UNITED STATES DEPARTMENT OF THE INTERIOR
J. A. Krug, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

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BARITE DEPOSITS OF CAMAMÚ BAY STATE OF BAHIA, BRAZIL

BY

A. J. BODENLOS

Prepared in cooperation with the
DIVISÃO DE FOMENTO DA PRODUÇÃO MINERAL
DEPARTAMENTO NACIONAL DA PRODUÇÃO MINERAL
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GEOLOGIC INVESTIGATIONS IN THE AMERICAN REPUBLICS, 1947

THE BARITE DEPOSITS OF CAMAMÚ BAY, STATE OF BAHIA, BRAZIL

By A. J. Bodenlos

ABSTRACT

In Camamú Bay, on the east coast of central Brazil, are two islands containing barite deposits. The islands, known as Ilha Grande and Ilha Pequena, are at latitude 13°56′ S. and longitude 39°02′ W., 115 kilometers S. 27° W. of Salvador, capital of the State of Bahia.

Ilha Grande and Ilha Pequena are underlain by Cretaceous rocks and by Quaternary sediments. The oldest Cretaceous rocks consist of conglomerate, sandstone, and shale of Neocomian(?) age. Overlying them is a Cretaceous dolomitic limestone of Albian(?) age. Quaternary unconsolidated sand, swamp deposits, and coral-reef rock complete the stratigraphic column. The barite occurs as a bed replacing an arkosic sandstone member at the top of the Neocomian strata. The Cretaceous rocks and the included barite bed are irregularly domed and gently folded. Numerous small flexures are superimposed on the larger structures. The barite bed occupies a dip-slope position wherever it occurs.

The barite consists mainly of finely fibrous, spherulitic, laminar, and nodular aggregates. Bedding planes of the original rock have been preserved in the replacement. The fibrous barite is very porous and vuggy. Small amounts of crystalline barite line the vugs and secondary fissures. Associated with the barite are minor amounts of quartz, marcasite, galena, iron oxides, sulfur and clay. Replacement of the arkosic sandstone is so nearly complete that residual material of the original bed is rarely found.

The area underlain by barite is 1,700 meters wide from east to west and 2,950 meters long from north to south. Most of the outcrops occur along the beaches where erosion has stripped the soil cover. On Ilha Grande barite underlies at least 12.6 hectares. The maximum measured thickness is 4.3 meters, but much of the deposit is thinner, due to primary differences in thickness or to subsequent erosion of the ore in its dip-slope position. Reserves on Ilha Grande are: 191,400 tons measured, 225,600 tons indicated, and 279,300 tons inferred; a total of 696,300 metric tons. In addition, barite eroded from the rock in place forms a beach shingle containing 47,000 tons of indicated reserve. Barite crops out along the beaches of Ilha Pequena for a strike length of 2,900 meters. The island was not explored and reserves were not calculated. Comparison of its geology with that of Ilha Grande leads to the conclusion that future exploration should establish the presence of large reserves.

Analyses indicate that the barite rock contains an average of 89.5 percent $BaSO_4$. Impurities consist of the minerals listed above and also clay from the overburden, which has worked into the fractures and vugs of the barite.

The deposits were probably derived from low-temperature hypogene waters and deposition took place at shallow depths.

The deposits have been recently developed. The barite is milled to 300 mesh and marketed as mud-weighting media for oil-well drilling. The mill has a capacity of 6 tons per hour. Production from 1943 to the spring of 1946 was less than 5,000 tons, but completion of the mill in January 1946 now permits large-scale operations.

INTRODUCTION

Barite (for general references see Bärtling, 1928; Simpson, 1937; and Weigel, 1937), the sulfate of barium ($BaSO_4$), is an orthorhombic mineral with a specific gravity ranging from 4.3 to 4.6. Pure barite is white, transparent when crystalline and opaque when fine-grained or cryptocrystalline. Bituminous material colors the mineral gray or black, and small amounts of other impurities color it pale shades of yellow, green, blue, or red. The mineral has widespread distribution and is found in veins, as replacement bodies or fracture filling in sedimentary rocks, or in clays as residual material derived from primary deposits. Its principal industrial uses are (1) in the manufacture of lithopone, a white paint pigment; (2) as an inert filler in manufactured products; (3) as a source for barium in the chemical industry; and (4) as a weighting medium in oil-well drilling muds.

On Ilha Grande and Ilha Pequena, in Camamú Bay, State of Bahia, Brazil, is a large deposit of barite which was developed for mining during the years 1941 to 1946. The deposit consists of a bed of barite in a sedimentary sequence of Cretaceous rocks. The bed has a maximum thickness of 4.3 meters and crops out over an area extending 1,700 meters from east to west and 2,950 meters from north to south. Because of the large reserves in sight and its favorable situation for low-cost production, the deposit promises to become a major South American producer.

In March and April 1946, the writer made an investigation of the deposits as part of a program of geological cooperation between the Departamento Nacional de Produção Mineral, of the Brazilian Ministeria de Agricultura, and the Geological Survey, United States Department of the Interior. The Geological Survey work in Brazil is sponsored by the Interdepartmental Committee on Scientific and Cultural Cooperation with the American Republics, of the United States Department of State. This investigation was made at the request of the Divisão de Fomento da Produçãa Mineral of the Departamento Nacional da Produção Mineral, to determine the distribution, grade, and reserves of the barite, and to study the geology necessary for the calculation of these data.

All measurements in this report are metric. A table of conversion factors is appended, p. 32.

LOCATION AND ACCESSIBILITY

The islands Ilha Grande and Ilha Pequena, at latitude 13°56′ S. and longitude 39°02′ W., lie on Camamú Bay, 115 kilometers S. 27° W. of Salvador, the principal city and capital of the State of Bahia. (See fig. 1.) Camamú bay is sufficiently deep to permit docking of oceangoing ships at Ilha Grande. The islands can be reached from Salvador by coastwise tugs and small sloops; overland, the roads to Camamú are poor. A small airfield on Maraú Peninsula, just east of the islands, makes the area accessible by light plane.

GEOGRAPHY

Camamú Bay, one of the largest in Brazil, is approximately 20 kilometers long from north to south and 10 kilometers wide from east to west. (See fig. 2.) Essentially it consists of two major estuaries, the Maraú and Acaraí (or Camamú) Rivers. The Maraú Peninsula separates the bay from the Atlantic Ocean. The Serhinhaen (or Santerem), Igrapiuana, and Condurú Rivers, and also the Maraú and Acaraí Rivers, flow into the bay from the Serra Condurú, which lies just west of the bay, and its surrounding lowlands. The city of Camamú is the largest in the area and is situated at the head of the Acaraí estuary, where the western upland begins. The margin of the upland forms a "fall line" in this area.

Ilha Grande (pl. 1) lies about 8 kilometers S. 40° W. of Quiepe Island at the mouth of the bay and 10 kilometers east-northeast of the city of Camamú. Ilha Grande and Ilha Pequena normally are separated by a narrow channel, but during the lowest spring tides are connected by bars. Ilha Grande is shaped like a reversed "L." It is 3.1 kilometers long from east to west and 2.7 kilometers wide from north to south. Ilha Pequena is pear-shaped, nearly 2 kilometers long from north to south and one kilometer wide near its southern end. The barite deposits are in the southwest part of Ilha Grande and along the beaches of Ilha Pequena.

On Ilha Grande groups of hills in the north, north-central, and southwest parts of the island, are separated by sand plains and swamps. The hills are moderately steep and rise to an altitude of nearly 50 meters above sea level. Outcropts of bedrock are found principally along the beaches or in wave-cut cliffs. Some barite is exposed on the hills in the southwest part of the island. In trenches cut to explore the barite, soil cover over the bedrock ranges in thickness from half a meter to 3 meters; the soil cover is probably thicker on hill tops. The soil is clayey on most hills but is sandy on some. Lowlands are usually covered by sand or by humus-rich muck.

The interior of Ilha Pequena is hilly and rises to about the same altitude as Ilha Grande. The hills are flanked by sand-plains at the

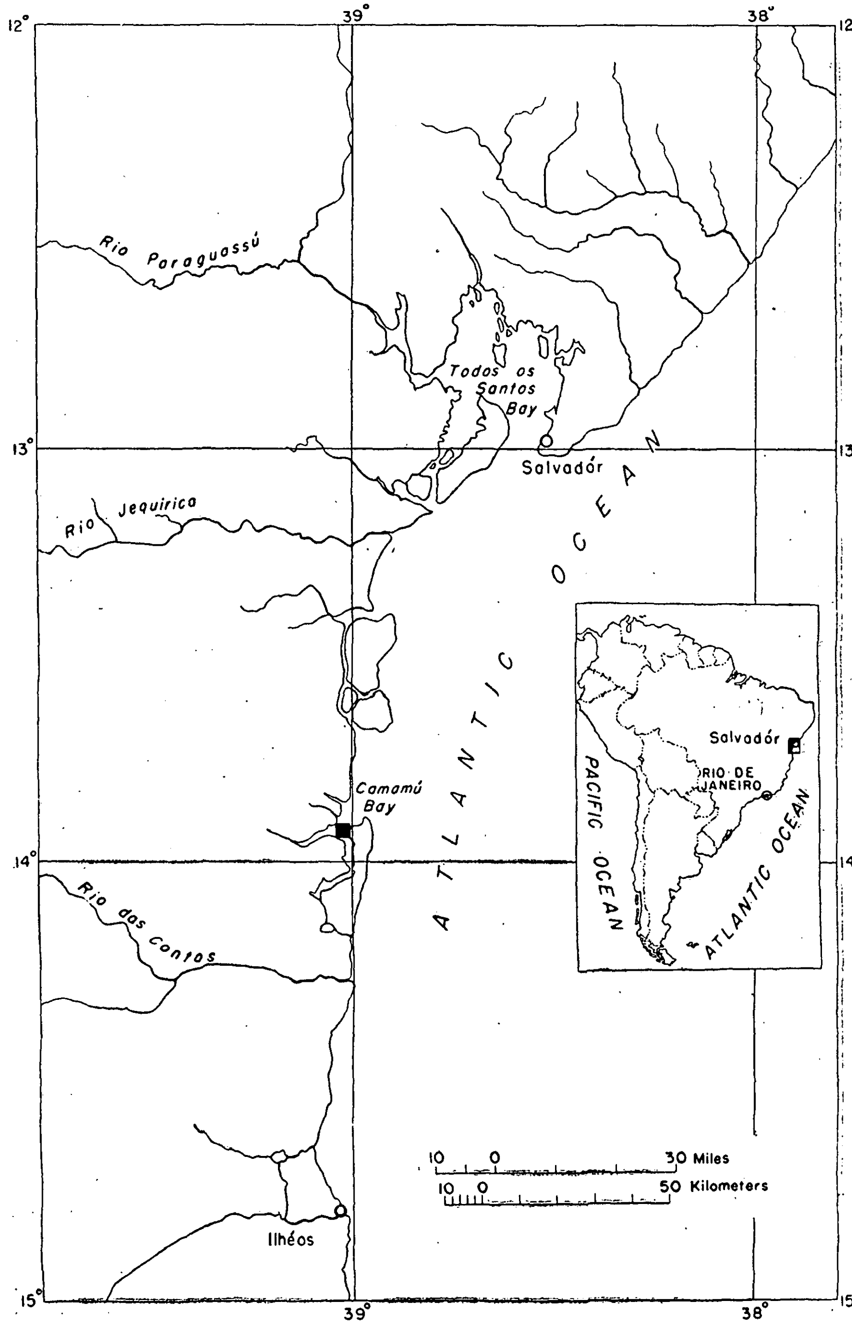


Figure 1.—Index map showing location of Camamú Bay, State of Bahia, Brazil.

