The Uraniferous Zirconium Deposits of the Poços de Caldas Plateau, Brazil

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GEOLOGICAL SURVEY BULLETIN 1185-C

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

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By GENE E. TOLBERT

URANIUM INVESTIGATIONS IN BRAZIL

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THE URANIFEROUS ZIRCONIUM DEPOSITS OF THE POÇOS DE CALDAS PLATEAU, BRAZIL

By GENE E. TOLBERT

ABSTRACT

The Poços de Caldas Plateau is about 350 kilometers northwest of Rio de Janeiro, Brazil, on the boundary between the States of Minas Gerais and São Paulo. Uraniferous zirconium deposits are associated with a circular intrusion approximately 1,000 square kilometers in area; the intrusion is composed mostly of feldspathoidal rocks. The zirconiferous deposits are chiefly mixtures of baddeleyite (ZrO_2) and zircon ($ZrSiO_4$); such mixtures are called caldasite; the higher grade zirconium ore contains more baddeleyite than zircon. Most of the production of ore at the time of the investigation (1952) was from placers of alluvial and eluvial origin. Lenticular vein deposits, the source of ore in the placers, are abundant throughout the plateau, but generally are too small and irregular to mine. Recommendations are included for trenching and drilling in certain areas to test the lateral and downward extension of the veins, to obtain data to calculate the volume of the deposits, and to explore for new ore deposits. The total production of zirconium ore concentrate from the Poços de Caldas Plateau from 1935 to 1952 is estimated to be about 100,000 metric tons. A conservative estimate based only on preliminary surface investigations is that an additional 50,000–75,000 metric tons of handpicked washed concentrate can be produced from the alluvial and eluvial ore in the region; these concentrates contain approximately 60–85 percent ZrO_2 and about 0.5 percent U (uranium).

INTRODUCTION

The Poços de Caldas Plateau is in southern Brazil on the border of the States of Minas Gerais and São Paulo (fig. 1). Radioactive zirconium deposits are clustered mainly in three areas in the Plateau.

Derby (1887), Barbosa (1934, 1936, 1948), Teixeira (1943), Freitas (1943), and Guimarães (1948) have written about the zirconium deposits in the Poços de Caldas Plateau, but very little systematic fieldwork has been done in the region. The radioactivity of the zirconium deposits has been known for many years, but identification of the radioactive element was not made until early 1952, when Max G. White and the writer studied samples of the radioactive zirconium ore from the Poços de Caldas Plateau in the mineral collection of the U.S. Geological Survey at Washington, D.C.

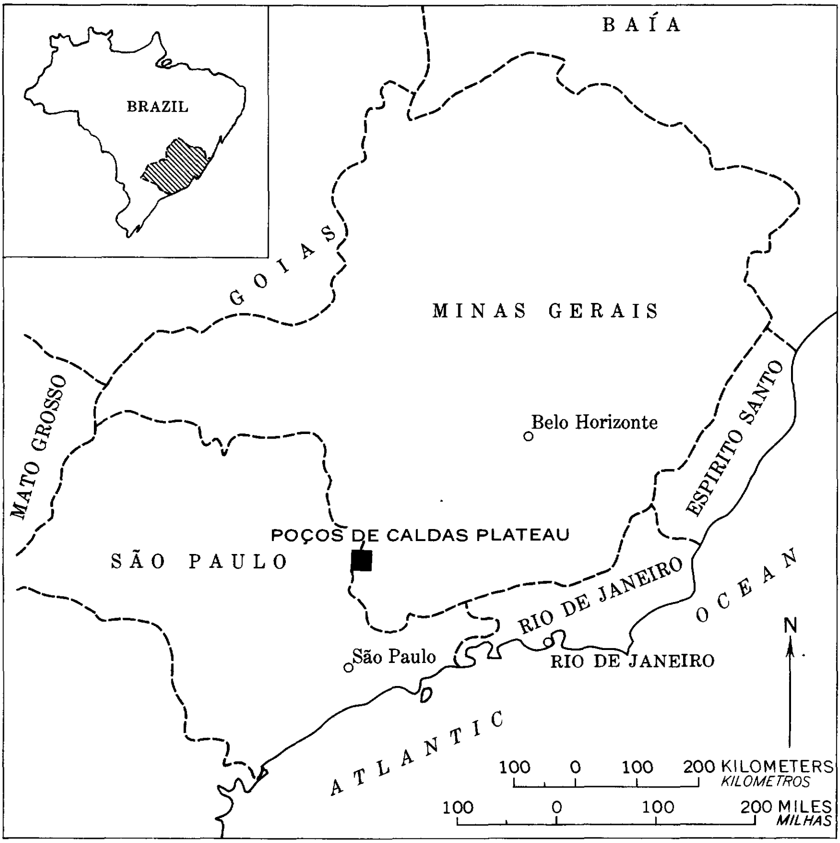

FIGURE 1.—Map showing location of the Poços de Caldas Plateau.

