Robertson—GEOLOGY OF THE LEAD-ZINC DEPOSITS IN THE MUNICÍPIO DE JANUÁRIA, BRAZIL—Geological Survey Bulletin 1110-B

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GEOLOGICAL SURVEY BULLETIN 1110-B

Prepared in cooperation with the Divisão de Fomento da Produção Mineral, Departamento Nacional da Produção Mineral, Ministério da Agricultura, under the sponsorship of the Agency for International Development, U.S. Department of State

Geology of the Lead-Zinc Deposits in the Município de Januária State of Minas Gerais Brazil

By JACQUES F. ROBERTSON

CONTRIBUTIONS TO BRAZILIAN GEOLOGY—NONFERROUS METALS

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[Plates are in pocket]

GEOLOGY OF THE LEAD-ZINC DEPOSITS IN THE MUNICÍPIO DE JANUÁRIA, STATE OF MINAS GERAIS, BRAZIL

By Jacques F. Robertson

ABSTRACT

Lead-zinc mines and prospects in the Município de Januária, in northern Minas Gerais, Brazil, are scattered along both sides of the Rio São Francisco for more than 100 kilometers. Seven deposits of lead and zinc and one fluorite prospect are grouped in a small area from 10 to 15 kilometers west of the village of Itacarambí. Others lie in a wide area surrounding the city of Januária, of which only two small occurrences are described in this report.

Production of lead from these deposits has been small and discontinuous, totaling only a few tons of lead and several hundred kilograms of silver. In 1957, the surface zone of residual blocks of oxide ore at Mina Janelão, west of Itacarambí, was explored; several thousands tons of hand-sorted ore was stockpiled and a few hundred tons was shipped to Rio de Janeiro for pilot-plant extraction of zinc. In the same year, a fluoride deposit near Mina Janelão was explored. Reserves of the deposits west of Itacarambí are judged to be small on the basis of surface showings; those of deposits near Januária are considered to be of no commercial importance.

Sedimentary rocks in the Januária region include the Bambuí series and the Baurú formation. The Bambuí series consists of flat-lying carbonate and fine-grained clastic rocks of possible Ordovician or Silarian age. The base of the series is not exposed. A section of part of the Bambuí series west of Itacarambí is 520 meters thick. The lower half includes six limestone and dolomite units of various types; the upper half is composed mainly of calcareous siltstone and mudstone. West of the city of Januária, the Bambuí series consists of substantially the same units but the section is only 104 meters thick. The Bambuí series east of the Rio São Francisco in the section at Alto de Palmeiras is 210 meters thick and consists mainly of calcareous mudstone and siltstone, with some interbedded dark-gray limestone.

The Baurú formation of Cretaceous age overlies the Bambuí series. It is continental in origin and consists of massive, fine-grained red-bed sandstone and small amounts of siltstone containing variable proportions of calcareous, siliceous, and limonitic cement. The Baurú formation characteristically caps buttes and mesas; near the city of Januária it is 90 meters thick.

Most strata of the Januária region are only slightly warped or faulted. West of Itacarambí, a broad anticline that is 6 to 8 kilometers in length, trends N,

40° W. Drag folds, longitudinal and cross faults of small displacement, and monoclinal flexures occur along the limbs of this fold. Northeast and west of the structure the strata are virtually flat lying. A low dome is defined at the southeast end of the anticline. Northwestward, the anticline dies out and the beds flatten. The Baurú formation is thought to have been involved in the deformation, but the evidence is inconclusive.

The mineral deposits in the Municípo de Januária contain the common primary and secondary lead-zinc minerals and occur as replacements and as vein fillings in fractures and faults; at a few places there are mantolike masses of silicified primary- or pseudo-breccia within flat to gently dipping carbonate rock. Most deposits west of the Rio São Francisco occur in a dark-weathering crystalline dolomitic limestone unit of the Bambuí series. West of Itacarambí they are related to the northeast-striking cross faults or to the northwest-trending faults and fractures that flank the anticlinal block. The location of these deposits seems to have been controlled by a combination of structure and lithology; clastic beds have not been favorable to the deposition of lead and zinc minerals.

All deposits are similar mineralogically. Primary sulfide minerals include argentiferous galena, sphalerite, and traces of chalcopyrite and bornite. The sulfide minerals were transported by solutions that silicified and dolomitized the country rock. Gangue minerals include quartz, calcite, barite, and fluorite; fluorite is sufficiently concentrated in lenses at one place to form a small minable deposit. Supergene alteration produced secondary lead and zinc minerals including anglesite, cerrusite, smithsonite, and willemite. Other secondary minerals include minor amounts of descloizite and vanadinite, as well as traces of chalcocite and malachite. Oxidation has appreciably concentrated and upgraded the lead and zinc content of some deposits.

The fissure veins range from 30 to 200 meters in length. Most are about 0.5 meter wide and are poorly mineralized; one fracture zone 180 meters long averages 10 meters in width and contains small, scattered, mineralized lenses and disseminations of lead-zinc minerals. The richest deposit, Janelão, consists of residual blocks containing a mixture of primary and secondary lead and zinc minerals in colluvium. A vein possibly exists below this zone. A nearby solution channel was filled with the mineralized rubble derived from a vein or lens that existed above the present topography. Two pseudobreccia beds at Mina Grande and Mina São João range from 0.5 to 5 meters or more in thickness and cover 10,000 square meters of area. They contain scattered small lenses of mixed sulfide and oxidized lead-zinc minerals.

The deposits are classified as hydrothermal in origin, probably mesothermal to epithermal. The source of the ore and gangue minerals is unknown.

The deposits have been prospected and mined from shallow trenches and pits. If drilling or tunneling in the deposits develops greater tonnage than is indicated by surface showings, 2 or 3 deposits might conceivably sustain modest operations. The rest are only showings that might provide a few tons of ore. Prospecting in the Januária region should be directed primarily toward tectonic features within limestone units of the Bambuí series. The dark-weathering dolomite unit is a favorable host rock, particularly where faulted and also near its contact with underlying limestone. Lower limestone units exposed in the area seem to be poor host rocks, but may be more favorable in other parts of the São Francisco valley. Indicators of possible ore deposits are silicified, bleached, and red to buff dolomite, and mantolike masses of siliceous pseudobreccia.

INTRODUCTION

Small deposits of lead and zinc are scattered along the Northward flowing Rio São Francisco in the Município de Januária, in the northern part of the States of Minas Gerais, Brazil. (See index map, fig. 4.) Growing demands by industry for lead and zinc in Brazil has made desirable a geologic study of these deposits and an appraisal of their potential value. Investigation of the Januária region was started in June 1957 as part of the nonferrous mineral deposits program of the U.S. Geological Survey in cooperation with its Brazilian counterpart, the Departamento Nacional da Produção Mineral, Ministério da Agricultura. The survey was sponsored by the Agency for International Development of the United States Department of State.

Past production of lead and zinc from the properties in the Município de Januária has been small. Both primary and secondary ore minerals are found at the surface in fairly high concentrations, but their distribution is spotty and irregular. The deposits are associated principally with fracture veins and zones that are narrow and short; there is relatively little replacement of limestone beds. Little underground exploration has been accomplished by which reserves of ore can be inferred and no information is available to estimate the character, depth, and amount of oxidation or secondary enrichment. Future production from this district will be short lived unless additional reserves are found.

On the basis of current knowledge, sustained production of lead and zinc from combined primary and secondary ores might be successful in the Itacarambí area for a few years, if all known properties are exploited jointly, operations are economical and kept on a small scale, and if capital investment is restricted to a minimum. Deposits should be explored before mining is attempted to determine whether adequate reserves of the desired ores exist. The Januária area is remote from the nation's industrial plants and transportation costs of ore or concentrates, therefore, will be relatively high.

LOCATION OF MINERAL DEPOSITS

The more important deposits in the Município de Januária are grouped within a few kilometers of each other, and are 10 to 15 kilometers west of Itacarambí, in the dissected margin of the plateau that lies above the valley of the Rio São Francisco. (See fig. 5.) Capão do Porco, a small deposit of lead and zinc minerals that has been mined for silver, is in the Serra de Cantinho, 35 kilometers to the southwest of the river port of Januária. A minor showing of lead and zinc on the Fazenda Palmeiras is located 30 kilometers southeast

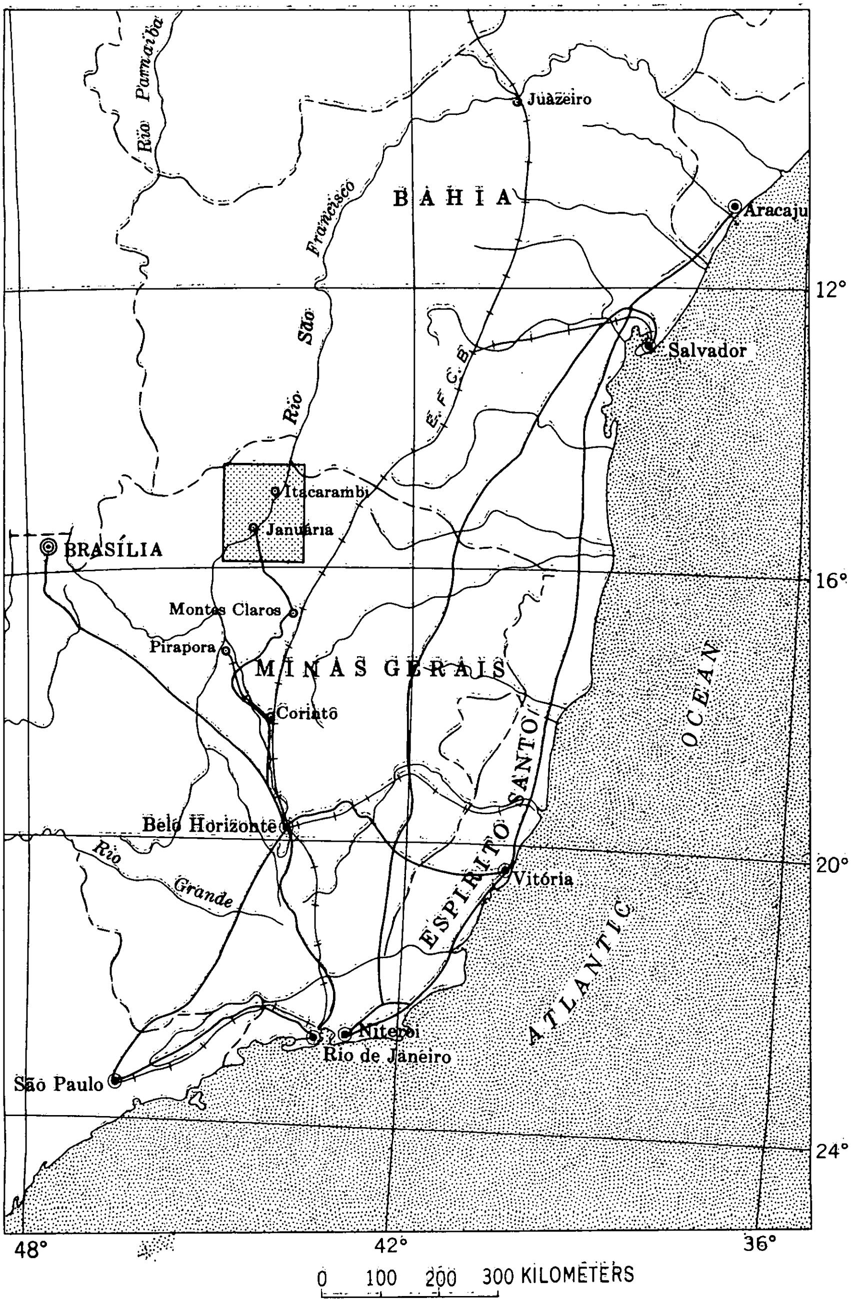

FIGURE 4.—Index map, showing location of the region of Januária.

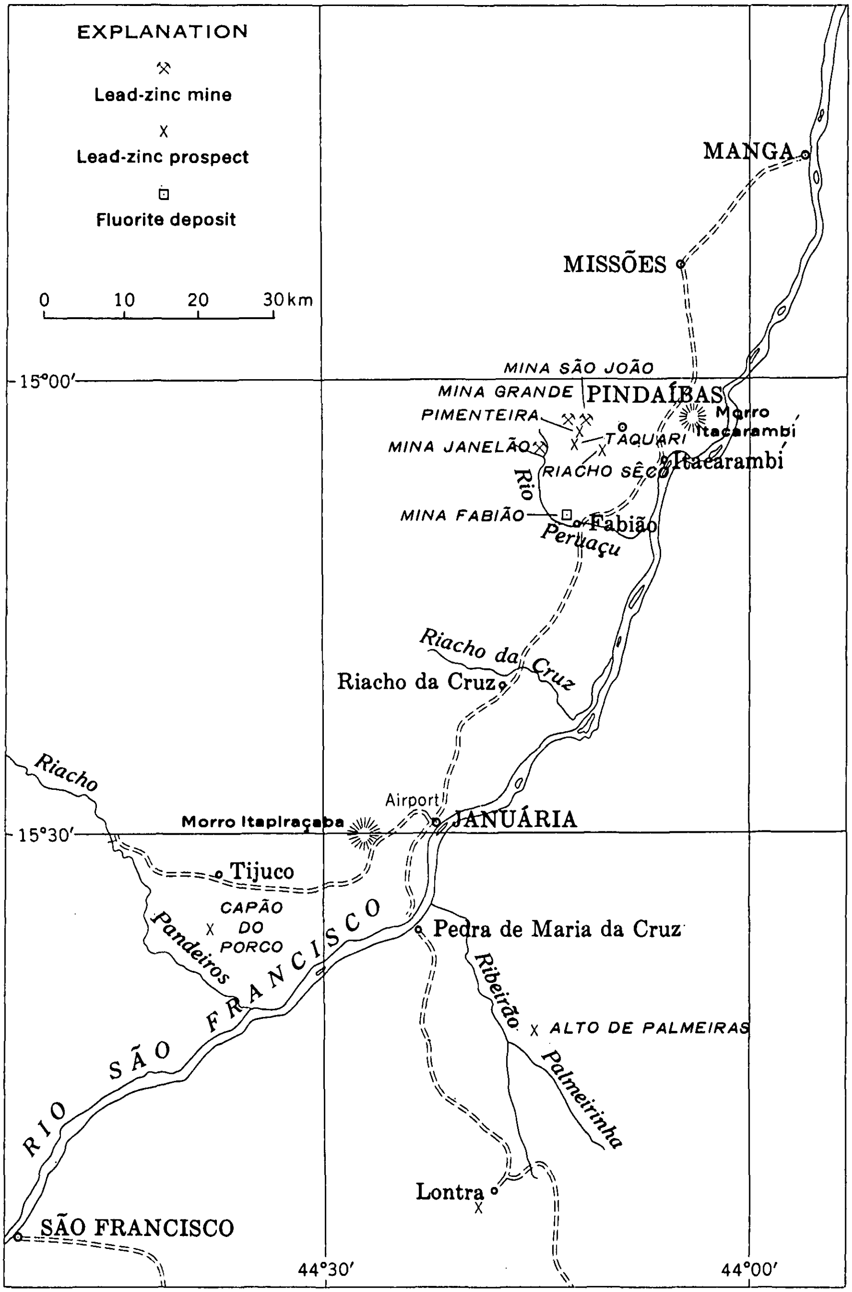

FIGURE 5.—Region of Januária and Itacarambí, showing locations of principal deposits.

of Januária. Another deposit occurs 50 kilometers or so south of Januária near the small town of Lontra, and another has been reported (Moraes, 1958, p. 149) from Brejo do Amparo, 5 kilometers northwest of Januária. All of these are referred to as the Januária deposits.

TOPOGRAPHIC FEATURES

The Rio São Francisco flows north-northeast in a trenchlike valley carved out of the great central peneplain of Brazil. The valley ranges from 20 to 30 kilometers in width, has a relatively flat alluvial floor, and is bordered by steep erosional escarpments at least 200 meters high. The escarpments are developed in virtually flat-lying limestone and clastic sediments of the Bambuí series. The few perennial tributary streams that interrupt the escarpments at wide intervals have valleys that are relatively deep as compared to their widths. Normally, the Rio São Francisco is about 0.5 kilometer wide, but the swath cut by its flood plain averages 6 kilometers. Well-defined but somewhat dissected terraces, the tops of which stand 10 meters or more above the flood-plain level and which slope gently toward the river from the escarpments, border the flood plain on either side. The plateau west of the river has an altitude of about 700 meters and a relief of more than 250 meters.

The level of the river fluctuates as much as 16 meters between the normal high and low stages; its gradient is about 15 meters in 100 kilometers.

GEOGRAPHY AND TRANSPORTATION ROUTES

Januária, a city of about 8,000 inhabitants, is the seat of the government of the município, a political unit corresponding in function to a county. The city lies on the west bank of the Rio São Francisco at an altitude of 451 meters and is the main trade and transportation center for the region. It is a port for river traffic, the terminus of regular truck and bus transport, and a scheduled stop for an airline. Most commerce is handled by the steamships and launches that ply the river from the railhead and rapids at Pirapora, Minas Gerais, 468 kilometers south and upstream from Januária, to Juàzeiro, Bahia, 1,052 kilometers north and downstream from Januária. The Comissão do Vale de São Francisco, a government corporation, has the largest and fastest river boats and is the main operator on the river. A rail line that is part of the network of the Central do Brasil Railroad (E. F. Central do Brasil) connects Pirapora with Belo Horizonte to the south, a distance of 432 kilometers. The northern river terminus of Juàzeiro, Bahia is connected to the seaport at Salvador to the southeast, a distance of 571 kilometers by the railroad Viação Férrea Federal Leste Brasileiro.

Overland, Januária is reached by a road 215 kilometers long from Montes Claros, Minas Gerais, a city also on the Central do Brasil Railroad. The road from Montes Clarosto Januária is unpaved, and much of it is in poor condition because of sand, water, and insufficient maintenance. The Central do Brasil Railroad leads south from Montes Claros, past the junction with the trunkline from Pirapora, to Rio de Janeiro, via Belo Horizonte. The railroad also extends north to Salvador in Bahia. Rail distance from Montes Claros to Rio de Janeiro is about 1,000 kilometers and to Salvador is about 1,150 kilometers.

A barge ferry crosses the Rio São Francisco at Pedras de Maria da Cruz, 12 kilometers south of Januária. The area is served also by an airline from Rio de Janerio that makes stops at Januária several times a week.

The town of Itacarambí with a population of several thousand is nearest to the largest group of deposits. Although it is built on the west bank of the river, it is not a port for river boats during most of the year. During intervals of high water, boats and steamers can approach the town; for the rest of the time, the nearest landing is at Russinho, a point 4.5 kilometers south. Fabião and Pindaíba, loosely defined and unorganized communities near Itacarambí (pl. 3; fig. 5), are typical settlements in the region. They consist of a slightly denser group of farm settlements, developed in the more fertile areas along perennial streams, and are near the more enterprising and prosperous fazendas or at important crossroads.

Mineral deposits in the Município de Januária are not reached easily, owing to lack of roads or to poor maintenance. Some deposits including Capão do Porco and Riacho Sêco are accessible only by foot or on horseback. Most of the deposits near Itacarambí can be reached by roads suitable only for four-wheel drive vehicles and oxcarts; these roads ascend the limestone escarpment west from Pindaíba and northwest from Fabião. (See pl. 3.) The roads are rough and, in places, steep; they deteriorate extensively during the rainy season. Roads in the area become overgrown in a short time if not used continously or if not cleared periodically. Between Itacarambí and Januária the main roads are no more than enlarged trails that traverse swamps, sandy flood plains, and silty river terraces. During the dry season from May to October the roads are choked with dust and filled with irregular ruts and holes produced during the wet season. Travel by jeep or truck from Januária to Itacarambí, a distance of 52 kilometers, takes 3 hours or more because of these conditions. The same roads are impassable during most of the rainy season, from October to April, because of mudholes and high water. Mining activity and commerce in general are curtailed during these months.

Only two seasons are recognized in the Januária region, the rainy season from October to April during which virtually all the total annual rainfall of about 1,000 mm (Serebrenick, 1953) occurs, and the dry season from May to October when near-critical arid conditions develop. Temperatures the year round are moderate; the mean annual temperature is 24°C (75°F), and the average maximum daily temperature is 31°C (88°F). Rarely does the temperature reach the maximum for the Januária region of 40°C or the minimum of 6°C. The daily variation in temperature is about 13°C.

Vegetation in the Município de Januária varies from place to place, in accordance with drainage characteristics and soil. Because of the extensive karst topography in the limestone and dolomite areas, much of the drainage is underground in the plateau region. The disappearance of surface drainage serves to aggravate conditions of aridity during the dry season. Nearly desert conditions that permit growth of only poor scrub brush (caatinga), cactus, and small hardy trees prevail on the plateau. Forests of large trees and dense underbrush (cerrados) flourish in the valleys and basins of the plateau, and along the escarpments where ground water keeps the soil moist. In many places not enough moisture exists at the surface to sustain small plants and bushes, but trees with deep roots grow well and produce parks that are relatively clear of brush and easy to traverse. On flood plains, vast areas are covered by loose sand that supports only sparse scrubby vegetation. Where the flood plain is swampy and dotted with oxbow lakes, rich silty soil supports dense, luxuriant forests; these are cleared for cultivation in places.

A plentiful supply of good timber for mining and construction purposes is available in the forests. Hard and durable woods include *cedro*, a hard tropical wood similar to the North American cedar in resistance to insects and to general deterioration, and *pau d'arco*, *arueira*, and *angico* with similar properties. Many other woods of suitable quality for rough construction are available in the immediate areas of the mining properties.

Electric power is not yet available for mine use. Small diesel powerplants furnish Januária and Itacarambí with electricity for municipal use. A hydroelectric plant of 5,000 kilowatts output to serve the region is being installed by the Comissão do Vale do São Francisco at the falls of the Rio Pandeiros, 40 kilometers west of Januária.

