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URANIUM IN THE AURIFEROUS CONGLOMERATES
AT THE CANAVIEIRAS GOLD MINE
STATE OF BAHIA, BRAZIL*

By

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URANIUM IN THE AURIFEROUS CONGLOMERATES AT THE CANAVIEIRAS GOLD MINE, STATE OF BAHIA, BRAZIL

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ABSTRACT

Uraninite has been identified in Precambrian gold-bearing conglomerates at the Canavieiras mine in the Serra do Jacobina in the north-central portion of the State of Bahia, northeast Brazil. The uraninite occurs in close association with gold in pyritic, silicified conglomerate beds in quartzite. There is some similarity of occurrence to the deposits in the Witwatersrand conglomerates of South Africa. The gold ores contain from 0.005 to 0.03 percent equivalent uranium. Because of the relatively low uranium content of the ore, it is unlikely that the uranium can be extracted economically except as a byproduct of gold mining on a scale larger than the current production of the mine. The distribution of the uranium in the materials from the various stages of the present mining and milling operations at Canavieiras shows that the present treatment of the ore does not appreciably concentrate the uranium at any one stage, probably because of the fineness of the uraninite grains. The available data suggest that the best part of the operations from which to recover the uranium would be the tailings.

INTRODUCTION

The Canavieiras gold mine is 6 kilometers (by a narrow, dirt road) south of the town of Jacobina in the north central part of the State of Bahia, northeast Brazil. Jacobina 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. Although the town is not a scheduled stop of any commercial airline, it has an airstrip which may be used by small planes. (See figure 1.) The Estrada de Ferro Leste Brasileiro (Brazilian Eastern Railroad) serves the region and connects it with the seaport of Salvador.

The Serra de Jacobina, in which the Canavieras mine is located, is a narrow, prominent range that stands out in sharp relief over the adjacent plains and has altitudes of 600 to 800 meters with peaks up to approximately 1,100 meters. The adjacent plains have an elevation of about 450 meters. The mine itself has an elevation of approximately 520 meters.

The gold ores in this region have been known and mined since the latter part of the 17th century. Most of the mining has been on a small scale, both of the ores and of the placer gold from the streams that drain off the serra. 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 ore.

Ownership of the Canavieiras mine is held by Mineração Northfield, Limitada, of Salvador, Bahia, a subsidiary of Ventures, Ltd. of Toronto and New York, holding an 87 1/2 percent interest, Mineração de Ouro de Jacobina, Limitada, holding 10 percent interest, and Mr. J. R. McCarthy of Diamantina, Minas Gerais, who holds a 2 1/2 percent interest.

The Canavieiras mine is near the base of the east wall of the canyon-like valley cut by Canavieiras Creek, a northward-flowing stream. Bedrock in the stream bed on the mine property is a highly disintegrated, dark dike with a strike nearly parallel to the enclosing sedimentary rocks. The geologic section at the property consists of an underlying white quartzite containing many beds of hard silicified conglomerate, overlain by a white barren massive hard quartzite that contains no conglomerate. The conglomerate beds range from a string of pebbles 2 or 3 centimeters thick to beds up to 2 meters thick. Most of the conglomerate beds are made up of gray to white quartz pebbles with diameters of as much as 3 inches, set in a white fine-grained quartzitic matrix. This type of conglomerate is called locally "chabú." A small amount of gold is reported to have been produced from some of the thicker of these conglomerate beds. There are two very hard, gray, light to dark green, and chocolate brown conglomerate beds on the property containing zones of heavy sulfide minerals--mainly pyrite. One, the Liberino reef 1/, has been opened and a small amount of development work done by the mine operators; the other, the Piritoso reef, constitutes the main gold-bearing, pyritic ore body of the Canavieiras mine. These reefs are known locally as the "piritoso" type of conglomerate beds. The thicknesses of the quartzite-conglomerate formations have not been measured. A magnitude of thickness is obtained from the difference in elevation of the mine, stated as 520 meters, and that of the highest peak in the vicinity of the Canavieiras mine, said to be about 1,100 meters, and reported to be of quartzite.

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

STRUCTURE

The Canavieiras mine is located on the east valley wall of Canavieiras Creek. The strike of the sedimentary formations, including the gold-bearing conglomerates, at the mine is about north. The dip of the rocks ranges from 45° to 65° E. The gold-bearing reefs are exposed for a distance of no more than about 600 meters on strike on the mine property. They are cut off to the north by a nearly vertical fault. On the south they are covered by a heavy mantle of soil and, inasmuch as none of the reefs are exposed to the south of this mantle, they are either cut off by faulting, or they pinch out.