The investigation of these deposits was recommended by Max G. White and the author, and the work was performed in cooperation with the Conselho Nacional de Pesquizas (Brazilian Natl. Nuclear Energy Comm.) on behalf of the U.S. Atomic Energy Commission. The objectives of this investigation were to determine the source of the radiactivity, to collect samples from all zirconium deposits that have produced ore, to determine the uranium content of the radioactive material throughout the plateau, and to collect sufficient geologic data so that recommendations concerning further surface and subsurface exploration could be made.

Preliminary fieldwork began in November 1952 and was completed in February 1954. The fieldwork was under the direction of White until March 1953, after which the writer assumed responsibility for the project. Most of the fieldwork was done without benefit of aerial photographs and without topographic maps on a suitable scale to plot geologic data and prospect locations. Aerial photographs at a scale of 1 : 25,000 are now available, and topographic maps at a scale of 1 : 10,000 have been prepared.

Most of the important radioactive zirconium deposits in the Poços de Caldas Plateau were investigated at various times from November 1952 through February 1954. Preliminary delineation of radioactivity anomalies was accomplished by measuring variations in gamma radiation intensity by means of an airborne scintillation counter; coextensive airborne magnetometer surveys were also conducted. On the ground, variations in radioactivity intensity were mapped at the Taquarí, Três Barras, and Tamanduá-Vilela-Moirões deposits. Zirconium prospects and other areas of anomalous radioactivity detected by airborne or ground work were investigated.

This report [1] describes the uranium-bearing deposits of the Poços de Caldas Plateau and discusses future exploration and development of the deposits. Whether or not uranium can be extracted economically from the ores is not a premise of the report; the ore is considered primarily as zirconium ore from which uranium may be extracted as a byproduct.

Chemical analyses of samples show that the radioactivity is due to uranium. The uranium content of the ore-concentrate samples ranges from 0.13 to 2.0 percent and averages about 0.5 percent; radioactivity measurements of approximately 600 ore and concentrate samples of various types indicate an equivalent uranium content approximately equal to the uranium content. The deposits probably were formed by hydrothermal leaching of zirconium-bearing syenite that was subsequently deposited as oxide and silicate ore in fractures and open spaces. The Morro do Ferro deposit contains significant amounts of thorium and rare earths but very little zirconium and uranium.

The cooperation and aid of the Departamento Nacional da Produção Mineral (hereafter referred to as DNPM), Divisão do Fomento da Produção Mineral, is gratefully acknowledged. Resk Frayha, district engineer for the DNPM at Poços de Caldas, kindly placed the facilities of his office at the disposal of the author. The author was ably assisted in the fieldwork and the laboratory work by Helem Bessa, engineer of DNPM. The Instituto de Pesquizas Technológicas of São Paulo cooperated in furnishing chemical and fluorimetric analyses of samples.

LOCATION, CLIMATE, AND GEOGRAPHY

The principal town in the Poços de Caldas Plateau is Poços de Caldas, a hot-sulfur-springs summer resort which has a population

[1] Updated to 1964 since the original writing in 1954; analytical and descriptive data have been added.

of about 30,000. Poços de Caldas is 310 kilometers from São Paulo and 389 kilometers from the port of Santos by the Estrada de Ferro Monganio narrow-gage railroad. By paved highway the city is 272 kilometers from São Paulo and 328 kilometers from Santos. Hard-surface roads connect Poços de Caldas with Belo Horizonte and Rio de Janeiro; regularly scheduled airlines connect the city with São Paulo, Rio de Janeiro, and Belo Horizonte.

The climate of the region is pleasant; summers are cool and winters are mild. Annual rainfall ranges from about 150 to 190 centimeters. Rainfall is heavy during the summer months (December, January, and February) and the winter months are dry. Fieldwork is possible during most of the year.