The creeks of the upland area are filled with water during the wet season, but most creeks dry up soon after the rains stop. This presents a problem of water supply at the mining properties for at least half the year. Small springs flow near Mina Janelão and Mina Grande, but these are not adequate to supply continuously the needs of mining camps. The Rio Peruaçu, a river that issues from an underground course about 1 kilometer from Mina Janelão, is capable of providing adequate water for the mine. A mill for concentration of ores from the Itacarambí area would have to be located along the Peruaçu or on the Rio São Francisco.

PREVIOUS GEOLOGIC WORK

Few geologists and mining engineers have published information on the deposits in the Município de Januária. Barbosa and Oppenheim (1937) passed through Januária in 1936, and recorded their impressions of the stratigraphy. After M. Pimentel Godoy visited the region in 1940, Guimarães, with the cooperation of Godoy, wrote a short paper (Guimarães, 1948) in which he described the mineralogy of the deposits and discussed ore genesis in detail. Guimarães did not include maps of the deposits or of the region. Gomes (1956) and Luciano Jacques de Moraes (1958), as well as Godoy (1958), have written review articles about the mines and minerals in the region. A few geologists of the mining companies have made reconnaissance examinations, but their findings are not available for publication.

FIELDWORK AND ACKNOWLEDGMENTS

In 1957, the Departmento Nacional da Produção Mineral and the U.S. Geological Survey agreed to study the deposits of the region of Januária. A preliminary reconnaissance, made to determine the general distribution and size of deposits, showed that only the deposits in the vicinity of Itacarambí are large enough to warrant commercial interest. Field studies occupied a period of 3½ months from June to October 1957. During this period, 10 deposits were examined; 4 were surveyed by planetable on a scale of 1:2,000 and 4 were mapped by compass and tape at scales ranging from 1:500 to 1:2,000. A triangulation control net was established with planetable and alidade along the Rio São Francisco from Morro Itacarambí southward for 11.5 kilometers, and westward to Mina Grande, a distance of 15 kilometers. A base line and several points established by Cruzeiro do Sul, S.A. were used. A planimetric map of the Itacarambí area, on a scale of 1:25,000, was compiled from the triangulation net and aerial photographs.

In addition to the studies of the mineral deposits, the geology of the Januária region was reconnoitered for features that might be significant to the occurrence of mineral deposits. Several stratigraphic sections were measured, including a composite one in the vicinity of Itacarambí, one on Morro Itapiraçaba near Januária, and a third on the Fazenda Palmeiras. The region near Itacarambí was mapped on aerial photographs and the results were then transferred to a planimetric base. About 40 square kilometers of area was covered on foot, and 180 square kilometers or more was mapped by photointerpretation after fieldwork was completed.

The bearings used by the author are based on an assumed magnetic declination of 17°30′ west of north, the orientation of north-south gridlines with meridians on maps of the Rio São Francisco surveyed by Companhia Cruzeiro do Sul. Isogonic lines on the Santa Maria Range chart (1140) of the World Aeronautical Chart series show a magnetic declination of 15° west of north for this area. Altitudes were carried from elevation bench mark RN 393 located in Itacarambí by Companhia Cruzeiro do Sul. Altitudes at Mina Janelão are based on an assumed elevation of 600 meters at estaca 3 (stake 3).

The author is indebted to many people for assistance rendered in this study. Dr. Avelino I. de Oliveira, Director of the Departmento Nacional da Produção Mineral, and Mr. John Van N. Dorr II of the U.S. Geological Survey were largely responsible for establishing the cooperative base-metal studies program in Brazil. Engenheiro Geraldo C. Melcher of the Departmento Nacional da Produção Mineral helped to formulate the program and gave impetus to the study of the Januária district. Mr. Emerson I. Brown, Minerals Attaché of the United States Embassy in Rio de Janeiro, provided useful information and encouragement in beginning the investigation. After June 1957, the studies were under the supervision of A. J. Bodenlos, U.S. Geological Survey. The work was sponsored by the Agency for International Development of the U.S. Department of State.

The author was ably assisted, in the field and office, by Engenheiro Clovis C. Carraro of the Departamento Nacional da Produção Mineral, who acted as interpreter and translator, helped greatly in assembling and maintaining equipment, performed many surveying operations, and was mainly responsible for the redrafting of maps and sketches. Srs. Lauro Morandi and Miran de Barros Latif of São Paulo were most generous in providing quarters at the company camp while the investigations were being made at Mina Janelão. They gave valuable assistance also in the surveying of properties in the Itacarambí area. Special thanks are due their associate, Engenheiro Prospero C. Paoliello, who acted as guide for 2 weeks in the preliminary reconnaissance of the region, arranged important introductions to inhabitants of the area, and passed along much useful information about the district. The investigations were greatly facilitated by Sr. João Ferreira de Souza, who opened his home at Fazenda Bela Vista to the author as a base of operations in the Itacarambí area, and also by Mr. L. C. Scofield, who extended the same courtesy in Januária. Many other

local inhabitants in the Município de Januária gave much assistance during the field study.

Various officials of the Departamento Nacional da Produção Mineral gave valuable technical assistance. Quimico Luiz Ignacio Miranda, Director of the Laboratório da Produção Mineral, arranged for analyses of mineralized rock; Engenheiro Elysiário Tavora Filho, Director of Laboratório de Mineralogia e Cristalografia, of the Seção de Petrografia, made mineral identifications by means of X-ray spectrography; and Sr. F. W. Sommer from the Seção de Paleontologia studied spherules that were thought to be fossils from limestone of the Bambuí series.

GEOLOGY

The rocks in the Município de Januária are flat-lying marine sedimentary rocks overlain by terrestial sandstone. On the west side of the Rio São Francisco, a sequence of limestone and dolomite overlain by argillaceous rocks is assigned to the Bambuí series of probable early Paleozoic age. On the east side of the river, the Bambuí series consists of argillaceous rocks in the lower part of the section, limestone in the middle, and interbedded limestone and argillaceous rocks at the top. A continental red sandstone, correlated with the Baurú formation of Late Cretaceous age, rests with apparent unconformity on the sedimentary rocks of the Bambuí series. Metamorphism has been very slight in the area being described; it is evident only in recrystallization of some beds of calcarous rocks, in the weak development of quartzite, and in the incipient development of sericite in the clastic rocks. Igneous rocks were not seen during the fieldwork on this project, but an aerial magnetometer survey by LASA[1] disclosed a strong anomaly 6 kilometers southwest of Januária. A field check disclosed an outcrop of igneous rock that appeared to be quartz diorite (E. P. Scorza, petrologist, Departamento Nacional da Produção Mineral, oral communication).

The strata throughout most of the region show little evidence of disturbance, appearing to be virtually horizontal. West of Itacarambí, however, they are warped into a broad anticline that plunges gently northwestward and is flanked by monoclinal flexures and other minor folds. (See pl. 3.) The monoclinal flexures are partly trans-

[1] Shortly after the author's project was started, the Departamento Nacional da Produção Mineral contracted with Levantamento Aerofotogrametricos, S.A. (LASA) to investigate an area in the Rio São Francisco basin, somewhat more extensive than that covered by the author, but with similar emphasis on the mineralized areas including Itacarambí and Januária. The LASA project included an aerial magnetometer survey and was designed to determine the relationships of magnetic anomalies and geologic structure to the location of the mineral deposits. The resulting maps had not been completed at the time this manuscript was written.

lated along strike into faults with small displacement. Some cross faults of slightly younger age also are found.

Three landforms are seen in the region of Januária. The principal one is a result of differential erosion of flat-lying rocks that underlie the extensive plateau of central Minas Gerais, exemplified by tablelands, by mesas and buttes, and by the steep, impressive escarpments along the Rio São Francisco. The second is represented by karst features, including sinkholes of many kinds and in every state of evolution, disrupted drainage patterns, and extensive areas of rough, serrated, and grooved erosion surfaces (lapiés), all produced by solution. The third is related to river channels and flood plains and includes terraces, channel bars, and natural levees. The flood plain also contains numerous lakes and swamps, formed in abandoned parts of the channel. Tributary streams traversing the Rio São Francisco flood plain commonly meander and in places are strikingly braided.

STRATIGRAPHY

Sedimentary rocks in the Januária region are limestone, dolomite, and fine-grained argillaceous rocks assigned to the Bambuí series, overlain unconformably by massive fine-grained sandstone and siltstone of continental origin, believed to be part of the Baurú formation. The Bambuí series is widely exposed in the bluffs along the Rio São Francisco, and is tentatively dated as of early Paleozoic age, although diagnostic fossils have not been found in the series. The nonmarine strata are correlated on the basis of lithologic similarity with the Baurú formation of the northern part of the State of São Paulo and the southwestern part of the State of Minas Gerais, where the unit contains vertebrate fossils of Cretaceous age.

The sedimentary rocks exposed in the bluffs west of the Rio São Francisco are about 600 meters thick, of which about 500 meters is in the Bambuí series and the remainder is included in the Baurú formation. Most of the lower half of the Bambuí series is dark-gray limestone containing some dolomite; most of the upper half is siltstone and mudstone. Although containing lithologically similar beds, stratigraphic units of the Bambuí series east of the Rio São Francisco cannot be correlated with units west of the river. Relationships are obscured by 6 kilometers of alluvium-floored valley between outcrops.

Stratigraphic sections of the Bambuí series and Baurú formation were measured and studied at three separate localities. One is west of Itacarambí, the second is several kilometers southwest of Januária on Morro Itapiraçaba, and the third is at Alto de Palmeiras, 30 kilometers southeast of Januária and east of the Rio São Francisco. Although time did not permit a comprehensive study of the regional stratigraphy, impressions gained of the character and distribution of sedimentary rocks in the Januária region are presented below.

BAMBUÍ SERIES

The oldest rocks exposed in the Januária region belong to the widespread Bambuí series of early Paleozoic age. The distribution of the Bambuí series is fairly well known throughout the drainage basin of the Rio São Francisco. Outcrops of the series extend from the Serra das Vertentes and the area of Sete Lagôas, Minas Gerais in the south to the curve of the Rio São Francisco in the northern part of the State of Bahia, and from the Serra de Espinhaço on the east to the boundary between the States of Goiás and Minas Gerais on the west.

HISTORICAL CONCEPTIONS OF THE BAMBUÍ SERIES

Much has been written about the general character, distribution, and age of the Bambuí series. The rocks of the series were first described by Liais (1872, p. 147–148). Derby (1879, p. 98–104 and 1882, p. 24–26) described the rocks along the Rio São Francisco and the Rio das Velhas in considerable detail. Although credited with first using the name São Francisco series (Oliveira and Leonardos, 1943, p. 260), Derby referred to the sequence only as a group of rocks characteristic of, and widespread in, the basin of the Rio São Francisco. Obviously, he considered his reconnaissance studies insufficient for naming the rock units. Later, Rimann (1917, p. 30) applied the name Bambuí to the series, and through popular usage since then, Bambuí has become firmly established in the literature. Freyberg (1932, p. 119–158) studied the series in central Minas Gerais, and others, including Barbosa and Oppenheim (1937), Guimarães (1948), and Gomes (1956) have described these strata in the Januária region.

In his reconnaissance, Derby (1882) obtained the impression that the series is divisible lithologically into three parts. He described the lower part as predominantly dark, hard, thinly laminated siltstone and fine-grained sandstone; the middle part as mainly black argillaceous "schist"; [2] and the upper part as predominantly bluish, compact calcareous rocks. Each of the rock types, however, occurs abundantly in each of the other main divisions. Throughout the section, several thousands of meters thick, the shaly beds quantitatively far surpass the limestone and siltstone. The predominance of limestone in the Januária area would seem to place those rocks in the upper part of the series as divided by Derby.

In a later paper, Derby (1906, p. 395) suggested the possibility that the limestone of the upper Rio São Francisco might be separated

[2] Older reports in Portuguese use only one word for fine-grained clastic rocks, "xisto," which can be interpreted as schist, slate, or shale.

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into two distinct groups, an older one to include the more disturbed, fine-grained sandstones and shales of "almost certain early Paleozoic" age, and a younger group of predominantly horizontal beds. These reflections, however, appear to be speculative, for nowhere does he state that he actually saw a horizontal series of beds of this description lying unconformably on folded, disturbed beds. Notwithstanding, the virtually horizontal calcareous beds in the Município de Januária would belong in Derby's younger group.

Freyberg, working in the southern part of the Rio São Francisco basin, divided the Bambuí series into eastern and western facies. He calls beds mostly east of the upper Rio São Francisco, "Camadas Gerais"[3] (Freyberg, 1932, p. 122). Rocks of only slightly different character that crop out west and southwest of the upper reaches of the Rio São Francisco to the Triangulo Mineiro of western Minas Gerais are referred to as "camadas Indaia." The "camadas Indaia" are said to contain more argillaceous and less quartzitic rock than the "camadas Gerais." He further states that the "camadas Gerais" are generally flat lying. This observation seems to be part of his definition of facies, but this is a curious extension of the meaning. Moreover, some of the area presumably underlain by undisturbed "camadas Gerais" in the valley of the Rio das Velhas, was described by Derby (1882, p. 25) as being underlain by deformed rocks. Nowhere was Freyberg able to see a contact or lithologic gradation between the two facies, and so was not able to ascertain the true stratigraphic relationship between the two "camadas."

In the Januária region, the beds are generally horizontal and so they presumably should be correlated with the "camadas Gerais." The criteria used by Freyberg to separate the two facies, however, is dubious, and cannot be reliably applied here, as a great distance separates the Januária region from the localities Freyberg studied. Nor can Derby's suggestions be applied with certainty because the character of the Bambuí series as exposed is different from the descriptions of these rocks to the south. The problem of whether the Bambuí series should be divided into an older and younger group based on relative amount of deformation as Derby suggested, or into two lithologic groups or camadas based on the facies concept propounded by Freyberg, awaits a great deal more detailed mapping and stratigraphic study in the basin of the Rio São Francisco.

[3] The word "camadas" is translated as layers or strata of rock.

SECTION NEAR ITACARAMBÍ

The Bambuí section near Itacarambí is representative of the series west of the Rio São Francisco in the Município de Januária. A stratigraphic section of a part of the Bambuí series was measured in the lower part of the escarpment north of the Chico Pacheco road (loc. A, pl. 3). The upward continuation of the stratigraphic section was studied 10 kilometers to the north on the trail to prospect Jacarèzinho (loc. B); a general correlation between the two is shown in figure 6. The carbonate rocks of the section are described by units.

Description of stratigraphic sections of parts of the Bambui series near Itacarambi

[Section A, scarp north of Chico Pacheco road. Section B, on trail to Jacarèzinho]

		Meters
6.	Limestone, light-gray, fine-grained, laminated; minor dolomite breccia interbedded	5+
5.	Limestone and dolomite, light-gray to pink and buff, saccaroidal massive, black-weathering; minor silica and chert along bedding planes	53
4.	Limestone, medium to dark-gray, fine-grained, thick-bedded to massive; crossbedded at top	35
3A.	Limestone, medium gray at base, fine-grained and laminated; interbedded dolomite breccia; primary limestone and dolomite breccia above	25+
3B.	Limestone and dolomite, primary breccia, interbedded with medium-gray, laminated limestone. Equivalent to 3A at locality B.	
2.	Limestone, medium dark-gray, thick-bedded (mainly more than 20 cm thick, fine-grained; mottled with redeposited calcite along bedding planes; minor interbedded dolomite breccia in section B	56
1.	Limestone, medium dark-gray, fine-grained, thin-bedded (less than 20 cm thick); base not exposed	30+
	Total	204+

Unit 1: The lowermost unit consists of at least 30 meters of a thin-bedded limestone cropping out at the base of the escarpment at locality A. On fresh exposure this limestone is dark gray, fine grained, and crystalline; it weathers medium light gray. Most of the individual beds are actually lenses, only a few of which exceed 20 centimeters in thickness and which thin out laterally within short distances.

Unit 2: Overlying the thin-bedded limestone is thicker bedded but otherwise nearly identical limestone with beds commonly more than 20 centimeters thick. Many beds have a mottled appearance produced by clots of recrystallized, buff to pink calcite along bedding

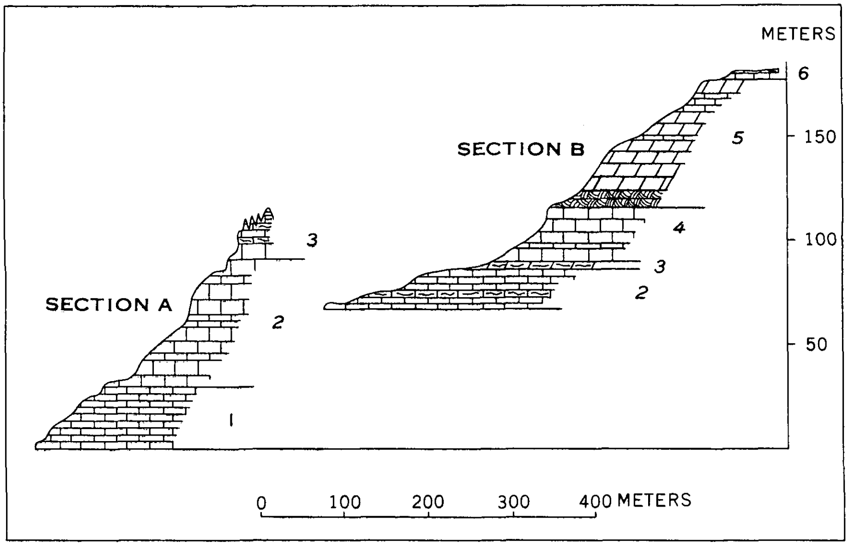

FIGURE 6.—Stratigraphic sections of parts of the Bambuí series near Itacarambí.

planes. The unit also contains a few thin lenses of dark-gray chert. At one or two places, tiny spherules of silica were found, but they are not considered to be of organic origin (F. W. Sommer, DNPM, written communication, May 1958). At locality B a few beds of dolomite intraformational breccia are interbedded with the limestone near the top of the unit. The thickness of unit 2 at locality A is about 56 meters; its thickness was not measured at locality B.

Unit 3: Primary breccia of limestone and dolomite, some of it undoubtedly intraformational, occurs above the thick-bedded limestone. This breccia contains lenses of fine- to coarse-grained, thinly laminated, light-gray limestone and dolomite, interbedded and grading in and out laterally with it; some laminae range from greenish to pinkish gray. The laminated limestone predominates near the base of the unit, but higher in the unit it occurs sparsely. The primary breccia consists of unsorted angular platy fragments of light-gray, fine-grained, laminated limestone and dolomite in a fine- to coarse-grained groundmass of clastic carbonates. In places, the angular platy fragments have been rotated only slightly from their original positions in the bedding planes; at other places disturbance appears to have been great, with turbulent mixing of fragments. Locally, a few thin layers are contorted, but their deformation is confined within a small part of this stratigraphic unit. Calcite crystals more than a centimeter long are abundant in the breccia and laminated limestone. They appear to have formed through recrystallization in such a way that textures, bedding structures, and color of the rock have been retained. Inasmuch as they are distinctly different in this respect from calcite crystals formed in fractures and veinlets in the other limestone and dolomite units, it is probable that they are diagenetic. Disruption relatively soon after deposition provided conditions of permeability that favored crystal growth of calcite.

A thickness of at least 25 meters of the conspicuous limestone and dolomite breccia of unit 3 is exposed at locality A, in contrast to a thickness of only 3 meters for the same unit at locality B. The difference expresses well the variations in thickness of the unit in the region. In fact, in some areas the primary breccia of unit 3 is absent, although thin lenses of similar breccias may occur at higher or lower stratigraphic horizons. It seems to supplant rather than augment the adjoining carbonate beds, apparently having little effect on the total thickness of the Bambuí series in the Itacarambí area. Along the escarpment the breccia of unit 3 weathers to a distinctive pinnacled and serrated lapiés surface, as shown in figure 7.

Unit 4: Thick-bedded to massive limestone overlies the primary limestone and dolomite breccia at locality B. The limestone is uniformly medium dark gray and medium grained, except for a few

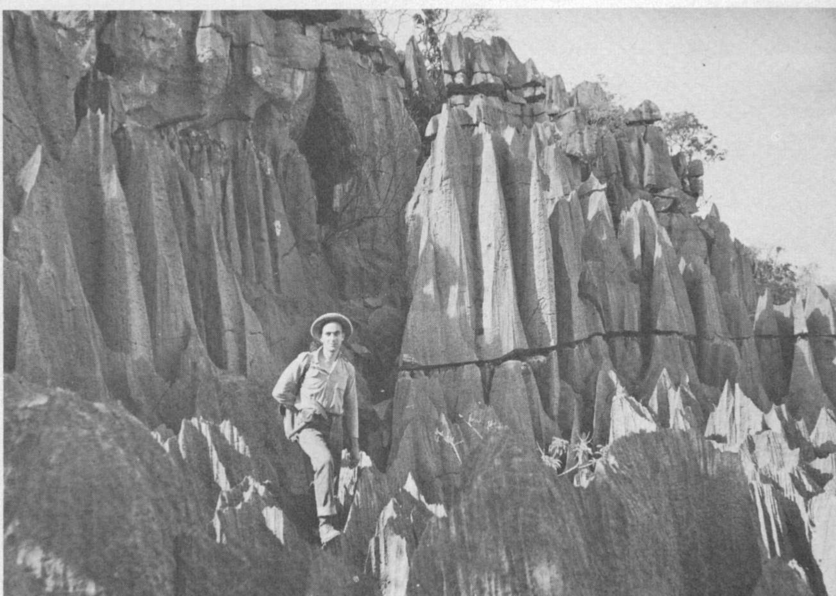

FIGURE 7.—Lapiés surface of erosion developed on primary limestone and dolomite breccia, on escarpment north of Chico Pacheco Road.

thin interlayered beds of laminated limestone and medium-grained, light-gray to buff dolomitic limestone that weathers dark gray. The top 8 meters of this unit is crossbedded. Unit 4 is about 35 meters thick at locality B.

