1,042 feet) near the bottom of the old pit and mining continued downward from the lower part of the old pit with the aid of heavy timbering. In 1886, with mining being carried on approximately 550 meters (1,800 feet) below the surface, the mine fell in, and all operations came to a halt.

In 1889, two new vertical shafts (*C*, pumping shaft and *D*, haulage shaft) were begun about 460 meters east of the center of the old open pit. Shafts *C* and *D* are located at the northeast end of the entrance adit, which enters the hill on the north edge of Nova Lima at N. 2,780, E. 2,510, and extends northeastward under the hill for about 275 meters. These shafts were sunk to a depth of 690 meters (2,264 feet) by 1892.

A crosscut was then driven 51.5 meters southward from *C* shaft at level 7 (Timber level—655 meters below surface) to the eastward plunging ore body. The lode was opened up eastward and westward from the crosscut at this level. A tunnel was then driven southward to the lode on level 8 from the bottom of *D* shaft and the lode was opened up at this level. During the next few years ore was mined between levels 7 and 8, and mining was extended on raises to level 6 (about 610 meters below surface). Ore between level 6 and the bottom of the old pit was not mined for fear of another disaster. A tunnel was driven eastward from the bottom of *D* shaft on level 8, approximately parallel with and north of the lode. Mining was extended downward 91.5 meters to level 9 by means of two winzes. Shafts *C* and *D* still provide the only access from the surface to the underground workings developed since 1892 (pl. 6A).

In 1897 a new vertical haulage shaft (*E* shaft) was begun at the east end of the tunnel from *D* shaft on level 8. Between 1898 and 1902 mining was extended downward by winzes to levels 10, 11, and 12 (depth 1,042 meters or 3,424 feet), with exploration and mining at given levels generally somewhat in advance of the sinking of *E* shaft.

In 1903 an eastward-trending tunnel was started from the bottom of *E* shaft on level 12, toward the proposed *F* shaft, which was begun in 1908 and bottomed at level 16 in 1909. By 1903, the system of using haulage tunnels north of the lode was finally settled on after experimenting with masonry haulage tunnels through the fill of the stopes on levels 9 and 10. Between 1903 and 1908 levels 13, 14 and 15 were put into production and later connected with *F* shaft.

The system of exploring and opening up new levels by means of winzes and later connecting the levels to main haulage shafts was continued nearly to the bottom of the mine.

Between 1909 and 1915, levels 16, 17, and 18 were developed, and *G* shaft was sunk from level 16 to level 20 (depth 1,777 meters or 5,826 feet). Between 1916 and 1919, levels 19, 20, and 21 were developed, and in 1919, *H* shaft was sunk from level 20 to level 22.

At these levels, the plunge of the lode is about 19°, and it was deemed more economical to sink the main haulage shafts on the incline below level 22.

Between 1922 and 1929, levels 23, 24, and 25 (depth 2,171 meters or 7,126 feet) were opened by means of inclined winzes and shafts *I* and *J*. A small ore body (Northwest ore body) of low grade was found northwest of the main lode on level 23, but during the first few years after its discovery, it was developed only on levels 24 and 25, where the grade is higher. Between 1931 and 1938 the Northwest ore body was also opened up and worked on levels 20, 21, 22, 26, and 27. The Northwest ore body was thought to be an extension of the Gamba lode, which, in the old open pit, lay north of and was separated from the main lode by a narrow septum of barren schist. The grade of the main lode dropped abruptly on level 25, and the Northwest ore body was the principal source of gold there.

In 1930 and 1931, levels 26 and 27 were reached by inclined winzes. Values improved in the main lode on level 27. This level was the deepest stoping level reached in the mine. Exploration winzes and tunnels opened up levels 28 and 29 (depth 2,417 meters or 7,938 feet) in 1932, but the grade of the ore was unsatisfactory. The deepest point in the mine was reached in 1934, at the bottom of a winze sunk from level 29 to level 30 (depth 2,453 meters or 8,051 feet). Rock temperatures of about 130° F, as well as the poor quality of the deposits, precluded deeper mining. In the same year (1934) all development work was suspended in the main lode below level 23, but was continued at deeper levels in ore bodies discovered after 1930. After 1936, all development work ceased in the main lode and thereafter virtually all production came from other lodes.

In 1930 a major ore body was found on level 22, a short distance south of the main lode. It was soon found at higher levels also. This lode was called the South ore body, and as this and other ore bodies were found, the original lode was designated the Main ore body. In the same year, a small lode was found west of the Main and South ore bodies on levels 11, 12, and 13, and was called the Black ore body. In 1931 a body of mineralized white quartz, markedly different from any other known deposit in the mine, was found on levels 10, 11, and 12, southeast of the old workings. It was named the White ore body. These deposits were developed extensively between 1930 and 1936. Development of the South ore body continued until 1941, then on level 24. The South ore body is now (1956) worked on level 8, and on all levels between 14 and 20.

In 1936, during the sinking of a new shaft (*X* shaft) between levels 12 and 15, a large ore body was discovered between levels 13 and 14, and named the "*X*" ore body. Since then, "*X*" ore body has been mined on level 8, and between levels 11 and 27, but in 1955 it was being mined only at level 8, and at all levels between 11 and a sublevel between 20 and 21. There was no output from level 27 after 1942, and none from level 26 after 1947. Since 1949 the deepest level worked has been 21.

In 1956 when this report was being written almost all production was from the South and "*X*" ore bodies, mainly between levels 11 and 20. However there was, and for many of the past 30 to 40 years has been, a small but steady production from the area of the old open pit.

In 1951, a new access shaft was started southeast of shafts *C* and *D*, but was discontinued for financial reasons in 1954, at a depth of 349 meters.