The plateau is roughly circular (pl. 1) and has an area of about 1,000 square kilometers; the maximum diameter is approximately 35 kilometers. The average altitude of the plateau is 1,300 meters; the highest point is the hill Morro do Ferro, which has an altitude of 1,541 meters. The plateau is 400–500 meters higher than the adjacent area which is bordered by a ring of mountains 300–500 meters higher than the plateau. Rolling hills, generally barren or grass covered, are representative of the topography. Streams in the western part of the region drain northward, and streams in the eastern part flow eastward.

PROSPECTING METHODS

The distribution of radioactivity in the plateau was determined by field traversing on foot using a Geiger counter mounted on a packboard, road traversing using a Geiger counter mounted on a jeep, and airborne traversing using a scintillation counter.

Radiometric traversing on foot was accomplished by standard portable survey meters mounted on packboards and equipped with interchangeable 2- by 20-inch gamma probes and 6-inch beta-gamma probes; the latter were used for detailed examination of outcrops. At the deposits of Taquarí, Três Barras, Tamanduá, Moirões, and Vilela (pls. 1, 3), radiometric traverses were made at regular intervals perpendicular to the trend of the deposits. Three arbitrary scales of radioactivity intensity were established and used in delimiting areas of different intensity. Dividing lines between the areas of different intensity were marked off in the field with small flags; the lines were subsequently plotted on a topographic map by means of compass or plane table.

Roads were traversed by using a jeep which had either one or two 2- by 40-inch gamma tubes mounted on top connected to a portable survey meter; when two tubes were used, they were connected in parallel.

An airborne scintillation counter and magnetometer survey was flown over the entire area in 1953 by Levantamentos Aérofotogramétricos, S.A., with technical assistance being given by the Aero Service Corporation of Philadelphia. The scintillation counter was equipped with a device for graphically recording variations in radioactivity intensity. The magnetometer, mounted under the wing of a DC–3, was perfected in the United States for routine aeromagnetic surveying. Correct positioning was obtained by using a continuous-strip camera and a radio altimeter whose recordings were synchronized with the recordings of the scintillation counter and magnetometer. Corrections for topographic variation were made during data compilation. The survey was flown at a height of 150 meters above ground and horizontal flight-line spacings of 250 meters. The scintillation-counter data were recorded on a scale sensitivity of 2; areas producing off-scale deflections were reflown on a scale sensitivity of 1, which is one-fifth as sensitive as the number 2 scale.

Thirty-eight radioactivity anomalies of high intensity were located by the airborne survey and are shown on plate 1. The survey also disclosed numerous other anomalies of lesser intensity. All the high-intensity and most of the low-intensity anomalies were investigated on the ground.

GEOLOGY

The Poços de Caldas alkaline intrusive is in the southwestern part of the Brazilian shield near the northeastern part of the Parana basin. The alkaline complex is emplaced in gneiss and granite of the shield. The underlying rocks of the plateau are dominantly phonolite,[2] nepheline syenite,[3] and minor amounts of volcanic and sedimentary rocks.

Nepheline syenite is mostly confined to the northern third of the plateau. This rock is medium to very coarse grained. Outcrops of it range from a few square meters to tens of square kilometers in area. The nepheline syenite appears to intrude phonolite in most places where the two rock types are in contact, but in other areas the two rocks appear to have been emplaced contemporaneously—for example, at some outcrops, blocks of phonolite, tens of centimeters in diameter, are enclosed in nepheline syenite, and in other outcrops blocks of nepheline syenite of similar size are within phonolite. The contacts between nepheline syenite and phonolite may be either sharp or gradational. The exact age relation between these rocks has not been definitely established because of the deep weathering and consequent scarcity of outcrops.

[2] Phonolite is used in this report as a general term for a fine-grained feldspathoidal rock including dikes of tinguaite.

[3] Referred to as foyaite in much of the Brazilian literature concerning this area. In this report, no distinction is made between nepheline syenite and foyaite.

