Magnesite Deposits in the Serra das Éguas, Brumado Bahia, Brazil

By ALFRED J. BODENLOS

GEOLOGIC INVESTIGATIONS IN THE AMERICAN REPUBLICS, 1950–52

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MAGNESITE DEPOSITS IN THE SERRA DAS ÉGUAS, BRUMADO, BAHIA, BRAZIL

By Alfred J. Bodenlos

ABSTRACT

Many outcrops of crystalline magnesite occur in the Serra das Éguas, a mountain range just west of the town of Brumado, in southwestern Bahia, Brazil. This area, in the drainage basin of the Rio do Antonio, is 600 kilometers by rail from Salvador, capital of the Estado da Bahia, and 1,000 kilometers by rail from Belo Horizonte, capital of the Estado de Minas Gerais. At least nine deposits are known, of which five are lenses of major size.

The rocks underlying the Brumado area are largely gneiss and schist, known as the Complexo Fundamental or Brazilian complex, of pre-Cambrian age. Overlying the gneiss and schist are dolomite and quartzite of later pre-Cambrian age, locally preserved in isolated mountain ranges such as the Serra das Éguas. The Serra das Éguas is a large synclinal structure characterized by close and complex folding. Intruded into the rocks of the range are several amphibolite dikes and a few small rhyolite dikes.

The dolomite is the most highly mineralized rock, containing deposits of magnesite, talc, quartz crystal, and gemstones. Magnesia bearing solutions deposited magnesite as replacement of dolomite, and altered quartz veins to enstatite and talc. Later solutions rich in silica and carrying some alumina deposited quartz (as veins and crystals) and lesser amounts of beryl, kyanite, tourmaline, topaz, and other minerals in the magnesite lenses.

The lime content in the magnesite deposits is low and occurs for the most part as residual dolomite; all deposits but one average less than 1.0 percent CaO. Iron oxide content likewise is generally low. In two deposits part of the iron oxide occurs as disseminated hematite which colors the magnesite red; these deposits also contain segregations of specular hematite which locally provide a somewhat higher content of iron oxide. In most deposits alumina is present only in small amounts but locally is as much as 4 percent. In parts of some deposits silica is the most deleterious impurity and contaminates several large blocks to the extent of rendering them useless for commercial recovery. It occurs as primary quartz veins that have been altered to enstatite and talc and as secondary quartz veins. Nevertheless, reserves of minable quality are large: On the basis of tons per meter depth the measured reserve is 302,000 tons, the indicated reserve 407,000 tons, and the inferred reserve 2,106,000 tons—a total reserve of 2,815,000 tons. Continuity in depth is indicated by the vertical

range of outcrops in individual deposits, which, for those reasonably well exposed, ranges from 130 to 165 meters; the same group of deposits range from 625 to 1,300 meters in length and from 20 to 810 meters in width. Other deposits are exposed only locally where streams have stripped the overlying laterite, so their sizes and shapes are indeterminate.

Magnesite crystals line open fissures and vugs in the magnesite deposits, but the crystals are too small to permit recovery of optical material. Talc veins in places attain sufficient size to permit extraction. The talc is massive, fine-grained steatite of high purity and it is probable that sufficient reserves are available to supply the Brazilian market. Quartz crystal occurs in veins and vugs and was mined from shallow pits for piezoelectric-grade material during World War II by local prospectors. Gem-quality emerald, aquamarine, topaz, and tourmaline also have been recovered from the quartz veins.

Presence of emeralds led to the beginning of mining in the area shortly before World War I, but magnesite was not discovered until 1939. The deposits since have been developed by Magnesita S. A., of Belo Horizonte, Minas Gerais. Magnesita S. A. holds concessions on all but the Boa Vista deposit which was claimed by G. W. Soares. To calcine the magnesite, Magnesita S. A. has built a kiln at Catiboaba railroad station, 9 kilometers south of Brumado, and has constructed a refractory-brick plant and a talc-grinding plant in Belo Horizonte. The critical economic factor for successful operation is considered to be the cost of transportation to domestic and foreign markets.

The magnesite deposits in the Serra das Éguas are hypogene and in the mesothermal(?) class. The minerals were deposited from solutions emanating from a large concealed magma possibly of granitic or granodioritic composition. The magnesium carried in solution may have been derived from the magma or from the underlying dolomite; some of the carbon dioxide probably had a magmatic source. An hypothesis of deposition postulates that solutions carrying magnesium under a pressure of carbon dioxide reached a zone where sufficient carbon dioxide was lost by escape through fissues into the vapor phase. The saturated solutions then started mineralization with magnesite replacing dolomite. Following initial replacement of dolomite by magnesite, further saturation was attained by an accelerated diffusion gradient for carbon dioxide. Replacement on a volume-for-volume basis results in withdrawal of carbon dioxide from the system, which tends to increase the gradient of pressure of carbon dioxide and hence facilitates saturation for magnesite. This in part may account for the completeness of replacement and for the large volumes of deposited material.

Quartz and aluminum silicate minerals deposited after magnesite are considered to be intermediate between pegmatites and simple quartz veins. If these occurrences are associated with the period of mineralization resulting in quartz veins and pegmatites in other parts of central Brazil, they then are of late pre-Cambrian or early Paleozoic age.

INTRODUCTION

In 1939 an important group of magnesite deposits was discovered in the Serra das Éguas, a mountain range just west of the town of Brumado, in the southwestern part of the Estado da Bahia, Brazil. The Geological Survey, of the United States Department of the Interior, studied the deposits in 1945, at the request of and in cooperation with the Divisão de Fomento da Produção Mineral, of the Departmento Nacional da Produção Mineral, Brazilian Ministerio da Agricultura. 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.

The geological study reported in this paper was made primarily to determine the reserves and chemical grade of the magnesite deposits. It was found that five of the deposits contain large magnesite blocks with sufficient chemical purity to be minable. Reserves are large but the future economic position of the deposits in the world market will depend on mining and transportation costs. Smaller but substantial amounts of chemically pure talc, some optical-grade quartz crystals, and a few semiprecious gemstones are associated with the magnesite deposits.

All measurements in this report are metric. A table of conversion factors between the metric and English systems is appended. (See p. 166.)

MAGNESITE OCCURRENCES

Magnesite, the carbonate of magnesium, has been found in a wide range of geologic environments: as a constituent of igneous bodies and of contact metamorphic aureoles, as massive replacement deposits, as vein deposits, and as sedimentary strata (Bodenlos, 1950b, p. 225). The only occurrences attaining minable size and purity are massive replacement deposits in carbonate rock, vein deposits in ultrabasic intrusive rock, and sedimentary strata or lenses. Of these, the massive replacement deposits are the most important commercially, although the vein deposits also have furnished large tonnages; the sedimentary deposits as yet have been mined only on a very small scale.

The appearance and texture of magnesite in the three principal modes of occurrence is markedly different. Massive replacement deposits consist of coarse-grained magnesite resembling marble; vein deposits consist of cryptocrystalline magnesite resembling unglazed porcelain; and the sedimentary deposits (Vitaliano, 1950) consist of very fine grained magnesite resembling limestone. The first two of these occurrences are classified by miners according to texture; thus, replacement deposits are known as "crystalline" deposits, and the vein deposits are known as "cryptocrystalline," "amorphous," or "bone" deposits. The deposits in the Serra das Éguas, occurring in dolomite, are of the massive-replacement, or crystalline, type.

Crystalline magnesite deposits have been found in widely separated parts of the world, and as a group are interesting because they are comparatively rare and yet always remarkably large. They are known in Austria, Czechoslovakia, Russia, Manchuria, Korea, Brazil, and the United States (Bateman, 1942, pp. 711–712; Birch & Wicken, 1949, pp. 522–528; and Harness and Jensen, 1943). The deposits of Austria were the first to be developed, and for many years that country led the world in magnesite production; in 1937 some 460,000 tons were mined.[1] The deposits of Czechoslovakia are smaller and have been mined to a lesser extent. Russia has four large deposits in the Ural Mountains; production from these expanded rapidly in the 1930's, reaching an estimated 550,000 tons in 1937. The deposits of Manchuria (Niinomy, 1925) are said to be the largest in the world, with reserves of several hundred million tons. The deposits were developed under the sponsorship of Japan and attained an annual production of about 330,000 tons in 1937. In the United States the deposits at Chewelah, Wash., produced the bulk of the 184,000 tons mined in the country in 1937. During the war years, the deposit at Gabbs, Nev., furnished an additional large tonnage after its development in 1941. In Brazil two groups of deposits, in the Estado do Ceará and the Estado da Bahia, were discovered in the late 1930's. Although they have not as yet been developed for large-scale production, they compare favorably in size and grade with most of the occurrences listed above (Bodenlos, 1950a).

The principal use of magnesite is in the manufacture of refractory material for linings of high-temperature furnaces; about 88 percent of United States consumption during the years 1938–42 was for this purpose (Harness and Jensen, 1943, p. 9). Lesser uses are in the manufacture of magnesium oxychloride cement, magnesium metal, and in the paper, ceramic, synthetic rubber, glass, insulation, and chemical industries. Details of processing of magnesite for these uses have been described by McDowell and Howe (1920), Comber (1937), Seaton (1942), and Harness and Jensen (1943). The first step in processing almost all magnesite is heating, or calcining, during which the bulk of the carbon dioxide is driven off, leaving a remainder consisting principally of magnesium oxide; the residue is known as "dead-burned magnesia," "periclase," or "caustic-calcined magnesia," depending on its purity and chemical reactivity.

At the beginning of World War II, magnesite was considered to be a strategic mineral because of its use as a refractory lining of open-hearth steel furnaces and as an ore for magnesium metal. Since that time processes have been perfected to extract magnesia from dolomite, from sea water, and from bitterns derived from sea water. Although most magnesia still is obtained by calcination of magnesite ore, industrial countries now are not as completely dependent on magnesite deposits as they had been prior to the war.

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[1] Statistics by Harness and Jensen, 1943, pp. 18–19. The year 1937 is here used because it was the last prior to the recent war for which reliable statistics are available for most countries.

GEOGRAPHY OF THE BRUMADO AREA

Brumado, formerly known as Bom Jesus dos Meiras, is on the west bank of the Rio do Antonio, a north-flowing tributary of the Rio de Contas (Rio das Contas) which empties into the Atlantic Ocean 150 kilometers south of Salvador. (See fig. 8.) The geographical coordinates of the benchmark in front of the town church, determined astronomically by the Brazilian Conselho Nacional da Geografia, are latitude 14°12′08″ S., and longitude 41°48′39″ W., and the railroad station is at an altitude of 430 meters above sea level. The local political subdivision is the municipality of Brumado, whose area includes the Serra das Éguas. The region has low relief except where isolated ranges, such as the Serra das Éguas, project several hundred meters above the lowland level.

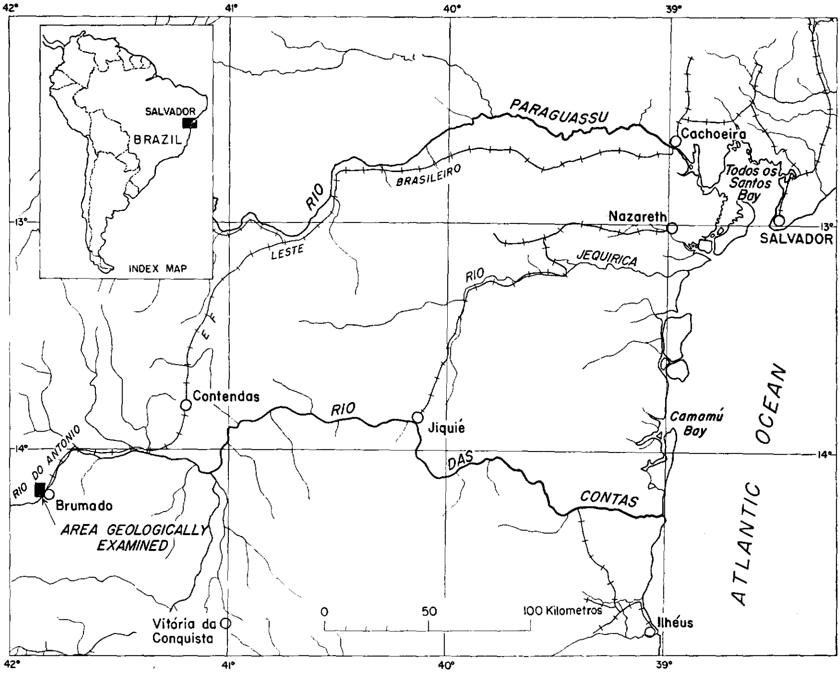

FIGURE 8.—Index map of south-central Bahia, showing location of Brumado with reference to rail lines connecting with Salvador.

The town is on the E. F. Leste Brasileiro (Leste Brasileiro Railway), and is 530 kilometers via rail from São Felix at the head of navigation of Todos os Santos Bay. A circuitous rail route, about 120 kilometers long, skirts the north edge of the bay, and connects Brumado to Salvador, capital of the Estado da Bahia and chief port in this part of Brazil. Steamer service across the bay offers a shorter alternative passenger route. Brumado may also be reached by railroad

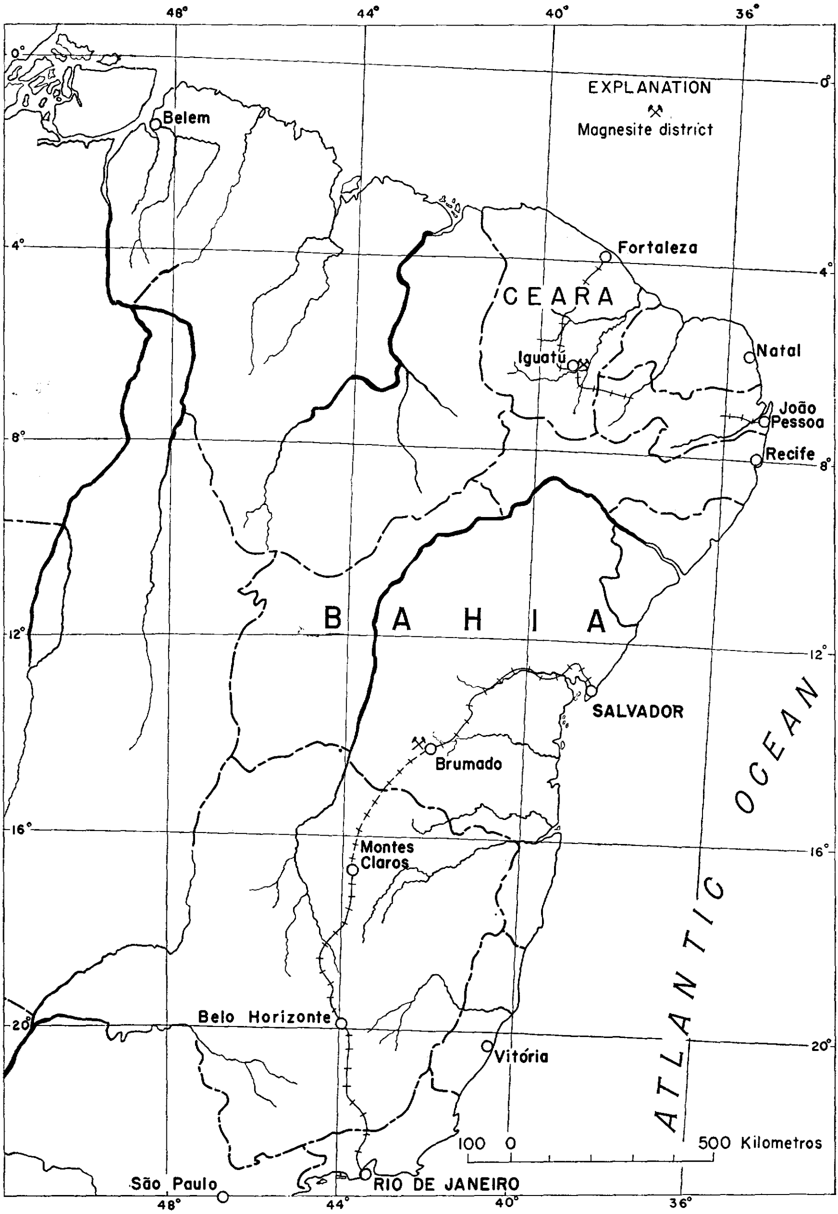

FIGURE 9.—Index map of eastern Brazil, showing location of Brumado, Bahia, and Iguatú, Ceará, the major towns of the magnesite districts.

and road from Rio de Janeiro, a distance of 1,500 kilometers, via Belo Horizonte, capital of the Estado de Minas Gerais. (See fig. 9.) In 1945, the E. F. Central do Brasil (Central Brazil Railway) provided service only to Montes Claros, about 1,000 kilometers from Rio de Janeiro, but the entire length of the connecting link to Brumado was under construction. In 1950 the roadbed was completed and Brumado and central Bahia now have rail connections with the industrial centers in the southern part of the country. Brumado is also on a highway extending from the coast at Ilhéus (Ilhéos) to the Rio São Francisco. Airports at Brumado and at Vitória da Conquista, about 120 kilometers to the southeast, permit charter air travel to the vicinity.

The region is classified by Brazilian meteorologists as tropical semihumid (Ministry of Foreign Relations, 1945, pp. 52–62.). The annual temperatures averages 23° C., the rainfall is from 500 to 1,000 millimeters, and the humidity averages 75 percent. Most precipitation occurs between the months of November and January, the season locally termed "winter" because the sky generally is overcast. At this time of the year the mountains have much fog caused by impingement of clouds against their flanks. Because trees on the crest of the Serra das Éguas lean to the northwest and vegetation is thicker on the southeast side of the range, it is judged that prevailing winds come from the southeast.

The Brumado area is drier than the coast of Bahia and is said to be the southern extension of the arid zone, or "sertão," of northeastern Brazil. The vegetation resulting from this climate is similar to that of the dry country farther to the north; it is generally sparse and consists for the most part of a miscellaneous assemblage of brush growing to a height of 2 to 4 meters. Along mountain streams vegetation is dense, consisting of tropical trees growing as high as 30 meters, palms, and a choking growth of vines and brush, but along lowland streams vegetation is considerably thinner. Cactus is found both in the mountains and lowlands and is especially common on outcrops. Grassland occurs on the crests of mountain ranges; several square kilometers of the flatter part of the Serra das Éguas are covered with natural pasture supporting many cattle, mules, and horses.

The Rio do Antonio is perennial, but little water is available in the lowlands away from its immediate course. In contrast, water is moderately plentiful in the Serra das Éguas, for the range is high enough to catch considerable rainfall. Five streams are perennial and although they are not large they carry enough water to permit substantial local agriculture. In 1945, Dr. E. B. Rosas, engineer for Magnesita S. A, calculated streamflows as follows:

Stream	*Liters per second*	
Jatobá	1.5	(measured)
Bate-Pé	10.0	Do.
Catiboaba	10.0	Do.
Coité	10–12	Do.
Pirajá	3	(estimated)

Agriculture and stock raising are the chief industries of the region. As is typical of the sertão these are conducted on a small scale and little other than cotton and hides is exported. Fruits, vegetables, wild coffee, and sugar are plentiful. Livestock consists of cattle, oxen, horses, mules, sheep, goats, and fowl. In the Serra das Éguas, stock raising and cultivation of sugar cane and bananas are the chief agricultural activities.

DISCOVERY AND DEVELOPMENT OF THE MAGNESITE DEPOSITS OF THE SERRA DAS ÉGUAS

During the early part of this century a local inhabitant mined and smelted a small amount of itabirite, a variety of banded iron ore, from the Serra das Éguas. This was the first mining in the area and apparently was of short duration. A few years later, probably in 1912 or 1913, emeralds were discovered on the west side of the range in Pirajá valley. These were recovered from surface pits and eluvial placers during the following 30 years. One large quarry and numerous small pits were cut in bed rock and 5 hectares of ground were panned or sieved in these operations. Specimens from the emerald occurrences were sent to Germany where mineralogists recognized magnesite associated with the gemstones (see p. 188), but their reports seem to have been overlooked in the following years and the magnesite was forgotten.

In 1938 or 1939, a specimen of the host rock to the emeralds was sent to the Divisão de Fomento da Produção Mineral in Rio de Janeiro, where it was analyzed and found to be magnesite. Unfortunately, no return address was included and the only legible part of the postmark read "Bahia." Shortly thereafter, two naturalized Brazilian citizens, Srs. Pierre Cahen and Georges Minvielle, became interested in magnesium metal and decided to prospect for magnesite. Upon inquiry at the Divisão de Fomento da Produção Mineral, they were advised of the small deposits of "bone" magnesite in central Bahia, near Jiquié, and also of the recently acquired specimen of unknown origin.

Officials of the D. F. P. M. loaned Cahen and Minvielle part of the specimen. The two prospectors started their search in the early part of 1939, beginning at Jiquié (Jequié). Their method was to show the magnesite to prospectors and miners, inquiring whether such rock was present in the vicinity and examining those localities recommended to them. After some four unsuccessful months they met a prospector who had formerly worked in the Pirajá emerald diggings. Srs. Pierre Cahen and Georges Minvielle (personal communication) stated that thereafter it was extraordinarily simple to discover the Serra das Éguas deposits.

Cahen and Minvielle formed the company Magnesita Ltda., and did the necessary work to acquire concessions on most of the deposits.

Lacking capital to develop their holdings, they interested a group of financiers in Belo Horizonte which in 1940 backed and reorganized the company under the name Magnesita S. A.

The major development work has occurred since this early reorganization. All but one of the remaining deposits in the area were claimed and the assessment work for permanent title was concluded. At the time of the writer's visit in 1945, a few tons of magnesite for pilot plant experiments and small amounts of talc for grinding experiments were being mined by hand. A kiln site had been selected at Catiboaba railroad station, 9 kilometers south of Brumado, and a road from the Pedra Preta deposit to the kiln site was begun. Since that time one stack kiln has been assembled at Catiboaba station and two kilns at Pedra Preta; their total capacity will be about 80 tons deadburn per day. (Personal communication from Mr. Miro Mihelich, Harbison Walker Refractories Co., Pittsburgh, Pa.) A townsite with water and electric supply has been built, and the Pedra Preta-Catiboaba station road has been completed. Power is furnished by a diesel and a steam plant, and the company is enlarging its supply by installing a hydroelectric plant at Livramento, located on high falls in the Rio de Contas 80 kilometers north of Brumado. Between 1945 and the beginning of 1948, 1,200 tons of talc and 2,000 tons of magnesite were mined; the latter was stock-piled waiting completion of the kiln, according to a personal communication from Dr. Antonio Chaves Diniz, General Manager, Magnesita S. A.

During this time the company also built a refractories plant in Belo Horizonte, Minas Gerais; the locality was selected for its intermediate position between the deposits and the manufacturing centers of Brazil. The plant has units for making magnesia, silica, and fire clay brick and is under the technical direction of Dr. George Merz. A talc-grinding plant has been built in Rio de Janeiro.

The Boa Vista deposit, the only one in the Serra das Éguas not acquired by Magnesita S. A., was claimed by G. W. Soares; more recently Raymond Linton acquired a concession in this area. The deposit was still being explored by engineers at the time of the writer's visit in 1945, and at that time no plans had been made for development.

Another type of mining in the Serra das Éguas, carried on only during World War II, was the recovery of optical-grade quartz crystal. Prospectors, working with hand steel, dug shallow pits on quartz pockets occurring in magnesite. The writer heard unverified claims that some 3,000 Brazilian contas ($150,000 U. S.) worth of quartz had been recovered from this area. With the lessened demand toward the end of the war, work of this type had nearly ended in the latter part of 1945.

FIELD WORK AND ACKNOWLEDGMENTS

The Geological Survey party, consisting of M. F. Denault and the writer, mapped and studied the Serra das Éguas from June to Novem- 1945. Dr. Jose Alvas Quesada, engineer for the Divisão de Fomento da Produção Mineral, was detailed to the investigation in September and stayed with the Geological Survey party 2 months.

The field work consisted of topographic and geologic mapping of the central part of the Serra das Éguas and of the five most important magnesite deposits, as well as geologic traverses of the remaining magnesite occurrences. The topographic map of the range, controlled by transit triangulation and completed by plane-table and alidade surveying, was compiled by Mr. Denault. The point of origin of the map is concession marker *D* of the Magnesita S. A. concession survey; the datum is barometric, as carried from the railroad station in Brumado to concession marker *A*, the base point of the Magnesita S. A. survey. The map and plane-coordinate system are oriented to true north, using an astronomically determined azimuth for the base line (Coast and Geodetic Survey, 1944). The magnetic declination at the base line is N. 16°40′W.; this varies as much as several degrees in areas underlain by rock containing hematite. The base line and triangulation stations are marked by sunken boulders engraved with crosses and covered with stone pylons.

The coordinate systems of the four deposits surveyed by plane table and alidade are correlated with the primary system, using either primary or secondary triangulation points set by Mr. Denault for local control. Mr. Denault also established auxiliary points to facilitate mapping of the smaller deposits and to control pace-and-compass traverses in the geologic mapping of the range.

The planning and execution of this project was possible only through the cooperation of many officials and technicians of both the Brazilian and American governments as well as those of the operating company Magnesita S. A. Chief among these were Dr. Jose Alvez de Souza, then Director of the Departmento Nacional da Produção Mineral, and Dr. Alberto I. Erichsen, Director of the Divisão de Fomento da Produção Mineral. Mr. Emerson I. Brown, Minerals Attaché of the American Embassy, also offered his entire facilities to the party. In Rio de Janeiro and in Belo Horizonte, officials of Magnesita S. A., principally Dr. Antonio Chaves Diniz, general manager, Dr. Georges Merz, Sr. Pierre Cahen, and Sr. Georges Minvielle, all very kindly furnished substantial information pertaining to the history and technical development of the company and also made available their files of surveying and chemical analytical data. At Brumado, the staff of Magnesita S. A., headed by Dr. E. B. Rosas, resident engineer, continued this assistance and also furnished quarters and arranged for mounts, guides, and rodmen. Dr. Odelio Costa and Dr. Custodo Braga Filho, of the Cia. Serviços de Engenharia, very kindly gave the writer information pertaining to the Boa Vista deposit.

