Uranium at Morro do Vento Serra de Jacobina Brazil

GEOLOGICAL SURVEY BULLETIN 1185-A

Prepared for the U.S. Atomic Energy Commission on behalf of the Brazilian National Nuclear Energy Commission

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By MAX G. WHITE

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By Max G. White

ABSTRACT

Uranium associated with gold and pyrite in conglomerate and quartzite of Precambrian age is found at Morro do Vento, about 12 kilometers south of the town of Jacobina in central Bahia, eastern Brazil. Morro do Vento is one of the hills that make up the western front of the Serra de Jacobina. The mineralization is thought to be of hydrothermal origin, the minerals having been emplaced from solutions introduced along a possible fracture or fracture zone. In the principal deposit, the Main Reef, the mineralized rock averages about 2 meters in thickness in a strike length of 1,260 meters. The mineralized rock crosses quartzite beds or conglomerate lenses or beds, and its distribution is in no way controlled by these lithologic units. Near-surface sampling of the Main Reef indicates an average grade of 0.008 percent equivalent uranium oxide. Gold assays of these samples show an average of 10.0 grams of gold per metric ton of rock.

INTRODUCTION

The Serra de Jacobina, of which Morro do Vento (Wind Hill) is a part, is in the north-central region of the State of Bahia, northeast Brazil. The Serra is a narrow, prominent range that stands out in sharp relief above the adjacent plains and has altitudes of 600 to 800 meters; peaks reach altitudes of approximately 1,100 meters. The adjacent plains have an average altitude of about 450 meters. The principal town in the area is Jacobina (fig. 1) which is accessible from Salvador, the capital city of the State of Bahia, on the coast, by a dirt road; the road distance is about 360 kilometers. The town is a scheduled stop of one commercial airline. The Estrada de Ferro Leste Brasileiro (Eastern Brazil Railroad) serves the region and connects it with the seaport of Salvador. Morro do Vento has an altitude of about 910 meters and is about 12 kilometers south of Jacobina.

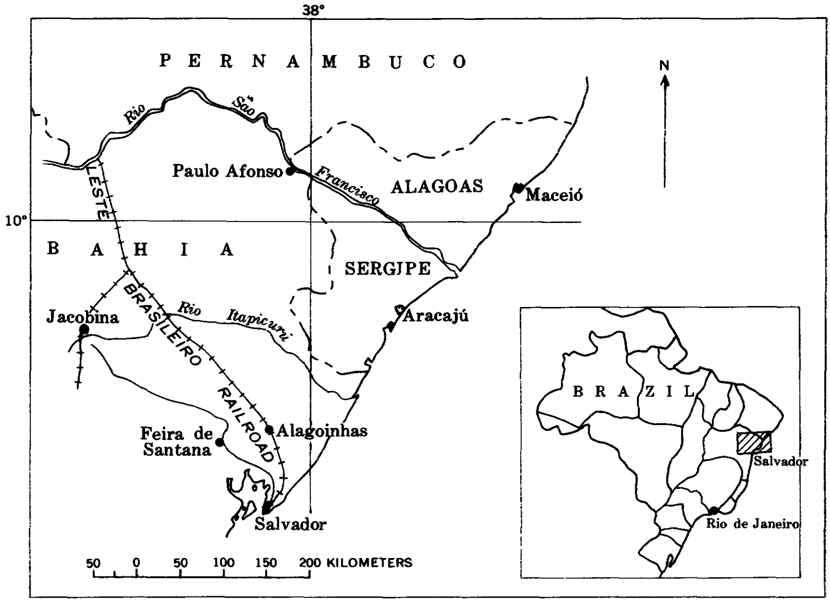

FIGURE 1.—Index map of a part of eastern Brazil, showing location of Jacobina, Bahia.

The gold deposits of this region have been known and mined since the latter part of the 17th century. Most of the mining of both the lode deposits and the placer gold from the beds of streams that drain the Serra has been on a small scale. A few attempts have been made to establish large-scale mining operations, but these have failed for various reasons, not always related to the tenor of the gold ores. The Canavieras mine (White, 1957) is the only operating mine in the Serra at the present time (1961).

The writer is indebted to Donald D. Haynes and John J. Matzko, geologists of the U.S. Geological Survey; to Haynes for work done in the field and for assistance in the compilation of the figures, and to Matzko for his contribution to the mineral determinations. Elysiario Tavora of the Departamento Nacional da Produção Mineral in Rio de Janeiro made the original determination of uraninite by X-ray diffraction. C. J. M. Hamilton and Armando S. de Oliveira, associated with Ventures, Ltd., in Salvador and at the Canavieiras mine, contributed in many ways to the reconnaissance investigation reported here. Uranium determinations were made in the Laboratorio da Produção Mineral in Rio de Janeiro. Fire assays for gold were made in the U.S. Geological Survey laboratory in Denver, Colo.

This work was done for the U.S. Atomic Energy Commission on behalf of the Brazilian National Nuclear Energy Commission.

GEOLOGICAL SETTING AND STRUCTURE OF SERRA DE JACOBINA

Branner (1910) described the rocks of the Serra de Jacobina and gave them the name Jacobina Series. The section he described consists mostly of quartzite but contains some slate and schist at the top and conglomerate beds at the base of the quartzite. Oliveira and Leonardos (1943, p. 128) report that the series commonly contains, interbedded in the quartzite, hematite deposits of the itabirite type of the State of Minas Gerais. They consider the Jacobina Series to be of early Algonkian age, corresponding for the most part to the Minas Series—which contains the extensive iron deposits of Minas Gerais—but partly also to the Itacolomi Series.