Unit 5: The thick-bedded to massive limestone in unit 4 is overlain by massive limestone and dolomite that weathers from dark gray to nearly black. The weathered color contrasts with the lighter gray of the limestone units stratigraphically above and below, and thus permits ready identification of the unit, especially in escarpments bordering the river. On fresh exposure the carbonate rock in unit 5 is medium grained and saccaroidal and ranges from rose or buff to light gray and white. It has the appearance of a recrystallized altered rock, as bedding planes are generally obscure and irregular, or absent. In places, unit 5 consists of recemented breccia of large blocks and small fragments. Although some of the breccia is of primary origin, at several localities it is recognized as a collapse breccia formed during erosion. Many irregular silica masses may be seen along fractures and bedding planes. This distinctive unit is found in the vicinity of all the known mineral deposits near Itacarambí. At locality B, unit 5 is 53 meters thick.

Unit 6: The uppermost unit of the section at locality B consists of medium light-gray very fine grained laminated limestone, similar to the laminated limestone of unit 3. Interbedded with this unit are thin layers of limestone or dolomite breccia. Only the basal 5 meters of the unit remains at locality B.

This unit is more completely exposed along the tributaries of the Riacho Embaúba east of Mina Janelão where it overlies the black dolomitic limestone of unit 5. In that area, the strata comprising unit 6 are about 90 meters thick and consist of thin-bedded medium- to dark-gray fine-grained limestone, several beds of which are dolomitic, argillic, or siliceous. The unit also contains a few beds of chert and calcareous shale and one bed, about half a meter thick, of limestone pebble conglomerate.

Clastic rocks above unit 6: Conformably overlying the limestone and dolomite in the plateau region west of Itacarambí are beds of calcareous siltstone, mudstone, and shale; a few thin beds of chert, limestone, and possibly fine-grained tuff are interlayered with them. The beds of fine clastic sedimentary rocks total more than 250 meters in thickness about 2 kilometers west-southwest of Mina Grande. The shales range from yellowish brown to greenish gray, and a few beds are red. Slightly lustrous bedding surfaces of some shaly rocks results from finely divided flakes of mica. Rocks of the unit are weakly indurated and crumble readily where weathered. They are capped at one or two places by quartzite of the Baurú formation.

The age of these clastic rocks is questionable. It is possible that they are much younger than the Bambuí series and equivalent to one of the formations of Mesozoic age that are widespread in western Minas Gerais. The author prefers to include the fine-grained clastic rocks with the Bambuí series, first, because the contact between these rocks and the limestone of unit 6 is gradational; second, because the clastic rocks are abundantly calcareous, in contrast to the noncalcareous continental clastic rocks of the overlying Baurú formation; and third, because comparable fine-grained clastic rocks are described as part of the Bambuí series in other areas.

The total thickness of the Bambuí series exposed in the vicinity of Itacarambí is about 520 meters, half of which consists of the clastic, fine-grained strata above unit 6.

SECTION ON MORRO ITAPIRAÇABA

The Bambuí series crops out also on the southeast slope of Morro Itapiraçaba near Januária (fig. 8) where the sequence of limestone and dolomite is the same as in the vicinity of Itacarambí but the thickness is much less. A comparison of the sections (fig. 9) follows: Unit 1 on Morro Itapiraçaba is a medium- to dark-gray fine-grained thin-bedded limestone, but is only about 20 meters thick, instead of 30 meters as at Itacarambí. This unit is succeeded by 12 meters of thick-bedded limestone of unit 2 (with beds generally more than 20 centimeters thick), whereas in the Itacarambí section unit 2 is 56 meters thick. Above this limestone on the north side of the morro is about 8 meters of laminated, light-gray limestone of unit 3. The fact that this limestone is absent on the southeast side of the hill indicates that the formation is lenticular. Unit 4, of thick-bedded to massive limestone, is absent at Morro Itapiraçaba. Next higher in the section is the distinctive black-weathering but light-gray saccaroidal limestone and dolomite of unit 5. This unit has dolomite primary breccia interbedded with it. Only 24 meters of the "black" dolomite and limestone is found on Morro Itapiraçaba, compared to 53 meters measured in the stratigraphic section near the Jacarèzinho prospect.

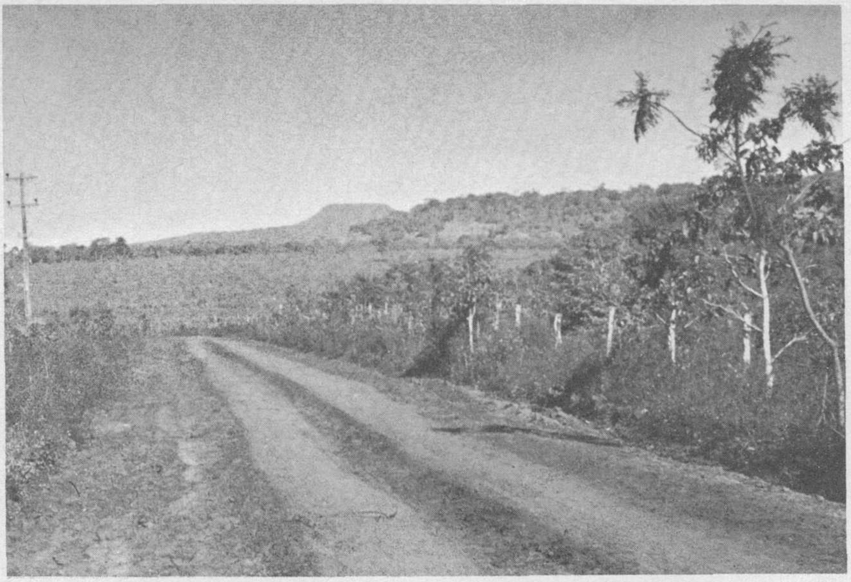

FIGURE 8.—The flat-topped hill in the far distance is Morro Itapiraçaba, seen from the northeast. The distinct break in its slope marks the contact between the Bambuí series and overlying Baurú sandstone. Limestone is exposed in the hill to the right in the distance.

The section immediately above unit 5 includes 12 meters of laminated limestone, overlain by 28 meters of dolomitic and argillaceous limestones and interbedded chert lenses. Litholrgically, this section is similar to the thin-bedded limestone above the "black" dolomite near Mina Janelão, but it is slightly less than half as thick. The dolomitic and argillaceous limestone is topped by calcareous shale with thin layers of interbedded dolomite and limestone. The contact appears to be gradational and entirely conformable. Only about 8 meters of shale beds are exposed; the contact with the overlying red sandstone and quartzite of the Baurú formation is covered by soil and rubble. From topographic expression, however, it is surmised that the shale member is thin in this locality, possibly 10, or at the most 20 meters thick. The total thickness of sedimentary beds of the Bambuí series exposed on Morro Itapiraçaba is only 114 meters as compared to 517 meters near Itacarambí.

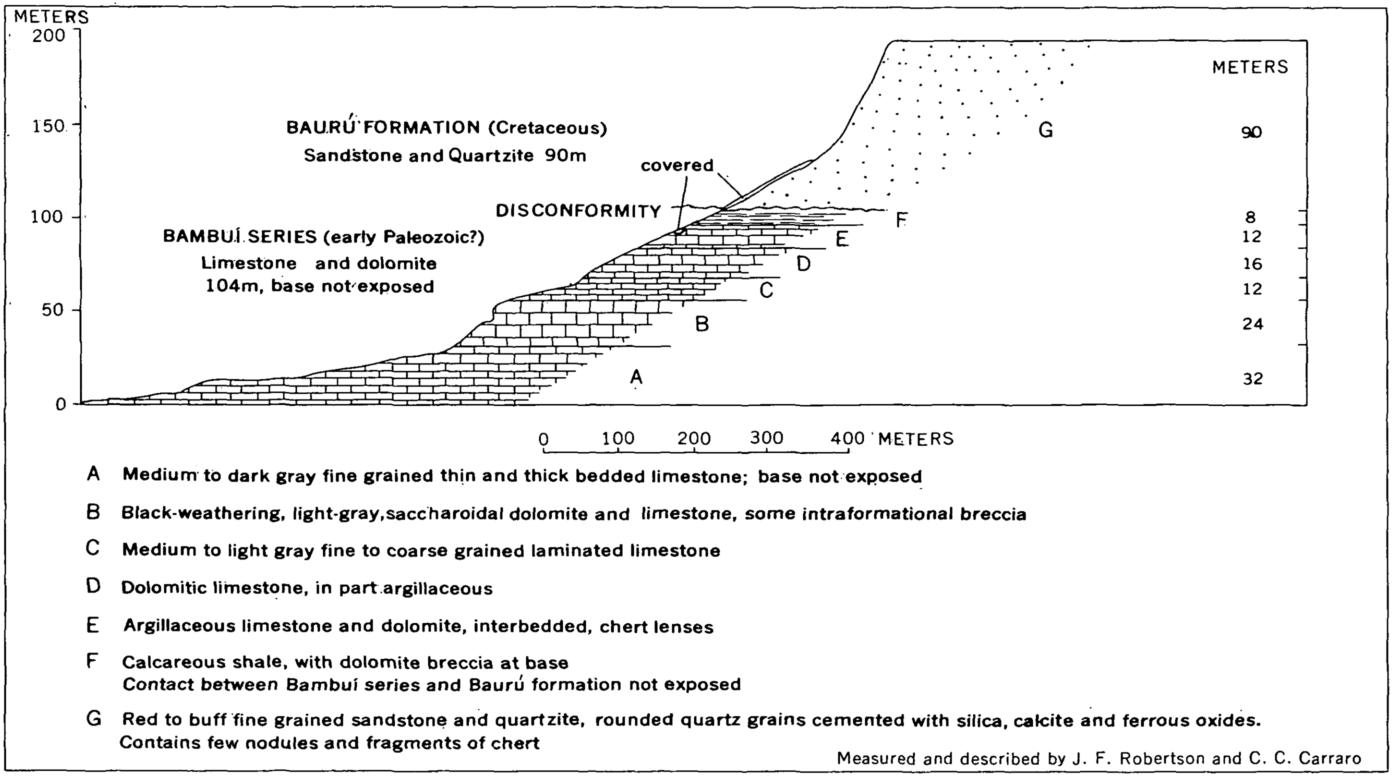

FIGURE 9.—Geologic section from southeast side of Morro Itapiraçaba.

The section at Morro Itapiraçaba is much thinner than the section measured near Itacarambí, although the rock units occur in the same order of deposition. A possible explanation for the consistent difference in thickness in the units between the two localities is a shoaling sea in the vicinity of Januária during the period of deposition. Part of the great difference in thickness of the clastic sedimentary rocks at the top of the section may have resulted from differential subaerial erosion before deposition of the overlying Baurú formation.

SECTION AT ALTO DE PALMEIRAS

The third section in which the Bambuí series was measured is near the prospect, Alto de Palmeiras, on the fazenda of Senhor Henrique Oliva Brasil, 30 kilometers southeast of Januária. Although the rocks belong to the Bambuí series, the section is different than that exposed west of the Rio São Francisco. At the base, beginning on the south side of the creek Riacho Palmeirinha (fig. 10), is about 35 meters of buff to light greenish-gray uniformly thinly laminated mudstone, in part calcareous. This rock contains very fine grained secondary mica, and possibly chlorite. It crumbles readily and erodes to subdued hummocks and slopes. Overlying this basal unit is 55 meters of reddish-brown, silty mudstone, also thinly laminated and slightly calcareous in part; it is somewhat harder and forms steep

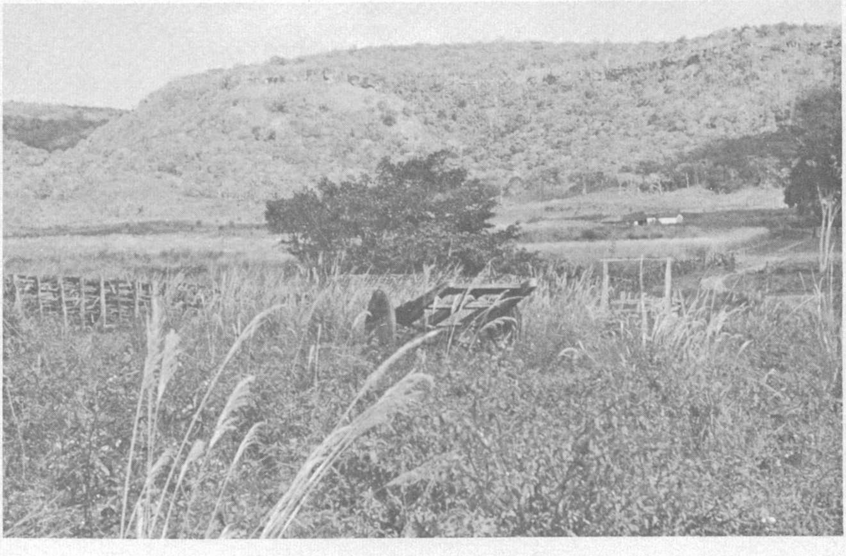

FIGURE 10.—Escarpment on the south side of Riacho Palmeirinha, exposing flat-lying beds of the Bambuí series. The contact between the clastic rocks and overlying limestone is at the base of the prominent cliff-former near the top.

slopes. Above this unit are 15 meters of cliff-forming slaty mudstone and siltstone that are reddish brown, greenish gray, and buff. Following is a unit at least 55 meters thick of thin-bedded dark-gray fine-grained limestone that weathers light gray and forms imposing cliffs. At the top of this section occur about 50 meters of cyclicly interbedded fine-grained limestone, calcareous shale, and mudstone, similar lithologically to the units occurring below in the section. Each cyclothem is several meters thick. The section exposed here totals roughly 210 meters.

The units in the section at Palmeiras do not correspond to those seen west of the Rio São Francisco. The clastic rocks in the lower part of the Palmeiras section, 105 meters thick, are uniform in composition compared to the upper part of the section at Itacarambí where chert, limestone, siltstone, and mudstone all are interbedded. The limestone in the middle of the Palmeiras section is similar to the limestone unit at the base of the Itacarambí and Morro Itapiraçaba sections, but the cyclically interbedded unit above bears no resemblance to any beds west of the river.

Tracing the strata from one side of the river to the other in the Januária region is hindered because the alluvium-covered flood plain separating outcrops is at least 8 kilometers wide. The difference in the sections could be attributed to facies changes in the series or to faults concealed by flood-plain deposits. It is also possible that an indiscernible regional dip exists in the region; even if as little as 2° in either direction, hundreds of meters difference in section could result.

AGE OF BAMBUÍ SERIES

Although considerable time and effort were spent in search of fossils in the Bambuí series, none were found.

At two localities in the Itacarambí area tiny siliceous spherules resembling algae or spores and ranging from 1 to 10 mm in diameter were found along bedding planes of thin-bedded limestone near the base of the exposed stratigraphic section. One locality is near the Chico Pacheco road in section A and the other is in a low knoll of limestone southwest of the community of Pindaíba. F. W. Sommer of the Laboratório de Micropaleontologia da Divisão de Geologia e Mineralogia, Departamento Nacional da Produção Mineral, examined the material and reported (written communication, May 1958):

> An assemblage of forms that, morphologically, produce small spheres (nodules) and configurations that remind one of algae or lichen with apparent centripetal growths. They do not belong, in spite of their form, to algal groups or other vegetable macro- or micro-fossils of my present acquaintance. I consider these configurations inorganic phenomena—ludus naturae—resulting from solution and redeposition (of silica).

It can be speculated that they were epigenetically formed by secondary silica that penetrated along bedding planes in successive waves and was deposited concentrically about various nuclei.

The age of the Bambuí series is open to question. Oliveira and Leonardos (1943, p. 259) cite Derby as having tentatively assigned an age between the Late Silurian and Permian. His fossils from Bom Jesus da Lapa, however, were admittedly poor and of doubtful value. Later, Ruedemann (1929, p. 46), on the basis of questionable *Favosites* coral fragments collected from the same area, gave the tenuous opinion that the age is Silurian for the upper part of the series, or "camadas Gerais" as implied by Oliveira and Leonardos (1943, p. 259). Oliveira and Leonardos conclude their discussion by saying that they have to admit, for the lower series (or "camadas Indaia"), an Early Silurian or Ordovician age. Beurlen (1955, p. 535–542), however, states that the forms by which the age was established for the Bambuí series are quite definitely of inorganic origin, and are not coral fragments of *Favosites*. It seems, therefore, that the age of the Bambuí series is still unknown. The best than can be said is that its age is probably early Paleozoic.

BAURÚ FORMATION

Overlying the Bambuí series in the Januária region are sedimentary rocks of continental fluvial origin, referred to as the Baurú formation. This formation was first studied and named by Gonzaga de Campos in 1905 in the northern part of the state of São Paulo (Oliveira and Leonardos, 1943, p. 600). His description of the rock occurring in the valley of the Rio Tieté matches well the lithology of the red-bed sandstone in the Januária region:

> It is a deposit of sandstone almost massive, rarely stratified, of calcareous cement, containing concretions and masses of a limestone more or less argillaceous. The material has little resistance, easily disintegrates, and on the surface takes on the aspect of a conglomerate filled with cavities. In this sandstone is not found any eruptive rocks, such as is intercalated in the underlying sandstone. Such is the rock of Baurú * * * (Translation from Portuguese to English by the author).

The Baurú formation is widespread, occurring in the states of São Paulo, Minas Gerais, Goiás, Mato Grosso, and probably Bahia. Characteristically, it stands up topographically as buttes and tablelands, called chapadas. The Cretaceous age of the Baurú formation is based on the identification of abundant vertebrate fossils collected from the formation in the states of São Paulo and Minas Gerais (Oliveira and Leonardos, 1943, p. 605–608).

Morro Itapiraçaba southwest of Januária (see fig. 8) is capped by more than 90 meters of the Baurú formation (see fig. 9). Here it consists mainly of red to light-yellow, medium- to fine-grained sandstone intercalated with occasional thin layers of argillaceous siltstone, and scattered, poorly defined, unsorted boulder conglomerate beds of continental origin. The massive sandstone is cemented by silica, calcium carbonate, and iron oxide in varying degree. Highly siliceous beds, where fresh, are actually quartzite, but in most places solution of the cement is taking place, with crumbling and disintegration of the rock. Because of this, good outcrops are rare. Many outcrops show the sandstone honeycombed with cavities where the cement has been leached so that the rock has the appearance of a poorly sorted conglomerate. The sandstone is composed almost exclusively of rounded to subrounded quartz grains mixed with a few grains of altered feldspar and dark minerals. Here and there are angular fragments of chert, as much as 3 to 4 centimeters in diameter, and reddish to yellowish brown and gray. The siltstone shows fair cross-bedding, but it is so friable that it is rarely exposed.

Remnants of the Baurú formation cap the mesas and peaks that occur at the nose and flanks of the large anticline west of Itacarambí. The remnants are only a few meters thick, or may be represented only by accumulations of residual boulders strewn over erosion surfaces at the top of the Bambuí series.

The contact between the Baurú and the underlying Bambuí series was not seen, but it is probable that an unconformity, or at least a disconformity, exists between the two formations. On the north side of Morro Itapiraçaba, a thin band of float of layered manganese dioxide, pyrolusite, contours the slope and indicates the probable location of the contact. The float is immediately above exposures of interbedded shale, chert, and limestone of the Bambuí series. The large difference in the thickness of the upper clastic beds of the Bambúi series between Morro Itapiraçaba and Itacarambí suggests that the unit was eroded before deposition of the Baurú formation.

STRUCTURE

Good exposures in the valley escarpments from Pedra de Maria da Cruz, south of Januária, to Itacarambí indicate that the strata of the region are virtually horizontal as viewed from roads in the valley of the Rio São Francisco.

As noted above, low regional dips to the east or west, or faults concealed by the flood-plain deposits in the valley of the Rio São Francisco, may exist. As a slight deviation from this regional pattern, a broad, gently plunging anticline, accompanied by lesser folds and several faults (pl. 3), is found west of Itacarambí on the plateau of Gerais. The anticlinal structure may be significant in the deposition of lead and zinc because the more prominent lead-zinc deposits of the region are clustered around it.

FOLDS

Along the Rio São Francisco, most of the sedimentary beds show slight undulations but are virtually horizontal. Possibly there is a regional dip of low magnitude in the Município de Januária but this could be determined only by accurate surveying.

The limestone beds are tilted in many places and thus give the impression that they are folded or faulted. In most cases such beds are in huge slump blocks, particularly well displayed along the escarpments of the river and along the tributary valleys. They are characteristic of limestone in a karst topography, occurring where blocks of limestone became detached by development of open joints and solution cavities, and where underground support for the blocks was weakened by solution. Examples of such slumped and rotated blocks are particularly well shown at the base of the main escarpment along the Chico Pacheco road (fig. 11). Locally, small-scale folding, crushing, and fracturing of beds accompanied the slumping of limestone blocks.

West of Itacarambí is a broad anticline with relatively small amplitude that lies roughly within the area bounded by Mina Grande on the east, Mina Janelão on the west, and Fazenda de Itabahiana on the north (pl. 3). This anticline is marked by dark-weathering massive dolomite and limestone at its center and calcareous shale and siltstone from the upper part of the Bambuí series on its flanks. The nose of the anticline is well defined by clastic rocks wrapping around the limestone, but the structure dies out to the northwest within 1

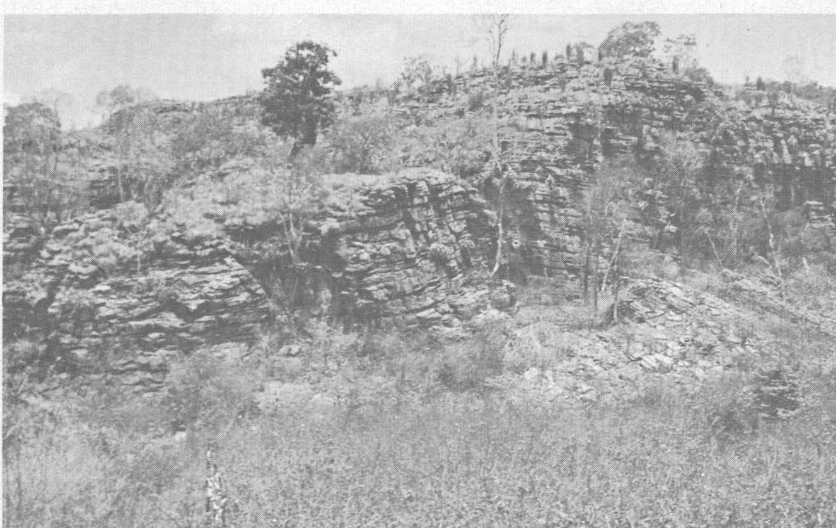

FIGURE 11.—Slumped and rotated blocks of limestone at base of scarp, Chico Pacheco road.

kilometer or more. The trace of the axial plane of the anticline strikes N. 40° W.; where the clastic sediments defined the nose of the anticline, the axis plunges about 10° in the same direction, but the axis flattens out to the northwest and southeast. The northeast limb strikes about N. 60° W. and dips roughly 25° NE. Farther to the southeast the beds dip more gently and become horizontal. A domal structure is defined at the southeast end of the anticline.

