Magnesite Deposits of Central Ceará Brazil

GEOLOGICAL SURVEY BULLETIN 962-C

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By ALFRED J. BODENLOS

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The economic geology of eight magnesite deposits in pre-Cambrian limestone

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THE MAGNESITE DEPOSITS OF CENTRAL CEARÁ, BRAZIL

By Alfred J. Bodenlos

ABSTRACT

Eight magnesite deposits, near the towns of Orós, Alencar, and Jucás are in a northeast-trending belt passing just south of Iguatú, the largest town in central Ceará. All these towns in the valley of the upper Rio Jaguaribe, are from 440 to 480 kilometers by rail from Fortaleza.

This area is underlain by metamorphosed pre-Cambrian rocks, for the most part schist and gneiss but also phyllite, quartzite, and crystalline limestone, all strongly folded and usually dipping steeply. Unconformably overlying are moderately warped, continental Triassic sedimentary rocks and unconsolidated Quaternary alluvial sands and gravels. Some amphibolite dikes and sills, and feldspar porphyroblasts introduced into schistose rocks, are the only evidences of igneous activity.

The magnesite deposits are in pre-Cambrian crystalline limestone. They were formed by replacement of the calcium in limestone or dolomitized limestone by magnesium, which probably was carried by hypogene solutions. The resulting bodies are massive and lenticular, and consist of fine-grained to coarse-grained crystalline magnesite. Only two contain appreciable amounts of residual dolomite; the remaining deposits contain an average of less than 1 percent CaO. The chief impurity in the deposits is talc, which gives an SiO_2 content ranging from 0.5 to 21.0 percent. Except for small blocks where talc is unusually high, the deposits consist of high-grade magnesite. Fe_2O_3 and Al_2O_3 average about 1.5 percent.

Five of the magnesite deposits are more than 1 kilometer long and are from 155 to 450 meters wide. Of the eight deposits, four were mapped in their entirety, and one was mapped in part. Reserves per meter depth of the mapped areas are 251,000 tons measured ore, 421,000 tons indicated ore, and 1,291,000 tons inferred ore, a total of 1,963,000 tons. In addition, about 2,000,000 tons per meter depth may be inferred as the reserve of other deposits which were mapped by the operators.

The deposits were discovered from 1938 to 1943. Production started in 1942; 9,700 tons were mined from 1942 through 1945, of which nearly 4,600 tons were burned to caustic-calcined magnesia in small stack kilns on the properties. The crude magnesite and caustic-calcined magnesia were sent, via Fortaleza, to São Paulo, Brazil, where the products were used by chemical and refractories industries.

INTRODUCTION

Magnesite deposits discovered recently in Brazil occur in two districts, one in the Estado do Ceará, and the other in the Estado da Bahia. The deposits in both districts are large and contain high-grade magnesite. In 1945 and 1946, the Geological Survey studied these deposits in cooperation with the Departmento Nacional da Produção Mineral

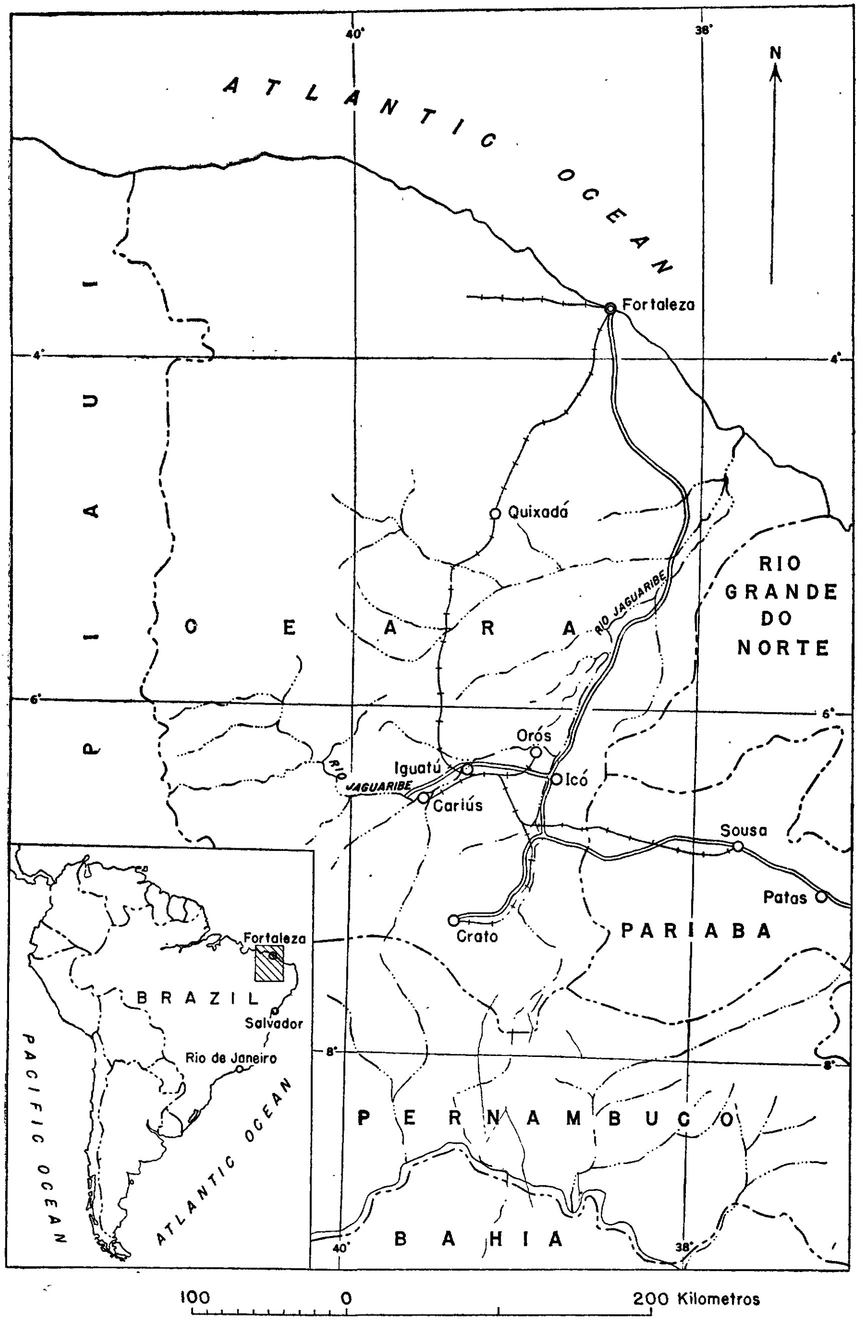

FIGURE 6.—Index map of Estado do Ceará, Brazil.

of Brazil. This report describes the magnesite occurrences in Ceará, in northeastern Brazil.

The deposits are in the vicinity of Iguatú, the largest town in central Ceará, and are approximately 300 kilometers south of Fortaleza, the capital and main port of Ceará (fig. 6). Iguatú is at longitude 39°18′ W. and latitude 6°22′ S. The deposits are near the towns of Orós, Alencar, and Jucás (formerly São Mateus), in a northeast-trending belt passing just south of Iguatú.

The purpose of this study was to investigate the quantity and quality of the magnesite, and the writer concludes that this group of deposits constitutes one of the major reserves of high-grade magnesite in the Western Hemisphere. The ore could be used in the production of any commercial grade of magnesia with little or no beneficiation. Soil and alluvial overburden is thin between widespread outcrops, so all the deposits could be mined from open pits.

OCCURRENCES AND USES OF MAGNESITE

Magnesite, the carbonate of magnesium, has world-wide distribution (Lumsden, 1939; Niinomy, 1930; Himmelbauer, 1933; and Birch, 1937) and occurs either as an obviously crystalline or marblelike material, or as a dense cryptocrystalline aggregate resembling either porcelain or a sedimentary carbonate rock. Crystalline magnesite occurs in many associations, such as the contact aureoles of ultrabasic rocks (Redlich, 1909), veins in schist and ultrabasic rocks (Cockfield and Walker, 1932), and primary constituents in ultrabasic rocks (Barth, 1930); but the only occurrences sufficiently high in grade for mining are massive replacements deposits in dolomite (Callaghan, 1933; Niinomy, 1925; Petraschek, 1932; and Wilson, 1917). The Ceará deposits are of the replacement type. Cryptocrystalline magnesite is found as nodules and veins, chiefly in ultrabasic rocks (Bradley, 1925; von Braunmühl, 1930; Gale, 1913; and Hess, 1908), but also in dolomite or tuff (Faust and Callaghan, 1948; Callaghan, 1933; and Redlich, 1927). Another type of cryptocrystalline magnesite occurs as sedimentary beds (Gale, 1913; and Rubey and Callaghan, 1936). The cryptocrystalline deposits are mined but on a much smaller scale than the crystalline deposits.

Most magnesite is processed for market by burning, or calcining, thus driving off the carbon dioxide and leaving magnesia. Magnesite calcined at low temperatures (600° to 800° C.) results in chemically reactive magnesia known as "caustic-calcined magnesia". Magnesite calcined at high temperatures (1300° to 1700° C.) results in chemically inert magnesia known as "dead-burned magnesite" or "artificial periclase" (Comber, 1937; McDowell and Howe, 1920; and Seaton, 1942).