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Nepheline syenite which contains 1–30 percent of the pink zirconium silicate eudialyte crops out approximately 3–5 kilometers northeast of Poços de Caldas in the area marked Pedra Balão-Fazenda Teixeira in plate 1. Eudialyte [(Na, Ca, Ce)$_5$ (Fe, Mn) (Zr, Ti) Si_6O_{18}(OH, Cl)] was identified in X-ray diffraction patterns. X-ray fluorescence analyses by the writer revealed Zr, Hf, Fe, and Sr in this mineral. Probably Sr substitutes in the (Na, Ca, Ce) position, although the structure of eudialyte is not known. The optical properties of this mineral show that it is uniaxial positive and has an index of refraction of $O=1.60$ and $E=1.61$. X-ray analyses of sodic pyroxene in the same rock disclosed Fe and minor amounts of Mn, Zr, Hf, and Sr.

Although eudialyte is the only zirconium silicate positively identified, other rare zirconium and titanium silicates have been reported (Guimarães, 1948) in rocks in this area. The eudialyte syenite strikes east to west in a belt 100–1,000 meters wide and about 8 kilometers long. In the Pedra Balão area the eudialyte syenite has a trachytoid texture in which feldspar laths are parallel to needles of sodic pyroxene. Where the eudialyte content of the rock is 20–30 percent, the rock is pink on a fresh surface. A broad radioactivity anomaly outlines the eudialyte syenite and led the writer to investigate the area. The radioactivity is due to a small amount (<0.01 percent) of uranium in the eudialyte. Eudialyte also occurs sparsely as an accessory mineral in nepheline syenite and phonolite in the interior of the plateau. The uraniferous zirconium veins cut both nepheline syenite and phonolite.

Massive fine-grained gray to black phonolite underlies most of the Poços de Caldas Plateau. In a few places the phonolite is porphyritic. Flow structure is visible in the phonolite, or tinguaite, on the rim of the plateau. Pseudoleucite was found in phonolite near the town of Águas da Prata. Zeolites are common in fractures and open spaces in many places.

Volcanic tuff, breccia, and agglomerate and associated sandstone and siltstone crop out mainly along, or adjacent to, the northwest border of the plateau. These rocks underlie a very small part of the total area of the plateau. The sandstone that is cut by phonolite at Ozório (pl. 1) has been correlated with the Botucatú Sandstone of Triassic age (Barbosa, 1948).

Most of the rocks of the plateau are highly decomposed. The feldspathoidal rocks weather to clay or laterite. In the northern part of the plateau, aluminous laterite or bauxite commonly is the product of decomposition. Commercial deposits of bauxite are being mined (1964) on a small scale along or near the northern rim.

RADIOACTIVITY ANALYSES

The radioactivity of the zirconium deposits is due to uranium. The radioactivity of the zirconiferous samples, when expressed as percent equivalent uranium, is equal (within the limits of experimental error) to the percent uranium determined by chemical analysis.

Analyses of approximately 600 samples show that the radioactivity of the zirconium ore concentrate ranges from 0.13 to 2.0 percent eU; the average is about 0.50 percent. The ore containing the highest percentage of equivalent uranium in the plateau is from Serrote, where several large blocks (1–2 m in diameter) (fig. 2) contain about 85 percent ZrO_2 and 1.4–1.6 percent eU. These blocks are probably remnants of a massive lens which has been exposed by stream action. Blocks of comparable size and zirconium dioxide content are unknown elsewhere in the plateau and, to the writer's knowledge, have not been reported from other zirconiferous rock provinces in the world.

The intensity of radioactivity diminishes rapidly away from the ore bodies, although locally this diminution is masked by the radioactivity of uraniferous zirconium minerals in the eluvial cover. Wallrock samples collected 10–15 centimeters from zirconium veins average 0.03

FIGURE 2.—Block of caldasite, Serrote. This block, which contains about 85 percent ZrO_2 and 1.4–1.6 percent eU, is unique in the plateau and perhaps in the world.

percent eU. The wallrock is commonly clay derived from highly decomposed phonolite and nepheline syenite.

Intense radioactivity in several large areas in the southeastern part of the plateau is mostly due to thorium. At Morro do Ferro the source of the radioactivity, as confirmed by chemical analysis, is thorium which occurs with rare earths. Samples of the disintegrated eluvial material contain 0.05–0.50 percent eU. Most of the anomalies in the southeastern part of the plateau are associated with secondary manganese concentrations, and the few samples that have been analyzed contain thorium and rare earths, no zirconium, and very little uranium.

The eudialyte syenite in the Pedra Balão-Teixeira area is also radioactive (pl. 1); two samples of this rock having abundant eudialyte contain 0.005 and 0.008 percent eU, respectively.

