Reconnaissance for Uranium in the Central Tucano Basin Bahia, Brazil

GEOLOGICAL SURVEY BULLETIN 1185-B

Prepared on behalf of the
U.S. Atomic Energy Commission
in cooperation with the Commissão
Nacional de Energia Nuclear, Brazil

Haynes—RECONNAISSANCE FOR URANIUM IN THE CENTRAL TUCANO BASIN, BAHIA, BRAZIL—Geological Survey Bulletin 1185-B

Reconnaissance for Uranium in the Central Tucano Basin Bahia, Brazil

By DONALD D. HAYNES

URANIUM INVESTIGATIONS IN BRAZIL

GEOLOGICAL SURVEY BULLETIN 1185-B

Prepared on behalf of the
U.S. Atomic Energy Commission
in cooperation with the Commissão
Nacional de Energia Nuclear, Brazil

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library card for this publication appears after page B16.

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

URANIUM INVESTIGATIONS IN BRAZIL

RECONNAISSANCE FOR URANIUM IN THE CENTRAL TUCANO BASIN, BAHIA, BRAZIL

By Donald D. Haynes

ABSTRACT

Uraniferous sandstone has been located in two drill holes in the Tucano basin, Bahia, Brazil, but thus far various radium-rich spring deposits are the only radioactive rocks that have been found on the surface.

In October 1957 pieces of radioactive core were found at the Petrobrás warehouse in Candeias, Bahia; this led to the discovery of a 5-meter-thick bed of uranium-bearing sandstone and conglomerate that contains 0.096–0.136 percent chemical U_3O_8 and occurs 1626.1–1631 meters in depth in Petrobrás Macaco 1 hole (MC–1) at Jorro, Bahia, in the central Tucano basin. Although the uranium-bearing bed was too deep to be economically explored, it, and many thermal springs having radioactive waters, indicated the possibility of additional uranium occurrences in the central Tucano basin.

Subsequent uranium investigations in the basin disclosed another occurrence of uranium-bearing sandstone in Commissão Nacional de Energia Nuclear exploration hole PRe–1. Selected samples of the uraniferous sandstone from this hole contain as much as 0.2 percent U_3O_8.

Geobotanical investigations indicated that several areas contain plants having anomalous amounts of uranium in their ash. Samples having as much as 8.1 parts per million uranium content in their ash were taken from plants south of Cicero Dantas. Southwest of Tucano, plants having as much as 2.9 parts per million uranium content in ash were found.

Airborne investigations identified two areas of anomalous radioactivity. One is the already known area of radioactivity near Pôço Redondo; the other is near Greguenhem but has not been ground checked.

Coffinite and montroseite were identified for the first time in Brazil in samples from the MC–1 and PRe–1 drill holes. Uraninite was also identified in the samples from drill hole MC–1.

The MC–1 uranium occurrence has no economic importance at this time because of its great depth. Additional drilling near the PRe–1 occurrence may find uranium reserves of sufficient tonnage and grade to be of economic importance.

INTRODUCTION

This report summarizes work in the central Tucano basin, Bahia, from January 1957 through June 1960 by Brazilian personnel of the

Commissão Nacional de Energia Nuclear (CNEN) and by geologists of the U.S. Geological Survey, in evaluation of the uranium resources of Brazil. This work was done on behalf of the U.S. Atomic Energy Commission.

The central Tucano, or Rio Itapicurú, basin lies about 200 kilometers north of Salvador, Bahia. The area can be reached by graded gravel road from either Alagoinhas or Feira de Santana (pl. 1).

The basin, which is eroded to a mature stage of dissection, is crossed from west to east by the Rio Itapicurú. Most of the rock exposures are of the Marizal and Cicero Dantas Formations, of Tertiary age, which form large mesas, or "tabuleiros." Within the central and lower parts of the Tucano basin there are few outcrops. Most of the geologic features are concealed by an extensive gravel cover, windblown sand, or heavy brush (caatinga).

Previous investigations for uranium in the Tucano basin were made in the Paulo Afonso region (Haynes and Mau, 1958) and in the Mosquête region (Haynes and others, 1958).

Radioactivity investigations in the Tucano basin were begun because of reports of radioactive fossil bones occurring south of Jorro on the Rio Itapicurú (Price and Haynes, written commun., February 1957) and because some of the thermal springs in the basin reportedly contain radioactive waters.

The author thanks the following members of the CNEN who participated at various times in the work: Arnoldo Sobanski, Henry Mau, José A. Paione, Maria do Sócorro, and Diana Mussa, geologists; Alceu Silva, geochemist; Llewellyn I. Price, paleontologist; Sergio de Almeida and Geraldo Pedrozo, electronics technicians; Marcelo V. Queiroz, assistant geochemist; Arnaldo Girotto, Alcyr Ferrari, Luiz Furtado, Francisco Teodoro, Laudenir Furtado, and Augusto Souza, field assistants; and Plinio Martins, driller.