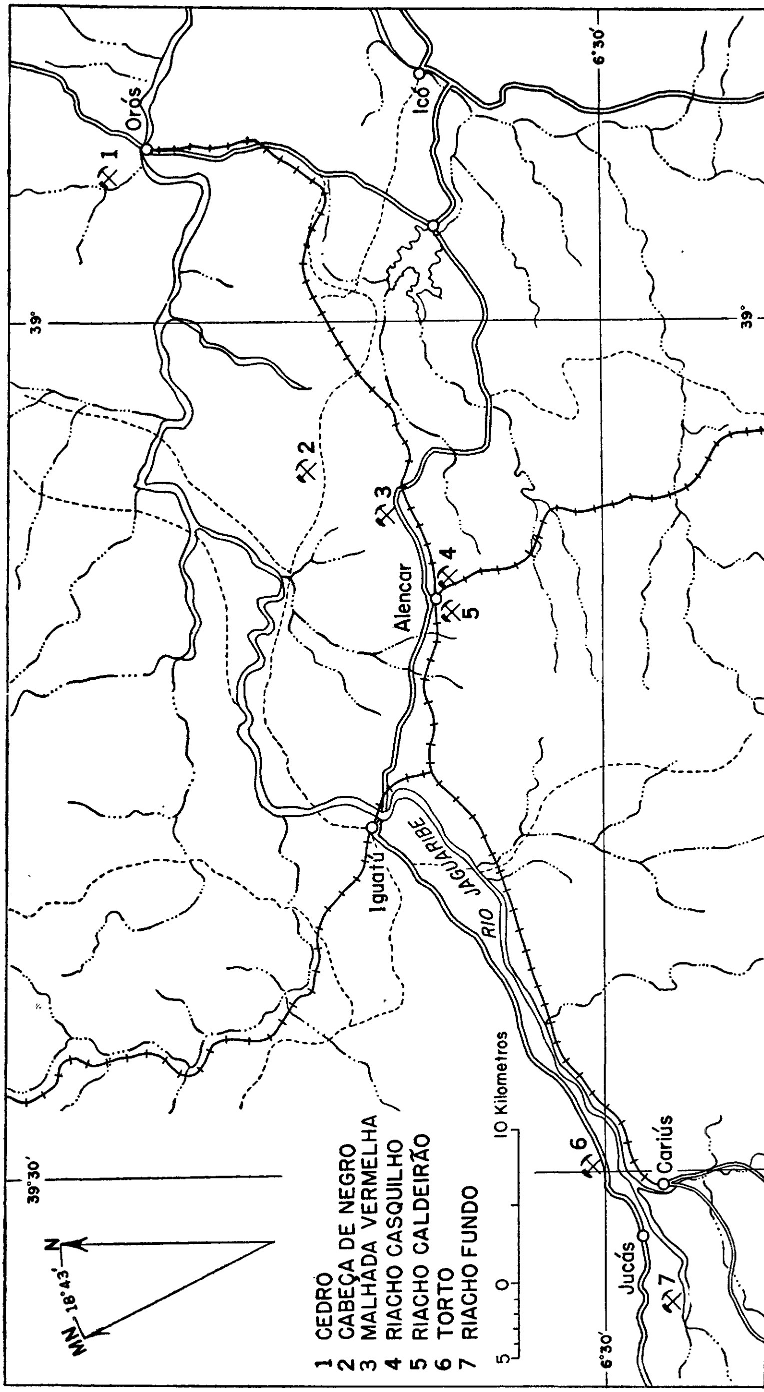

FIGURE 7.—Index map of central Ceará, showing locations of the magnesite deposits.

Caustic-calcined magnesia is used to produce insulating materials and, in the chemical industry, to produce other magnesium compounds and magnesia pharmaceuticals. Chemical combination of the magnesia with magnesium chloride forms magnesium oxychloride cement (similar in composition to the zinc compound, Sorrel cement), a waterproof compound capable of adhering to many types of surfaces and used in stuccos, ship decking, and waterproofing concrete. Magnesium metal is manufactured by the further reduction of caustic-calcined magnesia. Dead-burned magnesite is used exclusively as a refractory material, chiefly in metallurgical furnaces. The largest consumption of all mined magnesite is in the furnace linings of open-hearth steel furnaces.

LOCATION AND ACCESSIBILITY

Iguatú, the largest town in the area, is 416 kilometers south of Fortaleza via the Rêde de Viação Cearense (R. V. C.), the Ceará Railway System. (See figs. 6 and 7.) The part of the railroad serving the magnesite area is the E. F. de Baturité (Baturité Railroad). Alencar is east of Iguatú and on the main line of the railroad and Orós, also east of Iguatú, is at the end of a branch line. Jucás, west of Iguatú, is 4 kilometers from the end of a branch line running between Ignatú and Cariús. All these towns may be reached also via the main highways in the area. Distances via railroad and highway between Fortaleza and these towns are as follows:

	Kilometers	
	Railroad[1]	*Highway*
Iguatú	416	485
Alencar	437	468
Orós	480	460
Jucás	---	521
Cariús[2]	457	525

[1] All measurements in this report are given in the metric system. (See p. 152.)
[2] 4 kilometers southeast of Jucás.

Two deposits are close to Jucás, four in the vicinity of Alencar, and two near Orós. Local access is poor and consists of either unimproved roads or trails leading from the highways to the deposits. A notable exception is the Riacho Casquilho deposit south of Alencar, where the deposit is directly on the main line of the railroad.

GEOGRAPHY

The magnesite deposits, extending along a belt 80 kilometers in length, are in the valley of the Rio Jaguaribe or its tributaries. (See fig. 7.) The largest geographic and physiographic unit is the wide part of the Rio Jaguaribe valley extending from the Serra de Orós at the northeast end to mountains 10 kilometers east of Jucás at the southwest end. This area has low relief with the exception of several disconnected quartzite ridges. The southern boundary is transitional; the valley merges with low hills rising to greater elevations southward. For convenience, this area of low relief will be called the Iguatú basin. At Jucás relief is greater and valleys are comparatively narrow although the major streams have restricted flood plains. At Alencar, near the south side of the Iguatú basin, the Serra de Moraes, a quartzite ridge, rises above gently rolling country. At Orós, the Rio Jaguaribe cuts through a narrow water gap in the Serra de Orós.

All rock units in this area (pp. 129–132), except the ridge-forming quartzite, underlie the areas of comparatively low relief. The altitude of the magnesite deposits is comparable with the surrounding country. The Orós deposits are 160 meters above sea level; the Alencar deposits are on the average 240 meters above sea level; and the Jucás deposits are 270 and 310 meters above sea level. The quartzite ridges rise several hundred meters higher than their surrounding lowlands.

The climate in this part of Brazil is classified as "tropical semiarid" (Ministry of Foreign Relations, 1945). The annual average temperature is 28° centigrade, the humidity is less than 65 percent, and the rainfall is less than 500 millimeters. Normally most rain falls in the months of February and March, but cyclic variations result in a shortened or lengthened rainy season. Every few years the region is subject to disastrous drought which forces most of the population to migrate from the interior. During 1945 and 1946 the rainfall was heavier than usual, and the rainy season started in December. Highway transportation is difficult in the rainy season because the unsurfaced roads are covered with deep clayey mud.

In this semiarid region, water supply is limited. During the rainy season, water for operations at Orós can be obtained from the Rio Jaguaribe or the creek, Riacho Livramento. Local reservoirs and wells can supply water for operations south of Alencar, but it will be difficult to obtain adequate water for operations at the deposits east of Alencar. Water is obtainable from the Rio Jaguaribe for operations at the deposit west of Jucás, but the deposit east of Jucás is in an area having limited surface supply. It seems that water supply for magnesite operations will be a problem during dry seasons or during years of drought.

Agriculture is the chief industry of this area. Cotton is the largest crop and main export, and staple foods and fruits are the other principal products. Much of the flat country, especially that close to the Rio Jaguaribe, is cleared, but the hilly country is brush-covered. The brush is the typical flora of the semiarid regions of Brazil, and is called "caatinga". It grows to a height of 2 to 4 meters, and its thickness ranges from sparse to impenetrable. Spiny shrubs are rare, although some cats-claw, cactus, and spiny palmettos are scattered through the growth. During very dry years the crops fail and much of the brush dies.

HISTORY AND PRODUCTION

The first magnesite discoveries were in the vicinity of Alencar, (the Riacho Casquilho deposit) in 1938. Sr. Germano Paulo Frank, and Eng. Luiz Holanda Montenegro, claimed concessions on the area. After a legal hearing in 1941, Montenegro was granted a concession of 500 hectares on the Riacho Casquilho deposit, and Frank was granted the remainder (Leonardos, 1943). Montenegro also obtained concessions on the Riacho Caldeirão deposit just west of the Riacho Casquilho deposit. Frank joined Eurypides Chaves Mello, and the associates former Chaves & Cia., subsequently reorganized and named Magnesium do Brazil Ltda. The remaining deposits were discovered and claimed by the Chaves group between 1940 and 1943 (d'Albuquerque, 1943).

To calcine magnesite, Montenegro built a special furnace at Alencar in 1942, and Magnesium do Brasil Ltda. constructed stack kilns at Alencar and Orós in 1944. These kilns are small, and for fuel use wood from local sources. They produce only caustic-calcined magnesia. Magnesium do Brasil Ltda. plans to produce dead burned magnesite and began installation of a rotary kiln in Fortaleza during the early part of 1946.

Both Montenegro and Magnesium do Brasil Ltda. have been mining magnesite since 1942; all mining was done by hand. Production was limited because machinery was not available during the war period. In addition, an acute shortage of railroad cars prevented shipment of magnesite products. The operators stated they would mechanize operations as fast as they could obtain equipment.

The production from 1942 to 1945 inclusive is shown in the following table. About 2.2 tons of crude magnesite are required to produce 1 ton of caustic-calcined magnesia, and therefore the 2,077 tons of caustic-calcined material is equivalent to 4,600 tons of crude magnesite. When this is added to the tonnage shipped as crude magnesite, the total production from the mines in 4 years of operation is 9,700 tons. In addition, several thousand tons had been mined and stockpiled at the Cedro, Cabeça de Negro, and Riacho Casquilho deposits when the writer visited the area.

All shipments of crude and calcined magnesite were sent via Fortaleza, to São Paulo in southern Brazil, where the material was used by chemical and refractories industries.

Production in tons of magnesite in central Ceará [1]

	1942	1943	1944	1945	Total
Caustic-calcined:					
Cedro	------	------	166	192	358
Riacho Casquilho [2]	156	350	645	568	1, 719
	156	350	811	760	2, 077
Crude:					
Cedro	------	------	583	684	1, 267
Cabeço de Negro	------	------	150	510	660
Riacho Casquilho [2]	380	443	1, 524	815	3, 162
	380	443	2, 257	2, 009	5, 089

[1] Courtesy of Luiz Holanda Montenegro and Magnesium do Brasil Ltda.
[2] Deposit mined by two companies.