Plans of levels 8, 12, and 14, and the locations of ore bodies on those levels can be seen in plate 6.

GEOLOGIC SETTING

The ore bodies of the Morro Velho mine are located in massive thick- to thin-bedded quartz-dolomite or quartz-ankerite rock (lapa sêca). The lapa sêca is lenticular and is interbedded with schist (mainly quartz-carbonate-sericite-chlorite or quartz-sericite-chlorite schists; locally some schist is graphitic).

The dominant structure of the schists is a northward- to northeastward-striking, eastward- to south eastward-dipping schistosity; bedding is not commonly seen.

Within the mine the lapa sêca occurs in one main bed in which the Main, South and "*X*" ore bodies are found. Lapa sêca evidently occurs also in at least one other thinner bed in which the Black, Northwest, and Gamba ore bodies are located and in several thin beds that have not been mineralized. It is possible, however, that each bed of lapa sêca in which the three smaller ore bodies occur is at a different stratigraphic horizon; on the other hand, each bed may be at the same stratigraphic horizon as the lapa sêca enclosing the Main ore body, and may be folded or faulted into its present position.

Graton and Bjorge believed that the Northwest ore body was a folded-over extension of the Main ore body.

The lapa sêca is folded into four or more eastward-plunging folds in the mine. At least three of these folds persist between levels 8 and 22. These folds are evidently on the north flank but near the nose of a larger fold shown on plate 1, extending from southwest of Nova Lima to about 1 kilometer west of Raposos.

The attitudes of bedding in lapa sêca have been mapped on three levels during the present study, and are shown on plate 6. On plate 6, it can be clearly seen that the stopes of the Main, South and "*X*" ore bodies follow the trends of bedding in lapa sêca very closely. The plans of these stopes therefore represent, in effect, a plan of the folds in the mine.

The map of level 12 (pl. 6) indicates that the Main and South ore bodies are in two adjacent folds. The tight fold containing the Main ore body opens eastward. From the maps of the three levels (pl. 6) it can be seen that the Main ore body occupies both the axial region of this fold (the west end of the Main ore body) and part of the north limb of the fold, eastward from the axial region.

Graton and Bjorge noted that the Main lode had the form of a ribbon set on edge and plunging S 85°E at about 45° in the upper part and 15° in the lower part of the mine. (See also Lindgren, 1933, p. 676–677.) The "ribbon" is about 150 meters wide, averages 4.5 meters in thickness, and has a plunge length of more than 3.2 kilometers. They stated that the Main ore body is bounded on the north by lapa sêca and on the south by schist. The map of level 12 (pl. 6) shows that along the tunnel between shafts *E* and *F*, there is also considerable schist within 50 to 100 meters north of the Main ore body. Within a few inches of the lode on the south side of the Main ore body the schist commonly has stringers of sulfide and light-colored recrystallized carbonate. Graton and Bjorge observed that in many places the change from schist to lapa sêca is abrupt and the contact is steeply dipping across schistosity. On the other hand, in some places, where the contact is parallel to schistosity, a gradational change from schist to lapa sêca is more common. Graton and Bjorge point out that near the Main ore body the lapa sêca has a well-defined banding that trends eastward and dips steeply southward in approximate parallelism with the plane of the lode.

These observations of Graton and Bjorge, when combined with results of the present study, make it clear that the mineralization of the Main ore body occurred in lapa sêca adjacent to the contact between lapa sêca and schist on the north limb of an eastward-plunging fold. The locus of mineralization evidently was along the keel or along the north side of the keel, and extended upward onto the north limb of the fold for as much as 150 meters from the axial region. Possibly differences in the structural competency of lapa sêca and schist produced openings along, or near, the contact of these rocks during folding, along which mineralizing solutions were able to move.

The South ore body occupies mainly the axial region of the next fold south of the Main ore body (fold opens to the west). However, on level 12 a considerable part of the South ore body also extends northwestward along the common limb between the folds containing the South and the Main ore bodies.

The maps of levels 12 and 14 (pl. 6) clearly bring out the relationship of the South and "*X*" ore bodies. The main part of the "*X*" ore body is in the axial region of the second fold (fold opens westward) south of the ore in which the South ore body is centered. However the ore zone of the "*X*" ore body extends northwestward to the axial region of the fold lying between the main parts of the South and "*X*" ore bodies. The "*X*" ore body also extends southwestward into the next fold to the south (fold opens eastward—see pl. 6, maps of levels 8 and 14). The relationships of the lodes of the South and "*X*" ore bodies to the contact between lapa sêca and adjacent schist are not known.

Graton and Bjorge considered the ore of the Morro Velho mine an outstanding example of a deep-seated high-temperature deposit. The evidence they cited consisted mainly of the association of arsenopyrite, pyrrhotite, pyrite, chalcopyrite, quartz, and gold, the reported occurrence of scheelite and wolframite, and the remarkable uniformity in texture, mineralogy, and chemical composition of the ore from the top to near the bottom of the mine.

Pyrrhotite has long been considered an indicator of high-temperature mineralization in the range, 300°–500°C (McLaughlin, 1933, p. 558). Recent work by R. G. Arnold (written communication, 1958) at the Geophysical Laboratory of the Carnegie Institution on a sample of ore from the Morro Velho mine, using the pyrrhotite–pyrite geothermometer showed the minimum temperaure for crystallization of the sulfides at the Morro Velho mine to be 325° C. The typical low-temperature assemblages of chlorite, sericite, and sodic plagioclase in wallrock near the ore evidently were not affected by the temperature of the ore solutions.

ORE

Most of the data in this section were taken from Graton and Bjorge's reports and so far as is definitely known, they apply only to the Main ore body.