Max G. White, U.S. Geological Survey, participated in the first road traverse in February 1957. The author supervised all the Tucano basin operations.

Uranium determinations were made in the CNEN Rio de Janeiro laboratory by Carlos Pires Ferreira, Oswaldo Erichsen de Oliveira, Henrico Schlotterbeck, and Marcelo V. Queiroz. Mineral determinations were made by John J. Matzko, U.S. Geological Survey, and Maria H. Falabela and Augusto Baptista, Departamento Nacional do Produção Mineral.

The author also thanks the many officials of the Companhia Hidroeléctrica São Francisco (CHESF) for the use of a helicopter and the assistance extended, and the following officials and geologists of Petróleo Brasiliero, S. A. (Petrobrás): Dr. Geonísio Barroso, Superintendente da Produção da Região Bahia, Dr. Ivan Carvalho, Dr.

Langdon Smith, Dr. Raymundo Nery, William M. Young, Dr. Carlos Walters, and Allen E. Disbrow.

GENERAL GEOLOGY

Very little has been published on the geology of the Tucano basin. Andrade (1926) studied the thermal springs in the southeast part of the basin but only briefly mentioned the geology.

Geologists of Petrobrás have made reconnaissance studies through the basin, but detailed study was only begun in late 1959, when Carlos Walters began mapping in the southwest part of the basin near Biritingas. His stratigraphic section (Carlos Walters, oral commun., March 1960) for the sedimentary sequence of the Tucano basin has been adopted, with only slight modification, for this report.

The Tucano basin is an area of about 40,000 square kilometers and extends from Alagoinhas north beyond the Rio São Francisco into the State of Pernambuco (pl. 1).

Rocks exposed in the basin are from Jurassic(?) through Recent in age, the most extensive being Tertiary. Deposition of sediments in marine- and brackish-water environments probably began during Late Jurassic or Early Cretaceous time and continued to the end of Cretaceous time (Link, 1959).

The basin is bordered as follows: on the north by Precambrian granite and granite gneiss; on the south by Tertiary sedimentary rocks and scattered granite inliers of Precambrian age; on the west by Silurian schist, granite gneiss, phyllite, and metamorphosed limestone; and on the east by metamorphosed Silurian limestone and graywacke.

STRUCTURE

The Tucano basin, a north-trending graben valley, has faults along the south, east, and west margins. The faults along the east margin seem to have the largest combined displacement, possibly as much as several thousand meters, and dip as much as 70°. The thickest sedimentary section also occurs along the east margin. The displacement of the north-trending normal fault on the west margin increases from north to south, where, at Arací, it may be as much as 1,000 meters.

The major faults and fractures trend N. 10°–30° E., north, and east, and dip 5°–15°. Small local structures may dip as much as 80°.

Anticlines and synclines occur throughout the basin. Two wells—one west of Jeremoabo and the other 5 kilometers south of Tucano—were drilled on structures in exploration for oil but did not produce.

STRATIGRAPHY

The sedimentary rocks of the Tucano basin have been divided into the following formations: the Aliança, of Jurassic(?) age, which is found in other parts of the basin but is not yet known in the area shown on plate 1; the Sergí, Itaparica, Candeias, Ilhas, and São Sebastião of Cretaceous age; and the Marizal and Cicero Dantas of Tertiary age. These formations have been mapped and given these names by Petrobrás only in the southwest part of the basin to within approximately 60 kilometers south of Arací; therefore, the geologic maps (pls. 1 and 2) show the Sergí, Itaparica, Candeias, Ilhas, and São Sebastião Formations grouped together as Cretaceous rocks. These Cretaceous formations are mapped as the Jatobá series in the north part of the Tucano basin near the Rio São Francisco.

Recent geophysical surveys in the basin show that there is more than 4,000 meters of sedimentary rocks north of Cipó (Petrobrás geologists, oral commun., March 1960). The character and thickness of the formations change greatly from east to west and from north to south. The facies change from coarser to finer grained clastics south from Rio Vasa Barris; calcareous shales and argillaceous limestones are more abundant south of Ribeira do Pombal.

The Sergí Formation has been described in more detail than the other formations, as it presumably includes the uranium-bearing beds at both the MC–1 and the PRe–1 drill holes. Thickness and stratigraphic data for all formations discussed in this report pertain only to the south and central parts of the Tucano basin.

The Aliança Formation, where it is known in other parts of the basin, overlies slate, schist, and phyllite of Silurian age. It consists of red to maroon, brown, and purplish-gray shale, containing green streaks and a few limestone beds, and red and light-gray coarse-grained to conglomeratic sandstone of continental origin. It ranges from 200 to 350 meters in thickness and is considered to be of Jurassic(?) age.