FIELD WORK AND ACKNOWLEDGEMENTS

Dr. José Alves Quesado and the writer studied the deposits from January 19 to February 23, 1946. The joint project was cooperative between the Divisão de Fomento da Produção Mineral of the Departamento Nacional da Produção Mineral, Brazilian Ministerio da Agricultura, and the Geological Survey, U. S. Department of the Interior.

The cooperative work in Brazil is sponsored by the Interdepartmental Committee on Scientific and Cultural Cooperation with the American Republics, under the auspices of the U. S. Department of State.

The emphasis of the study was toward the economic geology of the deposits. Limited field time curtailed areal geologic mapping, so the description of the regional geology is the result of spot studies in the field coupled with study of the literature and of air photos of the region. All the deposits except one were visited. Of these, four were completely mapped by plane table and one was mapped in part. Plane table scales were 1:5,000 with a contour interval of 2 meters, except for the Riacho Fundo deposit which was mapped on 1:2,000 scale with a 1 meter contour interval. Elevations of all but the Riacho Casquilho deposit are barometric and calculated from the nearest bench mark or railroad station. The Riacho Casquilho datum was taken from the official elevation of the Alencar railroad station as surveyed by the Rêde de Viação Cearense. The maps are oriented to true north. Magnetic declinations have been interpolated from the U. S. Army Air Forces Aeronautic Chart No. 1018 (Cape São Roque).

The field work was greatly facilitated by the courteous cooperation and assistance of Luiz Holanda Montenegro and Magnesium do Brasil Ltda. Montenegro graciously furnished quarters for the field party during its stay in Alencar. Representatives of Magnesium do Brasil

Ltda. accompanied the party during its studies of the company's concessions. Both groups assisted the field party by obtaining the necessary field assistants to aid in mapping. Montenegro and Chaves Mello made all of their data available for inspection and study, and additional information was given to the writer by Othon H. Leonardos, consultant to Magnesium do Brasil Ltda.

The writer also wishes to express his appreciation to the Departamento Nacional da Produção Mineral, whose whole-hearted cooperation made the project possible. Thanks are due to Dr. José Alves de Souza, Director, and Dr. Alberto I. Erichsen, Chief of Divisão de Fomento da Produção Mineral, for their assistance in planning and organizing the project. The Departamento also furnished accessory field equipment, as well as a jeep and chauffeur. Analyses of ore were made by the Laboratory of Mineral Production at Campina Grande, Pernambuco. The collaboration of Dr. José Alves Quesado made the work most interesting, and Dr. Quesado's knowledge of his native state greatly expedited the work.

The manuscript was read by George T. Faust and W. D. Johnston, Jr. The writer thanks Mr. Johnston for the use of several analyses and mineral descriptions.

GEOLOGY

STRATIGRAPHY

The larger part of central Ceará is underlain by pre-Cambrian rocks which are mostly schists and gneisses but also include phyllites, quartzites, and finely crystalline limestones and dolomites. The rocks are strongly folded and steeply dipping. Unconformably overlying them are Triassic sandstones, arkoses, and conglomerates. The youngest sediments are unconsolidated Quaternary alluvial sands and gravels.

PRE-CAMBRIAN ROCKS

The pre-Cambrian terrane in central Ceará consists mainly of schists and gneisses which have been referred to the Archeozoic by A. I. de Oliveira and O. H. Leonardos (1943, pp. 121–123). Overlying these rocks is a distinct sequence of quartzite, schist or phyllite, crystalline limestone, and schist, called the Ceará series. The Ceará series was first recognized and described by Roderic Crandall (1910, pp. 21–23). Luciano Jacques de Moraes (1924) and Djalma Guimarães (1924) studied these rocks in greater detail, and they classified the rocks as "Proterozoic". Because the limestone of the Ceará series contains the magnesite deposits, this series will be described in some detail.

De Moraes (1924, p. 29) briefly describes the principal units of the

Ceará series as follows: quartzite, the lowest formation, consists of comminuted quartz grains and some muscovite and sericite; schist, the next formation, consists of quartz and either sericite or biotite; crystalline limestone, the top formation, is medium-grained and thin-bedded. De Moraes states that some of these rocks may be missing in places, but that quartzite always is present. Crandall (1910, p. 22) suggests that the limestone may be lenticular.

Crandall includes the schist overlying the limestone in his definition of the Ceará series. Wherever the present writer observed these rocks, between Orós and Jucás, the limestone was overlain by schistose rocks, and he believes they should be included in the Ceará series. By this definition, the Ceará series maintains its position as the youngest pre-Cambrian rock group. The lower limit of the series also is not clearly defined by de Moraes. At Orós, for example, he includes gneiss in the series below the quartzite (p. 133).

Section of the Ceará series at Orós where the Rio Jaquaribe cuts through the Serra de Orós

Age	Character of formation	Estimated thickness (meters)
Archeozoic.	Biotite gneiss	
	—Fault (?)—	
Proterozoic.	Ceará Series: Limestone, finely crystalline, thin gray and white beds.	300 minimum.
	Phyllite, fine-grained, gray-green color, highly fissil, and consisting of quartz and sericite. Contains small garnet, hematite, and acicular tourmaline crystals. Some thin quartzite and schistose layers are included.	500 approx.
	Quartzite, very fine-grained, occasionally resembling novaculite. Color white to light-gray, and occasionally pink. Contains some sericite, and a few tourmaline and staurolite crystals. The middle of the formation contains several schist beds.	150 approx.
	Schist, graphitic, very dark-colored and strongly schistose. Consists mainly of biotite and quartz and contains much disseminated graphite. A few small almandite garnets and staurolite crystals are included. Schist, granitized, variable texture dependent on size of feldspar phenocrysts which are up to 2 centimeters in diameter. Color rose-gray. Coarser-grained material resembles prophyritic granite. The basal bed is biotitic quartzite.	Unmapped, at least several hundred meters thick.
	—Unconformity—	
Archeozoic.	Gneiss.	

The quartzite forms conspicuous ridges in most places, and its outcrops are extensive on both dip and scarp slopes of ridges. Phyllites, schists, or granitized schists form low rounded hills, but may underlie fairly rugged terrane when adjacent to the quartzite. Outcrops may be numerous but are comparatively small. The limestone always underlies the lower ground and its outcrops are small and scarce. Soil covering the rocks of the Ceará series is of subdued hues, generally yellowish to reddish brown. Schistose rocks below the Ceará series have comparable physiographic expression and weathering.

A well-exposed section of the Ceará series is seen at Orós, where the Rio Jaguaribe cuts through the Serra de Orós. The column (p. 130) was compiled by de Moraes (1924, pp. 29–31). The present author has added some descriptive material and the estimated thickness of beds.

Moraes (1924. p. 31 and fig. 4) maps an unconformity between biotitic quartzite at the base of the granitized schist, and the underlying gneiss but presents no proof of this structure. The concept of a fault, between limestone and the overlying biotite gneiss, is probably based on his opinion that limestone is the uppermost formation of the Ceará series and that the biotite gneiss is the same as the gneiss underlying the Ceará series (pp. 130 and 134). The present writer questions the presence of a major fault in this area (see p. 134) and includes the biotite gneiss in the Ceará series.

The present writer observed a comparable column at Alencar:

Section of the Ceará series at Alencar

Formation	Character	Estimated thickness (meters)
Ceará series.	Schist, finely foliated, dark-gray to greenish-gray. Consists of biotite and quartz, and possibly some chlorite. The rock contains a few quartzite layers.	400 minimum.
	Limestone, fine-grained and occasionally saccharoidal. White to light-gray color. Thin-bedded, and contains small biotite flakes in some bedding planes.	400 maximum.
	Gneiss, gray to light-gray, finely banded, and consists mainly of quartz and biotite, together with numerous feldspar streaks and porphyroblasts. The feldspar content is variable.	300–800.
	Quartzite, white to cream quartzite and sandstone, weathering to buff. Both thin-bedded and massive-bedded, some material very finely laminated. Fine-grained to extremely fine-grained, resembling novaculite.	150 minimum.

The quartzite and limestone are similar at Orós and Alencar, but the intervening formation is phyllite at Orós and is gneiss at Alencar. The gneiss contains feldspar porphyroblasts and is believed to have been somewhat granitized (p. 134). Therefore, the differences are due to metamorphism rather than to primary composition.

The Ceará series also is present in the Jucás area, but the rocks were not examined in detail. DeMoraes (1924, p. 40) describes the quartzite and biotite gneiss at Cariús.

TRIASSIC ROCKS

Triassic sandstone, sandy shale, arkose, and arkosic conglomerate occur in the Iguatú basin from 20 kilometers west of Iguatú to Lima Campos, south of Orós. These rocks are named the Iguatú formation (Oliveira, 1940, p. 187; and Oliveira and Leonardos, 1943, p. 452). They are mainly medium-grained dark-red thin-bedded sandstone but include a few thin beds and lenses of light-gray to white sandstone. Some bedding planes are ripple-marked and some strata are cross-bedded. The top member is massive-bedded medium-grained light-gray arkose, in part conglomeratic. The colors and textures indicate continental and fresh-water origin. The writer judges that the sequence is at least 100 meters thick, although sections were not measured.

The Triassic rocks weather distinctively; they are soft and gully readily. The red sandstone weathers to red soil markedly different from the yellowish soil derived from the crystalline rocks. The thin light-colored strata weather to light-gray or light-cream color, contrasting strongly with soil derived from the red strata.

The Iguatú formation was first thought to be Cretaceous (Moraes, 1924, p. 51), but Euzebio P. de Oliveira (1940) proposes Triassic age on the basis of lithologic similarity of these rocks with the Rio de Peixe series in the Estado da Paraiba. He suggests that the rocks were deposited in a fresh-water lake dammed by the Serra de Orós. The writer found similar rocks along the main highway between 26 and 34 kilometers north of Icó, east of the Serra de Orós, so deposition extended beyond the limits of the present Iguatú basin. Moreover, the Triassic rocks are gently folded (p. 133). At Lima Campos, the beds dip away from the Serra de Orós, an indication that the mountains have been raised since Triassic time.