The ore of the Morro Velho mine consists of replacement deposits of sulfides with gold and silver values in a gangue containing mainly quartz and dolomite or ankerite. In this section of the report, the term "gold" should be understood to include silver values. Siderite, chlorite, sericite, and sodic plagioclase are generally minor gangue minerals, and calcite is rare. Other minor or rare minerals reportedly in the ore are galena, sphalerite, scheelite, wolframite, tetrahedrite, bornite, rhodochrosite, and magnetite. The gangue minerals are believed by the author to represent either relicts from the lapa sêca, or secondary minerals derived in part or entirely by mobilization and recrystallization of material from lapa sêca during mineralization. The sulfides are in scattered grains, in stringers parallel to bedding of the lapa sêca, or are concentrated into irregular-shaped islandlike patches of massive granular mineral surrounded by lapa sêca. In some places sulfides and secondary quartz-carbonate fill tension joints trending across bedding of the lapa sêca. The contact between ore and lapa sêca is generally sharp. Small percentages of pyrite are commonly distributed throughout both lapa sêca and schist in the vicinity of ore bodies. In both texture and composition the ore has remarkable uniformity throughout the length of the Main ore body, down to Level 25.

The principal sulfides in the ore are pyrrhotite, arsenopyrite, pyrite, and chalcopyrite. The percentages of these minerals have been computed from bulk analyses of the ore. The chemical composition and variations in composition are shown in the following table:

Chemical composition of ore from main ore body, Morro Velho mine

[Taken from private company report by Graton and Bjorge, p. 73–74]

Oxide or element	Weight percentage	Distribution
SiO_2	16. 27–24. 10	Apparent decrease in depth.
Al_2O_3	0. 24–1. 38	Uniform.
Fe	31. 00–32. 15	Exceedingly uniform.
MgO	5. 93–7. 56	Apparent slight increase with depth.
CaO	1. 40–3. 30	Apparent slight increase with depth.
MnO	0. 90–1. 30	Uniform.
S	13. 34–15. 91	
As	1. 49–3. 61	Erratic variation.

A composite sample representing 1 million tons of ore mined between 1902 and 1908 indicated the following: pyrrhotite, 28.3 percent; arsenopyrite, 7.7 percent; pyrite, 2.3 percent, and chalcopyrite, 0.5 percent. Another composite sample representing the production for the year 1922–23 indicated: pyrrhotite, 31.5 percent; arsenopyrite, 7.5 percent; pyrite, 2.5 percent; and chalcopyrite, 0.35 percent. The percentages of pyrite and pyrrhotite were computed by assuming that, of the sulfur remaining after deducting an amount sufficient for arsenopyrite and chalcopyrite, one-tenth was derived from pyrite, and nine-tenths from pyrrhotite. This assumption evidently was based on megascopic and microscopic examination of the ore.

On the basis of a bulk analysis of the ore taken from the Morro Velho mine in July 1951, the total sulfide amounts to 27.38 percent of the ore.

Graton studied 60 polished sections of the ore and found the paragenesis to be pyrite, arsenopyrite, pyrrhotite, chalcopyrite, and gold. He noted that grain sizes become coarser with depth, with fine- to medium-grained ore above level 20 (about 1,776 meters), and medium-to coarse-grained ore below that depth. Arsenoypyrite is generally fine grained and uniformly distributed. It is commonly associated with pyrite, which it corrodes and replaces.

Gold is in very fine grains and is rather uniformly distributed throughout the ore. Almost invariably it is localized in fractures in arsenopyrite or pyrrhotite. This indicates that some deformation of the host rock occurred between the times of deposition of arsenopyrite and gold. In places on level 26, gold replaces pyrrhotite enclosed within crystals of arsenopyrite, or replaces veinlets of chalcopyrite crossing arsenopyrite. The gold is probably everywhere in actual contact with sulfide, and arsenopyrite seems to have been of critical importance in localizing the gold.

There is no consistent variation in gold content with depth. Graton and Bjorge noted that ore of the lowest grade in the Main ore body came from levels 10, 11, 12, where the lode was widest and had its greatest cross-sectional area. On the lower levels the better grade of ore is that which contains coarse-grained arsenopyrite, evidently because the finer grained ore on the lower levels has relatively low percentages of arsenopyrite.

The overall average grade of the ore thus far (through 1955) produced from the Morro Velho mine is 16.45 grams per ton, and the total ore mined is about 13,840,000 tons.

ORE RESERVES

At the end of 1955, total reserves of developed and probable ore were 4,527,108 metric tons with an average grade of 13.2 grams per ton. The distribution of these reserves within the mine is shown in the following table.

Distribution of reserves of gold ore in the Morro Velho mine, December 31, 1955

[Taken from Annual Report of Directors of St. John del Rey Mining Co. for 1955]