Supplementary to the field work, the chemical laboratory of the Departamento Nacional da Produção Mineral, headed in 1945 by Dr. Mario Pinto, made a most important contribution to this study by analyzing 160 samples collected in the field. This fundamental work has made possible a much more accurate and complete report, and the writer is greatly indebted to Dr. Pinto for his cooperation and direction of this very valuable research.

The author is indebted to Mr. G. T. Faust, of the Geological Survey for searching criticism and extended discussions on the subject of the origin of magnesite. Although this writer does not agree with all viewpoints expressed by Mr. Faust, the discussions resulted in revisions leading to a clearer expression of the hypotheses presented in this paper.

PREVIOUS GEOLOGIC WORK

Prior to the present investigation the geology of the Serra das Éguas had not been systematically studied, but a number of articles on aspects of the mineralogy were published. The first of these, by Saxe Cobourg-Gotha (1889), describes several specular hematite crystals from this range. Following discovery of emeralds, mineralogical suites from the Pirajá deposit were described by Siedel (1914), Uhlig (1915), and Arlt and Steinmetz (1915). Morais Rego (1932) visited the emerald deposits and reported their field relationships. The most recent mineralogical report is a careful morphologic study of magnesite crystals by Saldanha de Gama (1946).

Following discovery of the magnesite deposits several general articles appeared in the Brazilian mining journal, Mineração e Metalurgia, by Leonardos (1943), Barbosa (1943), and Lino de Mello (1945).

The writer has had access to several unpublished reports, one of the Foreign Economic Administration by Capper Alves de Souza (1944) on the commercial possibilities of the magnesite crystals, and others by mining engineers of Magnesita S. A., in the form of official reports to the Departamento Nacional da Produção Mineral. Of the latter, the report by Mello Viella and Souza (1941) contains considerable geologic information on the region.

GEOLOGY

METAMORPHIC ROCKS

Wide areas in Bahia are underlain by gneiss and schist, included in a unit which has been called the Complexo Fundamental, or

Brazilian complex, and considered in standard Brazilian publications to be of Archeozoic age (Oliveira and Leonardos, 1943, pp. 37–49 and 67–73). Few details of the lithologic character, structure, and age of these rocks are known. Overlying these crystalline rocks in the Serra das Éguas is a sequence of dolomite and quartzite, correlated by Morais Rego (1932) with the Minas series occurring to the south in the State of Minas Gerais, and considered to be Proterozoic (Algonkian) in age. Owing to insufficient evidence the dolomite and quartzite in the Brumado area are not here assigned to the Minas series; the entire group of metamorphic rocks is considered only as pre-Cambrian for the present.

The scarcity of outcrops in the Serra das Éguas, coupled with apparently close and complex folding, prevent detailed description of the stratigraphic sequence. The following discussion and the geologic map of the range therefore are generalized. (See pl. 12.) Undoubtedly, careful search for additional outcrops would result in more exact information, but time for such detailed work was not available during this investigation.

GNEISS AND SCHIST

Gneiss and schist of the Complexo Fundamental, or Brazilian complex, are the oldest rocks in the Serra das Éguas. The gneiss, medium gray in color, is composed of quartz, microcline, orthoclase, biotite, and minor amounts of muscovite. Microcline is the oldest feldspar and is partly replaced by albite and secondary quartz; muscovite also appears to be a later mineral, as its orientation is not so uniform as that of the biotite whose orientation is alined with the foliation. The gneissic texture is most pronounced and the color is darkest in those areas where secondary albite, quartz, and muscovite are least common. Schists included in the complex are dark gray and are composed principally of quartz and biotite, although some quartz-chlorite schist was found. Smoothly rounded dark-gray or rusty-gray outcrops characterize weathered surfaces of both the gneiss and the schist.

The largest area in the range underlain by rocks of the Brazilian complex is on the ridge flanking the northwest side; in this area the contact of the complex with dolomite is most accurately mapped in the Coité valley where only a few meters between outcrops of the two types of rock are covered by soil. On the east side of the range, the same contact lies beyond the area shown on the geologic map; gneiss and schist crop out along the roads and trails leading from Brumado to the Catiboaba, Bate-Pé, and Jatobá valleys.

DOLOMITE

A thick sequence consisting principally of dolomite forms the lower unit of the rocks overlying the schist and gneiss. The dolomite contains some thin quartzite and sandstone beds and, in places, veins and lenses of tremolite. Numerous euhedral tremolite and actinolite crystals are found in other areas.

In most places the dolomite is saccharoidal and light gray, although pink and cream dolomite is moderately common. The rock consists of anhedral grains ranging from 0.2 to 1.5 millimeters in diameter. Weathered material is medium gray or buff and moderately hard, but in places the rock disintegrates along crystal boundaries and forms dolomite sand. Microscopic study and chemical analyses indicate that most dolomite is close to the theoretical composition of the mineral (table 14, sample analyses PR 1–4), although one sample has a deficiency of magnesia and effervesces slightly in dilute hydrochloric acid. (See table 14, sample analysis PR 5.)

Primary quartzite and sandstone layers are the only remnants of bedding; elsewhere such structures have been destroyed in the regional deformation and accompanying crystallization. In a few places actinolite and tremolite crystals are roughly alined and may possibly represent original bedding.

With limited data on the attitude of bedding, only the most general figures on the width of the dolomite may be given. In the Coité valley area, it is thought that the dolomite is dipping steeply on one flank of the major syncline. Assuming that the dolomite has not been unduly thickened by subsidiary folds or thinned along the flank of the fold, the minimum width of 450 meters would roughly correspond to its thickness. Elsewhere the outcrop widths are greater and across the Bate-Pé and Pirajá valleys, where the sequence is thought to be repeated by folding the dolomite and the included magnesite bodies extend across the strike of the regional structure for a distance of 4 kilometers.

The most extensive dolomite outcrops are in the Pedra Rolada area and north of the Gravatá deposit. A considerable number of outcrops surround the Cabeceiras and Cordeiro deposits and are west of the Pirajá deposit. In areas where mineralization has resulted in magnesite replacing dolomite, outcrops of the latter may be scarce or lacking. The distribution of dolomite and included magnesite deposits reflects the general synclinal structure of the range, modified by smaller folds. (See pl. 12.)

QUARTZITE

The youngest rock unit in the Serra das Éguas consists principally of quartzite. Massive beds, each from 0.5 to 2.0 meters thick, compose the lowest 20 meters. These are dominantly white or gray but several are pink or yellow; all are very fine-grained. North of the Bate-Pé valley a steel-gray sandstone is included in these beds. Outcrops are craggy and weather gray, yellow, or red; the brighter outcrops owe their color to iron oxide. Above the basal beds, the quartzite consists of thin beds ranging from 5 to 15 centimeters in thickness. The colors of the upper beds are darker, probably due to greater iron content; these beds weather red and brown and generally form low ledges. The thickness of the formation is not known but judging from its widespread extent in the south-central part of the range it must be several hundred meters. The quartzite is folded and underlies the axial areas of synclinal structures.

The upper beds of the quartzite contain banded quartz-hematite rock, or itabirite. Individual bands of both quartz and hematite are from 1 to 5 centimeters thick and hematite forms from 25 to 50 percent of the bulk of such rock. No more than a 3-meter thickness of itabirite was seen in any one locality; owing to its comparatively widespread distribution several such sequences must exist unless the rocks have been folded very intricately. The upper quartzites also contain a few thin layers of quartz-biotite and quartz-chlorite schist.

Octahedral crystals of martite, a hematite pseudomorphous after magnetite, occur as float in areas underlain by itabirite. Such crystals range from 0.5 to 3.0 centimeters in diameter.

INTRUSIVE ROCKS

Dikes of green amphibolite are the only common intrusive rocks in the Serra das Éguas, although a few very small dikes of rhyolite also occur.

As far as can be determined from outcrops, the amphibolite dikes range from about 0.5 to 20.0 meters in width and are from several meters to 500 meters long. Most of them are dolomite but several are in magnesite. (See pls. 12, 13, 14.) Thin sections show that the rock consists of green hornblende, some oligoclase, and lesser amounts of albite, orthoclase, and microcline; accessory minerals include beryl and zircon. Hornblende crystals have corroded boundaries and the feldspars, especially the oligoclase, are poikilitic and contain innumerable hornblende blebs. The hornblende has been altered to biotite, chlorite, and magnetite, and the feldspars are slightly sericitized. Most rock has massive texture but in places gneissic texture is produced by alternating thin laminae, as much as 2 millimeters thick, of dark hornblende and light feldspar. The gneissic variety contains more feldspar and should be classed as a melanocratic diorite. Pecora and others (1950, p. 233) suggest that in Minas Gerais such amphibolites are metamorphosed from ultrabasic rocks.

Another variety of amphibolite consists principally of actinolite schist. This type, judged to be sheared and altered hornblende-rich rock, is not common.

Most contacts between amphibolite and dolomite or magnesite are covered but where they are exposed there is little or no contact metamorphism. In the Pirajá area, one dike has a selvage of biotite about 10 centimeters thick in contact with dolomite.

Rhyolite dikes are from 10 to 20 centimeters thick and were seen in outcrops as much as 5 meters long. The rock consists of a buff-colored groundmass containing numerous quartz phenocrysts. One small dike north of the Pedra Preta deposit is bordered by a narrow zone of recrystallized dolomite containing tremolite and garnet crystals.

It is certain that the dikes were introduced following the regional folding because they do not show signs of rupture or extensive internal deformation. Their age relative to mineralization can only be surmised. At the Pirajá deposit, two dikes occur over a distance of 700 meters, close to the contact between magnesite and dolomite. This may be an indication that the dikes influenced the location of the deposit by channelling solutions, in which case they were emplaced prior to mineralization.

Closely spaced veins of enstatite and talc occupying sheeting structure are common in many magnesite deposits. The veins are inferred to be altered from quartz veins introduced prior to mineralization. Quartz veins also were emplaced after magnesite mineralization in sheeting structure and in joints.

STRUCTURE

The rocks underlying the Serra das Éguas are closely folded into a large syncline striking about N. 20° E. In most of the range and most of the mapped area, the structure plunges south at low angles; this reverses in the vicinity of the Catiboaba valley so that the structure of the range as a whole is canoe-shaped.

Knowledge of details of the structure is limited by scarcity of outcrops and evidence of bedding in the carbonate rocks, but the distribution of the rock units—especially the width of areas underlain by dolomite and quartzite—is best explained by close and repeated folding. Several sharp folds are visible; one, a syncline, is just west of the Fabrica deposit, and another, consisting of an adjoining syncline and anticline, is in the ridge extending westward from the northwest corner of the regional map. (See pl. 12.) The other folds shown on the map are known only from patches of quartzite in carbonate rock areas or the reverse. For this reason most of the folds shown on the structure sections of the range are schematic. North of the mapped area two regions underlain by quartzite, one on the northeast peak, Morro Chapeo, and the other in less prominent hills in the northwest part of the range, mark the troughs of two deeper synclines extending to the end of the range. South of the mapped area, the region underlain by quartzite extends without ramifications nearly to the southern end of the range.

Outcrops of both dolomite and quartzite show characteristic structures of deep-seated and plastic deformation. Quartzite and tremolite bands included in dolomite have been torn apart to form boudinage, or sausage structure. Each isolated fragment is surrounded by uniformly crystallized dolomite, indicating that crystallization or adjustment of crystals took place during deformation. In places the thin beds of the upper part of the quartzite are intricately and closely crumpled; such features indicate intense deformation under heavy load.

Zones of numerous quartz, tremolite, and pyroxene bands occur in dolomite and magnesite and represent either primary beds or secondary injection along either foliation planes or sheeting structure. These bands dip steeply and in places such as at the Pirajá deposit, are in large sinuous folds. North of the Gravatá deposit they strike northwest and in the central part of the Bate-Pé valley they strike almost due west. Although the bands conform with the expected attitude of bedding in the Coité and Cabeceiras areas, their configuration in the north-central part of the range is anomalous with respect to the regional synclinal structure. Because the large sinuous folds plunge much more steeply than the larger known folds in the quartzite, it is improbable that they are drag folds of primary siliceous beds. The structures cannot be simple foliation planes because they are discordant to the expected orientation parallel to the axial plane of major folding. Secondary cross-folding on such a scale is not apparent in the general outcrop pattern of either the gneiss and schist or the quartzite. The writer can only conclude that the structure is a type of sheeting formed by movement of unknown origin in highly plastic dolomite.

A few faults of small displacement formed during the latter part of the period of mineralization at the Pirajá and Cabeceiras deposits (see pp. 156 and 158). Widespread fracturing resulting in open fissures and breccias occurred during magnesite deposition in nearly all deposits. Wide silicified zones in magnesite and dolomite probably mark other zones of fracture or movement, but none of the abovementioned structures seem to have resulted from a significant amount of displacement.

PHYSIOGRAPHY

The Brumado area generally is one of low relief, above which project isolated mountain ranges. The lowlands are said to be part of an extensive peneplane cut on the Complexo Fundamental, or Brazilian complex, underlying much of central Bahia. Brumado is 300 kilometers from the coast and at an altitude of 430 meters, so the peneplane slopes eastward at less than 1.5 meters per kilometer. Owing to recent incision of drainage, the peneplane has a local relief of 20 to 40 meters, which, combined with extensive ramification of the drainage system, cuts the entire area into low hills. This has been detrimental to regional development; agriculture is limited because the hilly terrane has a low water table and rail routes are confined to following tortuous drainage courses.

The mountain ranges owe their elevation to cappings of harder rock. The Serra das Éguas is typical in size and shape. It is 20 kilometers long, as much as 6 kilometers wide, and rises about 600 meters above the lowland peneplane. From a distance its longitudinal profile resembles a whaleback, with a few rounded prominences projecting above the generally smooth crestline. The flanks of the range are comparatively steep and parts of the broad-topped area have been sharply incised by youthful streams. (See fig. 10.) Some slopes in these valleys are as much as 53°. This is well above average and is attributed to a combination of active down cutting by streams and a tough vegetative mat which holds the soil cover intact and prevents slumping.

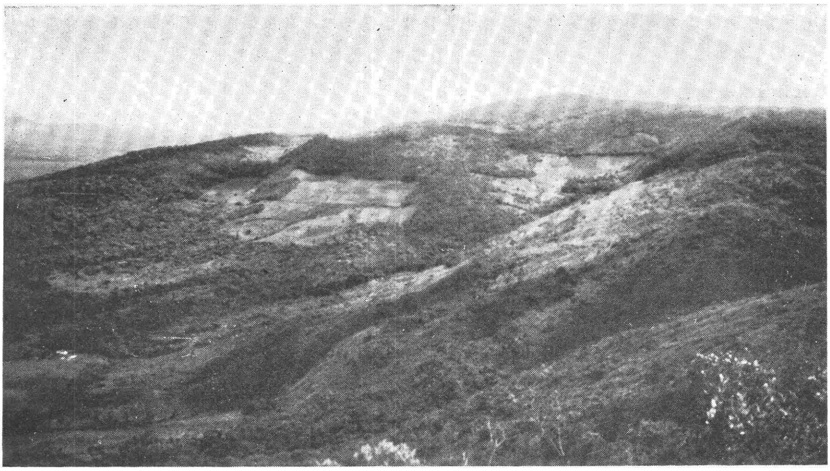

FIGURE 10.—View of the lower Bate-Pé valley, looking south. Steep valley at lower right is beginning of highly dissected upper area. Magnesite crops out on lower hill slope and in stream bed, bottom center; the Boa Vista deposit lies beyond. Gneiss and schist underlie ridge at far left.

The drainage pattern of the Serra das Éguas in part reflects the underlying geologic structure. Those stream systems or parts of stream systems crossing but one type of rock have dendritic patterns, whereas those that cross several types of rock have rudimentary trellised patterns. Along the east side of the range, subsequent streams or tributaries follow the syncline west of the Fabrica deposit and the anticline at the Catiboaba deposit, have opened a large valley in carbonate rock behind the gneiss and schist in Bate-Pé valley, and have cut behind the quartzite syncline at the Pedra Preta deposit. Along the west side of the range several streams have opened a large subsequent valley on dolomite and magnesite east of the hills underlain by gneiss and schist. (See pl. 12.)

Almost the entire upland surface is covered by laterite from 3 to 20 meters thick, although small areas in the central and northwestern part of the range have comparatively thin cover. Elsewhere outcrops of bedrock occur only in sharp valleys or in the floors of gullies cut in laterite. Such gullies, locally known as "barrocas," have very steep walls which slope from 60° to 80° and continue to their heads. The heads of some gullies are dissected into badland topography with many sharp pinnacles or perched rocks. The precipitous heads probably form because vegetation holds the original surface intact until breached by actively-growing gullies—possibly through the process of "gully gravure," (Pecora and others, 1950, p. 223); these features are most common in areas covered by undisturbed grassland. (See pl. 14.)

The laterite in general can stand in very steep cuts, either natural (as in the gullies) or man-made (as in roadcuts). Whereas undisturbed laterite stands well, laterite fill slumps readily when wet. In road cuts, the cut wall may be left nearly vertical but the road must be excavated into hillslopes sufficiently so that a minimum of the roadbed is on fill. Roadbeds not so designed deteriorate rapidly during rainy seasons.

GEOLOGIC HISTORY

Subsequent to deposition of carbonate rock and sandstone, the area was subjected to orogeny and the rocks were closely folded and metamorphosed. Thereafter igneous dike rocks, mostly amphibolites, were intruded and quartz veins were introduced. The age of dolomitization of the carbonate rocks is unknown.

Nothing is known of the history thereafter until the present erosion cycle, when the area was extensively peneplaned. Small areas capped by hard rock resisted erosion and now form isolated mountain ranges. Very recently the entire area has been raised and the meandering drainage of the previous cycle has been incised from 20 to 40 meters.

Discussion of possible age of mineralization and accompanying fracturing and minor faulting of the rocks and mineral deposits follows on page 140.

MINERALIZATION IN THE SERRA DAS ÉGUAS

MINERALOGY

Magnesite, which replaces dolomite, is the principal mineral in the Serra das Éguas deposits. Accompanying it is dolomite occurring as unreplaced residual material and to a very small extent as material deposited in cavities. Talc, quartz, and enstatite are the common silica and silicate minerals. Smaller amounts of iron oxide, aluminum silicate, and other minerals also occur in the deposits. Mineralization was accomplished by hydrothermal solutions rising from a concealed igneous source and depositing the suite in the hypothermal and mesothermal zones. On tenuous evidence mineralization is dated as early Paleozoic.

MAGNESITE

Magnesite, the carbonate of magnesium, theoretically consists of 47.6 percent magnesia (MgO) and 52.4 percent carbon dioxide (CO_2). Magnesite has very limited miscibility with the calcium-bearing carbonates, dolomite and calcite, but apparently a continuous series can exist between magnesite and the iron carbonate, siderite. The mineral crystallizes in the rhombohedral class of the hexagonal system and has perfect rhombic cleavage. Crystalline magnesite has a hardness ranging from 3½ to 4½, a specific gravity from 3.0 to 3.12, and a vitreous luster (Ford, 1932, pp. 511, and 517–518). The physical properties of cryptocrystalline, or "amorphous" magnesite are more variable and the material is characterized by porcelainic luster (Bodenlos, 1950b, p. 238). Magnesite in the Serra das Éguas is preponderately crystalline although a few insignificant veins of cryptocrystalline magnesite have been found.

The following are methods, short of chemical analysis, for distinguishing between magnesite and dolomite.

Most massive crystalline magnesite is similar in appearance to massive crystalline dolomite, the carbonate of calcium and magnesium. This similarity gives rise to the problem of accurately identifying the minerals where the two are in close association, as in the Serra das Éguas. Where the two minerals are mixed, the problem of determination of the chemical composition must be solved, because material containing excessive lime cannot qualify as commercial magnesite. Magnesite, with a specific gravity of 3.0 to 3.12, is slightly heavier than dolomite with a specific gravity from 2.8 to 2.9. The vitreous luster of magnesite is a little brighter than that of dolomite. Neither mineral is noticeably effervescent in cold dilute hydrochloric acid. Identification of the two minerals as based on these properties is qualitative and although it becomes more certain with the experience of the examiner, it never is completely reliable in the course of routine field work. It has been the writer's experience that differences in luster are easier to discern in coarser-grained material (grain size more than 3 millimeters diameter) than in finer-grained material and that the criterion is comparatively unreliable in very fine-grained rock (grain size less than 1 millimeter diameter). Auxiliary field and laboratory tests therefore are of considerable assistance in these determinations (Himmelbauer, 1933, pp. 250–251); they include chemical spot tests

(Feigl, 1946, pp. 442–443), pH abrasion tests (Stevens and Carron, 1948, pp. 31–49), staining tests (Feigl, 1946, p. 444), thermal analysis tests (Faust, 1944, pp. 142–151), chemical tests (Harness and Jensen, 1943, pp. 2–3), and microscopic examination.

Feigl's spot tests uses an alkaline solution of diphenycarbazide in alcohol: a few drops of hot solution on a fragment of magnesite gives a deep-red color whereas dolomite so treated remains colorless. The pH abrasion test utilizes the differences of the two minerals in water (dolomite pH 9–10; magnesite pH 10–11). The abrasion test is less sensitive than the spot test because indicator papers in this range are not sufficiently sensitive (Stevens and Carron, p. 36), but is convenient for field use because the necessary equipment consists only of a porcelain scratch plate, water, and indicator paper. The staining test described by Feigl requires polishing of the sample and immersion in a weakly acidified solution of sodium alizarin-sulfonate. Calcium-bearing carbonates are stained violet and magnesite is stained yellow. Polishing is a rather lengthy procedure but the test is roughly quantitative in that the areas of each mineral are roughly proportional to its percentage in the tested specimen. The roughly quantitative chemical test described by Harness and Jensen consists of boiling the sample in dilute sulfuric acid; magnesite gives a clear solution, dolomite or calcite a white precipitate of calcium sulfate. Still other tests include the thermal-analysis technique suggested by Faust (1944) which utilizes differences in temperature of calcination to identify the minerals. By heating a screened sample crushed to 200 mesh at a temperature of 585° C., magnesite undergoes thermal dissociation to periclase whereas dolomite is unaffected. Examination under the microscope permits easy identification: immersed in an index liquid of 1.68 the periclase stands out and can further be distinguished from dolomite by its low birefringence. The percentage of CaO in the rock can be calculated from grain counts.

Microscopic examination of mineral fragments, the technique favored by the writer, utilizes the difference of the ω index of refraction of the two minerals—dolomite, $\omega=1.68$; magnesite, $\omega=1.70$ (Wright, 1913, pp. 76–77). (The method was successfully used by C. J. Vitaliano in the detailed examination of the deposits at Gabbs, Nev.) Immersed in a liquid with a refractive index of 1.70 and examined in plane-polarized light and oblique illumination, magnesite fragments show vivid indigo and orange borders in readily distinguishable contrast to dolomite fragments which show dull blue and shadowed borders. Preparation of the ground sample and its examination, including an approximate quantitative determination of the relative numbers of magnesite and dolomite grains, can be completed in 2 or 3 minutes. The method has the additional advantage of revealing other minerals included in the sample. Accurately located chip samples for such examination are collected in the course of field surveying.

It should be noted that these field tests are only aids to geological field examination and are not substitutes for quantitative chemical analysis of samples. However, data obtained by these tests help define the limits of minable magnesite and can be used to plan efficient sampling grids for chemical analysis.

FIGURE 11.—Outcrop of white saccharoidal magnesite. Contains numerous enstatite and talc veins and is characteristic of zones highly contaminated by silica-bearing minerals. Outcrop, 1 meter wide, is in stream bed, Pirajá deposit.

Crystalline magnesite in the Serra das Éguas occurs in three forms: massive aggregates, bladed or lathlike aggregates, and euhedral crystals. In quantity the massive aggregates form the bulk of the deposited material, although bladed aggregates and euhedral crystals are common. Only blocks of massive aggregates have the necessary size and chemical purity to qualify as commercially valuable material.

Massive crystalline aggregates consist of anhedral grains and resemble crystalline calcite or dolomite in texture. Most massive material consists of grains ranging from 0.5 to 3.0 millimeters in diameter, but there is also considerable coarse-grained material with grains ranging from 3 to 20 millimeters in diameter. Finer material has equigranular, or saccharoidal (fig. 11), texture; coarser material resembles typical coarse marble. Colors of magnesite include white, cream, light gray, yellowish gray, maroon, dark red, red, pink, and orange. Subvarieties of massive aggregates in the Serra das Éguas, divided on the basis of grain-size and color, are:

1. Fine- to medium-grained white, cream, or light gray.
2. Fine-grained maroon or dark red.

3. Medium- to coarse-grained dark red, red, or pink.
4. Coarse-grained white.
5. Medium-grained yellowish gray.
6. Coarse-grained orange.

The reddish varieties differ from the white and light-colored varieties principally in that they contain small amounts of finely disseminated hematite. (See pp. 113 and 124.)

The fine- to medium-grained white, cream, and light-gray magnesite, variety 1, in association with coarse-grained white magnesite, variety 4, forms an assemblage which is typical of most deposits in the Serra. Fine-grained maroon or dark-red magnesite, brecciated and veined by the remaining coarser-grained varieties 3, 4, 5, and 6 (see figs. 13–15, and 17), form an assemblage which provides the bulk of two large deposits. Most deposits of light-colored, hematite-free magnesite contain small patches of reddish magnesite and the two deposits consisting principally of reddish hematite-bearing magnesite are fringed in part by light-colored magnesite. For convenience of description, the two characteristic assemblages hereafter will be referred to as white, or light-colored, magnesite and red, or dark-colored, magnesite.