QUATERNARY DEPOSITS

West of Orós, unconsolidated alluvial clays, sands, and gravels occur throughout the Rio Jaguaribe valley and in flood plains of tributary streams. The alluvial material extends well beyond the wide meander belts of the present drainage. This alluvium covers and partly conceals the magnesite deposits west of Jucás, southeast of Alencar, and northwest of Orós. The alluvial deposits are being dissected by the present drainage.

O. H. Leonardos (personal communication) suggests that some deposition occurred during the Pleistocene and continued into the Recent. These beds probably were deposited in a large lake dammed by the Serra de Orós; subsequent lowering of the outlet at Orós drained the lake and permitted the present dissection of the alluvial material. The writer believes the hypothesis is sound.

STRUCTURE

The regional structures of the pre-Cambrian rocks are principally large folds. The Serra de Orós is the east limb of a major syncline involving the Ceará series. This structure, the Orós syncline, pitches south. Between Lima Campos and Icó, south of Orós, the east limb swings westward toward the Cariús-Jucás area. The northwest limb of the Orós syncline extends toward Alencar where the rocks dip southeast. This limb continues toward Cariús and Jucás; the Ceará series is folded, and the distinctive quartzite and limestone formations crop out in several bands. Much of this structure was determined from the study of air photos. Where field observations were made the rocks dip steeply, from 40° to vertical. No major faults were seen.

Later sediments lie unconformable on the pre-Cambrian rocks. The Triassic rocks are gently folded or irregularly domed. Strikes are irregular and dips rarely exceed 20°, although some are as much as 30°. Comparatively uniform structure was seen only near Lima Campos, where the Triassic rocks dip generally west and northwest away from the Serra de Orós. No deformation was noticed in the attitude of the Quaternary alluvial deposits.

The geology in the vicinity of the magnesite deposits is comparatively simple. All deposits but one are on limbs of large folds. At Orós, the Cedro deposit is on the east limb of the Orós syncline. The strike of the Ceará series is slightly west of north; south of the deposit, the rocks dip 42° northwest and are vertical at the deposit. At Alencar, the deposits are on an extension of the northwest limb of the Orós syncline. The rocks strike northeast and dip southeast from 40° to vertical. There may be some faulting south of Alencar (p. 145). At Jucás the Ceará series is folded, and the limestone crops out in three subparallel belts in the several folds. The general direction of strike is northeast. One limestone band at the axis of a fold contains the Torto deposit, and another limestone band on the limb of a fold contains the Riacho Fundo deposit.

De Moraes (1924, fig. 4) postulates a fault between the limestone and the overlying gneiss at Orós (Moraes, 1924, pp. 14–15), using as proof the lithologic similarity of this gneiss with the "Archeozoic" gneiss at the base of the section. Both the limestone and the overlying gneiss have approximately the same attitude. There may be faulting between the two units, but the writer does not believe it has the magnitude suggested by de Moraes because a major fault cannot be discerned on the air photos.

Although the Triassic sedimentary rocks are widely distributed throughout the Iguatú basin, they normally do not overlap the magnesite deposits, with the possible exception of part of the Malhada Vermelha deposit east of Alencar. Triassic rocks occur near two other Alencar deposits, but they are absent in the vicinity of the Orós and Jucás deposits. Quaternary alluvium occurs at the Riacho Fundo deposit, Jucás; the Riacho Casquilho deposit, Alencar; and the Cedro deposit, Orós.

IGNEOUS ROCKS

The principal igneous rocks near the deposits are amphibolite dikes and sills. These rocks are most numerous near the two deposits south of Alencar. Many small sills are in the schist south of the Riacho Casquilho deposit, and a moderately large body of indeterminate shape lies east of the Riacho Caldeirão deposit. (See fig. 8.) A sill 50 meters thick is just east of the Cabeça de Negro deposit. In addition, a few small acidic dikes and quartz veins are in and near the Riacho Casquilho deposit, and a decomposed rock resembling pegmatite occurs in the Malhada Vermelha deposit.

Feldspar porphyroblasts are in schistose rocks near most magnesite deposits. Their distribution is irregular and their size variable. The writer interprets their presence as attributable to granitization (Johnston, 1945, p. 1023), the results of which are frequently seen in northeastern Brazil.

No large intrusions, such as might furnish the mineralizing magnesia solutions, crop out in the area studied. It is possible that either the intrusion of amphibolite or the introduction of feldspar was accompanied by the magnesia solutions forming the magnesite deposits.

MAGNESITE DEPOSITS

MINERALOGY

The theoretical composition of magnesite ($MgCO_3$) is MgO 47.6 percent and CO_2 52.4 percent. The mineral is rhombohedral; its hardness is from 3½ to 4½, and the specific gravity ranges from 3.0 to 3.12 in crystalline material. Colors may be white, yellowish, orange, red, brown, or gray.

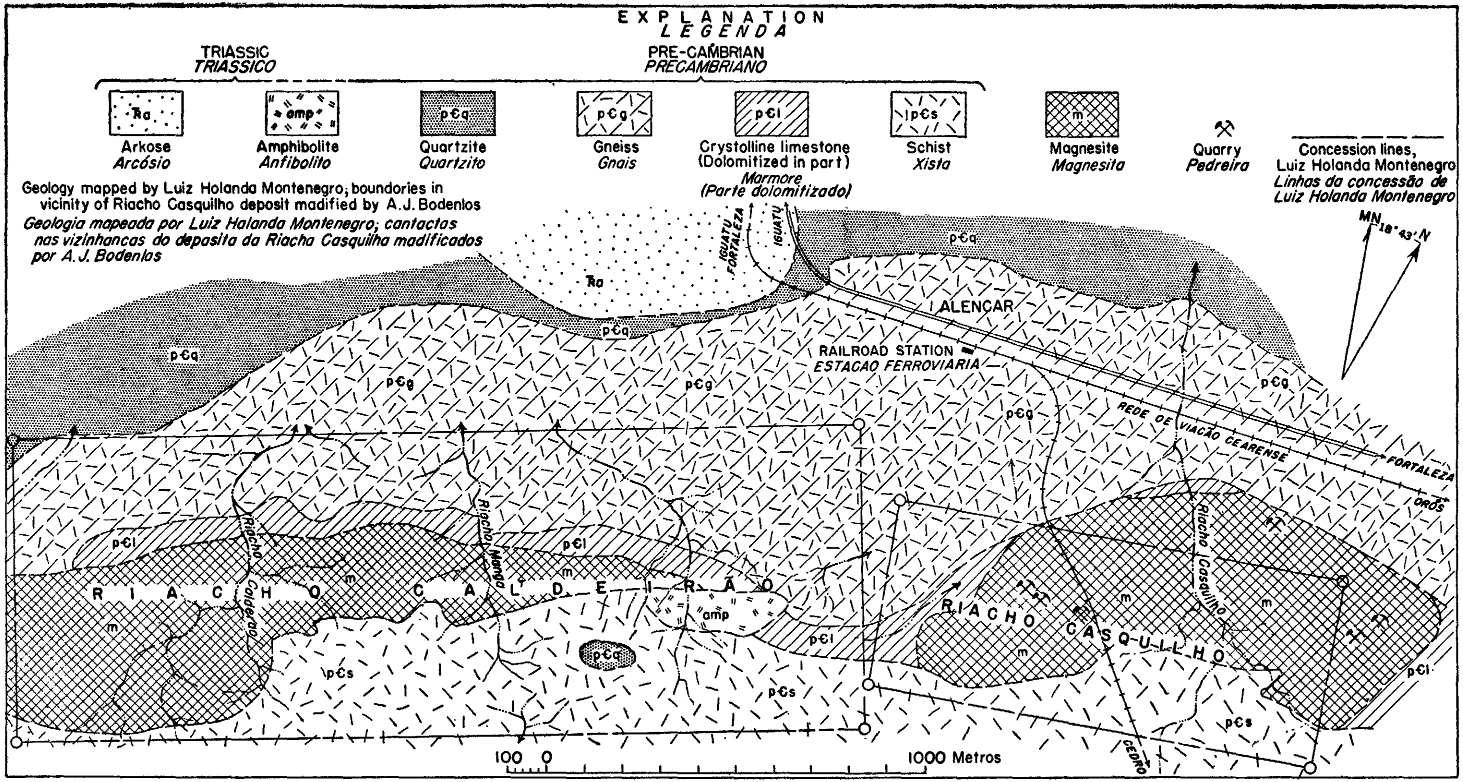

FIGURE 8.—Geologic map of the magnesite deposits at Alencar, Ceará.

The magnesite in the deposits of Ceará is crystalline and consists of anhedral grains ranging from 0.1 millimeter to 50 millimeters in diameter. The smaller grains tend to be equidimensional; whereas the larger grains are less regularly shaped. Some magnesite occurs as rosettes of bladed crystals as much as 50 millimeters long. Such crystals are younger than the anhedral grains. In color, the magnesite ranges from white to dark-gray, with very light-gray being the most common. One small deposit contains pink magnesite, colored by minute quantities of hematite. Magnesite outcrops weather to irregular shapes characterized by fluting and pitting, and the major forms are dependent on jointing (Leonardos, 1945). (See pl. 26 *B* and *C*.) Large outcrops are steep-sided and craggy (See pl. 26 *A*); small outcrops are less precipitous, but all are more prominent, comparatively, than those of dolomite or limestone in the surrounding country rock.

Talc is the most common impurity in the magnesite. Small quantities of quartz, pyrite, limonite, and hematite also occur in the deposits. Dolomite is rare except in two deposits.

Talc is white or tinted light green, and is very fine-grained. Occasionally plates of talc are up to 1 millimeter in diameter. The mineral occurs as very small scraps or "eyes" in the magnesite, and also in joints where it usually is slickensided. Talc fills intercrystalline voids in some coarse-grained magnesite.

Small clear quartz crystals, up to 3 millimeters in length, are in some vugs. Chert is rare, although in some places it forms fine intercrystalline boxworks between magnesite grains. Pyrite crystals, averaging 1 millimeter in diameter, may be sparsely scattered in magnesite. Pyrite close to the surface weathers to rusty pits and imparts a sulfurous odor to the magnesite. Limonite and less commonly hematite stain magnesite along some joint faces.