Recent geological investigations by various workers (White, 1956, 1957; Bateman, 1958) show that the geologic section of the Serra de Jacobina in the vicinity of the town of Jacobina consists of white quartzite that contains some sandstone but no conglomerate, and is underlain by white quartzite containing numerous conglomerate beds. The white quartzite beds comprise the rocks described by Bateman (1958, p. 419) in the vicinity of the Cañavieiras mine as the Canas Group (improperly spelled "Canus Group"). The conglomerates are restricted to the western flanks of the Serra, and thus far have been found only over a distance of 27 kilometers, from about 3 kilometers north of Jacobina south to the end of the range. The conglomerates lie in contact with granitic rocks. On the eastern border of the Serra the white quartzite is overlain by metasedimentary rocks—slate and phyllite. Pockets of high-grade manganese oxide that are found in the quartzite appear to be a local enrichment.

Highly weathered dark-colored dikes of what probably was an ultramafic rock (possibly pyroxenite) cut the quartzite-conglomerate section in a few places. No preferred orientation of the dikes has been observed, but many dikes are known to lie in some of the north-south faults.

The rocks in the Serra de Jacobina dip eastward at high angles (45° to 70°), and strike northward parallel to the trend of the range. Details of the structure of the range are not known as yet, but the high angle of dip of the rocks within the slight width of the Serra seems to indicate that any minor yet persistent variation in strike of the quartzite away from the elongation of the Serra would project the line of strike of the basal conglomerate out of the Serra at some short distance north of Jacobina. High-angle faults in the Serra de Jacobina are numerous, and many of the morros (hills) that make up the range are known to be fault blocks. Possibly the conglomerates north of Jacobina have been removed by faulting.

MORRO DO VENTO DEPOSITS

DESCRIPTION AND LOCATION

Morro do Vento, one of the hills that make up the western front of the Serra de Jacobina, is reached from Jacobina by jeep road through Itapicurú, a village near the base of the morro (fig. 2). Itapicurú is

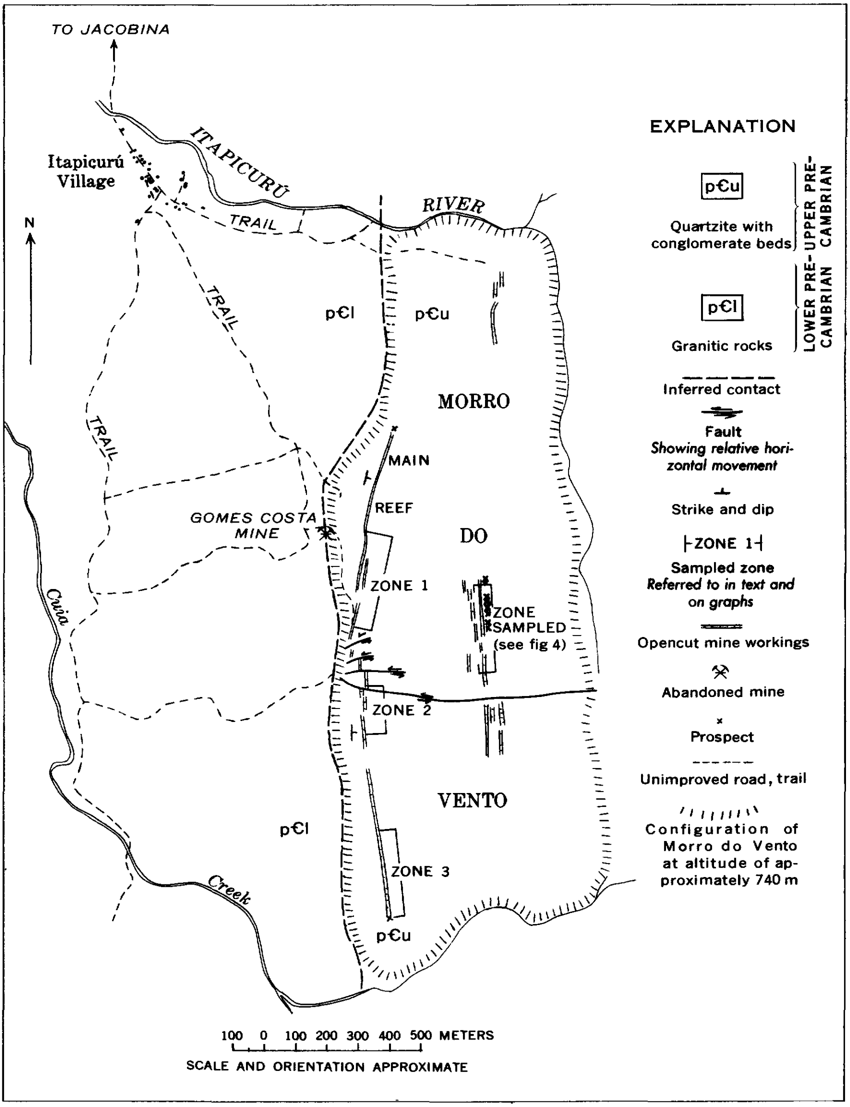

FIGURE 2.—Sketch map of Morro do Vento and vicinity, showing mines and prospects and principal deposits sampled. Base map compiled from aerial photograph; no vertical control available. Geology by Max G. White and Donald D. Haynes, 1957.

about 2 kilometers airline distance southwest of the Canavieiras mine, where the uranium of the Serra de Jacobina was first discovered and described (White, 1957; Bateman, 1958).

