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By JOHN VAN N. DORR II, CHARLES F. PARK, JR., *and* GLYCON DE PAIVA

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MANGANESE DEPOSITS OF THE SERRA DO NAVIO DISTRICT, TERRITORY OF AMAPÁ, BRAZIL

By John Van N. Dorr II, Charles F. Park, Jr., and Glycon de Paiva

ABSTRACT

In 1941 an impressive outcrop of manganese oxide was discovered in the tropical rain forest on the banks of the Amapari River, Federal Territory of Amapá, Brazil, at about latitude 1°02′ N., longitude 52°02′ W. Since then some 28 separate deposits of manganese oxide have been found in an area 7 kilometers long and 1 kilometer wide, known now as the Serra do Navio district. Other deposits probably remain undiscovered.

Soil hides the country rock, but isolated exposures of quartzite, amphibolite, schists, and gondite suggest that the ore probably occurs in a series of metasedimentary rocks, perhaps equivalent to the pre-Cambrian Minas series of central Brazil. Details of structure are obscure; the general trend of the rocks is N. 30° W., and they seem to dip to the north and east at angles ranging from 30° to nearly vertical.

Although the ore is probably derived from manganese silicate-carbonate-sulfide(?) rock by weathering processes, the only protore mineral now visible is spessartite, the manganiferous garnet, which is found predominantly on the footwall of the ore bodies.

Ore occurs as outcrops, bouldercrops (a term defined in the text), rolamentos (talus), and granzon (pellets). Many outcrops are impressive, rising in sheer scarps of high-grade ore to heights up to 20 meters. They range in length from a few meters to over 250 meters.

The grade of the ore on the outcrop is high, averaging about 50 percent manganese. The arsenic content of the ore ranges from 0.04 to 0.25 percent. Behavior of grade with depth is unknown—one outcrop has been penetrated to depths of 10 meters and 18 meters in two holes, each showing over 50 percent manganese at those depths.

Tonnage that can be calculated at the present stage of exploration was classed as visible (depth, 1 meter to 5 meters, depending on outcrop height), probable (10 meters under the visible ore), and possible (15 meters under the probable). In these categories are: visible, 585,000 tons; probable, 2,700,000 tons; and possible, 4,000,000 tons. The grade of the visible ore should average about 50 percent manganese; that of the other two categories will be somewhat lower. Tonnage of talus and granzon was not calculated but is at least half a million tons, undoubtedly somewhat lower in grade than the outcrop ore.

During late Tertiary or Pleistocene time the region was tilted, and the area north of the Amazon was raised some 90 centimeters per kilometer for at least 120 kilometers north of the city of Macapá. This caused the streams to become entrenched and indicates that sufficient time may not have elapsed for oxidation to reach to great depths.

Transportation of the ore from the Serra do Navio district to the Amazon, a distance of about 240 kilometers, will be difficult unless a railroad is built, as the Amapari River is navigable for barges only 8 months in the year and trucking of heavy tonnage is not practical on the existing road. Port facilities on the Amazon will have to be constructed, but an excellent site is available.

INTRODUCTION

The manganese deposits of the Serra do Navio, Territory of Amapá, Brazil, are approximately at latitude 1°02′ N., longitude 52°02′ W., or some 500 kilometers northwest of the city of Belem do Pará, the largest city in the region and the center of communication.

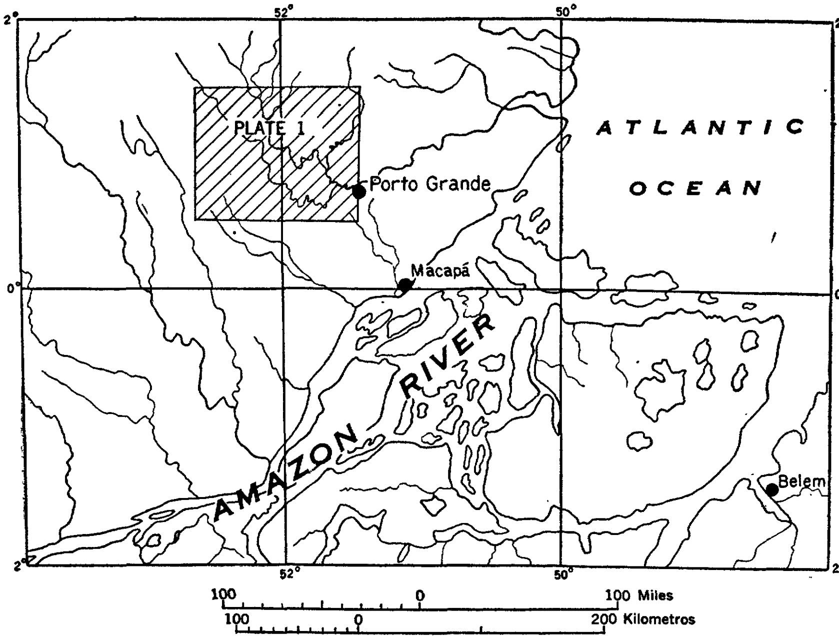

FIGURE 1.—Index map showing the location of the Serra do Navio district.

The deposits are reached by scheduled plane from Belem to Macapá, capital of the Territory of Amapá; thence by road from Macapá to Porto Grande on the Araguari River, 120 kilometers north of Macapá; thence by small boat or canoe on the Araguari and Amapari Rivers for a distance of about 120 kilometers. The trip takes about an hour and 20 minutes by plane to Macapá, 3 to 8 hours by car to Porto Grande, and 5 to 16 hours by boat or canoe to the deposits. At normal river level a small hydroplane could land at the deposits with no danger.

Macapá is a rapidly growing town that boasts several small industries, a small tin smelter, an excellent new hospital, schools, and a comfortable hotel. It has about 4,000 inhabitants. Porto Grande is a village of some 30 houses and a school.

The region between Macapá and Porto Grande is savannah country of low relief. From Porto Grande to the junction of the Amapari and Araguari Rivers, a distance of about 20 kilometers, the country is also quite flat but is covered with rain forest. Up the Amapari, the country gradually becomes more rugged, having a maximum relief of perhaps 200 meters in the vicinity of the deposit. The river elevation is reported to be about 81 meters at Porto Grande and 90 meters at the Serra do Navio. The country along the river is heavily forested, but the local woodsmen say that there are grassy canga plateaus in some places.

About 100 kilometers to the south-southeast of the Serra do Navio district are the Santa Maria iron deposits, explored by the Hanna Exploration Co. in 1946 and 1947.

It should be emphasized that this part of Brazil is very incompletely known and that no reliable maps exist except those compiled on a small scale from air photographs of the immediate vicinity of the Amazon River and of a strip along the coast. For example, it is not yet known whether the Amapari River at the deposits is about 15 kilometers west of the Araguari or about 42; local woodsmen do not agree, and the best available map (pl. 1) is unreliable in detail. Names of rivers and streams vary from map to map. For example, Igarapé da Pedra Preta has been known as Igarapé da Cachoeira, causing confusion with the stream of the same name shown on plate 2.

DISCOVERY AND EARLY HISTORY

Manganese was first found in the Navio district in 1941 by Snr. Mario Cruz, a woodsman searching for gold. He did not know what the material was and used a large piece for ballast in his canoe, dumping it on the bank when he reached Porto Grande. When the Hanna Co. began prospecting for iron in the Santa Maria area in 1946, Snr. Cruz brought the material to Capt. Janary Gentil Nunes, Governor of the Territory, thinking it was iron ore. The Governor sent the material to Rio de Janeiro and Belo Horizonte to be analyzed, where it was found to contain over 55 percent manganese. Snr. Cruz then guided the Governor's representatives to the deposit now known as Chumbo. Dr. Fritz Ackermann, the Territorial geologist, verified the importance of the prospect. Thereafter a number of geologists visited the area, among whom were representatives of Industria e Comercio de Minérios, Ltda., the M. A. Hanna Co., the United States Steel Co., and the Union Carbon and Carbide Co.

Rights for exploration and development of the deposits were made subject to competitive bidding between the various interested companies, and the award was made to a Brazilian company, Industria e Comercio de Minérios, Ltda. (hereafter referred to as ICOMI), of Belo Horizonte. ICOMI bought the equipment used by the Hanna Co. in exploring the Santa Maria iron district, enlarged a camp built by the Government, and, by the end of 1948, had started a number of prospect pits and one tunnel. Topographic maps of several deposits near the river were prepared.

FIELD WORK AND ACKNOWLEDGMENTS

The authors did not visit the district together. De Paiva visited the area in company with Dr. Fritz Ackermann and Dr. Viktor Leinz in 1947, spending 10 days in work on the part of the district near the river. At that time the Terezinha area had not been discovered. Dorr visited the area first in June 1948 in company with P. W. Guild of the United States Geological Survey and Dr. Iphygenio Soares Coelho of the Instituto de Technologia Industrial of Minas Gerais, who is in charge of the exploration for that agency. They spent two full days in the district and saw its full extent as then known. Dorr and Park spent 10 days in the district in September 1948, mapping four deposits with plane table and alidade and four more on a topographic base supplied by ICOMI. During this trip a new deposit was found, and the large scarps of manganese ore on either flank of the central spine of the Fritz Ackermann deposit were discovered.

In September 1948 Dr. N. H. Van Doorninck made an examination of the district for William H. Muller & Co., spending 20 days in a study of the deposit.

The investigations summarized herein were greatly aided by the support of the Governor of Amapá, Capt. Janary Gentil Nunes, who is largely responsible for starting the development of the deposits. Not less helpful have been the personnel of the Companhia Industria e Comercio de Minérios, S. A., the concessionaire company. The assistance given by Dr. Augusto Azevedo Antunes, managing director, was invaluable. Dr. Paul Bremer, the manager in Amapá, and Dr. Mario Garcia made the writers' visits comfortable and pleasant. The woodsmen Bacelar and Curuça, who discovered many of the deposits, were of signal assistance. Dr. Fritz Ackermann, Territorial geologist of Amapá, has contributed much to the knowledge of the deposits since their discovery, and his knowledge of the general geology of the Ter-

ritory will prove even more helpful as more detailed studies of the district are made. Thanks are due Dr. Van Doorninck and William H. Muller & Co., who gave the writers permission to use the results of sampling by Dr. Van Doorninck, as well as other data secured by him. A. E. Walker, geologist for the M. A. Hanna Co., kindly secured permission for the writers to use the results of his sampling in the district.

Dr. Evaristo Scorza, of the Departamento Nacional da Produção Mineral, examined thin sections of the rocks collected by De Paiva and was the first to determine the principal ore mineral of the deposits.

Plate 4 was furnished through the courtesy of ICOMI. The topographic base is by Dr. Clemente Santos, of the Instituto de Technologia Industrial of the State of Minas Gerais. It was made by the transit methods in vogue in Brazil, is based on an assumed datum, and has coordinates based on magnetic north. The geology was added by Dorr and Park. No attempt at field revision of the topography was made.

Plate 2, also furnished through the courtesy of ICOMI, was made by transit traverse. Elevations were not carried. No signs of cutting for side shots were seen, and outcrop outlines evidently were sketched from notes. The traverse was not closed.

Valuable criticism by S. G. Lasky, of the United States Geological Survey, has greatly improved this report.

CLIMATE, VEGETATION, AND HEALTH CONDITIONS

The Serra do Navio district is in the equatorial belt, with a climate similar to the rest of the lower Amazon Basin. Rainfall is distributed unevenly throughout the year, the months October through May being the rainy season and June through September the "dry" season. During the rainy season days without rain are infrequent; during the "dry" season days without rain are also infrequent, but rainfall is confined to sharp or gentle local showers that pass in a few minutes rather than the more continuous rains of the wet season.

Temperatures are usually moderately high, and humidity is almost always high. If suitable clothes are worn, the climate is neither uncomfortable nor, according to many doctors, unhealthy. Nights are cool, and a blanket is usually needed before morning.

The warm, moist climate produces, in areas of suitable soil, a typical tropical rain forest, characterized by large trees of diversified species, growing so closely at their crowns that sunlight rarely penetrates to the ground. Many of these trees would be very valuable commercially, were transportation available. Undergrowth is generally not dense except in cut-over areas, although many vines of great size and length interlace the tops of the trees and swing in graceful curves to the ground. Travel overland is not difficult on cut trails. If a good guide is available, slow but steady progress can be made through the forest. Without a guide, it is easy to become lost, as the all-enveloping forest, composed of huge trees, prevents any view of the surrounding country and, often, even of the sun. The prevailing shade makes the forest a cool and pleasant place to work, even on sunny days.

Second growth springs up rapidly in cut-over areas; according to an Indian who is farming a small clearing along the Amapari, it is difficult after 10 years to find an area that has been cut over and abandoned.

The soil in the rain forest is devoid of grass and nearly devoid of other low vegetation. It is covered by a mantle of dead leaves, vines, and trees from the forest above. This abundant mantle of decaying vegetation, in combination with the high average temperature and abundant but intermittent rainfall, accelerates natural weathering of the bedrock to a rate far greater than is encountered in dryer and more temperate zones. This weathering is undoubtedly different in character as well.