Limestone and dolomite, in the country rock adjacent to magnesite bodies, are fine-grained and crystalline. Their colors range from dark gray to creamy white. The outcrops of these carbonates are usually low and rounded in contrast with magnesite outcrops. The different appearance of outcrops and different grain sizes of these carbonates as compared with magnesite are helpful in field mapping.

Limestone is never found within magnesite deposits and dolomite is a rare constituent except at two deposits. The Cabeça de Negro deposit contains large blocks of dolomite, and the Malhada Vermelha deposit consists of magnesite containing disseminated grains of dolomite.

GENERAL FEATURES OF THE MAGNESITE DEPOSITS

It is generally agreed that crystalline magnesite deposits in carbonate rock are formed by the replacing of calcium in limestone or

A. LARGE MAGNESITE OUTCROP AT THE RIACHO FUNDO DEPOSIT.

Trench behind muck in left foreground was cut to 6 meters depth without encountering bedrock. Figure gives scale.

B. MONTENEGRO QUARRY, RIACHO CASQUILHO DEPOSIT.

Joint control in weathering may be seen in right foreground. Magnesite is covered by 6 meters of soil in the back wall of the quarry. Figure in central foreground gives the scale.

C. LARGE MAGNESITE OUTCROP, RIACHO CASQUILHO DEPOSIT.

Note the fluting and pitting of the magnesite. Figure on outcrop gives scale.

dolomite by magnesium, probably carried by hypogene solutions. The extent and degree of replacement determine the size and grade of the deposit.

The deposits in Ceará are massive and lens-shaped. The length of the deposits is from 3 to 7 times their width. One deposit is 3,500 meters long and 600 meters wide but mineralization is not continuous throughout this extent. The largest deposit mapped in this study is a massive lens 1,365 meters long and 450 meters wide. The smallest mapped is 350 meters long and 46 meters wide. Five deposits are entirely magnesite and contain a very low percentage of CaO, and two are mixtures of magnesite and dolomite. Most deposits are on one side of the limestone formation and have one contact with schistose rocks; several extend completely across the limestone.

The grade of this magnesite is high. Magnesite in all the deposits, except those two containing dolomite, averages less than 1 percent CaO. The SiO_2 content, usually dependent on included talc, differs even within deposits; it ranges from 0.1 percent to 21.0 percent. R_2O_3 (chiefly iron and alumina) normally is between 1 and 2 percent. With the exception of comparatively small blocks containing much talc, the ore is within grade limits for commercial requirements.

The first specimen analyzed and leading to discovery of these deposits is herewith included, for it is the only complete analysis made of this material:

Analysis No. 37,270/4, made by the Chemical Laboratory for Ceramics Industries, Berlin, Germany, reported Oct. 5, 1938

The sample was dried at 110° C.[1]

		Percent
CO_2 and H_2O		44. 94
Insoluble in acid:[2]		
SiO_2	5. 70	
Al_2O_3	. 52	
CaO	. 08	
MgO	2. 98	
		9. 28
SiO_2		2. 64
Al_2O_3		. 24
$MnO-Mn_2O_3$		1. 12
Fe_2O_3		. 83
MgO		40. 20
CaO		. 38
K_2O		. 08
Na_2O		. 23
SO_2		. 09
		100. 03

[1] Courtesy Magnesium do Brasil Ltda.
[2] Insoluble analyzed separately.

The analysis represents material containing approximately 85 percent magnesite and 9 percent talc, with the remainder as other impurities in the soluble portion of the sample. It is not known what mineral carries the Al_2O_3. The dissolved SiO_2 is unusual, as is the high manganese oxide content. (See tables showing analyses of samples from each deposit.) The SO_2 probably occurs with iron as pyrite.

Pyrite is the only mineral that was deposited with the magnesite. Talc, quartz, chert, and the iron oxides are found in joints and small cavities, and therefore are younger. The joints are the only secondary structures in the deposits; they are usually slickensided.

If it can be assumed that the bodies are pod-like and tend to be equidimensional in cross-section, then the deposits probably have great depth. Although the deposits have not been drilled, the writer thinks the ore will go to any minable depth within the limits of economic feasibility. Only the one deposit consisting of numerous small lenses (pl. 28) probably will bottom near the surface. Detailed descriptions for each deposit follow (pp. 140–150).

The bulk of the magnesite is covered by soil or alluvium to a depth ranging from 0.5 meter to at least 6 meters; therefore, most deposit boundaries are inferred. (See pls. 27–31.) They are drawn on the basis of observed outcrops and trenches, with emphasis on conservative limits.

It was hoped that additional data pertaining to the genesis of magnesite deposits would be obtained in the course of the study. However, extensive alluvial material covering the deposits prevented a detailed study of the relations between the limestone, dolomite, and magnesite. The following observations concerning these relations have genetic significance: Limestone is never found within magnesite deposits, nor was it ever seen in direct contact with magnesite. Contacts between magnesite and dolomite were seen at the Cabeça de Negro and Torto deposits (pls. 28 and 30), and dolomite occurs within two deposits (pp. 136, 143, 147–148).

Although these observations are limited to relatively small parts of the contact areas of these deposits and therefore are not conclusive, they tend to support the theory advanced by G. T. Faust and Eugene Callaghan (1948, pp. 50–72), which states that limestone and magnesite are never in contact because such a condition is not in chemical equilibrium. Faust and Callaghan maintain that a dolomitized zone always separates the two.

RESERVES

The summary of magnesite reserves is given in the following table. It should be noted that the figures represent the tonnages per meter depth. This method of presentation is adapted to enable the reader to make comparisons with facility. Comparatively shallow quarries or trenches greatly increase the known vertical extent in these areas of flat terrane, and reserve data given on this basis might be misleading. It has been emphasized that magnesite is believed to extend to any minable depth.

The tonnage factor used in calculating these reserves is 3 tons per cubic meter, based on the minimum specific gravity of crystalline magnesite (p. 134).

The reserve categories are measured, indicated, and inferred, conforming with the standard usage of the Geological Survey (Dorr, 1945, p. 36). As applied to the calculation of reserves in these deposits, the categories are defined as follows:

1. Measured ore: area of magnesite outcrop, usually extended two meters beyond the limits of outcrop. Where numerous closely spaced outcrops occur, and where it is quite apparent that such outcrops are continuous below the soil mantle, the areas are considered to be measurable. In contrast, where it is quite evident that outcrops are bold and have vertical walls, the measurable areas have not been extended beyond the areas of outcrops.

2. Indicated ore: areas between moderately closely spaced outcrops, where it is fairly certain that the magnesite is continuous beneath the soil mantle. This category also includes a further extension of area beyond the limits of large outcrops or numerous small outcrops, in the magnitude of from 10 to 15 meters.

3. Inferred ore: areas where magnesite is inferred to exist, as based on geologic evidence. The inferred limits of each magnesite body are discussed in connection with descriptions of individual deposits (pp. 140–150).

Reserves of the magnesite deposits of central Ceará, given as tons per meter depth

Deposit	Measured	Indicated	Inferred	Total
Cedro	181, 000	98. 000	131, 000	410, 000
Jurema [1]				
Cabeça de Negro [2]		7, 800	15, 000	22, 800
Malhada Vermelha [3]				
Riacho Casquilho	46. 000	273, 000	959, 000	1, 278, 000
Riacho Caldeirão [4]				
Torto	13, 800	27, 200	170, 000	211, 000
Riacho Fundo	10, 200	15, 000	16, 000	41, 200
	251, 000	421, 000	1, 291, 000	1, 963, 000

[1] Not visited.
[2] Only southern part of deposit.
[3] Magnesite too impure for mining.
[4] Not mapped. Deposit larger than Riacho Casquilho.

The reserves per meter depth of the four deposits mapped in their entirety and the south end of the Cabeça de Negro deposit are 251,000 tons measured ore, 421,000 tons indicated ore, and 1,291,000 tons inferred ore, a total of 1,963,000 tons.

Magnesium do Brasil Ltda. estimates reserves of 675,000 tons per meter depth at the Cabeça de Negro deposit. The writer thinks that this figure is too high because it is based on the assumption that 40 percent of the area contains minable magnesite. The south end of the deposit, mapped by the writer, is underlain by only 6 percent minable magnesite, although 30 percent of the area is mineralized (pp. 142–143). Montenegro maps the Riacho Caldeirão deposit (fig. 8) with a surface area of 568,000 square meters, which would contain 1,704,000 tons of magnesite per meter depth. The boundaries of the deposit were not checked by the writer, but probably are fairly accurate as based on comparison with Montenegro's mapping of the Riacho Casquilho deposit.

DESCRIPTIONS OF THE MINERAL DEPOSITS

The following are the magnesite deposits of central Ceará, listed from east to west:

Magnesite deposits of central Ceará, Brazil

Name	Nearest town	Township	Distance from rail shipping point (kilometers)	Means of access
Cedro	Orós	Icó	2. 0	Side road and trail.
Jurema	do	do	10. (?)	Trail (?).
Cabeça de Negro	Alencar	do	13. 3	Main and side road.
Malhada Vermelha	do	do	7. 1	Main road.
Riacho Casquilho	do	Iguatú	. 5	Side road and railroad.
Riacho Caldeirão	do	do	1. 0	Side road and trails.
Torto	Jucás	Jucás	9. 0	Main and side roads.
Riacho Fundo	do	do	10. 0	Side roads.

The operators holding the above concessions have been unable to locate other magnesite deposits after prospecting the limestone between Orós and Jucás. Inhabitants of Jucás make unverified claims that other deposits occur between Jucás and Crato, 80 kilometers to the south.

CEDRO

The Cedro deposit (pl. 27) begins 2 kilometers northwest of the Orós railroad station, the end of a branch line from Alencar. The deposit is approximately 600 meters west of the Serra de Orós, and its south end is within 1 kilometer of the Rio Jaguaribe. It is on the flood plain and in the valley of the Riacho Livramento, a south-flowing tributary of the Rio Jaguaribe, and it is flanked on both sides by low hills having a maximum relief of about 40 meters. A poor road extends from the railroad station to the south bank of the river, and wide trails on the north bank of the river afford access to the deposit. During the rainy season, large skiffs are used to cross the river, which, although relatively shallow is 140 meters wide. At present ore is hauled out by burros; an unfavorable grade necessitates a 40 meter climb to the railroad station from the south bank of the river.