URANIFEROUS ZIRCONIUM DEPOSITS

Uraniferous zirconium deposits are scattered throughout the Poços de Caldas Plateau but cluster chiefly in three main areas: the Pocinhos area in the east-central part of the plateau, the Cascata area in the west-central part, and the south-central area. (See pl. 1.) The three principal types of uranium-bearing zirconium deposits in the plateau are alluvial, eluvial, and vein deposits.

Confusion has arisen concerning the ore reserves of zirconium in the Poços de Caldas area because all writers have not used the term "ore reserves" with the same meaning. The Portuguese equivalent for "ore" is "minerio," and the latter term is used by some authors to mean material containing enough zirconium minerals and gangue to be mined profitably; other authors have used the term as a synonym for "ore concentrate." The difference in usage results, in part, from the fact that most of the zirconium production comes from alluvial and eluvial deposits which require little concentration, and the ore, as mined, is virtually a concentrate in place. The material mined from the alluvial and eluvial deposits consists of zirconiferous pebbles mixed with decomposed wallrock, clay, iron hydroxide concretions, and a little bauxitic material. "Caldasite" is a local term that is used for the pebbles or vein material consisting mostly of zirconium oxide and silicate minerals. Therefore, caldasite is virtually the same as crude zirconium ore concentrate. It is commonly a very hard, friable, dense, heavy rock. The ore concentrate contains 60–85 percent ZrO_2 and a high proportion of oxide to silicate.

The term "ore" is used in this report in the conventional sense, that is, any material containing enough zirconium minerals and gangue to be mined and concentrated profitably. Caldasite is used as defined above.

ORE MINERALOGY

Franco and Loewenstein (1948) studied the zirconium minerals from the Poços de Caldas Plateau and described their physical and chemical properties. Loewenstein (1952) also worked on the chemical properties of the zirconium minerals, giving special attention to the hafnium content. The two chief minerals of the zirconium deposits are baddeleyite (ZrO_2) and zircon ($ZrSiO_4$).

Baddeleyite is a very hard, gray to black mineral which is resistant to weathering and is found as rounded alluvial pebbles. In a few areas baddeleyite is fibrous and has the appearance of botryoidal hematite or manganese. Where fibrous, baddeleyite seems to be a secondary mineral. The length of the fibers ranges from 1 millimeter to about 1 centimeter.

Franco and Loewenstein (1948) believe that fibrous baddeleyite was the first to form and that it was subsequently replaced by zircon through reaction with silica-rich solutions. The oxide crystallized on the walls of the veins, and the silicate precipitated as euhedral crystals in the open spaces in veins or in geodes.

Other terms and zirconium mineral names commonly used in the literature in reference to the Poços de Caldas ores are listed as follows (the term in parentheses after the name of the mineral is the Portuguese equivalent):

Baddeleyite (baddeleyita). Zirconium dioxide (ZrO_2); one of the two principal minerals in the zirconium ore of the Poços de Caldas Plateau; named for Joseph Baddeley by Fletcher in 1892. The type material was collected from Ceylon.

Brazilite (brasilita). Zirconium dioxide (ZrO_2); the name given to baddeleyite by Hussak in 1892 for specimens from Brazil; now usually applied to the fibrous variety of baddeleyite; also a trade name for caldasite used by the Foote Mineral Co. beginning about 1916.

Caldasite (caldasita). A mixture of baddeleyite and zircon.

Zircon (zircão, sometimes called zirconita). Zirconium silicate ($ZrSiO_4$); one of the two principal minerals in the zirconium ore of the Poços de Caldas Plateau.

Zirconia (zirconia). Zirconium dioxide or oxide of zirconium (ZrO_2); sometimes used interchangeably with baddeleyite.

Zirkelite (Blake and Smith, 1913) (zirkelita). An oxide of zirconium, titanium. calcium, ferrous iron, thorium, uranium, and rare-earth elements; unknown in the Poços de Caldas Plateau.

Zirkite (zirkita). A trade name for alluvial zirconium ore ("favas") consisting of caldasite which has a high baddeleyite content; formerly used by the Foote Mineral Co.

Zirkonoxyd (oxido de zircônio). Zirconium dioxide; a German term used by Hussak and Reitinger interchangeably with brazilite (baddeleyite).