The northeast limb of the anticline is made up of shaly sediments capped in places by remnants of Baurú sandstone, expressed topographically in a cuesta with an inward facing escarpment. This limb dies out along the strike to the southeast. Downdip to the northeast, the flank of the anticline is cut by a longitudinal fault that can be traced as far as the nose of the anticline. Northeast of the fault in the vicinity of Mina Grande the beds dip 25° SW. toward the fault. Within a short distance to the northeast, however, the bedding is horizontal. A monoclinal flexure, perhaps modified by a fault of slight magnitude, lies between the flat-lying beds and the southwest-dipping beds.

The southwest limb of the anticline is complicated by a narrow and shallow syncline. The west limb of the syncline is a monoclinal fold, the hinge line of which trends N. 20° W. along the east edge of the Mina Janelão property. West of Mina Janelão the limestone beds are flat lying, at the mine they dip 5°–15° E., and east of the mine they dip 20° E. The shale and mudstone sequence overlying the limestone occurs in the syncline about 100 meters east of Riacho Embaúba and Mina Janelão (pl. 3). Slightly to the east of the contact and near the axis of the syncline, the shales show minor drag folds and faults. Toward the nose of the anticline, the syncline and its accompanying monoclinal flexure are replaced by faults having minor displacements.

West of the Riacho Sêco prospect, the structure is obscure because of poor outcrops of calcareous rocks. A study from aerial photographs of the drainage pattern and topography shows that the anticline is terminated toward the southeast in a gentle dome. A large area between Mina Janelão and Mina Fabião is marked by flat-topped chapadas that suggest virtually horizontal sedimentary beds.

FAULTS AND FRACTURES

Most faults in the Januária-Itacarambí region are small, and all are in the area of the large anticline west of Itacarambí. Their displacements are small, the largest having a throw in the magnitude of 100 meters. The longest are traceable for 2 to 5 kilometers.

The most prominent fault is on the northeast flank of the anticline. It extends from near the east end of the blind sinkhole valley, Boqueirão do Cipoal, westward up the valley to the nose of the anticline beyond Mina Grande. Its trend, well marked topographically, follows the strike of the beds and changes from N. 80° W. near its east end to N. 60° W. near Mina Grande. It is a high-angle fault downthrown on the south or anticline side. On its south side, at a point opposite Mina Grande, the contact between limestone of unit 6 and overlying clastic sedimentary rocks of the Bambuí series is exposed at the bottom of deep ravines; there, beds dip about 10° NE. On the north side of the fault, the lower few meters of the dark-weathering dolomite unit is exposed at the faultline, its beds dipping from 10° to 25° S. The fault, therefore, appears to cut out roughly 125 meters of the topmost beds of limestone and dolomite in the Bambuí series. From Mina Grande toward the northwest, the vertical displacement progressively diminishes to only a few meters in the large sinkhole at Fazenda Itabahiana at the nose of the anticline. It is thus a hinge fault, with rotation on the southwest side about an axis normal to the fault, at the nose of the anticline.

At Mina Grande a minor fault that parallels the main valley fault strikes N. 80° W. and dips from 65° to 80° S. It is exposed for about 200 meters from east to west, but is probably longer. The same thin-bedded limestone unit occurs on both sides of it. About 40 meters north of this fault is the mineralized zone of Mina Grande, which includes small faults and fractures that strike N. 70°–80° W. and dip nearly vertically. This zone separates thin-bedded limestone on the south from dark-weathering dolomite on the north, as can be seen on the map of Mina Grande (see pl. 4). Considering the fault and the mineralized zone together, the northern block is downthrown from 40 to 80 meters.

The main valley fault is offset at intervals by four cross-faults that strike between N. 40° E. and N. 50° E. The offsets are not more than 100 meters each, with right lateral movement on the one closest to Mina Grande and left lateral movement on the other three. They could not be traced very far and do not seem to have perceptibly disturbed the outlines of the anticline (pl. 3).

Several relatively long faults occur on the west side of the anticline. Two of the most prominent faults are connected, extending northward from near the head of Riacho Embaúba to a point west of Fazenda da Itabahiana, a distance of 4.5 kilometers. The southernmost of the two strikes N. 15° W. and can be traced for 2 kilometers. The second or northern one branches from the first and extends 2.5 kilometers N. 35° W. The planes of these faults were not seen but are probably steep. The faults are well defined topographically, but do not seem to have displaced greatly the sedimentary beds. Movement seems to have affected only the east side and appears to have been mostly rotational, diminishing northwestward. Immediately west of the faults the beds underlying the plateau are not exposed, although they are believed to be virtually horizontal. The shaly beds east of the faults dip as much as 40°, outcropping as small flat irons against the fault scarp. These faults appear to be an extension of the monocline farther south since they occupy the same position in the regional structure. Although displaced eastward, they probably represent a translation from folding to rupture along the monoclinal hinge line.

Four hundred meters east of the two connected faults is another longitudinal fault that strikes N. 15° W. It occurs within shaly sediments and is well defined topographically but it is not exposed well enough to permit the determination of its dip or its movement, thought to have been small. Other minor longitudinal or strike faults seen in a few outcrops in this zone do not appear to affect critically the regional structure.

Cross faults also exist on the west side of the anticline. One, at the north end of the monocline, is between shale beds that strike north and limestone beds that locally strike east and dip south. The fault plane is not exposed, but the topography and dislocation of sedimentary beds suggest that it trends about N. 80° E. If the longitudinal fault north of the cross fault is related to the monocline south of it, as suggested above, the map pattern indicates right lateral movement on the cross fault. The attitude of the limestone and shale beds further suggest that movement was, in part, vertical, with the north side upthrown relative to the south side. The other two cross faults are inferred to truncate the two longitudinal faults at their south ends. They are poorly defined so that their strikes and exact locations are questionable, but they are suggested by loss of expression of the longitudinal faults, both topographically and geologically, and by anomalous changes in strike of shale beds in the vicinity.

Closely spaced parallel tension fractures occur in the limestone and dolomite along the axis of the monocline near Mina Janelão, especially along the ridge referred to as Estaca Onze (Stake Eleven) at the north end of the property. These strike N. 30° W., and are nearly vertical. The zone of tension fractures can be followed for at least 500 meters. They contain, here and there, slight amounts of lead and zinc minerals.

Two mineralized zones at Mina Janelão and the two at prospect Riacho Sêco are parallel to the cross faults in the area, N. 30°–35° E. One zone, at the north end of Mina Janelão, consists of a quartz vein containing very small amounts of galena, is 220 meters long, and is essentially vertical. The mineralized zone at the south end of Mina

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Janelão can be traced for 125 meters and is probably vertical. Both quartz veins at prospect Riacho Sêco conform to the cross-fault pattern, but dip 55° to 85° SE. All the Mina Janelão and Riacho Sêco veins show little or no displacement.

Faults and fractures are suggested throughout the district by linear scarps. Vertical joints containing fluorite are conspicuous on the escarpment along the Chico Pacheco road near Mina Fabião. The joints strike about N. 20° E. Joints enlarged by solution are prominent throughout the limestone and dolomite beds.

The folds and faults west of Itacarambí seem to have evolved concurrently and probably are varied responses to the same tectonic forces. The anticline is within a downdropped triangular block, bounded by monoclinal flexures and faults on its west and northeast sides. The longitudinal fault that trends up the valley northwest of Mina Grande apparently has greater vertical displacement than the monoclinal flexure and related faults on the west side. The author thinks that the monoclinal fold on the west side represents a hinge line, about which the whole anticlinal block rotated when movement occurred on the fault along the northeast side. At the same time compressive stresses squeezed the rocks in the block and warped them into a gentle anticline.

The age of deformation in the Januária region is open to question. Poorly defined beds of the Baurú formation observed on the anticline west of Itacarambí seem to dip in the same direction as the underlying strata of the Bambuí series. This attitude suggests that the Bambuí series and the Baurú formation were involved in the same deformation, occurring in Cretaceous or later time. However, only small remnants of the Baurú formation remain in the area and it is possible that present attitudes coincide with initial dips of its fluvial beds. In this case the Bambuí series was deformed before the Cretaceous.

PHYSIOGRAPHIC DEVELOPMENT

Three landforms occur in the Januária region: the widespread plateau, the valley of the Rio São Francisco, and the karst features in the calcareous rocks. The primary landform is the extensive erosion plain or plateau developed on the rocks of the Bambuí series. This plateau occupies a major part of the drainage basin of the Rio São Francisco, covering the western part of the states of Minas Gerais and Bahia, and extending far beyond into Goiás. The surface of the plateau, monotonously flat, is dissected slightly by widely spaced major rivers and by intervening, intermittent streams and tributary drainage, giving it a gently undulating aspect with relief of less than

100 meters. Isolated mesas and buttes whose summits are 100 to 200 meters above the general level of the plateau occur in the interstream areas (fig. 6). They consist of the flat-lying, resistant sandstone of the Baurú formation, elsewhere stripped off of the underlying Bambuí series. The altitude of the plateau surface in the region of Januária is about 700 meters above mean sea level.

The Rio São Francisco, which flows generally north-northeastward through central Minas Gerais and Bahia, has carved out an impressive valley trench in the great plateau. The valley, the second important physiographic feature, is relatively wide, ranging from 20 to 30 kilometers, but it is shallow, extending only a little more than 250 meters below the plateau surface. The valley sides are irregular, steep erosional escarpments that are interrupted at relatively long intervals by tributary streams, which have cut sharp valleys in the edges of the plateau. The flood plain of the Rio São Francisco averages 6 kilometers in width and is relatively flat. Small hills or outliers of limestone, such as Morro Itacarambí (see pl. 3) are sparsely scattered on the valley floor.

Slightly dissected terraces border the flood plain and rise 10 meters or more above it. The terraces slope gently upwards to the escarpments that form the valley sides, and are dotted in many places with sinkholes caused by subterranean solution of limestone.

The channel of the Rio São Francisco is 0.5 kilometer wide on the average. During the rainy season the river at times overflows onto the flood plain. In the drier part of the year, when the river is low, the channel reveals shifting bars and islands composed of silt and sand in crossbedded deposits. The Rio São Francisco is a graded river in the mature stage of the fluvial cycle, with erosion and deposition alternating as volume of water fluctuates between flood stage and low water. The river has no pronounced meanders but many curves and some straight stretches in the interval between Pedras de Maria da Cruz and Itacarambí. The flood plain contains many features common to large rivers, such as the scars of high-water channels or scour routes, abandoned river channels, a few meander scars occupied by lakes or swamps, and point bar or meander scroll deposits. Point bar deposits are long, curving ridges of sand and silt that during stages of high water have been deposited against the inner bank of the curved or meandering channel. Lakes commonly occur in the swales between point bars and along scour routes, and are relatively long, narrow, and arcuate. A few lakes along the Rio São Francisco are oxbow in shape; most other lakes, which probably occupy the cores of low-lying cutoff meanders, are irregularly oval and cover large areas. The broad extent and relative freshness of these erosional features near the river channel attest to the tremendous erosional activity of the Rio São Francisco at flood stage, and the vigorous shifting of the river back and forth across its valley.

The most common stream pattern of tributaries to the Rio São Francisco in the Januária district is dendritic. The pattern is complicated by underground solution of limestone that produces karst drainage features. Some drainage, mostly local, shows the influence of jointing. Because of its rectilinear pattern in part, the route of the Rio Peruaçu, though partly underground, appears to reflect some joint control (pl. 3). In the plateau west of Itacarambí, subsequent streams have formed along the longitudinal fault northeast of the anticline.

The third major landform in the Januária region is karst topography. Good examples of solution features in the calcareous rocks are widespread and diverse; these features include underground rivers, caves, several kinds of sinkholes and dolines, blind valleys, and lapiés erosion surfaces. An excellent example of an underground river is the Rio Peruaçu. It emerges from its underground course a few kilometers northwest of Fabião, near the valley of the Rio São Francisco (pl. 3). Its underground route through the limestone plateau from the northwest, however, can be traced for about 12 kilometers by a number of spectacular collapse sinks along the river course, each revealing the river emerging from a cave at one end and passing into another cave and underground course at the opposite end. The karst windows, as these collapse sinks are known, have steep sides, in many places sheer walls, and are as much as 100 meters deep. They range in length from 100 meters to 2 kilometers. Some karst windows are simple holes in the plateau, but others are compound sinks also known as poljes, formed from the coalescence of several smaller sinkholes and dolines of both solution and collapse types. These compound sinkholes display benches at various levels below the plateau surface, on which are scattered erosional remnants of limestone as pillars or buttes. Many smaller sinkholes in the plateau have visible openings to underground drainage. Others, especially in the sinkhole plain on the terrace level of the Rio São Francisco valley, close to the water table, have alluvium-covered floors and contain lakes, swamps, or temporary ponds. Most of the secondary streams in the area end in some kind of sinkhole.

At the Fazenda Itabahiana, at the nose of the anticline near Itacarambí, a karst valley 2.5 kilometers long by 0.6 kilometer wide formed across a strike fault, and is partly developed in limestone and partly in fine-grained clastic rocks of the Bambuí series. It furnishes a good example of underground capture of surface drainage in karst terrain. The author postulates that originally surface drainage, on clastic rocks in the area encompassed by the sinkhole and the nose of the anticline, passed down the strike-fault valley. North of the fault, in more recent times, a sinkhole formed in the limestone, diverting drainage underground. The sinkhole gradually expanded until it impinged on the soft clastic rocks to the south, and progressively captured the surface drainage by sapping from below. When capture of the trunk stream occurred at a point on the fault, all drainage in the basin above this point was diverted to the sinkhole. Rapid downcutting by the short streams in the clastic rocks as a consequence of the lower base level produced the present form of the karst valley. The floor of the valley locally has alluvial deposits on it and is inclined slightly to the north, with most of the intermittent surface drainage collecting and eventually disappearing through a pond near the northeast end.

Surface drainage in the strike-fault valley southeast of Fazenda Itabahiana occurs only during the wet season. As in many other valleys, much of the water percolates downward through stream gravels into the underlying limestone, but it also passes underground at several places through swallow holes. The normal valley profile has been disrupted by local discontinuity of downcutting on the downstream side of the swallow holes, producing blind terminations of the stream valleys. The deep, steeply walled, blind sinkhole valley of Boqueirão do Cipoal east of Mina Grande is a good example of this feature. Water that goes underground at Boqueirão do Cipoal probably emerges as springs on the Fazenda Bela Vista at Pindaíba. Along the base of the limestone escarpment bordering the Rio São Francisco valley are many caves from which underground drainage issues in springs during part of the year.

Weathered exposures of limestone and dolomite in the Januária district commonly are etched by solution into serrated and grooved pinnacles and crevices that form irregular and rugged surfaces called lapiés. A lapiés surface is well formed on the limestone escarpments and on the top surfaces of hills underlain by calcareous rock. It is highly characteristic of the massive beds, such as the recrystallized primary dolomite breccia (fig. 7), but occurs in the thin-bedded limestone as well. Many enlarged open joints and pits are formed by solution on these surfaces and make extensive areas difficult or impossible to traverse. The lapiés surface appears to form on tilted beds as well as on flat-lying strata. It is formed by circulating waters under cover of soil, as suggested by recently excavated areas at Mina Janelão that reveal channeled and grooved limestone; the fine details, including the small-scale pits, pinnacles, serrations, and flutings, are thought to have been formed directly on the exposed bedrock.

From 5 to 10 kilometers west and southwest of Januária is an area of 5 to 10 square kilometers where the limestone is highly dissected, consisting of a profusion of remnant blocks distributed on a plain near the level of the valley of the Rio São Francisco. The blocks range in size from a few meters across, to hills several tens of meters in height and diameter. Some are rounded and others are roughly shaped and grotesquely sculptured from solution weathering. This kind of karst topography is similar to that known as pepino hills in Puerto Rico.

MINERAL DEPOSITS

The nine deposits of lead and zinc and the one deposit of fluorite described in this report occur in a span of 80 kilometers from north to south along the Rio São Francisco in the Município de Januária. Seven of the lead and zinc deposits are grouped within a 4-kilometer radius, 10 to 15 kilometers west of Itacarambí. They represent the principal reserves of the district, and include Mina Janelão, Mina Grande, Mina São João, and prospects Taquarí, Pimenteira, Riacho Sêco, and Jacarèzinho. At the time of this study all but Riacho Sêco and Jacarèzinho were consolidated under one mining company, operated by Senhores Lauro Morandi and Miran de Barros Latif of São Paulo. Of these deposits only Mina Janelão, Mina Grande, and Mina São João are large enough to merit exploration. The fluorite deposit, Mina Fabião, is about 3 kilometers north of the community of Fabião, near the edge of the escarpment.

The deposit of Capão do Porco, 30 kilometers southwest of Januária, is worked sporadically on a small scale for silver, which is crudely smelted from handsorted sphalerite and galena ore. It is the largest of several tiny isolated pockets containing lead and zinc that are scattered in three small hills of limestone. It has little economic value.

Alto de Palmeiras, 30 kilometers southeast of Januária, has hardly more than a showing of galena and sphalerite along a small fracture, and is not in itself of economic value. The deposits farther south near Lontra are reportedly similar to that at Alto de Palmeiras but are remote and devoid of economic interest (Jacques de Morais, 1958, p. 149), and so were not included in this investigation. No underground workings exist at any of the mines or prospects; shallow pits and trenches only scratch the surface.

LITHOLOGIC AND STRUCTURAL CONTROL

All deposits west of the Rio São Francisco occur in the uppermost limestone and dolomite units of the Bambuí series. In particular, they are associated with a distinctive bed of black-weathering, saccharoidal dolomite. The one deposit visited east of the Rio São Francisco occurs in the unit of interlayered limestone and mudstone at the top of the section of the Bambuí series measured at Alto de Palmeiras; the lead and zinc minerals, however, are confined to limestone. Lead and zinc minerals were not seen either in the calcareous shale and mudstone beds within the Bambuí series or in sandstone of the overlying Baurú formation, suggesting that clastic beds are unfavorable host rocks for their deposition. The association of ore minerals with limestone and with dark-weathering dolomite suggests lithologic control in the locale of deposition. The deposits seemingly related to these calcareous horizons, however, have not been explored at depth, and nothing is known at present of their extent and size in stratigraphically lower beds.

The largest lead-zinc deposits are northeast and west of the anticline west of Itacarambí, and seem to follow the main fault trends. The Mina Grande mineralized fracture zone northeast of the anticline is closely parallel to the large longitudinal fault in the valley immediately south of the mine. The Estaca Onze fracture zone at Mina Janelão is on the hinge line of the monocline west of the anticline. Other mineralized zones are parallel to a system of northeastward-trending cross faults in the area, as the Estaca Quatro zone and the quartz vein at Mina Janelão, and the quartz veins at Jacarèzinho and Riacho Sêco prospects. The orientation of the veins at Alto de Palmeiras and Capão do Porco seem to be unrelated to any regional structures.

The deposits are basically fissure veins with subordinate bedding replacement. The deposits along fractures vary in aspect, depending on the size of fractures and the intensity and extent of hydrothermal alteration. The simplest type is the short narrow fissure whose walls have been silicified and mineralized slightly. The modification of fissure zones and wallrock by abundant quartz replacement produces veins that range from less than half a meter to several meters thick and from 30 to 200 meters long. One deposit at Mina Janelão consists of a zone at least 70 meters wide of short discontinuous mineralized tension fractures. Another type is the compound fissure zone, 5 meters wide or more, consisting of altered and mineralized rock, laced through with fairly prominent fractures. This type is exemplified by the Mina Grande mineralized fracture zone that is at least 180 meters long.

Lateral extensions of mineralized fissures take the form of ramifying networks of fine quartz veinlets in the wallrock, and subsidiary mineralized fractures that, in places, lead to irregular pockets of mineralized rock crisscrossed by quartz veinlets. Limestone beds at Mina São João and Mina Grande seem to have been replaced by silica and ore minerals that migrated laterally. At Mina Grande the beds were altered by hydrothermal solutions that came from the mineralized zone. No fissure vein is exposed at Mina São João, where the deposit consists of flat-lying masses of silicified and mineralized limestone.

Fluorite occurs in a bedding-replacement deposit at Mina Fabião, as pockets in limestone immediately below the contact with overlying dolomite.

Mineralized fractures of the district show little evidence of displacement. The Mina Grande zone is the one exception; stratigraphic evidence indicates an apparent vertical displacement of 40 to 80 meters. No continuous fault plane is evident; the zone consists instead of many relatively short fractures with little breccia, gouge, and slickensides. Breccias that may be tectonic occur at the Pimenteira and Alto de Palmeiras prospects, although the short fractures show no displacements. It is not possible to determine whether or not postmineral movements occurred, because oxidation and secondary gangue minerals obscure the evidence. Post-mineral cross faults are nowhere apparent. Galena with deformed cleavage planes is found at Mina Grande and Mina São João, and sphalerite commonly is fractured, indicating possible movements of small magnitude after mineralization.