The Sergí Formation of Early Cretaceous age is presumably the host formation for the uranium and is an important oil reservoir in the Recôncavo basin, which joins the Tucano basin on the south. The Sergí is at the base of the marine sedimentary rocks. In the lower part it consists of reddish-gray to light-gray fine-grained arkosic well-cemented sandstone containing black accessory minerals. The middle part consists of light-gray and chocolate-brown fine-grained sandstone having scattered shaly lenses containing green blotches. The upper part, in general, consists of light-gray to gray medium- to coarse-grained sandstone that is micaceous in its lower beds. The uppermost part of the formation contains carbonaceous dark-gray micaceous siltstone.

The sandstones of the Sergí are poorly sorted, having subangular to angular pebble-conglomerate lenses, one of which is uranium-bearing in the Petrobrás hole MC–1. The Sergí is 90–150 meters thick.

The Itaparica Formation is composed of gray and maroon silty shale, thin interbedded limestones, and dark-gray siltstones. The formation, ranging from 90 to 100 meters in thickness, is carbonaceous in its lower part.

The Candeias Formation is a maroon or greenish- to olive-gray, marine shale containing thin limestone beds. The upper part contains buff to gray fine- to medium-grained sandstone lenses. The A zone, which is a fine- to medium-grained reservoir sand occurring at the base of the formation, produces oil in the Recôncavo basin. The thickness ranges from 400 to 850 meters.

The lower part of the Ilhas Formation is green and olive-gray shale, thin gray limestone beds, and pebble and cobble conglomerate in a coarse sand matrix. The upper part consists of light-gray and reddish-gray fine- to medium-grained thin-bedded to massive argillaceous sandstone containing interbedded greenish-gray shale and gray limestone. The Ilhas was deposited in fresh to brackish water and contains oil reservoir sands. In general, it ranges from 600 to 1,100 meters in thickness, but locally it may be thicker.

The São Sebastião Formation is primarily composed of red, gray, and pink fine-grained argillaceous sandstone containing beds of gray, locally greenish-gray, red, and maroon micaceous shale and siltstone. It is at least 400 meters thick.

The lower part of the Marizal Formation, of Tertiary age, is a tan and buff medium- to coarse-grained arkosic sandstone; a basal conglomerate contains boulders and cobbles of igneous and metamorphic rocks. The middle part is composed of tan to buff limy siltstone. The upper part is dark-tan or buff fine- to medium-grained arkosic sandstone in an argillaceous matrix. Locally, there are lenses of red and pink siltstone and greenish-gray or brownish-gray shale. This formation ranges from 0 to at least 200 meters in thickness.

The Cicero Dantas Formation, also of Tertiary age, consists of red, brown, and gray massive to crossbedded poorly sorted sandstone and intercalated varicolored shale, siltstone, gravel, and conglomerate. Its thickness may be as much as 400 meters.

Quaternary continental deposits of fluvial origin are found in the valleys of the São Francisco, Vasa Barris, and Itapicurú rivers. They consist mostly of unconsolidated sand, silt, and gravel terraces. These Quaternary deposits and the Recent deposits of windblown sand are not shown on the geologic maps.

740–242—64——2

RADIOACTIVITY INVESTIGATIONS

In the investigations for radioactivity, the following methods were used: road traverses, ground reconnaissance, exploration drilling, geochemical and geobotanical studies, radiometric probing, and airborne reconnaissance. Radioactivity-detection equipment used in the work consisted of an airborne-type scintillation counter with a graph recorder, hand scintillation counters, Geiger-Müller counter with probe, a portable scintillation counter with probe and graph recorder for well logging, and laboratory scintillation scalers.

The rock samples were radiometrically and chemically analyzed at either the Commissão Nacional de Energia Nuclear (CNEN) laboratory in Rio de Janeiro or the U.S. Geological Survey laboratory in Denver, Colo. The water samples, which were collected in polyethylene bottles without stabilization by hydrochloric acid, were analyzed in the CNEN Rio de Janeiro laboratory. The plant samples were analyzed chemically by fluorimetric method in the CNEN laboratory.

ROAD TRAVERSES

In February 1957 a road traverse to check for radioactivity was made from Araci to Cipó. The route traversed was along the principal highways and passed through Tucano, Euclides da Cunha, and Ribeira do Pombal. Later, traverses were made to the south, passing from Cipó through Nova Soure, Olindina, and Itapicurú, and to the north passing from Ribeira do Pombal through Cicero Dantas and on towards Jeremoabo (pl. 1). Road traverses for radioactivity in that part of the Tucano basin north of Paulo Afonso were previously described by Haynes and Mau (1958).

No anomalous radioactivity was detected along the routes traversed. There were very few rock exposures along the route, and nearly all those checked were in roadcuts and deeply weathered. About 60 percent of the route traversed was overlain by a mantle of windblown sand.

