Lead-Zinc Deposits of the Boquira District State of Bahia, Brazil

GEOLOGICAL SURVEY BULLETIN 1110-A

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

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By ROBERT F. JOHNSON

CONTRIBUTIONS TO BRAZILIAN GEOLOGY—
NONFERROUS METALS

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By ROBERT F. JOHNSON

ABSTRACT

The Boquira lead deposit in south-central Bahia, discovered in 1952, is one of the largest in Brazil. The ore bodies occur as veins in lenses of iron-rich metasedimentary rocks on the east flank of the Serra de Macaúbas. West of the crest of the serra is an extremely thick stratigraphic section of quartzite with minor units of interbedded quartz-mica schist. The section is at least 11,000 meters thick with no apparent repetition. Quartzite is also the dominant metasedimentary rock on the east side of the Serra de Macaúbas, but there it contains interbedded lenses of dacite, quartz-biotite-garnet schist, iron formation, and dolomite; the lenses are as much as 200 meters thick. The layered rocks are thought to be late Precambrian in age. Granodiorite with a gneissic texture, dacite, and basic igneous rocks, now amphibolite, intrude the metasedimentary rocks. The bedded rocks west of the crest of the Serra de Macaúbas dip westward whereas those east of the serra dip eastward. The beds on opposite sides of the serra cannot be correlated; those on the east side are thought to be older and to be faulted against those on the west along a reverse fault whose trace lies east of the crest of the serra. The rocks are also cut by northeast- and northwest-striking faults.

Mineração Boquira Limitada, S.A., a company formed in 1954 to develop the mine, began shipping ore in 1956. Only oxidized ore with a metal content of more than 45 percent lead could be shipped owing to smelter requirements and high transportation costs. The ore was shipped by truck to São Paulo where it was purchased by the Cia. Acumuladores Prest-O-Lite, a manufacturer of storage batteries. About 10,000 tons of hand-sorted ore was shipped up to December 1957, and an additional 30,000 tons of lower grade material and ore containing galena was stockpiled. The mine was purchased in December, 1957, by the Prest-O-Lite company which began construction of a concentrating plant at the mine and a smelter at Santo Amaro, near Salvador, the capital of the State of Bahia. The Companhia Plumbum, S.A., entered the Boquira area in 1957 and is prospecting ground adjacent to that owned by Mineração Boquira.

Galena, the dominant sulfide mineral in the ore, occurs with sphalerite and pyrite in a gangue of actinolite and quartz. Supergene lead minerals are cerussite, pyromorphite, and possibly anglesite. The supergene zinc carbonate smithsonite occurs with galena but is absent in near-surface ore. The ore bodies are tabular lenses from 1 to 3 meters thick and as much as 200 meters long.

The vertical extent is at least 80 meters. The ore bodies are in fault zones that are nearly everywhere parallel to bedding and commonly occur in thin beds in schist in iron formation. Several ore bodies have been found in a lens, more than 3 kilometers long, of iron formation lying west of Boquira.

INTRODUCTION

The discovery in recent years of the Boquira lead deposit in Bahia and the Vazante zinc deposit in Minas Gerais (Moore, 1956) has given considerable impetus to the search for base metals in Brazil. In accord with this increased interest the Departamento Nacional de Produção Mineral, of the Brazilian Ministry of Agriculture, entered into an agreement with the International Cooperation Administration of the United States under which the U.S. Geological Survey collaborates with the Departamento in a nation-wide study of nonferrous mineral resources, with primary interest in deposits of lead, zinc, and copper minerals. The purpose of the work is to increase knowledge of the ores of these metals in Brazil. The study described in this report was done as part of this cooperative program. The report describes the geology of the Boquira lead deposits and the results of a geologic reconnaissance of the surrounding area.

LOCATION AND PHYSICAL FEATURES

The Boquira lead deposits are on the outskirts of the town of Boquira, in the Município (county) do Macaúbas, in south-central Bahia (fig. 1), at approximately 12°49′ S. latitude and 42°45′ W. longitude. The altitude of Boquira as estimated from readings of an unchecked aneroid barometer is 600 meters (m). Boquira is about 400 kilometers (km) by road northwest of Vitória da Conquista, Bahia, the nearest supply point. The road from Conquista to Caetité (fig. 1) is part of the Federal highway and although not paved is kept in good repair. A secondary road leads from Caetité to Boquira. Travel on this road is precarious for trucks of more than 5 tons capacity and the road may be impassable after heavy rains for all vehicles except those with 4-wheel drive. Mineração Boquira, Ltda., S.A., the company that is developing the Boquira mine, is improving this road. The nearest railroad passes through Brumado, about 270 km by road from Boquira. Vitória da Conquista has scheduled airline service and Macaúbas, 30 km south of Boquira, has an airport suitable for light planes. Cia. Plumbum, S.A., has constructed an airfield near Tiros about 8 km north of Boquira.

The dominant feature of the landscape at Boquira is the Serra de Macaúbas, a north-trending range whose crest is about 300 m higher than the broad valley of the Riacho (river) Brejo Grande to the east.

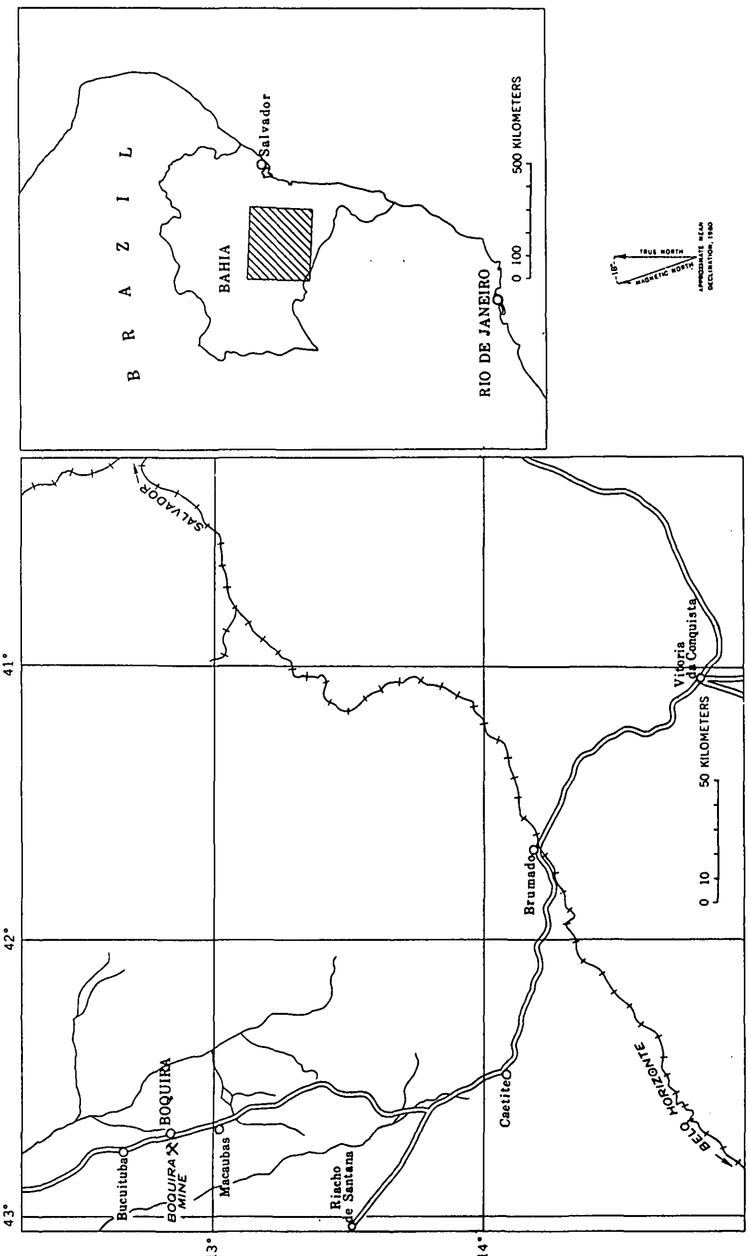

FIGURE 1.—Maps showing location of area mapped and location of the Boquira mine.

The eastern flank of the serra facing Boquira is steep; the western side has a gentle slope. Parallel to the serra on its eastern flank is a discontinuous lower ridge that rises 100 to 200 m above the valley. Small east-flowing streams whose sources are near the crest of the serra have cut through the lower ridge dividing it into segments 1 and 2 km long. The Boquira mine is on two of these segments west and northwest of the town.

Present exploration is not sufficient to establish measured ore reserves. Indicated reserves of the uppermost 80 m of the largest ore body total 110,000 tons of ore that contains 20 percent lead; about 30,000 tons of dump material of similar grade is also available. Another ore body is inferred to be of comparable size and grade; four others contain smaller but appreciable inferred reserves that total 4,000 tons of ore per meter of depth with a lead content of about 20 percent.

Geochemical prospecting was shown to be potentially useful for rapid surface exploration. Cia. Plumbum has used geochemical prospecting as a guide to subsequent trenching. In steep terrain, geochemical anomalies from massive cerussite float were found to limit the usefulness of the method.