Stope		Developed Ore (metric tons)	Grade (g per ton)	Probable Ore (metric tons)	Grade (g per ton)
Level	Ore body				
8	X	59,520	8.4	25,000	8.4
	South	56,600	12.0	23.500	12.0
11	X	------	------	182,500	8.6
	South	22,320	9.5	41,500	9.5
12	X	134,440	11.6	87,500	11.3
13	X	28,640	11.9	3,000	11.9
	South	7,870	10.4	10,000	10.4
	Black	62,232	10.8	------	------
14	X	47,000	11.9	3,000	11.9
	South	102,050	11.3	6,000	10.6
15	X	57,490	11.2	20,500	11.2
	South	113,520	12.8	------	------
16	X	46,280	20.1	1,000	14.8
	South	49,810	13.0	26,000	16.4
17	X	132,690	19.0	6,000	18.3
	South	48,460	22.2	12,500	21.3
18	X	145,780	17.7	5,000	16.2
	South	124,620	10.2	76,500	10.2
19	X	171,230	15.4	13,000	15.0
	South	106,630	16.4	54,000	16.7
	Northwest	12,450	9.7	10,500	9.7
20	X	140,900	19.6	24,000	23.3
	South	50,410	23.6	8,000	24.2
20–1	X	84,270	12.5	40,500	12.5
21	X	186,310	12.5	------	------
	South	112,521	15.7	------	------
	Main	11,411	16.2	------	------
	Northwest	7,183	13.5	------	------
22	X	295,606	12.8	------	------
	South	50,238	13.0	------	------
	Northwest	12,232	10.8	------	------
23	X	398,706	10.9	------	------
	South	37,318	17.1	------	------
	Main	31,933	16.2	------	------
	Northwest	30,857	12.0	------	------
24	X	211,798	15.0	------	------
	Main	60,066	12.5	------	------
	Northwest	66,107	13.9	------	------
25	X	175,001	13.0	------	------
	Main	34,590	12.1	------	------
	Northwest	84,193	15.7	------	------
26	X	125,885	11.2	------	------
	Main	110,003	9.9	------	------
	Northwest	265,425	9.6	------	------
27	X	100,254	14.4	------	------
	Main	205,065	10.3	------	------
28	Main	109,194	11.4	------	------
Total	X	2,541,800	13.7	411,000	11.0
	South	882,367	14.2	258,000	13.2
	Main	562,262	11.2	------	------
	Northwest	478,447	11.5	10,500	9.7
	Black	62,232	10.8	------	------
Grand total		4,527,108	13.2	679.500	11.8

EXTENSIONS OF KNOWN ORE BODIES

Within the general area of existing workings, ore probably extends upward from the South and "*X*" ore bodies on level 8 toward the surface. The upward extension of lapa sêca that encloses these ore bodies evidently becomes very thin or lenses out before reaching the surface, but it may persist for a considerable distance upward and westward from level 8.

The area between levels 8 and 11 evidently has never been extensively explored for the "*X*" ore body, and that ore body may extend continuously between these two levels.

Although some high-grade ore was mined near the west end of the old pit in 1956 (oral communication, D. Kochersperger, mine superintendent) there is small likelihood that the ore zone will extend very far directly west of the old pit. The eastward-plunging axial part of the fold, along which the western end of the Main ore body appears to have been localized, probably passes above the present erosion surface a short distance west of the old pit. Rubble of lapa sêca at N. 3,400, E. 1,800, may come from the extreme west end of the Main ore body. It is unlikely that the outcrop of lapa sêca at N. 4,000, E. 1,000 is a direct continuation to the west of the rock carrying the Main ore body. Rather, it may be at a different (lower) horizon, but on the keel of the same fold as the Main ore body, it may be a downfaulted segment of the lapa sêca of the Main ore body, or it may be on the limb of a fold adjoining the fold of the Main ore body on the north. The last is the simplest interpretation and is adopted here in the absence of evidence to the contrary.

RAPOSOS MINES

Historical information and production data for the Raposos mines come from Annual Reports of the Directors of the St. John del Rey Mining Co. In the annual reports, production data generally have been listed under the heading "Espirito Santo," the name of the largest producing lode. Mineralogical data for the ore come from the report by Graton and Bjorge. Geologic maps of several levels (pl. 7) were made by A. F. Matheson.

HISTORY

Exploration near the present Raposos mines evidently was started by the St. John del Rey Mining Co. shortly before 1910, although sporadic and unorganized searching had been carried on there previously.

Production started at Raposos in 1910 but was small for some years. Exploration was carried on intermittently and several lodes had been discovered by 1930, principally the Mina Grande and Espirito Santo lodes west of the Rio das Velhas, and the Morro das Bicas lode about 1 kilometer south of Raposos on the east side of the Rio das Velhas. Production between 1910 and 1928 was 23,404 tons of ore from which 8,388 ounces of gold was extracted. Mining was discontinued at Morro das Bicas in the early 1930's, but since then extensive development has been carried on in the mines west of the Rio das Velhas and they have been important producers. Production data (incomplete) for the years since 1928 are listed in the following table:

Production data (incomplete) for the Raposos mines, 1929–1955

[Asterisk (*) indicates weight is approximate]

Year	Gold (ounces)	Ore milled (metric tons)
1929	*2, 000	----------
1930	----------	----------
1931	*3, 530	----------
1932	*6, 225	----------
1933	*7, 268	----------
1934	*5, 707	29, 961
1935	7, 878	42, 464
1936	10, 728	49, 481
1937	30, 158	106, 200
1938	29, 085	94, 000
1939	35, 758	131, 900
1940	36, 317	146, 900
1941	36, 050	150, 900
1942	----------	150, 700
1943	----------	120, 000
1944	----------	119, 500
1945	27, 643	99, 100
1946	24, 132	83, 200
1947	26, 799	92, 400
1948	30, 632	105, 100
1949	29, 390	105, 000
1950	36, 114	136, 800
1951	37, 956	154, 200
1952	34, 864	145, 500
1953	27, 568	110, 000
1954	28, 544	107, 000
1955	28, 924	112, 000

At the present time, the important lodes are the Espirito Santo, the Mina Grande, and the Espirito West. They are connected by underground workings and mining has reached a depth of about 640 meters (2,100 feet).

GEOLOGIC SETTING

The ore bodies in the Raposos mines are replacement bodies of sulfide with associated gold and silver located in iron-formation. The iron-formation consists mainly of alternating laminae of quartz and sideritic carbonate, or of quartz, sideritic carbonate, and magnetite. It has commonly been called "caco" by miners and others working in the mine.