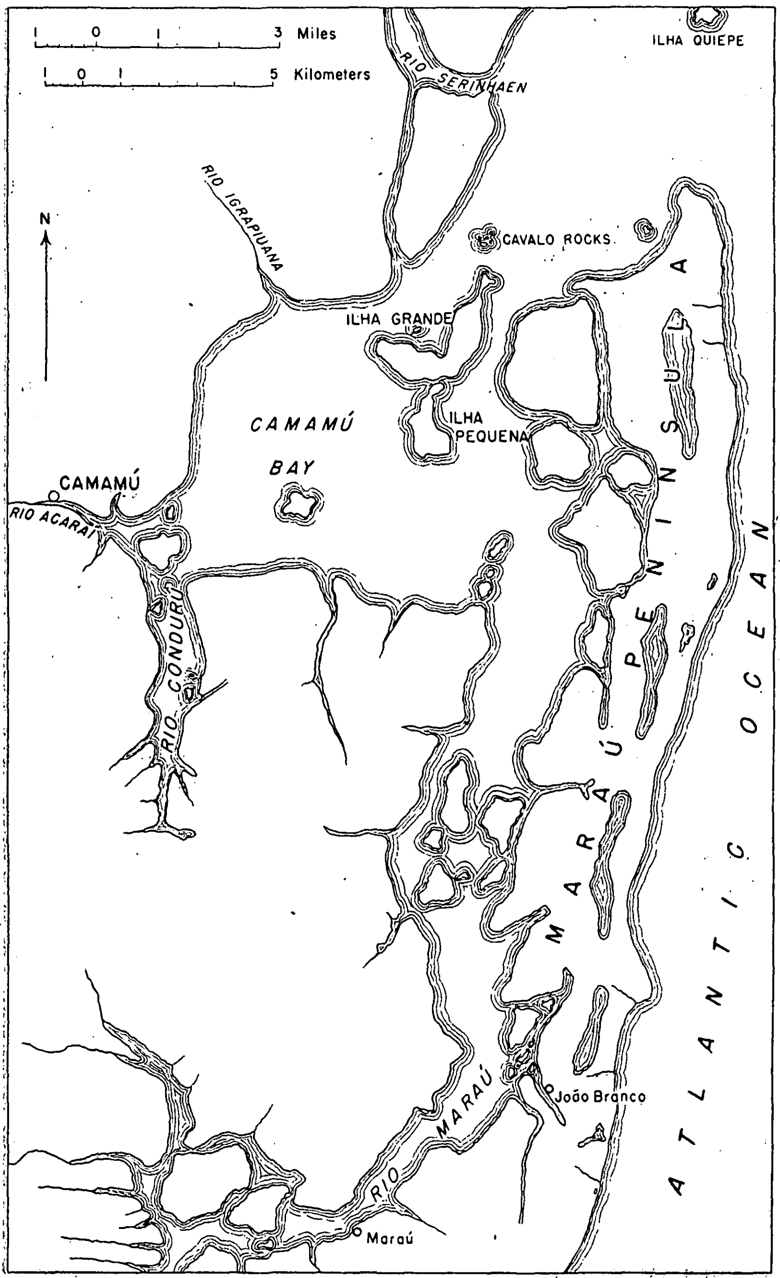


FIGURE 2.—Sketch map of Camamú Bay, State of Bahia, Brazil.

north end of the island and by swamps in the southeast and southwest parts of the island. Outcrops of bedrock occur along the beaches. Although the interior was not mapped, analogy with Ilha Grande would indicate that few outcrops would be found on the hills.

The climate [1] in this area is classed as tropical superhumid. Rainfall is reported to exceed 2,000 millimeters a year; engineers at Ilha Grande estimate at least 2,500 millimeters annual precipitation. Winter, lasting from May to August, has heavier rainfall than summer, but even in the slightly drier season it rains at least once a day. The humidity is always above 85 percent. The average annual temperature is 24° C., with but 3° variation from the average.

The water table is usually high and the water supply is obtained from wells. Fresh water can be obtained to within a few meters of the high-tide line of beaches and tidal inlets. Springs are reported at the base of some hills. Even when colored by the soluble humates of swamp vegetation the water is potable, but around areas of denser habitation it may be contaminated.

Vegetation varies with topography and extent of cultivation. On both islands, low sandy areas are grass-covered and swampy areas support low growths of various types. Hilly areas are densely forested by hardwood trees. Mangrove swamps are common on tidal flats bordering the islands. Much of the land on Ilha Grande has been cleared and palms have been planted. Unless clearing is maintained, however, new growths start immediately, usually with impenetrable "saw-grass." Aside from a few patches of sugar cane and some vegetable gardens, the only products are coconuts and dendê oil from the palm trees.

Several hundred people live on Ilha Grande and possibly 50 live on Ilha Pequena. Before barite mining started, most of the people lived by means of fishing, coastwise shipping, or by extracting babaçu oil from the palms. With the equable climate and abundance of fish, living is easy in this area.

HISTORY AND PRODUCTION OF THE DEPOSITS

The presence of barite on Ilha Grande has been known for some time. Leonardos (1934) states that Eugen Hussak visited the deposit years ago, but the date of examination is not known. Gonzaga de Campos (1922) briefly mentioned the presence of barite crystals on Ilha Grande but thought the crystals occurred in sandstone. Alberto I. Erichsen (1940; also Leonardos, 1934), who studied the geology of Camamú Bay in 1933, thought the bulk of the barite contained some sandstone and would have to be beneficiated for commercial use. Sílvio Fróes Abreu, studying the petroleum prospects of the area, was

[1] Brazil, 1943–1944, published by the Ministry of Foreign Relations, Rio de Janeiro; pp. 52–62. Classified by Brazilian meteorologists.

the first to consider commercial development of the deposits for barite.[2]

In 1941, Sílvio Fróes Abreu was instrumental in organizing a company, Pigmentos Minerais Ltda. (also known as Pigmil), to operate the deposits. The company obtained concessions for exploration and development from the Brazilian Government and conducted exploration from 1941 to 1944. This exploration included stripping the trees from the southern part of the Ilha Grande deposit and trenching the ore in this area. Pigmil had hoped to use the barite for the manufacture of barium chemicals and constructed a pilot plant near the Cordovil Station in the suburbs north of Rio de Janeiro, through its subsidiary company Bario Industrias S/A (BISA). BISA planned to manufacture pure barium sulfate, barium carbonate, and "Bariosulphur," a liquid insecticide and fungicide similar to the German Bayer product "Solbar." Although the products were satisfactory, the processes were expensive and the work was subsequently abandoned.

In 1944, Pigmil was sold, and a new company called Pigmentos Minerais Industrial e Comercial Pigmina S/A (known as Pigmina S/A) was organized. The new company, since late in 1944, has developed a quarry at the east end of the outcrop on the south shore of Ilha Grande (pl. 2), has erected a mill that had previously been operated in Cuba and a new warehouse and dock, and has built a 1.4-kilometer narrow-gauge railroad between the quarry and mill. The mill was completed in January 1946, at which time large-scale mining was begun. The first large shipment of barite was made in May 1946.

Pigmina plans to produce milled barite for mud-weighting media in oil-well drilling. The product, which carries the trade name "Baroid," has been purchased by the Conselho Nacional de Petróleo (National Petroleum Council) for use in drilling in the Bahian oil fields near Salvador and also by Venezuelan oil companies. To date production has been small, as shown below, but since the completion of the mill large-scale operation is anticipated.

Production of Camamu Bay barite deposits,[1] 1943–46, in metric tons

1943 [2]	507
1944	500
1945	618
1946 [3]	3,200
Total	4,825

[1] Published with the permission of Mr. Luiz Oscar Taves, president, Pigmina S/A.
[2] Production prior to 1943 not known.
[3] January through April, inclusive; figure obtained through the courtesy of Robert D. Butler, manager of operations, Ilha Grande.

[2] Taves, Luiz Oscar, President, Pigmentos Minerais Industrial e Comercial Pigmina S/A, personal communication.

FIELD WORK AND ACKNOWLEDGMENTS

The writer studied the deposits from March 11 to April 21, 1946. The topography and geology of the south half of Ilha Grande was mapped by plane table on a scale of 1: 5,000, with a contour interval of 2 meters. The geology of the remainder of Ilha Grande and Ilha Pequena was mapped on the same scale, on bases furnished through the courtesy of Pigmina. The topography of the remaining area is shown by form lines with a contour interval of approximately 10 meters.

The maps are oriented to true north, the orientation being based on star shots that fixed the azimuth of permanent concrete bench marks O and CA at N. 16°30′ E. Bench mark O is 0.4 meter north of the track between the plant and the dock and 22 meters east of the southeast corner of the warehouse. (See pl. 1.) Bench mark CA is 310 meters to the northeast of bench mark O. The magnetic declination was found to be 17°40′ west of north.

The writer wishes to thank the officials of Pigmina for their cordial cooperation and generous assistance in the course of the project. Especial thanks are offered to Mr. Robert D. Butler, manager at Ilha Grande, Mr. John Wilson, mill engineer, and Mr. Gus Nicolai, mining engineer, for much valuable statistical data, and more important, for their viewpoints and discussions on the geological problems. In addition, their wholehearted hospitality made the stay on Ilha Grande most enjoyable. The writer is indebted also to Mr. Luiz Oscar Taves, president, and Mr. Gustav A. Amberg, general manager, of Pigmina, for analyses of the barite, the history of the company, and for permission to use several of the company maps (pl. 1; fig. 2). The Conselho Nacional de Petróleo, through Dr. Avelino I. de Oliveira, director, has kindly consented to the use of the Solipema II well log (pl. 3), drilled on Ilha Pequena and logged by Dr. Sílvio Fróes Abreu. Lastly, the writer wishes to express his appreciation to the officials of the Departamento Nacional da Produção Mineral; to Dr. Jose Alvez de Souza, director, and Dr. Alberto I. Erichsen, chief of the Divisão de Fomento da Produção Mineral, for the cooperation of the Brazilian Government; and to Dr. Mario Pinto, chief of the Chemical Laboratory, for analyses of barite collected in the course of this work.

The manuscript of this report was critically read by W. D. Johnston, Jr., geologist, United States Geological Survey, whose familiarity with the area made his comments most valuable.

PREVIOUS GEOLOGIC WORK

The geology of the Camamú Bay area has been studied by many geologists over a long period of years; their work is concisely summarized by Oliveira and Leonardos (1943, pp. 587–592, 672–578).

The marine Cretaceous was named the Camamú series by Rev. Mr. Nicolay (see Hartt, 1870, p. 264) before 1870. Charles F. Hartt visited the area in 1866 (Hartt, 1870, p. 264) and added his observations to those of Nicolay. L. F. Gonzaga de Campos (1902, 1924, p. 694) studied and wrote about the area. The possibility of petroleum extraction from the bituminous shales at the south end of Camamú Bay led the Serviço Geológico to investigate the area and drill several wells during the period 1922 to 1925 (Oliveira and Leonardos, p. 589). The Maraú area was studied by Eugênio Bourdot Dutra (1920, pp. 79–90), Paulino F. de Carvalho, Alberto I. Erichsen, and others. C. J. Maury (1924, pp. 544–578) and Hollick and Berry (1924) described the paleontology of the Tertiary rocks at the south end of the bay. References to still other investigations are given by Oliveira and Leonardos (1934, pp. 587–592, 672–678).