A series of three subparallel ridges lie to the west of the Serra de Macaúbas, in the area between the serra and the valley of the Rio São Francisco, the major river of this part of Brazil. These ridges are the Serra das Palmeiras, (the easternmost), the Serra da Vereda, and the Serra da Garapa; the location of the first two are shown on plate 1. The Serra das Palmeiras is a double ridge of which the eastern part is the most prominent. The Serra da Vereda is an imposing ridge in the southern part of the mapped area where some peaks are higher than peaks of the Serra de Macaúbas, but the range dies out northward and merges with the Serra das Palmeiras. The Serra da Garapa lies west of the valley of the Riacho Santo Onofre. It was not visited as it lies outside the area covered by aerial photographs. The airline distance from the crest of the Serra de Macaúbas to the Serra da Vereda is about 11 km; the Serra da Garapa lies an additional 17 km farther west.

The Serra de Macaúbas is the drainage divide between the Rio Paramirim on the east and the Riacho Santo Onofre on the west, both tributary to the Rio São Francisco. Within the area studied the principal streams are the Riacho Brejo Grande east of the Serra de Macaúbas and the Córrego Taquarí west of the serra. The drainage in the basin of the Córrego Taquarí has a trellis pattern; the principal streams flow north or south parallel to the strike of the underlying rocks but in places cut through the ridges at right angles. Narrow gorges have been cut through the Serra das Palmeiras and the Serra da Vereda west of São João. (pl. 1).

Boquira is in the semiarid region that includes a large part of northeastern Brazil. Most streams in the mapped area are intermittent. The Córrego Taquarí is a perennial stream throughout most of its course, but all of its tributaries are intermittent. Water may be present at shallow depths in the larger tributary stream beds. Perennial springs on the east slope of the Serra da Macaúbas furnish water for the small communities located along the base of the range including Brejo Grande, Boquira, Tiros, and Pajeú. The waters from these springs flow only short distances into the valley before sinking beneath the surface; the Riacho Brejo Grande in the center of the valley is dry part of the year.

It is doubtful if enough water can be obtained from the springs near Boquira for both domestic use and for mine and concentrating plant use. The Rio Paramirim, 25 km distant, is the nearest adequate source of supply. Ground water can probably be developed in the valley of the Riacho Brejo Grande if care is taken to locate wells where the alluvium is deepest, as in old channels.

Vegetation consists of a dense growth of thorny shrubs and small trees, locally called caatinga. The larger trees can be used for mine timbers but they are not abundant and will only suffice for the early stages of mine development. The wood from these trees is hard, heavy, and difficult to work.

PREVIOUS WORK

No previously published geological work on the Boquira area is known. Derby (1878) and Sampaio (1905) studied the geology along the Rio São Francisco. They mention ridges of quartzite and metamorphic rock along that part of the river that is closest to Boquira; the river lies about 70 km west of the town. On the same voyage Sampaio left the river and traveled overland to Salvador, the capital of the State of Bahia. He passed through Caetité (fig. 1) and noted the presence of quartzite and siltstone in the vicinity. Derby (1906) and Williams (1930) describe the geology of the Chapada Diamantina, a diamond-bearing area in the Serra do Espinhaço about 100 km east of Boquira. Branner (1910 a, b, c) and Mello Junior (1938) made geological studies in the Serra de Jacobina and adjacent ranges about 300 km north and northeast of Boquira. Oliveira and Leonardos (1943, p. 127–132) summarized the findings of the previous workers and discussed the stratigraphy and regional correlation of the sedimentary rocks.

More recently Bodenlos (1954) described the geology of the Serra das Éguas near Brumado, about 170 km southeast of Boquira. King

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(1956) crossed the Paramirim valley in the course of his physiographic studies in Brazil and called it a rift valley. Geologists of the Cia. Plumbum, S.A., have been active in central Bahia in recent years but their work has not been published. They began work in the Boquira district in late 1957.

These references are cited with the view of presenting the known geology over a broad area in Bahia. The stratigraphy of the Boquira district differs in detail from that of other areas in Bahia.

FIELDWORK AND ACKNOWLEDGMENTS

The fieldwork for this report was done in July and October, 1957. The writer, with the assistance of Edmilson Dulce de Lemos, a student from Escola Politecnica in São Paulo, made a geologic map of the mineralized area. The geology was plotted on a map (scale 1: 5,000) furnished by Serviços Aerofotogrametricos Cruzeiro do Sul, S.A. (pl. 2). A planetable map (scale 1:500) was made of the Morro Pelado ore bodies (fig. 2), the most important ore-producing area. The writer also reconnoitered the geology of an area of about 400 sq km by traversing across the strike of the rocks in an easterly direction at intervals of about 5 km. The geology between traverse lines was mapped by interpretation of aerial photographs of this region. The Boquira mine was revisited in June 1958 in order to map the more recent underground workings.

The writer wishes to express his gratitude for the cooperation and hospitality of the owners and staff of Mineração Boquira, Ltda. Sr. Assis Tavora, president of the company, furnished base maps and survey data. Colonel Fidia Tavora and Sr. Pia Tavora made company facilities available in Boquira for housing and office space.

Sr. Antenor da Silva, another owner of the mine, furnished useful information on the mineral deposits of the region. Mr. N. Miagkoff, general manager, kindly contributed mineralogical information and data on mining development undertaken after the geologic fieldwork was completed. Mr. G. L. Boehringer, president of the Companhia Acumuladores Prest-O-Lite, purchaser of the mine in late 1957, kindly furnished data on developments during 1958, and made arrangements for the writer's visit in June 1958. Officials of Companhia Plumbum, S.A., furnished a base map of the Tiros area and data on geochemical prospecting.

Dr. Geraldo Melcher, in charge of nonferrous mineral deposit investigations of the Departamento Nacional da Produção Mineral, made the preliminary arrangements for the study. Rocks were thin-sectioned and ore samples were assayed in the laboratories of the DNPM in Belo Horizonte. Clovis C. Carraro of the DNPM assisted in the preparation of the illustrations.

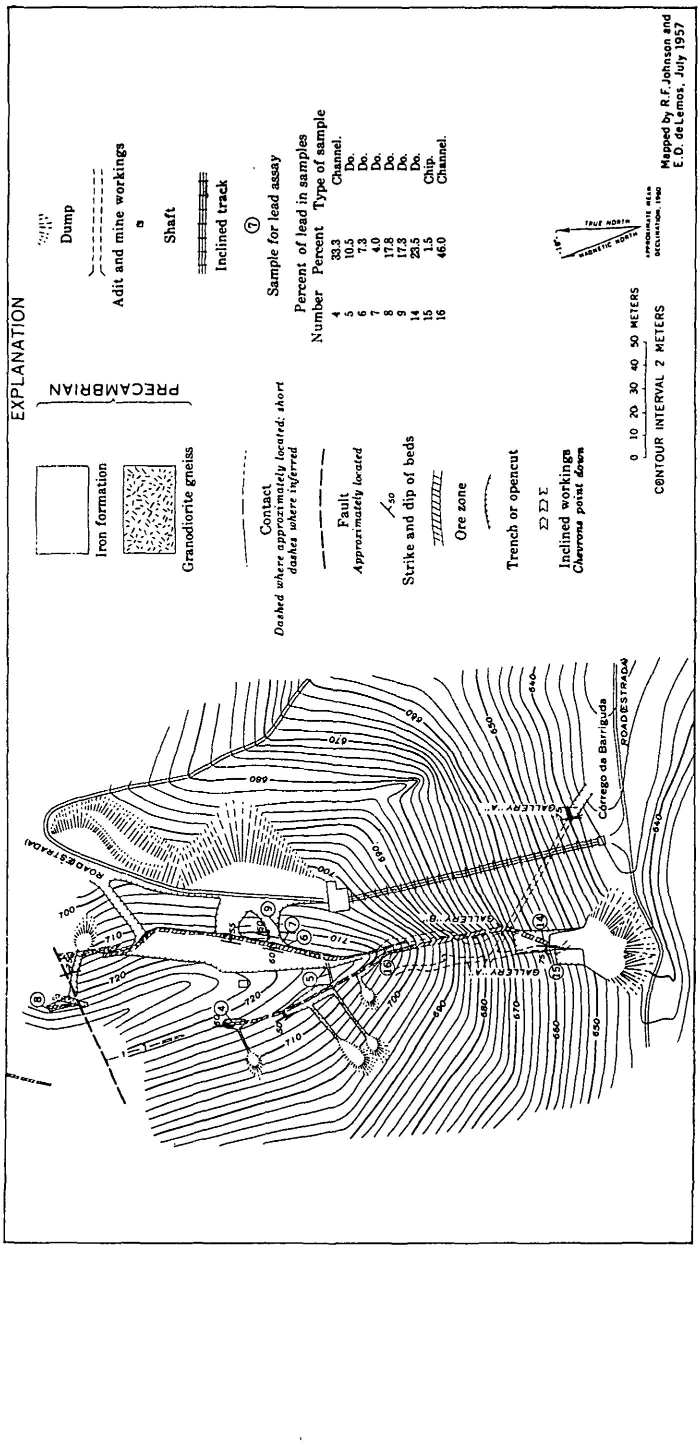

FIGURE 2.—Geologic map of Morro Pelado, Boquira mine.

Technical supervision was by Alfred J. Bodenlos, in charge of the U.S. Geological Survey nonferrous mineral investigations in Brazil.

REGIONAL GEOLOGY

Quartzite and quartz-muscovite schist are the predominant rocks in the area west of Boquira; amphibolite derived from mafic igneous rock is a minor constituent. Granitic gneiss underlies the valley east of Boquira. Iron formation,[1] garnet-bearing mica schist, and a fine-grained volcanic rock underlie a relatively narrow belt on the eastern front of the Serra de Macaúbas (pl. 1). The lead ore bodies of the Boquira mine are in iron formation. Quartzite and associated iron formation in central Bahia have been assigned to the Jacobina series (Oliveira and Leonardos, 1943, p. 127) thought to be late Precambrian in age.