The thickness and shape of many of the conglomerate beds are quite variable. They may thicken or thin out to a line of pebbles, and some appear to be lens-shaped. Because of the close proximity of the beds, the variable thickness, and the pinching out of many of them, it is frequently difficult to trace a given bed along its strike. The Piritoso and Liberino reefs, the two pyritic gold-bearing reefs at the mine, have an average thickness of about 60 centimeters; they thin to the north.

The thickness of the Piritoso reef at the outcrop, where it is being mined, is about 1.5 meters. This thickness is approximately maintained down dip to the cutting face of the mine. The dip of the reef at the outcrop is 45° E. At the 495 meter level and the 505 meter level the reef is cut by reverse faults, with displacements in each case of about 2.5 meters. (See figure 1.) Between the surface and the first fault the dip of the reef decreases to about 40°; between the first and second faults the dip decreases to about 35°, and at the mine face the dip is about 30°.

RADIOACTIVITY INVESTIGATIONS

A summary of information through June 1954, concerning the radioactivity of the gold-bearing reefs of the Serra de Jacobina has been presented by White (1954).

Standard Geiger-Mueller counters and scintillation detection equipment were used in the field studies. Detailed examination was made of four of the gold-bearing reefs on the Canavieiras property. These reefs are called, stratigraphically from top to bottom, Maneiro, Hollandez, Liberino and Piritoso. The first two are of the white, coarser, "chabú" type of conglomerate that is gold-bearing but otherwise not well mineralized. The latter two are the "piritoso" type of green to chocolate brown, pyritic reefs that are the principal gold-bearing rocks not only at the Canavieiras mine but in all of the conglomerate formation of the Serra de Jacobina. The principal workings of the mine are in the Piritoso reef.

Each of the four above-mentioned reefs were sampled at intervals of about 10 meters on the outcrop. These samples were tested for radioactivity and uranium content in the laboratory. The results listed below show the uranium content in terms of equivalent uranium (eU)1/ but chemical analyses for uranium of a selected number of the samples show the radioactivity to be due entirely to the uranium series and, because the results of chemical determinations are essentially the same as the equivalent-uranium results obtained

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1/ Equivalent uranium (eU) A measure of the radioactivity of a rock or mineral sample, derived by comparing the radioactivity of a given sample to that of a sample with a known uranium content that has the same geometry and grain size and in which the uranium is in equilibrium with its disintegration products.

from radioactivity determinations---thus indicating the uranium to be present in equilibrium amounts with its daughter products--, the eU values given may be considered as equivalent to uranium values.

	Outcrop length sampled (meters)	Average percent equivalent uranium in samples taken
Maneiro reef	300	Less than 0.001
Hollandes reef	420	Less than 0.001
Liberino reef	375	0.001
Piritoso reef	350	0.006

From the above listed eU values it is apparent that the average radioactivity of the reefs at the outcrop is relatively low. The values given for the Maneiro and Hollandes reefs closely approximate the magnitude of the radioactive highs in those reefs. The eU values in the Liberino reef range from nil to 0.006 percent, and the values for the Piritoso reef range from nil to 0.024 percent. Therefore, except for a few local highs, radioactivity traverses along the outcrops of the reefs do not present very impressive results, and it is only when the reefs are penetrated to some depth that apparently significant radioactivity is found.

There are no accessible mine workings in either the Maneiro or the Hollandes reefs, and, consequently, nothing is known of the radioactivity of these reefs at depth. Present indications are, however, they they will not be found to contain appreciable amounts of uranium inasmuch as they do not carry significant sulfide ore bodies.

The Liberino reef, which has been appreciably mineralised, has been opened to a depth of about 20 meters in a pyrite ore body. (See figure 1.) The sampling in this development indicates the presence of 0.005 percent eU.

The Piritoso reef has been opened for a distance of about 115 meters along strike and to a depth of over 80 meters, following the closely-spaced position of pyrite-gold ore bodies in the reef. The mine workings were sampled at intervals of 5 to 10 meters along the dip of the reef. (See figure 1.) This sampling shows the presence of an over-all average of 0.01 percent eU. The uranium content of the samples ranges from nil to 0.2 percent eU.