Several general references to studies of the barite have already been cited. (See pp. 6–7.) Another is a brief report in Mineração e Metalurgia (1945, p. 262.) The most recent report is a crystallographic study made by E. Tavera Filho (1946, pp. 47–58) in which the morphology of the crystalline barite is described in detail.

GEOLOGY

GENERAL GEOLOGY OF THE CAMAMÚ BAY REGION

The rocks in the Camamú Bay region comprise pre-Cambrian gneisses and schists; Cretaceous conglomerates, sandstones, shales, and limestones; Tertiary sandstones and shales; and Quaternary unconsolidated sand deposits and coral reefs.

Pre-Cambrian gneisses and schists are exposed in the hills west of the bay. The most easterly exposure seen was on the south shore of the Acaraí estuary, in a cut opposite the city of Camamú; it consists of decomposed gneiss. A well drilled to explore for petroleum on Ilha Pequena reached gneiss at a depth of 680 meters. (See pl. 3.) Oliveira and Leonardos (1943, p. 587) state that the gneiss is Archean in age and similar to the rocks of the large crystalline massif underlying much of this part of Brazil.

The Cretaceous rocks are exposed in the lowlands bordering Camamú Bay and on the islands in the bay. They have been found also in the course of well drilling near Maraú, João Branco, and Ilha Pequena. The Cretaceous rocks have been divided by Oliveira and Leonardos into an older series, the Neocomian Bahian; and a younger series, the Albian Camamú. The age determination of the lower or older series is based on paleontologic and lithologic similarity with the Bahian series exposed in the Bahian Reconcavo, the area including Todos os Santos Bay and the city of São Salvador, about 100 kilometers north of Camamú Bay. Fossils of the branchiopod genus

Estheria are found in the rocks of both regions, indicating a fresh- or brackish-water origin for those rocks. The younger or upper series contains marine fossils of Albian age. The most widely exposed unit is a limestone named the Algodões formation.

The well drilled on Ilha Pequena cut through 680 meters of conglomerate, sandstone, and shale. Sílvio Fróes Abreu logged the strata as Neocomian. At Joã Branco, below 130 meters at Tertiary strata, the drill cut through 257 meters of Cretaceous sandstone, limestone, and gypsum. According to Oliveira and Leonardos (1943, p. 589), the upper 210 meters is of Albian age, and the remainder of Neocomian age. At Maraú, the drill cut through 84 meters of the Albian sandstone, limestone, and conglomerate containing marine fossils and through 156 meters of the Neocombian dark sandstone, shale, and conglomerate.

Tertiary sedimentary rocks overlie the Cretaceous strata on the mainland and on the islands in the bay. The Tertiary rocks, named the Maraú formation, consist of poorly consolidated sandstones, shales, and bituminous shales. The paleontology of the series has been extensively studied and the rocks are considered to be of Pliocene age (Hollick and Berry, 1924). Interest in this work was stimulated by the possibility of petroleum recovery from the bituminous shales cropping out near the hamlet of João Branco. Tertiary rocks are absent on Ilha Grande and Ilha Pequena.

Quaternary sediments include unconsolidated sand, forming beaches, bars, and plains; coral reefs fringing the islands; and humic muck deposited in swamps.

The regional structure is comparable to that of the more thoroughly studied Bahian Graben, 100 kilometers to the north. The Cretaceous and Tertiary rocks are in a basin lying east of the pre-Cambrian crystalline massif. The Camamú region differs from the Reconcavo region in that crystalline rocks do not crop out east of the sedimentary basin.

The nature of the west margin of the basin is still not well known; geologists (Oliveira and Leonardos, 1943, pp. 588–589) now consider it to be a fault, downthrown to the east. Students previously considered the structure to be monoclinal, with the younger sedimentary rocks dipping seaward and overlapping and crystalline rocks. Within the sedimentary basin, the structures consist of minor undulations and gentle folds. Too little work has been done on structure to define any systematic orientations of the flexures.

GEOLOGY OF ILHA GRANDE AND ILHA PEQUENA

STRATIGRAPHY

Two Cretaceous formations are exposed on Ilha Grande and Ilha Pequena—the older an arkosic conglomerate and sandstone, the younger a dolomitic limestone.. (See pl. 2.) The rock containing the barite bed is in the upper part of the older formation, which consists principally of arkosic sandstone and shale. Stratigraphic relations between the two formations can best be seen in the area on Ilha Grande containing the barite deposit. Elsewhere exposures may be found only along the beaches; they usually include but one formation per outcrop.

Arkosic conglomerate and sandstone.—The lowest exposed part of the older formation is an arkosic conglomerate. Overlying it, along the south shore of Ilha Grande, is clay and quartzite. On the north shore of the Ilha Grande barite area the conglomerate is overlain by arkosic sandstone containing lenses of other sedimentary material.

The arkosic conglomerate consists of well-rounded pebbles and cobbles of decomposed gneiss and granite, some quartzite and sandstone pebbles, an a few decomposed limonite-stained pebbles. All are strongly altered and are cemented by a nondescript mixture of iron-stained yellow clay. The pebbles and cobbles range from about 5 millimeters to 15 centimeters in length. The distribution of unaltered quartz and mica flakes in the kaolin matrices shows the original texeture of the decomposed gneiss and granite pebbles. The quartz pebbles are thoroughly fractured and those of sandstone are friable.

There is only one natural exposure of the arkosic conglomerate. It occurs near the west end of the south shore of Ilha Grande, in a bluff just behind the beach where overlying barite and soil have been stripped by erosion. A thickness of 6 meters of it can be seen at this locality. The material has been uncovered in several trenches cutting through the barite and also at the east end of the present quarry, where the barite has been mined out. Exposures of the arkosic conglomerate have a peculiar mottled appearance, caused by the irregular distribution of iron-stained clay between the chalk-white kaolin masses of decomposed gneiss and granite pebbles and the white quartz and sandstone pebbles.

Clay and quartzite overlie the arkosic conglomerate along the south shore of Ilha Grande. Toward the eastern end of this area the clay is absent, but it thickens westward to a minimum of 1.70 meters. It is massive and yellow or pinkish in color, and it contains thin veins of hematite, limonite, and crystalline barite, the last-mentioned generally parallel to the overlying barite bed. The quartzite is directly beneath the barite. Usually the quartzite fractures across the grain like a true quartzite, but occasionally, even though the rock is silicified, the fractures follow the grain boundaries. When subjected to weathering, however, the cementing silica breaks down; the weathered rock then fractures along the grain boundaries, giving it the appearance of a sandstorm. When the rock is freshly fractured it appears glassy and dark gray; when weathered, it is gray, light gray, light buff, or pink. It is thin (0.16 meter) or absent along the eastern and central parts of the south shore. Although it is not seen in place westward, there is much weathered quartzite float in the colluvium and alluvial beach material and also commonly along the edge of the mangrove swamp extending westward from Ilha Grande. One boulder near the west end of the south shore is 0.50 meter thick; therefore, the quartzite probably thickens westward.

The arkosic sandstone of the older formation is extensively exposed along the north shore of the barite area on Ilha Grande. It is a soft, gray to dark-brown sandstone containing albite, microcline, muscovite and biotite; some horizons contain abundant muscovite flakes. It includes thin lenses of intraformational quartz conglomerate, quartz conglomerate with well-rounded small pebbles, limestone, very dark gray micaceous shale, and some thin beds or lenses of bituminous shale with asphaltic incrustations. Some beds contain secondary dolomite. Bedding planes of several horizons are ripple-marked and some shale layers are cross-bedded. Thin sandstone beds or lenses, lithologically similar to the weathered quartzites seen on the south shore, may be found in some localities between these strata and overlying barite.

Outcrops of this soft material are low and rounded. When weathered, the rocks break down to micaceous sandy clay. It may be in part stratigraphically comparable to the clay between the arkosic conglomerate and barite seen on the south shore. The thickness of these strata was not measured, because a width of only a few meters can be seen in any one exposure, and frequent changes of attitude make correlations between exposures unreliable.

The conglomerate and arkosic sandstone are not exposed along the shores of Ilha Pequena. Sandstone, quite probably comparable to the weathered quartzite lenses on Ilha Grande, underlies barite on the northeast shore of the island. Thin sandstone lenses are interbedded with barite on the southwest shore of Ilha Pequena.

The well drilled on Ilha Pequena (pl. 3) is in the west-central part of the island, just inshore from the beach. In this location the uppermost beds cut by the well would not be more than a few meters below the barite exposed along the shore. Sílvio Fróes Abreu logged the well as follows: The top 3 meters are beach sand; from 3 to 29 meters, bituminous shale; from 29 to 125 meters, predominantly conglomerate; from 125 to 435 meters, predominantly sandstone; and from 435 to 680 meters, predominantly shale. The bituminous shales are probably equivalent to the arkosic sandstone and its included lenses, and the conglomerate almost certainly is equivalent to the arkosic conglomerate on Ilha Grande because Abreu logged gneiss pebbles in the well cuttings. If the barite replaces a certain horizon in the upper shale member, as believed, then this member thins and becomes more clastic northward.

Dolomitic limestone.—Massive dolomitic limestone overlies the micaceous sandstone member of the arkosic conglomerate formation. The contact between the two formations is exposed only in one outcrop, at the extreme northwest corner of the Ilha Grande barite area. The most extensive dolomitic limestone outcrops are in the northern part of Ilha Grande and on small islands, lying about 600 meters north of Ilha Grande. No exposures of this formation were seen on Ilha Pequena. Elysiario Tavora Filho (1946, p. 47) cites Othon H. Leonardos as stating that the limestone is the Algodões formation.

The limestone is light buff in color and weathers to a medium gray. It is very finely crystalline, dense, and is mostly dolomitized. R. D. Butler, in a personal communication, states that the rock contains from 55 to 65 percent $CaCO_3$; the writer found some rock that was more nearly limestone. A few pelecypods and echinoderms, poorly preserved, were seen in some exposures in northern Ilha Grande. Several pieces of this dolomitic limestone were submitted to Dr. John B. Reeside, Jr., United States Geological Survey for examination. His determinations are as follows: "Most of the shells were broken before fossilization and are not definitely identifiable. The commonest form is a species of *Neithea*, and there are fragments of *Pinna* and *Gryphaea*. C. W. Cooke identifies an echinoid as *Holectypus* cf. *H. numismalis* (Gabb) (=*H. pennatus White*). These fossils by themselves could not be placed closer than Cretaceous." Small vugs contain minute calcite crystals and occasionally marcasite. The dolomitic limestone shatters easily and breaks very irregularly. Weathered surfaces are very rough, in part due to solution pitting. The rock forms blocky, massive outcrops in wave-cut cliffs, large boulders, and offshore stacks. Behind beach lines, the outcrops are less bold.

On Ilha Grande, exposures as much as 6 meters thick may fail to have one clear bedding plane; on the islets to the north, bedding planes are from 0.7 to 1.0 meter apart.

The Quaternary sediments consist of unconsolidated sand, swamp humus, and coral. Sand and swamp cover most of Ilha Grande, except hills rising higher than the sand plain. (See pl. 1). Swamp covers the lowlands of southwestern and southeastern Ilha Pequena, and sand the northern part of the island. The mudflats bordering the islands and supporting a growth of mangrove are probably of Recent age. Coral reefs fringe the northeastern part of Ilha Grande. Some Recent shell material is attached directly to massive limestone cliffs and blocky outcrops in this area.

STRUCTURE

Comparatively well exposed and explored and widespread in distribution, the barite bed constitutes the best key to the structure of Ilha Grande and Ilha Pequena. The barite bed is irregularly domed and gently folded, and it controls the topography of southwestern Ilha Grande. On the south shore it forms three major domes whose slopes are essentially dip slopes. On the north shore the structure consists of one major dome with a low anticlinal extension eastward. (See pls. 1 and 2.) Flanking this barite area, the beds are essentially flat-lying, as may be seen by the attitude of the conglomerate and the areal distribution of the dolomitic limestone.