ROCK UNITS

AREA WEST OF THE SERRA DE MACAÚBAS

The area west of and including the crestal area of the Serra de Macaúbas is characterized by broad north-trending ridges of quartzite from 2–5 km wide, separated by valleys underlain by quartz-mica schist, amphibolite, or by quartzite evidently less resistant to erosion. The regional strike of the bedded rocks is northward and the steep regional dip is to the west. East dips are locally present but they seem to represent local overturned flexures rather than flanks of major folds. Owing to the apparently very great stratigraphic thickness of quartz-rich rocks, a minimum of 11 km, it may be of interest to describe the section in some detail. A generalized section of the area is shown in pl. 1.

The crest of the Serra da Macaúbas is underlain by white hard vitreous quartzite from 700 to 1,000 m in outcrop width. Most beds dip westward but the eastern beds dip from 60° to 70° E. The vitreous quartzite of the serra shows only indistinct bedding and some crossbedding. West of the vitreous quartzite is a broad belt, 3.5 km wide, of gray well-bedded quartzite with a sugary texture; beds range from 20 centimeters (cm) to 1 m thick. Crossbedding is common in the rocks of this belt. The contact between the two types of quartzite is difficult to locate in the field but is shown by a distinct color difference on aerial photographs and in places is marked by a

[1] The term "iron formation" as used in this report refers to a unit of sedimentary rocks, usually banded, that contains abundant magnetite or hematite with quartz or amphibole. Thin beds of mica schist and quartzite interbedded with iron formation in the Boquira area were not mapped separately.

steepening of slopes in areas underlain by the vitreous quartzite. The gray quartzite dips from 30° to 75° W.

The gray quartzite is overlain by quartz-muscovite schist interbedded with quartzite. The rocks of this unit are less resistant to erosion and underlie a valley 2 km wide in the southern part of the mapped area and 1 km wide in the northern part. The beds dip west at angles greater than 65°. The eastern contact is well exposed and is located at the first appearance of schist. The western contact is not exposed but is located at the base of the Serra das Palmeiras; it is covered either by talus from the serra or by laterite formed on an old erosion surface lying from 40 to 50 m above the present valley bottom. The old erosion surface is partly dissected south of Mosquito, near the southern end of the valley, and remnants can also be seen in the Córrego das Palmeiras and the Córrego Taquarí.

Quartzite with a steep westward dip is present in the double ridge of the Serra das Palmeiras. The eastern ridge is the higher owing to the more massive nature of the quartzite; the massive quartzite does not form a continuous belt as in the Serra da Macaúbas. The total width of the Serra das Palmeiras ranges from 2.5 to 3 km, decreasing toward the north. The valley separating the ridges, less than 1 km wide, is underlain by quartzite but includes in its northern part a sill-like mafic intrusion, now amphibolite, more than 100 m thick.

The Serra das Palmeiras in the southern half of the mapped area is separated from the Serra da Vereda to the west by a broad valley 3 km wide underlain by thin-bedded quartzite which may contain some interbedded quartz-mica schist. The contact between the quartzite in the Serra das Palmeiras and the thin-bedded quartzite is at the base of a steep slope that is followed closely by the Córrego Taquarí. The valley narrows northward and, north of the bend of the Córrego Taquarí (pl. 1) is only 500 m wide. This northern valley is underlain in part by amphibolite derived from mafic igneous rock. The width of the valley north of Córrego Taquarí is due to topography and not to the decrease in stratigraphic thickness of the thin-bedded quartzite, as the distance between the quartzite of the Serra das Palmeiras and the distinctive quartzite of the Serra da Vereda remains constant.

The Serra da Vereda in the southern part of the mapped area is a prominent ridge 1,300 m wide underlain by hard vitreous quartzite. The quartzite thins to the north and the ridge becomes more subdued; the vitreous quartzite is only 250 m thick at the north border of the mapped area. Sky-blue dumortierite in fractures in along joints in the quartzite is a striking feature of the rock near the east base of the serra. Eastward dips are present in the Serra da Vereda but the contacts dip steeply westward. The eastern contact of the vitreous quartzite with the thin-bedded quartzite is located at the base of the serra. The contact appears conformable on the aerial photographs. The western contact with gray quartzite is disconformable in the southern part of the serra; bedding within the serra, as seen on aerial photographs, is truncated at the western contact. In the northern part of the serra the contact is apparently conformable.

Gray quartzite with a sugary texture similar to that on the west flank of the Serra de Macaúbas underlies the area west of the Serra da Vereda. The contact with the vitreous quartzite lies at the base of a steep slope; the western contact was not seen. The sugary-textured gray quartzite apparently extends for several km to the west and has a continuous westward dip as seen on the aerial photographs.

The rocks described above lie in a normal stratigraphic sequence with the most notable feature being a general thinning of the section northward. Individual beds can be traced for several km on the aerial photographs and the stratigraphic units are continuous across the entire mapped area. Nothing was seen to suggest that this section is repeated by isoclinal folds or by imbricate thrust faults.

EAST FLANK OF THE SERRA DE MACAÚBAS

The section on the east flank of the Serra de Macaúbas is mostly quartzite but also includes lenses of volcanic rock, quartz-biotite-garnet schist, iron formation, and carbonate rock. These lenses occur in a relatively narrow stratigraphic range in the quartzite. They are thickest west of Boquira where the total measures about 600 m. Elsewhere along the serra one or more of the rock types may be absent and in many places the sequence is missing and quartzite makes up the entire section. Carbonate beds crop out only near Contendas in the southern part of the mapped area (pl. 1). The layered rocks dip steeply eastward in contrast to the predominant westward dip of the quartzite west of the crest of the Serra de Macaúbas. The section is more than 1,500 m thick; the western contact is probably faulted and the eastern beds have been intruded by granitic rock.

The vitreous quartzite of the Serra de Macaúbas is bordered on the east by quartzite less resistant to erosion. The latter quartzite is white to light gray on fresh surfaces and darker gray or rust colored where weathered. The rock is fine to medium grained and is composed of rounded and subrounded quartz grains cemented by silica. Scattered flakes of sericite may be present. The thickness of this quartzite is not known but is at least 1,500 m. The western contact with the vitreous quartzite is located at a break in slope near the crest of the serra; it is believed to be a fault contact. Granitic rocks are emplaced in the valley of Riacho Brejo Grande and they probably intrude the quartzite near the base of the Serra de Macaúbas. North-trending ridges underlain by similar quartzite and surrounded by gneiss occur in the valley of Riacho Brejo Grande at distances of from 2 to 3 km from the base of the Serra de Macaúbas but their relation to the quartzite of the serra is not known.

Quartz-bearing volcanic flows are interbedded with the quartzite. A nearly continuous belt of volcanic rock extends from Tiros south to the vicinity of Brejo Grande (pl. 1). Float of similar rock that occurs near Pajeú, and boulders of volcanic rock seen near Contendas, indicate that flow rocks are present for at least 20 km along the east flank of the Serra de Macaúbas.

The flow rock is very fine grained and light to medium gray. In most places no bedding can be seen but the rock may be schistose near its upper contact. The maximum thickness of volcanic rock near Boquira is 250 m. Some zones contain abundant elliptical bodies of granular quartz that are thought to be amygdules. They have a random distribution in any given zone and range in length from a few millimeters to 2 cm. The rock is porphyritic; in thin section it consists of a groundmass of interlocking grains of quartz and plagioclase (An_{25-30}), from 0.01 to 0.10 millimeter in diameter, and it contains scattered phenocrysts of plagioclase, also An_{25-30}, about 1 millimeter (mm) in length. Small amounts of biotite may be present and magnetite is abundant, forming as much as 10 percent of one thin section. Apatite is a common accessory mineral and anatase was tentatively identified in one thin section. The mineral composition of the volcanic rock is that of dacite. It is an unusual dacite in that quartz phenocrysts are absent, that magnetite content is high, and in that the composition of plagioclase in both phenocrysts and groundmass is the same.

Quartz-biotite-garnet schist overlies the dacite in the area west of Morro Sobrado and Morro Pelado at the Boquira mine. The area underlain by this rock is lenticular, with a maximum width of 150 m and a length of 2 km. A lithologically similar schist crops out 1.7 km southwest of Boquira. The schist is greenish in hand specimen because of the presence of chlorite along the planes of schistosity. Red garnets about 1 mm in diameter occur individually and in clusters as much as 1 cm wide. Biotite and chlorite occur together as anastomosing layers enclosing quartz. Magnetite and pyrite are accessory minerals. Quartzite a few tens of meters thick overlies the schist and is itself overlain by iron formation.

Lenticular bodies of iron formation extend from Tiros south at least to the vicinity of Macaúbas, a distance of more than 30 kilometers (km). The lenses range from a few hundred meters to 2 km in length and are as much as 300 m thick. The iron formation is resistant to erosion and forms isolated hills and ridges that trend north, and rise from 100 to 200 m above the valley floor. The lens of iron formation within which the ore bodies of the Boquira mine occur is the largest in the region.