Uraniferous pyritic gold-bearing conglomerate and (or) quartzite have been found in various hills along the western front of the Serra de Jacobina from about 3 kilometers north of Jacobina southward to the end of the Serra, a distance of about 26 kilometers. The outcrop radioactivity of the deposits at Morro do Vento is higher than at any other deposits examined in the Serra de Jacobina.

Fieldwork done in 1957 on the uraniferous gold ores of the Serra de Jacobina was concentrated on the Morro do Vento deposits. Gold-mining development work has been more extensive here than on any of the other hills on the western front of the Serra, and has resulted in extensive workings in the gold-mineralized rocks, which also contain the uranium.

MINING

Gold has been mined on a small scale in the Serra de Jacobina since the late 17th century. The workings on Morro do Vento are relatively recent. Mining activity was most intense during the midthirties. Very little work is in progress at present. The commercial center of mining activity for Morro do Vento was the present village of Itapicurú, said to have been, during the 1930's, equally as important as the town of Jacobina. Most of the gold mining was done by rather primitive hand methods and little or no mining machinery has ever been used. The gold deposits were not developed to great depth—the deepest working reported is about 15 meters down the dip. Only one attempt at development has been reported by a mining organization. This was done by a Portuguese-Brazilian mining group that developed what is known as the Gomes Costa mine (fig. 2) on the lower slopes of the west side of Morro do Vento. This venture was of short duration and the mine is reported to have closed down in the late 1890's.

Although pits, trenches, and other prospecting operations can be found over much of the surface of Morro do Vento, mining operations were started in only four localities on the morro (fig. 2): in the extensive mineralized layer, the Main Reef[1] on the lower slopes of the west side of Morro do Vento in conglomerate and quartzite; on top of the morro in quartzite-conglomerate beds; on the northeast side of the morro, in a gold-bearing conglomerate-quartzite zone; and at the Gomes Costa adit and drift in a pyritized conglomerate, quartzite, and sandstone layer below the Main Reef near the contact of the quartzite and granite.

[1] The term "reef" is used locally, as in South Africa for the gold-bearing conglomerates. For convenience, "reef" is adopted here.

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Most of the investigations reported here were centered on the Main Reef and on the workings at the top of Morro do Vento, inasmuch as the highest radioactivity was detected in these two areas.

GEOLOGICAL SETTING

Quartzite, sandstone, and conglomerate comprise the sedimentary section of Morro do Vento; these rocks are white to light buff. Where mineralized, the rock is light green or reddish to dark brown. The quartzite is the commonest of the three rock types and is generally quite fresh, hard, and brittle. There is a small amount of sandstone on the morro. It is particularly evident on the western lower slopes of the morro at the north end of the main mineralized layer (Main Reef) and in the vicinity of the fault that bisects the hill in an east-west direction (fig. 2).

Conglomerate occurs throughout the quartzite in discontinuous beds or in lenses as much as 12 meters thick. The pebble-cobble constituent of the conglomerate ranges in size from pebbles averaging less than half a centimeter in diameter to cobbles of 10 to 12 centimeters in diameter. One elongated boulder found on the lower slopes of the morro measured 18 centimeters. The pebbles probably average between 3 and 5 centimeters.

At the foot of the west slope of Morro do Vento the sedimentary rocks are in contact with granite. These rocks are highly weathered, generally to a reddish clay. At best, only relict structures and kaolinized phenocrysts of the original rock can be seen. Whereas no fresh granite was seen in the vicinity of Morro do Vento, it is found along the western front of the Serra de Jacobina to the north of Morro do Vento. Where it is fresh, the rock is pink or gray granite gneiss. No abnormal radioactivity has yet been detected in this rock in the vicinity of Morro do Vento.

Quartzite and conglomerate beds containing gold, uranium, and pyrite have been found at various elevations on Morro do Vento—from the top (altitude about 910 meters) to near the granite contact at the Gomes Costa adit (altitude about 735 meters). At this location the interval between the floor of the adit and the underlying granite contract is covered, but is probably no more than 2 to 3 meters. Thus, mineralized rock is found very close to the base of the sedimentary section.

STRUCTURE

The rocks at Morro do Vento strike approximately north-south and have dips averaging about 55° E. The morro is a fault block bounded on the north, west, and south sides by faults. On the west side of the hill the conglomerate-quartzite is in contact with granite, which is highly weathered. The contact is not easily located because of cover. Within Morro do Vento, at least one major east-west fault cuts across it near its center, and several small faults parallel to the larger one offset the Main Reef (fig. 2). North-south faults (parallel to the strike of the rocks) are not easy to identify in the morro. Between sample localities J–195 and J–196 in zone 1 (pls. 1 and 2) of the Main Reef, the conglomerate and quartzite have a vertical displacement of 3 to 4 meters between what may be two parallel faults about 5 meters apart (it is not clear whether these are pre-erosion faults or slump blocks). If these are faults, they are normal and strike virtually north, parallel to the regional strike of the rocks; the dip of the fault plane is about 70° W., whereas the rocks dip to the east. This is the direction of strike of the faults that displace the uraniferous gold-bearing conglomerate bed (or beds) in the Canavieiras mine northeast of Morro do Vento (White, 1957). This is the only faulting observed that was parallel to and near the contact of the quartzite and granite. The faults can be traced for only a few meters on strike. Slumping, with the plane of movement parallel to the regional strike, occurs at the south end of zone 1 in the vicinity of sample localities J–200 and J–201 (pl. 2).