MINERALOGY

The mineral assemblages in these deposits are similar. Remnants of the primary sulfides, galena and sphalerite, are surrounded by the oxide ore minerals of lead and zinc, principally cerussite, anglesite, and smithsonite. Associated with the oxide minerals are the zinc silicate, willemite, and the vanadium oxide minerals, descloizite and vanadinite, all abundant at the surface. Chalcopyrite and the secondary copper minerals, chalcocite and malachite, are found locally in trace amounts, although minor concentrations of chalcocite are scattered throughout siliceous breccia at Mina Grande. Gangue minerals consist of calcite, dolomite, quartz and chalcedony, some barite, and fluorite and minor amount of iron oxides. Fluorite is the principal ore mineral at one small deposit.

The primary ore minerals, galena (PbS) and sphalerite (ZnS) occur in nearly equal proportions, although in detail their relative concentration varies considerably from place to place. They occur in clumps or pockets as replacements in silicified limestone and dolomite. Crystals are as large as 2 centimeters in diameter although the average is less than half of that. Most galena crystals are euhedral but at Mina Grande and São João they display curved cleavage surfaces, as though they had been slightly deformed. Most sphalerite occurs as scattered subhedral crystals of various shades of brown; less commonly it is light yellowish to greenish brown. Locally, the mineral occurs as aggregates of small well-formed tetrahedral crystals. Much sphalerite is fractured and altered.

The oxidized ore minerals of lead and zinc occur in close association with each other and with galena and sphalerite. They are difficult to distinguish, however, because they are fine grained and similar in color.

Anglesite ($PbSO_4$), derived from galena by oxidation, occurs in light to medium-dark gray masses with greasy luster that engulf remnants of galena. It penetrates cleavage fractures in galena with which it forms irregular replacement boundaries. Typical anglesite is massive and breaks with conchoidal fracture, but the mineral also is found as aggregates of prismatic tabular crystals.

Cerussite ($PbCO_3$) and smithsonite ($ZnCO_3$), the secondary carbonate minerals of lead and zinc, are commonly mixed and occur as light-yellow and white to gray, opaque, earthy, compact, and banded masses. Both carbonate minerals occur also as granular and botryoidal masses in cavities. Smithsonite can be distinguished by its superior hardness 5 as compared to that of cerussite at 3 to 3.5, but this property cannot be employed infallibly because of the fine-grained mixtures of the two minerals, and because of the probable mixture with quartz in many places. Smithsonite forms a covering over both galena and sphalerite in the Januária deposits. The walls of one large open fracture at Mina Grande are coated by 5 or 6 centimeters of crystalline smithsonite in bands 1 to 2 centimeters thick. Cerussite and smithsonite are found in all the deposits, but are particularly abundant in the Estaca Quatro zone at Mina Janelão and are also well represented at Mina Grande and Mina São João.

Hemimorphite, the hydrous zinc silicate, was not recognized in these deposits. Samples of mixed oxide minerals were analyzed spectrographically by Dr. Elisiário Tavora Filho, of the Departmento Nacional da Produção Mineral, but all tests for hemimorphite were negative. Although local miners and reports written about this district use the term "calamine," the alternate name for hemimorphite, these in fact refer to mixtures of the above described secondary minerals.

Willemite (Zn_2SiO_4) has been recognized in various deposits, notably at Mina Janelão and Mina Grande. It occurs as minute white to light-yellowish elongate hexagonal crystals in radial groupings that line cavities and open veinlets in rocks of the oxide zone. Commonly it is colored gray or brown by impurities, or stained reddish by iron oxides. Apple-green willemite was found in one tiny drusy cavity. The mineral fluoresces light greenish yellow to white under ultraviolet light. It is among the latest of the secondary minerals, forming crystalline coatings on anglesite, cerussite, and smithsonite.

The secondary minerals descloizite, $PbZn(OH)VO_4$, and vanadinite, $Pb_5ClV_3O_{12}$, are closely associated with other lead and zinc minerals in the deposits west of Itacarambí. Descloizite is much more abundant than vanadinite. It is nearly always in pyramidal or short prismatic crystals in cavities, breccias, and open fractures. Generally, it is associated with chalcedony and finely crystalline drusy quartz. Descloizite crystals are translucent, have a vitreous to adamantine luster, and are of several shades of brown, from honey to dark walnut, as well as tones of red, orange, and yellow. Its high specific gravity, between 5.9 and 6.2, distinguishes this mineral from the sphalerite which it resembles. Vanadinite occurs in vugs as granular aggregates of radiating prismatic crystals. It is mainly bright corn yellow, but orange and red vanadinite is also found. The crystals are opaque to subtranslucent and have a resinous to earthy luster. The mineral has a specific gravity of about 7 and occurs generally in the interstices of descloizite crystal aggregates, suggesting that it was derived secondarily from that mineral.

Minute specks of the copper minerals chalcopyrite, bornite, and chalcocite are found in a few residual blocks of lead and zinc ore at Mina Janelão, and in the mineralized, highly siliceous fracture zone at Mina Grande. The secondary copper carbonate mineral, malachite, is sparsely distributed in the Mina Grande deposit, but it is rarely found in the other deposits. It occurs in drusy cavities as small green prisamatic and acicular crystals in flat radial tufts, and also as a coating in fractures and veinlets with quartz and other secondary minerals. Chalcocite (Cu_2S) is found in the silicified limestone pseudobreccia south of the mineralized zone at Mina Grande. The chalcocite occurs in dense black nodules that most generally are rounded and elliptical and are as much as 20 centimeters in greatest diameter. These nodules are scattered in the leached pseudobreccia in a manner that suggests filling of secondary cavities. Most nodules are encased by thin layers of malachite. Why the chalcocite accumulated in such singular masses is unknown, but it is suggested that the original copper minerals, presumably chalcopyrite and bornite, were gradually altered to chalcocite that precipitated about isolated loci.

Silver minerals have not been seen or reported in the Januária district but assays indicate the presence of silver in several deposits, apparently contained in the lead minerals. Each of 4 samples from Mina Janelão contained more than 60 grams of silver per ton and 1 sample assayed 156 grams. Samples from Mina Grande, and the prospects Taquarí and Alto de Palmeiras, showed only traces of silver. In the Capão do Porco deposit, the silver content of the ore before hand concentration is probably in the same order of magnitude as that at Mina Janelão. The ore superficially seems to be pure sphalerite but spectrographic examination shows the mineral contains disseminated galena, according to J. J. Matzko, of the U.S. Geological Survey. He states that the silver is in the galena, probably in solid solution.

Fluorite (CaF_2) is present in all the lead-zinc deposits in the Município de Januária as a primary auxiliary mineral. It is amethystine purple to gray and occurs as medium- to coarse-grained euhedral crystals in clusters and in short irregular veinlets in crystalline limestone and dolomite. Fluorite with minor barite occurs in small concentrations in veinlets between the Estaca Quatro and Estaca Onze mineralized zones at Mina Janelão. Minable concentrations of coarse-grained fluorite occur at Mina Fabião, where the mineral is mixed with coarse-grained calcite in masses replacing carbonate rock. Local miners are apt to confuse gray fluorite for calcite, but these minerals can be readily distinguished by differences in cleavage.

Calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are the most abundant gangue minerals. Besides forming wallrock, they are contained in the deposits as veinlets and clumps of coarse white crystals, mixed with barite and quartz. Coarsely crystalline calcite forms one isolated pocket, 2 or 3 meters in diameter, at the west end of the quartz vein in the northern part of Mina Janelão. Calcite is thought to have been locally recrystallized rather than having been introduced by ore-bearing solutions. This may be true for the dolomite also, although dolomite seems to have been deposited with sulfide minerals at Mina Grande.

Barite ($BaSO_4$), in veinlets and in both large and small lenses associated with the lead-zinc ore minerals, is white to colorless, coarse grained, and crystalline. Lenses from 3 to 5 meters long occur at Mina Janelão, one about 200 meters south of the camp, and another west of Estaca Quatro, where a few transparent crystals and cleavage fragments can be seen.

Quartz and chalcedony are widespread gangue minerals that accompany lead and zinc minerals at all the deposits, occurring as well-defined veins in silicified fracture zones or as replacements in limestone beds. Fine, radiating quartz crystals, commonly colorless or porcelain white seem to be of secondary origin. They line vugs, cavities in pseudobreccia, and open fissures, deposited as overgrowths on chalcedony or on other secondary minerals such as descloizite and willemite.

A massive quartz vein at Jacarèzinho appears to have formed along the feeder route for a ramifying system of quartz veinlets in the wallrock. At Riacho Sêco the veins contain both massive and crystalline quartz. Multitudinous branching of fine quartz veinlets produce a pseudobreccia in the limestone and dolomite. At Mina Grande the fractured country rock is largely replaced by quartz and chalcedony and is laced with siliceous veinlets. Quartz and chalcedony have replaced much thin-bedded limestone at Mina São João, producing large siliceous masses. Subsequent leaching of limestone has left a vuggy siliceous pseudobreccia in which bedding planes are still discernible. Replacement of limestone is also extensive at Mina Grande.

Secondary iron oxides are generally meager around the mineral deposits. An exception is the Estaca Quatro zone at Mina Janelão, where residual blocks of secondary lead and zinc ore are honeycombed with cavities in which limonite has been deposited, are held together by limonitic cement, and are surrounded by colluvium rich in limonite. At the other deposits, minor amounts of limonite occur along fractures and coat altered sphalerite masses. A small outcrop of siliceous spongy gossan occurs at the Taquarí prospect, but no ore minerals were found in it.

Limonite cements sandstone of the Baurú formation and coats its weathered outcrops. Soil overlying the Bambuí limestone contains concentrations of iron oxides and the old erosion surface is capped in places by "canga," residual accretions of breccia cemented by secondary limonite. In places, the surficial limonite has moved downward along fissures in the limestone, and limonite also cements limestone blocks in masses of collapse breccia. Such occurrences of iron oxide should not be interpreted as indicators of nearby mineral deposits.

ALTERED WALLROCK

The calcareous country rock in the mineralized zones was hydrothermally dolomitized and silicified and subsequently was weathered. Weathering involved leaching of calcium carbonate with a corresponding rise in the content of silica minerals. At two deposits, leaching of silicified limestone formed large masses of rock consisting mainly of residual silica resembling bedded primary breccia.

Dolomitized rock is present in all deposits. In general, however, the dolomite that formed hydrothermally is closely related to the fracture zones, for it does not spread out far into the surrounding wallrock. The dolomitized rock is medium grained to coarse grained and unevenly textured, is unevenly colored and bleached, and ranges from grayish red to pink, and buff to white. More commonly the reddish shades immediately border mineralized fractures and concentrations of lead and zinc minerals; the lighter colors are distributed more generally in irregular patches throughout the mineralized zones.

The country rock in these mineral deposits is silicified in greatest concentration in dolomitized zones. In such zones, much of the rock consists of hard, dense chalcedony and fine-grained quartz. Relics of the limestone and dolomitized rock are surrounded and invaded by quartz along fractures and irregular veinlets.

Highly silicified carbonate rock occurs in mantolike bodies at Mina São João and Mina Grande (fig. 12). The silicified rock appears to have formed by lateral migration of hydrothermal solutions from the fracture zones, irregularly replacing the calcareous rock along bedding planes and fractures and giving the rock the appearance of primary breccia. At Mina Grande such silicified rock, overlying dolomite and limestone, is as much as 5 meters thick and covers more than 6,000 square meters of area. In general, remnant bedding in this pseudobreccia conforms to the bedding in the unaltered limestone, but its contact is irregular. Dolomitization seems to have been relatively weak

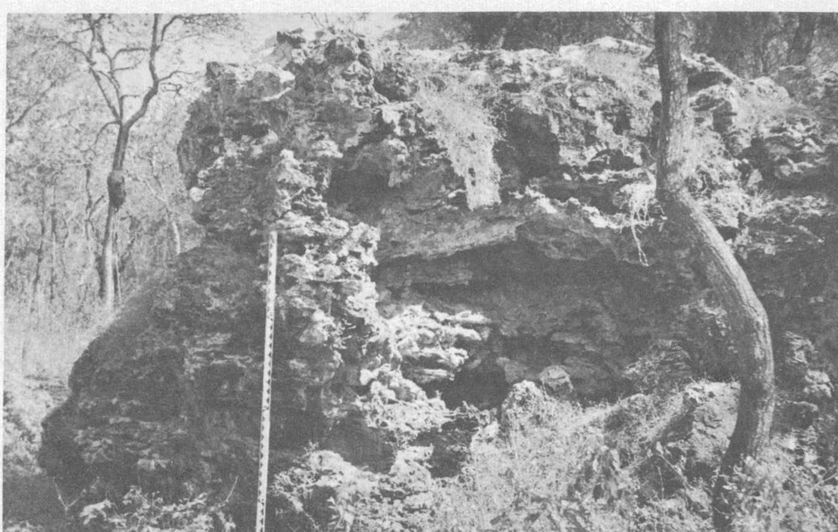

FIGURE 12.—View of one of the highly silicified limestone masses at Mina São João showing effect of calcium-carbonate leaching. The rock is mostly a boxwork of silica and is full of cavities and pseudobreccia, but bedding planes are still visible. The stadia rod is about 4 meters long.

in the silicified pseudobreccia masses. Small amounts of copper, lead, and zinc minerals are scattered through the masses.

Supergene alteration is widespread in the deposits. Carbonate minerals commonly have been leached from veins, mineralized fracture zones, and pseudobreccia, leaving silica boxwork and concentrations of secondary enriched lead and zinc minerals. Some silica appears to have been dissolved out also, and then redeposited as crystalline or amorphous incrustations and as cement binding together altered rock fragments, as shown in the Estaca Quatro mineralized zone at Mina Janelão. Leaching has modified the bedded replacement deposits at Mina Grande and Mina São João, now forming mantos of pseudobreccia consisting of fragments of collapsed bedding, silicified and etched, porous with cavities, and held together by knots and ribs of quartz (fig. 12).

CLASSIFICATION AND GENESIS

The Januária deposits resemble those of the Mississippi Valley (Lindgren, 1933, p. 423; McKnight, 1935, p. 130; and Behre, 1958, p. 915), although the comparisons are based on surface showings only. In points of similarity they are replacements and fillings in fissure veins and faults, and in shatter or pseudobreccia blankets and "runs" within flat or gently dipping carbonate rock. The deposits seem to occur principally in crystalline dolomite and dolomitic limestone, and less commonly in pure limestone. The assemblage of primary minerals includes lead and zinc sulfides that contain silver, copper and iron sulfide, quartz, fluorite, calcite, and barite. Silicification and dolomitization of host rock accompanied deposition of the ore and gangue minerals. The deposits have little or no affinity for shale or other clastic rocks and they do not seem to be associated with igneous rocks.

The Januária deposits are probably hydrothermal in origin, although some geologists who have visited the area have informally suggested that the deposits are of supergene origin. Deposits Capão do Porco and Mina São João, considered by themselves, might be classed by some as syngenetic in origin for lack of obvious ties to veins or fissures. When the region is considered in its entirety, however, the hydrothermal theory of origin for the deposits seems preferable.

According to the supergene theory of origin, lead and zinc deposits in limestone were derived from meteoric waters that leached disseminated mineral matter from overlying sediments and redeposited it in concentrated form in the carbonate rocks. This theory was widely held before 1925 to explain the lead-zinc deposits of the Mississippi Valley, but has been largely discarded since in favor of the hydrothermal theory of origin (McKnight, 1935, p. 138). Several important factors oppose the adoption of the supergene origin for the sulfide deposits in the Januária region. First, the deposits are most evident in the "black-weathering" dolomitic unit which is relatively high in the section of carbonate rocks west of the Rio São Francisco. Above it stratigraphically lie only 40 to 90 meters of carbonate rocks that are generally barren of syngenetic sulfide minerals. It is contended that the carbonate rock in this interval does not constitute a reservoir large enough to supply the leached minerals necessary to form concentrated deposits in the "black" dolomite. Although the amount of mineral deposition below the "black" dolomitic unit is not known, the amount of sulfide minerals localized within this one unit is sufficient to uphold the argument. The carbonate rock is overlain by fine-grained clastic sediments, a few meters to 270 meters thick, equally barren of lead and zinc minerals, and topped by sandstone of Cretaceous age. It is evident that the clastic rocks, mostly shale and mudstone, would have formed a relatively impermeable barrier to descending waters and would have substantially inhibited the downward movement of minerals from above.

Secondly, sphalerite, the zinc sulfide, is relatively unstable under oxidizing conditions and alters readily to the soluble sulfate and eventually to the insoluble carbonate mineral. At normal temperatures, which would have prevailed in the supergene environment, the reverse process of reduction of the zinc carbonate and sulfate to form deposits of secondary zinc sulfide is practically impossible, especially in a carbonate environment which would greatly hinder it. Iron sulfides, which would greatly aid deposition of lead and zinc sulfides by providing the reducing environment for replacement, apparently are deficient. Sphalerite is generally absent as a supergene mineral in deposits elsewhere (Bateman, 1950, p. 276). Galena, in the oxidized zone, alters to relatively insoluble lead sulfate and carbonate; its deposition as a supergene sulfide, therefore, is considered to be improbable.

Thirdly, the deposits have no overall relation to topography or to the upper surface of the dissected plateau. Near Itacarambí several deposits, including Mina São João, occur in virtually flat-lying rocks at about the same zone in the "black" dolomitic unit, and thus are at roughly the same altitude of about 700 meters above sea level. This could be interpreted by proponents of supergene origin as indicative of a relationship between the level of a former water table and the present uniformity in altitude of the deposits. Mina Grande, however, is 50 meters lower in altitude than Mina São João, although associated with the same unit of dolomite, and the Taquarí prospect is about 30 meters lower than Mina São João. At Mina Janelão about 40 meters of altitude exists between the Estaca Quatro and Estaca Onze mineralized zones. The Capão do Porco deposit occurs in the same general dolomite zone as the deposits near Itacarambí, but is at approximately 550 meters altitude instead of 700 meters, and is on the dissected plateau surface where it slopes gently downward toward the Rio Pandeiros. In detail, therefore, the deposits are related to a stratigraphic unit rather than to a water table or other planar surface.

The hydrothermal mode of origin is indicated by several factors. Most deposits occur near the large anticlinal structure and associated folds and faults west of Itacarambí. Alinement of nearly all the deposits with definite tectonic features suggests that tectonic structures, in part, provided the channelways for mineral solutions from depth. If the deposits were syngenetic they would have no particular relation to the regional structure, and if they were derived from descending solutions they would be found in randomly oriented superficial joints and probably would exhibit boxwork type of vein systems. Bedding replacement that forms the blanket deposit at Mina Grande seems to be completely subsidiary to the mineralized fracture zone. At Mina São João the east edge of the mantolike deposit in pseudobreccia cuts steeply across bedding, suggesting some connection at depth with a feeder channel or fracture zone. The replacement of carbonate rock by quartz in the mineralized veins, fracture zones, and breccia masses strongly supports the hydrothermal origin of the deposits. If the deposits had been formed syngenetically, silica would have replaced the rock more generally throughout the carbonate section instead of being limited to the oriented vein and fracture zones. Dolomitic alteration that accompanied the mineralization also conforms to the same vein and fracture pattern.

The primary minerals in the Januária deposits are considered to have been deposited at medium to low temperatures. All the deposits are similar mineralogically and suggest a single metallogenetic epoch. Galena and sphalerite, as well as fluorite and barite, generally occur in well-formed crystals. Chalcopyrite and bornite were found in a few places in minor amounts, but pyrite was not seen in any of the deposits. Quartz occurs in porous veins, in pseudobreccias, and in fracture zones replacing large amounts of country rock, as massive quartz, in fine crystals, and as chalcedony. These minerals and their textures classify the deposits as hydrothermal, and place them somewhere between the mesothermal and epithermal zones according to Lindgren's classification (1933, p. 211). The source of the ore and gangue minerals is unknown, but is probably related to some deep-seated igneous intrusive mass within or below the Bambuí series of rocks. The age of mineralization can be stated only as younger than the faults that cut the Bambuí series.

Supergene processes, though not responsible for the initial deposition and concentration of lead and zinc sulfides in the Januária region, have altered the deposits to a great extent. Oxidation has resulted in the formation of the secondary lead and zinc minerals anglesite, cerussite, smithsonite, and willemite, with concentration and upgrading of the lead and zinc content in some deposits. Accompanying these minerals are the lead-zinc vanadates, descloizite and vanadinite, and the copper minerals, chalcocite and malachite. Solution weathering of the carbonate rocks is general in the region, and undoubtedly extends to a great depth. The karst features and rather low water table, probably at least 100 meters below any known deposit, indicate underground drainage and the probable existence of abundant open channelways and cavities in the paths of descending surface waters. It is reasonable, therefore, to suppose that supergene alteration also extends to that depth, although the configuration of the veins and fractures below the surface is unknown. Below the surface the silicified rock may tend to inhibit the free circulation of ground water and the oxidation of primary minerals in the fracture zones. Nevertheless, if the zones are permeable the degree of oxidation of galena and sphalerite between the surface and the water table may be substantially the same as at the surface. The presence of minor chalcocite in outcrops at Mina Grande, raises the remote possibility that a zone of copper enrichment exists at depth, but the apparent lack of pyrite in these deposits is a discouraging sign. Pyrite is practically a prerequisite for effective precipitation of chalcocite (Bateman, 1950, p. 275).

SUMMARY AND CONCLUSIONS

Lead, zinc, and fluorite deposits were discovered in the Januária region in relatively recent times. The first deposit found was Capão do Porco in the mid 1930's. Although too poor in lead and zinc to be considered a source for these metals, the deposit yielded more than 300 kilograms of silver between 1936 and 1957. Mina Grande was found in 1938 in the area west of Itacarambí and other small showings in the vicinity, such as Mina São João, Pimenteira, and Taquarí, were found shortly thereafter. Selectively concentrated lead ore from Mina Grande and other nearby deposits were smelted in a small experimental furnace at Pindaíba some time after their discovery, and a few tons of lead bullion were produced. Litigation apparently stopped further development until 1956 when Mina Janelão was discovered and interest was revived in the area. Considerable surface

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exploration has followed since then at Mina Janelão and Mina Grande. Surface material high in lead and zinc has been stockpiled in the course of exploration, but no production has been reported from these deposits. In 1958 and 1959 several diamond-drill holes were bored in the larger deposits. Approximately 100 tons of fluorite ore was mined and stockpiled at Mina Fabião in 1957.