Itabirite, a laminated rock with alternating laminae of quartz and magnetite and (or) hematite is an important constituent of the iron formation. Equally important is an iron-rich laminated rock in which a brown-weathering amphibole occurs in place of quartz. The amphibole is nonpleochoric and is thought to be cummingtonite as it is optically positive with a 2V near 90°. Banding in this rock is less distinct where the iron oxide content is low; the rock grades from a well-banded rock to massive amphibole-bearing rock containing scattered grains of magnetite.

Other rock types within the iron formation, not mapped separately, (pl. 1) are chlorite schist, quartzite, and quartz-mica schist. These rocks occur as thin discontinuous bands within the iron-rich rocks. The quartz-mica schist is the most important of these economically as it is the most favorable host rock for the ore bodies. The schist belts range from 1 to 30 m in thickness and from a few tens of meters to more than 1 km in length.

Carbonate rocks crop out near Contendas, in the southeast corner of the mapped area (pl. 1). The beds occur in a lens several hundred meters long and as much as 70 m thick; contacts with the surrounding quartzite are concealed. Some beds have been metamorphosed to a mixture of calc-silicate minerals with interstitial carbonate but others are coarsely crystalline marble containing small amounts of calc-silicate minerals. The carbonate is principally dolomite; calcite is present in small amounts. Bedding is obscure owing to metamorphism and so the thickness of individual beds is not known.

The layered rocks on the east side of the Serra de Macaúbas, like those on the west side, apparently lie in a normal stratigraphic sequence. The different lithology, however, precludes any correlation of the rocks, although the opposing dips on the two sides of the serra suggest a fold. The structural relations between the two stratigraphic sections is discussed in the following section. The writer thinks that the sequence east of the serra is the older of the two.

REGIONAL STRATIGRAPHIC CORRELATION

Of the stratigraphic sections described in other parts of central Bahia only the section in the Serra de Jacobina (Branner, 1910c) bears any resemblance to the section at Boquira. In general the Serra de Jacobina consists of four parallel ridges of quartzite separated by valleys cut in talcose schist (Branner, 1910c, p. 387). The serra is about 6,000 m wide and all the rocks dip steeply east. Conglomerate is common on the west side of the serra and manganiferous schist occurs on the east side; iron formation is said to be present (Oliveira and Leonardos, 1943, p. 127). The conglomerate was deposited on gneiss; gneiss also crops out east of the range but the contact with the manganiferous schist is not exposed. Branner discussed three hypotheses that had been proposed to explain the structure: isoclinal folding, a series of parallel faults, and a large fault on the east side of the range to explain the reappearance of the gneiss. He did not find any of the hypotheses entirely satisfactory, but did not propose any other. Branner did not name the sequence, but it since has been designated as the Jacobina series by Oliveira and Leonardos (1945, p. 127–132).

Branner (1910a, b) found the serras west of the Serra de Jacobina to be capped by from 90 to 125 m of nearly flat lying sandstone and quartzite that he named the Tombador series. This series lies directly on gneiss in the Serra de Tombador, a range adjacent and parallel to the Serra de Jacobina. Farther west, in the Serra do Mulato, the Tombador sandstone lies on black eruptive rocks which in turn lie on hornblende schist (Branner, 1910a, p. 260). Branner thought that the rocks of the Tombador series are younger than the rocks of the Serra de Jacobina.

The area known as the Chapada Diamantina, about 100 km east of Boquira, is underlain by folded quartzite and conglomerate about 500 m thick (Derby, 1906, p. 386). Derby divided the rocks into two groups, the Paraguassú group at the base and the Lavras group above. Thick diamond-bearing conglomerate is at the base of the Lavras group.

Oliveira and Leonardos (1943, p. 127–132) attempt to correlate the various groups and series. They believe that the Jacobina series, as described by Branner, is the oldest series of sedimentary rocks lying on the Archean basement. The series is thought to be late Precambrian in age and is correlated by them with the Minas series of the State of Minas Gerais. (See also Dorr, and others 1957.) The Tombador series is correlated with the Paraguassú group (called Paraguassú series by Oliveira and Leonardos, p. 131) and is also late Precambian. The same authors opine that the Lavras group is either Cambrian or Precambrian. Kegel and Pontes (1957, p. 9) however, suggest that the Tombador series is much younger, possibly Devonian. Should this latter age determination be valid, the Tombador series

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cannot be correlated with the Paraguassú series. It is evident that the stratigraphy for central Bahia is not established with certainty.

The iron formation and associated rocks in the Boquira district can probably be correlated with the Jacobina series. To the writer's knowledge silicic volcanic rocks have not been described elsewhere in Brazil in rocks of this series. The variation in the amount of carbonate rocks in the series is also of interest. Branner (1910c) does not mention carbonate rocks in the Serra de Jacobina and at Boquira they only form a small part of the section. In the Serra das Éguas however, 170 km southeast of Boquira, (Bodenlos, 1954, p. 99) dolomite with a minimum thickness of 450 m is overlain by several hundred meters of quartzite containing a few meters of interbedded iron formation. The presence of iron formation and quartzite suggest that the Serra des Éguas section may be equivalent in part to the Jacobina series.

Further regional geologic mapping is needed before the rocks west of the crest of the Serra de Macaúbas can be correlated with confidence. The extremely thick section of quartzitic rocks, more than 11,000 m, seems too great to have been deposited as a single series. Kay (1957, p. 671–672) lists the maximum thicknesses of sedimentary sequence in many localities and emphasizes that measurements of some of the thickest sections contain errors. It is possible that rocks of the Jacobina series, the Paraguassú series and the Lavras group are all represented in the Boquira section.

INTRUSIVE ROCKS

The metasedimentary rocks at Boquira are intruded by dikes and a pear-shaped (in ground plan) intrusion of silicic porphyry, by likes of grandodiorite with a gneissic texture, and by dikes of amphibolite. Gneiss underlies the valley of the Riacho Brejo Grande.

The geniss in the area east of the serra was not studied in detail, but in general it is a light-colored medium-grained rock composed of quartz, plagioclase, potassium feldspar, and biotite. Foliation commonly is well developed. The gneiss is thought to have been originally intrusive into the metasedimentary rocks because of the irregular nature of the contact between the two (pl. 1). The presence in the metasedimentary rocks of dikes of granodiorite with a gneissic texture similar in appearance to the gneiss in the valley, tends to confirm the presence of a large intrusive mass.

The granodiorite dikes are exposed in mine workings on Morro Pelado (fig. 2) and Morro Sobrado; three dikes are known on Morro Pelado and one on Morro Sobrado. They range in thickness from a few centimeters to 3 m, and are of unknown length as they cannot be traced beyond the mine workings. As seen in thin section one dike is composed of 50 percent albite (An_7), 45 percent quartz, and 5 percent biotite; magnetite and apatite are rare accessory minerals. Foliation in this rock is marked by preferred orientation of biotite.

A quartz-rich porphyry intrusion occurs 700 m west of Tiros (pl. 1) along the projected strike of the volcanic horizon, and a dike of similar rock crops out at the base of the Serra de Macaúbas just north of the mapped area. The porphyry west of Tiros is pear-shaped in ground plan and is 375 m long in a north-south direction and 200 m wide. The rock is light gray and consists of plagioclase phenocrysts in a fine-grained groundmass; the phenocrysts make up about 10 percent of the rock. In thin section the rock is seen to contain plagioclase (An_{10}) phenocrysts as much as 5 mm long in a microcrystalline groundmass of quartz, plagioclase (composition not determined), microcline, epidote, and magnetite. The phenocrysts may be single crystals or they may be aggregates consisting of several grains with varied orientation. Quartz or microcline grains about 0.1 mm in diameter form incomplete borders around some phenocrysts but not around others. Epidote occurs as tiny grains scattered throughout the rock. The porphyry dike north of the mapped area is dark gray. It contains the same minerals as the mass west of Tiros but also contains carbonate. Magnetite is more abundant in the porphyry dike and may account for the dark color. These porphyritic rocks appear to be metamorphosed rhyodacites (Williams, Turner, and Gilbert, 1954, p. 126).

A tabular mass of amphibolite crops out 1.5 km southwest of Boquira near the source of the stream that supplies the town with water. Float of similar material is common along the Serra de Macaúbas; the rock was not seen in mine workings. The amphibolite is dark green where fresh and contains amphibole, plagioclase, and magnetite. The amphibolite is probably derived from mafic igneous rock (Guild, 1957, p. 28).

STRUCTURE

The rocks in the mapped area are both folded and faulted. The rocks dip at moderate to steep angles. Those west of the serra constitute one flank of a fold, as no evidence was seen to indicate repetition of the section (pl. 1). The rocks are cut by both oblique and strike faults. A scarp that has developed on the east flank of the Serra de Macaúbas may be due either to differential erosion or to faulting.

The most prominent faults are oblique faults that trend at high angles to the strike of the bedded rocks. The largest faults of this type are north of Pajeú (pl. 1). One can be followed from Pajeú westward to São João; its trace is curved; the strike of the fault is northeast at São João and east at Pajeú. The rocks north of the fault have been offset about 1,000 m along this fault with the north side displaced eastward relative to the south side. A smaller fault, 1,750 m north of the fault at Pajeú and parallel to it, has offset the rocks about 200 m with the north side displaced westward relative to the south side. Still further north, two north-northeast-striking faults cut the bedded rocks with the east side of each fault displaced northward relative to the west side. The offset could only be measured on the easternmost fault where the vitreous quartzite of the Serra de Macaúbas is offset about 500 m. Other oblique faults are shown on plate 1. They were mapped from aerial photographs and are marked by offsets of the contacts of the metasedimentary rocks. Most faults strike northeast but four are shown that strike northwest.