Health conditions in the area seem good to the casual traveler. Although malaria of the malignant variety is present, natural conditions in the Navio district are such that it could easily be eliminated if the effort were made, for there are no large natural breeding grounds for the mosquitoes. Generally speaking, the people of Amapá seemed well fed, strong, and healthy. The region is still virgin, and if efforts to maintain high standards of sanitation and preventive medicine were made, endemic tropical diseases could easily be kept out.

REGIONAL GEOLOGY

The regional geology of the Territory of Amapá is little known. The area visited is one of the least explored and most sparsely populated parts of Brazil. The lack of base maps precludes thorough geological work and makes difficult even superficial reconnaissance. Added to this are the difficulties caused by ubiquitous and usually deep soil, thoroughly weathered and leached and in turn covered by thick rain forest. Both soil and forest effectively mask the bedrock. For 8 months of the year the rivers are bank full; only at low water can more than a few scattered outcrops be seen in them.

PHYSIOGRAPHY

The major physiographic elements bearing on the ore deposits are the recent rejuvenation of the drainage and the fact that many of the deposits seem to be closely related to an ancient surface of low relief, now being dissected. Because the region is so little known geologically, a more detailed discussion will be made of physiography than would be found in the usual economic report.

A slightly dissected plain, underlain by river sediments usually attributed to late Tertiary or Quaternary time, lies between Macapá and Porto Grande. This plain is at an elevation of about 3 meters at Macapá and about 90 to 95 meters near Porto Grande, where the river sediments overlap gneiss. The river beds have been lateritized and, at a depth of 1 meter to 3 meters below the old surface, a zone of ferruginous and aluminous nodules occurs. This zone is present from Macapá nearly to Porto Grande and is older than the present topography, for the shallow valleys cut through it. The gentle rise in elevation of this nodular horizon indicates a tilting of the surface amounting to a net uplift of about 90 centimeters per kilometer to the north. Nothing is known as to relative uplift in the east-west quadrant; the general trend of the drainage and structure indicates that the direction of greatest uplift may have been more to the northwest than to the north.

As a result of this upwarping, consequent drainage to the southward has been established in this part of the Territory. The Matapi River, debouching into the Amazon about 12 kilometers to the west of Macapá, heads a short distance west of Porto Grande. The elevation of its headwaters is so close to that of the Araguari that proposals have been made to divert water from the Araguari into the Matapi by tunnels and canals for power and navigation purposes. Eventually the Matapi, cutting its channel in barely consolidated sediments, will behead the far more powerful Araguari, which is floored by very resistant gneiss at Porto Grande.

About 15 to 25 kilometers down the Araguari from Porto Grande the river leaps over large falls, said to be very spectacular. Upstream from these falls the Araguari-Amapari system is actively entrenching itself in steep-walled valleys with practically no flood plain and numerous entrenched meanders (pl. 1). This rejuvenation and the resultant incision of the major drainage complicates possible railroad and highway construction along the major rivers. With the exception of the Amapari from Porto Grande to a point just above the Navio district, rapids and small falls prevent river transportation except in small boats and canoes (pl. 1).

In the Serra do Navio district, the only part of the drainage basin of the Amapari-Araguari system seen in detail, there appears to exist an ancient erosion surface of low relief now being destroyed by the rejuvenated Amapari and its tributaries. A general concordance in elevation of the flat-topped ridges and plateaus over an area of tens of square kilometers suggests that a peneplain must have been present in this region before regional tilting initiated a new erosion cycle. The possible effect of this physiographic history upon the development of the ore bodies is discussed on page 20.

ROCK TYPES AND DISTRIBUTION

The river deposits of supposed Tertiary or Quaternary age between Macapá and Porto Grande have been mentioned. These are predominantly clay and silt. It is not known what rocks are hidden below these beds, but judging from information developed by the search for oil in the lower Amazon Basin, it is not improbable that at least part of the Paleozoic section that crops out upriver and underlies Marajo Island may be hidden.

At Porto Grande the river beds overlap a coarse phacoidal gneiss very similar to the famous gneiss of Rio de Janeiro. Abundant outcrops are present in and near the Araguari River at Porto Grande, but a few kilometers upstream outcrops end (with a few exceptions at extreme low water) for some tens of kilometers. Above the Rio Cupixi, a tributary of the Amapari (pl. 1), small reefs appear at low water in the river at wide intervals. These were not observed in detail but appeared to be bedded and foliated rocks, including quartzite and quartz amphibole schist.

Outcrops in the Amapari River are more abundant in the Serra do Navio district. A few specimens were obtained from the exposures near the mining camp, and thin sections were made of these materials. Most of the rocks are strongly foliated metasediments. Two types are distinguished. One type consists of granular quartz, epidote, muscovite, calcite, garnet, and small amounts of opaque minerals, an unidentified mineral (possibly cordierite), and tremolite. This rock is thought to have been derived from an impure calcareous quartzite. Similar rock was found in the stream bed at the Cachoeira deposit (pl. 2). The other type is an amphibole schist or gneiss. It consists largely of dark-green amphibole, intermediate plagioclase, quartz, a little carbonate, and lesser amounts of apatite and titanite. This material also is thought to be a metamorphosed product of calcareous sediment, possibly resulting from regional metamorphism but also suggesting igneous metamorphism. Several samples of similar "amphibolite" were obtained from the stream valley near the Antunes deposit (pl. 2). All the rocks are slightly stained with limonite.

One interesting and unusual rock crops out in the river bed just above the camp. It consists mainly of green to greenish-blue hornblende and unaltered analcite. The cores of many of the analcite crystals show tiny spots of albite. Apatite as opaque inclusions is abundant. The rock is probably a dike rock. In the specimen collected the analcite, a mineral that is readily altered, is entirely fresh, probably because of the scouring away of altered material by the river waters. Nevertheless, the presence at the surface of this material indicates that the rock probably formed in comparatively recent geologic times and is more likely of Tertiary age than pre-Cambrian.

Several kilometers above the Serra do Navio district, in the rapids known as Castanhal or Veado, the river flows over what appears to be a highly contorted injection gneiss (with dips and strikes in all directions), as well as a coarse granitic rock that contains partly digested fragments of hornblendite and other basic rocks. The granitic rock is in part strongly foliated and may be a border phase of a larger mass. Detailed mapping is needed to decipher the structures and rock relations at this locality.

That various intrusive rocks are hidden beneath the soils and rivers of the region is indicated by the numerous small cassiterite, tantalite, and gold placer workings on tributaries of the Amapari and Araguari Rivers. Plate 1 shows the location of these workings as compiled by Ackermann. Ilmenite placers have been reported a short distance northwest of the Navio district. Because of the almost complete lack of flood plains or alluvial deposits, the presence of large tonnages of placer material is hardly to be expected. The small placers have been very rich.

Canga is a limonite-cemented conglomerate or soil that is a common result of the weathering of iron-rich rocks (usually of the Minas series) in Brazil. It is an important ore for charcoal furnaces and contains from 30 to 60 percent iron. It forms a shield over large areas, protecting them from erosion.

Woodsmen report that back from the Amapari River a few grassy canga-covered plateaus are found. Two kilometers or so downstream from the Navio camp, at a place where a guest house is being built, outcrops of canga 10 meters or more wide occur on the river bank and in the steep hillside above. Dr. Djalma Guimaraes[1] reports that fragments of hematite have been found in thin sections of some of the rocks from the Navio district. Moreover, a line of canga boulders exists near one of the major manganese deposits in the Navio district.

This sketchy information might indicate that the rocks of the Navio district are related to those of the Santa Maria iron district some hundred kilometers to the south-southeast, which have been correlated on a lithologic basis with the Minas series of central Brazil. Ackermann[2] writes in this connection:

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[1] Personal communication.
[2] Personal communication (translation by Dorr).

I have the impression that we have a strip of terrain underlain by the Minas series running parallel to the Amazon River and following the turn to the north that the river makes at its mouth. This strip crosses the Vila Nova River at Santa Maria (hematite) and bends to the north, crossing the Araguari a short distance above Porto Grande, near the confluence of the Amapari. Thence it follows more or less a northwest-by-north direction, and I think it will reach the headwaters of the Jari River and the Serra de Tumac-Humac, to reappear in British Guiana. I don't know that this is the case, but judging by what I have seen, it appears to be.

If Ackermann is correct, there is of course no reason why iron deposits may not exist in the unexplored regions on both banks of the Amapari and Araguari Rivers.

GEOLOGY OF THE ORE DEPOSITS

The manganese deposits of the Serra do Navio district, as now known, are in belts about 7 kilometers long on both banks of the Amapari River (pl. 2). Within these belts are some 28 deposits that now appear to be separate; development will probably show that, of these, some are connected and others, which now appear to be one, are actually two or more individual lenses.

Toponymy of the deposits is chaotic, because of varying conceptions of the size of the individual deposits. For the purposes of this report the district will be divided into three areas: Clemente, Chumbo, and Terezinha. The extent of these areas and the names used for the individual deposits within these areas are shown on plate 2.

COUNTRY ROCK

Exposures are so poor that no idea of the stratigraphic section in the district can be obtained. The following information is a summary of data collected from small scattered outcrops in the district.

The rock enclosing the manganese deposits could be seen at the time the latest field work was done only in an adit at the base of the Chumbo deposit. In September 1948 this was perhaps 5 meters deep in a rotten gray schist with brown bands. The schist is too weathered to be identified definitely; it is probably an amphibole-mica schist. The portal of the adit is 15 meters from the footwall of the ore. In the schist can be seen several small lenses of manganiferous material composed largely of garnet and manganese oxide. The largest lens measures 1.5 meters by 1 meter in size.

In the bed of the river, a reef of dark quartzite crops out perhaps 40 meters above the projected horizon of the Chumbo outcrop. Scorza states that under the microscope this rock is seen to contain augite and amphibole resulting from the metamorphism of sandy dolomitic limestone. (See appendix, specimen D.) Pyrite and iron oxide also are present, as well as calcite grains between the augite crystals. Just above the swimming dock at the main camp (several hundred meters below the Chumbo deposit), a small reef of amphibolite schist is exposed at low water. Other reefs of amphibolite schist and quartzite occur in the river below the camp. The amphibole crystals were tested by Scorza and found to contain less than 1 percent manganese.

In the stream below the Antunes deposit (pl. 2), Igarapé da Media, are abundant pebbles of amphibolite schist, undoubtedly coming from the hanging-wall rocks.

The amphibolites and hornblende schists are interpreted by Scorza as being metasedimentary rocks, derived from calcic and magnesian sediments that had undergone regional metamorphism. Arsenopyrite was identified in one specimen of hornblende schist.

Fine buff sandstone, apparently unmetamorphosed, was found in the center of a cobble of manganese oxide near the Clemente II deposit by Van Doorninck.[3] No outcrops of this material are known to the writers. The cobble, which was found in a stream bed, may have been transported some distance or may have formed in place by contemporary deposition of manganese oxide (p. 14).

A coarse, angular white quartz sand cemented by manganese oxide is found in small quantities on the main Chumbo outcrop.

The stream beds in the area contain cobbles and pebbles of vein quartz. The source of these has not been located. It is reported that, in the stream that rises near Curuça and swings southeast around the Sentinella deposit before flowing west to join the Amapari River, placer gold is present below but not above the Sentinella deposit.

In summary, not enough of the country rock is now exposed to enable one to construct a stratigraphic section, or to clarify the relations between, the manganiferous rocks and the country rocks. The soil is generally a yellow clay that, as far as determined, does not indicate the character of the bedrock.

OCCURRENCE AND DISTRIBUTION OF THE MANGANIFEROUS ROCKS

The manganiferous rocks of the Navio district occur in patches of outcrops and boulders in a roughly linear pattern trending generally northwest by west. The deposits, with a few exceptions, are on or near the tops of long ridges. In the Clemente and Chumbo areas these are broad and gently rounded and have steep sides, but in the Terezinha area the ridges are generally long and narrow and the deposits occur on the river side (west) at the break in slope, as at De Paiva and Gruta, or forming the very crest, as at Fritz Ackermann.

[3] Personal communication.

Manganese oxide occurs (1) in outcrops, (2) as boulders not far removed from the site of formation, (3) as rolamentos (boulders that have rolled down steep slopes from outcrops above), (4) as granzon (concretionary nodules in the soil), (5) as nodules or lenticules in the footwall schist, (6) as cementing material in alluvial (?) sand, (7) as interstitial material in clayey(?) concretions or replacements of garnet by clay(?) and gibbsite, and (8) replacing sandstone in boulders. Manganese oxide is being deposited at the present time in at least one stream bed. Manganese silicates are found in outcrops, boulders, and rolamentos and as nodules in the footwall schist.

Of these modes of occurrence, only the first four are of economic interest at this time. It is often impossible to distinguish clearly between outcrops and boulders, for many outcrops are concealed by soil and rotting vegetation and many boulders weigh several tens of tons and are of such dimensions that, without exploratory work, one cannot be sure that the rock is not actually in place.