The Main Reef appears to conform to the strike of the conglomerate and quartzite beds, but possibly occupies a fracture zone along which are many quartz stringers and veinlets, pyrite, mica, and associated minerals in fracture and vug fillings. The quartz stringers are as much as 2 cm in width and cut both conglomerate and quartzite.

MAIN REEF DEPOSIT

LITHOLOGY

The Main Reef is a mineralized zone or layer in conglomerate and quartzite; it extends for 1260 meters from the south end of the lower slopes of the west side of Morro do Vento at least two-thirds of the distance to the north end. The workings on the reef at the north end terminate where the slope becomes vertical, and the reef was not traced further. The reef ranges from about ½ to 10 meters in thickness and averages about 2 meters. This mineralized layer does not coincide with nor is it controlled by any continuous lithologic unit in the quartzite-conglomerate section; rather it apparently is parallel to the strike of the enclosing sedimentary rocks and is composed of either mineralized conglomerate or mineralized quartzite or both.

The lithologic discontinuity of the rock types in the Main Reef is illustrated in plate 1. The geologic sections shown in the figure are those made across the reef (from the top to the bottom of the mineralized rock) at the locations where continuous chip channel samples were collected for gold assaying. This sampling was done over a strike length of 292 meters of outcrop of the part of the reef designated as zone 1 (pl. 1). The sections consist of quartzite and conglomerate. Quartzite represents about 45 percent of the rock in the sections and conglomerate about 55 percent. Two types of conglomerate were found: a small-pebble conglomerate in which the pebbles average less than 1 cm in diameter and grade downward into a grit or coarse sand; and a coarse-pebble conglomerate in which the pebbles average about 3 cm, but may have an extreme size of 10 to 12 centimeters. The small-pebble conglomerate constitutes 28 percent of the total rock in the geologic sections and the coarse-pebble 27 percent. The conglomerate within the mineralized reef forms discontinuous lenses or beds of varying thickness ranging from about 3 cm to several meters in the quartzite; there seemingly is no pattern of distribution of conglomerate or quartzite within the mineralized layer. This lack appears to be so whether one considers the rather sizable length of the part of the reef shown in plate 1 as between samples 11 and 16, or in a shorter length of the reef as between samples 6 and 10.

Both quartzite and conglomerate are generally fresh, hard, well compacted, and highly silicified and tend to shatter easily in a radiating pattern upon blasting. Individual pebbles in the conglomerate are difficult to distinguish in hand specimens because of the general blending effect of matrix with pebbles, produced by silicification and other mineralization. Effects of sericitization, which took place possibly along with silicification, are common throughout the reef.

Sections 1, 3, and 4 (pl. 1) are within mineralized rock, and terminate at the limits of that rock. The top of the sections is in a bed or lens of small-pebble conglomerate, and the bottom in quartzite. These circumstances demonstrate that the lithologic unit is not necessarily a controlling factor of the thickness of the mineralized zone. On the other hand, section 2, in quartzite, does terminate at the very base of the fine-pebble conglomerate shown at the top of sections 1, 3, and 4. Because the Main Reef has been extensively excavated in gold mining over most of its length, because most of the excavations are now filled with mining debris or water, and because only short lengths and pillars of exposed reef remain, it is rather difficult to follow any given conglomerate, quartzite bed, or lens along strike for any appreciable distance within the mineralized zone. For these reasons no detailed mapping of the reef has been accomplished to date. No relationship is apparent between the mineralization and the rock types or their thicknesses within the Main Reef.

INTRODUCED MINERALS

The principal minerals that have been introduced into the rock to form the Main Reef mineralized layer are pyrite, chlorite, biotite, quartz, gold, and uraninite.

The source of the radioactivity in the gold ores is uraninite, identified by Elysiario Tavora through X-ray diffraction methods in the Rio de Janeiro laboratory of the Departamento Nacional da Produção Mineral. The low values obtained for the unit cell edge of the mineral approach those of cerianite (CeO_2), (Graham, 1955). Spectographic analyses, however, failed to show the presence of cerium, and the identification as uraninite is confirmed. Tavora suggested (oral communication, 1960) that the uraninite is of low- to medium-temperature hydrothermal origin; he based his suggestion on work by Frondel (1957, p. 131), who postulates that low- to medium-temperature uraninite has small to intermediate ranges of cell dimensions and that high-temperature uraninite has the largest cell dimensions.

Pyrite is commonly distributed in the Main Reef in mineralized zones or shoots that have sharp boundaries. These sulfide masses are contained in both conglomerate and quartzite and their boundaries are by no means controlled by the rock types, for they cross both types of rock. These pyrite bodies are generally the most radioactive (as high as 0.5 milliroentgen per hour) parts of the reef and are fairly common throughout the Morro do Vento. At outcrop and to a depth of about 15 meters (depth to which reef has been mined) the pyrite is locally considerably weathered, and consequent oxidation of the pyrite has caused staining of the rock with red and brown limonite.