Faults that strike nearly parallel to the strike of the bedded rocks occur in the Serra de Macaúbas. The contact between the vitreous quartzite of the serra and the sugary-textured quartzite to the east is thought to be a fault. Bedding in the vitreous quartzite is truncated at this contact west of Brejo Grande (pl. 1) and the dacite northwest of Boquira is in contact with vitreous quartzite whereas it is normally separated from the vitreous quartzite by 200 m of sugary-textured quartzite. Physiographic expression suggests that the inferred fault dips steeply eastward and for stratigraphic reasons is thought to be a reverse fault, that is, the east side is displaced upward relative to the west side. This type of movement is postulated on the assumption that the iron formation and associated rocks are older than the rocks that lie west of the Serra de Macaúbas. As stated previously the section west of the serra does not seem to be repeated so a normal fault of unreasonably large displacement, over 11,000 m, would be needed to bring the rocks east of the serra into their present position.

Smaller reverse faults nearly parallel to the one described were mapped northwest of Boquira and southwest of Brejo Grande (pl. 1). Iron formation and underlying dacite and quartzite are faulted against the iron formation of Morro Sobrado northwest of Boquira and the vitreous quartzite southwest of Brejo Grande may be repeated by movement on a reverse fault.

The structual relationship between the bedded rocks on opposite sides of the crest of the Serra de Macaúbas cannot be determined on the basis of the present work. The fault relation described above and shown on the map and section (pl. 1) is one possibility. An alternative explanation is that faulting is local and that the beds on the east flank of the serra are older and are overturned. Either explanation implies compressive forces acting in an east-west direction.

The internal structure of the gneiss that underlies the valley of Riacho Brejo Grande and its structural relation with the metasedimentary rocks were not studied. The gneiss appears to be intrusive into the bedded rocks. (See p. 21.)

L. C. King (1956, p. 202), in the course of his physiographic studies in Brazil crossed the Paramirim valley and described it as a typical rift valley that is latest Pliocene or Pleistocene in age. He did not describe the western scarp of the rift but it must certainly coincide with the scarp on the east side of the Serra de Macaúbas, as there is no other continuous north-trending scarp between the Rio Paramirim and the Rio São Francisco. The present study did not cover a large enough area to check King's observations. However, nothing was seen in the Boquira area suggestive of tensional faults. An alternative hypothesis, that the scarp is erosional, could not be ruled out in the area studied. The sugary-textured quartzite could be less resistant to erosion than either the vitreous quartzite that forms the crest of the Serra de Macaúbas, or the iron formation that forms a line of lower hills that trend parallel to the serra. The gneiss can be interpreted to be even less resistant to weathering and underlies the valley. This erosional pattern is similar to that in the Serra de Jacobina (Branner, 1910c, p. 388) and in central Minas Gerais (Harder and Chamberlin, 1915, Guild, 1957, p. 40–41). Perhaps the location of the valley can be explained by a combination of faulting and differential erosion.

ORE DEPOSITS

HISTORY AND PRODUCTION

Lead minerals at Boquira were discovered in 1952 when samples of a heavy rock from Morro Pelado were brought to the attention of Sr. Macario de Freitas of Boquira. He took the samples to Sr. Antenor da Silva, a pharmacist in Macaúbas, who succeeded in reducing metallic lead from the samples in a home-made furnace. Prospecting, carried on by Sr. Antenor, proved the presence of high-grade ore in quantity large enough to be of interest. The Tavora family, of Rio de Janeiro, D.F., invested in the property and in 1954, together with Sr. Antenor and Sr. Macario, formed a company, Mineração Boquira Ltda., S.A.

The year 1955 was spent in preliminary work. Boquira lay in an isolated area where comparatively primitive agriculture was the only industry. Roads into the area were nearly impassable. To gain access to the deposits that are in steep hilly country from 2 to 3 km from Boquira, and to assure transit on the road from Boquira to

Caetité, the company purchased a motor grader, a scraper, and three bulldozers for road work. A new road, 6 km long, was started near Caetité to provide better access to the Federal highway, and the remainder of the existing road was improved. At the mine, development began at Morro Pelado. Water was piped from a spring about 1 km distant. The first ore mined was transported by mules and jeep. An inclined track with wooden rails was then built from the outcrop of the ore body to the base of Morro Pelado as trucks could not climb the steep slope. Temporary office space was procured in Boquira and work began on permanent offices, shops, and a diesel power station. No skilled labor was available and even the use of a shovel had to be taught to the local laborers as all agricultural work is done with a large hoe and a "foice," a billhook with a slightly curved blade and a long wooden handle used for chopping brush and small trees. Supervision was by the owners with an occasional visit by a consultant. Technical help was difficult to find; it was not until 1957 that a resident manager and resident engineer were obtained.

The early mining, which began in 1956, was from open pits. The surface ore is massive and occurs in lumps of from a few kilograms (kg) to over 100 kg in weight enclosed in a matrix of soft material. The larger lumps of ore were broken with sledge hammers and the material was then transported on workers heads, in wheelbarrows, or by jeep to the head of the inclined track where it was lowered and unloaded by hand onto a stockpile, or directly onto a truck. Fines, waste rock, and overburden were scraped out with bulldozers, with little attempt at separation. Some idea of the richness of the ore is shown by the fact that the metal content of the dumps derived from the large ore body on Morro Pelado is about 20 percent lead. Drilling and blasting were seldom necessary but two portable compressors and jackhammers were available when needed. The company purchased two dump trucks for use in the mine area.

The ore was shipped by truck from Boquira to São Paulo, a distance of nearly 2,000 km. All trucking was by contract and the company was able to take advantages of the fact that more freight moved north than south on the main north-south highway that passes through Vitória da Conquista. Consequently truck owners welcomed the opportunity of having a payload for the trip south and freight rates were fairly low. Even so the rate was about 4 cruzeiros per kg between the mine and São Paulo (about $50.00 per metric ton at the exchange rate prevailing early in 1957). In the first months of operation, trucks carrying ore from Boquira to Vitória da Conquista were delayed by the poor condition of the road, which resulted in irregular shipments. To avoid this, the company built a depot in Vitória da Conquista for stockpiling ore, and contracted its shipments with a truck owner in Vitória da Conquista who had a fleet of 5-ton trucks available for this purpose; a regular shipping schedule was established. The ore is loaded at the depot into larger trucks for the much longer haul to São Paulo.

The ore was purchased by the Cia. Acumuladores Prest-O-Lite, a manufacturer of storage batteries. The Prest-O-Lite company did not have a sintering plant and could not use sulfide ore. As a result of this and high costs, only oxidized ore with a metal content of over 45 percent lead was shipped. The Cia. Acumuladores Prest-O-Lite purchased the property in November 1957 and began to build a concentrating plant with a capacity of 400 tons per day, to handle both oxidized and sulfide ores. The company also started construction of a lead smelter at Santo Amaro near Salvador.

The Cia. Plumbum, S.A., a lead mining and smelting company with mines in the states of São Paulo and Paraná, begain a prospecting program in the Boquira area in the latter part of 1957. They obtained concessions and began prospecting near Tiros on the northern extension of the Morro Pelado ore zones. They plan to extend their search for ore over a wider area along the front of the Serra de Macaúbas; geochemical techniques will be used as an aid to prospecting. The presence of two operating companies in a new mining district has resulted in considerable confusion regarding mineral rights, concession boundaries, water rights, and rights-of-way for roads, pipelines, and powerlines.

Production from 1956 to December 1957 was about 10,000 metric tons of ore with a grade of about 45 percent lead. Production varied from less than 100 to nearly 2,000 tons of ore per month; the rate was largely dependent on the ability to move the ore to Vitória da Conquista. All production through 1957 came from opencuts and shallow shafts. Development was not carried on much ahead of ore extraction. A crosscut adit was begun at the base of Morro Pelado (fig. 2) in August 1957, and the vein was cut 71 m from the portal. More than 130 m of drifting on the vein, on two levels, was completed by June 1958.

GENERAL DESCRIPTION

The lead ore bodies occur in veins that in most places conform to the bedding of the enclosing rocks. The veins are either in schist lenses, that are interbedded with iron formation, or occupy sheared zones within the iron formation. Granodiorite dikes with a gneissic texture occur near some veins and on Morro Pelado (fig. 2) a dike locally forms one wall of a vein.

The primary sulfide minerals are galena, sphalerite, and pyrite; oxidized ore minerals are cerussite and smithsonite with minor quantities of pyromorphite; anglesite also is reported to be present. The oxidized ore is enclosed in an earthy gangue; the sulfide minerals are in a gangue of quartz, actinolite, and small amounts of chlorite.

The ore bodies are tabular in shape They range in size from pockets that contain a few tons of ore to bodies 200 m long, 2 m thick and at least 80 m in vertical extent. The grade of the oxidized ore bodies ranges from 20 to 50 percent lead; zinc is lacking in such ore. Sulfide ore contains about 20 percent lead and as much as 13 percent zinc.

Wallrock is altered by silicification and recrystallization of the iron formation and (or) the development of green clay and actinolite in the iron formation. Alteration may extend from 2 to 3 m into the walls or may be weak or absent. In the zone of weathering cerrussite may occur in varied amounts for distances as much as 10 m from the vein but the wallrock in underground workings seems to contain small amounts or no lead minerals.