Outcrops.—Outcrops of manganese oxide vary from a few meters in width to the magnificent central spine—230 meters long—of the Fritz Ackermann deposit, flanked on both sides by other outcrops with scarps over 20 meters high. Usually the outcrops have a scarp of at least a meter (often 2 or 3 meters) along the river side of the outcrop, rarely on both sides, and can be followed through the forest as low, dark-gray to black walls. When the scarps are more than 2 or 3 meters high, they become much more rugged and are sometimes masked by rolamentos and boulders. Bedding and other sedimentary and metamorphic structures have been completely destroyed in the outcrops, and only a faint planar structure is sometimes observable. This is thought to be related, not to primary rock structures, but rather to topography at the time of formation of the oxide outcrops.

An interesting feature of many outcrops, more particularly those in the Terezinha area, is the presence in the ore of many circular chimneys up to 70 centimeters in diameter and as much as 2 meters deep. Usually these are on the edge of the outcrop and have one side open for 45° to 180°. The chimneys have horizontal flutings 1.5 to 4 centimeters apart and, at first glance, look like pot holes. The difficulty of explaining the presence of pot holes on top of a ridge with 100 meters of relief is evident. Furthermore, none of the rounded stones that are generally within pot holes were found. The origin of these chimneys is explained by reference to present climatic conditions. When vegetation accumulates in a low spot on the outcrop, it lies in a pool of rain water that is replenished regularly. Organic acids that dissolve small quantities of ore are released as the vegetation decays. During the heavy rains, the water with manganese in solution is washed out. This process, repeated for long periods, seems to be a reasonable explanation of the chimneys. All phases of the process can now be observed. The rapidity with which the chimneys are excavated cannot exceed the rate of the development of relief between outcrop and adjoining soil, for, without periodic release of the trapped water, the solutions would become saturated and would not be effective. According to this hypothesis, the flutings represent a record of fluctuations in potency of solutions caused by outlet conditions. The Terezinha outcrops, in general, have more relief than those in the other areas, hence the greater prevalence of the chimneys there. As will be seen, these chimneys are of importance in the formation of one kind of bouldercrop deposit.

Boulders.—Outcrops sometimes merge into boulder deposits and in places are covered by boulders of ore. More important, there are some deposits whose surface expression consists only of boulders. In attempting to evaluate the district before exploration has opened such deposits, it is necessary to examine possible modes of origin of boulder deposits. In this examination, boulders that have clearly accumulated as talus below existing outcrops will be ignored here, as they offer no problem, and will be discussed as rolamentos.

Several possible modes of origin exist for the boulder deposits, all of which probably have contributed to greater or lesser degree.

1. The presence of manganiferous nodules in the footwall schist has been mentioned. As the schist eroded, these nodules would accumulate on the surface, the silicate in them would gradually oxidize, and a boulder deposit—underlain by very lean rock—would result. Several boulders on the edge of the Chumbo area contain manganiferous garnet, and it seems probable that this process has contributed to the formation of some boulder deposits.

2. If, as will be discussed, the rich manganese oxide bodies are lenticular or tabular in shape, it is probable that the erosion of the wall rock around such lenses would leave a high outcrop. This in turn would break down as erosion removed the footwall schists, leaving a scattered mass of rich boulders, almost as resistant to erosion as the original outcrop, on top of barren rock.

3. Some outcrops are blocky and tend to form boulders by breaking along joints. Root wedging and solution along joints are important. In such outcrops as Gruta and parts of Fritz Ackermann, it is impossible to tell where outcrop ends and boulders formed by this general process begin. This is an important source of boulders, and boulders so derived will probably be underlain by ore.

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4. On the Fritz Ackermann deposit it is possible to demonstrate the formation of large boulders by coalescing of the chimneys already described. Such boulders are, of course, underlain by good ore.

5. Small boulders form in the soil by concretionary action. These are generally different in aspect from boulders of mechanical origin, being more porous, black, and less pure. They are related to granzon and will be considered under that heading. They may form above ore or above barren rock.

Because all boulders, except those formed by processes 2 and 3, are rounded as formed (even these exceptions rapidly assuming rounded shapes), the effectiveness of the individual processes is difficult to evaluate. Many outcrops grade into masses of large and medium-sized boulders with no clear line of demarcation, and many boulder trains trend across the topography like outcrops indicating the location of the source rock beneath. The term "bouldercrop" will therefore be used in this report to indicate deposits of boulders thought to be near their source and to distinguish them from rolamentos.

Rolamentos.—Areas of manganese oxide boulders are usually found on steep slopes below outcrops. These have been moved by gravity during the weathering of the outcrop and have no genetic relation to the bedrock on which they lie. Bouldercrops and rolamentos may be indistinguishable when the trend is directly downhill, as illustrated on plate 3. In most cases they can be separated, for the structure of the bedrock usually determines the direction of ridges and valleys. Many accumulations of rolamentos will be of economic value.

Granzon.—The soil near the manganiferous horizons of the district contains myriads of small concretions of manganese oxide. Similar material is known as granzon in Cuba, where it is common. The name would be useful in Brazil, where many similar occurrences are known—notably the Saude manganese deposit near Dom Silverio, Minas Gerais.

These granzon deposits overlie or are on the down-slope side of the manganiferous horizons. The manganiferous rocks are attacked by organic acids, and the resulting solutions percolate slowly through the soil where, in a changed environment, the manganese is deposited as concretions.

Granzon consists of moderately soft, black, porous spheroids with, in some cases, dense hard centers or annular spheres within. Some granzon is impure and clayey but much appears fairly pure, and because of the ease of recovery it is economically important. Occasionally the individual pellets become welded together, sometimes into sheets, sometimes into fair-sized boulders. Possibly 50 percent of the soil is made up of this material in some areas, although this proportion is exceptional.

Granzon has been confused with conglomerate and with pebbles in the exploratory work in this district.

Silicate protore.—A rock consisting of manganese oxide and the manganese garnet spessartite crops out at the falls in the Igarapé da Pedra Preta (pl. 4) and at the deposit known as Cachoeira (pl. 2) at the Igarapé da Cachoeira. Leinz,[4] in his excellent paper on the origin of the Navio deposits, identifies this rock as gondite and shows photomicrographs of thin and polished sections of the material. His description of the rock is as follows:

> Macroscopically, the gondite is of compact structure, of a reddish hue, being made up of a millimetric aggregation of reddish garnet. Microscopically, the rock is observed to be composed exclusively of spessartite. Quartz and tourmaline occur as the only accessory minerals. The garnet has a tendency toward idiomorphism (110), is equigranular (1–2 mm.), has an index of 1.80 and a density of 3.9. Its color in transmitted light is rose or colorless. In some cases a slight zoning in dodecahedral fields is observed, most markedly at the beginning of decomposition. * * *

Although this rock contains considerable interstitial manganese oxide, it is of no economic importance other than that it is conceivably the source rock for the large manganese oxide bodies.

Siliceous material.—In a few localities, notably at Chumbo, white quartz sand is cemented by manganese oxide. It is not clear whether this material is vein quartz being replaced by manganese oxide or whether it is detrital material cemented by manganese oxide. The quartz is angular and is in grains up to 5 millimeters in maximum dimension. This material is of no economic significance.

Clayey ore.—On the footwall of the Chumbo deposit is a peculiar spotted material composed of manganese oxides and clay(?) or gibbsite. The whitish mineral is probably the result of alteration of garnets, as shown by the dodecahedral form of many of the spots. Other spots, however, are round, and some have concentric rings. Leinz [5] shows a photomicrograph of the material and states that the white mineral is halloysite and possibly kaolin.

MINERALOGY

The ore is quite hard and brittle on the outcrop. Fresh surfaces show a lustrous steel-gray material, usually with small specks and pockets of softer black oxide. Small pockets of white clay or gibbsite up to perhaps a centimeter in width occur but are not common.

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[4] Leinz, Viktor, Acad. Brasileira Ciencias Annaes, pp. 212–214, Rio de Janeiro, August 1948 (translation by Dorr).

[5] Leinz, op. cit., pp. 215–217, fig. 3.

Leinz[6] states that the ore is an intergrowth of psilomelane and pyrolusite, often showing delicate rhythmic precipitation. This rhythmic banding is well illustrated in figures 9 and 10 of Leinz' paper.

Scorza states that the main ore mineral is cryptomelane, a member of the psilomelane group. (See appendix.) J. M. Axelrod, of the United States Geological Survey, confirmed this in 1948 by X-ray analysis, finding lithiophorite also but not reporting pyrolusite. He reported gibbsite as being present as well.

A picked ore specimen (weight, about 20 kilograms) from the Chumbo deposit was submitted to the micro-optical section of the Squier Signal Laboratory, Signal Corps, United States Army.[7] This was examined by electron microscopy, X-ray, electron diffraction, and emission spectroscopy with the following results:

> The material is fairly pure manganese dioxide predominantly alpha (cryptomelane) phase, quite well crystallized. Gamma phase, if present at all, is minor. The presence of lithiophorite was not confirmed.

Chemical analysis showed the specimen submitted to contain 54.4 percent manganese, 3.30 percent iron, and 0.82 percent silica. Spectroscopic examination showed the following percentages of minor trace elements:

Al	1.4	Ca	0.12	Pb	0.04
K	0.48	Mg	0.11	Cu	0.04
Na	0.30	V	0.08	Ti	0.04
Sr	0.21	Co	0.08	Mo	0.006
Ni	0.16	Ba	0.05	Cr	0.004

Examination by electron microscopy (×32,000) showed

> the predominance of a single morphological habit, represented by * * * dense anhedral particles 0.1 to 1 micron in size. This indicates the predominance of a single phase. While most of the particles are quite irregular in shape, some particles exhibit a tendency toward rectilinear profiles. The loose, lace-like aggregates of much finer material may be a second phase.

Betaphase MnO_2 (pyrolusite) seems to be very minor if present at all.

Arsenic is present in almost all analyses made of the ore, but as yet no arsenical mineral has been found. It seems probable that it is adsorbed in the cryptomelane.

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[6] Leinz, op. cit., pp. 219–220.

[7] The report on the specimen was transmitted by Grenville B. Ellis, Chief, Battery Branch, Squier Signal Laboratory. S. Benedict Levin, Chief, Micro-optical Section, transmitted the major part of it to Ellis. The electron diffraction and microscopy were carried out under the direction of William F. Nye. X-ray diffraction patterns were prepared and diffraction data reduced by H. Estelle. Spectrochemical analysis was under the direction of M. Green.

ORIGIN OF THE ORE

Leinz, in his much-cited paper on the origin of the manganese ore in the Serra do Navio district, has given an admirable exposition of available evidence. He attributes the manganese oxide deposits to the weathering of manganese-rich silicates, of which the only visible example is the abundant spessartite. He also believes that before metamorphism the country rocks were magnesian clay sediments, giving rise through metamorphism to hornblende schist; sandstone, giving rise to quartzite; and manganiferous sandstone, giving rise to gondite. He states that the original source of the manganese is completely unknown. Several excellent microphotographs illustrate the replacement of the garnet by clay minerals (or gibbsite) and manganese oxide. Leinz believes that the formation of manganite is an intermediate step in the formation of pyrolusite and psilomelane from spessartite.

To the minor quantities of arsenic contained in the ore and country rocks, Leinz assigns a postmetamorphic pneumatolytic origin. According to this hypothesis these solutions were derived from a neighboring granitite intrusive. Evidently he sees no relation between the pneumatolytic solutions and the formation of ore and protore.

Scorza,[8] on the other hand, believes that the arsenic and tourmaline have been introduced during metamorphism by pneumatolytic-hydrothermal agents along microjoints. He makes no statement on possible effects of these solutions on ore formation.

With Leinz' belief that the ore is derived from the decomposition of manganiferous silicates and, possibly, other manganiferous minerals, there is no argument. The physical nature of the ore and its relations to the one protore mineral found point toward the fact that the ore is a decomposition product of older manganiferous minerals. This was set forth in June 1947 in an unpublished report by Mack C. Lake and was recognized by earlier workers in the district, including Scorza.

The present authors have little factual material to add, except to emphasize the fact that the greatest concentration of spessartite seems to be at or close to the clay-schist footwall of the bodies. Since the footwall is a relatively impermeable rock, it is to be expected that the waters which promote decomposition of the silicates would be concentrated on the footwall, thus carrying oxidation further in this horizon. If all or even much of the manganese oxide of the deposits had come from the mineral spessartite, one would expect the spessartite-rich footwall zone to be at least as completely altered as the

[8] Scorza, Evaristo Penna, unpublished report, Oct. 31, 1946.

center and upper parts of the deposits. This does not seem to be the case.

Another argument against the mineral spessartite's being the major source of manganese is that, in all fresh specimens seen by the writers and those examined by Leinz, the spessartite crystals are separated from each other by manganese oxide. Thus there is evidence for oxide other than that derived from the garnet spessartite. Among the minerals from which the oxide may have been derived are rhodocrosite, alabandite, rhodonite, and the hydrous silicates.