Surface mapping (pl. 1) indicates beds of iron-formation at three horizons in the vicinity of the mines. Underground mapping by Matheson indicates that the lodes are in at least 2 distinct beds of iron-formation (pl. 7), and possibly in more than 2 beds.

Iron-formation and associated schists in the mines occur in several relatively small folds that are a part of the larger fold shown on plate 1, about 1 kilometer west of Raposos. The folds plunge from a little north of east to slightly south of east at angles between 15° and 45°. Ore bodies follow the bedding of iron-formation. The lodes persist more downdip than along the strike of folded beds, and in some places, approximate a pipelike form.

The smaller folds evidently did not have a marked localizing effect on the lodes, inasmuch as the ore bodies occur both on the noses and along the limbs (pl. 7). It seems likely, however, that the larger fold, which includes the smaller ones in the mine, did localize a general area of mineralization.

At least four northeastward-trending dikes of metadiabase cross the iron formation and lodes of the Raposos mines. Dikes "C" and "D" (pl. 7) appear to lie approximately along the axial planes of folds, which planes here lie approximately parallel with regional foliation. The Espirito Santo and Espirito West lodes are separated from one another by an offset of the iron-formation along dike "D" on the 1,200-foot, 1,500-foot, and 1,800-foot levels (pl. 7). Evidently, local faulting as well as small-scale shearing occurred along some of the axial planes during folding and provided access for diabasic intrusions. Diabase was intruded either near the end of the period of folding or after folding.

ORE

The ore of the Raposos mines consists of sulfides with gold and silver in a gangue containing mainly quartz, sideritic carbonate, and locally magnetite. The gangue minerals are relicts of the host rock of carbonate iron-formation or are secondary quartz and carbonate probably derived largely from the host rock during mineralization.

Lodes are confined strictly to iron-formation, although within the iron-formation mineralization may be patchy and without enough gold to form ore in places. The sulfides occur in scattered grains, in seams, veinlets, and in irregular-shaped granular aggregates. The sulfides characteristically are disposed along and replace laminae of the iron-formation, especially the darker layers of sideritic carbonate. The lamination of the host rock therefore commonly imparts a lamination to the ore. Patches of sulfide and secondary quartz (with or without secondary carbonate) cut across bedding in some places.

Pyrrhotite evidently is the principal sulfide in the ore now being mined from the Raposos mines, although pyrite appears to have been the most abundant sulfide found during the early development of the mines. Pyrite and arsenopyrite are found in small amounts and chalcopyrite in very small quantities. Using chemical analyses of ore made in 1927, and by visual examination of the ore, Graton and Bjorge found that sulfide comprised 7.5 percent of the ore, distributed as follows: pyrite, 4.7 percent; pyrrhotite, 2.2 percent; arsenopyrite, 0.5 percent; chalcopyrite, 0.06 percent. Company chemists computed a total sulfide content of 9.58 percent from chemical analyses of the ore milled during July 1951. The sulfides were distributed as follows: pyrrhotite, 5.47 percent; pyrite, 2.96 percent; arsenopyrite, 1.15 percent. A value of 0.03 percent copper in the bulk analysis probably represents a very small amount of chalcopyrite which was not computed.

ORE RESERVES

At the end of 1955, the total reserves of the Raposos mines were 1,694,080 metric tons of ore with an average grade of 9.5 grams of gold per ton. All reserves at a grade of less than 8 grams per ton are excluded from the data presented here. The distribution of those reserves was as follows:

	Tons	*Grams per ton*
Espirito Santo lode	1, 090, 210	8. 7
Mina Grande lode	438, 690	8. 4
Espirito West lode	165, 180	11. 9

BICALHO MINE

HISTORY

No known record is available of the earliest work at the Bicalho mine at Honorio Bicalho in the north-central part of the Rio Acima quadrangle. Prior to 1925, the first recorded date of activity there in reports of the St. John del Rey Mining Co., some development work had evidently already been done, probably by other interests. In 1925, the St. John del Rey Mining Co. drove an exploration adit and evidently opened up at least one lode. Nothing more appears to have been done until 1936, when the old openings were unwatered, and exploration recommenced. Between 1936 and 1939 exploration continued to a depth of 1,500 feet and some 135,000 tons of ore was blocked out in two lodes, the Cata Funda and the Bahu. The Cata Funda inclined shaft followed eastward-dipping bedding and tunnels were driven northward from the shaft at vertical intervals of about 30 meters (pl. 8). Eventually the Bahu lode was found to be a northward extension of the Cata Funda lode. Exploration reached a depth of 610 meters (2,000 feet).

In 1940 and 1941, 36,800 tons of ore from Bicalho yielded 8,238 ounces of gold. In 1942 and 1943, 40,700 tons of ore was milled, but the production of gold was lumped with other production in company reports. During 1944 and 1945 there was no production, and in 1946, only 200 tons of ore was sent to the mill. All activity ceased after 1946.

GEOLOGIC SETTING

From the mine map (pl. 8), the examination of outcrops immediately south of the mine and drill core obtained in the mine, and from rubble on the mine dump, it is clear that the ore body lay in a northward-trending and eastward-dipping bed of lapa sêca. The tunnels at the different levels bend somewhat east of north in the northern part of the mine, and probably represent a flexure in the bed of lapa sêca. This probable bend in bedding is the only evidence of possible structural control in localizing the Bicalho deposit.

ORE

No systematic study of the ore from Bicalho has been made. Pyrrhotite and pyrite have been identified in hand specimen and by oblique reflected light in thin section. The sulfides occur mainly as a replacement of massive gray lapa sêca. The mineralization appears to be identical with that in the Morro Velho mine.

ORE RESERVES

Ore reserves at the Bicalho mine as of 1946 were 189,000 metric tons.