The mineralogy of the uraninite is not known in detail. The uraninite occurs in microcrystalline grains, dull in appearance and poorly crystallized. It is friable and breaks down easily with crushing. Inasmuch as fragments of the mineral are easily broken with a needle point, the angularity or sphericity of any grain is determined by the manner in which the grain breaks. As a species, the mineral may be technically classified as uraninite. Its general appearance and friability might justify its classification as sooty pitchblende, a variety of uraninite. Figure 3 is an autoradiograph of a rounded grain of uraninite. The fragment, broken in handling, is from a larger angular piece. There is no indication that roundness of the grains implies a detrital origin.

Nuclear-emulsion studies of some of the smaller grains of pyrite show strong alpha-ray emanation traceable to veinlets of uraninite in the pyrite. Some grains of pyrite show strong alpha emanation and, though no obvious source was detected, it is assumed that the tracks are from microcrystalline inclusions of uraninite.

Any part of the Main Reef that is heavily mineralized with pyrite is likely to contain uranium; in general the pyrite content of the rock is directly indicative of the uranium content—where pyrite is lacking, the reef is likely to be devoid of radioactivity.

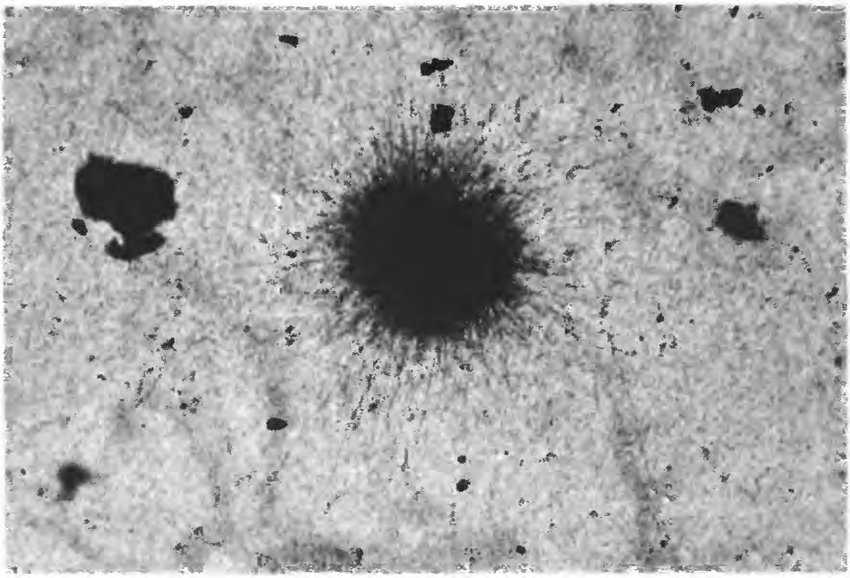

FIGURE 3.—Autoradiograph of rounded grain of uraninite showing intense alpha-ray activity recorded in surrounding nuclear emulsion (× 20). Smaller grains are pyrite or quartz.

An apparent close relation exists between the gold and pyrite. This relation is demonstrated by the gold-extraction practices of the local miners. Hard pieces of pyritized rock, conglomerate, or quartzite are ground in mortars hollowed from the fresh, hard quartzite formation. The resulting fines are panned and the freed gold recovered by amalgamation. The general rule is to select the most pyritic rock for grinding. The parts of the reef that carry little pyrite are worked only because the rock, being generally disintegrated, permits hydraulic recovery of what little gold is present with relative ease.

Free gold is found throughout the reef as exceedingly thin coatings on fracture walls. The presence of free gold in the pyritic rock is considered by the local miners as an indication of low gold content, and such rock is not generally worked. It may be inferred that some gold has been transported from the surface exposures of the mineralized rock, but this does not necessarily imply enrichment elsewhere.

Probably the most characteristic feature of the Main Reef is its green color. The color is due to the presence of sericite which has been stained green by chromium. The identity of this chromium-staining mineral (possibly fuchsite) has not yet been determined nor has its relation to the sericite been established. Octahedrons of chromite have been identified in quartzite. Sericite is widespread throughout the reef and is particularly common in the vicinity of sample locality J–196 (pls. 1, 2), where it comprises an apreciable percentage of the rock. At this locality, green-stained Main Reef is strongly mineralized with pyrite, and the green is mixed with various shades of brown, the result of oxidation of the pyrite. Green is generally characteristic of the Main Reef; brown is localized in the more pyritic zones of the reef. At the extreme north end in the 10-meter wide zone of gold mineralization (pl. 2), a very light green and light tan reflects the low content of chromium-stained sericite and pyrite. The radioactivity in this zone is quite low, as is the gold content. As a guide to prospecting, the green and brown coloration is useful in that it is generally indicative of the presence of uranium-gold-pyrite-rich rock.

The rectilinear extent of the Main Reef suggests that the deposit was emplaced in a fracture or fracture zone, although no direct evidence has yet been found. Such a fracture, probably parallel to the regional strike, is parallel to the major north-south fault system that cuts the Serra de Jacobina. It is possible but unlikely that the lack of continuity of rock types within the Main Reef may be an indication of a slight diversion from parallelism between the strike of the reef and that of the enclosing sedimentary beds.