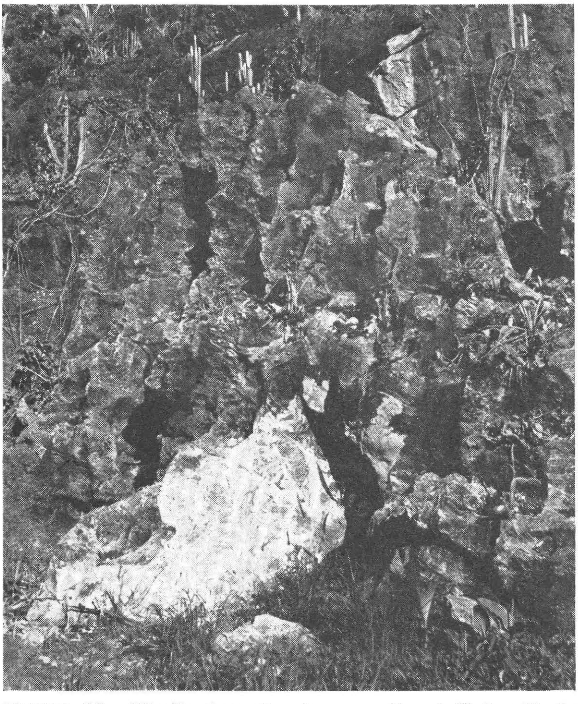

FIGURE 12.—Weathering of red magnesite at Pedra Preta deposit. Shows highly irregular crags and hollows; broken boulder in foreground is 1 meter high.

The field appearance of the two types of assemblages is markedly different. Outcrops of white (or light-colored) magnesite are low, smooth, and rounded, and weathered surfaces are light gray, medium gray, or buff. In stream beds, where most outcrops occur, surfaces are fresh and hard and have light color. (See fig. 11.) Away from streams, weathered surfaces of outcrops are darker; some material tends to separate along crystal boundaries and forms rotted-looking crusts or carbonate sand. In comparison, outcrops of red (or dark-colored) magnesite are craggy and cliffed and are characterized by irregular pinnacles, odd-shaped perched boulders, and caves. Huge blocks, some as much as 20 meters long, separate along widely spaced joints and produce deep crevasses; in cliffed areas such blocks fall and form jumbled and blocky talus. Surfaces weather to very dark reddish gray or black and are very rough, owing to innumerable pits and pinnacles having as much as 6 centimeters of relief. (See figs. 12 and 18.) Fresher faces left where joint blocks have fallen comparatively recently are buff in color. Outcrops and slumped blocks protrude through the soil over wide areas. Comparison of the maps of the Pedra Preta deposit, which consists mainly of red magnesite, with the map of the Pirajá deposit, which consists mainly of white magnesite, shows the characteristic differences in topography and distribution of outcrops. (See pls. 13 and 14.)

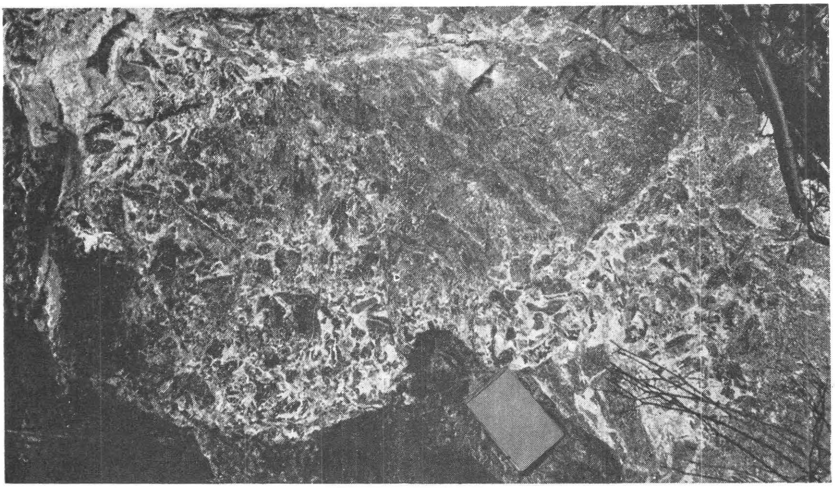

FIGURE 13.—Fine-grained red magnesite brecciated and cemented by coarse-grained white magnesite at Pedra Preta deposit. Notebook shows scale.

Bladed or lathlike aggregates of magnesite grains are from 20 to 40 millimeters long and from 1 to 10 millimeters thick; they are commonly exposed only in cross section so that their complete shape is unknown. Such blades or laths occur as disseminations in dolomite adjacent to bodies of massive aggregates of magnesite, and as such represent partial replacement of the host rock. They are seen at the Pirajá, Cabeceiras, and Gravatá deposits. (See pls. 14 and 15.) The area containing bladed magnesite aggregates at the Pirajá deposit is known to be 200 meters long and as much as 100 meters wide; magnesite forms from 20 to 30 percent of the material.

Megascopically the blades appear to be individual crystals but microscopic study indicates that they consist of rows of anhedral magnesite grains, roughly rectangular in shape. Narrow blades less than 1.5 millimeters thick consist of one row of grains, and wider blades consist of two or more rows having less regularity of shape and alignment with increasing thickness. The boundaries of the blades, as seen under the microscope, are comparatively ragged. The magnesite grains range from 1.2 to 4.2 millimeters in diameter and average 2.5 millimeters in diameter. The dolomite matrix consists of grains ranging from 0.15 to 0.3 millimeters in diameter; grains in contact with magnesite are extremely small and have a decomposed appearance.

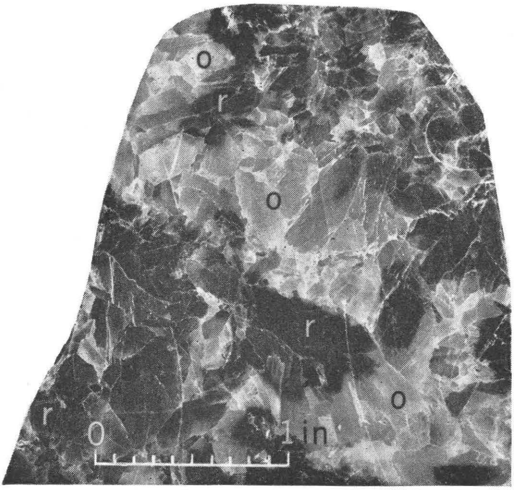

FIGURE 14. Polished specimen of coarse-grained orange and red magnesite. The color shadings within grains are clearly visible in the upper left center and lower right. Magnesite: (o) orange; (r) red.

Although these zones of partial replacement by magnesite have a much higher magnesia content than does pure dolomite, material from such areas always has a calcium content so high as to preclude its use as a source of commercially recoverable magnesia.

Magnesite crystals line openings, usually fissures and less commonly vugs, in massive magnesite. Some crystals are euhedral but in most places only a few faces on a crystal are well developed, the others being inhibited by adjacent crystals. The fissures containing crystals grade into completely filled veins containing coarsely-crystalline magnesite with grains as much as 20 millimeters in diameter.

Most crystals are transparent and colorless rhombohedrons, although some are translucent and white and a few in the Pedra Preta deposit are red or orange. Saldanha da Gama (1946), in a crystallographic study, found that the rhombohedron (100) and the second-order prism (101) are the dominant forms and that forms (311), (414), and (111) are well-developed (faces referred to the Miller axes); an additional 14 forms occur less frequently and only as small and narrow faces. Twinning is common.

With few exceptions, crystals are small, generally not more than 1 centimeter long on a rhombohedral edge but some have been found as much as 4 centimeters in length. Capper Alves de Souza (1944) noted that they are larger at the intersections of fissures. Faces of most crystals are fresh but many have been etched along cleavage planes or incipient cleavage planes. The small size and presence of cleavage fractures makes the material unsuitable for optical use. (Fries, 1948, pp. 131–132.)

Large numbers of magnesite crystals and cleavage rhombohedrons were seen in place or as float in all but the Coité, Noroeste, and Bate-Pé deposits. No other known locality contains such crystals except as rare specimens.

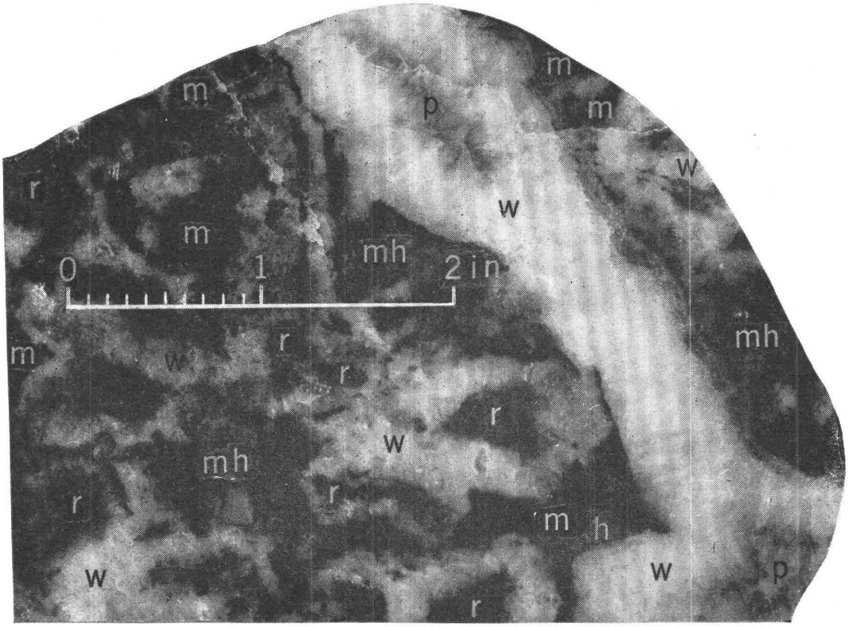

FIGURE 15.—Polished specimen of fine-grained maroon magnesite containing hematite veined and partly replaced by white magnesite. Red magnesite apparently is recrystallized from maroon variety. White magnesite grades into pink in wider parts of vein. Magnesite: (r) red; (m) maroon; (w) white; (p) pink. Hematite: (h).

Cryptocrystalline, or "amorphous" magnesite, is white, has a dull luster, and a conchoidal fracture, which gives it the appearance of unglazed porcelain. It was seen in place as a small vein of nodular aggregates cutting crystalline magnesite at the Noroeste deposit and the writer was told by engineers of Magnesita S. A., that a comparable occurrence was found in a trench, now slumped, in the Cabeceiras deposit. Float was seen at the Pirajá and Pedra Preta deposits. The scarcity of this type of magnesite precludes its commercial recovery.

Cryptocrystalline magnesite occurs most often in ultrabasic intrusive rocks but it also has been found in carbonate rock. It previously has been reported in crystalline magnesite at Gabbs, Nev. (Callaghan, 1933, p. 16).

DOLOMITE AND CALCITE

Most dolomite associated with the magnesite is the unreplaced host material and occurs either as individual grains or less commonly as blocks within lenses of crystalline aggregates of magnesite. It is not noticeably different in color, texture, or grain size than dolomite occurring away from areas of mineralization. Only at the Cabeceiras deposit is there some coarsely crystalline dolomite which could be either recrystallized or of secondary deposition.

Dolomite definitely known to have formed during mineralization occurs only as comparatively rare crystals deposited with magnesite crystals in open fissures. The largest piece seen by the writer, a cleavage rhombohedron broken from place by prospectors, was 4 centimeters along a cleavage edge. Dolomite crystals seen in this investigation were at the east edge of the Cabeceiras deposit and near the access road in the center of the Pedra Preta deposit. Dolomite associated with magnesite crystals was previously identified by Arlt and Steinmetz (1915) and more recently by G. T. Faust, of the Geological Survey, in the study of a mineral suite of the National Museum in Washington.

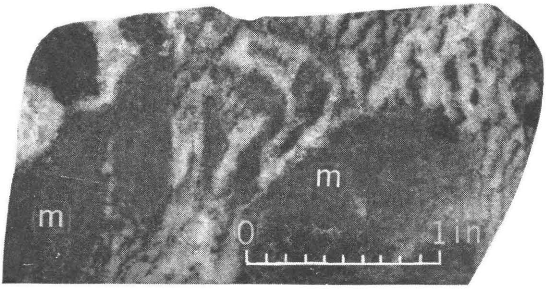

FIGURE 16.—Polished specimen of maroon magnesite veined and partly replaced by white magnesite. Vein filling and replacement took place from closely spaced fractures. Magnesite: (m) maroon.

Calcite deposited during mineralization is found only in veins from 10 to 20 centimeters wide and obviously is fissure-filling material. It is buff or cream-colored and has extremely fine grained texture. All occurrences are in dolomite, although one vein is within 5 meters of magnesite near the east side of the Cabeceiras deposit. Other calcite veins are west of the Pirajá and north of the Pedra Preta deposits.

Aragonite is being deposited at present in streams cutting dolomite, generally at falls where it builds out from the lips of bold outcrops. Aragonite deposition is a recent phenomenon and has no relation to the mineralization of the range.

IRON AND MANGANESE MINERALS

Hematite is the only common iron mineral associated with the deposits, although iron occurs also as a carbonate in isomorphous mixture with magnesite. (See p. 124.) The hematite is found in three forms: as disseminated and exceedingly small grains in magnesite, as aggregates of micaceous grains, and as euhedral crystals. Martite crystals, occurring in areas underlain by itabirite, are not related to magnesite mineralization. (See p. 100.)

Large numbers of minute grains, distinguishable only under the microscope, occur in all reddish varieties of magnesite. Such grains are opaque in transmitted light and red in reflected light; their color imparts the red hues to the carbonate mineral. Although the grains are too small to be positively identified by microscopic examination, they are considered to be hematite because magnesite containing them has higher iron oxide content than light-colored varieties. (See p. 124.) Some magnesite has an unusually high alumina content so it is possible that a part of such disseminated material may be spinel.

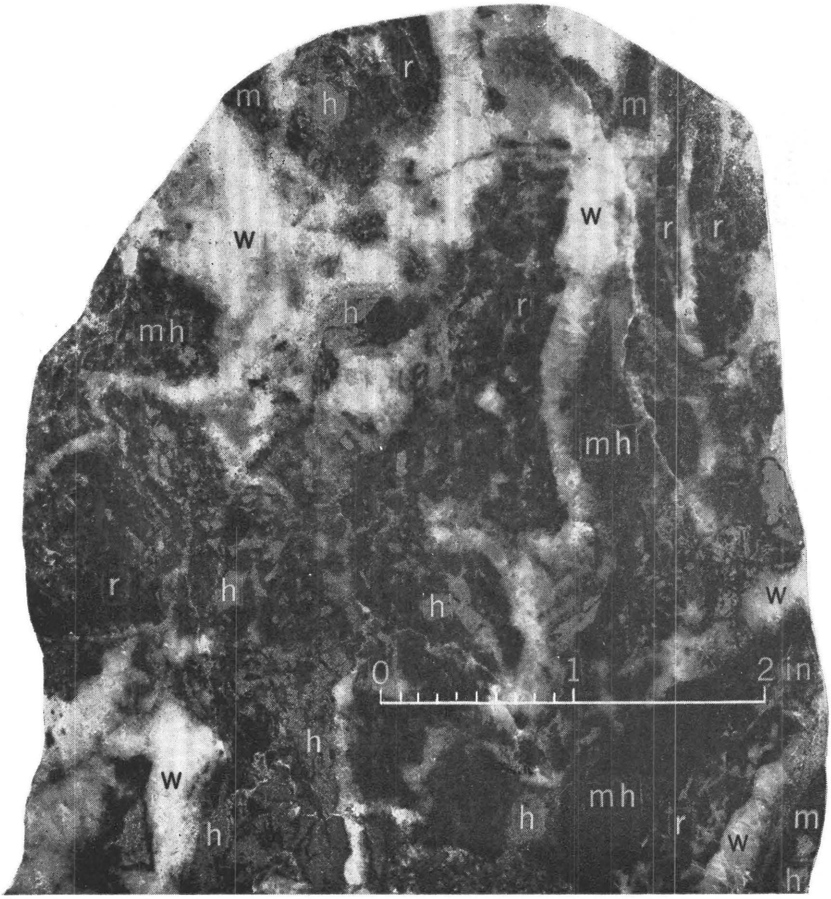

FIGURE 17.—Polished specimen of maroon magnesite containing hematite veined by white magnesite. Fine-grained maroon magnesite is partly recrystallized to coarse-grained red magnesite. Magnesite: (m) maroon; (r) red; (w) white. Hematite: (h).

Aggregates of micaceous grains of hematite with bright metallic luster occur as blebs, irregular small lenses, and pods or irregular vein-like masses in magnesite having red color. (See figs. 15 and 17.) Individual grains generally are from small fractions of a millimeter to 0.5 millimeter in diameter; their luster indicates them to be the specular variety. Such specular hematite in most places occurs only in small percentages in red magnesite but locally it forms more than 10 percent of the rock.

Crystals of hematite, thin and tabular where small and thicker in proportion to diameter where larger, range from 0.5 to 10 centimeters in diameter. In open fissures and vugs the smaller crystals occur on magnesite crystals and both on and in quartz crystals. The larger crystals were found only as float but rhombohedral molds of appropriate shape on their surfaces indicate that they likewise occupied openings lined by magnesite crystals.

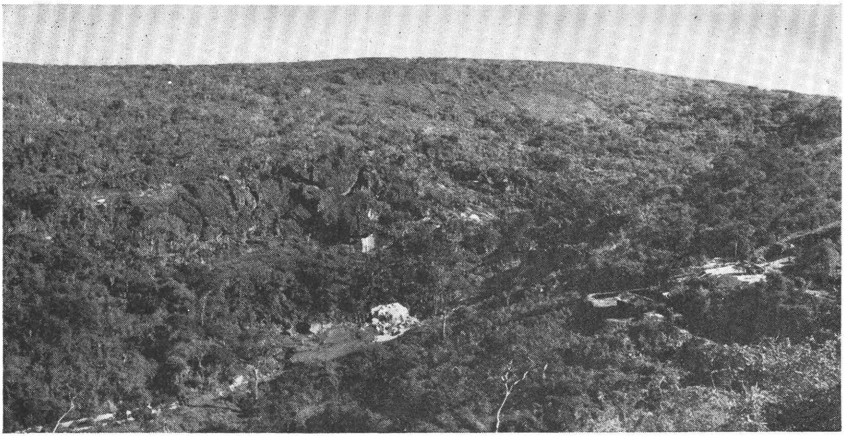

FIGURE 18.—View of the Pedra Preta deposit, looking southeast. The main magnesite exposure, with 80-meter cliff, is in center. One of talus blocks at foot has been mined. Talc pit is at far right. The ridge in background is underlain by quartzite.

Manganese is present in very small percentages in almost all magnesite and, inasmuch as no oxides were seen in the magnesite, it probably occurs as carbonate in isomorphous mixture with magnesite. In solution and during weathering by leaching the oxides are freed and redeposited as thin coats on rock surfaces. At the Pedra Preta deposit, where the manganese content is higher than in other deposits, talc float is coated with a thin layer of black oxide. The dark weathered surfaces of magnesite at the Pedra Preta and Catiboaba deposits probably owe their color in part to similar manganese oxide, although the predominant color of these outcrops is imparted by iron oxides.

PYROXENE AND AMPHIBOLE MINERALS

Enstatite is the only common mineral of the pyroxene-amphibole group in these deposits, although anthophyllite and tremolite have been found in limited amounts at several localities.

Enstatite is cream colored and coarse grained, and forms crystals as much as 30 millimeters long. Most enstatite is massive and occurs in veins, although groups of crystals forming rosettes are not uncommon. The mineral alters to talc and to a lesser extent to antigorite. Chemical analysis shows the mineral to be almost free of iron. (See table 10, sample analyses D–1 and D–9.) One grain of diopside was found in thin section; the paucity of lime in chemical analyses confirms the rarity of calcic pyroxene.

Veins containing enstatite occur most commonly in closely spaced parallel groups and are as much as 30 centimeters thick. (See fig. 10.) Enstatite veins also occupy cross joints and irregular fractures. The mineral is found only in deposits of white magnesite and occurs in large quantities at the Pirajá, Cabeceiras, and Cordeiro deposits.

All anthophyllite forms masses of extremely fine fibrous material, generally brown. It apparently is in veins but both walls of such structures never were seen. The mineral occurs sparingly in the Gravatá, Pirajá, and Cabeceiras deposits. Tremolite, occurring as isolated crystals or rosettes of crystals, is whiter and has a more glassy luster than the enstatite. Although common in dolomite, tremolite is comparatively rare in magnesite and was seen only at the Cabeceiras and Pirajá deposits.

TALC

Talc occurs as fine-grained massive material, as coarser-grained platy aggregates, and as impure soapstone.

Most fine-grained massive talc, also known as steatite, is white but in places is tinted green or pink. Such talc consists of grains barely visible megascopically and is crudely foliated, tending to break with very uneven fracture in one direction. Pieces are sufficiently compact to carve into any shape with a jacknife but are still soft enough to be readily scratched with the fingernail. Samples of such material, analyzed by Magnesita S. A. have the theoretical composition of nearly pure talc, although all have from 0.4 to 1.6 percent alumina plus ferric oxide. (See table 2.)

Steatite occurs as veins, lenses, irregular blebs and scraps, and individual grains in magnesite. The larger veins attain sufficient width to be minable, but in most places the veins are only from 10 to 50 centimeters thick and lenses are from 5 to 20 centimeters thick The float blocks at the Pedra Preta deposit are covered with coatings of manganese oxide but in all other deposits float is superficially stained buff, probably deriving this color from the enclosing laterite of the weathered zone.

Coarse-grained talc consists of plates from 0.5 to 3 millimeters in diameter and generally is white or very light green. It occurs in narrow veins, stockworks, vugs lined by magnesite crystals, and in a few places as incomplete replacement of quartz veins. Some coarse-grained talc contains kyanite, tourmaline, phlogopite, and dolomite crystals.

Impure siliceous gray soapstone was seen in place and as float at the Pedra Preta deposit. One vein, in the southwest part of the deposit, is noticeably more siliceous at its core than at its contacts with magnesite—an indication that it is an alteration of quartz. Another vein contains coarse-grained red magnesite crystals replacing the soapstone.

Those parts of deposits consisting principally of red magnesite contain steatite, soapstone, and small amounts of coarse-grained talc; the light-colored magnesite deposits contain only steatite and considerable amounts of coarse-grained talc.

SILICA MINERALS

The principal silica mineral in the deposits is quartz; lesser amounts of jasper, and minor amounts of chalcedony and opal are also present. Quartz occurs as massive material in veins, as cellular intercrystalline boxworks in silicified zones, and as drusy crusts of crystals in open fissures and vugs. Jasper, or chert, occurs as massive veins; chalcedony is associated with the cellular quartz; and opal forms crusts on crystals of magnesite and quartz in cavities.

White quartz veins are preponderately in deposits consisting of light-colored magnesite; only one vein was seen in red magnesite and it was partly altered to soapstone. The veins are from 5 to 20 centimeters thick where straight but only a few centimeters thick where irregular. They are associated with and parallel to enstatite veins, and like enstatite, also fill the fractures of breccia zones. Some veins are partly replaced by coarse-grained talc. Quartz veins are most common at the Pirajá and Cabeceiras deposits and are numerous in parts of the Bate-Pé, Gravatá, and Cordeiro deposits.

Cellular intercrystalline boxworks of quartz impregnating magnesite are common in many parts of the deposits of white magnesite; they grade into quartz druses and crystals where open fissures and vugs are present. Where the rock is fresh the material is white and imparts a glassy luster to the carbonate; where weathered the carbonate is partly or completely dissolved, leaving a vesicular skeleton of quartz, generally brown in color. Under the microscope it is seen that the quartz impregnates the magnesite between grain boundaries and along cleavage fractures. The quartz grains, which are very minute in size, are deposited in both random orientation and parallel, or comb-structure, orientation; in places several layers of quartz can be distinguished. Growth is outward from the surfaces of magnesite grains to the point where intergrain veinlets are filled; later growth is inward where magnesite was corroded during the initial quartz deposition. To a lesser extent quartz replaces magnesite, an effect clearly seen along cleavage planes, and a part of the inward growth in intergrain areas may represent comparable replacement. A small fraction of the deposited material is thought to be chalcedony.

Cellular quartz was seen in place only in magnesite, but there seems to be no reason why dolomite could not have been silicified in a comparable manner because it likewise dissolves readily along grain boundaries. Much weathered cellular quartz occurs as float in many parts of the flat upland underlain by carbonate rock, especially in the area ringed by the Pedra Preta, Bate-Pé, Pirajá, and Gravatá deposits. In all the material of this type examined by the writer the carbonate had dissolved. If pieces containing carbonate should be found they would furnish excellent clues to the nature of the carbonate rock concealed by the heavy mantle of laterite.

Druses of quartz crystals lining the walls of open fissures and vugs consist of both cloudy and transparent crystals. These range from 5 to 60 millimeters in length and from 2 to 30 millimeters in width; it is possible that larger crystals occur but inasmuch as they were being mined they probably have been removed. The druses always lie on magnesite crystals so their attached surfaces contain numerous rhombohedral molds and their bases may enclose magnesite. Crystals of aluminum silicate minerals, specularite, and associated oxide minerals occur in and on quartz crystals. Quartz crystals were seen in all but the Bate-Pé deposit; associated cellular intercrystalline boxworks of quartz are in all deposits on the west side of the range and at the Fabrica deposit.

Large zones of brownish jasper or chert, as much as 40 meters wide, occur east of the Gravatá and Pirajá deposits and in the middle of the upper Bate-Pé valley; it is uncertain whether they are in magnesite or dolomite because carbonate rocks do not crop out in their immediate vicinity.

Opal encrusts magnesite and quartz crystals in cavities and forms frosted white translucent layers as much as 2 millimeters thick.