Meta-autunite, a hydrous calcium uranyl phosphate of secondary origin, is the only definitely identified uranium mineral found, and it occurred in but one of the ore samples studied. This secondary mineral was probably formed by the alteration of an unidentified primary uranium mineral in the zirconium ore that is considered of no commercial importance. Autoradiographs of caldasite and baddeleyite indicate that the uranium is disseminated throughout the caldasite. The uranium appears to occur as extremely small, mostly insoluble inclusions in baddeleyite. Uranium may substitute for zirconium in the zircon lattice. Table 1 shows equivalent uranium and approximate content of other elements in several of the radioactive deposits.

TABLE 1.—*Composition of radioactive samples from the Poços de Caldas Plateau*

[Analyses by K. E. Valentine. Uranium content by radiometric analysis. Other elements by semiquantitative spectrographic analysis]

Sample No.	Percent eU	Percent other elements					
		x0.	x.0	0.x	0.0x	0.00x	0.000x
We 59	0.41	Zr, Si	Al, Fe	Mn, La, Ti, Li, Hf, Nd, Ce, Dy, Pr	Ba, Y, Ho, Sr, Pb, Sm, Mo, B, Gd, V, Ni	Mg, Sn, Cr, Yb, Lu, Be, Sc	Cu
60	.35	Zr, Si	Fe	Al, Ti, Li, Ce, Hf, Dy, Sm	La, Y, Er, Ho, Nd, Pr, Ba, Mn, Mo, Eu, B, Gd, Pb, Ni, Sr	Mg, V, Sn, Cr, Yb, Lu, Sc, Be	Cu
To 95	.53	Fe, Si	Al, Ti, Ce, Th, La	Nd, Mn, Pr, Zr	Ba, Er, Dy, Mo, Eu, V, B, Sr, Gd, Zn, Lu, Y	Ho, Mg, Sc, Yb	Be
96	.32	Al, Si	Fe, Th, Ce	Ti, La, Nd, Er, Zr	Pr, Y, Mn, Mg, Dy, B, Zn, Mo, V	Ni, Ba, Sr, Ho, Sc, Lu, Yb	Be
110	.07	Si, Al	Fe, Zr	La, Ce, Ti, Li	Dy, Pr, Sm, Er, Mn, Nd, Cr, B	Mg, Ba, Ni, Y, Sr, V, Pb, Zn, Cu, Sn, Mo, Lu	Be, Yb
112	.16	Zr, Si	Al, Fe	Ti, Li, Ce, Hf, Dy, Sm	Ho, Sr, Nd, Ba, B, Pr, Cr, Pb, V, Mn, Ni	Zn, Mg, Y, Cu, Lu, Be, Yb	

We 59. Caldasite from vein in the Serrote mine.
We 60. Composite sample of zirconium ore, shipping grade (about 20 percent SiO_2 and 67 percent ZrO_2).
To 95. Highly radioactive wallrock from north side of main magnetite vein, Morro do Ferro.
To 96. Highly radioactive greenish-yellow altered wallrock from north side of main magnetite vein, Morro do Ferro.
To 110. Sample from purple alteration zone in radioactive sandstone, Ozório.
To 112. Radioactive sandstone, Ozório.

Thirty-three samples of commercial export-grade zirconium concentrate (60–85 percent ZrO_2) from the Poços de Caldas region were mixed together for a partial chemical analysis by the Instituto de Pesquizas Technológicas of São Paulo. Results are as follows:

	Percent		Percent
ZrO_2	70.0	TiO_2	1.1
SiO_2	14.5	U_3O_8	.64
Fe_2O_3	4.7	P_2O_3	.35

See table 1 for semiquantitative spectrographic analyses of samples from various types of radioactive deposits.

TYPES OF DEPOSITS

Alluvial deposits.—The alluvial zirconium ore occurs in streambeds and in terraces or benches along the margins of streams. In many places the mining of alluvial deposits is economically feasible because these deposits contain more baddeleyite than eluvial deposits and are close to the water required for washing purposes. Pebbles of caldasite, called favas, in the alluvial deposits have a specific gravity of about 5.5 and a submetallic luster. Most favas contain only a few percent zirconium silicate. The diameter of caldasite pebbles ranges from about 0.5 to 15 centimeters; the average is 2–3 centimeters. Locally, favas are found as partly to well-consolidated gravels in pockets a few meters in diameter along present or former stream channels.