The authors believe that at depth one or more of these other minerals, quite possibly rhodocrosite and alabandite (the presence of arsenopyrite and pyrite in the vicinity indicates that sulfide-bearing solutions were active) will be found in the protore, with spessartite more important near the footwall.

The Navio deposits seem to be quite similar to the great manganese deposit of Morro da Mina at Conselheiro Lafaiete, Minas Gerais, judging from descriptions of that deposit in its early days. In 1906 Hussak [9] suggested that the original protore mineral there had been rhodocrosite, that this had been changed to spessartite by contact metamorphism, and that the oxide had formed from the spessartite by weathering. Miller and Singewald,[10] in 1917, reached the conclusion that most of the export ore had been derived from oxidation of rhodocrosite in the protore. They believed the manganese silicates to have been formed by regional rather than contact metamorphism. Freiberg,[11] writing in 1934, seems to credit the oxide ore to the weathering of a mixture of rhodocrosite and various silicates derived from both contact and regional metamorphism. Haakala [12] believes that spessartite is hardly an important source of manganese oxide there. Recent microscopic work by Park on the protore of Morro da Mina indicates that alabandite and rhodocrosite are abundant in the unaltered rock.

No evidence is at hand as to the ultimate source of the manganese in the Navio district nor as to the original nature of the rock that is now ore and protore. Should manganese hydrosilicates or other more soluble manganese minerals be found at depth, it would be reasonable to infer that the pneumatolytic (according to Leinz) or hydrothermal solutions suggested by the presence of arsenic and tourmaline had some effect in concentrating the manganiferous protore. The solutions or

[9] Hussak, Eugen, Über die Manganerzlager Brasiliens: Zeitschr. prakt. Geologie, Jahrg. 14, pp. 237–239, 1906.

[10] Singewald, J. T., and Miller, B. L., The manganese ores of the Lafayette district, Minas Geraes, Brazil, Amer. Inst. Min. Eng. Trans. 56, pp. 7–30, 1917.

[11] Freiberg, Bruno von, Die Bodenschätze des Staates Minas Geraes, pp. 153–162, Stuttgart, 1934.

[12] Haakala, Harvey, personal communication.

gases may possibly have introduced manganese. It is difficult to imagine the transit of hot solutions or gases through a manganiferous horizon without some effect upon that rock. Aside from some possible dike rock and vein quartz, the only rock of probable igneous origin now exposed in the area is the foliated granitic gneiss a few kilometers upstream.

Until both the regional geology and the true nature of the protore are known, it will not be possible to evaluate the roles played by regional and contact metamorphism in the formation of the protore.

Of scientific interest is the deposition of manganese oxide in the rapids a short distance above the large silicate outcrop on the Igarapé da Pedra Preta. Here the manganese is being transported and redeposited under tropical weathering conditions. As can be inferred from plate 4 (inaccurate in detail), upstream from coordinates 200 N., 1100 E., the stream has a low gradient and forms many stagnant pools and swamps during low water. There will be noted, also, the manganiferous outcrops and boulders of the Janot deposit, through which the Igarapé da Pedra Preta flows. A show distance below the outcrops, the gradient steepens abruptly and the stream leaps and splashes from rock to rock with many little plunge pools. In the quiet stretch above, choked with rotting vegetation, the water is thoroughly charged with vegetable decomposition products and becomes reducing in chemical nature, capable of carrying manganese in solution. In the rapids and falls the water is thoroughly aerated and charged with oxygen, and the manganese it contains is precipitated on the surface of the rocks and boulders as manganese oxide. The surface of the rocks takes on a washboardlike aspect, with litttle corrugations building up that further aerate the water that passes over them. The depositional shell is only a few millimeters to a couple of centimeters thick and, being soft, is probably in part removed each rainy season when the stream becomes a roaring torrent.

Other examples of solution and redeposition of manganese have been described on pages 12–13 and 14–15.

DEPTH OF OXIDATION

Of major economic interest is the depth to which alteration of original manganese minerals and their replacement by manganese oxides have taken place. In considering this, two opposed factors must be evaluated: (1) the accelerated rate of decomposition due to climatic factors, mentioned on page 6, and already illustrated, and (2) the relatively short period of time available for such processes to be effective, as indicated by the recent uplift of the area.

If the physiographic evaluation of the district, made without maps or relative elevations, is correct, one may consider that the area was a low-lying peneplain for long periods of geologic time. Under such conditions, where the water level is shallow, underground circulation of water is usually not active, and it is hardly to be expected that oxidation proceeded to great depth, although it must have been complete near the surface.

Evidence for relatively recent uplift has been presented on pages 6–8. One result of rejuvenation is that the drainage has formed areas of sharp local relief. Such local relief increases the underground circulation of water, permitting waters charged with weak acids and carbon dioxide to penetrate deeply into the underlying rocks, reacting with them and causing the break-down of silicates and other minerals. Because the only manganese silicate seen, spessartite, was found with manganese oxide at or near stream level (the local water table), it seems probable that at least incomplete oxidation has taken place down to the water table. How far below the water table alteration has proceeded is not known, but it is not likely to have occurred much below the level of the Amapari River, for underground circulation should be slow at such depths. In fact, it is probable that oxidation has not even proceeded to river level beneath the major ridges unless the accelerating effect of local climatic conditions is greater than now believed, for, geologically speaking, not much time has been available for such alteration to take place. If the effect of climatic conditions has been overestimated, alteration may have proceeded to only a few tens of meters on the highest ridges, less on the lower ones. In any case, the contact between altered and unaltered rock will be very irregular, with horses of unaltered material and pipes and shoots of altered material far above and below the average level. In the Morro da Mina mine at Conselheiro Lafaiete, Minas Gerais, shoots of manganese oxide of commercial grade enclosed in protore are found more than 100 meters below the original outcrop.

STRUCTURE

Both regional and local structures are obscure. Only at the Chumbo deposit could the writers secure information on the attitudes of the enclosing rocks, and nowhere is it possible to determine whether the ore beds are crosscutting or concordant. Since no topographic map of the area as a whole is available, and since the reconnaisance on which plate 2 is based may be unreliable in detail, even the distribution of the deposits gives an inadequate basis for inference as to the structure of the rocks or deposits.

Judging from outcrop patterns as seen in the field, it seems probable that the deposits are tabular, steeply dipping lenses, which occur in at least two and possibly four horizons. The Terezinha area has two definite lines of discontinuous outcrop all the way from Antunes to

Padeiro, a distance of over 4 kilometers, plus the erratic deposit at Baixinho to be discussed.

The schist exposed in the adit at Chumbo is contorted. At the portal it strikes east, but 20 meters underground it has swung around to about N. 54° W. Dip at the portal is about 30° N.; at the crosscut it is about 55° NE. The trace of the outcrop and bouldercrop with relation to the topography, as shown on plate 4, indicates that the lens may have a generally low north to northeast dip. Similarly the Antunes deposits, although not mapped topographically, seem to have an outcrop pattern on the north end, where the ridge is cut by the stream, that indicates a moderate dip, possibly around 45° E. The outcrop pattern from Antunes south definitely indicates a general N. 30° W. strike; evidence as to amount and direction of dip is lacking, although the observer has the impression that it is steep to the east. There is, however, a possibility that these lenses may be nearly flat (pl. 3, Fritz Ackermann deposit). From a tonnage point of view, this question must be resolved.

It is now impossible to tell what the attitude of the rocks in the Clemente area may be. The outcrop of the Navio deposit (pl. 3) is accurate but trends generally north-northeastward. A large boulder train extends eastward toward Chumbo. There may be a fold in the manganiferous horizon that swings the ore horizon eastward to connect with the main Chumbo outcrop across the river. It is more probable, however, that the Navio deposit is on the same horizon as the Baixio deposit and the Clemente I and Clemente II deposits. Much more exploratory work is needed before this can be settled.

The swing in strike and dip from the Terezinha area to the north indicates some folding in the district. It is premature to say whether this is of major or minor character or whether faults are present that offset the manganiferous horizons.

INDIVIDUAL DEPOSITS

With the exception of Juracy and Cordovil, all deposits known in the Serra do Navio district up to September 10, 1948, have been visited by one or more of the authors. Some the authors merely walked over; others they mapped in detail. The limited time available precluded a thorough study of all of them. Two days were spent on the Fritz Ackermann deposit and a day and a half at Chumbo.

CLEMENTE AREA

Four definite outcrops are known in the Clemente area. There are also many small and large patches with granzon and manganiferous boulders in the soil not certainly related to any outcropping ore body.

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Such patches are present around the camp buildings and on the nose between Clemente II, Navio, and the river.

A series of shallow test pits between Clemente I and Navio has exposed a continuous layer of granzon in the soil; most of the pits bottomed on what is said to be either large rolamentos or a ledge of ore. Further test pitting and drilling in the area will show whether there is one continuous body with only three outcrops or whether the soil overlies a long zone of rolamentos, with possibly one or two hidden ledges of ore.

Other ore bodies may be found to the west, north, or south of the Clemente area by further exploration.

Structure in the area is obscure. It is not known whether one, two, or three manganiferous horizons exist, although it seems probable that there are at least two.

Juracy.—This deposit was not visited and is not shown on plate 2; data thereon come from Dr. Antunes, of ICOMI, and Dr. Van Doorninck. The deposit is some 900 meters N. 30° W. of Clemente II, thus continuing the main trend for the district.

Judging from descriptions, the deposit seems to be mixed outcrop and bouldercrop and is some 40 meters long and possibly 8 meters wide. The ore crops out in Igarapé do Clemente and is said to be of average quality for the district.

Clemente II.—This deposit is an outcrop a meter or so high, about 100 meters long, and 7 to 10 meters wide. The general strike of the outcrop is N. 20° W. The ore appears to be of average grade for the district. Boulder ore in the vicinity is sparse.

Clemente I (pl. 3).—This deposit was mapped because it was a more or less typical small outcrop. The outcrop is obscure and rises above the soil only a few decimeters. Its shape probably does not give a true picture of the size or shape of the ore body beneath, because it is overlapped by soil and vegetation. The outcrop area is roughly oval, the longer axis being 75 meters and the shorter axis about 22 meters. The deposit is surrounded by boulders, larger ones down slope and close to the deposit, smaller ones and cobbles elsewhere. The large down-slope boulders are probably rolamentos. Soil in the area contains considerable granzon and offers no hint of bedrock conditions. Judging from surface exposures, there is no reason to suppose that this body is connected with any other body at depth. The grade of the ore seems average for the district.

Navio (pl. 3).—This deposit, a typical medium-sized body, was mapped in an effort to decipher the structural relations between the Clemente and Chumbo areas. The attempt was unsuccessful because of the heavy soil and the absence of structural information.

The Navio deposit forms a bold scarp on the edge of a broad flat nose, on the other side of which the Clemente deposits are located. The scarp has a maximum height of 15 meters at the south end and becomes progressively lower to the north, where it disappears under soil and vegetation, although still causing a break in slope. The outcrop is about 130 meters long and 20 meters in maximum width. The boulder zone on the up-slope side of the outcrop, probably derived from ore in place beneath, averages perhaps 5 meters in width. To the north a boulder zone continues 35 meters to the northwest of the end of the outcrop, emphasizing the arcuate shape of the outcrop. A train of boulders trends across the topography in a southwesterly direction at least 40 meters from the south end of the outcrop. The outcrop itself is blocky, botryoidal, vuggy black ore, which is stalactitic in the larger vugs and cavities.

The slopes below the south scarp have been deforested, and two small trenches and a bench have been started. None of these cuts reaches bedrock, though tiny fragments of schist can be found in the soil at depth. The cuts show much granzon, which in places forms 50 percent of the mantle, though usually not more than 30 to 45 percent. Many rolamentos, ranging in size from a few grams to many tons, are also exposed. Some are hidden under the soil, and others are half buried. (Note the irregular contours shown on pl. 3, particularly on the nose under the outcrop.)

Certain geologic features shown on plate 3 are significant. On the map of the Navio deposit the long extension of boulders down the nose to the river level may be seen. The edges of this boulder train are not clear-cut, but outside the area mapped as boulders only a few scattered chunks of manganese oxide are found, whereas within the boulder zone they are profuse and, in some cases, large. (Note irregular contours at 55- and 50-meter levels.) The flat bench at the 65-meter level will also be noted. This bench may mark an erosional terrace formed during a period of lateral cutting by the Amapari River, or it may be a reflection of bedrock characteristics. Inasmuch as it dies out rapidly to the north and south, the second explanation seems more probable.

The problem posed by this distribution of boulders is whether the boulders represent rolamentos or a bouldercrop and, if the latter, what the nature of the manganiferous bedrock may be. There is no question that many of the upper boulders are rolamentos. However, if all the boulders were rolamentos, a notable concentration would be expected on the bench. This concentration does not exist. Therefore it seems probable that most of the lower boulders are derived from a lower manganiferous horizon that causes the bench and may correlate with one of the manganiferous horizons across the river, perhaps with Chumbo. Aside from the fact that no silicates have been found in the boulders, there is no evidence as to the nature of the manganiferous horizon.