On the west flank of the Serra de Orós, phyllite and schist underlie low hills, and the limestone containing the magnesite underlies the lowlands. Magnesite crops out for a length of 1,080 meters, roughly parallel to the strike of the limestone. The deposit is 190 meters wide, and from 157 to 172 meters above sea level. Nowhere is the contact between magnesite and limestone exposed; the east side of the deposit probably is in contact with phyllite. Dr. Quesado collected dolomite from the vicinity, but its extent is not known.

Exposures of magnesite are large and numerous. Two areas of nearly continuous outcrop are found at the north and south ends of the main body. The northern area is 220 meters long and as much as 180 meters wide; the southern area, cut by Riacho Livramento, is 540 meters long and as much as 120 meters wide. Between and flanking these two areas are smaller exposures. A small lens of magnesite is shown north of the main body. The intervening area may be underlain by magnesite, but lacking exposures, it is tentatively mapped as limestone. Alluvium in the central part of the area is from 0.5 meter to 3 meters thick, whereas at the north and south ends it is thicker.

The magnesite is light gray in color and medium-grained to coarse-grained in texture. The magnesite outcrops are irregular in shape, but tend to be less rugged than in other deposits. Talc is persistent throughout the deposit, occuring as thin surfacing on slickensided joint faces; the talc content in the deposit is always very low. No dolomite was observed within the magnesite, and analyses show the CaO content to be very low, usually less than 1 percent. (See the following table.) In addition to the samples shown in the table, Dr. Quesado collected 15 others whose localities are not designated. The 15 samples average 0.61 percent SiO_2, 1.05 percent R_2O_3, and 0.78 percent CaO. These figures conclusively show that the grade of magnesite is extraordinarily high.

No magnesite was seen in reconnaissance extending to 5 kilometers north of the deposit where Magnesium do Brasil Ltda. has requested concessions. O. H. Leonardos (personal communication) states that he found one small outcrop in the northern area.

Three pits, the largest of which is 40 by 30 meters, had been cut to a depth of 4 meters each when the writer visited the area. All operations were by hand. The stack kiln on the property can produce caustic-calcined magnesia at the rate of 320 tons per month. Production from 1942 to 1945 is shown in the table on page 128.

Analyses of magnesite, Cedro deposit, Orós, Ceará

	1	2	3	4	5	6	7
Ig. loss [a]	51.4	51.1	51.5	51.5	51.6	50.9	51.59
SiO_2	.5	.5	.4	.1	.5	.7	.27
Fe_2O_3 } Al_2O_3	.8	1.2	1.0	1.0	.8	.9	{ [b] .78 / .20
CaO	.5	.5	.6	.4	.1	3.9	.25
MgO	46.8	46.8	46.5	47.1	47.3	43.7	46.67
MnO	------	------	------	------	------	------	.005
Total	100.0	100.1	100.0	100.1	100.3	100.1	99.77

Samples 1–6: Coarse-grained to medium-grained, white to very light gray, with traces of talc. Samples 1–5 collected by A. J. Bodenlos from quarries in southern part of deposit. Sample 6 collected by J. A. Quesado from southwest corner of deposit, near the contact between magnesite and limestone close to the Riacho Livramento. Analyses by Chemical Laboratory of Mineral Production, Campina Grande branch, reported March 30, 1946.

Sample 7: Very white, fine-grained (1 millimeter), sugarlike, equidimensional grains. Collected and described by W. D. Johnston, Jr. Analysis by Chemical Laboratory of Mineral Production, Belo Horizonte branch, reported July 1944.

[a] Ignition loss represents CO_2.
[b] FeO.

JUREMA

The Jurema deposit is said to be 10 kilometers west of Orós, near the south bank of the Rio Jaguaribe. It is reported to be small, and the writer has not seen analyses of the material.

CABEÇA DE NEGRO

The Cabeça de Negro deposit (pl. 28) is 13.3 kilometers via road northeast of Alencar. An unimproved side road, going north from the highway 7.5 kilometers east of Alencar, affords access. According to surveys by Magnesium do Brasil, Ltda., the deposit is 3,600 meters N. 11° W. of the 446 kilometer mark of the railroad (Orós branch line). The deposit is at the headwaters of the northward-flowing Riacho Maniçoba, and at the foot of the southeast slope of the Serra de Moraes.

The crystalline rocks strike generally north and dip from 53° E. to vertical. An amphibolite dike (?), as much as 50 meters wide and consisting of fine-grained green foliated amphibole, intrudes the crystalline rocks at the south end of the magnesite area. The limestone formation here is completely dolomitized. Triassic sedimentary rocks overlie a wide area between the highway and the south end of the deposit. The dolomite and magnesite are well exposed because the soil is very thin.

Only the south end of the deposit was visited or mapped. The mapped area is 750 meters long and includes a mineralized area as much as 200 meters wide. Exposures are from 230 to 242 meters above sea level, a vertical range of 12 meters. The magnesite is white and ranges from medium-grained to very coarse-grained. It occurs as lenses and veins replacing gray fine-grained crystalline dolomite. Only 30 percent of the area contains magnesite. The largest lens is 120 meters long and 75 meters wide; it is the only block large enough to warrant development. The next largest body is 45 meters long and 10 meters wide, and other lenses are much smaller.

The replacement of dolomite by magnesite is clearly shown in numerous outcrops. The contact between the two minerals is always sharp, and the replacement is complete. One sample, taken from within 10 centimeters of a dolomite contact, has less than 2 percent CaO. (See analysis 2 in the following table.) Replacement started from foliation and joint planes; where the process was complete, sutures between coalesced replacement bands can be seen. Where incomplete, comparatively regular dolomite blocks are left within magnesite. Intercrystalline voids along the sutures of coalesced magnesite bands are filled with talc.

Talc is very light-green in color and is fine-grained, occurring as intercrystalline filling and as slickensided joint filling. In the largest lens, it forms about 7 or 8 percent of the rock, on the basis of 5 percent SiO^2 in the analyzed sample. (See analysis 1 in the following table.) Intercrystalline chert silicifies some magnesite at the north end of the mapped area. The magnesite has low CaO content.

Analyses of magnesite, Cabeça de Negro deposit, near Alencar, Ceará

	1	2	3	4	5	6	7	8
Ig. loss [a]	48.2	49.82	50.8	48.1	49.2	49.9	46.93	51.04
SiO_2	5.0	2.81	.9	4.1	2.87	2.4	.60	1.28
Fe_2O_3	} 1.5	[b] 1.00	} 1.1	} 1.6	} 1.04	.14	[b] .20	[b] .64
Al_2O_3		.68				.84	.81	.36
CaO	.7	1.55	tr.	-------	tr.	-------	29.71	.10
MgO	44.3	43.98	46.7	46.1	46.8	46.7	21.54	46.35
H_2O+	------	-------	.15	-------	.2	.04	-------	------
MnO	------	.006	-------	-------	-------	-------	.002	.004
Total	99.7	99.85	99.65	99.9	100.11	100.02	99.79	99.77

Sample 1: Coarse-grained white magnesite containing some intercrystalline talc, from south quarry. Collected by A. J. Bodenlos. Analysis by Chemical Laboratory of Mineral Production, Campina Grande branch, reported April 29, 1946.
Sample 2: Light-gray, medium-grained (0.3–1.0 centimeter) magnesite with small amount of talc. Is 10 centimeters from contact with pure dolomite. Collected by W. D. Johnston, Jr., analyzed by Chemical Laboratory of Mineral Production, Belo Horizonte branch, reported July 1944.
Samples 3–6: Magnesite (no descriptions given), collected by Magnesium do Brasil Ltda. Analyzed by Instituto de Pesquisas Tecnológicas do Estado de São Paulo, reported Jan. 17, 1941; Nov. 17, 1941; and Dec. 9, 1941.
Sample 7: Dolomite, dark-gray, fine-gained (0.05 millimeter), collected by W. D. Johnston, Jr. Analysis by Chemical Laboratory of Mineral Production, Belo Horizonte branch, reported July 1944.
Sample 8: Light-gray, medium-grained (2–5 centimeters) magnesite with small amount of talc. Collected by W. D. Johnston, Jr., analysis as sample 7.

[a] Ignition loss represents CO_2.
[b] FeO.

A company map shows that the deposit is 3,600 meters long and up to 600 meters wide, averaging 150 meters in width. The entire area consists of lenses or blocks in dolomite. Comparison between maps made by the writer and those of the company shows that the latter include much mixed material in areas designated as ore blocks. Two quarries are cut in the south end of the deposit; one in the large block of magnesite, and the other at the north end of the mapped area. A dolomite rib separates the magnesite lenses in the north quarry. (See pl. 28.) Ore has been shipped from the south quarry via the Alencar station, but the company plans to use the Igaroi station (at kilometer 443) if the deposit is further developed. Production figures are given in table on page 128.

MALHADA VERMELHA

The Malhada Vermelha deposit is 7 kilometers east of Alencar, about 150 meters north of the Alencar-Icó highway. Schist in contact with the magnesite strikes N. 35° W. and dips 17° NE. Triassic rocks crop out northwest of the deposit, and soil conceals the remaining contacts.

The magnesite is exposed in an area only 40 meters long and 10 meters wide. It is pink and moderately coarse-grained. The pink color is imparted by minute amounts of finely disseminated hematite. One small pit cut in the magnesite exposes a small stockwork of decomposed rock which appears to be pegmatite. The veinlets of this material are thin but numerous. According to analyses in the following table, the magnesite contains up to 4 percent SiO_2, and from 6.8 to 16.6 percent CaO. W. D. Johnston, Jr. states that the CaO content is

Analyses of magnesite, Malhada Vermelha deposit, near Alencar, Ceará

	1	2	3
Ig. loss[a]	46. 4	50. 07	48. 8
SiO_2	4. 0	1. 00	1. 73
Fe_2O_3	1. 4	[b]. 93	1. 61
Al_2O_3		. 43	
CaO	16. 6	6. 75	8. 1
MgO	31. 5	40. 52	39. 6
H_2O+	----------	----------	. 2
MnO	----------	. 006	
Total	99. 9	99. 71	100. 04

Sample 1: Pink, coarse-grained magnesite with some talc, from small quarry. Collected by A. J. Bodenlos. Analysis by Chemical Laboratory of Mineral Production, Campina Grande branch, reported Apr. 29, 1946.