On the basis of outcrops and shallow workings, the lead and zinc deposits seem to be of limited size and extent. In the area west of Itacarambí are several deposits that might conceivably sustain small-scale operations on a combined basis. They are Mina Janelão, Mina Grande, and possibly Mina São João. The other deposits are only showings that might provide a few tons of supplemental ore.

The form of the deposits are known only at the surface; underground exploration has been minor and has produced little positive information. The deposits appear to be fissure veins in limestone that are locally modified by bedding replacement. Ore at the surface is complex and contains mainly secondary minerals of lead and zinc associated with their primary sulfide minerals, but includes minor amounts of vanadium oxide, silver, and copper. The Estaca Quatro zone at Mina Janelão contains float blocks and rubble of rich oxidized lead-zinc ore in the soil. This surface ore is concentrated along a line, suggesting that a vein 120 meters long exists at depth. Data from a few holes drilled below this zone into limestone have been inconclusive. More definitive drilling and further exploration of bedrock 3 to 10 meters below the surface by deep trenching is necessary before the potentialities of the deposit can be adequately appraised. A similar problem is found at Mina Grande; outcrops suggest a well mineralized fracture zone 180 meters long by 5 to 20 meters wide, but the character of the deposit is virtually unknown 2 or 3 meters below the surface. It is necessary to establish whether the ore minerals were deposited mainly within fissures at depth, or were deposited selectively within limestone and dolomite beds, as is noted at the surface. Important to determine as well are the quality and quantity of lead and zinc minerals at depth, involving such factors as whether the zone of mixed sulfide and oxide minerals continues downward to considerable depth or whether the oxide minerals become supplanted by sulfide minerals within shallow depths, and whether the veins thicken or thin appreciably at depth. Exploration by diamond drilling, begun at Mina Janelão and Mina Grande in 1959, is needed at both deposits to answer these questions.

Other deposits in the region are smaller and much poorer in grade than the Estaca Quatro and Mina Grande zones. Ore minerals in the veins at the Riacho Sêco and Pimenteira prospects are confined to stretches 10 meters long by 0.5 meter wide. As such, they offer little in the way of possible ore reserves at depth. Estaca Onze at Mina Janelão and the Taquarí prospect have ore minerals in small clots scattered through dolomitic rock over areas 800 to 1,000 meters square; Mina São João is similar but is somewhat larger and occurs in a manto of highly silicified dolomitic pseudobreccia.

Combined reserves are indicated in the Estaca Quatro and Mina Grande mineralized zones to a depth of 5 meters, amounting to 8,000 tons of lead-zinc ore containing about 20 percent zinc and 15 to 20 percent lead. Ore reserves can be inferred only on assumed data below 5 meters of depth; if the same conditions prevail below 5 meters of depth as on the surface, approximately 1,000 tons of ore per meter of depth can be inferred at Estaca Quatro and 500 tons at Mina Grande. Not more than 100 tons of lead-zinc ore of comparable grade can be inferred at Mina São João, considering its mantolike form. To judge by surface showings, only a few tons of lead-zinc ore can be inferred to exist at each of the other prospects. Vanadinite and descloizite, late-forming and widely dispersed minerals in the oxidized zone at most of the deposits, are a possible source of vanadium; grade and reserves estimates, however, require more information on their distribution at depth.

More objective underground exploration, both diamond drilling and trenching to bedrock, is needed to properly assess the potentialities of the larger deposits, particularly to learn their size and structural characteristics, to determine the type and grade of minerals existing in given blocks, and ultimately to establish the magnitude of reserves. In 1959 two holes were drilled at Mina Grande and four at Mina Janelão to obtain information about the magnitude and continuity of the mineral zones. The program was plagued by the shortage and loss of water caused by open ground, by difficulties in maintaining the alinement of drill holes and by poor core recovery. Results were incomplete and inconclusive, so it has been suggested that a few additional holes be drilled in the same and adjacent areas. If these indicate that ore continues at depth, an expanded program of diamond drilling and underground workings would be advisable to outline potential ore reserves.

Besides the size and grade of ore reserves, the development of the Januária deposits is dependent upon many inter-related economic factors. Foremost is the cost of transportation of ore or concentrates to distant treatment plants and markets, and the reciprocal transportation of equipment, supplies, and men to the mining operations. The Januária deposits, actually, are scarcely more remote from industrial centers than other known lead-zinc deposits in Brazil. Ore can be shipped by boat up the Rio São Francisco to Pirapora, from whence it can be transported by railroad or truck to Belo Horizonte and points south.

Water supply for mining and concentration is plentiful in the Peruaçu and São Francisco valleys. Ground water probably can be tapped at many points in the flood plain of the São Francisco. Near the mines on the plateau, surface water is lacking, but ground water should be plentiful along the principal underground streams passing through the karst terrain. Considerable work may be necessary, however, to locate such channels. The karst conditions will free mining operations from water problems above the water table. These same conditions, however, most probably will limit depth of mining to above the water table. The water table, being near the level of the main streams, is roughly 100 meters below the surface at most of the deposits.

Although the hydroelectric plant at the falls on the Rio Pandeiros near Januária was completed recently, its capacity is insufficient beyond present demands to meet the needs of both mill and mine operations. The large Três Marias dam being constructed on the upper Rio São Francisco eventually will supply the Januária area.

For a fuller description of roads, transportation facilities, water and timber supply, and other economic considerations, the reader is referred to the introductory section of this report.

Undoubtedly, base-metal deposits similar to the lead and zinc deposits of the Januária region remain to be discovered in carbonate rocks of the Bambuí series, which underlie the greater part of the Rio São Francisco basin as well as the land to the west beyond the boundaries of the states of Minas Gerais and Bahia. An example of the potentialities for mineral exploration in this vast area was the recent discovery of the large zinc deposit near Vazante, state of Minas Gerais; the deposit occurs in an extensive fissure zone cutting carbonate rocks of the Bambuí series. The present study of the mineral deposits in the Januária region suggests some of the more obvious guides that might be used for prospecting in areas underlain by the Bambuí series. The Januária deposits are associated with (a) structural features, particularly faults and fractures, (b) the crystalline dark-weathering dolomite unit, (c) silicified, bleached, and red to buff-stained dolomite, and (d) mantolike masses of siliceous pseudobreccia.

Most of the deposits in the Januária region are distributed around the periphery of the broad anticline near Itacarambí. The few others, located where the carbonate beds are flat lying, are small or very poor. From this it appears that structurally disturbed areas underlain by the Bambuí series are generally more favorable for mineral deposits than undisturbed areas. It would be practical to delimit by aerial photographs the structurally disturbed areas underlain by the Bambuí series of rocks, then systematically reconnoiter the most promising folded and faulted areas for mineral deposits. In detail, the majority of deposits in the Januária region are in faults or fractures. Some mineralized fracture zones are related to major structural features, such as the Estaca Onze zone at Mina Janelão that follows tension fractures along a monoclinal fold, or the Mina Grande fracture zone that is parallel to the longitudinal fault in the valley of Cipoal. Other deposits are along regionally oriented cross fractures, as the Estaca Quatro zone at Mina Janelão and the fracture veins at the Riacho Sêco deposit.

All the mineral deposits on the west side of the Rio São Francisco are closely related to the dark-weathering dolomite and dolomitic limestone unit near the top of the section of carbonate rocks, whereas limestone and clastic rocks seem for the most part to be barren. Although the Alto de Palmeiras deposit east of the river is in limestone, it is relatively minor. Dolomite, therefore, seems to be a more favorable host rock for mineral deposits, and may be a decisive factor for mineral deposition in other regions. Dolomite by itself, however, does not presage mineralization; fractures, faults, or other structural features apparently are necessary as well. A significant locus of mineral deposition is near the contact between dolomite and limestone, as at the Mina Fabião and Capão do Porco deposits.

The appearance of dolomitic wallrock may serve also as a guide. Commonly, silicified dolomite at the Januára lead-zinc deposits forms resistant outcrops, and shows a moth-eaten appearance due to solution weathering of the purer dolomitic parts. Quartz stands out in large veins or in tiny veinlets. Some altered dolomite, normally light gray to off-white, is bleached white; other patches, impregnated with ore minerals, are stained red, rose, or buff, probably from small amounts of iron oxide associated with the ore minerals. This alteration should not be confused with rock that is superficially stained with limonite derived from overlying lateritic soil.

Finally, mantolike masses of silicified pseudobreccia that form conspicuous outcrops at Mina Grande and Mina São João are important indicators of mineral deposits. Though they contain little of value in the Januária region, one mass is subsidiary to the fracture zone at Mina Grande and contains some copper, lead, and zinc minerals. Such masses in other areas or in lower stratigraphic horizons could contain bedding replacement deposits.

DESCRIPTION OF DEPOSITS

MINA JANELÃO

Mina Janelão is at the west edge of the mineralized area west of Itacarambí. The deposit was found early in 1956 and is the most recent discovery in the district. The mine is near the margin of the plateau where the valleys are young and sharply incised. Although slopes are steep, relief is only about 60 meters; the altitude is more than 600 meters above sea level. Riacho Embaúba, an intermittent tributary of the Rio Peruaçu, passes through the property from north to south. The best access road passes near the other deposits to the northeast and connects with the road from Mina Grande to Itacarambí. The distance from Itacarambí to Mina Janelão is about 26 kilometers. The Chico Pacheco road is shorter, only 16 kilometers to the property from the main road between Fabião and Itacarambí at a point 4 kilometers northeast of Fabião, but includes a very steep grade where it climbs the 200 meter-high escarpment. The workings at Mina Janelão consist of surface trenches and small pits from which several thousand tons of ore has been extracted in the course of exploration; some ore is stockpiled at the deposit, but most has been transported to the river landing at Russinho.

The country rocks (pl. 4) consist of beds of medium dark-gray, fine-grained limestone and overlying black-weathering, light-gray to pink, saccharoidal dolomite and dolomitic limestone of the Bambuí series. The limestone is thin bedded and compact, the dolomitic rock is thick bedded and massive. Along Riacho Embaúba the limestone and dolomite form cliffs that show many solution cavities, open joints, and serrated and pinnacled summits (fig. 13). Collapse breccias of recent origin are evident here and there, especially around the spring toward the north end of the property. A solitary patch of sandstone of the Baurú formation lies on top of the ridge east of Riacho Embaúba in the central part of the mine area, resting directly on dark-weathering dolomite. It consists of boulder- and cobble-size blocks of sandstone embedded in residual soil of the same rock.

The area is on the west side of the main anticline. The hinge line of the monocline, striking N. 35° E., passes just west of Riacho Embaúba. Rocks to the west are virtually horizontal, those along the Riacho dip 7°–15° E., and farther east dip 20° E. Three siliceous mineralized zones occur at Mina Janelão. Two strike from N. 20° to 40° E. and appear to be related to the system of cross faults in the area; the third strikes N. 20° W.

The zone from which most ore has been extracted, known as Estaca Quatro (Stake Four), is at the south end of the property. In that

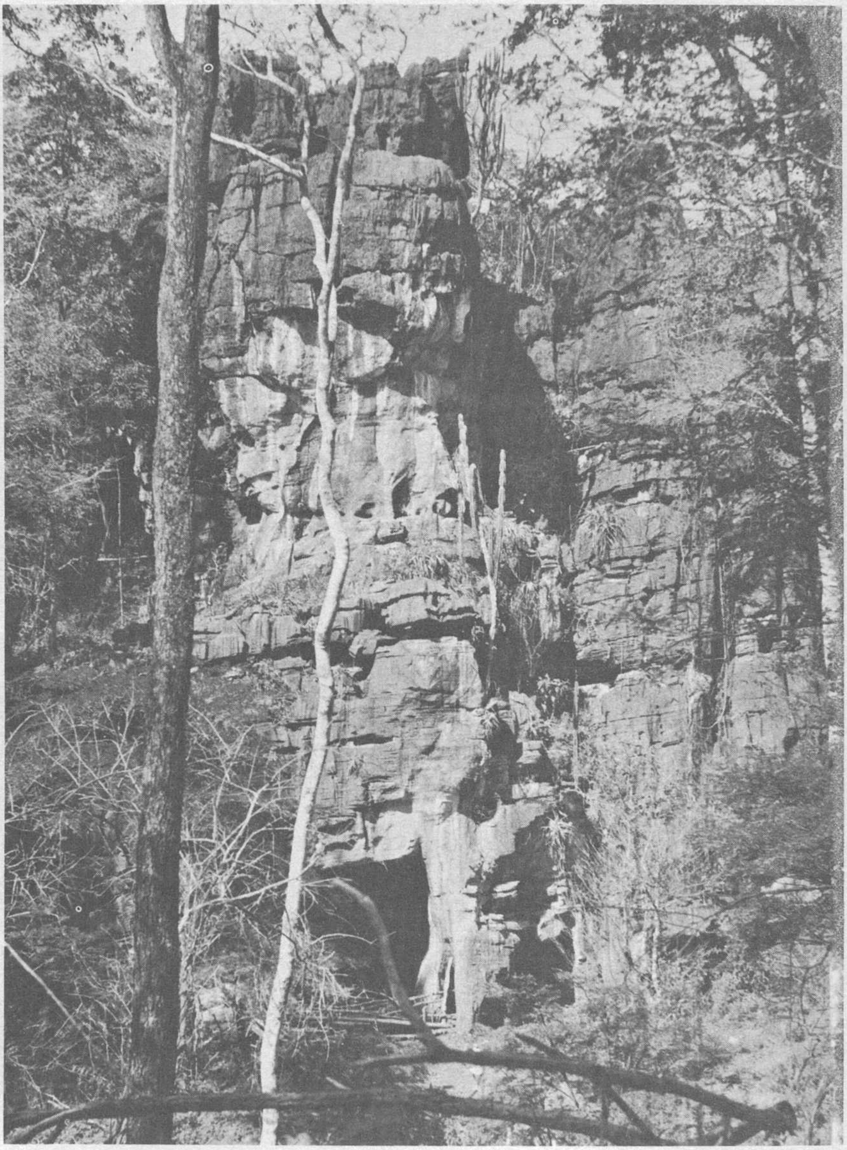

FIGURE 13.—Cliff along Riacho Embaúba of limestone topped by "black" dolomite showing effects of solution weathering. Note cave at bottom of cliff and vertical open joint to its left. Dripstone occurs on the face of the cliff.

FIGURE 14.—View of the Estaca Quatro zone at Mina Janelão, looking south. To the right the residual blocks mixed with colluvium contain secondary ore minerals of lead and zinc. The blocks are concentrated along a line that extends beyond the dump in center background. Dumps to right consist of hand-sorted oxide ore minerals.

area, large, loose, residual blocks of rock containing a high concentration of secondary ore minerals and some galena and sphalerite occur in colluvium in a line 120 meters long (fig. 14). Many of the loose blocks are nearly a meter long and contain more than a ton of mineralized rock. At present it cannot be said that any definite vein exists at depth, for exploration by underground workings or drilling has been inadequate or inconclusive. Shallow exploratory pits and trenches have been dug along and across this line of blocks, but few of the excavations reach bedrock. In two trenches, bedrock limestone is cut by a few tiny quartz veinlets that contain galena and sphalerite. Several inclined holes drilled along the Estaca Quatro zone during 1959 to search for a mineralized vein at depth, found mostly unaltered compact dark-gray limestone and only 1 or 2 minute veinlets containing lead and zinc minerals. This may indicate that the mineralized zone is irregular, or that mineralized, altered, and fractured parts were not recovered in the drill core. The blocks probably are too large to have been moved far by natural agencies; their linear concentration suggests that they accumulated more or less in place while some vein and its wallrock were dissolved, weathered, and eroded. As indicated by the size of the blocks, the vein could be as much as 1 meter wide in the oxidized zone. The depth to which oxide ore extends is not known.

Scattered through the soil between the zone of large blocks of oxide ore and the floor of the valley, 25 meters to the east, are similar boulders apparently derived by erosion from the inferred vein. The area underlain by this float covers about 2,700 square meters. Exploratory trenches and pits were dug in the soil of this zone to a depth of 2 to 4 meters; blocks of ore found during exploration were stockpiled.

At the top of the cliff 50 meters west of the main-vein zone, mineralized float blocks, mixed with soil and rubble filled a channelway that was formed by erosion and solution of carbonate rock. The channelway measures nearly 40 meters long, from 3 to 8 meters wide, and from 3 to 8 meters deep. Its gross appearance is that of a line of partly coalesced potholes, revealed after complete excavation of the filling. The walls and floor of the channelway are completely devoid of fractures and mineral veins, so it is assumed that the mineralized float blocks accumulated in the depression through erosion of a nearby vein or lens above the present topographic surface.

The second mineralized zone is at the northwest end of the property. It is marked by a discontinuous but prominent vein of quartz that trends N. 35° E. for 200 meters, parallel to the cross faults in the region to the northeast. The vein ranges from a few centimeters to more than 5 meters in width and dips nearly vertically. The quartz is grayish white, contains vugs, and locally appears to have replaced dolomite. Only scattered blebs of galena have been found at the several trenches along the vein; several clusters of galena crystals are exposed at the east end of the vein. If the surface showings are representative, there is little likelihood that commercial quantities of lead and zinc minerals can be found in this vein at depth.

The third mineralized zone is along a ridge 0.5 kilometer north-northwest of the Estaca Quatro zone and 150 meters east of the second vein. It is called "Estaca Onze" (Stake Eleven) and consists of scattered outcrops of mineralized dolomite alined N. 35° W. (pl. 5). This zone, more than 200 meters long and 70 meters wide, is made up of many closely spaced steeply dipping to vertical tension fractures striking N. 20°–35° W. Individually the fractures are small and discontinuous. Each contains minor amounts of quartz and is bordered by bleached white- to rose-colored dolomite. Clots of galena with some sphalerite and traces of descloizite occur throughout the recrystallized dolomite lenses; secondary minerals seem to be quite scarce. Because these fractures differ in density and size from one side of the ridge to the other, the lateral boundaries of the mineralized zone are poorly defined.

There is little ore in the mineralized zone at Estaca Onze. Mineralized rock in an elliptical-shaped area, about 20 meters wide and 80 to 100 meters long, near survey station 11, might possibly justify limited exploration. As primary minerals are exposed at the surface, little or no secondary ore minerals can be expected at depth. Assuming that ore minerals are as thinly disseminated at depth as at the surface, the prospects for developing large reserves are not favorable.

In summary, Estaca Quatro is the only mineralized zone of the three at Mina Janelão that contains oxide zinc and lead ore in sufficient amount to invite exploration and development. The quartz vein at the north end of the property contains no secondary minerals of zinc, and insufficient content of lead sulfide or other materials in outcrops to indicate minable ore bodies at depth. The Estaca Onze zone in the northeastern part of the property is a relatively small lens that contains both primary and secondary minerals. The primary minerals are relatively more abundant than secondary minerals in the outcrops.

The Estaca Onze area was geochemically sampled to test the feasibility of such prospecting in the district. Soil samples were taken along four traverses across the zone and analyses for lead concentration in parts per thousand were made under the direction of Dr. Geraldo Melcher, of the Departamento Nacional da Produção Mineral. (See fig. 15.) Two sets of soil samples were collected independently as a check on the reliability of the sampling. The northern and

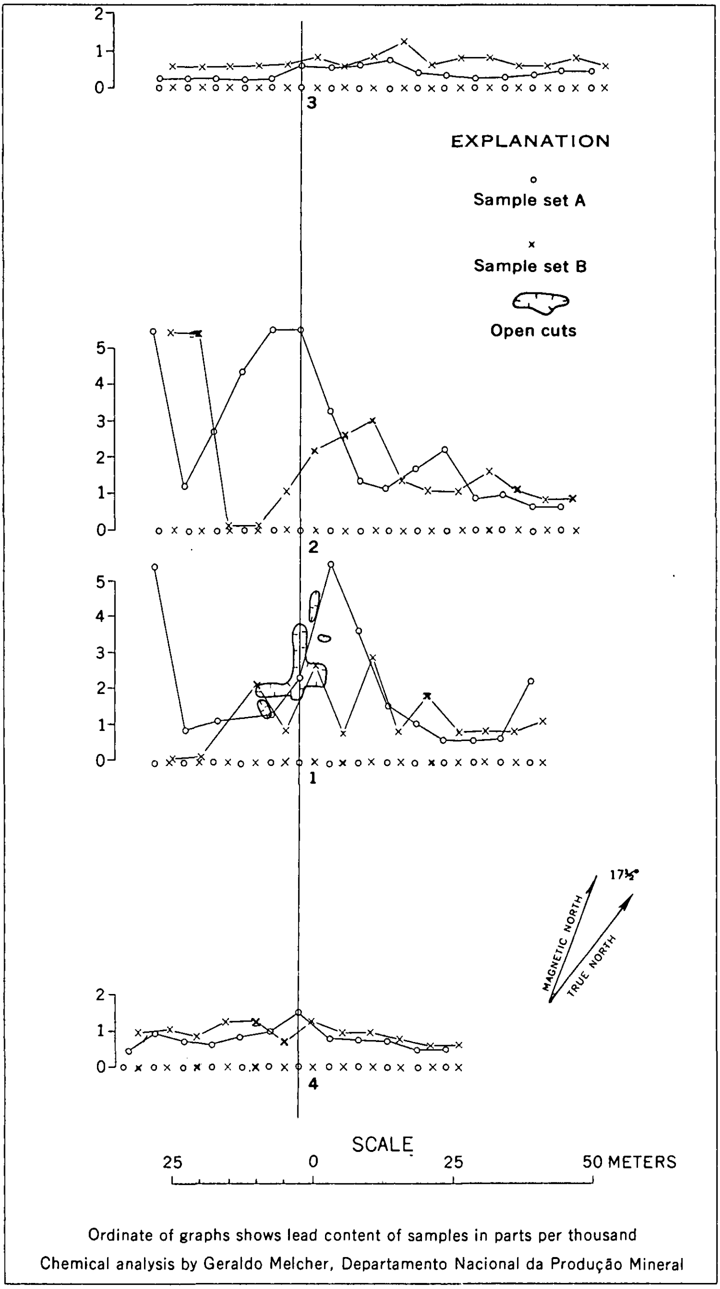

FIGURE 15.—Sketch map of Estaca Onze, Mina Janelão, showing graphically the results of geochemical prospecting. Two sets of soil samples A and B, and four traverses across the mineralizd zone are represented.

southern traverses, 3 and 4, show hardly more than the background values for lead in the soil of the region. The two crossing the middle part of the zone, 1 and 2, have irregular values, as shown by differences in the lead content of the alternate sets of soil samples. Nevertheless, they demonstrate a central zone of relatively high concentration of lead with rapid decline in values along the trend to the northwest and southeast. Laterally, the traverses end at outcrops of virtually barren dolomite. Inasmuch as zinc is closely allied with lead in the district, this method of geochemical prospecting probably can be used as well in the search for zinc in soil-covered areas.