CHUMBO AREA

The Chumbo area, as shown on plate 2, contains at least four known outcrops of manganese oxide, as well as five major areas of bouldercrop that have possible economic value. In addition, there is a line of limonite boulders that have been confused with manganese oxide boulders in the past. These are in the northeast part of the area, and their distribution suggests a high iron horizon in the bedrock trending about N. 40° W.

Topographically, the Chumbo area is characterized by broad, flat-topped ridges essentially concordant in elevation, which are cut by streams with steep-sided valleys. No bedrock crops out on these ridges; the soil is yellow and clayey, and it is probable that the ridges represent the remains of an extensive surface of low relief now being incised by the rejuvenated Amapari River system. No stream gravel has been found on them.

There was considerable difficulty in delimiting ore bodies in this area. Two factors were responsible: (1) The forest had been cut down but not burned over a considerable area, leaving a practically impenetrable jumble of fallen trees and brush. Even when the sweating geologist penetrated the mass by climbing along tree trunks and branches, it was usually impossible to see the ground below for more than a square meter at a time. Often the ground was not visible at all. The climate is so humid that felled trees are difficult to burn, and, after they have been down a year, a rank jungle of second growth between the original logs results in an impenetrable mass that cannot be burned. (2) Outcrops fade into areas of jumbled boulders with indefinite boundaries in which scattered outcrops occur. These areas of boulders in many cases are bouldercrops and in others are composed of rolamentos; in still others the boulders are probably derived from small, economically unimportant lenses and nodules in the schist. Only subsurface exploration will resolve the true boundaries of the ore deposits.

As mentioned on page 21, the schist in the gallery near the main Chumbo outcrop strikes due east to N. 54° W., and the general trend of the manganiferous horizons seems to be nearly N. 50° W. The northerly dips of 20° to 54° exposed in the tunnel may be somewhat low for the area as a whole, although the west end of the Chumbo deposit crops out with relations to the topography that generally satisfy conditions imposed by a low or moderate northerly dip. Elsewhere in the area there is no clear-cut evidence bearing on structure.

There seem to be two and possibly four manganiferous horizons. Chumbo II and Chumbo I may be separate horizons. The main Chumbo horizon can be traced for nearly 600 meters without a break and conceivably ties in with Janot and Bacelar and possibly the main line of deposits in the Terezinha area. It is thought that Baixio is a separate horizon. Far more structural data are needed before the relations between ore bodies will be understood.

To the writers' knowledge, the Chumbo area is not limited to the north or east, but it does not seem probable that important new finds will be made in those directions, as they are off the regional trend of the deposits.

Chumbo II.—This is a small deposit on the south bank of the Igarapé do Antonio near its confluence with the Amapari. It consists of mixed bouldercrop and outcrop, possibly in equal proportions, and is about 120 meters long and 60 meters wide. Upstream and upslope are small areas of medium small boulders that may be bouldercrop, although they are not mapped as such. The long axis of the deposit trends about N. 20° E. On the west and southwest sides, the ore seems to contain a moderately high percentage of iron with a dark-brown hue, but the main mass of the ore appears to be of the good quality usual in the district.

Chumbo I.—This deposit was covered by fallen timber and slashings at the time field work was done and thus was completely inaccessible. The southern limit was taken as the edge of a boulder zone, possibly bouldercrop; the rest was sketched from local information. Nothing is known of the deposit, not even whether true outcrops exist. Above the deposit is a zone of small boulders and granzon in the soil. The boulders appear to be of average quality.

Chumbo.—The main Chumbo deposit, located as it is on the bank of the river, is one of the most important in the district from an economic viewpoint and also may be one of the largest if the extensive area of bouldercrop is underlain by good ore. The deposit crops out at the river's edge in a bold crag about 20 meters high. From the outcrop at the river a mixed jumble of bouldercrop and outcrop runs about S. 50° E. for approximately 600 meters, where the deposit seems to feather out. Much of the north-central part of the deposit is nearly inaccessible, owing to felled trees and second growth, but the parts that have been deforested and burned and those that have not been deforested at all are well exposed.

The river outcrop (pl. 4) was only some 25 meters wide in June 1948. Hydraulicking of the soil on the north side had revealed another 15 meters of outcrop width by early September, and it is possible that the ore may be even wider under the remaining soil cover. It seems probable that the true thickness of the ore bed may be at least 30 meters.

On the footwall of the river outcrop, with an undetermined thickness, is a zone of white nodules a millimeter or two in diameter in a matrix of soft manganese oxide. This rock seems to grade upward into the ore, but its relation to the footwall schists is obscured by cover. The white mineral has been shown by Leinz [13] to be halloysite or kaolin derived from spessartite.

On the hanging-wall side of the outcrop, starting about 15 meters above river level, is the white, coarse, angular quartz with a cement of manganese oxide mentioned on page 11. There is no clue as to the nature of the hanging-wall country rock.

The river outcrop itself is craggy, hard, black manganese oxide with many vugs. On breaking, the ore is seen to be a mixture of hard, dense, steely oxide and black, soft, powdery oxide, the latter constituting a very small percentage of the whole, all delicately intergrown in colloform structures. Sparse, irregular pods of white clay or gibbsite are seen, but the ore is obviously of good quality. This outcrop is impressive.

The true outcrop ends at the break in the slope above the river, giving place to a mass of boulders with little interstitial soil. This bouldercrop widens rapidly to the south, and soil becomes more common. Along the south edge near coordinate 400 N. are a few iron-rich boulders, some of which are within but most of which are outside the area mapped as bouldercrop. The southwestern and western boundaries of the bouldercrop area are somewhat arbitrary, and it is quite possible that the ore body below does not extend as far as mapped in these directions. Many rolamentos are found down slope from the boundary as drawn, but the abrupt change in size and frequency of boulders along the line as drawn must indicate a corresponding change in bedrock conditions at or near the contact as mapped. The same is true of the northeastern boundary of the body, except that felled trees make part of this area more difficult of access.

Manganese silicates are exposed where the southwestern boundary of the body crosses the Igarapé da Pedra Preta. Just below a 2-meter waterfall is a fine outcrop of mixed spessartite and manganese oxide. The bedrock of the waterfall and the rapids above it is composed of impure manganese oxide, apparently containing clay and iron oxide

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[13] Leinz, Viktor, Acad. Brasileira Ciencias Annaes, pp. 215–217, fig. 3, Rio de Janeiro, August 1948.

About 80 meters to the magnetic north are outcrops of good ore in the bouldercrop.

Long reentrants of barren soil or of soil with sparse rolamentos project into the ore body at its southeastern end. The body here is bouldercrop with some scattered outcrops. Here too the relation between topography and the bouldercrop and outcrop distribution is difficult to explain except on the hypothesis that the boulders are derived from manganiferous bedrock below and have not moved far. The peculiar outcrop pattern at the southeast end of the body is difficult to explain on the hypothesis of a concordant body; the deposit appears more like an irregular replacement body.

In summary, the Chumbo deposit is an irregular body about 600 meters long with an average width of perhaps 65 meters. The surface expression is both outcrop and bouldercrop in proportions of about 75 percent bouldercrop, 25 percent outcrop. Not all, but much, of the ore is of high quality, particularly in the river outcrop. If subsurface exploration bears out the supposition that bouldercrop overlies workable ore in place for 60 percent of the area mapped as bouldercrop, the Chumbo body will have considerable economic importance.

Janot.—This body crops out on both sides of the Igarapé da Pedra Preta 120 meters east of the end of the Chumbo body. Discontinuous outcrops are exposed for a length of 160 meters, and boulders occur for another 40 meters at least. The average width is about 60 meters, including bouldercrops. The highest outcrops seen were about 2 meters above the soil. Most of the ore seems to be of average quality, although Van Doorninck [14] reports the presence of silicates at the foot of one of the outcrops.

No structural data were obtained, but the trend of the deposit seems more nearly due east than is usual in the district.

Baixio.—This body of ore, on the steep south slope above the Igarapé da Pedra Preta near its confluence with the Amapari river, is nearly inaccessible because of rank second growth. One large craggy outcrop a few tens of meters in width and perhaps 5 meters high is surrounded by profuse blocky boulders, probably bouldercrop with ore at depth, as there is no apparent source up the hill. Maximum dimensions of the bouldercrop were estimated to be 50 meters and 20 meters, with many rolamentos below.

No structural information could be gained from this deposit. The ore seems to be of excellent quality.

Platon.—On the broad flat nose above Baixio and about due south of the south end of Chumbo is a small area of bouldercrop, perhaps

[14] Private report, through the courtesy of William H. Muller & Co.

40 meters by 30 meters in size. No outcrop is known here. The deposit will be of economic value only if transportation facilities are available.

Bacelar.—Also on top of the broad flat ridge above Baixio, to the southeast of the Platon deposit, is an elliptical area of bouldercrop with a little possible outcrop, measuring perhaps 100 meters by 35 meters. The ore appears to be of average quality.

No structural information could be gained from this deposit.

TEREZINHA AREA

The Terezinha area (pl. 2) contains the largest and highest-grade outcrops in the district and seems to have the simplest structure. It is also, unfortunately, the farthest from the river, so that transportation will be more of a problem.

The division between this area and the Chumbo area is arbitrarily placed at the Igarapé da Media between the Antunes and Bacelar deposits, to some extent for convenience in description but also because the structure and nature of the ore bodies south of the Igarapé da Media are somewhat different from those to the north. Moreover, the ore from the Terezinha area will probably move downstream to the Santa Terezinha landing on the Amapari River from the southern part and to a point somewhat to the north of this from the northern part, whereas ore from the Clemente and Chumbo areas will arrive at the river near the present camp. The Terezinha area is characterized by a single long ridge cut by streams in two places. The southern end of the ridge, south of Sentinella, is also cut off by a stream, and a search for possible extension of the ore zone to the south has not yet been made. It is not improbable that other deposits may be found there. The country to the east of the ridge also has yet to be prospected for manganese. Other deposits might be found in this area although it seems less promising than the southern extension. It is improbable that large deposits remain undiscovered between the Amapari River and the Terezinha ridge.

The Terezinha ridge is steep-sided toward the river, and where seen, the side away from the river is also rather steep, although less so than the river side. The crest is quite level, with low saddles just south of Fritz Ackermann and north of De Paiva; descents to the through-cutting streams are abrupt. The ridge varies in width from a few meters at Gurita to a width of well over 100 meters. This ridge appears to be essentially concordant with those to the north.

With two exceptions, the deposits are on the top of the ridge or on the west side a few meters to tens of meters below the top. The Fritz Ackermann deposit occupies both flanks and the top of the ridge. The Baixinho deposit is far down in the lowlands east of the ridge.

Structurally the area seems simple. Plate 2 shows that the alinement of the deposit is about N. 60 W. from Sentinella to Macaco, where the line of deposits swings abruptly to about N. 20 W. to the deposit called Forno. If the two Antunes deposits are correctly located, a swing back to about N. 50 W. is indicated just to the south of these deposits.

Seventeen deposits are known in the area, 13 with good outcrops, 4 mainly bouldercrop. On the basis of outcrops there are two or in places possibly three manganiferous horizons. Two horizons are present at Antunes; Cancão and Cachoeira are on separate horizons. Possibly two horizons are present at Gruta; De Paiva has two parallel outcrops, and Fritz Ackermann has two or possibly three horizons. The Padeiro deposit is too covered by boulders for the number of horizons to be ascertained, but it seems probable that there is more than one. Of two horizons in a given deposit the higher, or more easterly, outcrop is usually much more imposing than the other.

The grade of the ore in the Terezinha area seems higher and more regular than in the other areas. Possibly this is because outcrops are more pronounced and the sampling has included a higher percentage of ore derived from outcrop and less from boulders either of possible concretionary origin or derived from silicate lenses in the schist. Another explanation might be found in the somewhat different physiographic setting, as the ridge is narrower and ground-water circulation probably more active.

Although existing evidence derived entirely from surface exposures provides no basis for definite statements, the group of deposits from Macaco to Gurita may be connected under the soil cover.

Antunes I.—The Antunes I deposit crops out on the south and west slopes of the Terezinha ridge where it is cut by a small stream. The outcrops are perhaps 30 meters above stream level where crossed by the trail; they gain elevation rapidly to the southwest as they swing around the hill and less rapidly where they follow the generally southeastward-trending ridge. This outcrop pattern in its relation to the topography suggests a northwest strike and a dip of around 40° to 45° NE.

Two horizons crop out in the Antunes I deposit; contrary to the general rule, the lower seems to be the thicker. Between the two is an area of rolamentos, and rolamentos are scattered widely on the steep slope below the lower deposit. The outcrops are blocky and craggy, standing several meters above the soil, but in places are so broken that they must be called bouldercrops. The two horizons each seem to crop out for about 220 meters; the upper was paced, but the lower was not. The upper outcrop may average 20 meters in width on the slope; the lower, perhaps 30 meters. The two horizons are some 30 meters apart.