Sample 2: Pink, medium-grained (1-3 centimeters) magnesite. Pink color due to minute (0.03 to 0.08 millimeter) translucent hematite grains. Specimen contains relicts of unreplaced dolomite. Some mortar structure suggests movement. Collected and described by W. D. Johnston, Jr. Analysis by Chemical Laboratory of Mineral Production, Belo Horizonte branch, reported July 1944.

Sample 3: Pink magnesite, collected by Magnesium do Brasil Ltda. Analyzed by Instituto de Pesquisas Tecnológicas do Estado de São Paulo, reported Dec. 9, 1941.

[a] Ignition loss represents CO_2.

[b] FeO.

due to included dolomite. Inasmuch as all analyses indicate high lime content, the magnesite is too poor for use as ore. Company data show that 120 tons have been excavated, but no material has been shipped.

RIACHO CASQUILHO

The Riacho Casquilho deposit (See pl. 29), also known as the Alencar deposit, is 0.5 kilometer southeast of the town of Alencar, and is accessible by side roads. It is ideally situated for transportation because it is crossed by the main line of the railroad, and its eastern part is within several hundred meters of the Orós branch line. The area is traversed by shallow valleys of intermittent streams; away from such streams the terrane is essentially flat or slopes very gently.

At the deposit, the limestone strikes N. 60° E., but it narrows and swings westward southwest of the deposit. The strikes of foliation of the gneiss and schist parallel the boundaries of the limestone in the vicinity of the deposit, and the dips of the schistose rocks range from 40° SE. to vertical. The gneiss northwest of the carbonate rocks has been granitized and the schist southeast contains numerous thin amphibolite sills and dikes. These intrusive basic rocks are not shown on the map. There is one small patch of basic dike rock in the eastern part of the magnesite deposit, and a fine-grained acid sill crops out in the gneiss just north of the limestone contact near the creek, Riacho Casquilho.

The magnesite lens occupies the full width of the limestone formation for part of its length. Some dolomite flanks the northwest edge of the magnesite body, but outcrops are too scarce to warrant distinction of dolomite and limestone on the map. Limestone outcrops and trenches cutting the limestone indicate a definite limit to mineralization at the southwest end of the magnesite lens, but thick alluvial gravels and silts conceal the northeastern boundary of the magnesite.

The magnesite lens is 1,365 meters long and up to 450 meters wide. Exposures occur from 237 to 252 meters above sea level. No contacts are exposed and the shape of the lens is inferred. Outcrops and trenches permit a good approximation of the shape except at the northeast end. The trenches are now slumped, so the writer has used the data furnished by Eng. Montenegro. It is inferred that the whole area is underlain by magnesite because magnesite is almost continuously exposed across the lens along Riacho Casquilho and because all trenches and quarries within the inferred limits reached magnesite.

Four main areas of magnesite exposures are located as follows: the east end of the lens where exposures are small and scattered; the northern block east of Riacho Casquilho where exposures are comparatively closely spaced; the stream bed of Riacho Casquilho where exposures are nearly continuous; and the central area southwest of the railroad tracks. Actual dimensions of outcrops range from very small boulders less than a meter square to the large exposure along Riacho Casquilho which is 150 meters long and up to 20 meters wide. Covered areas are blanketed by soil or alluvium from 1.5 to 6.0 meters thick.

The magnesite is white to light gray in color and weathers to buff color. Its texture is coarse-grained and less frequently medium-grained. Talc occurs throughout the deposit in all forms previously described (p. 136). There are pyrite crystals in the magnesite, and limonite and hematite stain magnesite along some joint planes. A few small quartz crystals are found in vugs, and several minor silicified zones are at the northeast end of the deposit.

Analytical data in the following table indicate that CaO and R_2O_3 are uniformly low. CaO is never more than 1 percent, and iron and alumina average about 1.5 percent. SiO_2, on the other hand, ranges from 1.46 percent to 21.0 percent; the maximum figure is an analysis of high talc-bearing magnesite in the eastern corner of the deposit. (See pl. 29, sample locality 2.) In the remainder of the deposit, some areas have critically high content, but field inspection indicates that numerous good blocks are available for mining. The largest area having uniformly low talc content is in the valley of Riacho Casquilho.

Both Eng. Montenegro and Magnesium do Brasil Ltda. hold concessions on the deposit. Three quarries are on each concession. The largest Montenegro quarry is 55 meters long, 35 meters wide, and is

Analyses of magnesite, Riacho Casquilho and Riacho Caldeirão deposits, Alencar, Ceará

	1	2	3	4	5	6	7
Ig. loss [a]	50. 2	35. 6	48. 4	47. 9	49. 8	50. 94	47. 42
SiO_2	1. 8	21. 0	4. 0	5. 0	2. 4	1. 46	5. 03
Fe_2O_3	1. 5 (with Al_2O_3)	1. 5	1. 5	1. 6	1. 5	[b] . 91	[b] . 82
Al_2O_3						. 63	3. 76
CaO	. 5	. 4	. 7	. 5	. 4	. 11	. 16
MgO	46. 1	41. 4	45. 6	45. 3	46. 2	46. 12	42. 90
MnO	-------	-------	-------	-------	-------	. 006	. 006
Total	100. 1	99. 9	100. 2	100. 3	100. 3	100. 18	100. 10

Samples 1-5: Magnesite, Riacho Casquilho deposit, collected by A. J. Bodenlos. Numbers correspond with sample localities (pl. 29). Campina Grande branch, reported Apr. 13, 1946. Mineral descriptions are as follows:

1. Coarse-grained to medium-grained, white to buff color.
2. Coarse-grained to medium-grained, light-gray color, and containing much talc.
3. Coarse-grained, white color.
4. Coarse-grained, light-gray color.
5. Coarse-grained, light-gray to white color.

Sample 6: Light-gray, very coarse-grained (2-6 centimeters) magnesite from Riacho Casquilho deposit, with small amount of talc. Collected by W. D. Johnston, Jr., Analyzed by Chemical Laboratory of Mineral Production, Belo Horizonte branch, reported July 1944.

Sample 7: Light-gray, medium-grained (1-2 centimeters) magnesite from Riaco Caldeirão deposit, containing some talc. Collected by W. D. Johnston, Jr. Analyzed by Chemical Laboratory of Mineral Production, Belo Horizonte branch, reported July 1944.

[a] Ignition loss represents CO_2.
[b] FeO.

cut to a depth of 6 meters. (See pl. 26 *B*.) The main quarry of Magnesium do Brasil Ltda. is 46 meters long, 12 meters wide, and 6 meters deep. The volume of magnesite taken from the quarries is considerably less than the figures indicate, for overburden as much as 6 meters thick was stripped before operations began. More than 1,000 tons of mined magnesite were stock piled in 1946.

RIACHO CALDEIRÃO

The Riacho Caldeirão deposit (fig. 8) is southwest of Alencar and west of the Riacho Casquilho deposit. Access is poor and consists of wide trails, one of which is passable by car. The northeast end of the deposit is within 1 kilometer of the main line railroad, and favorable grades prevail to the Alencar railroad station. The geology of the area is similar to that of the Riacho Casquilho deposit. A quartzite block southeast of the magnesite lens probably was faulted into this position, although it is difficult to see how this structure was formed. This area is slightly hillier than the area at the Riacho Casquilho body.

The magnesite resembles that in the Riacho Casquilho lens. Outcrops and trenches indicate the magnesite body is about 2,000 meters long and up to 450 meters wide. Most of the outcrops are found in the shallow valleys of the Riacho Caldeirão and the Riacho Manga. The magnesite has low CaO and R_2O_3 content, but talc provides moderate to high SiO_2 content. (See preceding table.) No ore had been mined or shipped at the time of the writer's visit.

TORTO

The Torto deposit (pl. 30) is 5 kilometers east of Jucás, about 400 meters north of the Jucás-Iguatú highway. The short access road to the southwest end of the deposit is only a wide trail but easily passable by car; the northeast end of the deposit is accessible only by foot-trails. Via existing roads, the deposit is 9 kilometers from the Cariús railroad station. A direct road from the deposit to Cariús would be only 5 kilometers long but would have many unfavorable grades. Two rivers, neither of them bridged, lie between the deposit and the railhead. The southwestern end of the deposit is in a moderately broad valley draining to the southwest, and the northeast end is in a narrow valley at the headwaters of a northeast-flowing intermittent stream. A low divide separates the two drainages.

Gneiss and dolomite are the only country rocks exposed. Gneiss is exposed southeast of the southwest end of the deposit, and gneiss and quartzite float occur on both sides of the northeast end of the deposit. Undoubtedly the rocks are folded, but the structure was not determined because of the limited field time spent in the area. Light-gray, fine-grained dolomite crops out on the south side of the northeast end of the deposit. This is the only part of the magnesite contact that can be fixed with any degree of accuracy. The carbonate rock is mapped as dolomite, on the basis of the few outcrops in this area, but it may be partly limestone.

As inferred from outcrops, the deposit consists of two magnesite lenses. The intervening area is covered by thick soil; the lenses may be connected, but the area is conservatively mapped as dolomite. The southwest lens is inferred to be 480 meters long and as much as 60 meters wide, although the maximum width of outcrops is only 15 meters. The northeast lens is 460 meters long and up to 110 meters wide. The over-all extent of the outcrops is 1,260 meters, oriented from N 45° E to N 70° E along the strike. Exposures are from 308 to 328 meters above sea level, a vertical extent of 20 meters. Outcrops in the northeast lens are larger, more numerous, and stand out more prominently than those in the southwest lens. The difference is attributed to the deeper incision of drainage in the northeast lens. The soil covering the southwest lens is much thicker and at least 4 meters deep over parts of the lens. The size and shape of the northeast lens is better known than that of the southwest lens because of the greater number of outcrops.