Commonly the concentration of the carbonate, sulfate, and silicate minerals in veins that contain lead and zinc is high at the surface, but this concentration decreases at depth as the primary sulfide minerals are reached. The secondary ore minerals at Estaca Quatro form an impressive cap, but this cap may be quite thin, inasmuch as sulfide minerals are mixed with oxide minerals in float blocks at the surface. The oxide cap may also be enlarged by accumulation into the form of a mushroom with a broad top; it may have a thin stem where it joins sulfide-bearing veins. Careful and extensive underground exploration or drilling should be continued to determine the nature and extent of the oxidized zone and the nature of mineralized bodies in bedrock before any large-scale mining operation is started.

The rock in the Estaca Quatro zone and boulders of mineralized rock from the adjacent colluvium contains about 20 percent zinc and 15 percent lead, as based on 4 representative samples of stock-piled, hand-sorted rock assayed by the Laboratório of the Departamento Nacional da Produção Mineral. The silver content exceeds 60 grams per ton in three samples and reaches 156 grams per ton in the fourth.

For estimating ore reserves in the Estaca Quatro zone, the line of loose mineralized blocks is considered to be a vein 105 meters long and 1 meter wide, containing an indicated reserve of about 300 tons per meter depth of rock with the above-cited grade. In the colluvium between the Estaca Quatro zone and the creekbed covering an area of about 2,500 square meters, a reserve of nearly 750 tons of ore per meter depth is indicated. The reserves of the vein and colluvium together, therefore, are about 1,050 tons per meter depth. On the basis of completed exploration, this type of ore cannot be safely projected to depths greater than 5 meters.

MINA GRANDE

Mina Grande is 12 kilometers west from the crossroads at Pindaíba, on the north side of the strike-fault valley bordering the main anticline (pl. 3). Access to the area is by way of the main mine road between Pindaíba and Mina Janelão. The road continues west of Pindaíba for 9.5 kilometers, where a side road branches north for 2.5 kilometers to the valley below the mine. A trail leads upslope to the mineralized area. The main deposit is at an altitude of 650 meters above sea level. Relief in the area is about 150 meters; slopes along the valley below the deposit are steep and marked by many limestone cliffs. Solution weathering probably played a part in the formation of the oversteepened outcrops.

The lead and zinc deposit at Mina Grande, discovered about 1938, was the first found in the Itacarambí area. Capitão Lélio Graça mined the deposit and attempted to smelt the ore locally in the following year. Beyond this, the history and record of production of Mina Grande are obscure; it is known that for a time the mine was operated by a company with French capital and that operations ended in litigation. A small experimental furnace set up near Pindaíba at one time smelted some lead ore and reportedly produced 204 ingots totaling 9.5 tons of 97 percent pure lead (Moraes, 1958, p. 166). Workings at Mina Grande consist of surface gougings, shallow opencuts, and trenches. A shaft near the central part of the mineralized zone, now caved, is reported to have been no more than 10 meters deep.

The deposit consists of dolomitized and highly silicified limestone containing galena and sphalerite with some secondary minerals within a fracture zone that is at least 180 meters long, from 10 to 20 meters wide, and trends about N. 70° W. (pl. 4). The limestone is laced with steeply dipping, irregular, short fractures and poorly defined and discontinuous veins, is brecciated, and is highly silicified. Nevertheless, bedding planes are fairly well preserved (fig. 16).

The mineralized fracture zone (fig. 17) separates black-weathering massive crystalline dolomite on the north side from dark-gray, thin-bedded fine-grained limestone on the south side. The north side appears to have been downfaulted an estimated 40 meters with respect to the south side. The calcareous beds on both sides of the mineralized zone strike about N. 65° W. and form a dipslope of 25° SW. toward the longitudinal fault in the valley. The dolomite wallrock on the north side of the mineralized fracture zone is stained red and recrystallized for 20 to 30 centimeters from the contact. Limestone on the south wall of the mineralized zone is only slightly dolomitized.

Adjacent to the fracture zone and overlying the dolomite and limestone are mantolike masses of silicified pseudobreccia containing minor concentrations of lead and zinc minerals. The patch overlying dolomite north of the mineralized fracture zone covers 350 square meters of area and averages 1 meter in thickness. Between the fracture zone and the westward-trending fault to the south the manto of

FIGURE 16.—Highly silicified rib of limestone in the center of the mineralized zone, near survey point A, Mina Grande. Although the rock is altered, brecciated, and contains concentrations of galena, bedding is still discernible.

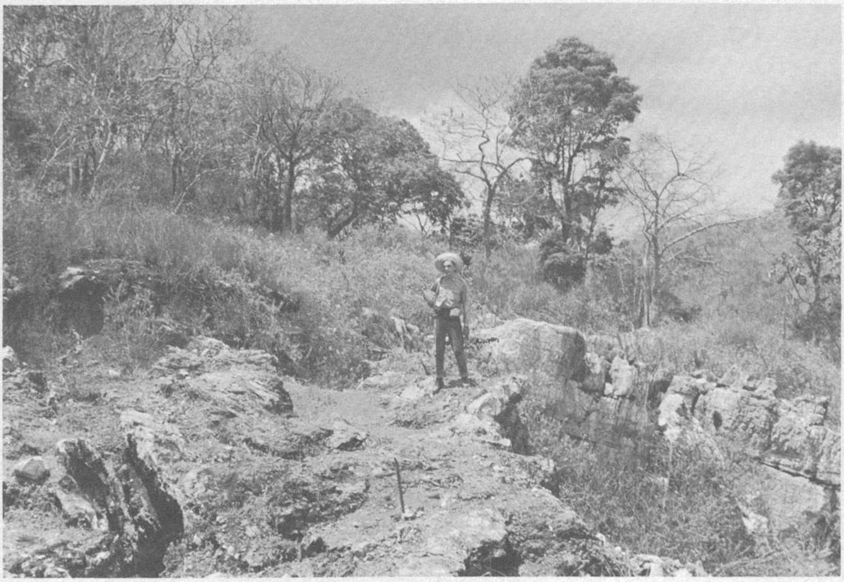

FIGURE 17.—View looking east along fracture at south edge of Mina Grande mineralized zone near survey point B. Fracture dips 65° N. Bedding in limestone wallrock to right dips 25° S. Open fracture at left is lined with smithsonite and dips essentially vertically.

silicified rock overlying limestone is as much as 5 meters thick and covers more than 6,000 square meters of area. Although the siliceous pseudobreccia contains little lead and zinc, small nodules of chalcocite, the largest weighing several kilograms, are found in this area.

Toward the west end of the deposit, the mineralized fracture zone narrows to about 5 meters and ends abruptly in a large outcrop of barren country rock; no crossfaults were seen. The mineralized zone bifurcates about 60 meters from its west end. The south split is 10 meters wide and parallels the main zone for 50 meters; it lies 10 meters south of the main mineralized zone. In the middle part of the fracture zone is a lens of barren limestone, 2 meters wide by nearly 15 meters long, only slightly silicified, bleached, and fractured. Eastward the main part of the mineralized zone ends abruptly in a cliff, beyond which the zone consists of a band of dolomitized and slightly silicified rock that can be traced about 150 meters. Four hundred meters southeast of the mineralized zone an isolated pocket of silicified limestone, circular in shape and 25 meters wide, is crisscrossed by poorly mineralized fractures and veinlets. It has been explored by an open pit.

Lead and zinc minerals are scattered along fractures, veins, and bedding in the bleached, dolomitized, and highly silicified limestone at Mina Grande. Galena and sphalerite crystals, surrounded by anglesite, cerussite, smithsonite, and willemite, occur in scattered rosettes, 1 to 3 centimeters across, and in larger clusters as much as 20 centimeters in dimension. Such crystal and mineral masses are concentrated in small lenses, from 1 to 4 meters long, randomly distributed through the fracture zone. In the relatively larger areas between lenses, the ore minerals are sparsely disseminated. Secondary lead and zinc minerals form roughly half the ore at the surface. In the lenses they appear as dense, white to gray masses. Cavities are common, and contain fine crystals of willemite, sparse amounts of the vanadium minerals, descloizite and vanadinite, traces of malachite, and an abundance of quartz crystals and chalcedony. The boundaries of mineral concentrations are irregular and vaguely defined, although the silicified dolomite surrounding such concentrations normally is bleached and silicified.

Two samples of mixed ore, collected to find the upper range of values for lead and zinc, were analyzed at the Laboratório of the Departamento Nacional da Produção Mineral. One, a chip-channel sample from a pocket of ore several meters long in a vein 14 meters west of survey point B, assayed 25.4 percent lead and 26.1 percent zinc. About half of the sample consisted of galena and sphalerite. Several meters closer to survey point B a grab sample of mostly oxidized lead-zinc minerals was taken that assayed 15.3 percent lead and 26.7 percent zinc. Both samples contained only traces of silver and vanadium. These values are representative only of pockets of ore.

Roughly 10 percent of the mineralized rock in the fracture zone at Mina Grande is estimated to contain ore having a grade of approximately 20 percent lead and 20 percent zinc. On this basis, about 500 tons of measured lead-zinc ore is calculated in the first meter of depth of the 180 meter long by 10 meter wide zone. If it is assumed that mineralized rock of the same grade extends to 5 meters of depth, then an additional 2,000 tons of ore is indicated; because the zone at depth has not been explored effectively, this estimate is questionable. Inferred ore reserves are a matter of even broader speculation. The pseudobreccia masses are unexplored at present but are so weakly mineralized surficially as to make estimates of their reserves inconsequential.

Two diamond-drill holes were drilled during 1959 at Mina Grande to determine whether the mineralized fracture zone extends downward as a vein, more or less vertical, whether it is part of a preferentially mineralized and fractured bed, or whether mineralized beds similar to the pseudobreccia occur at depth. Both holes, one vertical and the other horizontal, were drilled from a point about 10 meters south of the fracture zone, 50 meters from the west end, and 4 meters below the general level of the zone. The holes, 30 and 20 meters long respectively, penetrated buff-colored crystalline dolomite transected by calcite veinlets and minor quartz, but neither hole encountered ore minerals or definite indications of mineralized veins or fractures. The results are not considered conclusive, however, because the vertical hole was drilled parallel to and several meters distant from any projected vertical mineralized fracture zone, and the horizontal hole, passing barely 4 meters below the outcrops, conceivably entered a leached or barren stretch. In addition, both holes encountered broken, difficult ground where parts of the drill core record were lost. Several inclined holes should be drilled at intervals along the mineralized zone to further explore its character at depth, and to obtain some idea of mineral reserves. The steep slope south of the zone is an excellent area in which to establish sites for such diamond-drill holes.

If trenching and sampling at the surface, diamond drilling, and other factors warrant investigation of the mineralized zone at depth, then underground exploration could follow. An adit driven N. 10° E. from the south side of the fault trending N. 80° W., at an altitude of about 625 meters, would give abundant information about the mineralized zone at a relatively shallow depth. The mineralized zone could be reached by an adit 40 meters long if the working was begun south of survey point A. It would encounter the zone at about 25 meters below the surface. In addition, this adit would disclose the presence or absence of siliceous pseudobreccia and whether or not it has been mineralized, and could readily be used for limited development. A north-trending adit from the the base of the slope to the south, if begun at an altitude of 590 meters, would intersect the mineralized zone 60 meters below the surface about 100 meters from the point of entry.

MINA SÃO JOÃO

Mina São João is about 1 kilometer southwest of Mina Grande and is near the top of a ridge at about 700 meters altitude, 50 meters higher than Mina Grande. It is 300 meters south of the sinkhole valley, Boqueirão do Cipoal (see pl. 3). The area is 8.2 kilometers west of the crossroads at Pindaíba by way of the road to Mina Grande. A few tons of lead ore were extracted from the deposit during past operations at Mina Grande, of which several tons of low-grade ore were left stockpiled. Workings consist only of a few small trenches and pits. The terrain around the deposit is an impressive solution topography, consisting of well-like depressions with sheer walls 10 to 20 meters deep, and lapiés surfaces that are practically impossible to traverse.

The deposit at Mina São João is small and consists of both primary and secondary lead and zinc minerals disseminated in nearly flatlying, silicified, leached, and brecciated limestone (fig. 18). Some altered and mineralized limestone crops out in shallow depressions within barren, dark-weathering, dolomitic limestone of the Bambuí series. Other mineralized bodies occur as resistant erosional remnants on top of the dolomitic limestone. A few small inaccessible masses are perched on limestone pinnacles in a deeply etched lapiès surface to the north of the mapped area. It is surmised that all the altered and mineralized rock originally formed one continuous mass that covered an area at least 120 meters long by 70 meters wide. The largest remnant is at the east end of the mine area, measuring about 65 meters long by 20 meters wide. It and the mass in the southwest corner of the Mina São João area are the only ones that contain ore minerals in any significant quantity.

The mineralized rock does not seem to be related to any specific stratigraphic horizon. Although the lower contact of the silicified pseudobreccia masses, on the average, is flat, in detail it is irregular and undulating and at several places dips steeply. The mineralized masses range in thickness from a fraction of a meter to more than 5 meters (fig. 12). The attitudes of bedding planes in the altered limestone are

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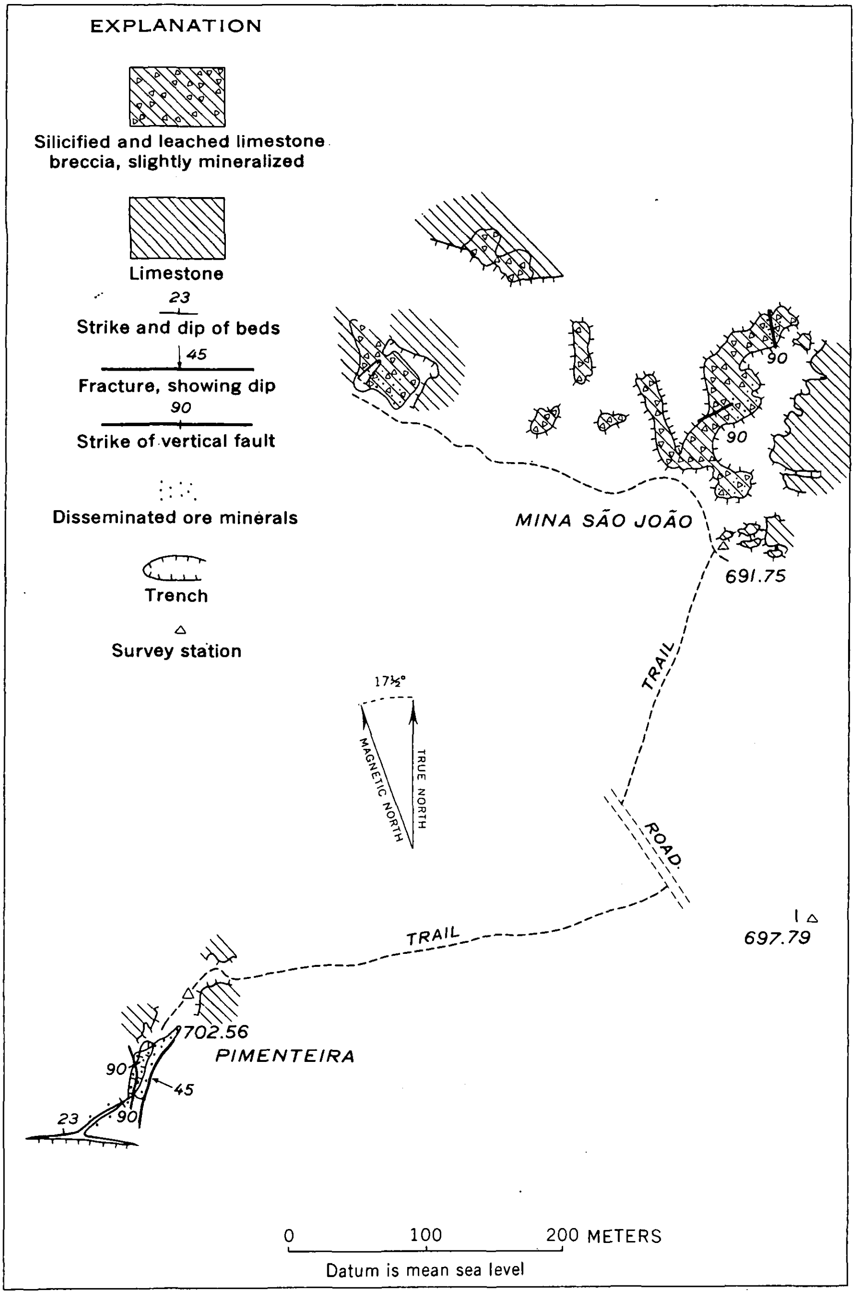

FIGURE 18.—Geologic sketch of map of São João mine and Pimenteira prospect near Itacarambí, Minas Gerais.

concordant with those of surrounding and underlying limestone. The general form of these masses is that of some sort of a manto deposit.

Several small pockets of both primary and secondary lead and zinc minerals crop out in the east and southwest parts of the area. They are irregular-shaped, about 2 meters long, and less than 0.5 meter thick. They contain galena and sphalerite in clumps 20 to 30 centimeters across and in rosettes of a few crystals scattered about in the silicified, bleached, and leached rock. Galena and sphalerite alter to white and gray oxides that commonly are massive, globular, or stalactitic. Here and there are a few dark crystals of descloizite with vanadinite. The ore minerals, besides occurring in pockets, are weakly disseminated in the silicified masses.

Mina São João does not contain sufficient ore to warrant extensive exploration. The mineralized parts, however, are easily accessible and some open pit exploration and mining could be undertaken in conjunction with operations at Mina Grande.

PIMENTEIRA, JACARÈZINHO, AND TAQUARÍ PROSPECTS

The three small deposits of Pimenteira, Jacarèzinho, and Taquarí, near Mina Grande and Mina São João, are similar. They consist of thin veins of lead and zinc minerals in randomly oriented, silicified fractures in limestone. These deposits have no particular stratigraphic or structural link to each other or to other deposits. They are of low economic value.

The Pimenteira prospect is near Mina São João (fig. 18), about 200 meters west of the main access road. The silicified fracture zone that makes up the deposit strikes about N. 30° E. and dips roughly 45° NW. The zone, 30 meters long, is a narrow outcrop of brecciated and silicified limestone at the north but thickens to 6 meters at the south end, where it ends abruptly against a thin vertical vein striking N. 55° E. The vein is 25 centimeters thick and extends to the southwest for 24 meters where it ends against a quartz vein that strikes N. 85° W. and dips 23° N. The surrounding limestone and dark-weathering dolomitic limestone are nearly flat lying.

The prospect is cut by a trench 20 meters long that trends about N. 12° E., slightly diagonally to the fracture zone. The rock in the fracture zone consists of gray to white limestone, brecciated in part, transected by irregular fractures and quartz veinlets, and largely replaced by quartz. At the north end of the zone the breccia is composed of silicified angular limestone fragments in a matrix replaced by silica. The mass is probably a pseudobreccia for it does not continue into nearby limestone. Minor amounts of galena, sphalerite, and secondary minerals, are scattered through the fracture zone.

The Jacarèzinho prospect is 0.5 kilometer north of the Pindaíba-Mina Grande road, and 200 meters east of the trail to Gerais that begins at the east end of the sinkhole valley, Boqueirão do Cipoal (pl. 3). It can be reached also by way of an oxcart road that leaves the Pindaíba–Mina Grande road 0.8 kilometer east of Boqueirão do Cipoal. The deposit is near the summit of the plateau at an altitude of roughly 700 meters.

At the Jacarèzinho deposit, a large vein of barren white quartz strikes about N. 60° E. and dips vertically. The vein is roughly 250 meters long and at most 1.5 meters thick. It tapers out toward the southwest near the Gerais trail, and seems to split and become dissipated in a cliff of limestone and dolomite northeastward. In the central part of the area the vein is flanked by a zone, measuring roughly 6 by 8 meters square, of ramifying quartz veinlets that suffuse and replace the calcareous rock. The veinlets consist of finely crystalline quartz, massive euhedral quartz, and white to gray chalcedony. Associated with the veinlets are patches of recrystallized limestone and dolomite. Some calcite occurs in vugs. Two pits in this zone northwest of the quartz vein expose isolated crystals and grains of galena and sphalerite in the country rock. In the same mass, small amounts of crystalline descloizite were seen in drusy cavities. The tenor of lead and zinc in the silicified mass is extremely low.

The Taquarí prospect, 1 kilometer southwest of the Pimenteira prospect (pl. 3), is on the north edge of a deep canyon and lies at an altitude of about 660 meters. It is reached by a jeep road 1 kilometer long that branches from the main road 9.5 kilometers west of Pindaíba. The Taquarí deposit is geologically similar to the Jacarèzinho prospect, but is smaller and contains more ore minerals. The country rock is limestone that dips as much as 10° E. The limestone is silicified and in places rich in lead and zinc minerals associated with irregular, branching veinlets of quartz. The area of this deposit is about 1,000 square meters but this includes large patches of barren limestone.

The north end of the deposit was explored by an open pit 12 meters wide, 16 meters long, and as much as 3 meters deep. The limestone in the pit contains scattered bunches of sphalerite crystals with some galena, together with secondary lead and zinc minerals.