ALUMINUM SILICATE AND ASSOCIATED MINERALS

The open fissures and vugs, lined with magnesite crystals, contain a number of oxides and aluminum silicate minerals associated with quartz. The writer found crystals of specular hematite, kyanite, tourmaline, topaz, beryl, and, in places, dolomite. Kyanite, tourmaline, phlogopite, and dolomite were also seen in coarse-grained talc. The entire group is probably contemporaneous, as indicated by the minerals common to both quartz and talc. In addition to these, mineralogists have identified rutile, monazite, xenotime, spodumene, albite, and lepidolite in specimens from the same group of veins (Saxe Cobourg-Gotha, 1889; Siedel, 1914; Uhlig, 1915; and Arlt and Steinmetz, 1915). The following table summarizes the minerals identified by these students and those found in the present investigations.

Minerals occurring in open fissures and vugs, Serra das Éguas magnesite deposits

Minerals	Saxe Cobourg-Gotha	Siedel	Uhlig	Arlt and Steinmetz	USGS
Aluminum silicate minerals:					
Kyanite	---	---	---	---	x
Tourmaline	---	x	---	x	x
Topaz	u	x	x	x	x
Beryl	u	x	x	x	x
Spodumene	---	---	---	x	---
Lepidolite	---	---	---	x	---
Albite	---	---	---	x	---
Oxide minerals:					
Specular hematite	u	---	---	x	x
Rutile	u	x	---	u	---
Phosphate minerals:					
Monazite	---	---	x	x	---
Xenotime	---	---	---	x	---
Silica minerals:					
Quartz	u	x	---	x	x
Opal	u	---	---	---	x
Carbonate minerals:					
Dolomite	---	---	---	x	x
Magnesite	---	u	x	x	x

x. Reported, with known associations.
u. Reported, with unknown associations.

In addition to this suite, Siedel identified epidote, zircon, and actinolite; Arlt and Steinmetz found garnet, pyrite, titanite, and martite. Inasmuch as all these mineralogists were studying material of which the field relations were unknown, they were not able to report on associations of minerals which were unaccompanied by other minerals; thus Siedel did not know that magnesite was from the veins containing aluminum silicate minerals and Arlt and Steinmetz could not relate rutile to the group. Considering that several of the above-listed minerals are not related to magnesite deposition (martite and actinolite, in particular), it is hard to judge whether the remainder actually were collected from the same veins; it would not be improbable, however, to find zircon and pyrite with quartz crystal.

Of those minerals seen by the writer, kyanite was the most common, occurring as blue-gray flat blades as much as 40 millimeters long and 20 millimeters wide. Some crystals are transparent and many contain rhombohedral molds of magnesite. Hexagonal beryl crystals are green or blue green and as much as 12 millimeters long; no transparent gem-quality crystals were seen in the course of the investigation. Both transparent and opaque tourmaline occurs as stubby green or brown crystals as much as 5 millimeters long. One irregular-shaped yellow topaz crystal about 5 millimeters long was seen. Specular hematite forms small flat crystals in quartz, and plates of honey-brown or yellow-brown phlogopite, as much as 3 millimeters in diameter, are in talc.

In mineral descriptions by other writers, few details of mineral habits are given. Saxe Cobourg-Gotha (1889) describes the morphology of several specular hematite crystals. Siedel (1915) reports yellow-green, emerald-green, and aquamarine beryl; white to reddish topaz; and brown, black, and reddish tourmaline. Rutile crystals are both twinned and not twinned. Other information in these reports includes chemical analyses of monazite and magnesite by Uhlig (1915), and description of complex mineral relationships by Arlt and Steinmetz (1915).

It may be noted that this suite of minerals include the following elements in their composition: B, F, Be, Fe, Ti, Ce, Th, Y, Li, and Na.

MAGNESITE TEXTURES AND THEIR RELATION TO DEPOSITION

Replacement and fracture filling are the two mechanisms by which magnesite was deposited in the Serra das Éguas, and of these, replacement has been by far the more important volumetrically. The type of deposition is indicated by the texture of the deposited material. Below are described the mechanisms producing three textures resulting from replacement of dolomite by magnesite, two textures resulting from the filling of fractures in magnesite, and two textures resulting from a combination of fracture-filling, replacement, and recrystallization of magnesite.

Field and laboratory evidence indicate that magnesite completely replaces dolomite, and it follows that the textures of magnesite are not inherited from the textures of the dolomite it replaced. (See p. 134.) Instead, the replacement textures of magnesite seem to reflect the permeability pattern of the host rock as shown by the distribution of loci of deposition. The three types of replacement textures seen in Brazilian deposits are equigranular massive type, disseminations of bladed aggregates, and banded.

Equigranular massive texture (see p. 107) in magnesite results where the host dolomite was uniformly permeable and saturated throughout with mineralizing solutions at the time of deposition. Deposition within a given block occurs from innumerable loci and more or less concurrently throughout a zone having physicochemical conditions favorable to replacement. On completion of the process a massive block of magnesite exists in place of the dolomite, and although the texture of the magnesite may be comparable to that of the dolomite it is not necessarily the same. Where the process is not carried to completion, residual dolomite grains remain and have random distribution in the mass of magnesite. Areas of lower permeability and lower saturation by mineralizing solutions are less susceptible to replacement and are left as unmineralized or partly mineralized blocks in the magnesite lenses.

Disseminations of bladed aggregates (see p. 109) are deposited in zones of uniform permeability but replacement begins from comparatively isolated loci. No areas were seen where replacement of this type proceeded to completion; where it continued to the extent of impingement of magnesite blades against each other, the rock consists of a skeleton of magnesite laths enclosing angular remnants of dolomite.

Banded magnesite is the result of permeability controlled by parallel fractures. No examples of it were seen in the Serra das Éguas but the texture is well exhibited in the Cabeça de Negro deposit in Ceará, where foliation and joint planes were the loci of initial deposition. (Bodenlos, 1950a, p. 143.) Complete replacement is characterized by parallel coalesced layers of magnesite crystals and incomplete replacement by banded magnesite containing dolomite veins or lenses.

In the Serra das Éguas most magnesite is of the equigranular massive type. Areas containing bladed aggregates are on the fringes of the massive lenses, although in the Cabeceiras deposit such material lies in dolomite embaying the magnesite lens. (See pl. 15.) It is not known why the two types exist side by side; it is improbable that in the massive lenses the blades recrystallized or were replaced by equigranular material because no traces of such processes were found. Possible conclusions are that such areas were not as thoroughly soaked by mineralizing solutions or that the bladed magnesite formed during the second stage of mineralization when magnesite was deposited in open fractures cutting the massive lenses.

Magnesite deposited in open fissures is coarser-grained than equigranular magnesite and may be divided into two textural groups which differ somewhat on the basis of fissure patterns. The first, magnesite in joints and regular fractures, is characterized by comparatively coarse grained crystals and grains which are euhedral in partly filled fissures and anhedral in completely filled fissures. (See p. 110.) The material may be banded as the result of growth from opposite walls. The second, magnesite in breccias, is characterized by a predominance of smaller grains and less uniformity of grain size, and banding that results from growth from opposite walls is not common. (See fig. 13.) Most joints and comparatively regular fractures occur in deposits of light-colored magnesite and fissure-filling material also is light-colored. Breccias are found in deposits of red magnesite but fissure-filling magnesite ranges in color from maroon and red to white.

In deposits of red magnesite, fissure-filling material has two additional textures which result from replacement and recrystallization of earlier equigranular magnesite. The first texture of this type occurs in breccias (see figs. 15 and 17), the second in magnesite broken along closely-spaced and roughly parallel fractures. (See fig. 16.)

In breccias, the equigranular groundmass consisting of maroon magnesite and containing segregations of specular hematite is veined by coarse-grained red and white magnesite. The coarse-grained white magnesite in places is solely fracture-filling but elsewhere partly replaces the equigranular material. Apparently the coarse-grained red magnesite also replaces the equigranular material, but close observation shows that individual grains of white magnesite grade in color into red, as indicated by the vague boundaries of several of the veins of white magnesite. It is concluded that the coarse-grained red magnesite is recrystallized from the fine-grained maroon magnesite. One specimen consisting entirely of coarse-grained red and orange magnesite shows a number of examples of such color gradation within grains. (See fig. 14.)

Some equigranular magnesite was fractured along closely-spaced, roughly parallel fractures, and was impregnated by equigranular yellow-gray magnesite. The light-colored material fills fractures and also replaces some red material along the walls of fractures. The resulting pattern resembles that of a lit-par-lit injection. This texture is comparatively rare in the Serra das Éguas deposits whereas replacement and recrystallization in breccias is common.

TABLE 1.—*Comparative tables of impurities in magnesite and dolomite, Serra das Éguas*

A. Average CaO and MnO Content of Magnesite, by Deposits

Deposit	Calcium oxide						Manganese oxide	
	Number of samples[1]	Average analysis	Number of samples with indicated CaO range, in percent				Number of samples	Average analysis
			0–1	1–2	2–3	3–5		
Pedra Preta	34	0.74	22	11	1	--------	36	0.23
Bate-Pé	11	.19	10	1	--------	--------	11	.03
Boa Vista	5	.06	5	--------	--------	--------	5	.07
Catiboaba	29	.64	25	2	1	1	29	.03
Fabrica	15	.86	10	3	1	1	15	.08
Noroeste	1	tr.	1	--------	--------	--------	1	.02
Gravatá	6	.82	4	1	1	--------	6	.03
Pirajá	11	.96	7	1	3	--------	11	.04
Cabeceiras	5	1.48	3	1	--------	1	7	.06
Cabeceiras[2]	16	.77	12	2	2	--------	--------	--------
Coité	8	.43	7	--------	1	--------	8	.04
Cordeiro	5	.44	4	1	--------	--------	6	.06
Total	130	--------	98	21	8	3	--------	--------

[1] Excluding samples analyzing more than 5 percent CaO.
[2] Analyses furnished through courtesy of Magnesita S. A. Not included in totals.

B. Average Composition of 14 Dolomite Samples, Compared With Composition of Theoretical Dolomite

Dolomite	Insol.[1]	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	Ig. loss [2]	Total dolomite	Total impurities
Average	1.23	1.29	0.29	0.21	29.54	21.26	45.92	96.72	3.02
Theoretical					30.4	21.7	47.9	100.0	

[1] Insoluble represents SiO_2.
[2] Ignition loss represents CO_2.

C. Iron and Alumina Content of Red Magnesite, Red Magnesite Containing Specular Hematite Segregations, White Magnesite, and Dolomite, by Deposits

Deposit	Red magnesite			Red magnesite containing specular hematite segregations			White magnesite			Dolomite		
	Number [1]	Fe_2O_3	Al_2O_3	Number [1]	Fe_2O_3	Al_2O_3	Number [1]	Fe_2O_3	Al_2O_3	Number [1]	Fe_2O_3	Al_2O_3
Pedra Preta	9	0.97	0.88	5	1.92	1.15	8	0.61	0.73			
Bate-Pé							4	.62	.28			
Boa Vista							3	2.50	.65			
Catiboaba	5	2.44	.82				2	1.10	.18			
Fabrica							10	.94	.43			
Gravatá							1	.51	.44			
Pirajá	1	1.78	.49				10	.49	.49			
Cabeceiras							4	.68	.20	4	0.58	0.15
Coité							6	.59	.18	1	1.26	.77
Cordeiro							4	1.90	.40	4	[2]1.72	.35
Pedra Rolada										5	.46	.20
Average	15	1.58	.81				52	.85	.33	14	1.29	.21

[1] Number of samples used in compiling average.
[2] Excluding one sample containing 4.0 percent Fe_2O_3.

CHEMICAL COMPOSITION OF MAGNESITE

Minerals associated with magnesite and containing non-magnesia oxides constitute impurities which lower its chemical purity. Calcium silicon, iron, aluminum, and maganese are the principal contaminating elements in the Serra das Éguas deposits. Minerals containing them were deposited before, during, and after magnesite deposition. Silica minerals altered to magnesium silicate minerals during magnesite deposition constitute another source of impurities but in most places do not represent an addition of deleterious material.

Unreplaced dolomite grains furnish most of the lime in the magnesite deposits. Dolomite also contains other impurities: 14 samples free of visible impurities average 3.02 percent in total of silicon, iron, aluminum, and maganese oxides. (See table 1–B.) In places dolomite contains quartz and tremolite veins which furnish higher percentages of silica. Undoubtedly part of the contaminating material in magnesite is inherited from the dolomite it replaced. The quantities of such residual impurities, and also the secondary impurities in magnesite are discussed below.

Lime.—In the deposition of crystalline magnesite, replacement of dolomite can progress to any degree of completion. Pure dolomite contains 30.4 percent CaO and 21.7 percent MgO; magnesite contains no CaO and 47.6 percent MgO. The composition of mixed material is between these limits of lime and magnesia contents. The largest parts of the magnesite deposits in the Serra das Éguas contain only small amounts of dolomite but zones of mixed material occur along the borders of several deposits and in one deposit, as islands surrounded by nearly pure magnesite. Secondary dolomite, deposited as crystals in cavities with magnesite crystals and possibly extending into completely filled veins of coarse-grained magnesite, provides only minor amounts of lime. Somewhat larger areas of coarsely crystalline dolomite at Cabeceires may be secondary but probably result from recrystallization of primary material.

Chemical analyses of samples collected in this investigation show that the magnesite in the Serra das Éguas is of good chemical grade from the standpoint of lime content. Excluding samples having a lime content of more than 5 percent, the limit selected by the writer as commercially recoverable material—38 of 130 samples, or 29 percent of the total—contain less than 0.1 percent CaO. Sixty samples contain from 0.1 to 1.0 percent CaO and 21 samples contain from 1.0 to 2.0 percent CaO. (See table 1–A.) All deposits other than the Cabeceiras average less than 1 percent lime content, which compared with magnesite deposits elsewhere, is exceedingly low.

Silica.—The silica content of the selected samples of dolomite averages 1.23 percent and minimum SiO_2 is 0.5 percent. (See table 1–B.) Where dolomite contains quartzite and tremolite veins and lenses the silica content is considerably higher and reaches as much as an estimated 50 percent in parts of the Pedra Rolada area. It is thought that much silica in the magnesite deposits is inherited from dolomite; during magnesite deposition part of the quartz and tremolite that was contained in dolomite altered to enstatite, anthophyllite, and talc. Parts of a number of magnesite deposits also contain silica in the form of quartz veins and silicified zones which were deposited after the close of magnesite deposition. Talc, formed after the close of this period of silicification, seems to be altered largely from quartz by late magnesia-bearing solutions but some may have been introduced as such.

Only the Pedra Preta and Catiboaba deposits, consisting mostly of red magnesite, have generally low silica content throughout although parts of these deposits do contain talc veins. (See pls. 13 and 16 and tables 4 and 7.) Twenty of 36 samples from the Pedra Preta deposit and 22 of 29 samples from the Catiboaba deposit contain less than 1.0 percent SiO_2. The Fabrica deposit is the only deposit of light-colored magnesite to contain low percentages of silica. (See pl. 17 and table 8.) All other deposits of light-colored magnesite contain higher percentages and actually the largest parts of these contain such excessive amounts that the magnesite could not without benefication be considered minable material. (See pp. 150 and 160.)

Iron oxide.—Iron oxide, listed in the analytical tables of this report as ferric oxide, averages 1.29 percent in the analyses of 14 dolomite samples. (See table 1–B.) One sample containing 4.0 percent Fe_2O_3 was excluded in calculating the average because it is not representative of the mass. It may be noted that in different parts of the Serra the iron oxide content of dolomite ranges from 0.46 to 1.72 percent. (See table 1–C.) The dolomite is light-colored and inasmuch as iron can form a continuous series of carbonates with calcium and magnesium, it probably occurs as ferrous carbonate.

The iron oxide in white magnesite probably occurs as the ferrous variety; although chemical analyses made for this report did not test for both ferrous and ferric iron, Saldanha da Gama (1946) and Uhlig (1915) verified the ferrous nature of iron oxide in white magnesite crystals. Deposits of white magnesite average from 0.49 to 2.50 percent iron oxide; most white magnesite contains less iron oxide than does red magnesite. Comparison of samples of white magnesite and dolomite shows that white magnesite contains slightly more iron oxide than does dolomite at the Cabeceiras and Cordeiro deposits and slightly less at the Coité deposit. Although an insufficient number of dolomite samples were analyzed to formulate more specific data on the relative movement of iron in the deposition of this type of magnesite, the available data indicate that the magnitude of iron migration is small. (See table 1–C.)

Clearly, free hematite was introduced during the deposition of red magnesite, some occurring as disseminated and exceedingly small grains, and the remainder as aggregates of visible micaceous grains. The lower limit of iron oxide content of samples containing visible hematite grains is not consistent; five samples from the Pedra Preta deposit containing such grains average 1.92 percent iron oxide, but five samples from the Catiboaba deposit without visible hematite grains average 2.44 percent iron oxide. (See table 1–C.)

Red magnesite probably carries part of its iron oxide as ferrous carbonate; with the available analytical data the proportions of each cannot be determined directly. Should the ferrous content of both red and white magnesite be moderately consistent in a given deposit, the differences between the iron oxide content of red and white magnesite would represent the ferric iron content. The following compilation, based on this assumption, fails to show such consistency:

Deposit	Red magnesite, percentage of iron oxide (ferric and ferrous)	White magnesite, percentage of iron oxide (ferrous)	Difference, percentage of iron oxide (ferric)	Approximate ratio, ferric to ferrous iron oxide
Pedra Preta	0.97	0.61	0.36	1:2
Catiboaba	2.44	1.10	1.34	1:1
Pirajá	1.78	.49	1.29	5:2

Alumina.—The alumina content of dolomite ranges from a trace to 0.77 percent Al_2O_3 and averages 0.29 percent Al_2O_3 in the analyzed samples of dolomite. (See table 1–B.) No obvious aluminum-bearing minerals were seen in the dolomite. The alumina content of magnesite ranges from a trace to 4.03 percent Al_2O_3; light-colored magnesite averages 0.33 percent Al_2O_3 and red magnesite averages 0.81 percent Al_2O_3. Other than the fact that the darker magnesites average higher in alumina content than do the lighter magnesites, the occurrence of this oxide is very erratic, not only with respect to absolute quantity but also in its ratio to iron oxide and silica. A number of samples contain more alumina than silica or more than normally combines with silica in hydrous aluminum silicate minerals.

Nearly every analyzed magnesite sample contains alumina, yet there are no conspicuous aluminum-bearing minerals in the deposits other than the aluminum-silicate group restricted to late quartz veins and to coarse-grained talc. Where the silica content is low, it is probable that alumina combines with magnesia, and possibly with magnesia and iron in red magnesite, to form spinel. Magnesian spinel can be colorless, and should it occur as finely disseminated material, as does hematite, it would be difficult to find, even under the microscope, because its index of refraction is very close to that of magnesite (spinel, $n=1.716$; magnesite, $\omega=1.70$). Such an occurrence would indicate that alumina was deposited with magnesite.

Where the alumina content is lower than the silica content, the two might be combined in aluminum silicate minerals. Minute folia of talc-like material were seen in the microscopic examination of many magnesite samples, but these were assumed to be scraps of the very common talc and were not further studied because the writer was not aware of the ubiquity of alumina at the time of the examination. Three minerals resembling talc and containing alumina are pyrophyllite ($H_2O.Al_2O_3.4SiO_2$) and the chlorite minerals clinochlore ($4H_2O.5MgO.Al_2O_3.3SiO_2$) and prochlorite whose lighter varieties contain less silica than clinochlore. In his revision of Dana's Textbook of Mineralogy, Ford (1932, pp. 671–672 and 683), states that clinochlore commonly is associated with talc. He also notes that a greenish-white prochlorite, named rumpfite, has been found in talc and magnesite in three of the Austrian magnesite deposits. Pyrophyllite is known to form a gangue for kyanite. Kerr and Callaghan (1935, pp. 1969–1970) found leuchtenbergite, a low-iron variety of clinochlore, in the magnesite deposits of Brucite (Gabbs), Nevada. The possibility of the presence of any of these minerals cannot be excluded; should they be present; their alumina could have been inherited from dolomite or introduced at the time of deposition of the anhydrous aluminum-silicate minerals or of late talc.

Manganese oxide.—Dolomite averages 0.21 percent MnO, with a maximum of 0.4 percent in one sample. (See table 1–A.) Magnesite contains an average of from 0.03 to 0.08 percent MnO in all deposits but the Pedra Preta where it contains 0.23 percent MnO. With this one exception manganese oxide was removed during mineralization. The small residual content probably occurs as carbonate in isomorphous mixtures with both dolomite and magnesite.

Other impurities.—The analyses of dolomite show traces of sodium and potassium; and analyses of some magnesite show traces of titanium and phosphorous. Data are insufficient to determine the genesis of these elements.

A large number of elements occur in the aluminum silicates and in other minerals deposited after quartz. (See pp. 118–119.) They all seem to be younger than the magnesite. However, Arlt and Steinmetz (1915) report finding one beryl crystal in magnesite, so a possibility exists that these elements were in the solutions depositing magnesite.

SEQUENCE OF MINERALIZATION

During mineralization the ore-forming solutions and deposited material changed in composition and the process of deposition was interrupted by several periods of fracturing, as shown in figure 19.

The first and most important stage of mineralization was characterized by deposition of most magnesite as replacement of dolomite and alteration of quartz and silicate minerals to magnesium silicate minerals. It is thought that enstatite was the first mineral to form because of its high temperature of formation. At lower temperatures talc formed either by hydration of enstatite or alteration of quartz and silicate minerals.

It is probable that most magnesite replacing dolomite was deposited at about the same time. Bladed aggregates of magnesite possibly were deposited in this stage but no evidence of its relative position with equigranular magnesite was seen.

Hematite was deposited throughout the stage in red magnesite and spinel(?) was deposited in both red and white magnesite. Veinlets of hematite may indicate that red magnesite was fractured during the stage.

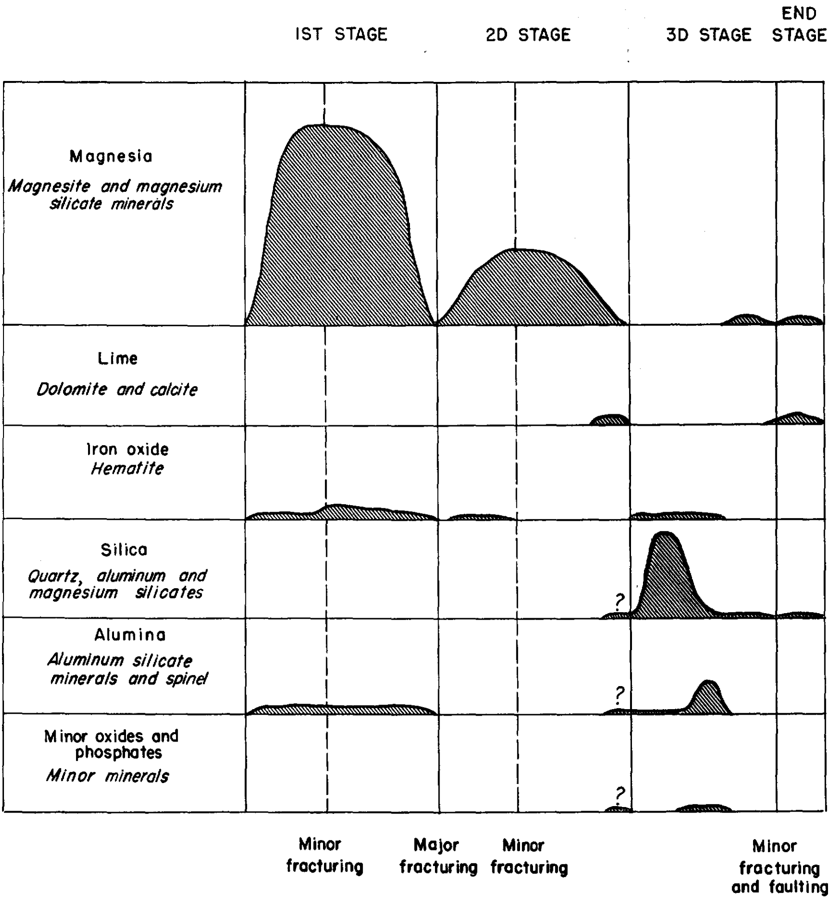

FIGURE 19.—Diagram showing the sequence of mineral deposition in the Serra das Éguas deposits.

At the end of the first stage of mineralization the area was extensively fractured and open fissures and breccia zones were formed. The second stage of mineralization was characterized by deposition of coarse-grained magnesite in the openings; euhedral crystals formed in partly filled cavities. In red magnesite, some replacement and recrystallization accompanied the fracture-filling. Several generations of vein material indicate that some red magnesite was fractured more than once during the stage. In a few localities red magnesite replaced talc which had been sheared during deformation. Dolomite and beryl associated with magnesite crystals indicate that the mineralizing solutions carried minor amounts of calcium, silicon, aluminum, and beryllium at the end of this second stage.

Deposition of silica and aluminum silicate minerals characterize the third stage of mineralization. Quartz, in various forms, and minor amounts of chalcedony were deposited in fissures; jasper was deposited either in fissures or as replacement of carbonate rock. The deposition of hematite in small amounts started before the close of quartz deposition. Thereafter, aluminum silicate, oxide, and phosphate minerals carrying B, F, Be, Ti, Ce, Th, Y, and Li were deposited in the fissures. The stage closed with a minor resurgence of magnesia resulting in the alteration of some quartz to talc and possibly the deposition of some primary talc.

Minor fracturing and faulting preceded the fourth or end stage of mineralization. Opal was deposited on quartz crystals and cryptocrystalline magnesite was deposited as veins in magnesite; calcite filled veins in dolomite. Inasmuch as the opal, cryptocrystalline magnesite, and calcite do not occur together their relative ages cannot be more closely determined.