GROUND RECONNAISSANCE INVESTIGATIONS

Ground reconnaissance investigations in the Tucano basin were begun by Price and Mau in January 1957 at Jorro, at an area southwest of Jorro, and at Cipó (pl. 1). At Cipó, radioactive material deposited by thermal springs was found. Chemical analyses of a sample of this material collected by White and Haynes showed only a trace of chemical uranium but a high percentage of equivalent radium 226 and its daughter products. No further work was done at Cipó.

In May 1957 manganiferous sinter deposits in the Mosquête area (pl. 1) southeast of Cipó were found to be radioactive. The deposits were sampled and mapped in some detail, but no further work was done after chemical analyses had shown the radioactivity to be principally due to equivalent radium 226 and its daughter products (Haynes and others, 1958).

In October 1957 the stored drill cores, as well as some that had been discarded, at the Petrobrás warehouse in Candeias, Bahia, were scanned radiometrically, and several pieces of radioactive greenish-black medium- to coarse-grained conglomeratic sandstone were found. These pieces of radioactive core had been discarded outside the warehouse and had no marks of identification to indicate the well or the depth from which they had been taken.

A representative sample of the core contained 0.082 percent eU_3O_8 and 0.105 percent chemical U_3O_8.

Spectrographic determinations on a heavy-mineral separation by John J. Matzko, U.S. Geological Survey, showed that copper, zinc, manganese, iron, vanadium, and uranium are present in the uranium-bearing sandstone. Fresh pyrite is abundant as massive aggregates but is scarce as single crystals. Chert, smoky and milky quartz, chalcopyrite, magnetite, garnet, zircon, hematite, and limonite occur in minor amounts. The quartz grains are weakly cemented, principally by manganese oxide. An unidentified white clay causes a spotty appearance.

Sparse brownish-gray nodules are principally composed of a heavy dead oil. From the oil, a light-red petroleum ether was extracted by a 2-hour distillation. The nodules are estimated to contain 15 percent oil (John J. Matzko, written commun., October 1960).

From X-ray determinations made on alpha-plate concentrates, coffinite was identified as the principal radioactive mineral by Maria H. Falabela. This occurrence of coffinite is the first recorded in Brazil. Montroseite and uraninite were also identified when the sample was rechecked.

In January 1959, during a study of Petrobrás well logs, well cuttings, and core-chip samples, the author found three bottles of radioactive chip samples collected from the core of the 1626.1–1631 meter interval in Petrobrás Macaco 1 drill hole (MC–1) (drilled by Consêlho Nacional de Petróleo) at Jorro, Bahia (pl. 2). Megascopically, the MC–1 samples resemble the radioactive discarded cores found at the Candeias depository; therefore, the radioactive pieces of core probably came from the same interval as the chip samples. The Sergí Formation of Cretaceous age occurs at this depth. Chemical analyses of the MC–1 chip samples from the three bottles are as follows:

Bottle	*Percent* eU_3O_8	*Percent* U_3O_8	*Depth (meters)*
1	0.083	0.129	1626.1–1627.7
2	.096	.136	1627.7–1629.3
3	.087	.096	1629.3–1631.0

A reconnaissance of selected areas west of Jorro between the Federal north-south highway (Br–13) and the contact of the sedimentary and crystalline rocks (pl. 2) was made by Laudenir Furtado and the author in May 1959. An anomalously radioactive outcrop of yellowish-brown fine- to coarse-grained massive- to crossbedded sandstone was found on the east bank of the Rio Itapicurú near Pôço Redondo (pl. 2). The radioactivity of the sandstone was as great as 0.75 milliroentgens per hour (mr per hr). Analyses of three samples collected from the most radioactive part of the outcrop are as follows:

Sample	*Percent* eU_3O_8	*Percent* U_3O_8
T1	0.017	$<$0.001
T2	.021	$<$ .001
T3	.013	$<$ .001

As shown, the samples are in disequilibrium, for the chemical uranium content is almost nil. The radioactivity is seemingly associated with the abundant limonite in the sandstone and is possibly due to radium 226 and its daughter products. The presence of barite in the concentrates suggests that the radioactivity is caused by radium-bearing barite (L. B. Riley, written commun., October 1959). These analyses are very similar to those reported for the radioactive manganiferous sinters at Mosquête (Haynes and others, 1958).

The radioactive outcrop and the surrounding area were also investigated by drilling and aerial surveys.

During October 1959, J. A. Paione, Diana Mussa, Maria do Socôrro, and M. V. Queiroz made a geologic and radiometric traverse along the Rio Itapicurú from the Ponte Euclides da Cunha to the contact between sedimentary and crystalline rocks on the west margin of the basin. Very few outcrops were found along the river, and the only anomalous radioactivity found was at the outcrop of sandstone near Pôço Redondo, which was already known as a result of work done by the author.