A vertical vein, trending N. 45° E. and 12 meters long, lies about 15 meters south of the test pit. Its wallrock is silicified for a width of 1 meter at the northeast end and for 0.5 meter at the southwest end. Galena, the main sulfide mineral, is most abundant in the northeastern part of the fissure. The limestone wallrock is silicified, bleached to a light color, and slightly recrystallized. Twenty-five meters beyond the southwest end of this fissure is an outcrop of siliceous spongy gossan that is 12 meters long and trends N. 55° W. It is 2 meters wide at the south and wedges out at the north. It probably forms the weather-resistant core of a short fracture or joint. No lead-zinc minerals were seen in the gossan, but the iron oxides indicate the former presence of ore minerals. The iron-bearing sulfide minerals such as sphalerite and chalcopyrite are the only readily available source from which such gossan material could have been derived.

A cleared area a few meters southeast of the pit at the Taquarí deposit is paved with broken hand-sorted ore. A grab sample, analyzed by the Laboratório of the Departamento Nacional da Produção Mineral, assays 10.4 percent lead, 26.2 percent zinc, 0.1 percent vanadium, and a trace of silver. Although high in grade, the amount of ore available for extraction is small. Surrounding outcrops of barren limestone plainly indicate limited possibilities for development of the deposit. Records of ore production are lost, but it is possible that some ore was used in the small lead smelter at Pindaíba.

In summary, the three deposits have small reserves of minable rock. Pimenteira and Jacarèzinho are small and weakly mineralized. Taquarí is larger and contains some high-grade ore but its total reserves are insufficient to warrant development.

RIACHO SÊCO PROSPECT

The Riacho Sêco prospect is on the edge of the escarpment overlooking the Rio São Francisco valley, and is about 3.5 kilometers southwest from the crossroads at Pindaíba (pl. 3). It is reached by way of 2.5 kilometers of trail that extends south from the Pindaíba–Mina Grande road and the house of Senhor Jackson, located 2 kilometers west of the crossroads at Pindaíba. The trail rises an estimated 150 meters up the steep escarpment from the valley floor in a distance of 0.5 kilometer. The Riacho Sêco deposit is an isolated occurrence; it is about 4 kilometers southeast of Mina São João and Mina Grande. Workings consist of three small exploratory trenches.

The deposit consists of two parallel veins of quartz between which lie two small irregular areas of mineralized silica boxwork and pseudobreccia in limestone. All these masses contain small concentrations of lead and zinc ore minerals (fig. 19). The veins strike N. 30° E., parallel to the cross-faults in the Itacarambí region, and dip steeply to the east. The eastern vein is about 50 meters long and averages about 0.5 meter in thickness. The western vein, 130 meters distant and roughly 20 meters higher, is equally as thick but only 30 meters long. The veins transect essentially flat-lying limestone and dolomite that is thickbedded, crystalline, and rose, buff, and light gray.

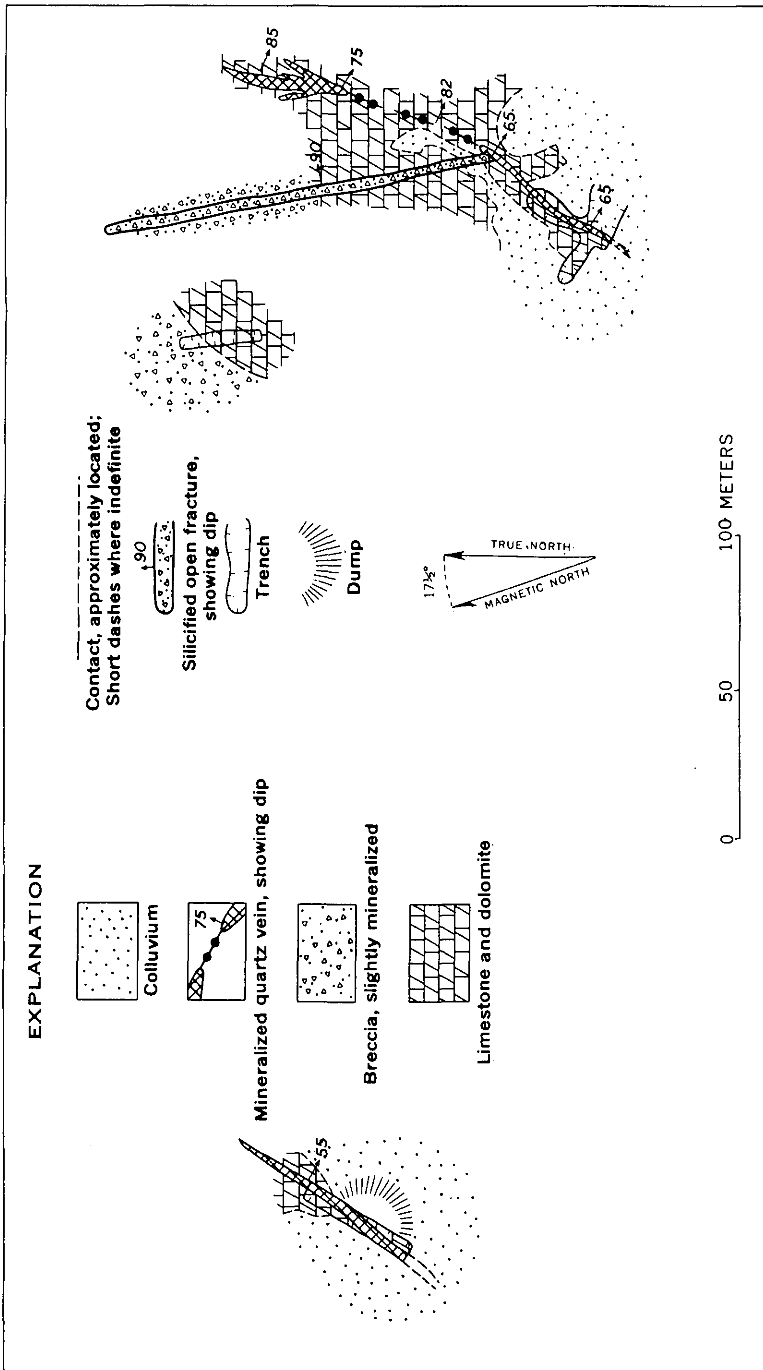

FIGURE 19.—Geologic sketch map of the Riacho Sêco lead-zinc occurrence.

Both veins are formed of white to gray quartz that replaces dolomite and limestone along minor fractures. The veins are not solid quartz, but consist of parallel thin irregular sheets and blotches of quartz and chalcedony, with bleached recrystallized and mineral-bearing screens of country rock between. The northern ends of both veins are discontinuous, consisting of masses of quartz in barren country rock. The eastern vein is dispersed at its northern end in a horsetail of quartz veinlets. The southern ends of both veins contain small pockets of galena and sphalerite, the amount progressively diminishing northward. The south ends of the veins are covered by soil but barren outcrops of limestone to the south indicate their nearby termination.

Branching from the eastern vein 20 meters from its south end is a vertical open joint striking N. 10° W. It is at least 50 meters long and is uniformly 1 meter wide. Its wallrock contains a filigree of white quartz veinlets and some calcite; a few small silicified outcrops are exposed in its floor. An outcrop of silicified limestone, also laced with quartz veinlets, occurs 15 to 30 meters west of the open joint. It covers roughly 100 square meters and contains a few patches of pseudobreccia. Scattered sparsely through all the pseudobreccias and silicified limestone are small isolated bunches and crystals of lead and zinc minerals and smaller amounts of barite and fluorite.

Minerals at the Riacho Sêco prospect are principally galena and sphalerite, but include minor amounts of lead and zinc carbonate minerals and descloizite. Except for the pockets found by trenching in the southern parts of the veins, the ore minerals are thinly dispersed. There is little likelihood that the veins become larger or contain appreciably more lead and zinc ore minerals at depth.

MINA FABIÃO

Mina Fabião (fig. 20) is a small fluorite deposit near the top of the escarpment overlooking the valley of the Rio São Francisco. The community of Fabião is 2.5 kilometers to the south (pl. 3), from whence the deposit can be reached on foot by a trail. Mina Fabião is 2 kilometers south by a fairly good road from the Chico Pacheco road. The spur road leaves the Chico Pacheco road near the top of the steep grade up the limestone escarpment about 4.5 kilometers west of the Fabião-Itacarambí highway. Mina Fabião is owned and operated by a group headed by Amynthas Jacques de Moraes.

The deposit is in a small valley several hundred meters west from the main escarpment. The valley trends S. 15° E. and is about 30 meters wide. Both walls are vertical and from 12 to 15 meters high. Outcrops in the east wall show the contact between medium-gray somewhat fragmental limestone and overlying dark-weathering dolomite.

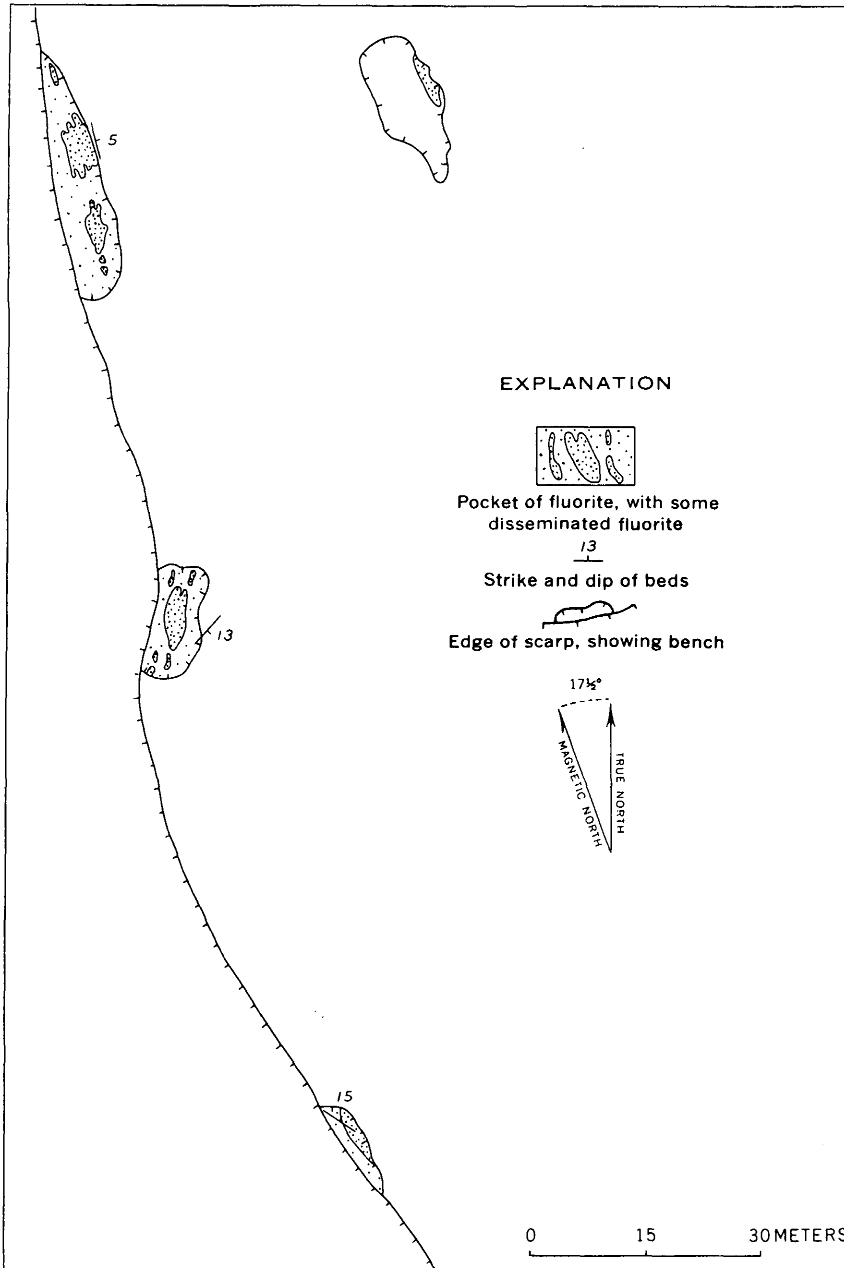

FIGURE 20.—Geologic sketch map of Mina Fabião.

The contact is slightly undulating, striking approximately north-northwest and dipping from 5° to 15° NE. The contact is from 4 to 5 meters below the top of the small scarp and parallels the topographic surface to the east. Karst features are prominent in the area and the dolomite cap is lapiés, full of solution cavities and enlarged joint planes.

Fluorite occurs in lenses replacing limestone just below the contact with dolomite. Large lenses are 5 meters long and from 0.3 to 1.0 meter thick; others are stringers 1 meter long and a few centimeters thick. They consist of moderately coarse grained purple to gray fluorite mixed with gray to white calcite. Surrounding limestone is recrystallized to coarse-grained, reddish-gray to buff rock containing scattered blebs and irregular veinlets of fluorite. A few small grains and crystals of galena and a small amount of quartz occur in these mineralized zones.

Four mineralized zones crop out in a distance of 100 meters along the east side of the valley and a fifth is exposed at the floor of a solution cavity 30 meters to the east. Those in the scarp were mined from 3 benches, 10 to 20 meters long and from 2 to 5 meters wide. Ore was mined and sorted by hand. The deposit was opened only in 1957 and at the time of our examination no ore had been shipped. An estimated 3 tons of high-grade, and 100 tons of low-grade fluorite were stockpiled.

Owing to the thickness of the dolomite caprock, surface workings cannot be extended to any significant distance. Exploration for further lenses would be difficult owing to lack of mineralization in dolomite. Solution of carbonate rock also removed fluorite, as is shown in the lens in the cave to the east. The area, therefore, is considered to have limited potential unless much larger masses are found by exploring caves and solution cavities.

MINA CAPÃO DO PORCO

Mina Capão do Porco is a small lead-zinc deposit that has been mined by Antonio Moreira dos Anjos as a one-man operation for its silver content. It is 35 kilometers southwest of Januária near the top of a hill called Serra de Cantinho. The deposit is reached by way of the village of Tijuco, 32.3 kilometers from Januária along the road to the damsite on the Pandeiros river (fig. 5). An oxcart road 5 kilometers long leads from Tijuco to the southwest base of the Serra de Cantinho. A good trail ascends about 100 meters to the deposit in a distance of less than 1 kilometer from the end of the road.

Serra de Cantinho is made up of flat-lying limestone and dolomite units of the Bambuí series. At its crest is thin-bedded medium- to dark-gray limestone, partly laminated and partly of primary breccia. It is underlain by buff to white, crystalline dolomite and dolomitic limestone that weathers black.

The dolomitic limestone unit has been weakly silicified and mineralized in various places in the hill just below its contact with the overlying limestone. The main source of hand-cobbed ore is an open vertical joint that strikes N. 10° W. The depression is 20 meters long, 5 meters deep, and at most 2 meters wide. Its walls, essentially stripped bare now, were reportedly coated with disseminated sphalerite, galena, and secondary lead and zinc minerals. For 40 meters west and 100 meters north of the joint, tiny clots of sphalerite and oxides of lead and zinc are disseminated sparsely over the lapiés surface of black weathering dolomitic limestone to a depth of about 1 meter.

The operator scraped the walls of the joint to a depth of 2 meters and selectively mined the mineralized clots to the west. He also piled float ore found below the escarpment 100 meters west of the joint.

Reserves in the Serra de Cantinho are small and low in grade. Senhor Antonio Moreira dos Anjos, with the aid of Capitão Lelio Graça, mined the occurrences and extracted silver in a hand-built smelter between 1936 and 1940. The son of Moreira more recently continued the work on a smaller scale. About 220 kilograms of silver were recovered in the earlier operation, and an estimated 100 kilograms have been produced between 1940 and 1957. The ore at present is treated on hand-concentrating tables, ground and mixed with charcoal, and smelted in batches of several kilograms in a blacksmith's forge.

ALTO DE PALMEIRAS PROSPECT

The Alto de Palmeiras lead-zinc prospect is on the Fazenda Palmeiras, 30 kilometers southeast from Januária and east of the Rio São Francisco (fig. 5). The Fazenda Palmeiras is reached from Pedras de Maria da Cruz by following the highway southward for 7 kilometers and then a jeep trail eastward for 19 kilometers over the sandy flood plain of the Rio São Francisco. From fazenda headquarters the prospect is reached by horse trail that trends up the creek, Ribeiro Palmeirinha, for about 5 kilometers, then ascends 200 meters to the top of the escarpment northeast of the creek. The deposit is on a steep northwest slope above a tributary of the Ribeiro Palmeirinha.

The Alto de Palmeiras prospect (fig. 21) is at the top of the section of the Bambuí series on the east side of the Rio São Francisco described earlier in this report. The limestone and shale in the immediate vicinity of the deposit strike N. 40° E. and dip 10° SE. The limestone is thin bedded, dark gray, and fine grained, and the shale is

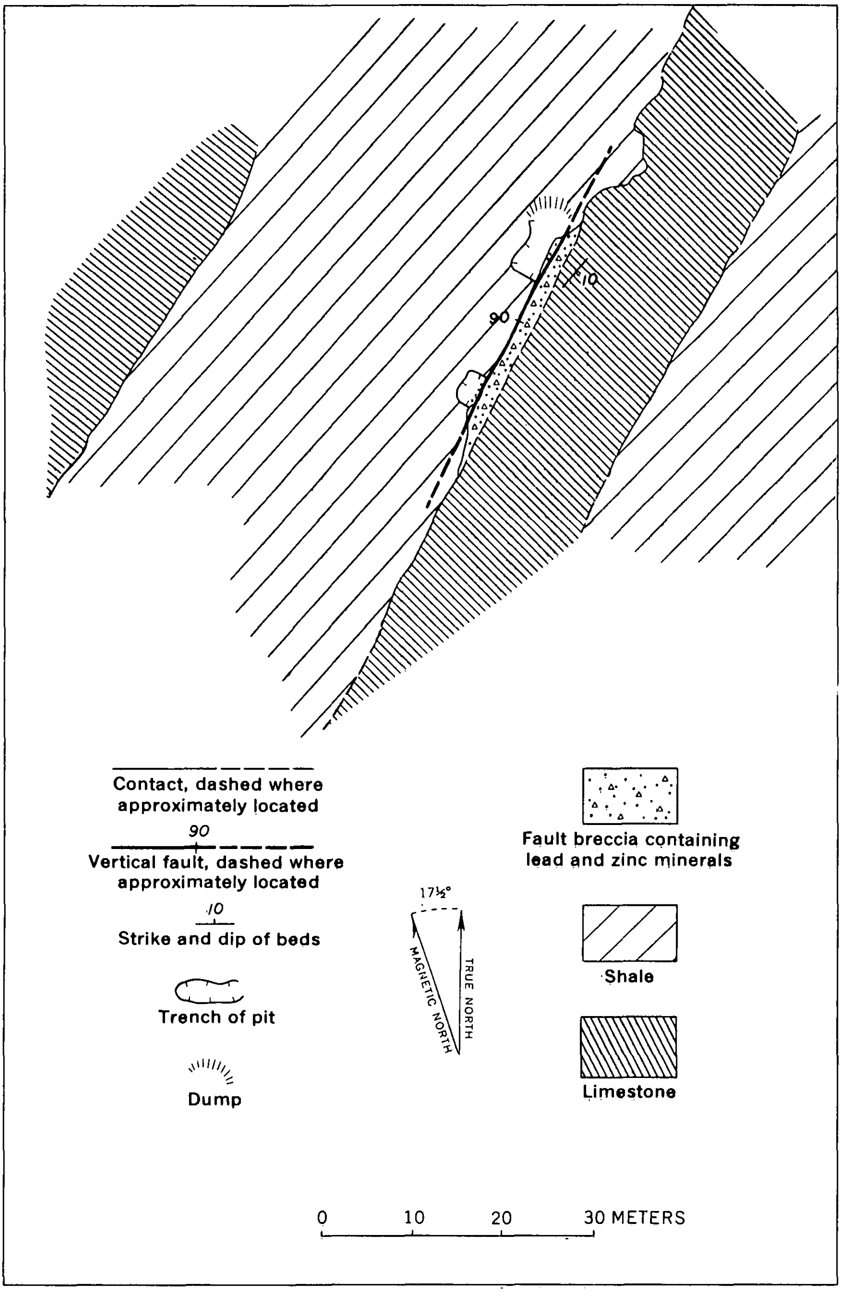

FIGURE 21.—Geologic sketch map of the Alto de Palmeiras lead-zinc occurrence.

olive gray to buff, slightly calcareous, and somewhat friable. The limestone forms bold ledges, whereas the shale weathers to smooth slopes with poor outcrops.

The deposit is along a steep fracture, striking N. 35° E., intersecting the contact between the limestone and underlying marly shale. Lead and zinc minerals are scattered through the bordering silicified and brecciated limestone for a length of 30 meters. Although ore minerals are found several meters from the fracture along irregular veinlets in limestone on the east, they are mainly concentrated within a zone 1.5 meters thick, and do not penetrate into the shale west of the fracture. Two small prospect pits, 1 to 2 meters deep, have been dug near each end of the zone. They expose relatively rich lenses, 3 and 6 meters long but only 0.5 meter wide, of mixed oxide and sulfide ore minerals, including galena, sphalerite, smithsonite, probably willemite, and traces of anglesite and cerussite.

Chip samples from each lens were submitted to the Laboratório of the Departamento Nacional da Produção Mineral for analysis. A chip channel sample from the lens at the southern end assayed 4.1 percent lead and 14.4 percent zinc. A channel sample from the northern pit contained 1.3 percent lead and 22.4 percent zinc. No vanadium and only traces of silver were found in these samples. Although the assays are encouragingly high in zinc, the concentration of ore minerals in the zone is irregular so that the average grade for the whole zone would be very much less, probably on the order of a few percent.

Only a few tons of mineralized rock of minable grade could be realized from the Alto de Palmeiras deposit as represented on the surface. Prospecting along the northern and southern extensions of the deposit by trenches and pits might uncover similar small lenses, but the likelihood of finding more extensive mineralized fracture zones in the vicinity appears remote.

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