The magnesite is fine-grained to medium-grained, gray to dark gray in color, and weathers to light-buff color. Coarse-grained white magnesite veins cut the finer-grained material. Small amounts of talc in joints are the only noticeable impurity; talc veinlets are usually from 1 millimeter to 3 millimeters thick. The analyses of the samples of this deposit are shown in the following table. The maximum SiO_2 con-

Analyses of magnesite, Torto deposit, Jucás, Ceará

	1	2	3	4	5	6	7	8	9
Ig. loss [a]	49.4	49.3	51.3	50.4	50.7	48.9	51.2	51.2	50.7
SiO_2	2.7	3.0	.4	.8	1.1	3.3	.3	.6	.8
R_2O_3 [b]	1.8	2.0	1.3	1.7	1.6	2.0	1.0	1.4	1.9
CaO	.4	.2	.9	2.5	.3	.7	3.4	.1	.4
MgO	46.0	45.6	46.5	44.8	46.7	44.9	44.5	46.9	46.5
Total	100.3	100.1	100.4	100.2	100.4	99.8	100.4	100.2	100.3

Samples 1–9: Fine-grained to medium-grained, light-gray to dark-gray magnesite. Collected by A. J. Bodenlos. Analyzed by Chemical Laboratory of Mineral Production, Campina Grande branch, reported April 29, 1946. Following are mineral descriptions and sample localities (pl. 30). In addition, several dolomite samples were analyzed. These have a slight excess of MgO over the theoretical composition of dolomite.

Sample No.		*Locality No.*
1.	Medium-grained, light gray	1
2.	Fine-grained, dark gray	2
3.	Fine-grained to medium-grained, dark gray to gray	4
4.	Fine-grained, light gray to white	5
5.	Medium-grained, very light gray	6
6.	Fine and medium-grained, gray to light gray	7
7.	Medium-grained, gray to white	8
8.	Medium-grained, various shades of gray	9
9.	Fine-grained, light gray	3

[a] Ignition loss represents CO_2.
[b] Fe_2O_3 and Al_2O_3.

tent, dependent on the talc, is usually less than 3 percent. The CaO content usually is less than 1 percent, except near the east contact (sample locality 8, pl. 30), and iron and alumina are 2 percent at maximum. Most of the ore is very high grade.

Development work prior to 1946 consisted of trenching on both lenses and the sinking of a shallow quarry 30 meters long at the very southwest end of the deposit. Material excavated from the quarry was still stock piled next to the pit and no ore had been shipped. Trenches in the alluvium of the southwest deposit were up to 4 meters deep and had not reached lateral extensions of adjacent outcrops. Trenches in the northeast lens expose additional magnesite.

RIACHO FUNDO

The Riacho Fundo deposit (pl. 31) is 5.6 kilometers west of Jucâs on a back road, nearly impassable in places by car. The deposit is 10 kilometers from the Cariús railroad station, via the same back road and the main road from Jucás to Cariús. As in the case of the Torto deposit, two unbridged streams must be forded to get shipments to the railroad. The magnesite deposit is on the flood plain of the Rio Jaguaribe fairly close to the north side of the valley.

The deposit seems to be on one limb of a major fold. Schist crops out at the edge of the flood plain, but the geology in the vicinity of the deposits is concealed by thick alluvium. Schist cropping out through the alluvium dips 65° NW., and one quartzite outcrop shows vertical foliation. This quartzite is thought to be a lens in the schist. It is inferred that the schist extends to the northwest side of the magnesite lens and that the other contacts of the body are with limestone or dolomitzed limestone.

The magnesite body trends N. 50° E., and is exposed for a length of 350 meters and a maximum width of 46 meters. The largest area of exposure, at the northeast end of the lens, is 80 by 46 meters. The central part of the lens is exposed in several large, bold outcrops (pl. 26 *A*); the southwest end is marked by a few small outcrops. The magnesite occurs between 264 and 284 meters above sea level. Alluvium covering the deposit is from 2 to 3 meters thick at the northeast end, at least 6 meters thick in the central part, and about 2 meters thick at the southwest end of the deposit.

The magnesite is moderately fine-grained, consisting of grains usually from 2 to 3 millimeters in diameter. The material is white to very light gray in color and it weathers to light buff occasionally with a pinkish cast. Talc occurs sparingly in joints. SiO_2 rarely exceeds 2.4 percent but may be as much as 3.4 percent as is shown in the following

857899—50——3

table. The CaO content is always less than 1 percent and R_2O_3 averages 1.3 percent.

The deposit is lens-shaped, as inferred from the distribution of outcrops. The thick alluvial cover prevents more accurate determination of the size and shape, and all boundaries are inferred.

The property is under concession to Magnesium do Brasil Ltda, which sank several exploratory trenches. These extend the known magnesite at the northeast end of the deposit, but do not reach bedrock in the central part. No ore had been mined in 1946.

Analyses of magnesite, Riacho Fundo deposit, Jucás, Ceará

	1	2	3	4	5	6	7
Ig. loss [a]	49.2	50.9	51.1	48.5	51.5	51.2	51.0
SiO_2	2.4	.7	1.1	3.4	.7	.6	1.1
R_2O_3 [b]	1.8	1.5	1.0	1.5	1.6	1.1	[c] .8
CaO	.5	.6	.3	.3	.1	.1	tr.
MgO	45.8	46.2	46.6	46.1	46.7	47.0	47.0
Total	99.7	99.9	100.1	99.8	100.2	100.0	99.9

Samples 1–6: White, fine-grained to medium-grained magnesite. Number corresponds with sample localities shown on map (pl. 31). Collected by A. J. Bodenlos. Analyses by Chemical Laboratory of Mineral Production, Campina Grande branch, reported Apr. 8, 1946.

Sample 7: Magnesite, collected by Magnesium do Brasil Ltda. Probably analyzed by Instituto de Pesquisas Technológicas do Estado de São Paulo.

[a] Ignition loss represents CO_2.
[b] Fe_2O_3 and Al_2O_3.
[c] Fe_2O_3 0.7 and Al_2O_3 0.1 percent.

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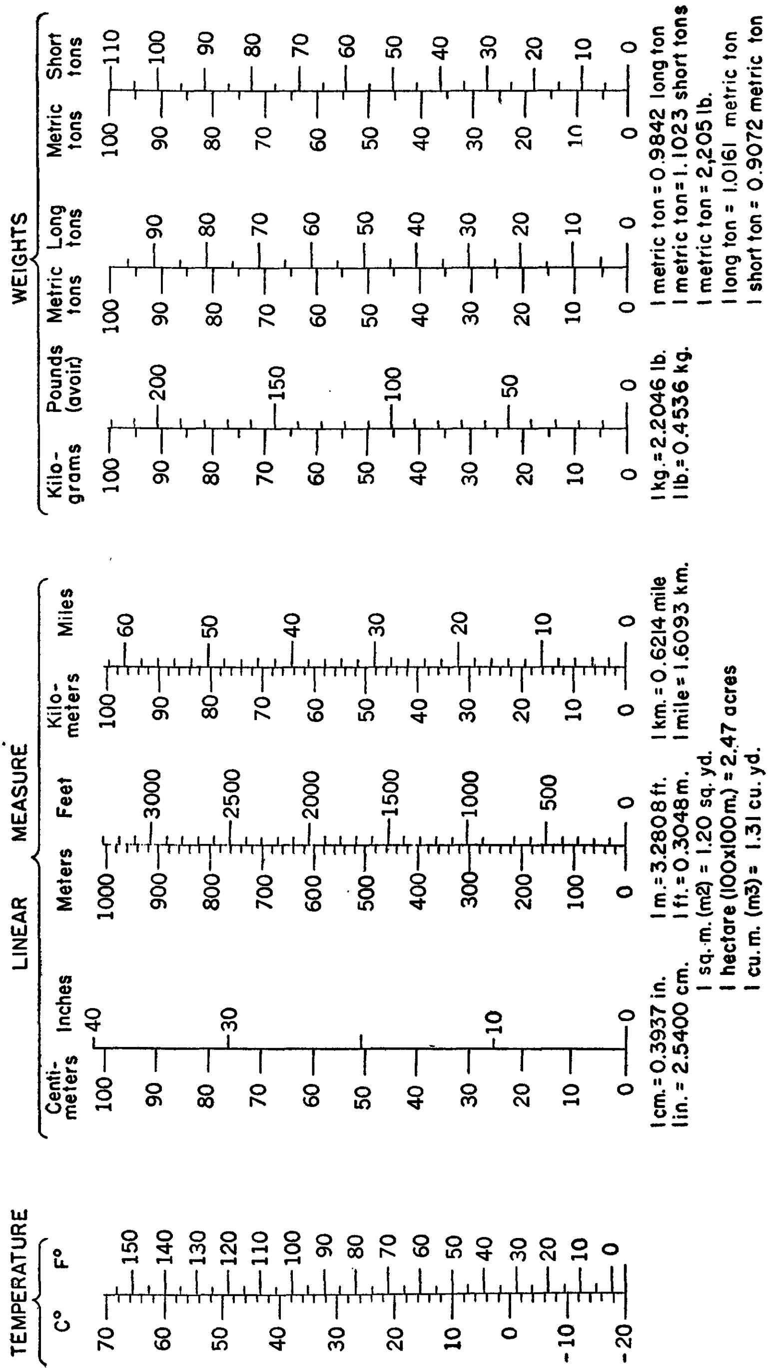
METRIC EQUIVALENTS
TEMPERATURE
C°
F°
LINEAR MEASURE
Centi-meters
Inches
Meters
Feet
Kilo-meters
Miles
1 cm. = 0.3937 in.
1 in. = 2.5400 cm.
1 m. = 3.2808 ft.
1 ft. = 0.3048 m.
1 km. = 0.6214 mile
1 mile = 1.6093 km.
1 sq. m. (m2) = 1.20 sq. yd.
1 hectare (100x100m.) = 2.47 acres
1 cu. m. (m3) = 1.31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

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