The ground reconnaissance in the basin was concluded in October 1959. All subsequent fieldwork consisted of drilling at Pôço Redondo and airborne investigations.

EXPLORATORY DRILLING

The first exploratory drilling done by the joint group in the Tucano basin was in February 1959. Seven holes were drilled in the Mosquête area (pl. 1) to test the possible subsurface extension of the radioactive manganiferous sinter deposits and to search for radioactive materials in the sandstone underlying the manganese deposits. An eighth hole, F–8, was drilled to explore an outcrop of sandstone on the south bank of the Rio Itapicurú, 100 meters west of Ponte Euclides da Cunha (pl. 2). The number of each hole drilled, the location, the total depth drilled, and the amount or type of core or samples recovered are as follows:

Drill hole	Location	Total depth (meters)	Amount or type of core or samples
F–1	Fazenda Cajazeiras	3. 4	Sludge samples only.
2	do	3. 4	No sludge or core samples recovered.
3	Fazenda Mosquête	7. 85	Sludge samples only.
4	do	8. 4	Do.
5	do	9. 35	1. 02 m of core recovered from various depths. Weakly radioactive zone from 0. 3 to 3 m.
6	Fazenda Olhos d'Agua	3. 4	No samples recovered. Drilled through 0. 3 m of radioactive manganese at surface.
7	Balneario Fervente, Itapicurú.	3. 3	No samples recovered.
8	Ponte Euclides da Cunha	16. 9	5. 44 m of core recovered. Radioactive zone from 2. 5 to 6 m (0. 04 mr per hr).

Caving that occurred after the well casings were pulled precluded radiometric probing except in the upper parts of holes F–5 and F–8. The core recovery was very poor because of the unconsolidated nature of the sandstone and the small diameter of the diamond core bit.

Four holes (PRe –1, –2, –3, and –4) were drilled in May 1960 in the outcrop of radioactive sandstone near Pôço Redondo (pl. 2). Drill hole PRe–1, about 4 meters upslope from the most radioactive part of the outcrop, was drilled to a depth of 18.75 meters. Total recovered core was only 15 centimeters and came from a depth of 11 to 12.5 meters. Sludge samples were collected from the surface to total depth. Table 1 shows the results of the radiometric probing of drill hole PRe–1.

TABLE 1.—*Results of radiometric logging of CNEN drill hole PRe–1, Pôço Redondo, Bahia*

Depth (meters)	Radioactivity (mr per hr)	Depth (meters)	Radioactivity (mr per hr)
0 –1. 00	. 02	9. 50–9. 75	. 18
1. 00–1. 75	. 20	9. 75–10. 00	. 12
1. 75–2. 00	. 50	10. 00–10. 25	. 10
2. 00–2. 25	. 70	10. 25–10. 50	. 20
2. 25–2. 50	. 80	10. 50–10. 75	. 18
2. 50–2. 75	. 10	10. 75–11. 00	1. 20
2. 75–3. 00	. 13	11. 00–11. 25	. 50
3. 00–3. 25	. 90	11. 25–11. 50	. 15
3. 25–3. 50	. 50	11. 50–11. 75	. 08
3. 50–4. 00	. 02	11. 75–12. 00	. 10
4. 00–4. 50	. 05	12. 00–12. 25	. 15
4. 50–4. 75	. 06	12. 25–13. 25	. 05
4. 75–5. 00	. 04	13. 25–13. 50	. 03
5. 00–5. 25	. 08	13. 50–13. 75	. 04
5. 25–5. 50	. 07	13. 75–14. 50	. 02
5. 50–6. 25	. 05	14. 50–14. 75	. 05
6. 25–6. 75	. 06	14. 75–15. 25	. 03
6. 75–7. 25	. 10	15. 25–15. 50	. 08
7. 25–7. 50	. 20	15. 50–16. 00	. 15
7. 50–7. 75	. 13	16. 00–16. 75	. 10
7. 75–8. 00	. 07	16. 75–17. 00	. 13
8. 00–8. 25	. 15	17. 00–17. 25	. 15
8. 25–8. 50	. 10	17. 25–17. 50	. 10
8. 50–8. 75	. 05	17. 50–17. 75	. 11
8. 75–9. 00	. 10	17. 75–18. 00	. 50
9. 00–9. 25	. 70	18. 00–18. 25	. 40
9. 25–9. 50	0. 15	18. 25–18. 50	. 18
		18. 50–18. 75	Caved

An analyzed sample of medium- to coarse-grained dark sandstone from the interval between 11 and 12.5 meters deep contains 0.066 percent chemical U_3O_8 and 0.062 percent eU_3O_8. Selected chips of sandstone from the sludge samples of this interval contain as much as 0.2 percent eU_3O_8. Coffinite has been identified as the principal radioactive mineral in the samples by Maria H. Falabela and Augusto Baptista, of the Departmento Nacional da Producão Mineral; montroseite, a vanadium-bearing mineral, has also been identified by them. The occurrence of montroseite in drill hole PRe–1 is the first recorded in Brazil.