The dip of the barite beds along the south shore of Ilha Grande is usually from 10° to 30°. (See pl. 4.) Occasionally the beds are flat-lying, and less frequently they dip as much as 50°. At the west end of the strip the beds are vertical near the beach, but undoubtedly they flatten a short distance behind the exposures in the trenches, because the beds face the hill. Because the bedding is massive on the north dome of Ilha Grande, the dip cannot always be determined; one outcrop in the southeast part seemed to be dipping nearly 40°. In the low eastward extension, beds dip as much as 30° and are flat-lying on the crest of the structure. Other dips along the north-coast strip are very low.

Extrapolating this structural habit northward, the hills in northern Ilha Grande are interpreted as being anticlines and domes. On the islets 600 meters north of Ilha Grande, dolomitic limestone outcrops with clear bedding can be seen to be generally flat-lying but with irregular and compensatory minor undulations. On Ilha Pequena the barite dips seaward all around the island except in one small anticlinal nose at the south shore. (See pl. 1, section H–H′.) The structure seems to be comparable to that of Ilha Grande; in which case the hills in interior Ilha Pequena probably represent various anticlinal or domal flexures.

It will be noted that much of the hilly area in northern Ilha Grande is shown as "Kls?" on the map. This symbol indicates that dolomitic limestone possibly underlies the area but that it may be discontinuous; reference to cross sections will make this relation clear. (See pl. 1.) There are no outcrops in this area, and the soil is somewhat sandy.

Superimposed on the major folding are minor folds, best seen in the barite beds on the south shore and in the arkosic sandstone on the north shore and west shore of Ilha Grande. Small rolls, noses, and troughs are common in the barite bed. The rolls may be only 5 meters across; the noses and troughs are from 10 to 50 meters across. The rolls and noses are readily eroded, as the barite occupies a dip-slope position. (See pl. 4.) Similarly, sandstone exposures on the north shore and west shore show many minor and very irregular flexures that may be as little as 3 meters across.

Two distinct sets of fractures can be seen in the barite beds. One is very irregular and contains crystalline barite and associated minerals. The other set consists of regular joints, breaking the barite into nearly rectangular blocks whose dimensions are, at the minimum, about 0.50 meter long and 0.25 meter wide. Along the south shore of Ilha Grande, toward the eastern end of the barite deposit, the jointing is closely spaced. The most regular set strikes almost due north and the other set strikes approximately at right angles to the first. Both sets are close to vertical. Elsewhere, jointing is less regular and less closely spaced, but barite blocks are never more than 1.5 meters in their longest dimension.

Brecciated barite, cemented by the same mineral, is exposed in one locality on the southwest shore of Ilha Pequena. It is the only indication of possible faulting in the area. No displacement could be discerned.

Most of the conglomerate and arkosic sandstone exposures are weathered, and pointing is not noticeable. The dolomitic limestone has been brecciated and recemeted, probably owing to dolomitization. Superimposed on the older features is a rude, widely spaced jointing, breaking the limestone into large blocks several meters in width. Slump of blocks and solution of faces prevent accurate determination of jointing directions.

Irregular fractures in the barite, containing veins of crystalline barite, show that one period of stress occurred near the end of barite mineralization. As structures within the barite bed are not related to the jointing, it is concluded that the major folding, which produced the joint sets, must have followed the close of mineralization. It follows that present structures have no direct control on ore distribution. No further evidence on the age of folding was seen in this area.

PHYSIOGRAPHY

The most noticeable physiographic features in this area indicate a change in the level of the land. The estuaries forming the main part of Camamú Bay clearly point to submergence as the dominant land movement. The cliffed limestone exposures and the offshore stacks at the north end of Ilha Grande confirm this conclusion. The main part of the island, however, is covered by a sand plain rising to several meters above mean sea level, and coral and other Recent shell material are found more than one meter above high-tide level. Possibly these features indicate that the most recent movement was a slight emergence of land.

MINERAL DEPOSITS

MINERALOGY

Barite is the only important mineral on Ilha Grande and Ilha Pequena. Associated with the barite are minor amounts of quartz, marcasite, galena, iron oxides, and sulfur. Small quantities of strontium, calcium, aluminum, and magnesium appear in chemical analyses, but minerals carrying these elements have not been identified either in the field or in the laboratory. Residual constituents of partly replaced arkosic sandstone are found occasionally in barite.

BARITE

Crystalline aggregates of barite are known to possess a wide variety of forms. In the Camamú Bay deposits, the barite is fibrous, granular, and crystalline. Fibrous aggregates are fine-grained and form spherules, nodules, or crustiform laminae. (See pls. 5 and 6.) Granular barite varies from microcrystalline to fine-grained and may be found either with fibrous barite or in granular masses. Crystalline barite occurs as individual crystals or as massive intergrowths and sometimes is transitional with lamellar barite. The fibrous barite is a replacement of arkosic sandstone; the granular and crystalline barite fill vugs or open fissures.

The bulk of the deposits consists of finely fibrous aggregates in crustiform and subparallel irregular laminae that grade into nodular forms. (See pls. 5*A*, 6 *B*.) Another type of fibrous aggregate consists of closely packed spherules. (See pl. 5*B*.) The basic structure of the barite, as seen in thin section, consists of microcrystalline to fine-grained fibers combined in radiating sheaves. In the initial stages of replacement, groups of microcrystalline fibers are unoriented. At later stages of replacement, the radial sheaves develop, either as crusts or as spherules. All these structures have radial extinction under crossed nicols. (See pl. 7.) Both nodular and laminar barite aggregates consist of two distinct parts, a core consisting of an aggregate of fine-grained spherules, and an enveloping crust consisting of an aggregate of fine-grained fibrous radiating sheaves. (See pl. 7*B*.) The core material may include also a minor amount of barite ranging from that which is cryptocrystalline to a very fine grained, granular barite deposited between spherules; the granular barite is later than the fibrous barite. The crustal material terminates in normal crystal faces at the surfaces of laminae or nodules.

Megascopically, the core material is dead-white in color and usually is spongy (pls. 6, 7, 8), although occasionally it is compact (pl. 8*A*). It is always soft and sometimes it is actually chalky. The crustal material is banded normal to the fibers and therefore parallel to the growth. The banding is marked by an alternation of glassy and translucent white layers, the latter being somewhat less porous than the former. (See p. 21.) In thin section, the banding is marked by a difference in transparency, but not by breaks in crystal growth (pl. 7).

The aggregates of fibrous material occur in three principal megascopic textures, all being gradational with one another. They are: (1) small, closely packed spherules or globules; (2) crustiform subparallel and irregular laminae; and (3) nodular aggregates.

(1) The spherulitic barite usually is compact. (See fig. 7–*B*.) The spherules are from 2 to 3 millimeters in diameter but may be smaller, especially in denser material. The slightly vuggy material may include microcrystalline granular barite between spherules. The spherulitic barite differs from laminar and nodular barite in that it is not enveloped by crusts of fibrous radiating sheaves. Where it grades into laminar material, crusts do develop. This type of barite occurs at the base of individual barite beds. (See below.)

(2) Laminar barite (pl. 5*A*) is made up of subparallel irregular plates, each of which consists of a layer of core material enveloped by layers of fibrous barite. Individual plates may be solid or may consist of a number of semicoalesced "buttons." Thicker plates may show growth bands in the fibrous layers, parallel to the surfaces of the plates. The usual plates are from 5 to 10 millimeters thick. The spongy white core is from 1 to 3 millimeters thick, and the fibrous bands are from 2 to 4 millimeters thick on each side of the core. The laminae may be contiguous or as much as 10 millimeters apart; nodular protuberances develop where as little as 3 millimeters of vug space separate the laminae. (See pl. 6*B*.) The laminae are subparallel and apt to be contorted. Where thin laminae are badly contorted, the cross-section of the rock is very similar in appearance to coarse-grained spherulitic barite.

(3) Nodules consist of the usual cryptocrystalline spherulitic core material, surrounded by radial, sheaflike aggregates of fibrous material. (See pl. 6 *A*, *B*.) Noting that the basic crystalline structure is radial, it is readily understandable that nodules develop from laminar barite wherever vug space permits. Larger nodules develop botryoidally (pl. 6 *A*), and in thin section this structure is seen to be marked by sutures between adjacent groups of radial fibers. (See pl. 7 *B*.) Nodules may be as small as 3 millimeters in diameter and range up to 80 millimeters in diameter. In the larger nodules the microcrystalline core may be as much as 6 millimeters thick and the fibrous barite as much as 38 millimeters thick.

Surfaces of laminae and nodules appear frosted, due to fine crystal terminations. Crystal terminations of laminae and small nodules are equidimensional, but larger nodules may have crested terminations, indicating that the fibrous material develops into columnar barite where growth is greater.

The barite deposit is conspicuously bedded. (See pl. 7 *C*.) Beds are from 0.20 to 2.0 meters thick; some cuts show as many as seven beds across a given exposure. The three textures described above are associated with definite parts of any given bed. The compact spherulitic barite always occurs at the base of the bed. It grades upward into the vuggy laminar barite, the laminae usually developing at an angle to the compact bedding material; this gives a cross-bedded appearance to the beds. Nodular barite is usually most common at the top of the bed. The compact spherulitic material may range in thickness from 3 to 15 centimeters. The thickness of laminar barite is dependent on the width of the bed and also on the relative amount of nodular barite. The distribution of nodular barite is irregular. Some parts of any one bed may have much; other parts may have none, in which case the laminar variety extends to the overlying bed. Thus the porosity of the barite is constantly variable; it is judged to be from 5 to 10 percent in almost all beds.

In contrast to the gradation of spherulitic bedding material into laminar material at the base of any given barite bed, there is always a clean break between laminar or nodular barite and the spherulitic bedding material of the overlying bed. Both nodules and laminae may be distorted where they abut against this overlying material.

The barite described above is usually pure and ordinarily contains no contaminating minerals. Should such minerals be present, they always occur in very small amounts, except at the fringes of the deposit, where barite replaces arkosic sandstone. Such minerals include (1) unreplaced constituents of arkosic sandstone, (2) minute amounts of hematite, (3) small scattered galena crystals. All other impurities are in the vugs between laminae and nodules and are discussed in more detail below.

(1) In several localities along the north shore of the Ilha Grande barite area, barite replacing arkosic sandstone can be seen. The sandstone contains quartz, albite, microcline, muscovite, biotite, limonite, clay, and secondary dolomite. The feldspars are partly altered. Barite replaces all, starting as a mass of unoriented fibers (p. 16) and then developing as spherules and crusts (pl. 8*C*). Apparently the unoriented fibers are themselves replaced by the spherules and crusts as mineralization progresses. In several thin sections examined, the unreplaced arkose makes up at least 25 percent of the rock. Elsewhere, unreplaced material in barite is rare, although some thin sections show a few grains of quartz (pl. 8*C*) and aggregates of sericite flakes (probably from alteration of feldspars). Such impurities occur both in the core and in the fibrous portions of the barite.

(2) Hematite in minute amounts may be disseminated as small particles throughout the barite, giving the mineral a strong pink color. All the barite cut in trench 12 (fig. 3) is pink, but elsewhere

hematite as an impurity is rare in the barite itself. Greater amounts of hematite occur in vugs between barite aggregates. (See p. 20.)

Galena occurs occasionally as small euhedral crystals scattered between growth bands of the outer layers of some larger nodules. This impurity is found only where comparatively large amounts of marcasite and galena were introduced following the close of this period of barite deposition.