The upper bed is composed of both good hard ore of the usual type and lower-grade material with an appreciable iron content; the lower appears to be of average grade.

Antunes II.—This deposit of mixed bouldercrop and outcrop is some 100 meters long by 30 meters wide. The presence of one or two ore horizons was not established, as the forest here is particularly thick. It cannot be stated with certainty whether this deposit connects with either of the Antunes I horizons, but it is believed that they are separate deposits. The grade of the ore here seems average for the district.

Forno.—The Forno deposit, discovered in the course of a traverse from the camp near Macaco to Chumbo, is a small deposit trending N. 30 W., some 60 meters long by 30 meters wide. It is composed of good ore and takes its name from the presence of the ovenlike chimneys described on pages 12–13. The outcrop stands more than a meter and a half above the surrounding soil in places.

The finding of this deposit suggests that other, as yet undiscovered deposits may exist in the gap between Antunes II and Canção.

Canção.—The Canção body crops out on the side of the hill above the Igarapé da Cachoeira. It is at least 100 meters long and not less than 40 meters wide. The strike of the long axis is about N. 70 W., thus appearing to crosscut the general structural trend. Much of this deposit is bouldercrop, but outcrops up to a meter and a half high are found. Granzon and rolamentos are found on the steep slope below the deposit.

The ore in this body appears to be of high grade.

Cachoeira.—This deposit occurs in the creek known as the Igarapé da Cachoeira, down slope from Canção. It is apparently a second horizon more or less parallel to the higher deposit. The outcrop, about 50 meters long and 30 meters wide, contains mixed spessartite-manganese oxide rock near the footwall. Although some high-grade manganese oxide rock is present, much of it seems low in grade with a higher than usual iron content that gives it a brownish hue.

According to Van Doorninck,[15] downstream from the deposit is an imposing 12-meter waterfall in amphibolite or, possibly, metadiabase. The rock has a foliation, according to the same source, of N. 30° W. to 35° NE. Below this fall are said to be a few weathered outcrops with recognizable garnets.

Macaco.—The forest on this deposit had been cut but not burned at the time of the field work, and so the area was inaccessible. Large

[15] Private report, through the courtesy of William H. Muller & Co.

rounded boulders of good ore were profusely scattered around the edges of the deposit, and low outcrops are said to exist under the felled trees. The manganiferous area is about 150 by 100 meters in maximum dimensions and elliptical in shape. The slopes here are gentle, and it seems probable that the boulders should be classed as bouldercrop with an ore body under a good part of the area.

Presépio.—This deposit, the first crossed by the trail from the Santa Terezinha landing to the Terezinha area, is composed of mixed outcrop and bouldercrop, many of the boulders resting on solid ore. The total length was not measured but is more than 150 meters; if, as stated by the local woodsmen, this deposit connects with Macaco, it must be nearly 350 meters long. The width of outcrop may average some 15 meters where seen. The maximum height of outcrop is possibly 6 meters, though the average is around 2 meters or less. Only one ore horizon was seen, although this might be two outcrops a few meters apart masked by boulders. Structure is simple, for the outcrop seems to have no major flexures and has a general trend of N. 40° W. A steep northeasterly dip is probable, but there is no definite evidence of this. The ore seems to be of good qualtiy.

In the soil below the outcrop is an area of rolamentos possibly 50 meters in width. This does not seem to be particularly rich on the surface.

Gruta.—No good outcrops were seen on the Gruta deposit. It is an area of bouldercrop and rolamentos on the steep west slope of the Terezinha ridge, perhaps some 200 meters long, with a width of 20 to 25 meters of bouldercrop and twice this of rolamentos. No structural information is available. The ore appears to be average for the area, though a few pieces of impure manganese oxide were found among the rolamentos below the deposit.

According to plate 2, this deposit seems to be on the same horizon and trend as Macaco and Presépio. It is possible the same horizon represented by De Paiva and Cordovil and the small area shown below Gurita on plate 2.

Gurita.—This small deposit, on the very top of the ridge, is 50 meters long including bouldercrop. The maximum height of outcrop is some 3 meters, though most of it is lower. The maximum width is about 10 meters. The ore seems to be of good quality. This deposit appears to be somewhat out of the main trend as described. The outcrop shown on plate 2 on the steep slope below this deposit was not visited, and its presence cannot be vouched for.

De Paiva (pl. 3).—The De Paiva deposit is one of the most interesting of the Terezinha group because of the problems it poses on the shape of the ore body. As can be seen on plate 3, the deposit consists of two outcrops, the lower about 4 meters wide, not less than 90 meters long (it was not followed to extinction), and a few decimeters high. The upper outcrop is some 150 meters long, averages about 10 meters wide, and has a maximum height of over 20 meters, with an average height of perhaps 4 meters. This outcrop terminates abruptly to the north in a high overhanging cliff. The lower horizon is not offset by a fault; so it seems probable that the main deposit is a lens that terminates very abruptly to the north and tails out to the south. The top of the upper outcrop is an isolated crag, rising nearly 5 meters above the saddle to the east. The map also shows that, to the south of the high cliff, a lower cliff 3 to 5 meters high develops with a straight wall in some places and angular blocks and reentrants in others. Above this scarp the outcrop is flat and broadens to the south. The upper edge of the outcrop is overlapped by soil and vegetable debris from the slope above.

This outcrop pattern is best explained by the assumption that the deposit is a lens, either vertical or dipping quite steeply to the east. Were it a flat bed, an arch not reflected in the lower bed would have to be assumed to bring the north end down. This pattern is very suggestive of a replacement deposit generally, but not entirely, concordant with the enclosing rocks. Below the outcrops is a considerable mantle of rolamentos.

The ore of this deposit seems to be of high grade and is vuggy and hard. No silicates were seen.

Cordovil.—This deposit was not visited but is said to be smaller than De Paiva. It is on a steep hillside about in line with De Paiva. There is said to be a good outcrop here.

Between Cordovil and Fritz Ackermann, the next deposit to the south, is a gap of about 600 meters without outcrop and with few fragments of manganese oxide along the trail. This is the largest gap between known deposits in the district, with the exception of the gap between Juracy and Clemente II.

Fritz Ackermann (pl. 3).—This deposit, about 600 meters long in two outcrops, has the most imposing exposure of any deposit in the district. The ore is of good quality.

The central spine, consisting of a continuous outcrop averaging 3 meters in height and perhaps 14 meters in width, has a length of 210 meters. The trail runs along the east wall of this outcrop. On the west side, connected by bouldercrop with the central spine at the south end and consisting of outcrop (perhaps 70 percent) and bouldercrop, is another area of manganese oxide some 280 meters long, between 1 meter and 20 meters high, and 10 to 50 meters wide. Off the east side of the central spine juts an extension of outcrop (70 percent) and bouldercrop some 100 meters long with an average width of 20 meters and a maximum height of a little over 20 meters. The area between the central spine and the west crop is covered with soil and boulders, probably rolamentos. The corresponding area to the east is similar. Mantling the slopes below the deposit are areas of rolamentos, broad and rich to the southwest, rather narrow elsewhere. Below the high scarp on the east side are huge fallen blocks of hundreds of tons each.

The outcrop pattern suggests two possibilities. The first is that the deposit is a bed or tabular lens striking approximately northwest with a low dip to the south. Alternatively, we may be dealing with three coalescing, steeply dipping lenses. On the basis of field evidence, the latter explanation seems the more probable, but the first possibility cannot be disregarded.

The junctions between the main horizons at the south end of the deposit are bouldercrop. It is thought that at depth this bouldercrop will prove to represent manganiferous material in place, for most of the boulders are large and blocky and do not appear to be rolamentos.

At this deposit the chimneys described on pages 12–13 are found in perhaps their fullest state of development. Near the north end of the central spine one may follow the growth of these chimneys to its ultimate conclusion, the formation of boulders.

Between the Fritz Ackermann and the Curuça deposit to the south is a low saddle with sparse rolamentos. On the northeast side of this saddle, some 20 meters below the top, is a flowing spring. Flowing springs are not common in the district despite the high rainfall, and as this one occurs quite high on the ridge, it probably is due to structural or stratigraphic features. No bedrock is visible, although the spring has formed quite a steep wall in the soil by headward sapping.

Curuça.—The Curuça deposit is principally composed of a bouldercrop some 70 to 80 meters long with large and craggy boulders on the crest of the ridge. According to Van Doorninck,[16] there are two horizons roughly parallel to those in the Fritz Ackermann deposit. The width is about 40 meters, of which half may be rolamentos.

Padeiro.—The Padeiro deposit also is largely bouldercrop but has a main central outcrop about 150 meters long. According to Van Doorninck, at least seven smaller outcrops are present, two to the northeast and five to the southwest. The width of outcrop is 15 to 20 meters, but the outcrops are low and unimpressive. The area contains many boulders that appear to be either rolamentos or bouldercrop; one has the impression both here and in the deposits to the southeast that much of the ore body may have been removed by erosion. The length of the boulders plus outcrop along the ridge is over 300 meters.

[16] Private report, through the courtesy of William H. Muller & Co.

The quality of the ore is excellent. No structural information is available except that the northwesterly trend of the Terezinha group of deposits is continued.

The three horizons that are present, according to Van Doorninck, may correlate with the three major ore bodies in Fritz Ackermann.

Nelly.—The deposit marked on plate 2 as Nelly was not certainly identified in the field. A large patch of boulders, possibly bouldercrop, occurs in this neighborhood, but no other information is available. The ore quality appears good.

Sentinella.—This deposit is an ill-defined area of boulder ore some 200 meters long spread over the broad ridge, which from here on to the south loses elevation rapidly. The width may be in the neighborhood of 50 meters, although this was not measured. The ore occurs in large boulders, and as at Padeiro, these boulders may represent the remnants of a deposit largely removed by erosion.

The ore quality appears good.

Baixinho.—This erratic deposit, far out of the trend of the other known deposits, occurs in and near a creek bed in the lowland to the west of the Terezinha ridge. Much of it can hardly be called manganese ore, as it is high in iron and is really in part manganiferous limonite, mostly dense and hard but in places soft and cellular. Certain zones and boulders high in manganese are present, however, as shown by analyses to be cited.

The outcrop zone appears to measure about 100 by 50 meters, the long axis trending N. 50° W. The maximum height of the steep-walled outcrop is about 5 meters.

RESERVES

No close estimate of reserves or grade can be made at this stage in the development of the Serra do Navio district. Not only are depth factors for calculating ore tonnages unknown, but the probable changes in the grade of the ore from outcrop to depth are impossible to evaluate even approximately. Furthermore, and possibly even more important, the validity of working field hypotheses on ore occurrence has yet to be tested. It is possible that areas now thought to be barren will prove to have ore hidden under the soil; conversely, it is probable that some of the area covered by bouldercrop under which ore is presumed to be present will prove barren.

Because of the meagerness of the data, it seems better to treat areas rather than individual deposits in estimating reserves, for probabilities of serious error are larger as the individual area considered is smaller. On the other hand, if groups of deposits are considered, errors should tend to compensate.

The authors are keenly aware of the shortcomings in data available and offer these estimates only as being possible within the depth limits assumed.

TONNAGE

The dimensions of individual ore bodies are imperfectly known. Perhaps the clearest is length; less clear, because of masking boulders and rolamentos, is width. Depth is merely a matter of assumption, guided by the facts set forth in the individual deposit descriptions and by basic geological concepts.

Table 1, which gives tonnage estimates for the district, is based on the following calculations and assumptions: Deposits have been separated as far as possible into outcrop, bouldercrop, and mixed. In the outcrop deposits, the estimated outcrop area is multiplied by the depth factors here discussed to secure volume. In the bouldercrop deposits, the estimated area for categories other than "visible" ore is multiplied by a correction factor of 0.6 to cut down possible overestimates caused by spreading of boulders.

Mixed ore bodies also are calculated with the bouldercrop correction factor of 0.6, though in some cases, as at Navio and Fritz Ackermann, this factor is used only for the bouldercrop part of the area.

In estimating proved or visible ore, deposits having bold scarps and outcrop heights of more than 15 meters are given 5 meters of depth. Deposits having outcrop heights between 5 and 14 meters are given 3 meters of depth, and deposits having outcrop heights less than 5 meters are assigned 1 meter of depth. This compensates somewhat for ore visible in scarps but not given due weight by outcrop length or width. These depth assumptions seem safe for two reasons: (1) No boulders of any magnitude have been found with silicates. (2) A drill hole and a tunnel at Chumbo have penetrated 10 and 18 meters, respectively, below the outcrop into ore said to be as good as that at the surface.

"Probable" ore is calculated as the ore within 10 meters below the visible ore, a purely arbitrary assumption.

"Possible" ore is calculated as the ore within 15 meters below probable ore.