HYPOTHESIS OF ORIGIN

GENETIC CLASSIFICATION

There is little doubt that massive aggregates of crystalline magnesite are deposited from hydrothermal solutions and therefore are hypogene because recent geochemical research has shown that magnesite is deposited from solutions carrying carbon dioxide under pressures greatly in excess of those carried by meteoric waters (Faust and Callaghan, 1948, pp. 54–57). On the basis of temperatures and pressures prevailing at the time of deposition, hypogene deposits have been subdivided by Lindgren (1932, p. 212) as follows: epithermal deposits, 50°–200° C.; mesothermal deposits, 200°–300° C.; and hypothermal deposits, 300°–500° C. Anhydrous magnesium carbonate, or magnsite, appears to be the stable phase at temperatures above 100° C. and is definitely stable at 150° C.; below this only hydrated varieties are deposited (Hähnel, 1924; Himmelbauer, 1933, p. 252; and Faust, 1949). Further data concerning the physical conditions under which magnesite may be deposited can be extrapolated from the behavior of its associated minerals. Pyroxene and specular hematite, two early minerals in the Serra das Éguas, are cited as belonging to the hypothermal class (McKinstry, 1948, table 10, p. 380), and talc, formed during various stages of mineralization, has been synthesized only above 350° C. (Bowen and Tuttle, 1949, p. 443). Tourmaline, deposited after magnesite in these deposits, has been synthesized at temperatures as high as 450° C. (Smith, 1949, pp. 186–192). Apparently, sustained high temperatures prevailed during the main period of mineralization in the Serra das Éguas and the mineralization may be classed for a minimum as mesothermal.

The latest minerals, cryptocrystalline magnesite, opal, and calcite, which here occur only in small amounts, have elsewhere been considered as deposited under epithermal conditions (Bodenlos, 1950b, p. 263).

ORIGIN OF MAGNESITE

Most speculation concerning the genesis of magnesite deposits has been devoted to the type of magma furnishing the solutions and the sources of magnesia and carbon dioxide carried in solution. Attention is directed to the recent papers of Faust (1949) and Faust and Callaghan (1948) which carefully investigate these problems. Together with a review of the various opinions on these subjects, an examination of the mechanism of the deposition of crystalline magnesite is here presented.

MAGMATIC SOURCES OF MINERALIZING SOLUTIONS

The igneous rocks associated with magnesite deposits have considerable range in composition and form, as shown in the following compilation:

Igneous rock types associated with magnesite deposits

Locality of magnesite deposits	Igneous rock	
	Massive	Dike
Serra das Éguas, Brazil		Amphibolite and minor rhyolite.
Ceará, Brazil	None exposed, but schists are partly granitized, suggesting a granitic magma.	Amphibolite and minor acidic rocks.
Gabbs, Nevada	Granodiorite stock	Basalt, andesite, aplite lamprophyre, and rhyolite.
Chewelah, Washington		Green hornblende, altered (amphibolite?).
Argenteuil County, Quebec	Batholitic granite, said to be younger than magnesite.	Peridotite and pyroxenite.
Austria	Granite laccoliths, andesites, and basic intrusives.	Porphyroid(?).
Manchuria	Granite, 5 kilometers from the deposit.	Diabase porphyry, quartz porphyry, and lamprophyres.[1]
U. S. S. R		Diabase.

[1] Kato, 1929, pp. 90–92.

It has been generally accepted that solutions depositing magnesite emanate from large magmas rather than from dike rocks. Callaghan (personal communication) and Niinomy (1925, p. 49) both consider that granodiorite and granite furnished the mineralizing solutions in Nevada and Manchuria, and Bain (1924, p. 423) asserts that granitic rocks played a comparable role in the genesis of the magnesites in Quebec. Students of the magnesite deposits of Austria arrive at different conclusions concerning the parent rock: Weinschenk favors granite, Petraschek the andesites, and Redlich the basic intrusives (Himmelbauer, 1933, p. 265). The source rock is concealed in the

State of Washington where Bain (1924, p. 423) suggests that the magmatic source may be comparable to those occurrences in Quebec. The source is concealed in Ceará, Brazil, but granitization of the schists indicates that possibly the magma was granitic (Bodenlos, 1950a, p. 134). Although the dikes at Ceará are more basic, such types of intrusive bodies associated with granodiorite can have a wide range of composition, as shown by the intrusive suite at Gabbs, Nevada, (Callaghan, 1933, pp. 12–14).

Apparently, then, magma of granitic or granodioritic composition is believed by most students to be the source for solutions depositing crystalline magnesite. In the Serra das Éguas it is obvious that the dikes are not large enough to have furnished the quantity of solutions necessary to deposit the vast amounts of magnesite, so the source must be below the present erosion level. That the parent magma could well have been granitic is indicated by the presence of quartz veins and associated aluminum silicate minerals, whose general composition may be considered as intermediate between true quartz veins and pegmatites that are derived from granitic magma. (See p. 140.)

SOURCES OF MAGNESIA AND CARBON DIOXIDE

The sources of both magnesium and carbon dioxide are obscure and theories have been proposed by a number of investigators. Hewett (1928, pp. 857–861) lists five general sources of magnesium as follows: the waters of the sea, the shell of sedimentary rocks, the underlying crystalline rocks such as gneisses, the shallow bodies of intrusive rocks, and the deeper magma reservoirs. Of these he excludes sea water and crystalline rocks such as gneisses as improbable, but states that recourse to a magmatic source is unwise until dolomite and sercitized shallow intrusive rocks are thoroughly considered. Austrian students considered the igneous rocks as the source (Himmelbauer, 1933, p. 265). Niinomy (1925, p. 51) proposed that the leaching of magnesium from dolomite at depth by hot solutions emanating from the magma was the source of the deposits in Manchuria, but Kato (1929, p. 93) considers the magnesium as being derived from the underlying granite. Faust (1949) and Faust and Callaghan (1948) more recently describe the derivation of magnesium-rich solutions, (1) by dedolomitization of dolomite followed by the extraction of magnesium from the partly calcined dolomite, and (2) by congruent solution of dolomite followed by the metastable deposition of calcite, leaving a magnesium-rich solution.

The carbon dioxide in solution likewise may be derived from either magmatic or carbonate-rock sources. Bowen (1940, p. 266) has stated that the quantities of carbon dioxide involved in large-scale carbonatization of rocks probably is derived from pro-grade metamorphism of carbonate rocks close to magma, because igneous sources could not provide the requisite volumes. Faust and Callaghan (1948, p. 58) suggested that the hydrothermal solutions which formed the deposits at Current Creek, Nevada, obtained the necessary carbon dioxide as well as the magnesium in their passage through dolomitic rocks. Faust (1949) has shown how magmatic solutions containing carbon dioxide may be enriched in this constituent by the ingestion of xenoliths of carbonate rocks entrapped within the magma, or by the mixing of the gaseous CO_2, released by the dissociation of carbonate rocks at the contact, with the magmatic emanations.

Faust presents a carefully documented case for consideration of dolomite as the source of magnesium and the present writer can accept this as a possible derivation where magnesite deposits are in dolomite terrane. However, a number of magnesite deposits are in limestone terrane and only locally surrounded by dolomite (Bodenlos, 1950a, p. 138; Hewett, 1928, p. 856; Himmelbauer, 1933, pp. 262–265 and 275; and Wilson, 1917, pp. 31–32). In Ceará, Brazil, samples collected by prospectors along the outcrop of carbonate rock proved to be nearly pure limestone; three samples collected near the Orós deposit in the course of the cooperative investigation by the Departamento Nacional da Produção Mineral and the Geological Survey contained only 0.2 to 1.2 percent MgO. Where carbonate rock is poor in magnesium prior to mineralization it seems an improbable source for the large quantities of magnesium now found in the deposits. Much additional data is needed to determine the exact relationships of deposits to limestone in such terrane and, for the present other sources of magnesium still merit consideration. These include magma and shallow bodies of igneous rock. Of the two, magma would be the more probable source because shallow bodies of igneous rock have not been reported near crystalline magnesite deposits. The carbon dioxide involved in solutions depositing magnesite is at least partly derived from magma even where magnesium may have been derived from partly calcined dolomite.

NATURE OF SOLUTIONS

In addition to magnesium and carbon dioxide, the solutions depositing magnesite in the Serra das Éguas carried only minor amounts of iron and aluminum. Silica probably was scarce as indicated by the lack of magnesium silicate minerals deposited during magnesite deposition, but was comparatively abundant after magnesite deposition ceased. Essentially, then, an investigation of the nature of the mineralizing solutions is concerned with those carrying magnesium bicarbonate and little else. The solutions probably were dilute because concentrated or gel-like solutions are more likely to deposit only cryptocrystalline magnesite (Faust and Callaghan, 1948, p. 51). The following résumé outlines the data resulting from the physicochemical investigations of others.

In the system MgO-CO_2-H_2O the solubility of magnesium in water increases with carbon dioxide pressure and decreases with temperature (Faust, 1949, pp. 805–809). At lower temperatures and pressures the magnesium is precipitated as hydrated magnesium carbonate; from 18 to 56 atmospheres pressure and at 18° C., the stable solid phase appears to be magnesium bicarbonate. The system has not been studied in detail at higher temperatures which include the stability field of magnesite itself.

A probable phase diagram for the system CaO-CO_2-H_2O also was prepared by Faust. The principal differences between these systems is the great difference between the solubility of calcite and magnesium carbonate trihydrate; the former is less soluble in water under carbon dioxide pressure and its solubility decreases with increasing temperature proportionately less than that of magnesia. The system MgO-CaO-CO_2-H_2O has not as yet been studied in detail.

DEPOSITION OF MAGNESITE

Laboratory investigations provide data which can be used in developing hypotheses on the deposition of magnesite. Faust and Callaghan (1949, pp. 54–57) have applied such a physico-chemical approach in their analysis of cryptocrystalline-magnesite deposition at Currant Creek, Nevada:

> As the hydrothermal solutions approached the surface of the earth, they entered rock masses of higher bulk porosity. The presence of more free space permitted the escape of CO_2 into the vapor phase. This loss of CO_2 changed the equilibrium relations between bicarbonic and carbonic acid in the solution. When the proper concentration of magnesium and carbonic acid was reached, replacement could take place. So long as dolomite and magnesite were forming the pressure of CO_2 remained constant until most of the CO_2 was used up. Thereafter, the pressure of CO_2, in the vapor phase in contact with the solution, dropped rapidly until it approached the pressure of CO_2 in the earth's atmosphere, about 0.00032 atmosphere.
>
> * * * the solutions with an excess of CO_2 were slightly acid. As CO_2 was lost from the solutions the pH passed through neutral to alkaline. At pH about 9 the carbonates, dolomite and magnesite, began to form in quantity, and the pH remained essentially constant until these phases were largely removed from solutions. Thereafter the pH of the hydrothermal solutions began to drop * * *

To arrive at a valid hypothesis for the deposition of crystalline magnesite such physicochemical data must be applied within the framework of the geologic environment, which is quite different from the environment in which the magnesite at Currant Creek was deposited in that the host rock is predominantly carbonate rather than volcanic. The field data to be here reviewed and pertaining to depositional environment of crystalline magnesite include the nature of the host rock, the size, the frequency, and the mode of emplacement of the deposits, as well as the textures of magnesite.

Deposits of crystalline magnesite usually are in dolomite or dolomitized limestone. Where magnesite occurs in ultramafic rocks it is cryptocrystalline with but two known exceptions, both in Europe and both small deposits, so crystalline magnesite apparently is the type deposited most readily as replacement of other carbonate rock.

Concerning the frequency of deposits, only 10 districts containing crystalline deposits are known throughout the world, with the exception of the occurrences in Austria and Czechoslovakia which are sufficiently numerous and widespread to indicate that they had multiple sources. Nevertheless, when compared with hydrothermal dolomite occurrences, crystalline magnesite deposits are rare (Hewett, 1928, p. 856). It is inferred that this comparative rarity must be indicative of special conditions of mineralization not often attained.

One characteristic of magnesite deposits is their large size, ranging from millions to billions of tons in all but the small Swedish and Spanish occurrences. The four best-exposed deposits in the Serra das Éguas (Pedra Preta, Pirajá, Catiboaba, and Cabeceiras) contained an estimated aggregate total of more than 3 billion tons of magnesite prior to erosion, conservatively assuming their vertical extent to have been no more than their present observed width. The surface extent of all occurrences in the Serra das Éguas covers about 1,700,000 square meters. The deposits in Manchuria are cited as having a surface extent of about 2,600,000 square meters (Niinomy, 1925, p. 52), and the Veitch deposit in Austria is reported to be a lens 1,600 by 450 meters and about 250 meters deep (Himmelbauer, 1933, pp. 269–270). The Gabbs deposit in Nevada is 1,500 by 900 meters overall and has been drilled to a depth of 180 meters (Callaghan and Vitaliano, 1948, p. 10). The occurrences in Ceará, Brazil, cover about 1,300,000 square meters.

That large volumes of solutions were necessary to deposit such quantities of magnesite is evident. Although this conclusion in itself may not have genetic significance, the data are pertinent in demonstrating the need of magmatic sources as large as batholithic proportions and also show that conditions favoring deposition were long-continued rather than temporary.

Textural evidence in the Serra das Éguas lenses indicates that deposition took place by replacement from innumerable closely spaced loci. (See p. 119.) To produce massive replacement lenses the entire block undergoing mineralization must have been reached, at one time or another, by the mineralizing solutions. According to Bateman (1942, pp. 95–96), solutions producing this type of body move along every possible channel, from larger fissures down to "minute fractures, cleavage planes * * * and minor openings down to capillary size." The textures thus require the mineralized block to have been saturated with mineralizing solutions and deposition from many points to have taken place more or less simultaneously.

It is improbable that magnesite replacing dolomite does so by merely substituting one unit of magnesia (MgO) for the unit of lime (CaO) in the dolomite molecule, because considerations of percentages and specific gravities shows that additional carbon dioxide must be added and that the specific gravity increases in the change from dolomite to magnesite. (See following table.) That magnesite as such replaces dolomite is further demonstrated by the compactness of massive aggregates of magnesite and lack of internal strain or slippage along cleavage planes, both or either of which might have been expected if volume changes had taken place. Additional evidence is afforded by contacts between magnesite and dolomite in the field: these are tight, the textures of the two minerals can be strikingly different, and replacement is always essentially complete (Himmelbauer, 1933, figs. 66–*A*, 69, and 83; and Bodenlos, 1950a, p. 143). It is concluded that replacement proceeds on a volume-for-volume basis rather than on a molar basis. This same evidence of compact texture and tight contacts leads to the conclusion that the removal of dolomite and the deposition of magnesite at any one point were concurrent and were accomplished by the same solutions.

Comparison of the weights of dolomite and magnesite, per cubic meter (in metric tons)

	Constituents			Total[1]
	CaO	MgO	CO_2	
Dolomite	0.87	0.62	1.36	2.85
Magnesite	----------	1.46	1.60	3.06
Addition to rock as the result of replacement	.87−	.84+	.24+	.21+

[1] Average of limits of specific gravity as cited by W. E. Ford (1932, pp. 512–517).

The foregoing facts and inferences derived from the study of geologic features of crystalline magnesite deposits may be summarized as follows. Magma of probable granitic composition and of batholithic proportions expelled great quantities of mineralizing solutions which either carried originally the necessary magnesium and carbon dioxide or picked up these constituents in their reactions with dolomite close to the contact with the magma. At the point where saturation was attained, the physicochemical environment was characterized by moderately high temperatures and pressures, and replacement of dolomite proceeded on a volume-for-volume basis. Solutions had to penetrate all parts of the mineralized ground and the equigranular textures of magnesite indicate that replacement took place from innumerable loci. That all but two small deposits of crystalline magnesite occur in carbonate rock indicates that this type of mineralization seems to be most readily accomplished in such an environment, and the characteristically large deposits indicate that physical and chemical conditions favoring mineralization were stable for comparatively long periods. The scarcity of crystalline magnesite deposits means that either expulsion of solutions carrying the proper constituents is uncommon or that conditions favorable to deposition are not often reached.

In this environment magnesite will form when the solutions reach saturation by loss of carbon dioxide, described by Faust (1949, p. 817) as follows:

> * * * the question arises as to the probable ways by which these hydrothermal solutions will give up their mineralizing constituents. If we assume that the solutions continue to migrate away from the zone of higher temperatures into the cooler country rock, these hydrothermal solutions will become cooler. If they enter zones of greater porosity, they may lose some of their carbon dioxide to the country rocks. Either, or both, of these changes may bring about the approach to saturation conditions for magnesium carbonate (magnesite). The structural relationships of the country rock, its texture, and chemical and mineralogical character will determine the manner in which the magnesium and carbon dioxide will be removed from the solutions.
>
> In areas where hydrothermal solutions rich in magnesium and carbon dioxide enter limestone, dolomitization takes place. Armoring of the calcite by dolomite will protect larger masses of limestone from reaction. This phenomenon is well illustrated by the description and figures in Hewett (1928) concerning the islands of limestone in dolomite at Iglesias in Sardinia. Zoning, by dolomitization, about the fracture system, or between limestone and an inert rock may yield channelways along which the hydrothermal solutions can migrate without further reaction with the limestone. These magnesium-rich solutions, because of their failure to react with limestone protected by armoring or zoning, may deposit magnesite in the fracture system. Magnesite may form in direct contact with dolomite with which it is in equilibrium * * *

To have achieved mass replacement such as is demonstrated by massive lenses of crystalline magnesite in carbonate rock, several additional conditions must have been met: The solutions must have penetrated all parts of the mineralized ground and must have reached saturation at some time everywhere in the block. The system also must have been open, with solutions carrying in magnesium and carbon dioxide and removing the calcium of the replaced dolomite. The nearly total absence of hydrothermal dolomite in the magnesite deposits strongly indicates that the solutions which removed primary dolomite did not remain in the zone of replacement for any great length of time, for had they done so, a sufficient concentration of calcium would have built up and permitted the deposition of hydrothermal dolomite with the magnesite; thus the solutions could not have been static and even may have moved fairly rapidly through the zone of deposition.

It is also indicated that the amount of solutions carrying the calcium of the replaced dolomite will increase as replacement continues and that it will form an ever-widening front preceding those solutions carrying only magnesium and carbon dioxide. Under these conditions it is improbable that pure magnesite would be deposited at the solution front but instead would be deposited from the solutions following those contaminated by calcium. Saturation for magnesite at this position requires loss of carbon dioxide or decreasing temperatures; the latter is excluded from this discussion owing to the lack of geochemical data on the higher temperature and pressure relations of this system. Inasmuch as the zone here under consideration undoubtedly is saturated with solutions, loss of carbon dioxide into pore spaces and fissures would be inhibited, so apparently the only manner in which the carbon dioxide could escape would be by dissipation into the vapor phase. To achieve saturation for magnesite, the movement of carbon dioxide in the vapor phase must be faster than the movement of solutions; the continuation of replacement on a large scale thus appears to be at least partly dependent on the establishment of an acceleated diffusion gradient for carbon dioxide.

Any factors tending to increase the diffusion gradient of carbon dioxide would facilitate saturation for magnesite and its replacement of dolomite, whereas any factors tending to lessen the gradient would decrease the amount of replacement. One factor effective in increasing the gradient would be the withdrawal of carbon dioxide from the system as the result of replacement of dolomite by magnesite. A given volume of magnesite contains more carbon dioxide than a comparable volume of dolomite (see table, p. 134), and inasmuch as replacement takes place on a volume-for-volume basis, the amount of carbon dioxide withdrawn from the system as magnesite is deposited is more than the amount introduced into the system as waste dolomite. Since this occurs above the zone where solutions carry excess carbon dioxide, its relative withdrawal should increase its diffusion gradient.

The withdrawal of carbon dioxide from the system during the replacement of dolomite by magnesite amounts to about 0.24 tons per cubic meter of rock. That this is a substantial quantity may be shown by considering the tonnages involved in the deposition of the four deposits in the Serra das Éguas which contained some 3 billion tons of magnesite prior to erosion. This magnesite occupied a volume of about 1 billion cubic meters and contained 240 million tons more carbon dioxide than did the replaced dolomite. In terms of gas at standard temperature and pressure, this quantity of carbon dioxide would have occupied about 122 cubic kilometers. The withdrawal of this amount from the system, even had the carbon dioxide been compressed under conditions prevailing in the zone of replacement, must have had a significant effect on the diffusion gradient of the carbon dioxide. This writer considers that it was of importance in achieving saturation for magnesite, especially in those parts of the lenses where the escape of carbon dioxide into openings in the rock might have been limited, and that it should be considered as one of the factors which permitted the deposition of such large quantities of magnesite as are common in most of the world's deposits.

During deposition of magnesite, the carbon dioxide pressure at any one point results from the balance prevailing between supply from below and loss into the vapor phase and withdrawal resulting from deposition. It may be that the proper carbon dioxide pressure for magnesite saturation is met only locally at each point where magnesite replaces dolomite but it is more probable that a broader zone of general saturation develops below the solutions contaminated by calcium of the replaced dolomite. Replacement of dolomite would be most effective in a given area during the period that the saturated zone is in contact with the host rock. Should any dolomite escape replacement during attack by saturated solutions it would tend to remain residual after the saturated zone passed upward. The undersaturated solutions following would have limited powers in effecting replacement unless the diffusion gradient for carbon dioxide were to be changed by some other means.

The saturated zone is pictured as migrating upward as long as supply from below is undiminished. Naturally, the solutions will not be introduced for an indefinite length of time; at some point they will flow less copiously, contain less magnesia, or be under less carbon dioxide pressure. Under conditions of diminishing carbon dioxide pressure the saturated zone would migrate in the reverse direction back toward its source. Replacement of residual dolomite could also occur at this stage, but the process would not be as effective as during the stage of upward migration because the decreasing pressure would locally be further depleted as additional carbon dioxide is consumed in the replacement of the host rock by magnesite.

It is possible that geologic accidents occurring during deposition could change the physicochemical balance. In the Serra das Éguas, for example, the massive lenses were fractured during mineralization, which probably permitted escape of possibly substantial amounts of carbon dioxide into the new openings. Although this did not terminate deposition of magnesite, not all fissures are filled and so the fracturing may have hastened the end of mineralization.

Where open fissures clearly were present, loss of carbon dioxide into such openings would result in saturation for magnesite and its deposition, a condition which prevailed in most deposits of cryptocrystalline magnesite and in some deposits of crystalline magnesite. An example of the latter is in the Cabeça de Negro deposit, Ceará, Brazil, where deposition unequivocally started from fractures and joints and produced banded textures. Even in such environments, fissures were filled and replacement of interposed blocks may have required an accelerated diffusion gradient for carbon dioxide to have permitted the solutions to reach saturation.

It was previously stated that two periods of magnesite deposition took place in the Serra das Éguas, separated by the fracturing of the deposited material. There is no way of determining whether this was accompanied by a break in the flow of mineralizing solutions, but it is true that in deposits consisting predominantly of red magnesite, the post-fracture veining material contained less ferric iron than did the equigranular magnesite deposited before the fracturing.

As Faust (1949, p. 817) noted, solutions of the type described will reach regions of lower temperature and pressure as they ascend. At some point the solutions should be saturated with respect to magnesite and they should deposit the mineral before reaching the surface. Thus, the general scarcity of magnesite deposits may not be based on the rarity of proper physicochemical conditions but rather on paucity of solutions of the proper composition. (See p. 135.) Magnesium-bearing solutions have been introduced into carbonate rocks in many places, as shown by dolomitization accompanying lead and zinc mineral deposition (Hewett, 1928). Lack of magnesite in these occurrences indicates insufficient concentration of magnesium, so the generation of magnesium and carbon dioxide in the necessary amounts appears to have been infrequent in the mineralization history of the earth.

DOLOMITIZATION

The replacement of calcite by dolomite on a volume-for-volume basis results in withdrawal of carbon dioxide from solution, so it would appear that the process would promote acceleration of the diffusion gradient for carbon dioxide (see following table). How this might affect subsequent saturation for magnesite is not known but it appears that indirectly it would favor subsequent deposition of magnesite if sufficient magnesium were carried in the mineralizing solutions. The general sequence of dolomite replacing limestone and magnesite replacing dolomite can occur without a break in the flow of the mineralizing solutions (Faust, 1949, p. 817).

Comparison of the weights of calcite and dolomite per cubic meter (in metric tons)

	Constituents			Total [1]
	CaO	MgO	CO_2	
Calcite	1.52		1.20	2.72
Dolomite	.87	0.62	1.36	2.85
Addition to rock as the result of replacement	.65−	.62+	.16+	.13+

[1] Average of limits of specific gravity as cited by W. E. Ford (1932, pp. 512–517).

ORIGIN OF ENSTATITE AND TALC

In the Serra das Éguas observations in several localities showed that talc undoubtedly formed by reaction between quartz in veins and magnesia carried by the mineralizing solutions. (See p. 116.) Enstatite is thought to have formed in the same manner; the absence of quartz is considered as evidence that the replacement was complete.

Bowen and Tuttle (1949, pp. 442–443) found that enstatite forms by reaction between silica and magnesia in the presence of a vapor phase at 700° C. Talc can form between 300° and 800° C.; above 800° C. only enstatite and quartz can coexist. Inasmuch as the field evidence indicates that only to a small extent is enstatite altered to talc, it is probable that most talc altered directly from quartz rather than by hydration of enstatite. Therefore distribution of these minerals seems to be dependent on the temperature prevailing at the time of formation, with talc forming at the lower temperatures. Bowen and Tuttle (p. 449) show also that the maximum temperature at which serpentine can form from enstatite is 500° C., so the minor alteration of enstatite to antigorite probably occurred after its minor alteration to talc.

These relations indicate that unaltered quartz veins associated with enstatite and talc veins must have been introduced after the close of magnesite deposition and hence are contemporaneous with the silicified zones and quartz crystals. Otherwise they surely would have been altered to magnesium silicates in view of the temperatures and quantities of magnesia-bearing solutions which soaked such areas.

Quartz veins partly altered to late talc indicate a resurgence of small amounts of magnesia-bearing solutions. Some narrow irregular veins of late talc do not have quartz cores, so some talc may have been introduced as such. (See p. 128.) The possibility remains that such veins are completely altered quartz veins.