The most radioactive samples are of fresh unweathered hard dense silicified conglomerate carrying large amounts of pyrite. The least radioactive are those samples that are in advanced stages of decomposition or that have been subjected to weathering. Thus the least radioactive samples collected were those from the outcrop of the reefs and the samples collected from the two fault zones in the mine where the rock is in advanced stages of decomposition. The uranium is closely associated with gold and pyrite and the more pyrite in an ore body, the higher the uranium content. Medium to low grade pyrite-gold ores show corresponding medium to low uranium values. Recent tests on the pyrite-gold ore that is being produced at the mine from the Piritoso reef show that there is approximately 0.03 percent uranium in the run-of-the-mine ore. The final reject tailings from the mill processing contain approximately 0.015 percent uranium.

MINERALOGY OF THE GOLD ORES

Essentially all of the uranium in the pyritic gold-bearing reefs occurs as uraninite. The cholclate-brown colored portions of the reef at outcrop are due to the limonite resulting from the decomposition of pyrite. The green color which is characteristic of the ore bodies is due to chromium, possibly to the presence of a chrome mica. Whereas no chromium minerals were found in concentrates of the conglomerates, the heavy-mineral concentrates in Canavieiras Creek contain 35 percent chromite, thus indicating a source for chromium in the rocks nearby.

Some visible free gold is present in the pyritic reefs, but the principal occurrence is in a rather intimate association with pyrite. The uraninite is closely associated with the gold-pyrite ore. Low, medium, and high grade gold ores have corresponding values of uranium. Fragments of uraninite have been found intergrown with crystals of pyrite.

Significant uranium values are found only in fresh, unaltered and unsheared pyrite-bearing ore. Heavy-mineral concentrates of the weathered surface or outcrop samples and those from the decomposed rock of the fault zones---all of the samples containing less than 0.002 percent eU---contain very little fresh pyrite. About 35 percent of the heavy-mineral concentrate can be removed with a hand magnet; the bulk of the remainder is limonite and decomposed pyrite. Fresh unaltered samples of the ore which contain relatively high amounts of uranium contain relatively little limonite and much fresh pyrite. The heavy-mineral concentrate of one fresh sample containing 0.2 percent eU contains only about 5 percent of material that may be removed with a hand magnet, very little limonite, some altered pyrite, and about 50 percent fresh pyrite.

Because of the uraninite-pyrite-gold association in the ore bodies it is assumed that uraninite at one time was present in the weathered or altered zones of the ore bodies, inasmuch as these zones contain commercial grade gold ore. It is apparent that the chemical processes that are attendant to the oxidation of pyrite and the formation of limonite have removed the bulk of the uranium from the weathered zones in the conglomerates. On the other hand, the sampling to date has shown no evidence of zones in which uranium is present in less than equilibrium amounts with daughter products as might be expected in an oxidizing sulfide environment. No secondary uranium minerals have been found as yet. Further studies will be needed to determine the reasons for the absence of uranium in the weathered outcrop as opposed to its presence in the fresh pyrite ore bodies at depth. It is obvious that this question is of importance, inasmuch as it has a direct bearing on the method of prospecting for uranium in other pyritic conglomerate zones throughout the Serra de Jacobina.

MINING OPERATIONS

Approximately 7-10 tons of material per day is mined from the Canavieiras mine. As the material is removed from the mine, it is hand sorted; the waste is discarded; and the ore is sent to the mill. The ore is crushed in a jaw crusher and fed to a ball mill where it is reduced to a size suitable for passing over a vibrating table. The material that passes over the riffles on the table is panned for removal of fine gold and then returned to the ball mill for further crushing before being returned to the vibrating table. The gold is removed from both the heavy-mineral concentrate from the table and the concentrate from panning by amalgamation with mercury. With this closed cycle in the milling operation, the only material that leaves the mill is that transported by the waste water from the operations. This material averages about 100-mesh in size. (See figure 2.) The waste water from the milling operations is ponded at some distance below the mill and the fine material is accumulated. This material is submitted to cyanidation for removal of most of the remaining gold. After cyanidation the material is discarded as waste. Seventy-five percent of the gold at the mine is removed by amalgamation and the remaining amount through cyanidation.