The uraniferous sandstone samples also contain abundant pyrite as finely divided granular masses and as cubic crystals 1 mm or less in size, carbonized plant material showing a woody texture, and very sparse grains of zircon, monazite, and xenotime. The dark color of the sandstone is due to manganese oxide cement, carbonized wood, and montroseite. Barite is an accessory mineral, which commonly occurs as tabular doubly terminated white to light yellowish-brown crystals about 1 mm in greatest dimension. Many of these crystals contain unidentified opaque inclusions and show strong alpha-particle radiation, but a second source of radiation is suggested by the complete strongly irradiated outline of the barite.

Barite tends to concentrate the radiocolloids (Stern and Stieff, 1959) and may form a coprecipitate of radium and barium sulfate—$(Ba,Ra)SO_4$. The barite crystals containing unidentified opaque inclusions and showing strong alpha-particle radiation, as well as the sample analyses showing more chemical uranium than equivalent uranium, suggest an alteration of the radioactive equilibrium by the recent movement of radium within the uraniferous mass (John J. Matzko, written commun., October 1960).

Holes PRe–2 and PRe–3 were drilled 200 meters east of PRe–1 (pl. 2). Both were abandoned because of caving: PRe–2 at a 4.5-meter depth and PRe–3 at a 8.25-meter depth. Neither hole passed through the overburden, and neither set of sludge samples showed any radioactivity.

Hole PRe–4 was drilled 95 meters south of PRe–1 (pl. 2). It was collared at the same altitude as PRe–1 and was drilled to a total depth of 17 meters. Because of a local 24° dip, S. 30° W., the hole did not intersect the radioactive zones cut by drill hole PRe–1. Sludge samples were collected at depths ranging from 2 to 17 meters, but no core was recovered. Radiometric probing of the hole detected no radioactivity.

GEOCHEMICAL INVESTIGATIONS

Geochemical investigations were begun in the central Tucano basin in January 1959 and were completed in May 1960. The first sampling was done haphazardly but by late 1959 the sampling techniques had become standardized; subsequent analyses were more reliable.

PLANT SAMPLING

The plant samples were collected along or near main highways or wagon trails to allow a larger area to be examined in a shorter time. The following plants, identified by their common names and Latin names, were collected in the first group of samples: Caatinga de porco, *Caesalpinia microphylla*; candeia, family Compositae; rabugem, *Cordia officinalis*; alecrim, *Rosmarinus officinalis*; pau de leite, *Pradosia* sp.; and quipé, *Caesalpinia* sp. From these, the two types that had the deepest root systems and the most widespread occurrences, caatinga de porco and quipé, were selected for sampling in the remaining geobotanical prospecting.

Table 2 shows the plant sample number, common name and Latin name, collection site, and chemical analysis in parts per million (ppm) uranium content in the ash for each sample.

TABLE 2.—*Identification and analyses, in parts per million, of plant samples from the central Tucano basin, Bahia*

Collection site	*Common name*	*Latin name*	*Sample*	*Uranium content (ppm)*
Cicero Dantas	Quipé	*Caesalpinia* sp	CD1	3.9
			2	.2
			3	5.6
Ribeira do Pombal	do	do	RP4	8.1
			5	.7
			6	4.3
			7	.7
			8	.6
			9	.5
			11	2.1
			12	.5
			13	3.0
Euclides da Cunha	Caatinga de porco	*Caesalpinia microphylla*	EC14	.5
			14a	.3
			15	.3
			15a	.3
			16	2.3
			16a	.1
			17	2.9
			19	1.9
			20	.1
			21	.6
			22	.3
			23	.4
			24	.1
			25	.3
			26	.7
			27	.5
			28	.1
			29	.1
			30	.2
			31	.4
			32	.2
			32a	.4
			33	.2
			35	.1
			36	.8
	Quipé	*Caesalpinia* sp	37	.9
			38	.5
			39	.1
			40	.5
			41	.6
	Caatinga de porco	*Caesalpinia microphylla*	42	.7
			43	.5
			44	.3
			45	.2
			46	.3
			49	1.0
			50	2.3
			51	.8
Tucano	do	do	TU10	.4
			11	.6
			12	.4
Atoleiro	do	do	AT13	.3
Fazenda Olho d'Agua	Rabugem	*Cordia officinalis*	OA2	.6
Fazenda Novo Sitio	do	do	NS5	.4
Pedreia Mangabeira	Alecrim	*Rosmarinus officinalis*	PG6	.2
	Candeia	Compositae fam	7	.1
Fervente	Pau de leite	*Pradosia* sp	FR8	.1
			9	.1
Fazenda Olho d'Agua	do	do	OA10	.1
Rua Nova	Caatinga de porco	*Caesalpinia microphylla*	RN17	.4

The preceding analyses indicate that several areas contain plants yielding anomalously radioactive ash—west and southwest of Tucano and south of Cicero Dantas (pl. 1). The area near Pôço Redondo has been field checked, and at least one occurrence of uranium and vanadium in sandstone is known (drill hole PRe–1). Only one plant sample (EC19) containing an anomalous amount of uranium came from within the area of anomalous radioactivity outlined by the airborne survey. Some of the radioactive plants are possibly accumulating uranium from the radioactive waters of the many thermal springs that occur throughout the basin.