Eluvial deposits.—Eluvial zirconium ore deposits are found on hill slopes as surface mantles consisting of a mixture of residual material and limonite, hematite, and bauxitic and manganiferous material. An eluvial mantle that is economical to mine for zirconium ore ranges in thickness from 5 to 200 centimeters; the average is about 50 centimeters. Most of this information is based on measurements made at the Taquarí deposit (pl. 1) in the Pocinhos area. The eluvial deposits contain from 5 to 10 percent caldasite pebbles that are angular, light gray, and lower in zirconium dioxide content than the alluvial ore.

Vein deposits.—Vein deposits containing zirconium minerals are scattered throughout the Poços de Caldas Plateau, but the more significant deposits are found in the Pocinhos, Cascata, and south-central areas (pl. 1). The vein deposits have not been extensively developed because alluvial and eluvial deposits are more economical to mine. A few veins and lenses have been mined to a depth of a few meters, but the caving of unsupported walls prevents deeper mining. Owing to these adverse factors, the veins may never be important sources of zirconium ore. Another adverse factor economically is the small size of the vein deposits. Most of the veins are narrow and irregular; their width ranges from 1 to 10 centimeters and averages about 2 centimeters (figs. 3, 4). Lenses range from a few centimeters to several meters in width, and the average width is about 15 centimeters.

Disseminated deposits.—At Quirinos, Rodrigues, and Tamanduá (pl. 1), the zirconium ore minerals are in irregular masses from 1 to 4 centimeters in size and are disseminated in decomposed wallrock. These deposits are small and are not considered economic to mine for zirconium ore, but they contain uranium in amounts comparable to the other types of deposits.

FIGURE 3.—Three large lenses of caldasite in a trench at the top of Morro do Taquarí. (Sta. A, pl. 3)

FIGURE 4.—Old trenches and surface workings, Serrote mine.

ORIGIN OF THE ORES

Franco and Loewenstein (1948) and most of the previous investigators of the Poços de Caldas zirconium deposits believed that the primary deposits are of hydrothermal origin. According to Franco and Loewenstein (1948, p. 150), "the following stages can be recognized: first, the formation, either by magmatic segregation, or by reaction of the essential minerals of the alkaline rocks of the region, orthoclase, nepheline, aegirine, augite, sphene, melanite, sodalite, wollastonite, magnetite, biotite, hastingsite, scapolite, natrolite and muscovite. With these occur the complex silicates of zirconium: rosenbuschite, eudialyte, astrophyllite, lavenite, eucolite and very likely zircon." They postulated that the zirconiferous silicates and possibly acmite, a common mineral in the nepheline rocks of the region, were the source of the zirconium in the ore deposits. Hydrothermal solutions dissolved the zirconiferous silicates and deposited the stable oxide and silicate in fissures. Subsequently, some of the rocks containing baddeleyite and zircon—a combination called caldasite—were decomposed by weathering processes. Eluvial placers were formed by the concentration of the caldasite in the residual mantle; further concentration by streams resulted in the formation of the alluvial placers.

The writer concurs with Franco and Loewenstein's conclusion that a source for the zirconium is the zirconiferous syenite. Unfortunately very little information exists concerning the downward extent of the veins or the type of rock existing below the surface. Until more subsurface data are available, it is not possible to state with assurance whether the zirconium and uranium were leached from an overlying body of zirconium-bearing rock, now removed by erosion, or from an unexposed zirconiferous rock at depth. The amount of eudialyte syenite in the plateau, estimated from outcrops, is too small to have furnished a significant part of the considerable quantity of zirconium in deposits scattered throughout the alkaline massif. The only area larger than a few square meters known to the writer to be underlain by eudialyte syenite is that north of Poços de Caldas (Pedra Balão-Teixeira), which is 10–12 kilometers from the nearest zirconium deposits.

In summary, the emplacement of zirconium-bearing alkalic rocks was followed by the leaching of zirconium and uranium by hydrothermal solutions, probably alkaline, accompanied by wallrock alteration and subsequent deposition of oxide and silicate ore in open spaces. Later oxidation and enrichment upgraded the uranium content and possibly the zirconium content of some deposits.

WALLROCK ALTERATION

The hydrothermal solutions that deposited the zirconium veins also altered the wallrocks to white clay (kaolinite?) in a zone 1–10 centimeters wide next to the vein. Outward from the white clay zone is a red (ferriferous) zone that ranges from a few centimeters to several meters in width. Whether the red clay is a product of hydrothermal alteration or of weathering was not determined. This alteration zone is characteristic of most of the veins and is generally recognizable, although in some areas it is obscured by deep weathering. The fresh wallrock in most deposits is phonolite.