Granular and crystalline barite occur in veins cutting the bedded deposits and therefore are products of a later stage of the mineralization. They occur also in the vuggy portions of the bedded deposits. Most conspicuous is crystalline barite; associated with it in veins is granular and lamellar barite. The crystalline barite is clear and has a glassy luster; it occurs usually as massive intergrowths with crested surfaces. Euhedral crystals are frequent and show many crystal forms (Tavera Filho, 1946); these crystals have a maximum length of 50 centimeters. In veins, the crystalline barite may form directly on the walls, or it may be separated by a thin crust of granular barite with a glassy luster or by lamellar barite. The lamellar barite occurs as aggregates of curved scalelike plates or in arborescent growths. The lamellar barite usually grades into clear crystalline barite toward the middle of the fissures. Crystalline barite occurs also as druses in the vugs between laminae and nodules. The crystals are usually smaller in such vugs, ranging in length from 1 to 20 millimeters. A layer of sulfides or their oxidized equivalents may separate the crystalline barite from the underlying fibrous barite. Barite crystals occur also in clay below the main barite bed. They may occur individually or may form stringers or lenses of crystalline intergrowths. The stringers are usually less than 0.20 meter thick, but in one locality (trench 15, pl. 2), a lens 0.50 meter thick and 5 meters long down dip was seen.

The crystalline barite veins form but a very small part of the bulk of the deposit. Their relative percentage varies, being dependent on the extent of open fractures at the time of mineralization. W. D. Johnston, Jr., in a personal communication, estimates that crystalline barite forms about 1 percent of the deposit, and agrees with their estimate.

Still another variety of barite is occasionally seen. It has ropy reticulate structure and sometimes it is crustiform. It is very vuggy and may have quartz in the vuggy parts. This type of barite is deposited on crystals or on nodules of barite, and its position indicates that it is the last stage of barite deposition. In quantity it is unimportant.

A rather unusual feature of the barite is its form of weathering. Barium sulfate is soluble in pure water, in concentrations of 1 : 400,000 at the base of crystal druses and between the outer growth bands of some nodules the mineral is distinctly corroded. Inasmuch as the corroded barite is found always in the position in which sulfides occur, such corrosion may accompany the solution and removal of the sulfides.

Another variety of weathering is the break-down of the microcrystalline or the very fine-grained spherulitic barite of the core material into chalky powder. Under the microscope, in plane-polarized light, certain spherules are seen to be much more opaque than others. (See pl. 8 *B*.) They correspond to chalky spots seen megascopically on the cut face of the hand specimen. The reason for this break-down is not known.

Some nodules contain many pits and hemispheric depressions, of which some are coalesced. Under the microscope the barite fibers are seen to bend toward these pits and the fibers are all terminated by crystal faces (pl. 7 *B*); therefore, these features are primary.

ASSOCIATED MINERALS

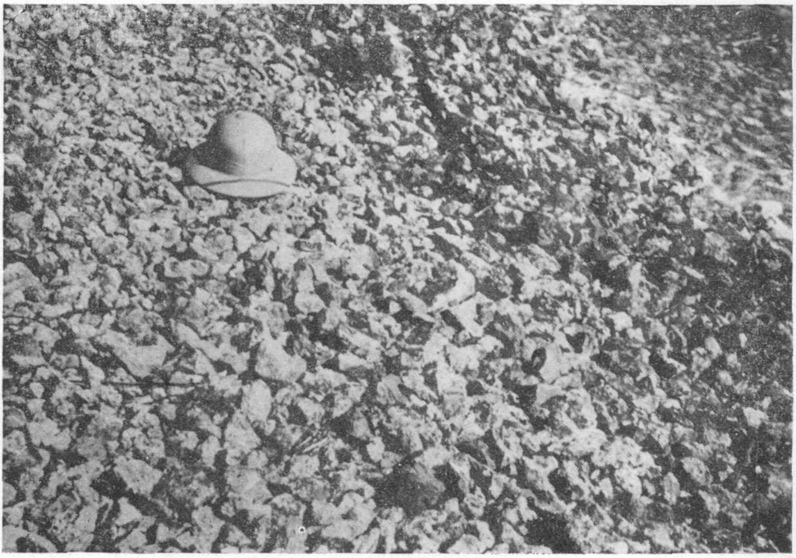
Galena occurs in limited amounts as small crystals on the surfaces of barite nodules and more sparingly between growth bands of the nodules. (See p. 19.) The crystals, always about 1 millimeter in diameter, are never more than 5 millimeters below the surface of nodules. They are always isometric cubes.

Marcasite forms thin crusts and small rosettes directly on the surface of barite laminae and nodules, or on the galena if it occurs. The crusts and rosettes are usually thin but are occasionally as much as 3 millimeters thick. Marcasite weathers readily and is seen only in fresh exposures.

In the initial stages of marcasite weathering, sulfur is released. Sulfur is not common on barite seen in place, but specimens rich in marcasite developed strong blooms within 5 months after they were collected.

Limonite and hematite have widespread distribution in the barite beds. These minerals form but a small percentage of the barite deposits but conspicuously stain the surfaces of barite laminae and nodules. Occasionally hematite is disseminated in the barite itself. (See pp. 18–19.) Other than the disseminated hematite, these oxides are the weathering product of marcasite, and their distribution is indicative of that of the marcasite, although they tend to have wider distribution than the less-soluble sulfide. Limonite and hematite occur in veins in the clay underlying the barite and in veins occupied by barite crystals. It is not known whether this material is primary here or an alteration of some other mineral. In the clays and in the veins the limonite and hematite are earlier than the crystalline barite.

A



B

A. SLUMP BLOCKS OF BEDDED BARITE AT SLIGHT ANTICLINAL NOSE ON THE SOUTH SHORE OF ILHA GRANDE.

The blocks average 1 meter in length.

B. BARITE BEACH SHINGLE, SOUTH SHORE OF ILHA GRANDE.

Quartz usually may be found as drusy crystalline crusts lining the vugs between barite laminae and nodules. It is crystalline and usually clear and colorless but is occasionally amethyst-tinted. The crystals range in length from 1 to 10 millimeters. Large crystals are singly terminated, but small doubly terminated crystals are found. Fine-grained quartz sinter occurs in the clay, associated with hematite, limonite, and barite crystals.

PETROLIFEROUS MATERIAL

In many parts of the Camamú Bay region petroleum seeps are found. Asphaltic crusts are seen on the west shore of central Ilha Grande, and the well on Ilha Pequena was drilled because of the seeps present in this area. Apparently a seep has worked into some of the barite now being mined on Ilha Grande. The oil has followed cracks into the barite and also has soaked the mineral to some extent, staining it dull brown. In part the staining is selective, for alternating growth bands of some nodules are stained. It is believed that this differential staining indicates different porosities in the growth bands (p. 16).

CLAY

Clay has worked into the barite beds from the overlying soil. It is found along joints, irregular fractures, and in vug space between laminae and nodules. At present it amounts to several percent of the uncleaned material, but it could be washed from the mined product.

PARAGENESIS

Barite, mostly as fibrous aggregates, was the first mineral to be deposited Before barite deposition was completed, galena was deposited sparingly, and at the end of the first period of barite deposition larger amounts of galena were deposited. Marcasite followed, after which the deposits were fractured and more iron minerals, now represented by limonite and hematite, were deposited. Subsequently, crystalline barite was deposited in the open fissures and in vugs. Barite with reticulate structure was the last of the barite to be deposited. Drusy crusts of quartz were deposited on all preceding minerals, with the possible exception of the reticulate barite. The marcasite weathered to limonite or hematite, and this process is continuing at the present time, sulfur being the first mineral to be liberated during the decomposition. The mineralization was probably effected by low-temperature hydrothermal waters (p. 29).

DESCRIPTION OF THE DEPOSITS

STRUCTURE, SHAPE, AND SIZE

The major and minor structures of the deposit have been described, as has the texture of the barite and the appearance of individual barite beds. (See pp. 15–17). The deposit consists of a number of superimposed beds of various thicknesses and numbers. Exposures are usually not adequate to correlate these beds. The beds are from 0.20 to 2.0 meters thick; the maximum thickness is found only in slump blocks of massive barite, and the figure may be slightly high. On the south shore of Ilha Grande the basal bed is from 0.75 to 1.0 meter thick at the east end and thinner westward. It is overlain by thinner beds, usually between 0.2 and 0.3 meter thick. Two trenches in this area cut seven beds, but elsewhere fewer beds are exposed, probably because erosion has stripped the upper ones. The maximum thickness of barite is 4.3 meters (trench 4), where the deposit comprises seven beds.

The writer believes the barite deposit thins to the northward on Ilha Grande. In the northern deposits, barite replacing arkosic sandstone can be seen (pp. 15–16, 18) ; therefore the deposit probably lenses out in this direction. No mineralization occurs on the rest of the island. Vertical outcrops in the westernmost trenches along the south shore seem to be as little as 1 meter thick; therefore, the deposit apparently thins in this direction as well. The deposit is 4 meters thick along the beach of southwest Ihla Pequena, 1,700 meters south of Ilha Grande, so it appears that the thickness is fairly constant in that direction.

The barite deposit has been gently folded with the rest of the stratigraphic sequence and at present occupies a dip-slope position facing the hills. Fluvial erosion has stripped barite from the crests of some structures, and marine erosion has cut away some of the deposit along the beach, especially where anticlinal noses have projected beyond the main line of outcrop. Undoubtedly barite originally covered all the anticlines and domes (pp. 13–14) ; it is not known how much remains. Beyond the trenched areas, outcrops are small and scarce. The inferred limit of barite (pl. 2; fig. 3) is based on those few outcrops. The shape of the body available for mining will be known only after extensive trenching of all hills in southwester Ilha Grande and Ilha Pequena. Potentially, barite may underlie the entire area shown by the symbol "Kcgl?" on the map (pl. 2). This symbol designates areas believed to be definitely underlain by arkosic conglomerate and quite possibly by barite.