The anomalously radioactive plants south of Cicero Dantas grow on the Marizal Formation, which contains no known uranium occurrences. The significance of their anomalous uranium content will be known only after detailed geobotanical sampling and field reconnaissance are completed in this area.

WATER SAMPLING

Springs, artesian wells, and Rio Itapicurú were sampled in conjunction with the geobotanical program. The river was sampled during low-water stage. Table 3 shows the results of chemical analysis in parts per billion (ppb) uranium content of the water for each sample.

TABLE 3.—*Water-sample analyses from the central Tucano basin, Bahia*

[Analyses in parts per billion]

Sample	Collection site (pl. 2)	Source	Uranium (ppb)
RN1	Rua Nova	Rio Itapicurú	0.4
1a	do	Ground seep[1]	[2]1.0
2	do	Rio Itapicurú	.4
PR3	Pôço Redondo	do	.5
AT4	Atoleiro	do	.3
EC5	CNEN hole F-8	Spring[3]	5.0
6	Ponte Euclides da Cunha	Rio Itapicurú	[4].7
7	Below Ponte Euclides da Cunha.	do	[4].7
8	do	do	.3
9	do	do	.5
J10	Hole MC-1, Jorro	Artesian well	.6

[1] From radioactive rocks cropping out at drill site PRe-1.
[2] Much lower than expected.
[3] Water (temp approx 35°C) issuing from drill hole.
[4] Higher uranium content than in other river water because of contamination by water from drill hole F-8 and thermal springs.

The uranium content of sample J10 is much lower than would be expected in water presumably from a deep source and probably in contact with the uranium-bearing beds that lie at 1626.1 meters in depth. The high temperature (48°C) of the water may diminish its uranium-carrying capacity, inasmuch as thermal waters usually contain less uranium than cold waters (Fix, 1956).

RADIOMETRIC LOGGING INVESTIGATIONS

A radiometric logging program was begun in April 1959 by Geraldo Pedrozo and several field assistants, and in May 1959 this program was terminated because of technical difficulties. Significant anomalous radioactivity was not found in any of the wells probed. Table 4 shows the hole location, depth probed, background radiation, and maximum radiation for each hole logged radiometrically.

TABLE 4.—*Results of radiometric logging of holes of the Departamento Nacional Obras Contras Secas in the central Tucano basin, Bahia*

Well	Depth probed (meters)	Background radiation (mr per hr)	Maximum radiation (mr per hr)
Mulungú Reservoir (1 km northwest of Cipó)			
1	13.8	0.012	0.026 (at 11.5 m)
2	9.0	.016	.028 (at 5.5 and 8.5 m)
3	19.5	.012	.028 (at 14.5 m)
4	46.5	.012	.025 (at 8.8 and 10.8 m)
Euclides da Cunha area (north of area shown on pl. 1)			
1 [1]	27	0.016	0.032 (at 25.8 and 27 m)
2 [2]	15	.016	.024 (at 1.2 and 13.8 m)
3 [3]	66	.018	.030 (at 13.8 m)
Fazenda Maracuja, Araci (south of area shown on pl. 1)			
1	39	0.016	0.032 (at 16 and 18.6 m)

[1] 12 km north of Tucano on Br-13.
[2] At Fazenda dos Mangues.
[3] At Fazenda Cariricí.

AIRBORNE INVESTIGATIONS

In October 1959 approximately 9 hours of aerial reconnaissance was done in the middle of the central Tucano basin and along its western margin by using a scintillation counter mounted in a helicopter (pl. 1). Because of the brief time that the helicopter of the Companhia Hidroeléctrica São Francisco was available, only those formations or areas known to contain radioactivity occurrences were covered by the airborne reconnaissance. The flights were made at altitudes of about 50 feet (15 meters) above good rock exposures and at about 200 feet (61 meters) on cross-country flights.

Two areas of significant radioactivity were outlined—one in the Pôço Redondo area and the other east of Greguenhem (pl. 1). The rocks within the area of anomalous radioactivity at Pôço Redondo consist of gray and green shales and mudstones and of gray and brown sandstones, all of Cretaceous age. Although their exact stratigraphic position is not known, the radioactive rocks are presumed to be equivalent to the basal part of the Sergí Formation, which is probably the host for the uraniferous beds in hole MC–1 at Jorro.