DISTRIBUTION OF URANIUM

Figure 2 illustrates graphically the distribution of uranium in the gold ores and mill products of the Canavieiras mine. Seven samples were chosen, each weighing 1,000 grams, that are representative of the various types of material at the mine: one sample of fresh, unoxidized gold ore with high content of radioactive material; two samples of partly oxidized gold ore containing a medium amount of radioactive material; one sample of heavy-mineral concentrate from the concentrating tables at the mill, and three samples from the mine tailings, two of the three being from the tailings before they are passed through the cyanidation process for the extraction of remaining gold, and the other sample from the final tailings after cyanidation. All samples were reduced to minus 20-mesh size. Each sample was then agitated for 30 minutes in a stack of nine standard eight-inch diameter sieves. The following sieve sizes (meshes to the inch) were used: 40, 50, 70, 100, 140, 200, 230, 270, and 325. The ten sample fractions thus obtained (the material remaining on each of the nine sieves plus the material that passed through the 325-mesh sieve) for each of the seven samples were weighed (grams) and the A graphs compiled from those weights. The B graphs were compiled from the values for percent equivalent uranium determined for each of the fractions of the screened samples. The C graphs were compiled from rough estimates of the amount in grams of equivalent uranium present in each of the sample fractions, calculated from the percent of equivalent uranium (as shown in graphs B) and the weight of the various sample fractions as shown in graphs A. It should be noted that these estimates are based on the assumption that the radioactivity in each fraction is due to uranium in equilibrium with its daughter elements and that the error in the estimates can increase with departure from this assumption. On the other hand, the general patterns of the C graphs are probably not in error, particularly if it can be assumed that variation of the eU content from one fraction to another of a given sample is due to variation in the amounts of the same type of radioactive material.

A comparison of the seven B graphs shows that the clay-size fractions (minus 325 mesh) have the highest percentage equivalent uranium. However, the size fractions of the seven samples must be evaluated in terms of the amount of uranium present in the fractions as shown by the C graphs. These graphs show that the amount of uranium present is a function not only of the percentage of uranium in each fraction but also of the amount of material in the fraction. Thus, in sample 1 the B graph indicates that a higher proportion of the minus 325-mesh fraction is radioactive material than of any other fraction in the sample but the C graph shows that the plus 40-mesh fraction contains a greater amount (in terms of weight) of radioactive material, largely because of the greater total weight of this fraction as indicated by the A graph. Whereas the minus 325-mesh fraction is in all cases the most radioactive (B graphs), it follows that whenever the minus 325-mesh bar in the A graphs assumes even a small prominence, the same bar in the C graphs is prominent also, and the more prominent that bar is in the A graphs, the more prominent it is in the C graphs. The A graphs in samples 1 and 2 show the minus 325-mesh fraction to be relatively inconspicuous and in conformity with the general size distribution of the samples. The C graphs for these two samples, accordingly, show uranium content of the minus 325-mesh fraction to be relatively unimportant. In samples 3 and 4 the plus 40-mesh and minus 325-mesh bars in the A graphs show isolated prominence. Taking into consideration the volume of the plus 40-mesh fraction, and the high radioactivity of the minus 325-mesh fraction, the bars for these two fractions in the C graphs are of approximately the same importance. Furthermore, the first five fractions contain as much uranium, by weight, as the last five fractions, in both samples.

Sample 1 is fresh, unoxidized gold ore containing a relatively high amount of radioactive material. The bars in the A graph for the sample show a relatively uniform decrease in length from the coarsest to the finest fraction. This is reflected in relatively uniform decrease in the bars of the C graph. Samples 3 and 4 on the other hand are of partly oxidized gold ore. The oxidation products bring about an increase in the amount of material in the clay fraction (minus 325-mesh), which results in the U-shaped appearance of the C graphs.

Samples 5, 6 and 7 are of tailings---before and after that material has been processed by cyanidation. There is apparently no significant loss of uranium from this process. The minus 325-mesh fractions of the tailings materials are the most important fractions of these samples in the C graphs, not only because of the relatively large volumes of these fractions but also because they contain the largest amounts of equivalent uranium. The distribution of uranium in the size fractions of these samples is of interest as it shows the possibility for selecting certain size fractions for uranium extraction purposes. If only the last three fractions of material were processed, that is, the plus 270-, plus 325-, and minus 325-mesh fractions, a minimum amount of material would need to be handled to recover an appreciable amount of the uranium present:

	Percent of material to be processed from total sample	Percent of uranium of total sample in fractions to be processed
Sample 5................	14	54*
Sample 6................	31	60
Sample 7................	17	45

* For example, in sample 5 above 14 percent of the total sample of tailings contains 54 percent of the total uranium in the sample.

In contrast to the above is sample 2, a concentrate from the table at the mill. The amount and distribution of uranium in the various size fractions are such as to make any selection of material for processing apparently impractical, thus necessitating the processing of all the material for removal of uranium.