Outcrops of the barite are smooth or blocky. The barite breaks readily along regular joint planes and along bedding planes (pp. 16, 18), so that dip-slope outcrops along the beach are surfaced by bedding planes except where the upper beds are partly eroded and bounded by joint planes. On the hills, the outcrops consist of individual joint blocks or a group of separated blocks. In trenches it can be seen that the erosion of barite proceeds bed by bed. Outcrops are

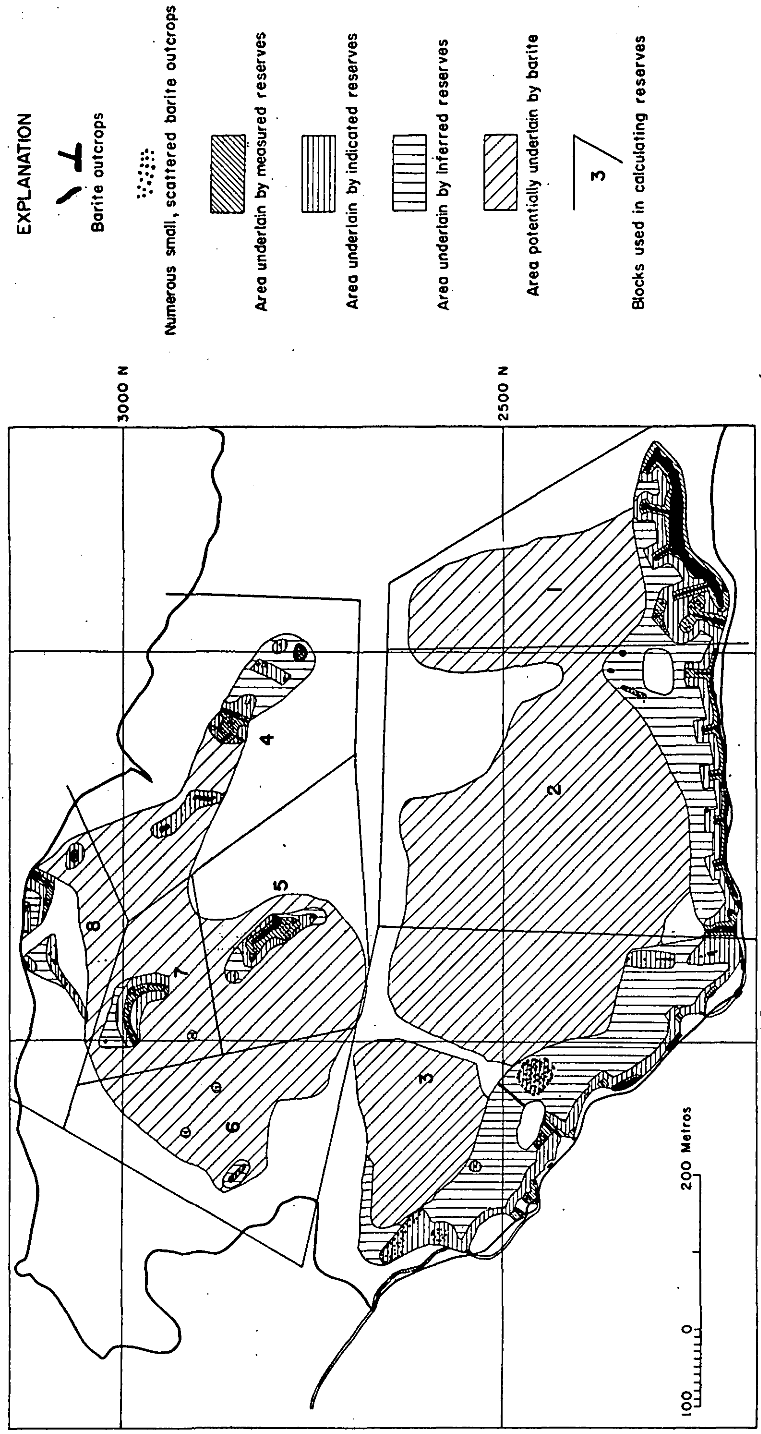


FIGURE 3.—Reserves map, Ilha Grande barite deposit.

sometimes white in color but are usually stained yellow or buff by clay and limonite. These impurities can be easily removed. Barite containing hematite and limonite veins is much darker in color, and special treatment would be required to remove such impurities.

The overburden is variable in thickness (p. 3), and in the trenches consists of half a meter to 3 meters of clayey soil. Where topography is uniform, the minor structural troughs (p. 14) in the barite bed are covered to a greater depth than the structural highs.

The area underlain by barite is extensive: 2,950 meters from north to south by 1,700 meters from east to west. On Ilha Grande nearly continuous outcrops are found along the south shore of the barite area for a length of 1,340 meters. The bed continues westward and is seen at the edge of the mangrove swamp 130 meters beyond the minable area on the island. The maximum observed width of exposures on the south-shore structure is 140 meters, and potentially the barite may extend across the entire hill, which is about 400 meters wide. The north-shore structure has outcrops over an area 700 meters from east to west by 370 meters from north to south. The actual configuration of this part of the deposit cannot be determined from the scarce outcrops.

Barite outcrops circumscribe much of Ilha Pequena and have a strike length of 2,900 meters. It is expected that systematic exploration wil locate dip-slope bodies on the flanks of hills in the interior.

An unusual deposit of barite occurs on the south shore of Ilha Grande. It consists of pebbles and small boulders of barite eroded from the deposits on the hillside above and rounded by wave action. (See pl. 4 *B*.) This area of shingle is 1,175 meters long and from 6 to 17 meters wide as measured to the low-tide mark. On the basis of a cross section of a lenslike body of nearly 3 meters vertical extent, wedging out at the low-tide mark and at the upper level of the beach where the barite in place dips below it, the thickness is estimated to average at least 1 meter. Many of the impurities have been removed by abrasion and washing, and the material is much cleaner than the barite in place on the hillside above. The western 230 meters of the shingle contain some weathered quartzite and shells. (See p. 11.)

GRADE

Analyses of Camamú barite indicate that the rock contains from 77 to 97 percent barite. The sample containing the 77 percent barite was found in the area of partial replacement on the north shore of the Ilha Grande deposits. (See p. 18.) All the other samples analyzed above 84 percent (tables 1 and 2), and the statistical average of Ilha Grande samples is 89.5 percent barite.

TABE 1.—*Analyses of barite, Camamú Bay, Bahia, Brazil*

[Analyses by the chemical laboratory, Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil. Specimens C-1 to C-7 and C-17 to C-21, inclusive, analyzed by David Goldstein, analysis No. 7734, reported Feb. 5, 1947. Specimens C-8 to C-16, inclusive, analyzed by Maria Yelda Esteves Ramos, analysis No. 7722, reported Jan. 16, 1947]

Sample No.	Trench No.	Description	BaO	SO_3	$BaSO_4$ [1]
C-1		Average mill run, month of March 1946	60.6	32.3	92.2
C-2	(2)	Channel sample, 1.90 meters [3]	61.2	32.5	93.1
C-3	[4] 4	Channel sample, 4.30 meters	60.4	31.9	91.9
C-4	5	Channel sample, 2.10 meters	59.5	31.7	90.5
C-5	6	Channel sample, 1.40 meters	60.6	32.6	92.2
C-6	7	Channel sample, 1.90 meters	60.4	32.1	91.9
C-7	8	Channel sample, 1.35 meters	57.6	30.8	87.6
C-8	9	Grab sample from excavated material	59.3	33.2	90.2
C-9	10	Channel sample, 1.80 meters	56.3	33.3	85.7
C-10	11	Channel sample, 1.10 meters	57.5	33.4	87.5
C-11	12	Grab sample across width of bed	55.5	31.3	84.4
C-12	14	Grab sample along dip-slope of bed	59.4	33.2	90.3
C-13	15	Channel sample, 1.60 meters	58.1	32.8	88.5
C-14	17	Channel sample, 1.50 meters	55.5	33.2	84.4
C-15	18	Channel sample, 1.00 meters	56.4	32.6	85.9
C-16	25	Grab sample, excavated material and outcrops	50.9	29.3	77.4
C-17	26	Grab sample, excavated material	62.4	33.2	94.9
C-18	27	Grab sample across width of bed	62.2	33.2	94.6
C-19	28	Grab sample along both dip and strike	62.9	33.9	95.7
C-20	29	Grab sample along dip-slope and across width of bed.	61.6	33.2	93.7
C-21		Composite of samples C-2 to C-20, inclusive	60.3	32.1	91.8

[1] Analyzed separately; does not represent total of BaO and SO_3.
[2] This sample was taken from mine.
[3] All channel samples across exposed width of barite bed.
[4] Trench numbers according to plate 2, Ilha Grande barite deposit.

TABLE 2.—*Analyses of barite, Camamú Bay, Bahia, Brazil* [1]

[Analyses C-3, C-9, C-13, C-19, and C-78 by Glen Edginton, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture, March 1947. Analysis A by E. I. duPont de Nemours Co., Wilmington, Del.; reported Jan. 24, 1945. Analysis B by Ledoux & Co., New York, N. Y.; No. 561,021. Analyses C and D analyzed privately for Pigmina S/A in Rio de Janeiro]

	C-3	C-9	C-13	C-19	C-78	A	B	C [2]	D [2]
BaO	57.60	58.65	58.92	60.02	57.30				
SrO	.45	.91	1.25	1.37	1.31				
CaO	.50	.32	.34	.48	.69		0.07		
MgO	0	0	0	0	.04		.14		
SiO_2	2.09	1.71	2.25	1.37	6.86	4.29	1.52		
R_2O_3	4.59	3.62	2.80	1.64	.10				
SO_3	32.35	32.79	32.94	33.88	32.53				
$BaSO_4$						93.52	96.43	97.0	94.4
Fe_2O_3						1.37	.94	.5	1.3
Al_2O_3							.10		
Mn_2O_3						.003			
F						.002			
$SrSO_4$						1.96			
$CaSO_4$						.22			
Ig. loss	.90	.71	.71	.41	.12		.62		
Total	98.48	98.71	99.21	99.18	98.95	101.365	99.82		

[1] Analyses A through D through the courtesy of Luiz Oscar Taves, president, Pigmina S/A.
[2] Incomplete analyses; no total given.

A comparison of tables 1 and 2 shows a discrepancy between the results of two laboratories in the analyses of samples C-3, C-9, C-13, and C-19. This discrepancy is probably due to the different techniques used by the chemical laboratory of the Departmento Nacional da Produção Mineral and the laboratory of the Bureau of Plant

Industry, Soils, and Agricultural Engineering, United States Department of Agriculture. The chemical procedure is difficult and a difference of several percent is noted in analyses of comparable specimens.

Table 1 gives the analyses of barite sampled by the writer. Where possible, channel samples were cut across the exposed width of the barite bed. Clay in the barite was included in the channel samples because the ore is ground without beneficiation.[3] (See p. 29.) Much of the relatively high R_2O_3 content in specimens C–3, C–9, C–13, and C–19, in table 2, is due to this clay, and the grade of ore obviously could be beneficiated several percent by simple washing before milling.

The silica content of the barite is dependent on the amount of included clay and also of quartz. (See p. 21.) Specimen C–78, in table 2, is almost completely free of clay, as indicated by the low R_2O_3 content. The 6.86 percent SiO_2 therefore represents quartz. This specimen is very vuggy and contains late quartz (p. 21) between the lobes of nodules. It is doubtful that the quartz content of even small tonnages would ever reach this maximum figure, however, because in all observed sections across the barite bed, quartz never occurred persistently in such amounts.

The strontium content ranges from 0.45 to 1.37 percent SrO; the strontium does not occur as celestite and therefore is probably distributed throughout the barite as a substitution for a small part of the barium. The calcium content, ranging from 0.07 to 0.69 percent, probably occurs as finely disseminated calcite, but calcite was not seen in microscopically studied specimens. Specimens from the northwest corner of the Ilha Grande deposits contain conspicuous amounts of dolomite.

Because the product is designed for heavy specific-gravity specifications, the iron minerals are not injurious and all the barite can be mined without selection or beneficiation. Should pure white material be desired, however, some of the barite would have to be treated to remove the iron oxides and sulfides.

RESERVES

Reserves are given in table 3. Tonnages are calculated with a specific gravity of 4.0. This figure, 7 percent below the mill-run of the ore, allows for porosity, which ranges between 5 and 10 percent. (See p. 18.)

For convenience, the barite area on Ilha Grande has been divided into eight blocks and the tonnages have been calculated for each block. Figure 3 shows the blocks, the areas used to calculate each

[3] Since the middle of 1947 the ore has been washed to remove the clay.

category of ore, and areas where exploration should be made for future development.

Volumes of barite were calculated as follows:

Measured barite. Based on good outcrops and trenches; extended 5 meters beyond the limits of the measured areas. Thicknesses are averages for the block.

Indicated barite. Based on areas with many small outcrops and the areas extending 10 meters beyond measured ore areas. Thicknesses used are generally less than for measured ore because of the possibility of erosion of the barite body. (See p. 22.)

Inferred barite. Based on areas which, from geologic inference, are probably underlain by barite. A thickness of 1 meter was assumed in most cases.