Neither the source of the radioactivity nor the type of radioactive rock at the Greguenhem anomaly is known as it was not field checked.

CONCLUSIONS AND RECOMMENDATIONS

Geochemical, geobotanical, areal mapping, and airborne radiometric methods of investigation succeeded by exploratory drilling seem to be the most satisfactory means of prospecting for uranium in the Tucano basin. All the significant radioactivity anomalies were found by one or a combination of these methods.

The geobotanical sampling indicated that several species of plants which thrive in the Tucano basin may be good uranium-assimilating plants; however, additional plant sampling and core drilling would enable one to more precisely evaluate the usefulness of the plants.

Road traverses for checking radioactivity in the central Tucano basin are of very little use because of the lack of good rock exposures along roads and trails and the extensive overburden of windblown sand. No significant radioactivity anomalies were found as a result of the road traverses, and no further traverses are recommended except possibly in the extreme northern part of the Tucano basin, north and east of the Rio São Francisco, where rock exposures are more abundant.

An areal mapping program in the Pôço Redondo area would delineate the extent of the formation which contains the uranium-bearing beds cut by drill hole PRe–1. Closely spaced (50-meter centers) core drilling around drill hole PRe–1 to a minimum depth of about 250 meters would show the extent of the uranium-bearing beds.

Geobotanical- and geochemical-sampling programs should be carried out in conjunction with the areal mapping in the Pôço Redondo area. The geobotanical sampling should be done on a 25- to 50-meter grid. Significant radioactivity anomalies detected by the sampling should be drilled, and all holes should be logged radiometrically so that a correlation can be made between plant radioactivity and any uranium present in underlying rocks.

In the Cicero Dantas area, geobotanical sampling on a 25- to 50-meter grid should be done in the areas where samples CD1, CD3, RP4, RP6, and RF13 (pl. 1) were taken.

An airborne survey should be made of the area of Cretaceous and Tertiary rocks north of Ribeira do Pombal and Tucano and into that part of the basin northeast of the Rio São Francisco.

The radioactivity anomaly at Greguenhem (pl. 1) should be checked with scintillation counters, and plant and water samples analyzed to determine if drilling is warranted.

If possible, any exploratory holes drilled by Petrobrás in the Tucano basin should be logged radiometrically.

All springs and streams in the basin should be more completely sampled, preferably during the dry season when composition of the ground water is less affected by inflow of the surface water. Those areas where anomalous radioactivity is detected by water sampling should be prospected by geobotanical sampling and exploratory drilling.

REFERENCES

Andrade, J. F. de, Jr., 1926, Aguas thermo-mineraes do valle do rio Itapicurú, Estado da Bahia: Servico Geologico e Mineralogico do Brasil Bull. 17, p. 3-32.

Fix, P. F., 1956, Hydrogeochemical exploration for uranium, *in* Page, L. R., Stocking, H. E., and Smith, H. B., compilers, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 667-671.

Haynes, D. D., and Mau, Henry, 1958, Reconnaissance for radioactive rocks in the Paulo Afonso region, Bahia, Brazil: U.S. Geol. Survey TEM-1104, 8 p., issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Haynes, D. D., Mau, Henry, and White, M. G., 1958, Radioactive manganese occurrences in the lower Rio Itapicurú valley, Bahia, Brazil: U.S. Geol. Survey TEM-567, 12 p., issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Link, W. K., 1959, The sedimentary framework of Brazil, *in* Proceedings, 5th World Petroleum Congress, New York, 1959: sec. 1, Paper 50, p. 901-923.

Stern, T. W., and Stieff, L. R., 1959, Radium-uranium equilibrium and radium-uranium ages of some secondary minerals, *in* Garrels, R. M., and Larsen, E. S., 3d, compilers, Geochemistry and mineralogy of the Colorado Plateau uranium ores: U.S. Geol. Survey Prof. Paper 320, pt. 13, p. 151-156.

The U.S. Geological Survey Library has cataloged this publication as follows:

Haynes, Donald Duane, 1928–

Reconnaissance for uranium in the central Tucano basin, Bahia, Brazil. Washington, U.S. Govt. Print. Off., 1964.

iii, 16 p. 2 fold. maps (in pocket) tables. 24 cm. (U.S. Geological Survey. Bulletin 1185–B)

Uranium investigations in Brazil.

Prepared on behalf of the U.S. Atomic Energy Commission in cooperation with the Commissão Nacional de Energia Nuclear, Brazil.

Bibliography: p. 16.

(Continued on next card)

Haynes, Donald Duane, 1928– Reconnaissance for uranium in the central Tucano basin, Bahia, Brazil. 1964. (Card 2)

1. Uranium ores—Brazil—Bahia (State) I. U.S. Atomic Energy Commission. II. Brazil. Commissão Nacional de Energia Nuclear. III. Title. (Series)