Thus a maximum vertical range of 30 meters and a minimum range of 26 meters have been used. The assumption of a 30-meter depth of oxidation is not excessive for a global estimate such as this, for although it is quite probable that protore will be encountered within less than 30 meters of the surface in some deposits, in others there will be shoots and pipes of oxidized material to much greater depths. The deposit at Lafaiete, Minas Gerais, probably similar in original mineralogic composition, has minable bodies of manganese oxide a hundred meters below the original outcrops, although unaltered silicates are found near the surface.

In connection with depth assumptions, it is significant that at Chumbo at river level incompletely replaced garnets occur on the footwall beside an impressive thickness of high-grade ore. Thus it can be seen that the presence of footwall garnets does not mean that the bottom of the purer ore has been reached. All the unaltered manganese silicates in the Serra do Navio district are in valleys that have deeply incised the old upland surface, on and near which the manganese oxide deposits are usually found. These are, in the case of Chumbo, some 30 meters below the flat, and at Cachoeira, about the same distance below the good ore of Canção and even more below the flat.

The basic assumption as to the shape of the ore body is that the ore body extends downward on the dip that seems apparent on the surface.

The specific gravity of the ore was taken as 4.

No data were secured to form an estimate of the tonnage of rolamento ore or granzon ore. It may be approximately equal to the amount of visible ore; probably it is somewhat more, owing to the presence of large areas of granzon on the broad flats. How much of the granzon and rolamento ore will be economically recoverable is hard to predict.

TABLE 1.—*Reserves of manganese ore in the Serra do Navio district, Brazil, by areas, in metric tons*

Area	Visible ore	Probable ore	Possible ore	Total
Clemente	53,000	140,000	250,000	443,000
Chumbo	205,000	1,220,000	1,850,000	3,275,000
Terezinha	327,000	1,340,000	2,000,000	3,667,000
Total	585,000	2,700,000	4,100,000	7,385,000

Should prospecting prove the expanse mapped as mixed bouldercrop and outcrop in the Chumbo area to be underlain by low-grade or barren rock, estimates for that area may be 50 percent too high, despite the correction factors used. On the other hand, the small amount of prospecting now accomplished in the Clemente area suggests that ore may extend from Navio to Clemente under the soil cover and that estimates based on surface indications there are low. If this proves to be the case, the Clemente area may contain as much ore as the Chumbo area. Reserves in the Terezinha area are probably larger than the figure given in table 1. One reason is that oxidation should be deeper there, another is that the area is not well explored and new deposits may be discovered. No probable or possible ore was calculated for the Platon, Gruta, Cordovil, Nelly, or Sentinella deposits, for the writers are pessimistic about continuation in depth for those deposits. Should these prove to go to depth, estimates in the two categories may be raised at least 15 percent in the Terezinha area.

The tonnage at Baixinho was not calculated, as the ore did not seem to be comparable in over-all grade to the other deposits.

GRADE

No complete sampling work has been undertaken by the authors. They have available, however, the results of 156 samples taken by A. E. Walker, geologist for the M. A. Hanna Co., and of 17 samples taken by N. H. Van Doorninck for William H. Muller & Co. ICOMI has been kind enough to supply considerable information on grade. A number of analyses of grab samples taken by Fritz Ackermann have been published.[17]

The writers' information permits them to locate the samples taken by Walker only approximately. These are grab samples of surface ore; Walker, in a personal communication, emphasizes the fact that they cannot be taken to represent any great volume of rock.

Table 2 is a summary of Walker's sampling of the Terezinha group as known at the time of his work. This includes the Baixinho, Macaco, Gurita, De Paiva, and Fritz Ackermann deposits.

Table 3 is a summary of Walker's sampling of the Clemente and Chumbo areas. It is probable that some of the Chumbo samples represent the deposit herein called Janot. Which samples were from outcrop and which from boulder ore is unknown.

Table 4 is a break-down of the above samples by manganese content, which shows that 75 percent of Walker's samples contained above 45 percent manganese.

Van Doorninck took 17 composite grab samples of surface material during his work in Amapá, collecting chips from a number of points (as many as 50) in each deposit. He too wishes to emphasize the fact that these are surface samples.

Table 5 gives the results of Van Doorninck's sampling. Van Doorninck ascribes the great difference in grade between outcrop and boulder ore to the presence of lateritic soil in the talus. This is reasonable, for, with exceptions, the boulders appear to be nearly as high in grade as the outcrops.

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[17] Ackermann, Fritz, Recursos mineraes do Territorio Federal do Amapá, pp. 14–15, Imprensa Nacional, Rio de Janeiro, 1948.

TABLE 2.—*Results of sampling of Terezinha manganese deposits, Serra do Navio district, Brazil, by A. E. Walker, M. A. Hanna Co.*

[Analyst: W. A. Markert, M. A. Hanna Co.]

Sample	Deposit	Fe (percent)	P (percent)	Mn (percent)	SiO_2 (percent)	Composite As (percent)
1	Baixinho	7.0	0.161	51.70	1.32	0.203
2	do	7.3	.140	52.06	1.15	
3	do	25.5	.280	32.74	1.46	
4	do	4.8	.118	54.20	.81	
5	do	6.5	.100	52.40	.64	
6	do	4.3	.073	51.20	2.00	
Average		9.4	.145	47.40	1.23	
7	Macaco	3.7	.085	51.80	2.72	.128
8	do	3.8	.131	54.20	1.09	
9	do	3.0	.077	57.15	.39	
10	do	5.0	.135	58.48	1.23	
11	do	3.3	.110	54.40	.27	
12	do	4.1	.066	59.88	.59	
Average		3.8	.101	55.98	1.05	
13	Gurita	5.2	.139	53.80	1.21	.175
14	do	6.1	.072	54.70	.32	
15	do	3.8	.072	53.84	.65	
16	do	5.5	.114	55.08	.68	
17	do	3.5	.135	57.60	.50	
18	do	7.8	.100	51.46	.53	
Average		5.3	.105	54.41	.65	
19	De Paiva	4.7	.062	51.40	.64	.139
20	do	6.3	.108	46.20	2.44	
21	do	4.7	.077	53.64	.45	
22	do	5.7	.170	53.10	.59	
23	do	11.0	.118	39.36	1.82	
24	do	9.4	.230	49.04	1.12	
Average		7.0	.127	48.75	.98	
25	Fritz Ackermann	15.3	.184	43.16	2.54	.144
26	do	6.4	.077	51.00	.89	
27	do	11.2	.148	44.00	1.50	
28	do	8.4	.150	51.40	.67	
29	do	5.5	.114	50.06	.85	
30	do	5.5	.145	58.88	.84	
31	do	7.2	.104	48.20	1.19	
Average		8.5	.132	49.53	1.21	
Over-all average		6.8	.122	51.02	1.02	.186

TABLE 3.—*Results of sampling of Navio-Chumbo group of manganese deposits, Serra do Navio district, Brazil, by A. E. Walker, M. A. Hanna Co.*

[Analyst: W. A. Markert, M. A. Hanna Co.]

Trench	Deposit	Number of samples	Mn	Fe	P	SiO_2	Al_2O_3	CaO	MgO	TiO_2	As	S	V	Loss by ignition
NE 1	Chumbo	10	41.91	8.18	0.080	3.14	6.91	0.07	0.036	0.24	0.197	0.014	0.102	12.00
2	do	15	37.91	13.72	.167	4.84	6.94	.11	.043	.24	.122	.029	.127	10.91
3	do	11	48.60	4.80	.081	2.31	4.03	.09	.050	.25	.111	.007	.127	10.27
4	do	8	53.65	3.55	.049	.56	3.47	.08	.037	.16	.037	.008	.082	11.00
NW 1	do	12	52.92	4.93	.096	.88	3.07	.10	.036	.12	.117	.017	.102	10.25
2	do	8	48.09	6.84	.143	.79	4.16	.07	.036	.24	.110	.012	.127	10.43
3	do	9	46.31	5.50	.076	3.93	6.03	.09	.044	.32	.069	.008	.177	11.46
4	do	14	32.23	19.12	.203	3.09	6.43	.08	.035	.24	.249	.011	.152	12.08
S 1	Navio	9	41.38	10.61	.135	4.69	5.68	.08	.051	.34	.097	.011	.152	11.43
2	Clemente	10	50.92	5.25	.102	1.19	4.02	.06	.050	.22	.152	.020	.102	10.54
3	Unnamed	9	50.35	6.74	.118	1.01	2.90	.80	.050	.18	.113	.009	.127	10.28
Specials	do	10	45.87	4.53	.091	2.99	6.10	.07	.050	.36	.082	.006	.126	10.65

TABLE 4.—*Break-down of detailed sampling by manganese content of samples from Serra do Navio district, Brazil*

Sample group [1]	Present deposit name	Number of samples	Percent Mn				
			Above 50	50 to 45	45 to 40	40 to 30	Below 30
NE 1	Chumbo	10	2	2	3	2	1
NE 2	do	15	4	3	1	1	6
NE 3	do	11	7	2			2
NE 4	do	8	8				
NW 1	do	12	10	1	1		
NW 2	do	8	2	4	2		
NW 3	do	9	3	3	2	1	
NW 4	do	14	2	2	2	3	5
S 1	Navio	9	1	1	3	4	
S 2	Clemente	10	7	1	1	1	
S 3	Unnamed	9	3	6			
Specials	do	10	5	3		1	1
1 to 6	Baixinho	6	5			1	
7 to 12	Macaco	6	6				
13 to 18	Gurita	6	6				
19 to 24	De Paiva	6	3	2		1	
25 to 31	Fritz Ackermann	7	4	1	2		
Total		156	78	31	17	15	15
Percent			50	20	11	9	10

[1] See tables 2 and 3 for explanation of samples.

TABLE 5.—*Results of sampling by N. H. Van Doorninck, for William H. Muller & Co., of manganese deposits, Serra do Navio district, Brazil*

[Samples dried at 212° F. Analysts: Booth, Garret, and Blair]

Deposit	Sample	Boulder or outcrop	Mn (percent)	SiO_2 (percent)	P (percent)	Fe (percent)	Al_2O_3 (percent)	Cu (percent)	As (percent)
Fritz	A	O	50.89	2.07	0.107	4.36	4.45	0.04	0.15
Padeiro	B	O	52.33	1.11	.132	5.52	2.62	.05	.20
Navio	C	B	36.76	7.98	.075	6.84	12.19	.08	.11
Do	D	B ?	47.07	2.35	.111	6.83	5.62	.07	.15
Do	E	O	45.38	1.85	.175	8.88	4.93	.05	.13
Do	F	O	50.38	.78	.117	6.08	3.53	.14	.12
Baixio	G	O	53.17	.64	.074	2.65	4.44	.04	.11
Bacelar	H	O	51.90	1.17	.054	3.66	4.70	.02	.10
Chumbo	I	O	45.43	4.64	.099	7.01	6.42	.02	.10
Janot	J	O	43.57	5.63	.105	8.26	6.67	.01	.06
Antunes	K	O	51.41	2.36	.104	4.62	4.21	.02	.07
Chumbo	L	O	46.63	1.69	.125	9.18	4.73	.03	.07
Clemente I	M	O	52.09	.72	.089	5.32	3.27	.02	.11
Chumbo	N	O	45.06	4.26	.077	4.22	9.83	.02	.12
Do	O	O	52.67	1.22	.075	4.99	2.98	.02	.15
Do	P	O	53.74	.90	.072	3.93	3.06	.02	.12
Do	Q	B	43.67	2.39	.113	8.99	7.32	.05	.08
Average			48.36	2.46	.077	5.96	5.35	.04	.11

Lead: none in any sample.
Zinc: less than 0.01 in any sample.

Table 5 shows that Van Doorninck's samples average 48.4 percent manganese, including sample C, which, judging from the high Al_2O_3 and SiO_2 content, must have included much soil. The average manganese content of Van Doorninck's outcrop samples is 49.6 percent.

It is impossible to break down Walker's 156 samples into boulder and outcrop samples. Certain of them, however, do not seem to be consistent with the majority of the samples taken by Walker or other workers. These include 11 samples that contain over 20 percent Fe (maximum, 49 percent), which may represent canga and ferruginous laterite, and an average of 19.2 percent manganese. Four samples with more than 30 percent combined Al_2O_3 and SiO_2, which may represent partially altered protore or manganiferous laterite, contain an average of 21.7 percent manganese. The elimination of these 15 erratic samples results in an average grade of 50.1 percent manganese for Walker's samples.

Ackermann [18] gives the results of 25 partial analyses, all above 50 percent and running as high as 58.24 percent manganese. Seven complete analyses cited by the same author average 49.99 percent manganese.

Thus it would appear that the average outcrop ore might contain about 50 percent manganese. Boulder ore would be expected to run several percent lower, and granzon ore will possibly average even less.