TABLE 3.—*Barite reserves, Ilha Grande*

Block	Area (square meters)			Thickness (meters)			Tonnage			
	Measured	Indicated	Inferred	Measured	Indicated	Inferred	Measured	Indicated	Inferred	Total tonnage
1	8,350	6,525	4,735	3.0	3.0	2.0	100,000	78,500	38,000	216,500
2	4,605	5,734	17,161	2.0	1.5	1.0	36,800	34,400	68,800	140,000
3	2,854 459	15,326	35,120	1.4 1.0	1.0	1.0	16,000 1,830	61,400	140,500	219,730
4	1,413	4,362	3,225	1.5	1.0	1.0	8,500	17,500	12,900	38,900
5	1,600	1,600	1,300	2.0	1.0	1.0	12,800	6,400	5,200	24,400
6		150	706		1.0	1.0		600	2,820	3,420
7	1,600	2,313	1,015	2.0	1.5	1.0	12,800	13,900	4,060	30,760
8	675	3,225	1,750	1.0	1.0	1.0	2,700	12,900	7,000	22,600
Total							191,430	225,600	279,280	696,310

The known reserve underlies an area of 125,800 square meters, or 12.58 hectares. In comparison, the area potentially underlain by barite is 31.3 hectares. Reserves of less than 40 percent of the area can be calculated from the present known outcrops and trenches.

The length of outcrop along the shores of Ilha Pequena is 2,900 meters, and the hilly area covers about 75 hectares. No reserve figures are given for this island because it has not been mapped.

The beach shingle deposit on the south shore of Ilha Grande (p. 24) is 1,175 meters long and averages 13.4 meters in width to the low-tide mark. Using the estimated average thickness of 1 meter, and allowing for 25 percent porosity in the shingle, these data give 47,000 tons indicated reserve. Of this amount, 9,800 tons at the west end of the beach contain at least 10 percent quartz in the form of sandstone or weathered quartzite. The reserve is considered as indicated because the thickness has not been directly measured.

ORIGIN OF THE DEPOSITS

The barite clearly replaces arkosic sandstone (pp. 16, 18) in the northern part of the Ilha Grande deposit. That this is the bed being replaced throughout the area is substantiated by the presence of occasional grains of this same rock in other parts of the deposit (p. 18), and by the presence of thin sandstone beds in the barite on Ilha Pequena. The dolomitic limestone does not contain such sandstone stringers. The well-bedded appearance of the barite also indicates replacement of the arkosic sandstone because the dolomitic limestone is massive. (See p. 13.)

The writer believes that hypogene waters, rather than supergene waters, effected the deposition. Evidence to prove this point includes the following facts:

(1) Barite is an extremely insoluble mineral (1 : 400,000) and the possibility of transportation of barite in large quantities is extremely improbable. Also, more of the soluble minerals extracted from overlying beds should be found in greater quantities in the barite if it was deposited from ground water. For example, CaO apears in only very small amounts. (See analyses given in table 2, p. 25.)

(2) The facts that the area of deposition is limited and that the barite body apparently thins northward (p. 22), indicate that the source of barite was concentrated. Had barite been supergene it should be found in all exposures of arkosic sandstone on Ilha Grande. Veins of crystalline barite likewise occur only within the mineralized area.

(3) The strong alteration of the arkosic conglomerate beds below the barite (pp. 11–12) indicates that the passage of solutions was from below instead of from above. In contrast, arkosic sandstone having very similar composition to the arkosic conglomerate is very fresh beyond the area of mineralization. If supergene waters were responsible for the mineralization, the two rocks should be equally altered.

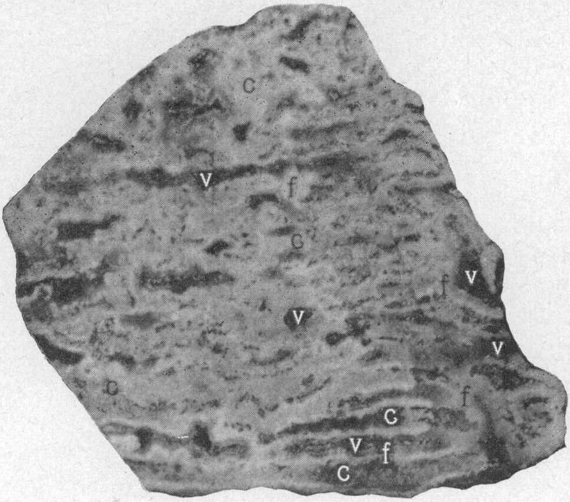
(4) The variable distribution and amount of impurities indicate that the solutions must have come from below, for otherwise the distribution of the sulfides and quartz should be more uniform.

(5) The paragenesis (p. 21) shows that the composition of solutions changed from sulfate to sulfide and back to sulfate, a variation that would be unlikely in supergene mineralization.

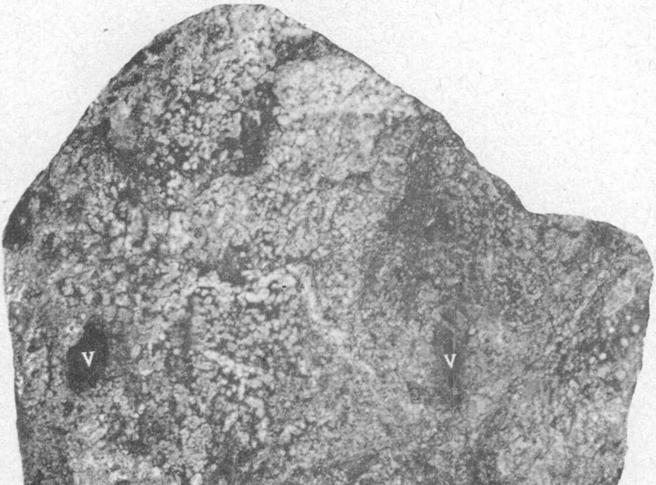
(6) Within individual barite beds replacement progressed from bottom to top and also laterally. (See pp. 17–18.) This is considered fairly strong proof that mineralizing solutions were ascending.

One feature of the deposit that is not easily explained is the texture of the barite. The vug space is considerable and it is difficult to imagine that all the arkosic sandstone was dissolved hardly leaving a trace. The writer cannot account for the laminar growth of the fibrous barite.

The study of these deposits adds little to speculation on the possible composition of barite-bearing solutions. The reader is re-



A

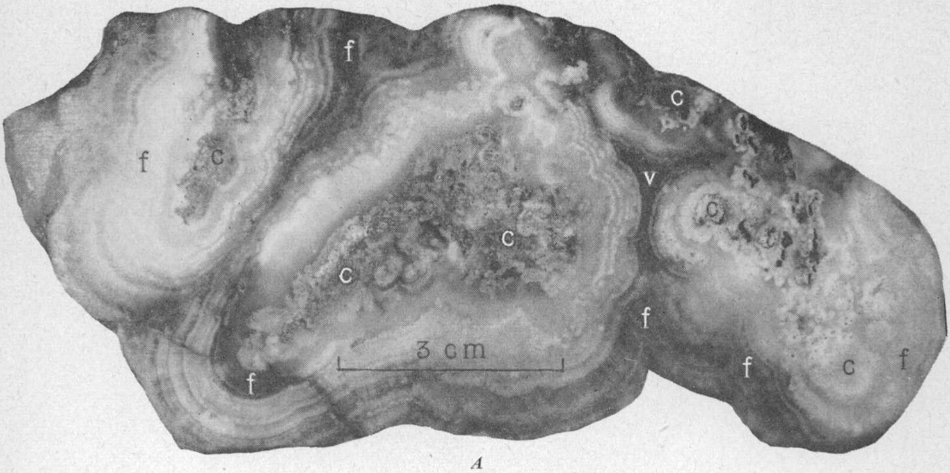


B

A. LAMINAR BARITE.
Typical of bulk of deposits.

B. SPHERULITIC BARITE.
At base of each barite bed. Note absence of laminar material and dense growth.

BARITE OF THE CAMAMU BAY DEPOSITS.
Spherultic core material (*c*); plates of fibrous barite (*f*); vug (*v*).



A

B

A. NODULAR BARITE.

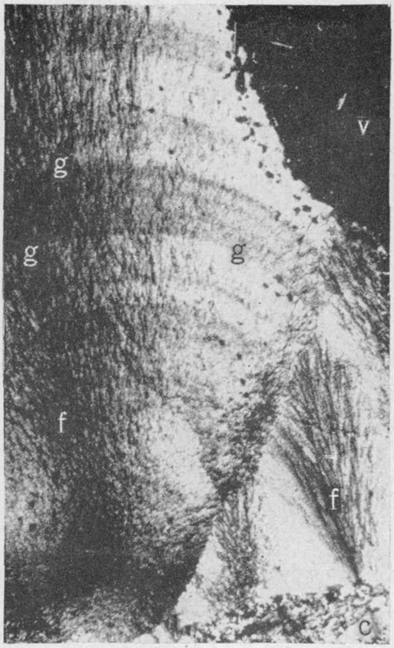
Shows cores of coalesced spherules and has spongy texture; it is surrounded by banded fibrous barite. Spherulitic barite (*c*); fibrous barite (*f*); vug (*v*).

B. SEMINODULAR BARITE.

Transitional between laminar and nodular barite. Shows nodular development of laminae where vug space is available.

BARITE OF THE CAMAMU BAY DEPOSITS.

A



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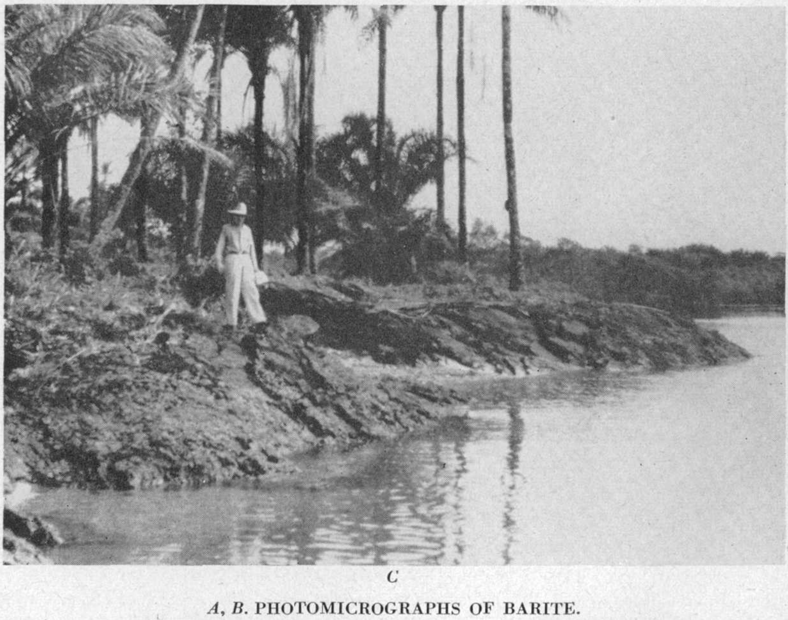


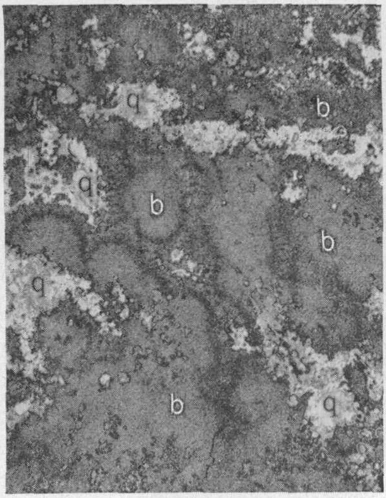
C

A, *B*. PHOTOMICROGRAPHS OF BARITE.