ORIGIN OF QUARTZ AND ALUMINUM SILICATE MINERALS

In a paper describing most major quartz crystal districts in Brazil, Johnston and Butler (1946, pp. 628 and 641) note that it is difficult to distinguish between quartz phases of pegmatites and quartz veins, and concluded that quartz deposits, both in pegmatites and veins, have a single genetic history with pegmatites forming deeper and closer to the inferred parent intrusive. Johnston also notes that a few deposits seem to be transitional between true pegmatites and true quartz veins. The Serra das Éguas occurrences, with their associated topaz, beryl, tourmaline, kyanite, and other aluminum silicate minerals, probably fit best into this latter intermediate classification.

Johnston & Butler (1946, p. 641) observed the paucity of quartz crystal occurrences in limestone and speculated as to the genetic significance. The occurrences in the Serra das Éguas would indicate that comparable deposits can form in carbonate rocks.

Magnesite withstood the ingress of solutions depositing quartz and associated minerals with remarkably little corrosion of crystal surfaces, so the late solutions possibly were alkaline in nature. (See p. 132.)

Johnston and Butler (1946, p. 641) correlate the pegmatites and quartz veins to mineralization occurring in early Paleozoic time. Pecora and others (1950, pp. 233–235) date this mineralization as ranging from late pre-Cambrian to early Paleozoic. If the deposits in the Serra das Éguas are related to the pegmatite and quartz crystal mineralization in other parts of central Brazil, they would be of comparable age.

MINERAL DEPOSITS

SIZE, SHAPE, AND GRADE OF THE DEPOSITS

MAGNESITE

Examination of the geologic maps shows that the border areas of most deposits are poorly exposed, so it is difficult to determine their exact size. (See pls. 13, 14, 15, 16, 17, and 18.) In the following deposit descriptions, the extent of outcrops rather than the inferred dimensions are cited. Of the occurrences mapped by the writer, moderately accurate data of size and shape are known only for the Pedra Preta, Catiboaba, Fabrica, Cabeceiras, and Pirajá deposits, all of which appear to be lenticular in shape. The length of outcrops ranges from 625 meters in the Fabrica deposit to 1,300 meters in the Pedra Preta deposit; the width from 20 meters in the Fabrica deposit to 810 meters in the Pirajá deposit; and the vertical extent from 130 meters in the Cabeceiras deposit to 165 meters in the Pirajá deposit. Knowledge of the extents of all other deposits is based on accidents of erosion; in the Bate-Pé valley, for example, all carbonate outcrops in an area 2,400 by 1,200 meters are magnesite. The continuity of outcrops is such that they cannot be correlated and magnesite bodies are inferred only in the vicinity of outcrops. At the other extreme of size, the south outcrop of the Coité deposit along the creek bed is only 108 meters long and as much as 15 meters wide; prospect pits show the deposit to be as much as 60 meters wide.

All the bodies excepting Cabeceiras and Gravatá are completely free of included blocks of dolomite.

From these data it can be seen that moderately well exposed magnesite bodies are very large. It will be hard to predict the size of the bodies largely concealed because overburden is thick. Considering the tonnage now in sight it is doubtful that operations in the future would require large-scale exploration of these lesser-known occurrences.

The chemical grade of the deposits has previously been discussed in general terms with reference to geology. (See pp. 122–126.) Of the possibly deleterious substances occurring in magnesite, lime occurring as dolomite and silica occurring as veins and lenses of quartz, enstatite, and talc are those which seriously affect the chemical grade of possible ore bodies. Lime reaches critical amounts in moderately large areas only in the Cabeceiras deposit; elsewhere it exceeds 3 percent only in the northeast corner of the Catiboaba deposit, the south central part of the Fabrica deposit, and in one of the outcrops of the Noroeste deposit. These do not include the areas of mixed magnesite and dolomite at the margins of the Pedra Preta and Pirajá deposits which are designated on the maps as noncommercial-grade material. Thus most of the potential ore is not seriously affected by included lime.

Contamination of magnesite by silica is far more widespread. Only the Pedra Preta, Catiboaba, and Fabrica deposits may be considered sufficiently free of silica to permit mining of nearly all of the areas exposed at present. Only limited zones containing talc veins in the Pedra Preta and Catiboaba and quartz veins in the Fabrica deposits may have too high a silica content for commercial use. All the remaining deposits contain such excessive amounts of silica and silicate minerals that by far their larger parts are useless as they now stand; the blocks considered to be sufficiently free of these impurities are shown on the deposit maps. (See pls. 14, 15, and 18.) The minable magnesite in the Cabeceiras deposit is confined to that small area free not only of silica but also of dolomite.

Neither iron oxide nor alumina reach excessive amounts except locally in the Pedra Preta and Catiboaba deposits. Further detailed descriptions of the distribution of impurities in individual deposits follow on pages 146–162.

TALC

Talc occurs in all deposits but veins of minable widths are found only in the Pedra Preta and Coité deposits; zones of numerous and closely-spaced veins which may be minable are in the Pirajá, Cabeceiras, and Cordeiro deposits.

The talc in such veins is white fine-grained compact steatite. Analyses show that it is pure and contains only 0.16 to 0.70 percent iron oxide and from a trace to 1.20 percent alumina. (See table 2.) In 1945 some material mined from the surface zones had small holes, from 1 to 2 millimeters in diameter, which may have contained carbonate grains before they were leached by surface waters.

TABLE 2.—*Analyses of talc, Serra das Éguas, Brumado, Bahia, Brazil*

[Analyzed privately for Magnesita S. A. Analyst not given]

Sample No.[1]	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	H_2O	Total
1	61.70	0.60	0.20	tr.	32.58	5.16	100.24
2 [2]	62.40	.32	1.20	tr.	31.39	4.61	99.92
3	61.96	.34	1.28	tr.	31.79	4.42	99.79
4	62.38	.30	.98	tr.	31.79	4.50	99.95
5	63.50	.16	.28	tr.	31.86	4.10	99.10
6	62.34	.70	tr.	tr.	32.83	4.43	100.30
7	61.70	.39	.55	tr.	32.04	5.10	99.78

[1] Sample 1. From Cordeiro deposit.
2. From Fabrica deposit.
3–5. From Pedra Preta deposit.
6. Unknown.
7. From Coitê deposit.

[2] Footnote with original analyses states that material in samples 2–6 is completely unaffected by hydrochloric acid.

The main talc vein at Pedra Preta is in the west-central part of the deposit. In 1945, talc was being mined from a zone 10 meters wide consisting of float blocks from 10 to 30 centimeters long and from 5 to 15 centimeters wide. Owing to the absence of magnesite it was judged that a good-sized talc vein lay underneath the weathered zone. A second talc area is in the east-central part of the deposit and consists of a vein as much as 0.5 meter wide flanked by thinner veins and lenses. The talc zone at Coitê is in the north outcrop area of the deposit, where a heavy concentration of float blocks probably overlies a wide vein. In 1945, several hundred tons of shipping-grade talc had been recovered and were stockpiled at this locality.

Areas where talc may be minable are in the southwest corner of the Pirajá deposit, the southern part of the Cabeceiras deposit, and the northern part of the Cordeiro deposit. Much talc float is seen in many areas overlying magnesite or areas close to magnesite lenses, and is especialy abundant at the Pirajá deposit and on the ridgecrest extending from the Cabeceiras deposit southward to the Coitê deposit. The entire length of the ridge has been prospected by deep test pits not reaching bedrock but containing much talc float.

All talc float has surficial stain, from 0.5 to 3.0 millimeters thick, which in most places is yellowish or a light-rust color; at Pedra Preta some talc is stained black by manganese oxide. (See p. 115.) At the time of this investigation the stain was removed by chopping with hand axes.

Owing to limited exploration for talc, exposures are insufficient for accurate determination of reserves. As judged from the above-listed occurrences, many thousands of tons are available, much of which could be gathered and shipped with a minimum of effort. The indications are that enough minable material is present to supply the domestic requirements of Brazil for many years.

QUARTZ CRYSTAL AND GEMSTONES

Quartz crystals in narrow fissures lined by magnesite crystals range from 5 to 60 millimeters in length; larger crystals undoubtedly were recovered during mining operations. (See p. 117.) Such occurrences were seen in all but the Bate-Pé and Noroeste deposits, but crystals of minable grade have been found only at the Pirajá, Cabeceiras, Cordeiro, and Fabrica deposits. The Pirajá and Cabeceiras deposits have been extensively prospected for quartz crystal.

The quartz was mined by local prospectors, or garimpeiros, who cut small pits from 1 to 4 meters deep with hand steel. Siliceous float served as a prospecting guide. From the narrow widths of veins it is judged that it would not be economically feasible to extend mining to greater depths. Shallow pits dot the landscape in large numbers in the areas mentioned above and incidentally provide many additional exposures of magnesite not afforded by natural outcrops or test pits cut by Magnesita S. A.

Details of quantity, grade, and work involved in mining optical-grade quartz crystals were not obtained so no estimate of reserves can be given. Work had nearly stopped in the latter part of 1945, following the decrease in demand at the close of the war. Undoubtedly, garimpeiros will renew operations whenever the demand and price increase sufficiently.

Of the associated minerals, kyanite and beryl were seen in largest amounts. Gem-quality beryl, as emerald and aquamarine, was the first mineral mined from the area; other stones of some value found here were topaz and tourmaline. Operations to recover gemstones centered at the Pirajá deposit where some 5 hectares were intensively prospected. Mining for gemstones has ceased but garimpeiros found some salable stones in their quartz operations.

From all accounts, the emeralds recovered from the Pirajá deposit did not have so desirable a color as those found in Colombia, and it is said that they were inferior to those occurring near Vitória da Conquista, the other known emerald deposit of Brazil about 120 kilometers southeast of Brumado.

RESERVES

Reserves of magnesite are based on that amount of material having the required purity for commercial use. This excludes considerable magnesite from reserves compilations; for example, the largest parts of the deposits on the west side of the range contain excessive silica.

A rather complex series of commercial specifications have been established for various uses of magnesite. The percentages of permissible silica, lime, iron, and alumina have considerable range; rather than calculating the tonnage as based on each specification, the chemical cut-off limit is based on the general summary of Harness and Jensen (1943, p. 7), "The lowest grade of commercial crude magnesite contains about 43 percent MgO." Theoretically pure magnesite contains 47.6 percent MgO, but inasmuch as it is combined with volatile CO_2, the 43-percent limit permits as much as 9.6 percent nonvolatile impurities (silica, silicate, iron, and alumina-bearing minerals), and as little as about 5 percent partly-volatile impurities (the lime of dolomite). Although considerable latitude of composition is permissible, it should be emphasized that purer grades command higher prices than inferior grades; prior to the war, dead-burned magnesite, containing less than 90 percent MgO, was valued at $22 a ton whereas artificial periclase with 94 percent MgO was valued at $65 a ton (Harness and Jensen, 1943, p. 15). Prices now are higher; in 1948 dead-burned magnesite sold for $27 a ton and 90 percent MgO sold for $45.50 a ton; and in 1951 dead-burned magnesite was $36.50 a ton; 90 percent MgO, $50.50; and 93 percent MgO, $75 (f. o. b. Washington and California).

The reserve categories are measured, indicated, and inferred, conforming with the standard usage of the Geological Survey (Dorr, 1945, p. 36, footnote 32). Where the outcrops of magnesite deposits were mapped in detail, measured reserves are in outcrop areas, indicated reserves are in areas between closely spaced outcrops, and inferred reserves are in areas beyond measured and indicated areas and extend to the inferred limits of the deposits; these classifications apply only to the Pedra Preta and Pirajá deposits. All other deposits were mapped in less detail with respect to limits of outcrop; in these deposits the indicated reserves are in areas of generalized outcrop and between closely spaced outcrops, and inferred reserves extend to the inferred limits of the deposits.

The reserves herein listed are calculated on the basis of tonnage per meter depth. (See table 3.) The reserve per meter depth is obtained by multiplying the area, in square meters, by the tonnage factor of 3, the minimum specific gravity of crystalline magnesite. This method of presentation is adapted, first to permit comparison of relative amounts of commercial-grade magnesite in the various deposits, and second because the deposits have not been tested at depth. Deposits of this type are lenticular and undoubtedly had great vertical extent at the time of deposition, but the proportion of the lenses remaining after erosion is not known. Nevertheless, the known vertical extent of outcrops in these deposits is considerable, and it is probable that a sufficient thickness of magnesite remains to supply Brazilian domestic requirements and permit the development of an export trade.

TABLE 3.—*Reserves of the magnesite deposits of the Serra das Éguas, given as tons per meter depth*

[Boa Vista deposit not included]

Deposit	Measured	Indicated	Inferred	Total
Pedra Preta	294,000	310,000	1,009,000	1,613,000
Bate-Pé			4,000	4,000
Catiboaba		34,000	742,000	776,000
Fabrica		30,000	35,000	65,000
Noroeste			1,000	1,000
Gravatá			1,000	1,000
Pirajá	8,000	10,000	70,000	88,000
Cabeceiras		22,000	233,000	255,000
Coité		1,000	10,000	11,000
Cordeiro			1,000	1,000
Total	302,000	407,000	2,106,000	2,815,000

ACCESS TO THE DEPOSITS

Deposits on the east side of the range may be reached via roads leading north, west, and south from Brumado. They are accessible from the kiln and townsite at Catiboaba station, 9 kilometers south of Brumado, via a new road along the east front of the range. Deposits on the west side of the range may be reached via the same routes and thence by trails extending across the range; one road between Pedra Preta and Pirajá was blocked by development work in 1945. The western deposits also are accessible via a trail leading around the south end of the range; this route would be the only practicable one for ore transport should the western deposits be developed, because all transmountain routes would require steep ascents and descents of ore carriers.

The Pedra Preta deposit is accessible via a 13-kilometer road leading northwest from Brumado to Jatobá valley. The new road connecting the deposit to the kiln is 17 kilometers long. From Pedra Preta, trails extend to all other deposits, with distances as follows: Bate-Pé, 4 kilometers; Boa Vista, 6 kilometers; Catiboaba, 10 kilometers; Fabrica, 12.5 kilometers; Noroeste, 4 kilometers; Gravatá, 4 kilometers; Pirajá, 4.5 kilometers; Cabeceiras, 8 kilometers; Coité, 9.5 kilometers, and Cordeiro, 10.5 kilometers. (See pl. 12.)

The Bate-Pé deposit is reached via a 6-kilometer road going west from Brumado to the Boa Vista fazenda (ranch); the fazenda is about 12 kilometers from the kiln via the new road. A trail leads beyond to outcrops in the valley and extends to Pirajá, 6 kilometers west of the fazenda. Trails south of the fazenda lead to the Boa Vista deposit.

A trail from the townsite and kiln at Catiboaba station leads west up Catiboaba valley; 5.5 kilometers from the kiln a branch trail 0.5 kilometer long reaches the Fabrica deposit. At about 6.5 kilometers a branch leads west across the divide into Cordeiro valley; the deposit is 2 kilometers from this branch. The Catiboaba deposit is on the north fork of the trail and about 7 kilometers from the kiln. An extension of the north fork continues across the range to the Coité, Cabeceiras, and Pirajá deposits, all from 12 to 15 kilometers from Catiboaba station.

Distances to deposits on the west side of the range on the trail leading around the south end of the range from Catiboaba station are as follows: Cordeiro, 11 kilometers; Coité, 12 kilometers; Cabeceiras, 14 kilometers, Pirajá, 17 kilometers; Gravatá, 18 kilometers; and Noroeste, 19 kilometers.

PEDRA PRETA

The Pedra Preta deposit, the most northerly of the magnesite occurrences on the east side of the Serra das Éguas, is in the upper part of the Corrego do Jatobá (Jatobá Creek). (See pl. 13.) The valley has comparatively gentle slopes in the upper, or southern, part of the deposit but very steep slopes in the lower, or northern part. A heavy growth of tropical trees and vines chokes the stream beds and the immediately adjacent slopes but these give way upward to brush and then grassland. (See fig. 18.) Soil cover is thin in the central part of the deposit, becoming thicker toward its limits. Water flows at the rate of 1.5 liters per second at the junction of the Corrego do Pedra Preta and the Corrego do Jatobá.

The deposit is on the west flank of a syncline which includes the upper quartzie along its axis. No part of the contact between magnesite and dolomite is exposed. Dolomite crops out north of the magnesite along the access road and west of the deposit in the bed of the Corrego do Pedra Preta. Along the central part of the easternmost exposures the magnesite contains more than average lime and it is thought that this mixture indicates a transition zone close to the dolomite contact. Elsewhere the limit of the lens is inferred to be beyond outcrops and test pits showing magnesite; should magnesite extend farther south and southwest it is apt to be siliceous because much talc and quartz occur as float in those areas. Magnesite crops out for a length of 1,300 meters, a width of 550 meters, and a vertical extent of 155 meters.

The only other rock exposed in the vicinity of the deposits is amphibolite which occurs as dikes in dolomite. A comparable body in magnesite is indicated by amphibolite float in the Corrego do Jatobá between sample localities 18 and 33, and another crops out in the Corrego do Pedra Preta near the engineering staff house.

The central and northern parts of the deposit consist of fine-grained red magnesite, containing segregations of specular hematite and veined by coarse-grained red, white, and orange magnesite. The southern part of the deposit consists principally of equigranular white or light-gray magnesite.

Residual dolomite is low throughout the lens except in the zones of mixed material along the east contact, and secondary dolomite, occurring as a few scattered crystals, was found only in one vug east of sample locality 10. Excluding the zone of mixed material, the CaO content is less than 2.0 percent throughout the deposit except in the vicinity of sample locality 20. (See table 4.) Iron oxide content is uniformly low, even in those areas containing segregations of free hematite; these are in a zone extending from the northeastern part of the deposit to the central southwestern part and are most common near sample localities 1, 26, 29, and east of locality 7. Alumina content likewise is low in all parts of the deposit except at sample locality 3 in the northwestern area.

Talc occurring as small blebs provides a low silica content in most parts of the deposit. The silica content is higher in areas containing talc beds and veins; these occur between sample localities 17 and 18 in the southwest part of the deposit, in the vicinity of sample localities 21, 22, and 23 in the eastern part of the deposit, and in the west-central part of the deposit where talc is being mined. Some secondary silica has been introduced near the east limit of the lens near sample localities 30 and 31, and quartz crystal float occurs west of sample locality 33.

Outcrops of magnesite are very large and especially numerous in the central area. The largest of these is irregular in shape, as much as 500 meters long and 200 meters wide, and forms in one place a bare cliff 80 meters high. This and the many other outcrops permit estimation of a large measured reserve. The chemical grade is uniformly high. Other than in the narrow zone of mixed dolomite along the east-central contact, all analyses of magnesite contain more than 44 percent MgO and the entire lens is considered to be of minable grade.

In 1945 one large talus boulder was being mined for pilot plant experimentation (sample locality 1) and the west-central talc zone was being developed. Other work completed by Magnesita S. A. in 1945 included construction of an access road and an engineering staff house. Test pits and surface blasting of outcrops at about 30 localities had provided the company with samples of its ore.

TABLE 4.—*Analyses of magnesite, Pedra Preta deposit, Serra das Éguas, Brumado, Bahia, Brazil*

Analyses by the chemical laboratory, Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil. Specimens A–1 to A–12 inclusive analyzed by Maria Yelda Esteves Ramos, analysis no. 7463, reported March 20, 1946. Specimens A–13 to A–19 inclusive analyzed by Oswaldo Erichsen de Oliveira, analysis no. 7462, reported March 20, 1946. Specimens A–20 to A–36 inclusive analyzed by Frida Ciornai, analysis no. 7461, reported March 18, 1946.]

Sample no.[1]	Insol.[2]	Fe_2O_3	Al_2O_3 $+TiO_2$	MnO	CaO	MgO [3]	Ig. loss [4]	Total [5]
A–1	0.18	2.30	0.60	0.17	1.16	44.98	50.61	----------
A–2	.53	.40	1.34	.44	.24	45.69*	51.46	100.10
A–3	6.25	2.10	4.08	.32	.10	44.21*	43.54	100.60
A–4	1.84	1.09	1.88	.31	.16	45.88*	49.06	100.22
A–5	2.67	1.19	2.31	.43	.26	44.97	48.17	----------
A–6	.10	.62	.20	.53	1.37	46.08*	51.54	100.44
A–7	.22	1.09	.59	.05	1.84	44.77*	51.32	99.88
A–8	.47	.27	1.17	.28	.05	45.94	51.82	----------
A–9	3.04	1.79	2.29	.32	.15	44.24	48.17	----------
A–10	1.68	.82	1.85	.25	.12	44.82	50.46	----------
A–11	3.10	1.02	1.66	.32	.50	45.32	48.08	----------
A–12	.16	.44	.24	.09	.86	46.52	51.69	----------
A–13	.4	.7	.4	.2	.3	46.1	51.9	----------
A–14	.6	1.0	.5	.5	.2	46.05	51.15	----------
A–15	.6	.5	.4	.5	.5	45.85	51.65	----------
A–16	1.8	.9	1.8	.4	.9	44.0	50.2	----------
A–17	2.6	.9	.2	.35	.1	46.15	49.7	----------
A–18	2.8	.3	1.3	.5	.3	45.25	49.55	----------
A–19	1.0	1.1	.3	.3	.2	46.05	51.05	----------
A–20	.1	1.4	.09	.01	2.8	44.1	51.5	----------
A–21	.2	.9	.09	.21	1.3	45.4	51.9	----------
A–22	.9	.6	tr.	.40	12.1	34.5	51.5	----------
A–23	4.3	.4	.64	.46	.8	45.0	48.4	----------
A–24	1.2	1.0	1.53	.07	4.9	41.4	49.9	----------
A–25	2.3	.7	.83	.07	.7	45.6*	50.3	100.5
A–26	.6	1.5	.86	.04	1.1	45.6*	50.9	100.6
A–27	.3	.2	.46	.04	1.4	46.0*	52.0	100.4
A–28	.5	3.5	.43	.07	.2	46.0*	49.9	100.6
A–29	.7	2.0	.18	.02	.4	46.6*	50.7	100.6
A–30	5.3	.7	.63	.07	.3	46.0*	47.7	100.7
A–31	1.7	1.0	.60	tr.	1.0	45.7	50.0	----------
A–32	.3	.6	.10	.20	.8	46.0	52.0	----------
A–33	.2	.3	.53	.07	1.1	45.8	52.0	----------
A–34	.8	.9	.36	.04	1.0	46.0	50.9	----------
A–35	.2	2.1	tr.	.10	1.5	45.1	51.0	----------
A–36	1.5	.4	.13	.07	1.6	45.5	50.8	----------

[1] Sample numbers correspond to sample localities as shown on plate 13.

[2] Insoluble represents SiO_2.

[3] Magnesia obtained by difference, unless marked with asterisk.

[4] Ignition loss represents CO_2.

[5] Totals shown only where magnesia was analyzed directly.

A–1—Fine-grained maroon, medium-grained red, and coarse-grained white, with minor specular hematite.

A–2—Coarse-grained maroon and red, few scraps of talc.

A–3—Medium- to coarse-grained red, numerous talc scraps, moderate amount of specular hematite.

A–4—Medium-grained red and maroon, veined by coarse-grained white. Moderate amount of specular hematite, minor amount of talc as scraps.

A–5—Same as no. A–4.

A–6—Medium-grained red magnesite.

A–7—Medium-grained white, some medium-grained red.

A–8—Medium-grained white, with few talc scraps.

A–9—Medium-grained red, with some talc scraps.

A–10—Medium- to coarse-grained white.

A–11—Coarse-grained gray, with few white and pink grains; many talc scraps.

A–12—Coarse-grained white and some medium-grained red.

A–13—Coarse-grained white.

A–14—Medium-grained red and white.

A–15—Medium-grained white and pink.

A–16—Medium-grained light gray.

A–17—Medium-grained white, gray, and red; small amounts of talc scraps.

A–18—Same as no. A–17.

A–19—Medium-grained gray and coarse-grained orange; minor talc scraps.

A–20—Coarse-grained white and some coarse-grained red.

A–21—Medium-grained white and pink, some coarse-grained orange.

A–22—Medium-grained gray, some fine-grained red.

A–23—Same as no. A–22, with numerous talc veinlets.

A–24—Coarse-grained white and red.

A–25—Coarse-grained white and pink; talc scraps.

A–26—Coarse-grained white and red.

A–27—Same as no. A–26.

A–28—Coarse-grained white and red; some specular hematite.

A–29—Same as no. A–28.

A–30—Coarse-grained red and white; some talc scraps.

A–31—Coarse-grained white and pink; talc scraps.

A–32—Coarse-grained white and pink.

A–33—Medium- and coarse-grained gray and white.

A–34—Medium-grained white and pink; minor talc scraps.

A–35—Coarse-grained white and red; some specular hematite.

A–36—Medium-grained white and red; talc scraps.

BATE-PÊ AND BOA VISTA

The magnesite occurrences in the Bate-Pé valley are known as the Bate-Pé deposit and those extending southward beyond the Magnesita S. A. concession line are known as the Boa Vista deposit.

Topographically the Bate-Pé valley in the Serra das Éguas consists of two parts, an upper area consisting of deeply incised streams and tributaries cutting the region into precipitous valleys, and a lower area consisting of a comparatively open valley. (See fig. 10.) The Corrego do Bate-Pé (creek) leaves the sharply dissected area near the east margin of the magnesite occurrences. From this point westward all outcrops are in the bed of the creek or its tributaries. Southward, magnesite crops out along the front of the ridge separating the open country from the area of deep dissection. The upper valley is covered with heavy timber which gives way upward to brush and grassland; the lower valley is covered with brush except where cleared for agriculture. The entire area is mantled by lateritic soil as much as 6 meters thick. The Corrego do Bate-Pé carries 10 liters per second of water where it enters the lower part of the valley.