GAIA, GABIROBAS, AND FARIA MINES

HISTORY

About 1863, the St. John del Rey Mining Co. acquired an area of land known as the Fernan Paes estate west of Honorio Bicalho, and there began to develop the Gaia and Gabirobas mines (pl. 2) as well as several smaller prospects. A stamp mill was built near the Gaia mine. Between 1867 and 1873, 5,777 ounces of gold were produced from the Fernan Paes property, mostly from the Gaia mine. Mining was discontinued at the end of 1873. Exploration began again at the Gabirobas mine in 1887 after the Morro Velho mine caved in, but the results were not promising.

The Faria mine, about 1 kilometer south of the Gabirobas mine, reportedly was first developed and worked for a short time by a French company about 1900, but there is no record of this operation known to the writer. In 1931, the St. John del Rey Mining Co. began to unwater and explore the old Faria mine.

In 1934, the driving of an adit in a west-southwest direction from the west side of the Rio das Velhas at Honorio Bicalho was begun. This adit is called the Gaia tunnel (pl. 4) by local mining people. It was intended to unwater and provide access to deeper levels in the old Gaia mine, and eventually to be extended to and drain the Faria mine. During 1935 the Gaia tunnel was extended west-southwestward from the Gaia mine and was completed to the bottom of the Faria mine in 1936.

During the explorations of 1935, 8 tons of ore from the Gaia mine and 447 tons from the Faria mine were sent to Nova Lima for milling.

The old Gabirobas mine was unwatered in 1936. Exploration was carried on there to a depth of 30 meters below the old workings, and in the Gaia mine to about 30 meters below the Gaia tunnel. Exploration was discontinued at both the Gaia and Gabirobas mines in 1937 because of low gold values. Development of the

Faria mine continued and regular production began in 1940.

Production continued at the Faria mine from 1940 until 1947, and 176,286 tons of ore was milled. Gold production figures for 1942, 1943, and 1944, were lumped with production figures for other mines, so the total production of gold from Faria cannot be stated. However, in 1940, 1941, 1945, 1946, and 1947, a total of 96,986 tons of ore yielded 32,364 ounces of gold.

Operations at the Faria mine were suspended in 1947.

GEOLOGIC SETTING

The Gaia, Gabirobas, and Faria ore bodies are located in or in contact with iron-formation. As mapped at the surface, iron-formation at the Gaia mine strikes east-southeastward and dips vertically or steeply southwestward. Iron-formation at the Gabirobas mine strikes northeastward. The dip is unknown but is probably steep to the southeast. Iron-formation at the Faria mine strikes northeastward and dips 50° to 70° southeastward. The lode at Faria is reported to be mainly in schist with iron-formation forming the footwall.

The ore bodies are not located near the bends of known folds, and other structures that may possibly have controlled the localization of orebodies are not evident.

ORE

Ore from these mines has not been seen by the present writer, and very little about the ore is on record. Gold is reportedly associated with veinlets and stringers of pyrite and pyrrhotite in the Gabirobas mine.

Unweathered carbonate iron-formation from several places in the Gaia tunnel has isolated grains and small clusters or stringers of sulfide, generally within laminae of iron-rich carbonate, or along the contact between the laminae of carbonate and quartz. This sulfide has been identified in thin section by oblique reflected light as pyrite and pyrrhotite. Pyrite appears to have been earlier than pyrrhotite.

The grade of ore taken mainly from the Gaia mine and mixed with a little ore from the Gabirobas mine was reported, during the early development work of 1863–65, to have been 21.5 grams per ton. The only other known value for the grade of Gaia ore is 7.28 grams per ton, for production during part of 1868–69. Ore sampled in the Gabirobas mine during the explorations of the 1930's averaged 9 grams per ton, and ore from the Faria mine ranged from 10 to 18 grams per ton.

ORE RESERVES

No estimates of reserves at the Gaia and Gabirobas mines are known to the writer. At the time work was suspended at the Faria mine in 1947, reserves there were estimated to be 66,000 metric tons with a range of some 10 to 18 grams of gold per ton.

OTHER MINES AND EXPLORATIONS

MORRO DA GLORIA EXPLORATION

In 1931, the St. John del Rey Mining Co. began exploration at Morro da Gloria, about 1 kilometer west of Santa Rita in the north-central part of the Rio Acima quadrangle (pl. 1). A drill loaned by the Brazilian government helped in this work (for petrographic descriptions of drill core, see report by Guimarães, 1935, part 1). Company reports indicate that there were old workings at Morro da Gloria in 1931, but no other record of the earlier work is known to the writer. Exploration continued at Morro da Gloria until 1935 and several small lodes of low grade were found in iron-formation. Activity was suspended in 1935.

URUBU MINE

The St. John del Rey Mining Co. began exploration of the Urubu mine, about 700 meters east of Santa Rita, in 1934. A large excavation was made near the top of the ridge east of the Rio das Velhas, and several adits were driven into the ridge from the east and northeast. The deposits are in a northward-trending and eastward-dipping bed of lapa sêca, but the ore bodies were found to be small and low in grade (5 to 12 g per ton). There was no regular production and there is no record of ore produced during exploration. Work was discontinued in 1936.

BELLA FAMA MINE

Old workings at Bella Fama near the south edge of the Nova Lima quadrangle, south-southeast of Nova Lima, were explored in 1939 by the St. John del Rey Mining Co. In addition to the workings at the Bella Fama mine itself, there is a large eastward-facing excavation in iron-formation and schist, 600 meters to the east-southeast. It evidently predates the exploration done in 1939, but no record of this excavation or of the earlier work at Bella Fama is known to the writer. The deposits at Bella Fama evidently contain sulfides in a northwestward-trending, northeastward-dipping bed of lapa sêca. During the exploration, several adits were driven eastward or northeastward into the ridge, and from them openings were made downdip along the bedding for a short distance. Exploration continued until 1941, during which time two ore bodies were found. They evidently were too small and of too low a grade to warrant further mining.