RADIOACTIVITY INVESTIGATIONS

A special sampling program was undertaken to determine the amount of uranium present in the Main Reef. Forty-two samples were collected over a strike length of 1,260 meters. The distances between sample locations range from 13 to 70 meters and average about 30 meters. This wide spacing of the sampling was necessary because much of the reef has been worked throughout its length, and the samples had to be taken from the remaining pillars and where the bottoms of cuts were not too deeply covered with fill. The samples, therefore, were taken where available rather than where it would have been desirable to take them. At each sample locality, the entire width of mineralized rock was checked in detail with scintillometric equipment, and a sample was collected from a small zone that seemed to represent "average" radioactivity for the width of the reef. An attempt was made to collect samples of the Main Reef from within the outcrop at approximately uniform depth because it was discovered, in sampling at the Canavieiras mine in 1954 (White, 1957), that chip samples taken from the surface of outcrop of the radioactive conglomerate reef in laboratory determinations did not reflect the radioactivity detected at the outcrop—owing to removal of radioactive material from the surface by weathering. After the specific place on the reef where a sample was to be taken was selected, a 6-inch hole was driven into the rock. Approximately one-third of a stick of dynamite was exploded in the hole and a sample collected from the bottom of the cavity thus created. A sample taken from a depth of 6 inches or more in the outcrop is probably not beyond the zone of leaching of uranium and its decay products, but it is believed that the samples were taken from sufficient depth to be more representative of the radioactive rock than would be samples taken directly from the surface.

The rock of the Main Reef commonly is weathered and oxidized. In general, the uranium was found in equilibrium amounts with its decay products in samples of fresh conglomerate or quartzite. Where the rock is weathered, the uranium is not present in equilibrium amounts. The disequilibrium is in favor of the radioactivity readings (laboratory model gamma-ray detectors) and indicates that appreciable amounts of uranium have been leached from the rock. In some samples apparently as much as 50 percent of the uranium has been removed. No thorium was found in any of the samples tested.

Plate 2 shows graphically the distribution of uranium and gold in the samples collected from the Main Reef mineralized layer. The samples contain an average of 0.0076 percent eU_3O_8 (equivalent uranium oxide) and an average of 10.0 grams of gold per metric ton of rock. It should be pointed out that the primary purpose of the sampling was to determine the amount of uranium at each sample site and that, though the samples may have a content representative of the rock, they probably do not have a representative gold content. To determine the latter a different sampling technique would be necessary. The sampling does show, however, that in general the distribution of gold in the samples seems to parallel that of uranium (pl. 2, fig. 4).

Sampling indicates that the uranium in the Main Reef is concentrated in three zones (pl. 2) which are designated as zone 1, zone 2, and zone 3, the first and third being the most pronounced. Zone 2 is not as apparent in the graphic presentation as it is when examined in the field. The cover from mining operations, slumping, and faulting in this general part of the reef makes sampling difficult.

The following summarizes data on the distribution of uranium and gold in the Main Reef, Morro do Vento:

Area sampled	Total length (meters)	Average equivalent uranium oxide (percent)	Average gold (grams per metric ton of rock)	Highest radioactivity in samples (percent eU_3O_8)
Main Reef (42 samples)	1,260	0.0076	10.0	-------------
Zone 1 (11 samples)	292	.012	7.2	0.057
Zone 2 (5 samples)	151	.005	14.3	.013
Zone 3 (8 samples)	276	.011	10.0	.031

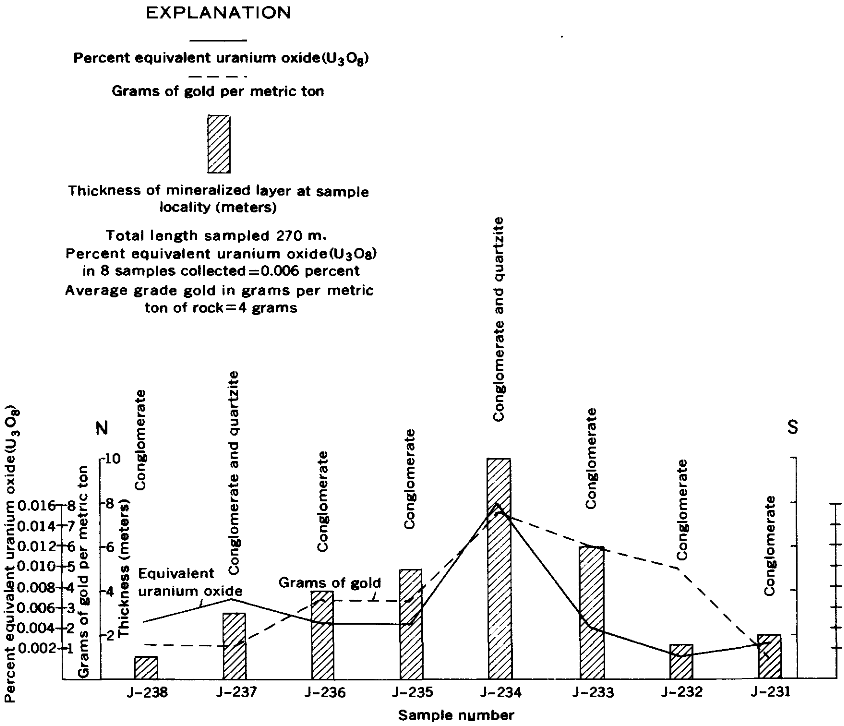

FIGURE 4.—Distribution of uranium and gold in the mineralized quartzite-conglomerate layer at top of Morro do Vento.