Data on tenor at depth are sketchy. The maximum ore penetrations are said to be about 10 meters below the outcrop at Chumbo, where a diamond-drill hole penetrated to that depth in the river outcrop, finding ore said to run over 53 percent manganese. The adit in the same deposit entered the ore about 18 meters below the outcrop and 20 meters in from the portal, showing ore running just over 50 percent manganese, according to the concessionaire company.

In February 1949 the use of diamond drills was started on the Chumbo deposit. The first hole, located in the area mapped as bouldercrop some distance back from the river, was drilled for some 55 feet (18 meters) in manganiferous material. Some of this material was hard, giving cores that ran to over 50 percent manganese; some, however, was soft and gave no cores. Sludge analyses, judging from descriptions of the sludge boxes, cannot be truly representative. They are said to range from 42 percent to over 50 percent manganese. The drilling was stopped at 55 feet because of lack of proper bits and casing.

The high-grade ore is not likely to continue to great depth, for it is a result of solution and precipitation, possibly many times repeated by surface waters. Impurities are removed during this process, and the manganese is concentrated. Relatively free circulation must occur in the upper vuggy zone, but at greater depth the rock will be more impure and probably somewhat less porous. The writers believe that the samples described will probably be valid for almost all the ore classed as visible and possibly for a fair percentage of the ore

[18] Ackermann, Fritz, op. cit., pp. 14–15.

classed as probable. There is now no indication as to how much of the ore classed as possible may be of high grade; almost certainly some of it will be, but with equal certainty, some of it will not. It is to be expected that silica will become more abundant with depth as well as iron and alumina.

A low, but fairly constant, percentage of arsenic has been found in almost all samples. Because the effect of arsenic in steel making is not widely known, the following citation from a handbook of the United States Steel Co.[19] is made:

Influence of Arsenic:—This element does not occur in any of the iron ores from the Lake Superior region, and is, therefore, never found in steels made from these ores. When present, however, in small amounts, unless special precautions are taken in making an analysis of the steel, it is reported as phosphorus. Arsenic does not affect the hot or cold working properties of steel until its content reaches 1.0 percent; above 0.25 percent its effect is similar to that of phosphorus. In normalized low carbon (0.15 percent) steel arsenic up to 0.1 percent raises the tensile strength and elastic limit about 560 lbs. per square inch for each 0.01 percent increase in the arsenic content. From 0.1 percent to 0.8 percent the strength increases more slowly, declining to about 180 lbs. per sq. in. for each 0.01 percent of arsenic. The ductility and impact values suffer a corresponding decrease. In harder grades of steel, the loss in ductility attributable to arsenic is more pronounced. With up to 0.25 percent arsenic, the welding properties remain unaffected, injurious effects beginning to appear only in gas welding. The element is without effect upon the solidification phenomena, arsenic segregating as does carbon, phosphorus, and sulphur. Arsenic used in conjunction with copper, or with chromium, silicon and certain other elements is said to increase the resistance to atmospheric corrosion, and to be beneficial as an addition to steel for ship plates.

It can be seen that if 14 pounds of ferromanganese made from Navio ore were used in making 1 ton of steel and if the ferromanganese contains 0.2 percent arsenic, only 0.025 pounds or 0.001 percent arsenic would be added to each ton of steel (assuming no loss by volatilization). According to the paragraph quoted, this would not affect the properties of the steel.

Physically, the outcrop ore is hard enough to stand transportation with the development of only a very small percentage of fine material. It is porous enough to be easily reduced in the furnace. With depth, these characteristics can be expected to lessen, but at what depth the change will occur cannot be surmised. It is probable that all the visible ore and much of the probable ore will be of good physical quality.

EXPLOITATION PROBLEMS

The tonnage and grade of ore present in the Serra do Navio district appear to be satisfactory for commercial purposes. It may therefore

[19] Camp, J. M., and Francis, C. B., The making, shaping and treating of steel, 5th ed., p. 920, Carnegie-Illinois Steel Corp., 1940.

be said that development of the district is largely a problem of transportation. Because the type and scale of transportation should be determined by details of quantity and distribution of ore, it is essential that the reserves at each deposit, as well as for the district as a whole, be established with some care. Transportation by truck to the river, thence by barge to Porto Grande, thence by rail to a port to be established near Macapá might prove most economical if the reserves are scattered and prove to be of the magnitude estimated. If, as is possible, reserves prove to be significantly greater, it might be more economical to build a railroad into the district and to bring ore from the deposits by aerial tram to one or two central loading areas, for the ore would move downhill to the railroad and trucking roads would be hard to maintain. These questions cannot be settled until drilling, tunneling, and test pitting have established the amount and location of the reserves with some precision.

MINING

Most of the ore can be extracted by simple open-pit methods. Bodies such as Chumbo and Antunes, which seem to have a relatively low dip, may eventually have to be attacked by underground methods, but until water level is reached, no unusual mining problems should arise. Though the nature of the hanging wall is unknown, it is probably deeply weathered and soft, facilitating stripping operations. Stripping of soil and concentration of granzon may be accomplished in some localities by damming streams to provide water for hydraulicking; in most places this will not be possible, as the ore is high on the slopes.

Deforestation of the ore bodies will be difficult. Because of the wet climate and consequent rapid development of second growth, cutting probably should not be done on a large scale until operations are to begin. Bulldozers and stump pullers will be very useful. The forest in most places is open enough for easy movement, and if adequate maps are made, there is little advantage to be gained from premature deforestation.

RIVER CONDITIONS

No precise data are available on the regimen of the Amapari and Araguari Rivers. They are said to be full 8 months of the year, low for 4 months. At flood they are swift, wide, and unbroken by rapids. In a few places swirls and chutes mark the presence of rocks and reefs that present a danger to navigation, but generally speaking, navigation by well-designed, well-powered barges of several hundred tons should not be too difficult during 6 to 8 months of the year. Controlling depth is said to be 4 feet from Chumbo to Porto Grande for 8 months of the year, much more during the 6 months of greatest flow. At low water jagged reefs are seen, and in September much care must be exercised in navigation with a canoe and outboard motor. The velocity of the current in flood was visually estimated at about 6 miles per hour in the faster spots; this must be carefully checked before transportation plans are made.

ROADS AND RAILROADS

The road from Macapá to Pôrto Grande, now under construction, is marked by long tangents, easy curves, and—with minor exceptions—very slight grades. According to Van Doorninck's count, there are 60 to 70 culverts and a bridge in the 120 kilometers between Porto Grande and Macapá. Much of the road is now unsurfaced, and much of it lies at or below the level of the plain. Drainage ditches in many areas do not fulfill their function and remain full of water. Were the road built up above the surface of the plain, surfaced with material from the layer of laterite nodules mentioned on page 7, and carefully maintained, a fine all-weather road suitable for heavy trucking would result.

That the stretch between Macapá and Porto Grande would be easy for cheap and rapid railroad construction can be inferred from Van Doorninck's culvert count.

Two railroad routes have been considered by engineers interested in the development of the Navio district: (1) from the Navio district more or less in a straight line to the projected port of Sant' Ana and (2) from Sant'Ana to Porto Grande and up the Araguari-Amapari river system to the deposits. The first would have the advantage of passing within some tens of kilometers of the Santa Maria iron district, which then might become economically important, but this route would have the disadvantage of being built through extremely difficult, hilly, forested country as yet almost unexplored. The second might be somewhat longer but would take advantage of the flat, open country between Macapá and Porto Grande. River transportation for supplies and materials could be effectively used during construction, thus speeding the work and making it cheaper. The easily built stretch from Porto Grande to Macapá could be combined with river transportation for the export of ore while the stretch from Porto Grande to the Navio district was being completed. This route would tap the Araguari-Amapari river system, the natural arteries of this part of the Territory, for forest products as an extra source of revenue.

PORT FACILITIES

No port facilities now exist for handling ocean freight in the Territory of Amapá. Macapá is served by a jetty some 400 meters long, but there is only a fathom or so of water at the end. Some 12 kilometers up the Amazon is the projected port of Sant'Ana, where soundings have shown that deep water extends right to the river bank. Several steamship companies have investigated this site as an alternative to Belem, now the chief port of the Amazon Valley. According to information available in Macapá, there is no natural reason why this place cannot be developed as a port for large oceangoing vessels. Soundings have shown that the north arm of the Amazon is navigable for oceangoing ships, with a controlling depth at the bar of 6¾ fathoms at mean low water.

APPENDIX

PETROGRAPHIC DESCRIPTION OF SPECIMENS FROM THE SERRA DO NAVIO DISTRICT, BRAZIL

By Evaristo Penna Scorza

The following specimens were collected by Glycon de Paiva and described petrographically by Evaristo Penna Scorza, of the Departamento Nacional da Produção Mineral, Brazil:

Specimen R (amphibolite).—Gray rock of granoblastic texture, jointed. Composed of hornblende, labradorite, augite, titanite, scapolite, apatite, epidote, calcite, and iron oxide. The feldspar crystals are fine and show no signs of disturbance. They are usually zoned.

Specimen Aa (amphibolite near Navio).—Gray rock of granoblastic texture, slightly laminated. Composed of hornblende, labradorite, apatite, hematite, and altered titanite. Feldspar crystals are fine and usually zoned.

Specimen Bb (hornblende schist from Navio).—Gray rock of laminated texture. Composed of hornblende, labradorite, pyrite, arsenopyrite, hematite, and a little apatite. Some of the hornblende and plagioclase crystals are bent and fractured.

These three rocks appear to have resulted from a regional metamorphism of calcic and magnesian sediments.

The large number of elements forming the minerals of specimen R, the presence of scapolite and calcite among the minerals, and the presence of fine crystals of plagioclase forming groups that occupy continuous areas lead to the supposition that the rock has a sedimentary rather than an igneous origin.

Chemical tests of specimen Bb, hornblende schist, show that the content of manganese in the rock is less than 1 percent, indicating that the amphibole is common hornblende rather than the manganiferous amphibole dennemorite.

Specimen E1 (hornblende schist).—The lamination of this rock is fine and shows distinct layers of plagioclase and quartz, intercalated in the darker parts of the rock. It is composed of hornblende, labradorite, quartz, titanite, pyrite, arsenopyrite, iron oxide, and a little apatite.

This schist seems to have the same origin as those already described. The quartz appears to have been introduced into the rock, at least in part, as veins.

Specimen E. R. A. (alkali granite from Castanhal or Veado rapids upstream from Navio district).—A light-colored, coarse-grained rock with dark spots produced by biotite. It is composed of very abundant microcline, quartz, biotite, oligoclase, myrmekite, zirconite, and iron oxide. Some of the biotite is chloritized.

Specimen C (quartzite from Navio). Metamorphic rock composed principally of quartz. Many very tiny crystals of amphibole are disseminated among the quartz crystals. There is a little iron oxide.

Specimen D (quartzite in river near Chumbo).—This quartzite has many knots of augite and amphibole crystals resulting from the metamorphism of impure dolomitic limestone deposited with sand grains. Pyrite and iron oxide also are found. Among the augite crystals are remnants of calcite crystals.

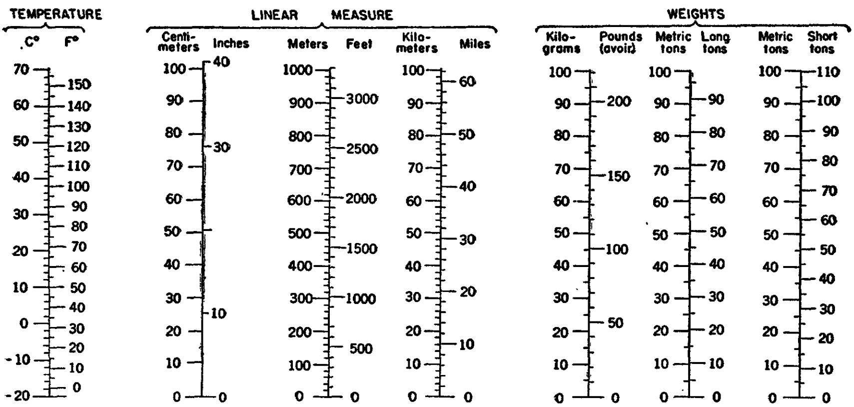
Specimen J (gondite).—A metamorphic rock composed principally of spessartite and quartz. In this specimen are much manganese oxide (cryptomelane) and iron oxide (hematite) derived from the alteration of spessartite. The spessartite appears as euhedral rhombododecahedral crystals with fracture planes along which the formation of iron and manganese oxides has already started. This alteration along fracture planes causes an interesting reticulate network in the body of the spessartite crystal.

Specimen (diabase from the Igarapé da Pedra Preta).—Eruptive rock of ophitic texture composed of labradorite, augite, magnetite, and biotite. Uralite and chlorite are found as alteration products.

Manganese ore.—The manganese ore collected by Glycon de Paiva in the Territory of Amapá is the mineral cryptomelane. As well as manganese and oxygen, the elements iron, potassium, and zinc and traces of arsenic and calcium are present. The absence of barium and cobalt was established.

Physical properties are as follows: specific gravity, 3.9; hardness, 6.5; streak, brown.

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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