RIBEIRÃO DA PRATA EXPLORATIONS

Between 1939 and 1941 sporadic explorations were conducted along the Ribeirão da Prata, a short distance southeast of Raposos. Mineralization evidently occurred in iron-formation.

AGE OF GOLD MINERALIZATION

The age of gold mineralization is not definitely known. The association of the lodes with areas of eastward-plunging fold axes in the Morro Velho mine and near Raposos indicate that mineralization occurred late in the period of post-Minas deformation, or following deformation (Gair, 1958b). Mineralization may be related to post-Minas granite intrusion. The common localization of sulfides in cracks that cross the bedding at an angle is a further indication of the late- or post-deformational emplacement of the gold. Matheson (written communication to St. John del Rey Mining Co.) thought that the process of mineralization in the Raposos mines may have been related to the intrusion of the diabase. Several of his maps that contain the results of assays show that adjacent to dikes of metadiabase the tenor of the ore either remains constant or decreases. A decrease in tenor of the ore adjacent to metadiabase may have been a result either of temperature zoning during deposition of the ore from diabase, or of leaching of the ore during intrusion of the diabase. Several of the lodes in the Raposos mines are offset along faults along which diabase was later intruded. It is possible that mineralization developed only in favorable beds of iron-formation that had already been faulted. However, it seems more likely to the writer that the sharply defined offset ore bodies had been mineralized prior to being faulted, hence before the intrusion of diabase. The likely sequence of events, in close succession was post-Minas folding, granite intrusion, and regional metamorphism; mineralization (probably with some continuation of folding); shearing and faulting along axial planes of some folds; intrusion of diabase; and, falling off of regional metamorphism.

IRON

There was no mining of iron within the Nova Lima and Rio Acima quadrangles in 1956. In this report, potential iron ore is divided into several types on the basis of age and physical properties. These types are:

From rocks of Rio das Velhas age: Weathered iron-formation (estimated 65 percent iron).

From rocks of Minas age: Weathered itabirite (approximately 30 to 50 percent iron); hard blue hematite (more than 67 percent iron); canga (approximately 50 to 66 percent iron).

The canga is derived from the rocks of Minas age and is grouped with other types of potential ore from such rocks, although its age of formation probably is not older than Tertiary.

POTENTIAL ORE FROM ROCKS OF RIO DAS VELHAS AGE

Most of the weathered pre-Minas iron-formation probably has considerably less than 50 percent iron (see table 4), and will be of no value as iron ore in the forseeable future, but that on the upper slopes of Morro do Pires in the northwestern part of the Rio Acima quadrangle may be a potential source. There, in the vicinity of N. 11,300, E. 600, outcrops and rubble of weathered iron-formation cover an area of about 10,000 square meters. Megascopic examination of hand specimens and sawed rock surfaces indicate very little quartz and a high magnetite-hematite content. The iron content is estimated to be not less than 65 percent, but systematic sampling has not been done, so the actual grade and the depth to which the relatively high-grade weathered material extends are not known.

POTENTIAL ORE FROM ROCKS OF MINAS AGE

ITABIRITE

The strike-length of itabirite (Cauê itabirite) across the northwestern part of the Nova Lima quadrangle is about 9,000 meters, and the formation has an estimated minimum thickness of 125 meters.

The iron in the weathered rock known at the surface occurs mainly as hematite (in places specularitic) and as yellow-brown iron oxide, with relatively small amounts of magnetite. Thin layers or laminae rich in iron alternate with layers rich in quartz. Weathered itabirite commonly is friable and can be crushed rather easily into grains of iron oxide and sugary quartz. The grains commonly range from 0.03 to 0.15 mm in diameter. The chemical analyses in table 5 indicate that the iron content of this itabirite ranges from about 30 to 50 percent.

The depth to which weathered itabirite extends is not known, but probably is not generally less than 100 meters down dip of the formation.

Using a strike length of 9,000 meters, a thickness of 125 meters, a dip length of 100 meters, and a specific gravity of 3.5, the calculated minimum amount of itabirite in the Nova Lima quadrangle with 30 to 50 percent of iron is about 400 million metric tons.

HARD BLUE HEMATITE

Three small areas containing hard blue hematite are known along the belt of Cauê itabirite crossing the northwestern part of the Nova Lima quadrangle. They center approximately at N. 9,720, E. 2,660; N. 10,880, E. 4,660; and N. 11,520, E. 4,920 (pl. 1). These areas are along or close to the contact between the Cauê itabirite and the overlying Cercadinho formation.

The hard blue hematite has been seen definitely in place only as thin seams adjacent to quartz veins in the itabirite at N. 10,880, E. 4,660. It is generally found as small chips, as platy fragments as much as 15 cm across, or as cobble- and boulder-size lumps on the surface or embedded in rubbly slumped itabirite. The boulder-size lumps are not common, and have been seen only at N. 11,520, E. 4,920.

The hard blue hematite, commonly known in the iron industry as "hard ore," is dense and tough, and has almost no quartz. It is of similar composition to hard blue hematite from larger deposits in nearby quadrangles as shown in the following table. It is notable for its high iron and low phosphorus content.

Some test pitting and trenching has been done at N. 10,880, E. 4,660. About 20,000 tons of hard ore was mined near N. 11,520, E. 4,920, about 2 kilometers southwest of Sabará, in the late 1940's. This mining was essentially a stripping operation, and removed material to a depth of probably not more than 4 meters. The area of this operation now contains a large boulder and abundant rubble of platy fragments of hard blue hematite. Evidently the material mined consisted largely of lenticular nodules, bouldery masses, and thin beds of hard blue hematite, essentially in place in enclosing itabirite.