Quartzite lies east of the deposits in the core of the syncline extending from the Pedra Preta deposit. Undoubtedly the carbonate rock extending across the range is folded but outcrops are too few to determine details of structure. (See section *B–B′*, pl. 12.) Talc, enstatite, and quartz veins are nearly vertical; they strike nearly north at the east end of the upper area and swing eastward in the central part of the upper area. All outcrops are magnesite with the exception of one of gray sandstone (part of the quartzite) several hundred meters east of the "water gap" separating the lower and upper valleys, one of jasper in the middle of the upper valley, and several of amphibolite in eastern part of the upper valley. With the paucity of carbonate outcrops it is impossible to determine the size or shape of the magnesite deposits. Perhaps it is just fortuitous that all outcrops of carbonate rock are magnesite, or perhaps the area is underlain by an unbelievably large deposit; in the upper valley magnesite outcrops have an east-west extent of 2,400 meters, a north-south extent of 1,200 meters, and a vertical range of 310 meters.

In the upper valley all magnesite is white, cream, or light gray and has saccharoidal texture with grain size ranging from fine to medium. Analyses of samples shows that it contains very little residual dolomite. All but one sample carries much less than 1 percent CaO; iron oxide and alumina content are also low. The silica content, in contrast, is high in nearly all outcrops, occurring as numerous closely spaced veins and lenses of talc and enstatite and as quartz veins near the large jasper outcrop in the central part of the valley. Such veins provide from 10 to 30 percent quartz and magnesium silicate minerals in most magnesite. Only two areas having low silica content were seen. The first, near the mouth of the upper valley is about 20 meters wide and crops out in the stream bed; another possible block is in the shoulder along the trail following the valley. (See table 5, sample localities B-1 and B-3.) The second, near the head of the major northwest tributary, is about 50 meters long. Extensive stripping of soil and timber would be required to prepare both for mining operations.

TABLE 5.—*Analyses of magnesite, Bate-Pé deposit, Serra das Éguas, Brumado, Bahia, Brazil*

[Analyses by the chemical laboratory, Departmento Nacional da Produção Mineral, Rio de Janeiro, Brazil. Specimens B-1 to B-8 inclusive analyzed by Aida Espinola, analysis no. 7643, reported Oct. 29, 1946. Specimens B-9 and B-10 analyzed by Esther Vaccani Levy, analysis no. 7646, reported October 30, 1946]

Sample no.[1]	Insoluble[2]	Fe_2O_3	$Al_2O_3 + TiO_2$	MnO	CaO	MgO[3]	Ignition loss[4]	Total[5]
B-1	0.1	0.7	0.3	0.07	0.1	47.0	51.8	----------
B-2	6.4	.7	.2	tr.	.02	44.0*	48.4	99.7
B-3	.5	.9	.6	.01	1.2	45.3	51.5	----------
B-4	6.5	1.6	.9	.01	.1	44.8	46.1	----------
B-5	6.2	.9	.4	.08	.1	45.6	46.8	----------
B-6	3.0	.8	.2	.09	.2	45.8	50.0	----------
B-7	1.8	.5	.1	.06	.3	46.2	51.1	----------
B-8	1.2	.4	.1	.07	.1	47.5*	51.1	100.4
B-9	3.23	.47	.27	tr.	tr.	45.85*	50.08	99.90
B-10	.95	.34	.23	.06	tr.	47.15*	51.29	100.02

[1] Sample numbers correspond to sample localities as shown on plate 12.
[2] Insoluble represents SiO_2.
[3] Magnesia obtained by difference, unless marked with asterisk.
[4] Ignition loss represents CO_2.
[5] Totals shown only where magnesia was analyzed directly.

All samples are fine- to medium-grained white to light-gray magnesite. Samples B-2, B-5, and B-7 to B-10 contain enstatite; sample B-4 contains talc; and sample B-6 contains quartz and enstatite.

Several other samples in table 5 show low silica content but were collected from narrow silica-free bands in zones of low-grade material to determine principally the lime, iron oxide, and alumina content of the magnesite.

Magnesite in the Boa Vista area has color and grain size comparable to that in the Bate-Pé valley. The area was not visited and the following information was graciously given the writer by Engs. Costa and Braga Filho, who examined the occurrences for G. W. Soares. Outcrops of magnesite are reported to extend 2 kilometers south of the Magnesita S. A. concession line and are as much as 400 meters wide. Quartz, talc, and enstatite veins crop out, but several zones are comparatively free of silica. Samples collected by Costa and Braga Filho and given the writer analyze from 0.4 to 8.6 percent SiO_2, all of which occurs as talc. The lime content is very low but the iron oxide content ranges from 2.1 to 2.9 percent, unusually high for white magnesite in the Serra das Éguas. (See table 6.)

TABLE 6.—*Analyses of magnesite, Boa Vista deposit, Serra das Éguas, Brumado, Bahia, Brazil*

[Analyses by the chemical laboratory, Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil. Specimens BV-1 to BV-5 were collected by Eng. Odelio Costa and Eng. Custodio Braga Filho, and were analyzed by Frida Ciornai, reported March 18, 1946, analysis no. 7461]

Sample no.	Insoluble [1]	Fe_2O_3	Al_2O_3 $+TiO_2$	MnO	CaO	MgO [2]	Ignition loss[3]
BV-1	8.6	2.9	0.83	0.07	0.2	43.5	43.9
BV-2	.4	2.1	1.03	.07	.1	44.7	51.6
BV-3	4.3	2.4	.78	.12	tr.	44.6	47.8
BV-4	2.4	2.7	.26	.04	tr.	45.3	49.3
BV-5	2.6	2.7	.66	.04	tr.	45.3	48.7

[1] Insoluble represents SiO_2.
[2] Magnesia obtained by difference.
[3] Ignition loss represents CO_2.

BV-1—Medium-grained white; numerous talc scraps.
BV-2—Medium-grained white.
BV-3—Medium-grained white; minor talc scraps.
BV-4—Medium-grained white; minor talc.
BV-5—Moderately fine grained white with buff cast.

CATIBOABA

The Catiboaba deposit, also on the east side of the range, is near the head of Catiboaba valley, starting about 100 meters north of the junction of the Corrego do Catiboaba (Catiboaba Creek) with its main west tributary. (See pl. 16.) The part of the valley containing the deposit is shaped like an amphitheater, opening into a basin behind a narrow mouth. The Corrego do Catiboaba and its tributaries all occupy steep-walled valleys and gullies which terminate in boxlike heads. The creek carries little water in this area and is intermittent above the central part of the deposit. The lower parts of the amphitheater are heavily forested, grading upward to brush and grassland. Laterite soil blanketing most of the deposit is from 2 to 5 meters thick.

The local geologic structure is anticlinal because the quartzite and included itabirite beds occur both east and west of the carbonate outcrops. In the immediate vicinity of the deposits dolomite does not crop out, so the entire shape of the magnesite lens is inferred on the basis of limit of magnesite exposures. Several outcrops of magnesite in the northeast part of the body contain higher lime content—a possible indication that they are the edge of a transition zone near dolomite. Quartzite crops out in the southeastern part of the area, west of sample locality 8, and may be the root of a small synclinal fold. The only indication of intrusive rock is amphibolite float found between sample localities 7 and 12 in the east-central part of the deposit.

Magnesite crops out as bold ledges, as huge slump blocks, and in the beds of streams and tributary gullies. The shape of these outcrops is comparable to the ones in the central part of the Pedra Preta deposit. The magnesite is also comparable to that of Pedra Petra, in that it is a fine-grained red mineral containing segregations of specular hematite. However, the average iron oxide content is higher and specular hematite occurs in larger percentages in some outcrops. Veins of later coarse-grained white and red magnesite are less abundant than in the red magnesite of the Pedra Preta deposit. White saccharoidal magnesite free of hematite occurs in the southeast corner of this deposit.

Other than in the northeast corner of the deposit (sample localities C–14 and C–15, and table 7), the magnesite has uniformly low lime content. The silica content is low throughout the deposit except in the southeast corner where talc scraps are abundant in several localities (sample localities C–8, C–18, and C–27). Alumina is persistent but low and iron oxide is consistently moderate in quantity except in three outcrops where excessive hematite occurs. Excluding the northeast and southeast corners, the entire lens could furnish magnesite of minable grade if the few areas containing high-hematite material were reserved for blending with low-iron material.

On the basis of extent of outcrops, the lens is 1,000 meters long, as much as 440 meters wide, and has a vertical range of 125 meters. On the basis of size and chemical grade of the magnesite, this deposit contains the second largest reserve in the district. In 1945 the deposit was undeveloped; Magnesita S. A. had sampled more than 20 localities from pits and from small tonnages blasted from outcrops.

FABRICA

The Fabrica deposit, the most southerly of the eastern group, is on a hillside just below a quartzite cliff at the south edge of the Catiboaba valley. The area is grass-covered, is only thinly mantled with soil and talus, and has no water. The deposit is on the east limb of a north-plunging syncline. (See pls. 12 and 17.) The quartzite outcropping west of the carbonate rock provides the only exposures of bedrock other than those of magnesite. Amphibolite float lies in the head of a small tributary gully of Catiboaba Creek below the central part of the deposit.

The inferred boundaries of the magnesite are based exclusively on the extent of outcrops, trenches, and quartz prospects exposing the mineral. These have a strike length of 625 meters, a width ranging from 20 to 42 meters, and a vertical extent of 135 meters. The magnesite is white or light gray with fine- to medium-grained saccharoidal texture. In the central part of the deposit one outcrop consists of red magnesite. Individual outcrops are small but numerous and together with prospect pits furnish eight areas of general exposures.

TABLE 7.—*Analyses of magnesite, Catiboaba deposit, Serra das Éguas, Brumado, Bahia, Brazil*

[Analyses by the chemical laboratory, Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil. Specimens C-1 to C-10 inclusive analyzed by Luiz Baumfeld, analysis no. 7467, reported March 26, 1946. Specimens C-11 to C-20 inclusive analyzed by Maria Yelda Esteves Ramos, analysis no. 7463, reported March 20, 1946. Specimens C-21 and C-22, and C-24 to C-30 inclusive analyzed by Frida Ciornai, analysis no. 7461, reported March 18, 1946]

Sample no.[1]	Insoluble[2]	Fe_2O_3	Al_2O_3 $+TiO_2$	MnO	CaO	MgO[3]	Ignition loss[4]	Total[5]
C-1	0.10	10.80	1.94	0.02	0.22	41.52	45.40	----------
C-2	.38	.98	.55	.02	.54	45.93	51.60	----------
C-3	.30	1.10	.28	.02	1.30	45.95	51.05	----------
C-4	.40	.84	.24	.04	.30	46.94	51.24	----------
C-5	1.00	2.22	.92	.02	.06	46.10	49.70	----------
C-6	.56	.84	.74	.02	.07	46.57	51.20	----------
C-7	1.06	1.26	2.02	.02	.26	44.38	51.00	----------
C-8	9.36	1.68	1.84	.04	.32	41.36	45.40	----------
C-9	.10	.84	.20	.02	.60	46.74	51.50	----------
C-10	1.52	12.87	2.35	.04	.70	38.82	43.70	----------
C-11	.98	.83	1.34	.23	.38	45.27*	51.32	100.34
C-12	2.64	29.19	.48	.04	.07	32.62	34.96	----------
C-13	.17	.82	.87	.04	.16	46.32	51.62	----------
C-14	.33	.77	.33	.04	2.58	44.28	51.67	----------
C-15	.64	4.60	1.04	.05	4.60	40.81	48.26	----------
C-16	1.44	2.03	.46	.04	.12	45.73*	50.10	99.92
C-17	.44	.89	.30	.01	.41	46.63*	51.44	100.12
C-18	1.45	1.93	.49	.05	.59	46.06	49.43	----------
C-19	.06	1.14	.33	.05	.76	46.17	51.49	----------
C-20	.02	3.99	.61	.04	1.68	43.70	49.96	----------
C-21	.3	1.2	.1	.tr.	.3	46.3	51.8	----------
C-22	.4	6.1	.26	.04	tr.	44.2	49.0	----------
C-23[6]	----------	----------	----------	----------	----------	----------	----------	----------
C-24	.7	1.3	.5	tr.	tr.	46.3	51.2	----------
C-25	.3	1.0	tr.	tr.	.4	46.3	52.0	----------
C-26	.2	1.0	.1	tr.	.6	46.2	51.9	----------
C-27	3.2	2.3	.56	.04	tr.	45.2	48.7	----------
C-28	.7	1.3	.06	.04	.4	45.7	51.8	----------
C-29	.4	3.4	.26	.04	.5	44.9	50.5	----------
C-30	.4	4.7	.1	tr.	.5	45.0	49.3	----------

[1] Sample numbers correspond to sample localities as shown on plate 16.
[2] Insoluble represents SiO_2.
[3] Magnesia obtained by difference, unless marked with asterisk.
[4] Ignition loss represents CO_2.
[5] Totals shown only where magnesia was analyzed directly.
[6] Not analyzed. Magnesite determination made with microscope.

C-1—Medium-grained gray and some white, coarse-grained red; much free specular hematite.

C-2—Coarse-grained white, some pink and red.

C-3—Medium- to coarse-grained white and some red.

C-4—Fine-grained white and pink; some medium-grained red.

C-5—Medium-grained white, some red.

C-6—Medium- to coarse-grained white and red.

C-7—Moderately fine-grained white, very little red.

C-8—Moderately coarse-grained white; talc scraps.

C-9—Medium-grained red and gray and coarse-grained white.

C-10—Medium-grained gray, some coarse-grained white; considerable free specular hematite.

C-11—Medium-grained white, some red.

C-12—Medium-grained white and red; much free specular hematite.

C-13—Moderately fine-grained white and pink; with slickensided talc veinlets.

C-14—Medium-grained white and pink; some coarse-grained pink.

C-15—Medium-grained red and coarse-grained pink.

C-16—Fine-grained red and white, moderately coarse-grained pink.

C-17—Fine-grained to medium-grained white and minor coarse-grained white.

C-18—Medium-grained white and gray, medium- to coarse-grained red; trace of talc.

C-19—Medium-grained red and gray, coarse-grained white.

C-20—Medium-grained dark gray and maroon; some hematite.

C-21—Moderately coarse-grained red and coarse-grained white.

C-22—Moderately coarse-grained maroon and white.

C-23—Medium-grained white and red, coarse-grained red.

C-24—Medium-grained white, red, and gray, white grading into moderately coarse grain.

C-25—Medium- to coarse-grained white and pink, some fine-grained pink.

C-26—Fine-grained white, trace of red and gray.

C-27—Medium-grained white, trace of red and gray.

C-28—Medium-grained white.

C-29—Medium-grained gray, some coarse-grained white.

C-30—Medium-grained white and pink; some free specular hematite.

The lime content of the magnesite is low throughout the deposit except in the south-central area. (See pl. 17; and table 8, sample localities F-3 and F-4). Iron and alumina likewise occur only in small percentages. The silica content varies and is dependent on the amount of talc and quartz; talc scraps occur throughout the deposit and silicified areas are found for the most part at the south end of the deposit. Other than in the area containing high lime, where the magnesia content is just below the 43 percent cut-off limit, the entire lens contains magnesite of minable grade. The high-lime areas and those containing moderate silica are small enough to permit their blending with purer material if desirable.

The Fabrica deposit, by virtue of its generally good chemical composition and its proximity to the kiln at the Catiboaba station, could provide the basis for operations recovering hematite-free magnesite. In 1945 the deposit was undeveloped and had only been generally samples by Magnesita S. A.

TABLE 8.—*Analyses of magnesite, Fabrica deposit, Serra das Éguas, Brumado, Bahia, Brazil*

[Analyses by the chemical laboratory, Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil. Specimens F-1 and F-2 analyzed by Maria Yelda Esteves Ramos, analysis no. 7463, reported March 20, 1946. Specimens F-3 to F-8 inclusive, analyzed by Esther Vaccani Levy, analysis no. 7504, reported April 30, 1946. Specimens F-9 to F-15 inclusive, analyzed by Luiz Baumfeld, analysis no. 7467, reported March 26, 1946]

Sample no.[1]	Insoluble [2]	Fe_2O_3	Al_2O_3 $+TiO_2$	MnO	CaO	MgO [3]	Ignition loss [4]	Total [5]
F-1	1.18	1.36	0.53	0.05	0.46	45.31*	50.68	99.57
F-2	1.00	1.16	.45	.05	.17	46.73	50.44	----------
F-3	1.71	.96	1.14	.06	3.44	42.62	50.07	----------
F-4	4.12	1.19	1.27	.11	3.00	42.63	47.68	----------
F-5	1.89	.77	.76	.09	.68	45.63	50.08	----------
F-6	2.24	1.32	.84	.17	1.29	44.65	49.49	----------
F-7	.61	.89	.20	.06	.84	46.11	51.29	----------
F-8	.41	1.42	.38	.09	1.85	45.31*	51.34	100.80
F-9	.56	.54	.35	.15	tr.	47.10	51.30	----------
F-10	.47	1.13	.46	.14	tr.	46.66	51.14	----------
F-11	.57	.84	.16	.04	1.20	45.91	51.28	----------
F-12	1.51	1.42	.65	.08	tr.	46.06	50.28	----------
F-13	1.17	.66	.38	.03	tr.	46.95	50.81	----------
F-14	1.43	.66	.79	.07	tr.	46.73	50.32	----------
F-15	.68	.78	.35	.05	tr.	46.94	51.20	----------

[1] Sample numbers correspond to sample localities as shown on plate 17.
[2] Insoluble represents SiO_2.
[3] Magnesia obtained by difference, unless marked with asterisk.
[4] Ignition loss represents CO_2.
[5] Totals shown only where magnesia was analyzed directly.

F-1—Fine-grained white and friable, some medium-grained.
F-2—Fine-grained white and friable.
F-3—Fine- to medium-grained white to pearl gray.
F-4—Fine-grained light gray; considerable talc.
F-5—Fine-grained white; talc scraps.
F-6—Medium-grained white; minor talc.
F-7—Fine-grained white.
F-8—Medium-grained white, some pink crystals.
F-9—Medium-grained white to pearl gray.
F-10—Coarse-grained white.
F-11—Fine-grained white.
F-12—Fine-grained white with pinkish cast.
F-13—Fine- to medium-grained white.
F-14—Medium-grained white.
F-15—Fine-grained white.

NOROESTE

The most northerly of the deposits on the the west side of the range is the Noroeste, so named by the writer because it was heretofore unnamed. It lies just west of the divide between east and west drainage at the head of a westward-trending gully and is far from perennial streams. The slopes are comparatively gentle and are grass-covered. (See pl. 12.)

Only dolomite and magnesite crop out in the area. The largest magnesite outcrop, on the south side of the gully, is 160 meters long and averages 30 meters in width. Some 120 meters north are the remaining outcrops, one 40 by 30 meters and the other 30 by 10 meters. Dolomite crops out east of the magnesite. The magnesite in the south outcrop is red and in the north outcrops is white; all has medium grain size. Talc scraps provide minor silica content.

Of the two analyses made of samples collected here, one shows high lime content. (See table 14, samples N–1 and N–2.) The combination of poor chemical grade and limited exposures coupled with inaccessible location and lack of water indicate that the area merits little consideration.

GRAVATÁ

The Gravatá deposit is in a sharp ravine on the west side of the range about 1.5 kilometers northeast of the Pirajá deposit. (See pl. 12.) The area is grass-covered and overburden ranges from 1 to 3 meters in thickness. The Corrego do Gravatá (Gravatá Creek) usually is dry.

There are only six outcrops of magnesite in the area, one in the gullied head of the ravine, two in the central part of the ravine, and the others on the north and south shoulders of the valley. All are low and rounded and consist of cream or gray magnesite having medium-grained saccharoidal texture. Magnesita S. A. sank a row of prospect pits on the south slope and several in the northern area. These disclose magnesite over an east-west extent of about 800 meters and a north-south extent of about 450 meters. Dolomite crops out between magnesite exposures on the north shoulder and mixed dolomite and magnesite occurs in several of the southern prospect pits, so it is doubtful that the deposit is continuous over the entire area.

Nearly all the magnesite, other than in dolomitic areas, has low lime, iron oxide, and alumina content but a very high silica content. (See table 9.) Silica-bearing minerals include quartz, talc, and asbestiform anthophyllite. Only one trench and one outcrop contain magnesite essentially free of these impurities and thus the grade of the deposit is too poor to furnish minable material. The reserve of 1,000 tons given for the deposit is a nominal figure based on the two exposures of good material.

PIRAJÁ

The Pirajá deposit, in the central part of the western group, is in Pirajá valley and 3.6 kilometers southwest of the Pedra Preta camp. Most of the area has steep slopes except along the western edge of the deposit and is covered with grassland except along the Corrego do Pirajá (Pirajá Creek) where tropical trees grow to considerable heights and brush is moderately thick. Below the workers' dormitory the creek flows at the rate of about 3 liters per second. Soil cover is from 1 to 4 meters thick and almost all outcrops are in stream or gully beds. Additional exposures are afforded by the emerald and quartz diggings and by Magnesita S. A. prospect pits. (See pl. 14.)

TABLE 9.—*Analyses of magnesite, Gravatá deposit, Serra das Éguas, Brumado, Bahia, Brazil*

[Analyses by the chemical laboratory, Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil. Specimens G–1 and G–2 analyzed by Luiz Baumfeld, analysis no. 7467, reported March 26, 1946. Specimens G–3 to G–7 inclusive analyzed by Esther Vaccani Levy, analysis no. 7504, reported April 30, 1946]

Sample no.	Insoluble [1]	Fe_2O_3	Al_2O_3 $+TiO_2$	MnO	CaO	MgO [2]	Ignition loss [3]	Total [4]
G–1	16.44	0.47	1.65	0.02	0.06	39.12	42.24	----------
G–2	17.42	.42	2.06	.04	.08	39.28	40.70	----------
G–3	1.28	.51	.44	tr.	2.37	45.51*	50.62	100.73
G–4	7.65	1.02	1.75	.11	.85	43.02	45.60	----------
G–5	19.01	.40	2.60	tr.	1.85	40.51	35.63	----------
G–6	22.22	.84	2.23	.04	tr.	42.32	32.35	----------
G–7	1.41	.59	.09	tr.	tr.	46.95*	50.97	100.01

[1] Insoluble represents SiO_2.

[2] Magnesia obtained by difference, unless marked by asterisk.

[3] Ignition loss represents CO_2.

[4] Total only shown where magnesia was analyzed directly.

G–1—Medium-grained buff; contains black specks of undetermined mineral and also quartz.

G–2—Fine- to medium-grained white and friable, stained buff; silicified.

G–3—Moderately fine grained, white; talc flakes.

G–4—Fine-grained white; contains some talc.

G–5—Fine-grained white; contains much enstatite.

G–6—Fine-grained white; silicified.

G–7—Fine-grained white.

The only structure in the carbonate rock is that indicated by the attitude of quartz, talc, and enstatite veins, which dip steeply and strike northeast in most of the deposit but strike nearly east in the eastern part of the deposit. One small fault occurs in the northwest wall of the main emerald pit.

Dolomite and amphibolite are the only country rocks cropping out in the area. Dolomite is seen in a number of exposures west of a long and wide dike system and also east of the dikes near the northern end of the deposit. A large block of dolomite is partly mineralized by bladed magnesite northwest of the magnesite lens. Only the western contact of the magnesite body is known so the shape of the remainder of the lens is inferred from the extent of exposures. These continue nearly to the head of the Corrego do Pirajá, about 200 meters east of the limit of the deposit map. The most southerly outcrops are in Corrego Seco (Dry Creek), a major tributary of the Corrego do Pirajá. Heavy soil cover effectively conceals the geology in the upland areas.

As based on outcrops, the Pirajá deposit is 910 meters long, as much as 810 meters wide, and has a vertical extent of 165 meters. Magnesite is white, light gray, or cream and has saccharoidal texture; it is veined by coarse-grained white magnesite which forms crystals in open vugs. One small area along the Corrego do Pirajá contains medium-grained red magnesite veined by coarse-grained red, orange, and white magnesite. (Sample locality 6, pl. 14, and table 10.)

Most magnesite has low lime, iron, and alumina content. Lime is a little higher than average in the southeast part of the lens and near the west contact in the north-central part. (See table 10, analyses D–5, D–10, and D–11.) The red magnesite contains more iron than the white. (See table 10, analysis D–6.) The silica content is high throughout most of the deposit; it occurs as closely spaced veins or silicified zones of quartz, talc, and enstatite. (See fig. 10.) Of the four specimens collected from such areas two were selected from silica-free bands to determine lime, iron oxide, and alumina content of the magnesite. (See table 10, analyses D–1, D–7, D–8, and D–9.)

Only six areas in the deposit are low in silica minerals and have high enough chemical grade to be classified as minable material. (See pl. 14.) Block I, having a length of 360 meters and a width from 20 to 30 meters, is the largest and lies between a zone high in talc on the west and high in enstatite and talc on the east; included silica occurs as small scraps of talc. All other blocks are small; several are outlined by only a few exposures and so would require further exploration before it could be known with certainty that they contain material of minable grade throughout.

TABLE 10.—*Analyses of magnesite, Pirajá deposit, Serra das Éguas, Brumado, Bahia, Brazil*

[Analyses by the chemical laboratory, Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil Specimens D–1 and D–2, and D–4 to D–9 inclusive analyzed by Luiz Baumfeld, analysis no. 7467, reported March 26, 1946. Specimens D–3 and D–10 to D–12 inclusive analyzed by Esther Vaccani Levy, analysis nos. 7648 and 7504, respectively, reported October 30, 1946 and April 30, 1946]

Sample no.[1]	Insoluble [2]	Fe_2O_3	Al_2O_3 $+TiO_2$	MnO	CaO	MgO [3]	Ignition loss [4]	Total [5]
D–1	13.70	0.42	1.26	0.04	0.08	43.50	41.00	----------
D–2	2.26	.47	.67	.04	.60	46.20	49.76	----------
D–3 [6]	.71	.30	.24	tr.	tr.	47.55*	51.35	100.15
D–4	1.30	.54	.14	.04	.10	47.58	50.30	----------
D–5	.60	.47	.04	.04	2.80	44.85	51.20	----------
D–6	.58	1.78	.49	.08	.30	46.23	50.54	----------
D–7	1.02	.54	1.32	.04	.10	46.38	50.60	----------
D–8 [7]	.55	.54	.62	.08	20.00	30.54*	47.68	100.31
D–9	45.58	.59	.81	.04	.08	33.02	19.88	----------
D–10	1.75	.61	tr.	.04	2.73	44.26*	50.49	99.88
D–11	.38	.44	.15	tr.	2.59	45.53*	51.62	100.71
D–12	.20	.40	.32	.02	1.20	46.19	51.67	----------

[1] Sample numbers correspond to sample localities as shown on plate 14.