The ore minerals were deposited from hydrothermal solutions from an unknown source; the solutions possibly were related to the intrusions of granodiorite or rhyodacite. The deposits are classified as hypothermal.

MINERALOGY

The minerals related to the ore deposits are grouped as hypogene, minerals deposited by ore-forming solutions, and as supergene, minerals derived by weathering processes, and gangue minerals. Little work was done on the hypogene minerals as unweathered ore was found only after detailed fieldwork was completed, so the list may be incomplete. Pyrite is described with the ore minerals because of its close genetic association with them.

HYPOGENE ORE MINERALS

Galena, PbS.—Galena is the only hypogene lead mineral found at Boquira. It occurs as discrete, closely packed grains and in braided veinlets in greenish schistose vein matter, and is sparingly disseminated in the wallrock of some ore bodies. It may be the only sulfide or may be intergrown with sphalerite and rarely with pyrite. The steel-gray cubic crystals range from 0.1 to 1 mm in size. Galena has been replaced by cerussite and the two minerals may occur together in any proportion.

Pyrite, FeS_2.—Pyrite is a rare mineral in Boquira ore. Massive sulfide ore contains only an occasional grain of pyrite but it is more common in veinlets in schistose gangue where it is intergrown with galena and sphalerite. The pyrite in the ore zone does not show crystal faces but cubic crystals 3 mm on an edge were seen in a quartz veinlet in the wallrock west of the ore zone in Gallery A (fig. 2).

Sphalerite, ZnS.—Tiny grains of brown sphalerite are intergrown with galena. The sphalerite is difficult to see in hand specimen but it is visible on sawed, unpolished surfaces of ore. The galena-sphalerite ratio appears to be variable with galena the most abundant mineral. Sphalerite alters to smithsonite in the early stages of weathering; galena and smithsonite are commonly associated indicating that the sphalerite is more susceptible to weathering.

SUPERGENE ORE MINERALS

Anglesite, $PbSO_4$.—Anglesite is reported to be locally abundant by N. Miagkoff (1957, oral communication) but it was not seen by the writer.

Cerussite, $PbCO_3$.—Cerussite has been the most important ore mineral mined at Boquira. It occurs in large massive lumps, in disseminated grains, and as crystals. The massive cerussite is commonly dark gray but may be brown or nearly white. The brown iron-stained cerussite is surficial; it is nondescript in appearance and is distinguished from country rock chiefly by its higher specific gravity. Massive cerussite commonly contains disseminated grains of galena. Granular cerussite accompanies the lump ore and is also disseminated in the adjacent schist or iron formation. Tabular white cerussite crystals as much as 1 cm long occur in vugs in the ore. Veinlets of cerussite with lamellar texture about 1 cm thick are common adjacent to massive ore on Morro Sobrado; the lamellar texture is due to the partial development of crystals oriented perpendicular to the vein walls.

Pyromorphite, $PbClPb_4(PO_4)_3$.—A yellow mineral, both massive and as stubby hexagonal crystals associated with cerussite, is thought to be pyromorphite but this has not been confirmed. Mr. Miagkoff (1957, oral communication) states that pyromorphite is locally abundant in the ore zone.

Smithsonite, $ZnCO_3$.—A white powdery carbonate intergrown with galena is thought to be smithsonite. Mineral grain studies showed the highest refractive index of the mineral to be more than 1.80, the highest oil available, and the lowest index to be about 1.64. This is in the rhodochrosite, siderite, smithsonite range (Larsen and Berman, 1934, p. 229) and, as sphalerite is known to be present, the mineral is thought to be smithsonite. Zinc minerals have been nearly completely removed from the weathered parts of the ore bodies; only traces of zinc are reported.

GANGUE MINERALS

Actinolite, $Ca_2(Mg, Fe)_5(Si_4O_{11})(OH)_2$.—Greenish amphibole is one of the most abundant constituents of the gangue and also occurs in the hydrothermally altered wallrock adjacent to the vein in Gallery A. The mineral in the vein has optical properties that indicate that it belongs in the tremolite–actinolite series. The mineral grains are prismatic with ragged terminations and occur singly or in aggregates. Most crystals are less than 1 mm long and from 0.1 to 0.2 mm in diameter.

Biotite, $H_2K(Mg,Fe)_3Al(SiO_4)_3$.—A quartz vein with a dark-brown biotite selvage cuts the iron formation 20 meters east of the ore zone in Gallery A. Few biotite flakes are more than 0.5 mm in diameter. The vein also contains streaks and clots of biotite in the quartz.

Carbonate.—A carbonate of unknown composition, either calcite or dolomite, is a minor constituent of the gangue and altered wallrock. It occurs in veinlets less than 0.5 mm thick and as rare individual grains. The veinlets cut across all other structures so the carbonate is the youngest mineral deposited or may be secondary.

Chalcedony, SiO_2.—Veinlets of banded cryptocrystalline silica as much as 1 cm in thickness cut the iron formation and the wallrocks of the ore zone. Color banding in white, yellow, and brown is conspicuous in the veinlets. The veinlets are most abundant on Morro Sobrado. They are not common in the ore zones and are not known to be related to ore formation.

Chlorite, complex silicates of Al, Mg, Fe, and H.—Dark-green micaceous chlorite occurs as clots and in bands from 4 to 5 cm thick and of unknown length both within and on the margins of the ore zone in Gallery A. Chlorite is also seen in thin sections of the vein as an alteration product of actinolite. A small dike 20 cm wide is exposed in Gallery A and is largely composed of chlorite.

Epidote, $Ca(Al,Fe)(OH)Al_2(SiO_4)_3$.—Epidote is a rare alteration mineral in the wallrock of the ore where it occurs in tiny discrete grains. Crystals as much as 3 mm long were seen in a quartz vein about 20 m east of the ore zone in Gallery A.

Limonite, hydrated iron oxide.—Limonite is used as a field term for yellow, brown, or red secondary iron oxides that fill fractures and coat exposed rock surfaces in the zone of oxidation. The mineral is structureless at Boquira and occurs as a fine yellow powder in fractures or as a hard surface coating. The powder was examined microscopically in a search for plumbojarosite but none was found.

Magnetite, Fe_3O_4.—Magnetite grains are common in the gangue. The grains are about the same size and appearance as grains in the iron formation so it could not be determined if the magnetite is of hydrothermal origin or derived from the adjacent iron formation.

Quartz, SiO_2.—Quartz is the most important gangue mineral and also occurs in silicified wallrock. The quartz occurs as fine-grained masses intergrown with actinolite. Massive vein quartz is not common. Even the vein cut by the adit east of the ore zone (fig. 2) is made up of granular quartz rather than massive milky quartz. Individual quartz grains are as much as 3 mm in diameter but the average size is less than 1 mm; the quartz in the wallrock is finer grained than that in the vein. A vein of milky vein quartz about 3 cm thick occurs along a fault west of the ore zone in the adit.

Tourmaline, complex borosilicate of Al, Fe, *and alkalis.*—Needles of black tourmaline as much as 2 mm long occur in the quartz vein east of the ore zone (fig. 2).

DESCRIPTION OF ORE BODIES

The schist lenses and fault zones at Boquira do not contain ore along their full extent. The ore shoots or ore bodies are lenticular and are separated along the veins by low-grade or barren material.

The largest ore bodies are on Morro Pelado (fig. 2) where cerussite has been mined from an ore zone 200 m long and from 1 to 3 m thick that extends north from Côrrego Barriguda. The ore zone splits near the top of Morro Pelado, where both segments have been mined from surface cuts. Ore is continuous from the côrrego to the top of the ridge, a vertical distance of about 80 m. The ore zone and enclosing iron formation dip steeply eastward on the crest of Morro Pelado. The dip steepens with depth and slightly above the level of Gallery B the dip changes to 75° W. This west dip continues downward at least as far as Gallery A as shown by the location of the level working with relation to the surface trace of the vein (fig. 2). Drifts in Gallery A and Gallery B (fig. 2) follow the vein for 80 m and 50 m respectively. The vein in the galleries ranges from 0.5 to 2.5 m in thickness.

The main ore body on Morro Pelado is in a fault zone in iron formation. The west wall of the ore is a fault plane that is covered by a very thin layer of fault gauge, at most 1 cm thick. The fault follows bedding planes except for a short distance about Gallery B where it cuts across the bedding to form the west split of the ore zone. The southern end of the east split of the ore zone has not been explored and its relation to the west split is not clear; there seems to be only one vein at the level of Gallery A.