Chemical analyses of hard blue hematite from Cauê itabirite, Nova Lima quadrangle

[Analyst: Cassio M. Pinto, DNPM]

	1	2	3	4
SiO_2	1. 9	4. 2	1. 3	. 6
Al_2O_3	. 50	. 5	. 5	. 5
Fe	68. 1	66. 6	68. 9	69. 6
Mn	. 17	. 01	. 01	. 01
P	. 03	. 06	. 05	. 07
S	------	. 02	------	------
Loss on ignition	. 4	. 3	. 2	. 1
Sum [1]	99. 9	99. 8	100. 0	100. 2

[1] Sums based on given percentages plus sufficient oxygen to compute all the Fe as Fe_2O_3.

LOCATIONS:
1. Near N., 9,720, E. 2,640. Randomly selected grab sample. Four fragments of hard blue hematite selected at irregular intervals along line about 20 meters long across area where nodules and rubble of hard blue hematite abundant.
2. Near N. 10,860, E. 4,660. Grab sample. Five fragments of hard blue hematite taken at random from test trench and piles of hard hematite, evidently hand sorted during trenching.
3. Top of ridge about 1,500 m southwest of south end of highway bridge over the Rio das Velhas at Sabará. Grab sample. About 25 small fragments of hard blue hematite randomly selected every 3 to 4 m along 1 of 3 parallel traverses made across stripped-off area, at right angles to strike of Cauê itabirite. Traverses about 30 m long and about 10 m apart.
4. Same locality as No. 3. About 8 small pieces of hard blue hematite broken off large boulder of hard hematite. Samples every 25 to 30 cm along line around boulder. Boulder about 2 by 2 by 1.5 meters.

The form and scattered distribution of fragments of hard blue hematite in the three localities mentioned previously suggest that this material has not been broken from large underlying masses of "hard ore," but formed as isolated lenses or nodules in itabirite. Chips and platy fragments are probably pieces of laminae of itabirite, which had been locally changed into hard blue hematite. Of the hard blue hematite at the three localities listed, only that at the third is known to be (or have been) sufficiently abundant to warrant being classified as a "hard ore deposit."

CANGA

The only area of canga of mappable size in the Nova Lima and Rio Acima quadrangles occurs near the place where the Cauê itabirite crosses the western boundary of the Nova Lima quadrangle.

The canga has a surface area of about 90,000 square meters and is probably not more than 2½ meters thick. If a specific gravity of 4.0 is assumed, there are about 360,000 metric tons per meter of thickness. The composition and iron content of the canga is generally quite variable (commonly 50 to 66 percent iron), so that an accurate evaluation of it depends on close-spaced systematic sampling. This has not been done for the canga in the Nova Lima quadrangle.

CLAY

Small flat areas underlain by clay of probable Tertiary age in the northwest and southeast outskirts of Rio Acima support two large brickmaking and tilemaking plants, the Gianetti Ceramica and the Morgan Ceramica, respectively. Information presented here comes from an oral communication to the author by João Morgan da Costa, owner of the Morgan Ceramica, and therefore is less complete for the Gianetti Ceramica. Other small and impermanent brickmaking and tilemaking facilities are numerous in both quadrangles, but little is known of their operations. The deposits of clay that they work are not mappable at the present scale and are too small to be of any but immediately local interest.

The Gianetti Ceramica has been in operation about 30 years, and the Morgan Ceramica, about 20 years. The Morgan Ceramica has used an average of about 30,000 tons of clay per year. The production of the Gianetti Ceramica is probably close to that of the Morgan plant, and the amount of clay used yearly is thought to be about the same for both plants.

The clay used by these plants is white, reddish, yellowish, and dark gray or black. These colors probably represent small amounts of iron oxide and organic matter. The dark-gray or black clay is mixed with reddish, yellowish, and white clay for making bricks and roofing tiles. White clay could be used alone for making refractory bricks, but this is not produced by either plant.

Although the areas of clay are relatively small, to judge by the small amount used in the 20 to 30 years of operations of these plants, the remaining deposits should be adequate for many more years of consumption.

YELLOW OCHRE

A deposit of yellow ochre in the ocherous iron-formation of the Cauê itabirite is worked at a small paint factory near kilometer 16 on the highway between Belo Horizonte and the Triangulo, some 750 meters northwest of the Triangulo (Nova Lima, near N. 8,850, E. 1,600). No production figures are available for this operation.

Yellow ochre also occurs in the ocherous itabirite, northeast and southwest of the paint factory, but no exploration or development of this material has yet been carried out.

DOLOMITE

Two abandoned kilns in the west-central part of the Nova Lima quadrangle show that the dolomite of the Cercadinho formation was burned at one time.

Some dolomite is now being quarried about 750 meters northwest of Sabará, and is used for building stone and tombs. No production figures are available.

MANGANESE, COBALT, NICKEL

Some test trenches have been dug, reputedly by German interests during World War I, in schist-phyllite of the Nova Lima group near some veinlets of brownish-black manganese mineral a centimeter thick, in the southeastern part of the Rio Acima quadrangle, near N. 2,100, E. 12,125. Nothing more is known to the writer about this operation. Material examined in this area during the present study did not appear to be of value.

A sample of weathered manganiferous schist and phyllite of the Nova Lima group, collected by B. E. Ashley, 3.2 kilometers west of Raposos, contains 1.16 percent nickel and .79 percent cobalt, and may be classified as lithiophorite. This material is probably too limited in amount to be of economic value.

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U. S. GOVERNMENT PRINTING OFFICE : 1962 O - 637724