In view of the small amount of uranium present in the gold ores of the Canavieiras mine, there seems little doubt that uranium can only be produced from those ores as a byproduct of the production of gold. Any process for the extraction of uranium would have to be introduced into the flow sheet of the mine in such a way as not to interfere with the continued economic production of gold. It is probable that uranium extraction could be made best from the final waste products of milling operations. The graphs for samples 5, 6 and 7 would seem to suggest this.

In order to check the uranium content of the mining and milling products of the Canavieiras mine, a sampling program was carried out over a period of several weeks. This sampling was done by mine personnel under the direction of Engineer Armando Santos de Oliveira, the mine superintendent, and was carried out from August 19 through September 26, 1954. Each day a sample of what on visual inspection might constitute average-grade gold ore was collected from the operating face of the mine, ground to minus 20-mesh, and stored. Also each day representative samples of the pre-cyanidation and of the post-cyanidation tailings were collected, dried, and stored. At the end of a week the seven samples in each suite were mixed and a split from each mixture stored. At the end of approximately six weeks there were six samples each of the gold ore and of the two types of tailings, representing the material produced at the mine during that period. These samples were analyzed by the U. S. Geological Survey in Denver, Colo.; the results are given below.

	Percent Uranium
Each sample represents one week's average ore.	0.025
	0.024
	0.012
	0.055
	0.039
	0.021
	Average 0.03
Each sample represents one week's average from pre-cyanidation tailings.	0.012
	0.013
	0.015
	0.014
	0.018
	0.016
	Average 0.015

Each sample represents one week's average from post-cyanidation tailings.

0.011
0.010
0.014
0.012
0.015
0.019
Average 0.014

It is not believed that the sampling described above is representative of a given batch of material from the time it is taken from the mine face until it is discarded in the post-cyanidation waste, because of the lag in time between the mining of the gold ore and the deposition of the fine material on the pre-cyanidation tailings pile by waste water from the mill table, and the further lag that exists between the time the tailings are deposited and are processed through cyanidation. The flustuations in values listed for the average gold ore from the mine do not correspond to the flustuations in values listed for the two types of tailings material, which they should if the sampling were on the same material taken in various stages of its processing from mine face to waste pile. Nevertheless, it is believed that the average values listed above are representative of the average results that might be obtained if a uranium extraction plant were installed at the mine now.

Even if it is assumed that the two types of tailings material listed above are not truly representative of the uranium content of the average ore mined during the same period of time because of the time lag between mining and deposition of tailings, this does not completely explain the large difference that exists between the uranium values for average ore and those for average waste material. It would appear from the values given that the magnitude of loss of uranium from ore to waste is one-half. It is likely that most of the loss will be found in the waste water that passes over the tailings pile. This small stream drains into Canavieiras Creek and carries a load of fine silt, clay, and probably other material in suspension. As yet there are no data regarding the uranium content of the waste waters as they leave the waste pile. Because of the apparent original fine size of the uraninite, plus the fact that its brittleness causes it to be further reduced in size during milling, this mineral has a tendency to concentrate in the clay fraction of the samples studied. (See G graphs, figure 2.) Thus, at least one-half of the uranium is carried off in suspension, or possibly even in solution, in the waste waters.

CONCLUSIONS AND RECOMMENDATIONS

Because of the small amount of uranium (0.005 to 0.03 percent) in the gold-bearing reefs at the Canavieiras mine, it is likely that no uranium will be produced from those ores except as a byproduct of gold mining on a much larger scale than is at present conducted at the mine. Further studies would be needed to determine the magnitude of tonnage that could be mined at Canavieiras, but it is likely that a 200 ton per day operation could be developed there. This would be about the minimum required to establish a practicable uranium-extraction plant, adapted to the gold mining operations. The grade in uranium of the Canavieiras reefs are comparable to the grade of run-of-the-mine ore (0.004 to 0.04 percent uranium) published for the South African reefs. (Davidson, 1953, p. 4).

In the light of information gained from the study of the samples collected from the preliminary investigation of the mine, herein reported, it is recommended that the Canavieiras mine be mapped and sampled in detail in order to determine the distribution and relationships of the pyrite ore bodies to the enclosing reef, the geochemical relationship of the uraninite to the ore bodies, and the process by which uranium is removed from the ore. A study should be made of mill-waste water to determine the amount of uranium that is removed and in what manner it is removed. Surface prospecting should be extended to the rest of the Serra de Jacobina in an attempt to determine the extent of the uraniferous gold-bearing reefs and whether significant concentrations of uranium are present.

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