Both photographs show structure of radiating sheaves or fibers, sutures between groups of fibers, and lack of textural break across growth bands. Fibers in *A* are shorter and stouter than fibers in *B*. The prominent vug in *B* is primary. Spherulitic core material (*c*); fibrous barite (*f*); growth band (*g*); primary vug (*v*). Crossed nicols. x 8.3.

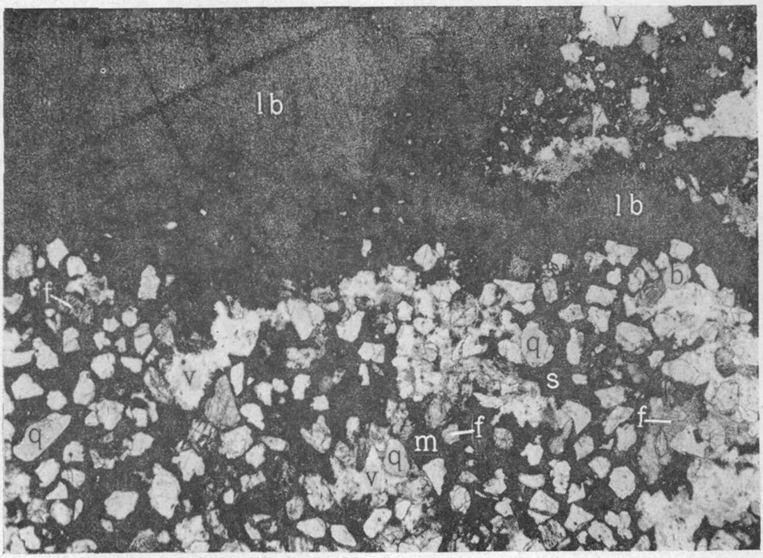
C. BEDDED BARITE, NORTHEASTERN PART OF ILHA PEQUENA.

Barite dipping to right.



A

B



C

A. NODULAR BARITE REPLACING SANDSTONE.

Barite (*b*); quartz (*q*).

B. LAMINAR BARITE.

Spherulitic core material (*c*); laminar barite (*f*); limonite (*l*); crystalline barite (*x*); void in slide (*v*).

C. BARITE REPLACING ARKOSIC SANDSTONE.

Fibrous laminae are growing upward. Barite in lower parts of photograph is spherulitic. Laminar barite (*lb*); spherulitic barite (*s*); quartz (*q*); feldspar (*f*); biotite (*b*); void in slide (*v*).

PHOTOMICROGRAPHS OF BARITE.

Plane-polarized light. x 8.3.

ferred to the excellent paper by B. S. Butler (1919) in which the origin of sulfate solutions is discussed and several mechanisms for the deposition of barite are suggested.

The age of barite deposition can be determined only as preorogenic and postdolomitic if the dolomite in the arkose was deposited at the time of the ingress of magnesia solutions in this area.

The vuggy texture of the barite indicates that the deposition took place at shallow depths. Temperatures of the solutions were probably low, because barite, galena, and marcasite all can be deposited at very low temperatures. The solutions were possibly quite strongly acid.

OPERATIONS AND ECONOMIC CONSIDERATIONS

The barite is being mined from the surface by drilling and blasting and by hand labor. Low-velocity dynamite or black powder is used because the barite is weak and porous. After blasting, the larger blocks are broken by double jacks and the material is loaded by hand into cars having a capacity of 2 tons. It is then hauled to the mill by a Diesel tram. Contract labor breaks the barite by hand using pry bars and double jacks; it is reported that the average man can break and stack 8 tons a day. This rate is possible because the ore is soft and is usually well-jointed and bedded. (See p. 22.)

Mining is done up the slope of the barite bed, and stripping of the overburden, by hand, precedes the mining. The overburden is moved to below the working face in the mined-out area.

The mill, on the east shore of central Ilha Grande, was completed in January 1946. The machinery was obtained from an abandoned Cuban barite operation.

The mine cars are unloaded into a pit, from which a conveyor belt takes the barite into the crushers and grinders. Below is shown the flow sheet of barite through the mill.[4] The mill is powered by 3 diesel-electric engines. Because speed and efficiency of grinding are in large part dependent on moisture in the ore, one of the diesel exhausts is fed into the system to dry the ore. At present the mill grinds 97.5 percent of the ore to 300 mesh at the rate of 6 tons per hour. For shipment, the bagged product is trammed from the warehouse to the pier head.

On a three-shift basis, the mill has an annual capacity of 42,000 metric tons. In the spring of 1946, the mill produced 1,200 tons a month, operating usually with one shift a day. The average sacked product consisted of 92.5 percent barite, with impurities of iron oxide, silica, clay, and moisture. The specific gravity of this product was 4.30.

[4] Courtesy of John Wilson, Mill Superintendent, Pigmina S/A.

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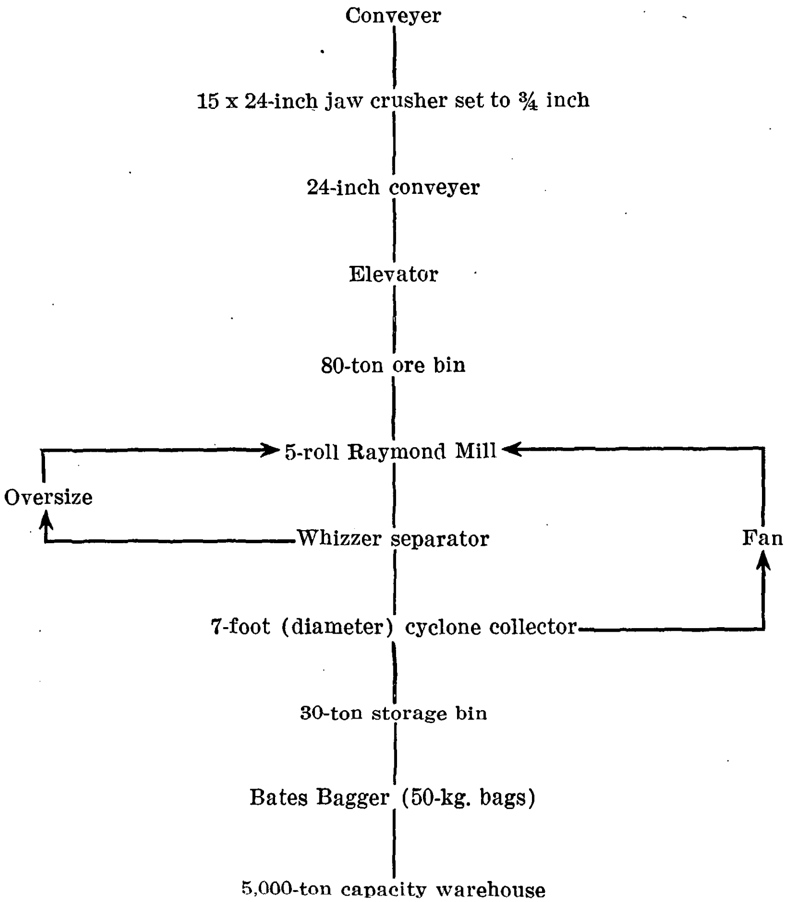

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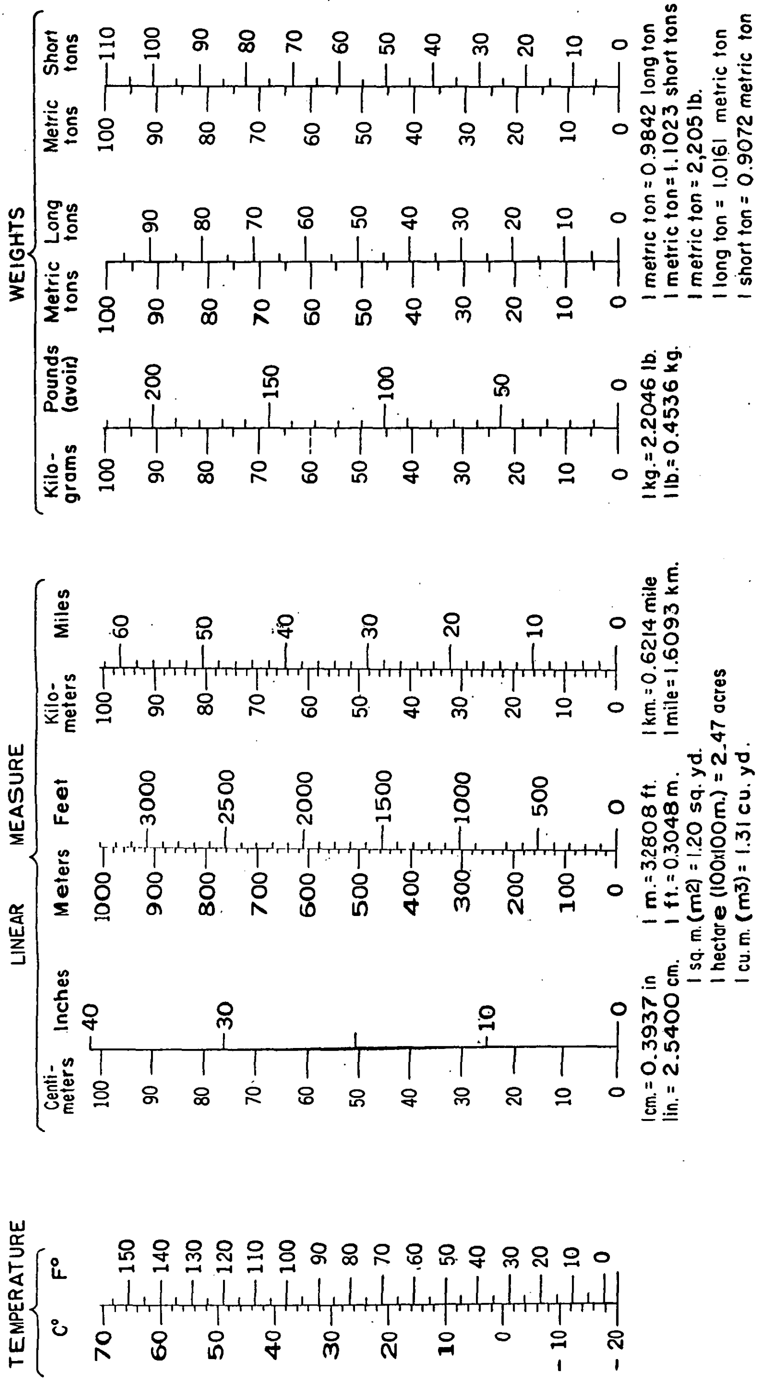
METRIC EQUIVALENTS
TEMPERATURE
C° F°
LINEAR MEASURE
Centi-meters Inches
1cm.= 0.3937 in
1in. = 2.5400 cm.
Meters Feet
1 m.= 3.2808 ft.
1 ft. = 0.3048 m.
1 sq. m. (m2) = 1.20 sq. yd.
1 hectare (100x100m.) = 2.47 acres
1 cu. m. (m3) = 1.31 cu. yd.
Kilo-meters Miles
1 km. = 0.6214 mile
1 mile = 1.6093 km.
WEIGHTS
Kilo-grams Pounds (avoir.)
1 kg. = 2.2046 lb.
1 lb. = 0.4536 kg.
Metric tons Long tons
Metric tons Short tons
1 metric ton = 0.9842 long ton
1 metric ton = 1.1023 short tons
1 metric ton = 2,205 lb.
1 long ton = 1.0161 metric ton
1 short ton = 0.9072 metric ton

INDEX

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