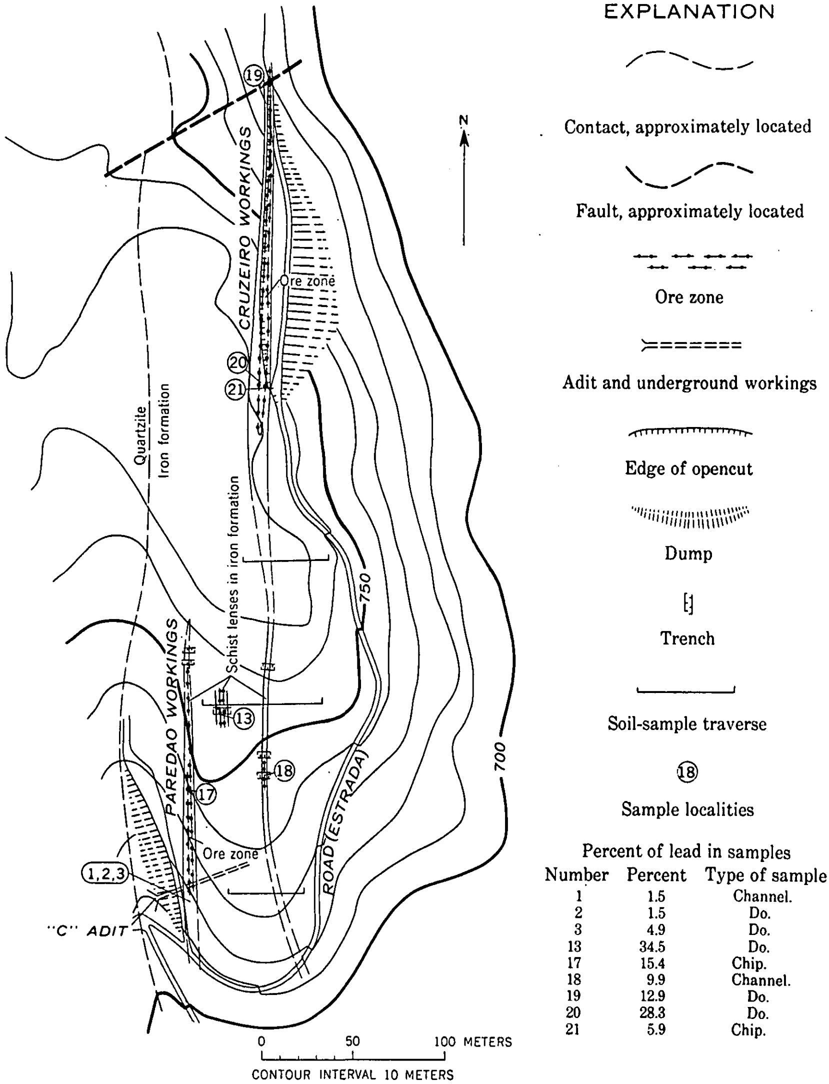
Several small ore bodies have been mined on Morro Pelado north of the main workings (pl. 2). Some are on a linear trend and indicate that the ore zone is continuous at least as far as Peladinho. Cia. Plumbum, S.A., has cut a trench across the strike of the ore zone 60 meters north of the Peladinho workings. Schist and low-grade ore were found in that trench but massive ore was absent. An ore zone 150 m southeast of Peladinho trends N. 20° E. for a distance of more than 50 m and then turns sharply to N. 75° E. Fifty meters beyond that bend it turns north again and enters property owned by Cia. Plumbum, S.A. The reason for the abrupt bend could not be determined from surface exposures.

Ore has been mined from both flanks of Morro Cruzeiro (fig. 3). The Cruzeiro workings on the east flank expose an ore body 200 m long and from 1 to 3 m thick; the known vertical extent is about 45 m. The ore is in a belt of schist from 8 to 10 m thick that appears to extend the entire length of Morro Cruzeiro. Not all the belt is mineralized but some ore has been shipped from the northernmost exposure near the base of the morro, and sample number 18 (fig. 3), taken about 200 m south of the principal ore body, showed a lead content of 9.9 percent. Galena cropped out at the surface in parts of the Cruzeiro ore body.

The Paredão workings on the west flank of Morro Cruzeiro follow an ore zone about 100 m long and as much as 4 m thick. The cerussite is spotty in occurrence and not much work has been done on the ore body. Gallery C is being driven to intersect the Cruzeiro ore zone at depth and has crossed the Paredão vein near its south end; about 30 cm of massive cerussite was found in an ore zone about 2 m thick. A third schist belt is known to lie between the Paredão and Cruzeiro belts; trenching on this belt has shown it to be mineralized, but it has not been explored.

Some ore has been obtained from trenches and opencuts near the north end of Morro Sobrado. The ore follows narrow schistose bands in the iron formation that may mark fault zones. A more promising ore zone lies near the crest of the ridge of Morro Sobrado about 800 m south of the portal of Gallery A (pl. 2). The area is difficult of access and has not been developed, but the ore zone can be traced on the surface for about 100 m and a trench near the south end exposes 4 meters of ore that assayed 37 percent lead.

Some idea of the grade of ore being mined in 1957 and of the amount of material that can be concentrated can be obtained from figures 2 and 3, which show the location and grade of samples taken during the course of the mapping. Most samples were taken from abandoned workings on the margins or ends of ore bodies. Samples 16, 17, 19 and 20 are from faces that were being mined in 1957 and range from 12.9 to 46.0 percent lead. Sample 16 is of direct shipping



Percent of lead in samples

Number	Percent	Type of sample
1	1.5	Channel.
2	1.5	Do.
3	4.9	Do.
13	34.5	Do.
17	15.4	Chip.
18	9.9	Channel.
19	12.9	Do.
20	28.3	Do.
21	5.9	Chip.

FIGURE 3.—Sketch map of Morro Cruzeiro, Boquira mine, showing location of samples, and location of soil-sampling traverses for geochemical prospecting.

ore; hand sorting of ore was required at the other localities to produce high-grade shipping material. Samples of the iron formation adjacent to the ore bodies are of much lower grade, as shown by samples 6 and 7, on Morro Pelado (fig. 4) and sample 21 on Morro Cruzeiro (fig. 3), all containing less than 7 percent lead. Samples 5 (10.5 percent) and 9 (17.3 percent lead), however, taken in iron formation on Morro Pelado 5 and 10 meters respectively from the ore zone are of higher grade and can be considered as concentrating ore.

Detailed sampling will be required on the margins of the ore bodies to determine the mining width of surficial material. The walls in Gallery A, in sulfide ore, are too low in grade to be of commercial interest.

ALTERED WALLROCK

The wallrocks of the ore bodies have been altered by hydrothermal solutions. The alteration does not seem to be continuous along the ore zones and even adjacent to the ore bodies it may be weak or absent. A distinctive surface feature on Morro Pelado and Morro Sobrado is the presence of a green and black banded rock from 1 to 2 m thick adjacent to the ore. The green color of this rock is due to the presence of a yellow-green clay mineral and of actinolite in the silicate laminae of the iron formation; the rock also contains carbonate veinlets. A similar type of altered rock is present in the iron formation north of Contendas. The alteration in this area is more widespread and is thought to be related to the intrusion of granitic rocks that are in contact with the iron formation. Small amounts of cerussite occur in the altered rock indicating that there is some relation between this type of alteration and ore deposition. The green and black banding is present but not prominent in Gallery A near the vein; the green color may be intensified by weathering.

A belt of dark-green rock as much as 1 m thick and composed entirely of coarse interlocking grains of hornblende lies on the east wall of the ore zone in Gallery A. The contact of this rock with iron formation is not sharp but consists of alternating thin layers of hornblende and fine-grained silicate minerals and magnetite. The hornblende is thought to be hydrothermal in origin rather than to be in a basic dike.

Locally on Morro Pelado the wallrock of the vein is silicified and the amphibole in the iron formation is recrystallized into a felted mass of acicular crystals resulting in a very hard tough rock. This type of alteration is also thought to be due to hydrothermal solutions, but the reason for its limited extent is not known.

ORIGIN AND CLASSIFICATION

The Boquira ore bodies were formed by minerals deposited from hydrothermal solutions. Deposition was by fracture filling and by replacement; the veinlets of galena represent filled fractures and replacement must have been important in the formation of the massive lenses of sulfides. The origin of the hydrothermal solutions is not known.

The deposits are classified as hypothermal in the pressure–temperature classification of Lindgren (1933, p. 637). The sulfide association of galena, sphalerite, and pyrite is not diagnostic as it occurs over a wide range of temperatures and pressures, but, according to Lindgren, the presence of amphibole in the gangue is diagnostic of hypothermal conditions. The vein matter is schistose and compact with no obvious banding; ore minerals are fine to medium grained. The actinolite could be a metamorphic mineral rather than hydrothermal but its presence indicates that hypothermal conditions existed at some time within the veins.

The age of mineralization is not known. Both the granodiorite and dacite are premetamorphic. If the veins are associated with the igneous rocks, as seems probable, they also could be premetamorphic.

RESERVES

Surface and underground showings of lead at Boquira are on a large enough scale to indicate the presence of a lead deposit of considerable economic importance. The mine, with an estimated lead production for 1957 of 3,500 metric tons, was the second largest producer of lead in Brazil in that year. Production declined during the first months of 1958, when the Cia. Acumuladores Prest-O-Lite put most effort into mine development and into construction of a concentrating plant of 400 tons capacity; it should increase rapidly when the plant is brought into operation. Not enough underground work has been done to enable estimates of reserves of measured ore to be made, but estimates of indicated ore and tonnages of surficial ore per meter of depth are possible at two ore bodies.

The ore body 200 m long on Morro Pelado is exposed on the surface and for 80 m in Gallery A, 80 m below the surface outcrops. The average thickness of the vein is 2 m and the average grade is 20 percent lead. The zinc content will not be considered as too little is known of its abundance; the supergene ore has only traces of zinc. The specific gravity of the ore is estimated to be 3.5, based on the lead content and the specific gravity of the gangue minerals. Using the above data and assuming that the vein splits above Gallery B it is estimated that the principal Morro Pelado ore bodies contain 110,000 tons of indicated ore above Gallery A. In addition, there is about 30,000 tons of dump material, from which grab samples assay about 20 percent lead. An additional source of ore is on Morro Pelado. Samples 5 and 9 (fig. 2) taken 5 and 10 m from the vein assayed 10.9 and 17.3 percent lead respectively. The content of the iron formation near the vein is spotty as shown by the low assay values of samples 6 and 7 (7.3 and 4.0 percent) but it may be possible to develop a low-grade ore body that could be mined from the surface.