Because zone 1 appeared to be the most promising of the three from the standpoint of average grade of uranium, it was resampled to determine the general grade of gold in the reef as well as the amount of uranium present in the gold samples. Plate 1 shows graphically the results obtained from this sampling, which yielded averages of 0.008 percent U_3O_8 and 6.0 grams of gold per metric ton of rock. The samples taken are chip channel samples across the total mineralized width of the Main Reef. Although these samples were not cut to a uniform depth and do not therefore represent a controlled volume of rock collected across the reef, as would be desirable for an accurate determination of the gold content, they probably do represent a fair estimate of the content. Twenty samples were taken within the length of zone 1.

WORKINGS ON TOP OF MORRO DO VENTO

Extensive mine workings on top of the morro extend north and south of an east-trending fault (fig. 2). The workings to the south of the fault are in slightly pyritized rock that is only slightly radioactive. To the north of the fault for a distance of approximately 270 meters, the workings are in mineralized conglomerate and quartzite that are the characteristic green and brown color of the sericitized, pyritic, uraniferous gold-bearing rock.

The principal rock in the mineralized layer or zone at the top of the Morro is conglomerate, mostly of the coarse-pebble type (average, about 3 cm in diameter); it contains very little of the small-pebble conglomerate. The mineralized layer does not occupy a single conglomerate bed or lens. The limits of introduced minerals are within conglomerate beds, and there seemingly is no controlling lithologic feature. At the thickest part of the mineralized layer, which is about 10 meters thick (sample J–234, fig. 4), the mineralized rock extends across a zone of interfingering beds or lenses of coarse-pebble conglomerate and quartzite. At sample locality J–237, the limits of the mineralized layer (includes conglomerate and quartzite beds) are within a quartzite bed; the remainder of the same bed is not mineralized. The mineralized layer pinches out to the north and is there contained within a conglomerate bed less than 1 meter thick. The termination of mineralized rock in that bed is abrupt and marked by a discernible contact between mineralized and unmineralized conglomerate. The strike of the mineralized rock seemingly follows the general north strike of the country rock. The dip is about 55° E. Irregularly distributed throughout the length of the layer are yellow to dark-brown mineralized shoots having sharp borders. These shoots are the more radioactive localities in the workings at the top of Morro do Vento and represent pyrite concentrations in various stages of oxidation. These radioactive shoots are fairly common throughout the Morro do Vento; they may cut conglomerate and quartzite beds or may be within conglomerate or quartzite alone.

Eight samples were collected at sites that represent "average" radioactive rock; their average grade of equivalent uranium oxide is 0.006 percent U_3O_8. Gold assays of the eight samples show an average grade of 4 grams of gold per ton of rock. Figure 4 shows the distribution of uranium and gold in the mineralized quartzite layer at the top of Morro do Vento. There is a general conformity in the distribution of the uranium and gold values, and in general this conformity coincides with the greatest thickness of the mineralized layer. Where as the value for gold in the samples is very low, it should be pointed out that these samples were collected on the basis of the average radioactivity of the mineralized layer and, as with the Main Reef samples, probably are not representative of the average content of gold for the same localities.

Immediately below (west) the workings which were sampled at the top of the morro are discontinuous workings in a mineralized zone about 1 meter in width. Investigation over about 85 meters of these workings shows a radioactivity content no higher than 0.004 percent U_3O_8.

NORTHEAST SIDE OF MORRO DO VENTO

Investigation of some rather extensive workings on the northeast corner of Morro do Vento (fig. 2) revealed no place where radioactivity is higher than 0.002 percent eU_3O_8.

GOMES COSTA ADIT

The Gomes Costa adit is the only underground working on Morro do Vento and was made more than 60 years ago. It was the property of a now defunct Brazilian-Portuguese gold mining company. During recent investigations, the portal to the mine was cleared, and the accessible workings were examined for radioactivity. The workings consist of a 25-meter access tunnel to a mineralized conglomerate quartzite layer that crops out about 40 meters below the outcrop level of the Main Reef. A drift follows the strike of the mineralized layer to the north for a distance of about 60 meters, where it is caved. Local residents reported that this drift has a total length of 130 meters. The highest radioactivity found in these workings is about 0.003 percent eU_3O_8 in a zone in conglomerate-quartzite. Showings of pyrite are slight, as is the green and brown coloration that is characteristic of the uranium-gold-pyrite mineralized rock on Morro do Vento.

RECOVERY

No study has as yet been made of the recovery of gold and uraninite from the deposits at Morro do Vento. There is some indication that the Morro do Vento mineralized rock contains more free gold than the ores of the nearby Canavieiras mine (White, 1957). The close association of uraninite and gold with pyrite that exists at the Canavieiras mine is also present at Morro do Vento.