[2] Insoluble represents SiO_2.

[3] Magnesia obtained by difference, unless marked with asterisk.

[4] Ignition loss represents CO_2.

[5] Totals shown only where magnesia was analyzed directly.

[6] Al_2O_3–0.24 percent, TiO_2–trace. Sample also contains trace of P_2O_5.

[7] Partly dolomite.

D–1—Fine- to medium-grained white; considerable enstatite.
D–2—Fine- to medium-grained white; talc scraps.
D–3—Fine- to medium-grained white.
D–4—Fine- to medium-grained white; talc flakes.
D–5—Fine- to medium-grained white.
D–6—Medium-grained maroon.
D–7—Fine- to medium-grained white; minor quartz and enstatite.
D–8—Bladed aggregates of magnesite in dolomite.
D–9—Fine- to medium-grained; much enstatite.
D–10—Fine- to medium-grained; talc scraps.
D–11—Fine-grained cream.
D–12—Medium-grained white.

In 1945, the company had put in test pits and had sampled about 50 localities to determine the quality of the magnesite. The only other development work at that time consisted of construction of an access road from the Pedra Preta deposit.

CABECEIRAS

The Cabeceiras deposit, 1.6 kilometers southwest of Pirajá valley, is on a ridge projecting farther westward than the average west front of this part of the range. (See pl. 12.) The ridge is nearly separated from the upland by the Corrego do Cabeceiras, (Cabeceiras Creek) and a tributary of the Corrego do Coité, and is mostly grass-covered except for scattered trees at its crest and brush along the intermittent streams. The soil mantle ranges from 1 to 4 meters in thickness.

Dolomite, which is the country rock, is exposed in outcrops and trenches peripheral to the north end of the magnesite lens and extends southward several hundred meters along the east contact of the lens. The dolomite has been chertified several hundred meters east of the deposit and tremolite crystals are common in the intervening area. Dolomite also occurs as embayments and islands within the magnesite body, both as pure material and as a mixture with magnesite.

The dips of quartz, talc, and enstatite veins are steep and their strike is parallel to the long axis of the magnesite deposit. Several faults with small displacement occur along the east contact of the deposit in the vicinity of sample localities E–1 and E–2.

Outcrops are uncommon except along gullies in the north end of the deposit, but extensive prospecting for quartz has furnished many more exposures of both dolomite and magnesite. Magnesita S. A. has sunk about 20 test pits, which, together with analyses of samples, have been most useful in outlining the distribution of magnesite at the north end of the deposit. (See pl. 15, and table 11, analyses M–1 to M–21.) Quartz prospects afford the means of determining the generalized southern extension of the deposit.

The magnesite extends from a low spur just west of the Corrego do Cabeceiras southward along the west flank of the ridge for a distance of 860 meters. The lens is from 80 to 235 meters wide, narrowest at the north end, and outcrops have a vertical range of 130 meters. All the magnesite is light-colored and has saccharoidal texture.

The northern end of the deposit contains irregular-shaped dolomite areas and the southern part has numerous and closely spaced quartz, talc, and enstatite veins. The parts of the northern area free of dolomite are the only ones suitable for development, for toward the south no zones as wide as 10 meters are free of silica or magnesium silicate minerals. The areas at the north end of the lens considered to contain commercial-grade magnesite are between sample localities E–1 and E–7 and in the areas surrounding sample locality E–3 and trench M–16. It should be emphasized that the rather large figure given for inferred reserve is based on the supposition that the areas concealed by soil cover do not contain blocks of dolomite. Exploration of such covered areas is recommended before using the reserve estimates as a basis for exploitation.

TABLE 11.—*Analyses of magnesite and dolomite, Cabeceiras deposit, Serra das Éguas, Brumado, Bahia, Brazil*

[Sample numbers correspond to sample localities as shown on plate 15. Specimens E–1 to E–7 inclusive analyzed by Maria Yelda Esteves Ramos, analysis no. 7463, reported March 20, 1946. Specimens E–8 to E–13 inclusive analyzed by Esther Vaccani Levy, analysis no. 7504, reported April 30, 1946]

Sample no.	Insoluble [1]	Fe_2O_3	$Al_2O_3 + TiO_2$	MnO	CaO	MgO [2]	Ignition loss [3]	Total[4]
ANALYSES BY THE CHEMICAL LABORATORY, DEPARTMENTO NACIONAL DA PRODUÇÃO MINERAL, RIO DE JANEIRO, BRAZIL								
E–1	0.62	0.84	0.52	0.08	13.73	34.65*	49.14	99.58
E–2	.77	.77	.12	.12	.69	46.51	51.02	--------
E–3	.41	.72	.25	.08	6.18	38.65	53.71	--------
E–4	.54	.89	.13	.25	29.91	21.54*	46.71	99.97
E–5	.90	.34	.14	.04	26.00	24.64	47.94	--------
E–6	.77	.94	.24	.01	4.48	42.87*	50.55	99.86
E–7	25.03	.47	.32	.16	21.22	18.12	34.68	--------
E–8	.81	.67	.10	.08	1.92	45.06	51.36	--------
E–9	11.42	.82	.54	.11	.16	44.21	42.74	--------
E–10	.48	.37	.18	.06	27.92	23.57	47.42	--------
E–11	1.25	.72	.15	.15	29.67	21.56	46.50	--------
E–12	4.63	.57	.32	.06	.13	45.93*	48.15	99.79
E–13 [5]	71.05	.37	.99	tr.	6.12	10.92	10.55	--------
ANALYSES MADE FOR MAGNESITA S. A.								
[Sample numbers correspond to "M" series of trenches shown on plate 15. Trenches M–4 and M–15 did not reach bedrock. Magnesia analyzed directly. Published with courtesy of Magnesita S. A.]								
M–1	0.96	1.00	0.02	--------	0.84	46.06	49.52	98.40
M–2	--------	.87	.13	--------	.83	44.95	--------	--------
M–3	--------	.85	.55	--------	5.34	37.70	--------	--------
M–5	--------	.73	.07	--------	1.32	43.80	--------	--------
M–6	--------	.87	.07	--------	.04	45.30	--------	--------
M–7	--------	.68	.82	--------	2.07	44.60	--------	--------
M–8	--------	.68	.12	--------	23.60	15.88	--------	--------
M–9	--------	.87	.13	--------	1.55	44.02	--------	--------
M–10	--------	.85	.20	--------	.06	45.61	--------	--------
M–11	--------	.95	.25	--------	2.64	43.50	--------	--------
M–12	--------	.97	.23	--------	12.05	36.50	--------	--------
M–13	--------	.82	.08	--------	.12	45.32	--------	--------
M–14	--------	1.04	.36	--------	.11	41.30	--------	--------
M–16	--------	1.02	.18	--------	.29	45.60	--------	--------
M–17	--------	1.27	.43	--------	.49	43.00	--------	--------
M–18	--------	1.53	.67	--------	.21	45.58	--------	--------
M–19	--------	.82	.18	--------	.54	43.20	--------	--------
M–20	--------	.90	.20	--------	.77	42.70	--------	--------
M–21	--------	1.12	.48	--------	.49	42.30	--------	--------

[1] Insoluble represents SiO_2.
[2] Magnesia obtained by difference, unless marked with asterisk.
[3] Ignition loss represents CO_2.
[4] Totals shown only where magnesia was analyzed directly.
[5] Highly silicified mixture of magnesite and dolomite.

E–1—Medium-grained magnesite, weathered buff.
E–2—Medium-grained friable white magnesite.
E–3—Medium-grained white magnesite.
E–4—Moderately fine grained light-pink dolomite.
E–5—Coarse-grained white dolomite.
E–6—Medium-grained white magnesite with vein of red magnesite.
E–7—Fine- to medium-grained white magnesite.
E–8—Medium-grained friable white magnesite.
E–9—Medium-grained white with buff cast, friable magnesite; silicified.
E–10—Coarse-grained white dolomite.
E–11—Medium-grained white dolomite.
E–12—Medium-grained white magnesite; some talc scraps.
E–13—Highly silicified mixture of magnesite and dolomite.

NOTE.—Sample descriptions of Magnesita S. A. prospecting are not available.

COITÉ AND CORDEIRO

The Coité deposit, in the southwest part of the range, consists of two outcrop areas in the Corrego do Coité (Coité Creek), and the Cordeiro deposit consists of two outcrop areas on the north side of the Corrego do Cordeiro (Cordeiro Creek). The occurrences may be part of the same magnesite lens and so are described together.

The northernmost outcrop area is on the east side of Cabeceiras ridge, in gullies branching from an intermittent and south-flowing tributary of the Corrego do Coité. (See pl. 12.) The area is grass-covered and has from 2 to 4 meters of overburden. Outcrops extend for a length of 180 meters along an access road to a highly gullied area at the north end where exposures have a width of 60 meters. The vertical extent of outcroppings is about 40 meters. The magnesite is light-colored and has fine- to medium-grained saccharoidal texture. It has low lime, iron, and alumina content, but silica content locally is high near talc veins; elsewhere silica content is low and is due to minor amounts of talc scraps and blebs in the rock. (See table 12, analysis H–9.) The only other rock exposed in the area is dolomite cropping out in the bed of the tributary stream; test pits on the crest of the ridge all contain talc float. (See p. 142.)

The second outcrop area is in the bed of the Corrego do Coité, where the stream cuts across the south end of Cabeceiras ridge. (See pl. 18.) At this point the Corrego do Coité has a substantial flow of 10 to 12 liters per second. The valley is moderately steep-walled and has a heavy growth of tropical trees and brush. Outcrops are confined to the stream bed, although test pits of Magnesita S. A., cutting through overburden up to 5 meters thick, furnish a few additional exposures.

Dolomite crops out both east and west of the magnesite. Talc and quartz veins dip steeply and trend nearly north-south; this attitude may indicate that the long axis of the magnesite lens is oriented in the same direction. The exposures, 108 meters long, then represent the width of the deposit. The width of exposures, about 15 meters, has been extended by test pits to 60 meters.

The magnesite is fine- to medium-grained, has saccharoidal texture and is light-colored except for one small area containing disseminated hematite. (See pl. 18, sample locality H–4, and table 12.) Lime, iron oxide, and alumina content is low but silica, occurring as talc and quartz veins, generally is high in all but the western exposures. The general silica content is indicated by the analysis of sample H–3 (table 12); other samples collected were of magnesite only.

Reserves of the deposit may be estimated from the western 35 meters of the outcroppings in the south deposit and the areas low in talc in the north outcrop area. The northern area is more promising because it has thinner overburden, no timber, and apparently larger amounts of low-talc magnesite. The southern area, with heavy overburden, timber, and a base level determined by the streamflow, would be difficult to develop.

Southward, over the divide into the drainage of the Corrego do Cordeiro, two areas of magnesite are exposed in gullies of the stream's tributaries, in prospector's pits, and in Magnesita S. A. test pits. Magnesite is flanked on the west by gneiss and on the east by dolomite. The area has little water, is grass-covered except along streams, and is covered by 1 to 3 meters of lateritic soil. Slopes are comparatively gentle except in steep-walled gullies.

TABLE 12.—*Analyses of magnesite and dolomite, Coité deposit, Serra das Éguas, Brumado, Bahia, Brazil*

[Analyses by the chemical laboratory, Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil. Specimens H-1 to H-9 inclusive analyzed by Esther Vaccani Levy, analysis no. 7504, reported April 30. 1946]

Sample no.[1]	Insoluble [2]	Fe_2O_3	Al_2O_3 $+TiO_2$	MnO	CaO	MgO [3]	Ignition loss [4]	Total [5]
H-1	2.19	0.72	0.02	0.04	0.19	46.30	50.54	----------
H-2	3.91	.51	.16	.04	.05	46.54	48.79	----------
H-3	9.80	.60	.37	.04	.06	45.10	44.03	----------
H-4	1.16	1.26	.44	.09	.16	46.80	50.09	----------
H-5 [6]	3.44	1.26	.77	.27	29.20	21.39*	44.45	100.78
H-6	.30	.61	.32	.04	2.05	44.86	51.82	----------
H-7	.08	.52	.21	.04	.48	46.77	51.90	----------
H-8	.13	.49	.37	.04	.34	47.03	51.60	----------
H-9	.03	.67	.01	.01	.10	47.98*	51.81	100.61

[1] Samples H-1 to H-5 inclusive correspond to sample localities as shown on plate 18. Samples H-6 to H-9 inclusive are from north deposit.
[2] Insoluble represents SiO_2.
[3] Magnesia obtained by difference, unless marked with asterisk.
[4] Ignition loss represents CO_2.
[5] Totals shown only where magnesia was analyzed directly.
[6] Analysis of dolomite.

NOTE.—Samples H-1 to H-4, inclusive are medium-grained white magnesite containing talc. Sample H-5 is fine-grained white dolomite containing tremolite. Samples H-6 to H-9 inclusive are medium-grained white magnesite.

TABLE 13.—*Analyses of magnesite and dolomite, Cordeiro deposit, Serra das Éguas, Brumado, Bahia, Brazil*

[Analyses by the chemical laboratory, Departamento Nacional da Produção Mineral, Rio de Janeiro, Brazil. Specimens J-1 to J-6 inclusive analyzed by Aida Espinola, reported October 29, 1946. Specimen J-3, analysis no. 7668; others, analysis no. 7643]

Sample no.	Insoluble [1]	Fe_2O_3	Al_2O_3 $+TiO_2$	MnO	CaO	MgO [2]	Ignition loss [3]
J-1	3.6	2.4	1.1	0.02	0.2	44.9	47.8
J-2	8.3	1.4	.1	.05	1.5	42.3	46.4
J-3 [4]	.7	1.4	.6	.05	26.1	24.9	46.8
J-4	1.0	1.1	.3	.05	.4	46.2	51.0
J-5	3.1	1.6	tr.	.1	.1	45.3	49.8
J-6	.6	2.5	tr.	.1	tr.	45.7	51.1

[1] Insoluble represents SiO_2.
[2] Magnesia obtained by difference.
[3] Ignition loss represents CO_2.
[4] Dolomite containing bladed magnesite crystals.

NOTE.—Samples J-1, J-2, and J-4 to J-6 are medium-grained white magnesite containing variable amounts of talc. Sample J-3 is dolomite containing bladed aggregates of magnesite.

Magnesite here has the same physical properties as at Coité and contains but little lime, moderately low iron, and low alumina. Talc and quartz veins are common and from present limited exposures little material of the required chemical purity is visible. (See table 13.)

The northern area of exposures is 375 meters long and as much as 175 meters wide; the southern area is 250 by 125 meters. The two have an areal extent of 10 hectares but magnesite is exposed in less than 25 localities. Until exploratory trenches uncover larger areas of silica-free material the reserve can only be listed as an arbitrary 1,000 tons as based on several small exposures of good material.

According to a map made by Magnesita S. A., magnesite also crops out in deep gullies south and tributary to the Corrego do Cordeiro, about 600 meters south-southeast of the area above described. These were not investigated or sampled in this investigation.

OTHER OCCURRENCES

Magnesite was seen in a few isolated outcrops in the Pedra Preta valley several hundred meters west of the Pedra Preta deposit. A piece of float collected east of the Pedra Preta ridge proved on analysis to be magnesite. (See table 14, sample AE–1). None of these are known over large enough areas to determine whether they are potentially minable.

TABLE 14.—*Analyses of magnesite and dolomite, other localities, Serra das Éguas, Brumado, Bahia, Brazil*

[Analyses by the chemical laboratory, Departamento Nacional da Produçáo Mineral, Rio de Janeiro, Brazil. Specimens PR-1 to PR-9 inclusive analyzed by Aida Espinola, analysis no. 7668, reported Nov. 19, 1946. Specimens AE-1, N-1, and N-2 analyzed by Esther Vaccani Levy, analysis no. 7646, reported Oct. 30, 1946. Specimen N-3, analyzed by Esther Vaccani Levy, analysis no. 7647, reported Oct. 30, 1946]

Sample no.	Insoluble[1]	Fe_2O_3	Al_2O_3 $+TiO_2$	MnO	CaO	MgO	Ignition loss[2]	Total
PR-1[3]	1.0	1.1	0.3	0.1	29.3	21.3	46.3	99.4
PR-2	1.3	.4	.3	.1	29.7	21.5	46.2	99.6
PR-3	2.0	.6	.2	.4	29.4	21.7	45.4	99.7
PR-4	.9	.6	.2	.4	30.1	21.7	45.8	99.7
PR-5	14.1	7.8	1.7	.05	28.2	11.6	35.0	99.8
PR-6	.7	1.4	.1	.2	24.4	25.6	47.0	99.4
PR-7	13.7	.6	.3	.2	28.0	20.3	36.5	99.6
PR-8	.6	.6	--------	.3	30.7	20.9	46.1	99.2
PR-9	3.1	1.1	.2	.4	28.9	21.2	44.4	99.3
AE-1[4]	2.52	.61	.38	tr.	tr.	46.86	50.06	100.43
N-1[5]	1.43	5.15	.55	.12	6.82	38.51	47.44	100.02
N-2	2.76	2.56	.45	.02	tr.	45.60	48.87	100.26
N-3	.89	.82	.39	.03	29.34	21.59	46.54	99.60

[1] Insoluble represents SiO_2.

[2] Ignition loss represents CO_2.

[3] Specimens from the Pedra Rolada area.

[4] Specimens from the east front of the Serra das Éguas, near the Pedra Preta deposit. Collected by Magnesita S. A.

[5] Specimens from the Noroeste deposit.

NOTE.—Samples PR-1 to PR-9 inclusive and N-3 are dolomite. Sample AE-1 is medium-grained saccharoidal white magnesite. Sample N-1 is medium-grained red magnesite and sample N-2 is medium-grained white magnesite.

In the course of prospecting and claiming concessions several dolomite areas were sampled. Magnesita S. A. sampled and analyzed 14 localities in an area 160 meters long and 120 meters wide lying about 600 meters north of the Cabeceiras deposit. The area, named the Tiú, proved to be completely lacking in magnesite.

Another zone, sampled both by Magnesita S. A. and G. W. Soares, is the Pedra Rolada area. This is 1.5 kilometers north of Pedra Preta and on top of a steep scarp. The scarp is formed by a highly siliceous zone in dolomite, consisting of steeply dipping quartz and tremolite veins and lenses which provide as much as 50 percent of the bulk of the rock. On the hills north and west of the scarp dolomite outcrops are common and there contain less silica. The writer collected nine samples from the area and found that in only one was the magnesia content slightly above that of pure dolomite. (See table 14.)

ECONOMIC CONSIDERATIONS

DEVELOPMENT OF THE DEPOSITS

The deposits may be classified in three groups, based on the relative proportion of material of commercial chemical grade to the total magnesite in the deposit:

Group	*Deposits*
A. All or most of known area consisting of minable grade.	Pedra Preta, Catiboaba, Fabrica.
B. Parts of known area consisting of minable grade.	Pirajá, Cabeceiras, Coité.
C. Few or no parts of known area consisting of minable grade.	Bate-Pé, Noroeste, Gravatá, Cordeiro.

In mining magnesite the attempt is made to select blocks with comparatively uniform chemical composition so that the mined product is uniform. This is achieved by sampling in such detail that the samples can be considered as representative of the composition of the prospective ore block. Good mining practice is to sample both the surface with a grid of pits and the subsurface by drilling so that the vertical as well as the horizontal range in composition can be known. In 1945, company sampling and the sampling done for this report were only of general nature needed to determine the general extent and grade of entire deposits; necessary sampling of potential ore blocks had not been started.

From the standpoint of development, the deposits in Group A require a minimum of exploration and sampling. Inasmuch as the largest parts of these deposits have a chemical composition pure enough to satisfy commercial requirements, ore blocks do not have to be delineated and sampling need be done only to select ore blocks consisting of the most uniform material. The central part of the Pedra Preta deposit requires a minimum of stripping to prepare the ground for surface mining operations but the other deposits of this group, Catiboaba and Fabrica, require considerably more preparation of this type.

The deposits in Group B have comparatively limited areas containing magnesite of commercial grade and require more development work than the deposits in Group A. The blocks containing good magnesite must be outlined by sampling and chemical analysis; this work should precede the detailed sampling of the blocks themselves. The deposits of this group are mantled by soil over most of their areas and potential ore blocks will require much stripping of overburden. The best method of surface exploration would be to cut trenches beyond areas of outcrop; these trenches should cross the strike of silica and silicate mineral veins. They would permit channel sampling of both the margins and interiors of the blocks and would afford determinations of the thickness of overburden.

The deposits in Group C contain little magnesite of commercial grade and, considering the tonnages available in other deposits, do not merit exploration at present. Of those blocks that are low in silica, several have chemical composition which might be minable for material of special grade. Should there be a demand for special material, such as high-magnesia material at Bate-Pé or low-alumina material at Cordeiro; then exploration should follow procedures as outlined for deposits in Group B.

In the above appraisal the assumption is made that magnesite will not be beneficiated. Metallurgical plants have been designed to separate dolomite and other impurities from magnesite and, conceivably, plants of this type would permit extraction of much magnesite here considered to be of inferior chemical grade. In view of the large tonnages of minable grade now available such plants would not be required for some time.

From the standpoint of reserves of minable magnesite, Pedra Preta, Catiboaba, Fabrica, Cabeceiras, and Pirajá are the only deposits worth considering at present. The north outcrop of the Coité deposit likewise may be minable and talc could be recovered from the same area.

Two other factors having a bearing on the relative value of the deposits are local transportation costs and water supply. Installations undoubtedly will be on the east side of the range and kilns already have been erected at Catiboaba station and at the Pedra Preta deposit. This automatically makes the deposits on the east side of the range cheaper to operate and gives the southern deposits of the western group an advantage in operation over the northern deposits of that group. Even installation of the kilns at Pedra Preta, for example, will benefit the northwestern deposits but little, because ore would have to be hauled uphill to cross the range. Regarding water, a commodity essential to mechanized mining, all the better deposits except Fabrica and Cabeceiras have adequate amounts.

OTHER FACTORS

With abundant magnesite, these deposits fall into the classification of "ore-exploitation prospects whose successful operation will be dependent on operating and transportation costs" (McKinstry, 1949, p. 440). The large tonnages will permit large-scale, and therefore low-cost, operations in extracting magnesite. Transportation therefore is the critical factor. The management of Magnesita S. A. is certain that the 1,000-kilometer freight haul to Belo Horizonte will not be too expensive to permit mining for the local market; and since initiation of a national steel industry, a moderately large tonnage could be consumed in refractories for basic hearths. Data are not available for estimating the costs of the 600-kilometer rail haul to Salvador and costs of ocean freight to world markets.

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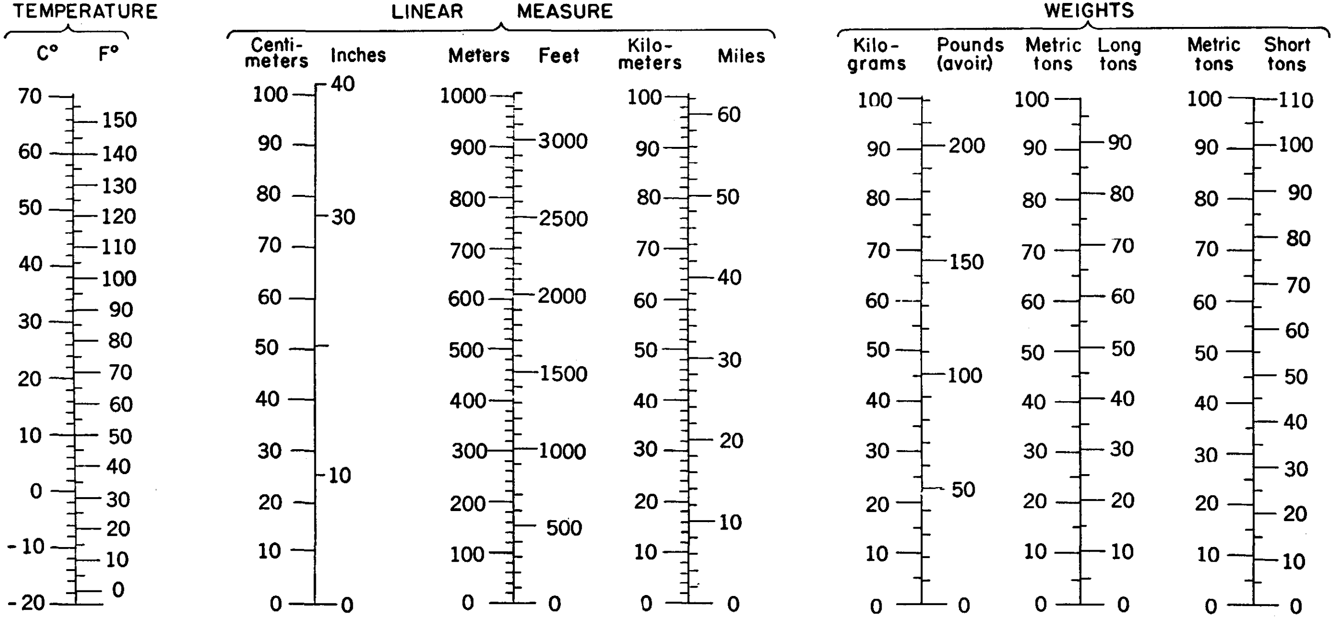
METRIC EQUIVALENTS



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

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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