Calculations of ore tonnage per meter of depth of the Cruzeiro ore body on Morro Cruzeiro, based on the surface length of 200 m, give

1,400 tons of 20 percent lead ore per meter of depth for the 2 m thickness of the vein. A figure of 4,200 tons of 10.5 percent ore per meter of depth is obtained if the grade (5.9 percent) and width (4 m) of sample 21 (fig. 3) is representative. A summary of reserve data is given in the following table:

Indicated and inferred ore reserves at Boquira

Ore body	Indicated ore (metric tons)	Grade (percent lead)	Inferred ore (metric tons per meter of depth)	Grade (percent lead)
Morro Pelado	[1] 140,000	20	5,600	11
Cruzeiro			4,200	10.5
Paredão			1,400	
Sobrado			1,400	
Peladinho			400	25
Southeast of Peladinho			700	

[1] Between Gallery A and the surface.

The estimates of inferred ore are based on surface exposures. Underground work at Morro Pelado has shown that at a depth of 80 m below the surface the wallrock contains no ore. It seems likely that the ore in the wallrock is confined to the zone of intense weathering that is about 40 m deep on Morro Pelado. Even in this zone, the ore content may be irregular so the figures should be used with caution. The ore at the Paredão ore body is only 30 cm thick in Gallery C, about 10 m below the surface, showing that large changes in thickness are possible in relatively short distances. More underground exploration and core drilling is needed before reserves can be more precisely estimated.

GEOCHEMICAL PROSPECTING

The use of geochemical prospecting as an aid in locating lead-bearing veins beneath soil cover was tested in a preliminary way at the Boquira mine, and tested more extensively by Cia. Plumbum, S.A. The testing at Boquira was done to determine the background lead content of the soils over different rock types. The samples were collected on gently sloping ground; the location of the sampling traverses is shown on figure 3. The samples were analysed by the dithizone method developed by the U.S. Geological Survey (Lakin, Almond, and Ward, 1952) and modified by Ing. Geraldo Melcher. A traverse in quartzite, west of the north end of Morro Cruzeiro, showed a lead content of from 100 to 400 parts per million in the soil, with an increase to 1,000 ppm where the traverse entered iron formation. The lead content of the soil derived from iron formation taken on traverses on the ridge crest of Morro Cruzeiro between the Cruzeiro and

Paredão ore bodies ranged from 400 to 900 ppm with anomalies over known ore zones ranging from 1,500 to more than 10,000 ppm. If further work is done, anomalies of more than four times background should be investigated by trenching.

Geologists of Cia. Plumbum, S.A., systematically sampled an area extending from the east flank of Morro Pelado north of Peladinho (pl. 2) northeastward out into the gneiss. Many anomalies were disclosed on the steep slope of Morro Pelado, but of those investigated by trenching prior to June 1958 only the one on the projection of the Peladinho ore body showed lead-bearing rock in place. Most other anomalies are apparently related to float of massive cerussite; about 50 tons of float ore have been obtained during trenching. No anomalies were found in the area underlain by gneiss.

Samples taken on two traverses made across the lens of iron formation southwest of Boquira (pl. 1) showed a strong anomaly located from 40 to 60 m from the west edge of the lens and midway between its north and south ends. On these traverses, background ranged from 10 to 500 ppm of lead and the anomalies from 2,500 to more than 10,000 ppm.

FUTURE POSSIBILITIES

Mine development, exploration, and geologic studies done to date in the Boquira district have been preliminary in nature but have shown the presence of ore bodies of moderate size. Exploration of the known ore bodies is underway and the exploration programs including diamond drilling planned by the management of Mineração Boquira Ltda. and Cia. Plumbum, S.A., should give adequate information on the lead ore bodies in the iron formation between Boquira and Tiros (pl. 1). Iron formation seems to be absent north of Tiros but lenses of iron formation occur toward the south at least as far as Macaúbas and should be explored. Lead minerals are known to occur in some of these lenses and, although the occurrences are small as compared to those at Boquira, further trenching may disclose the presence of mineable ore bodies.

Iron formation is the only known host rock for the ore and provides a convenient target for exploration. Lead deposits may occur in other rocks in the mapped area, particularly along the east flank of the Serra de Macaúbas, but the search for them will be difficult owing to the absence of any known stratigraphic or structural guides.

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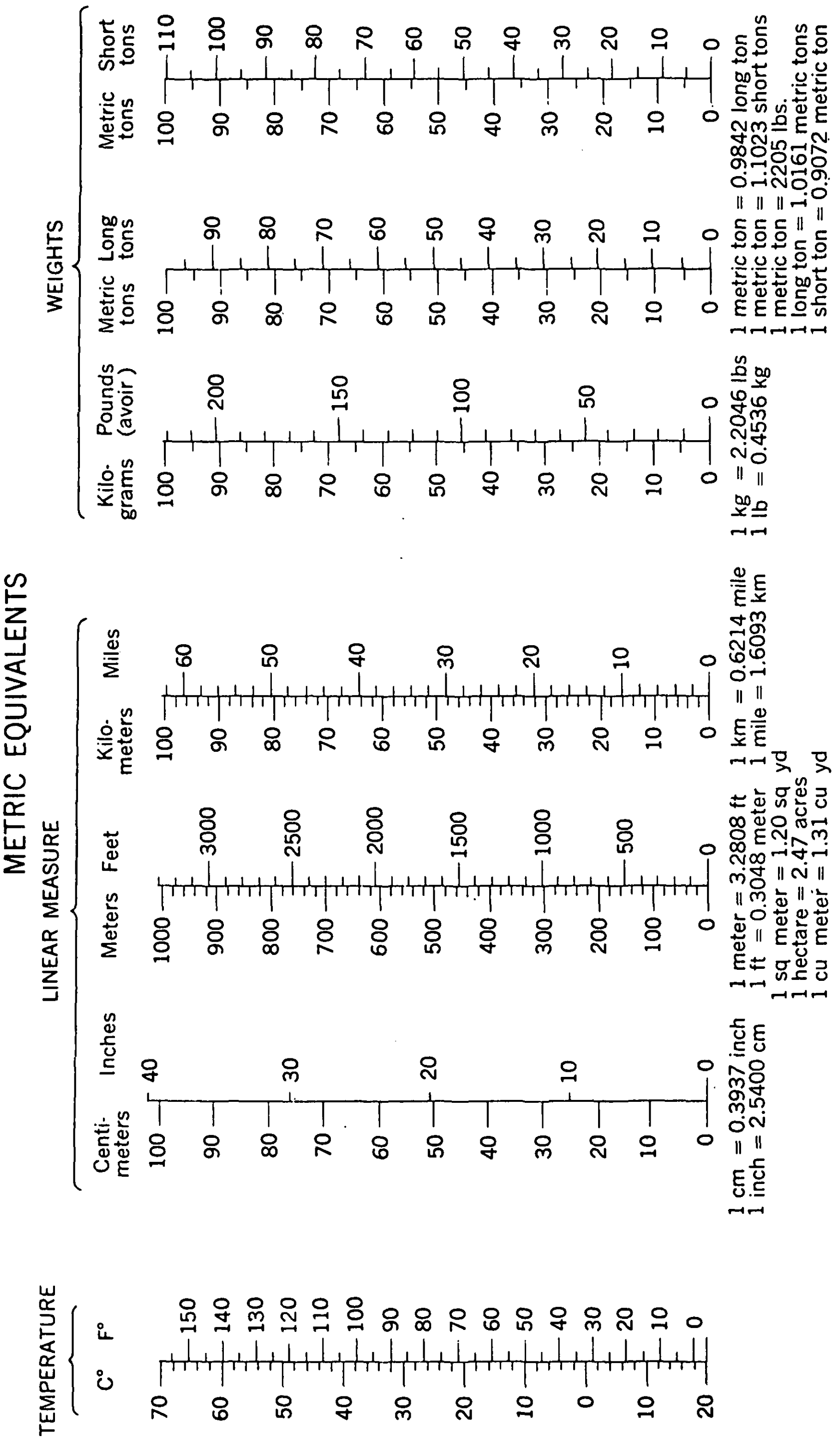
METRIC EQUIVALENTS
TEMPERATURE
C°
F°
LINEAR MEASURE
Centi-meters
Inches
Meters
Feet
Kilo-meters
Miles
WEIGHTS
Kilo-grams
Pounds (avoir)
Metric tons
Long tons
Metric tons
Short tons
1 cm = 0.3937 inch
1 inch = 2.5400 cm
1 meter = 3.2808 ft
1 ft = 0.3048 meter
1 sq meter = 1.20 sq yd
1 hectare = 2.47 acres
1 cu meter = 1.31 cu yd
1 km = 0.6214 mile
1 mile = 1.6093 km
1 kg = 2.2046 lbs
1 lb = 0.4536 kg
1 metric ton = 0.9842 long ton
1 metric ton = 1.1023 short tons
1 metric ton = 2205 lbs.
1 long ton = 1.0161 metric tons
1 short ton = 0.9072 metric ton

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