The uraninite is friable and breaks down easily with crushing. The results of a study of the distribution of uranium in various size fractions of the uraniferous rock are plotted graphically in figure 5. The sample studied was chip-channel sample 14 (fig. 3) which is of fresh unoxidized coarse-pebble conglomerate. This sample has the highest content of equivalent uranium oxide (0.058 eU_3O_3) of all the chip-channel samples taken in zone 1 of the Main Reef. A 700-gram sample was crushed to 20-mesh screen size. The sample was then screened for 20 minutes through a stack of seven standard screens that included the following mesh sizes: 40, 50, 70, 100, 140, 200, 325. The eight

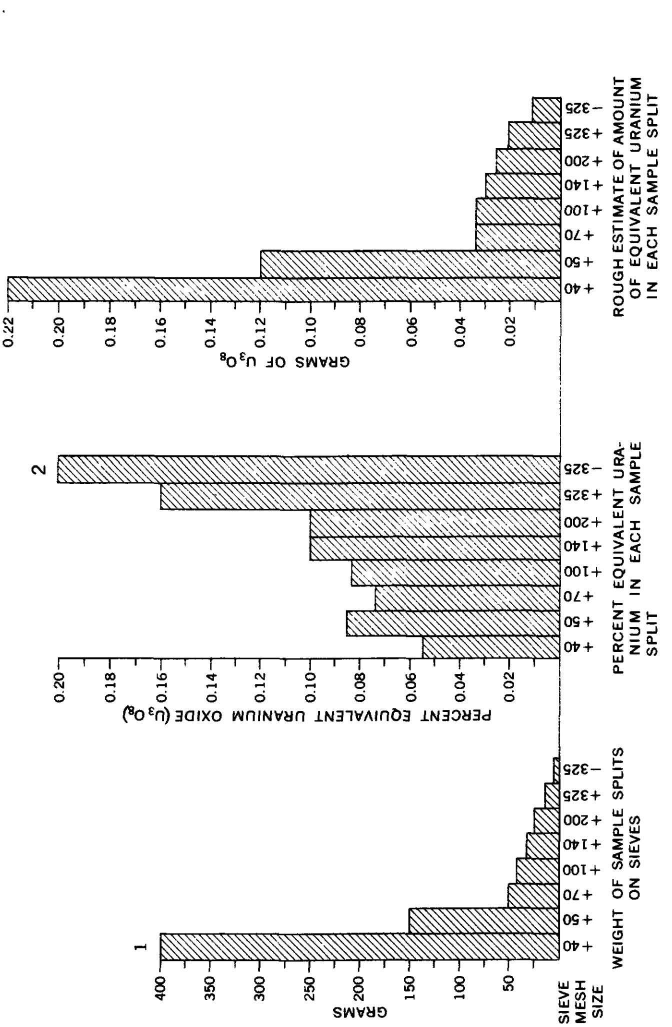

FIGURE 5.—Distribution of equivalent uranium oxide in sample splits of chip-channel sample 14, zone 1, Main Reef mineralized layer, Morro do Vento.

sample splits thus produced were weighed and plotted as graph 1 (fig. 5). Graph 2 represents the percent equivalent uranium oxide in each of the sample splits of graph 1 and shows that the finer fractions contain the higher percentage of equivalent uranium oxide. Graph 3 represents grams of equivalent uranium oxide derived by determining the percentage of equivalent uranium oxide (graph 2) in the various sample splits. The graph-3 data are only a rough estimate of the amount of equivalent uranium oxide present, for they are based on the assumption that the uranium is present in equilibrium amounts with its decay products. The ratio of uranium oxide to total volume of material is greater in the finer fractions of the crushed material, as is indicated by the progressively higher radioactivity readings obtained in the finer fractions (graph 2), although a greater amount of uranium may be recovered from the coarses sample splits (graph 3). These graphs compare favorably with similar graphs prepared for fresh unoxidized ore from the Canavieiras gold mine (White, 1957, fig. 2).

In mining operations, uraninite tends to be concentrated in the finer fractions of mill products. Thus in a sample that is ground to 100-mesh size or finer, the uraninite will be concentrated in the finest size fraction (325 mesh). In other words, the finer the rock is ground beyond 20-mesh size fraction, the more the uraninite tends to be concentrated in the finest fraction—the slimes.

ORIGIN OF DEPOSITS

There seems to be no lithologic control of the gold-uranium mineralization of the reef (pl. 1). The general content and distribution of introduced minerals in the conglomerate may be the same as that in the quartzite. Because there is no consistent pattern in rock types within the mineralized reef—it is thus apparent that the mineralization does not necessarily accompany any definite lithology in the quartzite conglomerate—and because there apparently is no correlation between high values of gold and uranium and any rock type, it is suggested that mineralization of the reef is hydrothermal and not placer concentrated and that the minerals were emplaced from solutions introduced along a possible north-south fracture or fracture zone along the western front of the Morro do Vento, apparently parallel to the strike of the quartzite and conglomerate beds. Direct evidence of the presence of a major fracture is lacking, but the persistent linear exposure of the Main Reef deposit, containing numerous quartz stringers and veinlets as fracture fillings cutting the silicified and sericitized gold-uranium-pyrite-bearing rock, would seem to indicate fracture filling as an explanation of the hydrothermal emplacement of minerals rather than deposition along a porous layer in the section. True, there is evidence of the emplacement of minerals in porous sandstone-quartzite-conglomerate in some of the scattered occurrences on Morro do Vento, but these weak-mineralization deposits occur as rounded masses of no great extent.

The similarity of these deposits (of the Serra de Jacobina) to the uranium-bearing auriferous conglomerates in the Witwatersrand, South Africa, and at Blind River in Canada has been pointed out (Davidson, 1957; Bateman, 1958). The extensive literature on the physical and genetic aspects of this type of deposit well reflects the state of discussion, argument, and even controversy on their origin: whether they are detrital, hydrothermal, syngenetic, or epigenetic deposits. Insofar as the Morro do Vento deposits are concerned, no field evidence was found that would imply that the introduced minerals (acceptably hydrothermal ones) are now or ever have been detrital in origin.

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