In some areas phonolite is altered or bleached to a white rock. Resk Frayha (written commun., 1953) found that this altered rock contained as much as 10 percent K_2O. He reported that this bleached rock underlies fairly large areas in the southern sector of the plateau and that its alteration is the result of hydrothermal processes. In this study it was not possible to determine the mineralogy of this rock.

STRUCTURE OF THE VEIN DEPOSITS

Most of the zirconium veins are associated with joints or faults which have a displacement of not more than a few meters. The fractures which occur singly or as sheeted zones do not have the same orientation in all places, but the orientation is consistent throughout areas of several square kilometers. Some of the veins filling these fractures are regular and continuous for strike lengths of several hundred meters, but most of the veins are extremely irregular and pinch and swell every few meters along the strike.

At Dona Rita-Irene, Três Barras-Itororó, Taquarí, Taquarí do Sul, Zotinho, and Tamanduá-Vilela, veins and lenses of zirconium are localized either along a fracture or along a system of parallel fractures that strike N. 30° W. to N. 30° E. At Quirinos-Serrote the veins are along east-striking fractures.

Because most of the veins are controlled by fractures, many of the fracture patterns serve as important guides to additional ore deposits which lie parallel to or are on strike of known deposits.

MINING METHODS, PRODUCTION, AND RESERVES

Mining methods used in the Poços de Caldas Plateau today differ little from those used 40 years ago; most of the mining is done with pick and shovel (fig. 4). The ore is transported by hand-carrying, wheelbarrow, oxcart, and by truck to washing stations, where crude concentrates are obtained by sluicing, handpicking, sieving, and handjigging.

Most of the zirconium properties in the Poços de Caldas Plateau are held by the Companhia Geral de Minas, a subsidiary of Byington and Company of São Paulo. The company does not mine the ore but buys it from contractors who do the actual mining. The crude concentrates are trucked from various collecting points to Poços de Caldas or Cascata, where they are further concentrated, crushed, graded, bagged, and shipped. Crude concentrates are purchased from the contractors in bulk lots of 100 kilograms; these concentrates average about 72 percent ZrO_2 and 15 percent SiO_2. About one-fifth of the crude concentrate delivered to Poços de Caldas or Cascata is sorted out as low grade or undersize. The low-grade concentrate contains about 60 percent ZrO_2 and is sold for the manufacture of refractory cement. Bulk ore is passed through a small jaw crusher set with an opening of about 3 centimeters, and the crushed ore is screened to 5 millimeters. The oversize material is bagged for export shipment, and the undersize is sold for use as refractories.

The production of zirconium ore concentrates from the Poços de Caldas Plateau from 1935 to 1952 is shown in table 2. The figures from DNPM are export figures; those from the Companhia Geral de Minas are production figures.

TABLE 2.—*Production of zirconium ore concentrates from the Poços de Caldas Plateau, 1935–52, in metric tons*

Year	DNPM exports	Companhia Geral de Minas		
		Pocinhos area	Cascata area	Total
1935	1, 627	----------	----------	----------
1936	1, 520	----------	----------	----------
1937	1, 590	----------	----------	----------
1938	1, 310	----------	----------	----------
1939	1, 336	----------	----------	----------
1940	1, 100	175	1, 372	1, 547
1941	4, 700	3, 302	2, 721	6, 023
1942	17, 000	9, 726	5, 384	15, 110
1943	5, 000	2, 538	2, 102	4, 640
1944	2, 100	1, 232	910	2, 142
1945	700	784	1, 865	2, 649
1946	4, 400	3, 249	2, 203	5, 452
1947	4, 000	3, 708	1, 960	5, 668
1948	3, 600	1, 956	1, 637	3, 593
1949	2, 300	1, 882	1, 146	3, 028
1950	960	2, 073	846	2, 919
1951	2, 400	900	1, 884	2, 784
1952	2, 200	1, 600	1, 800	3, 400
Total	57, 843	33, 125	25, 830	58, 955

Although no production figures are available prior to 1935, an estimated 25,000–30,000 tons of concentrate was produced before that year. If 10,000–15,000 tons is estimated to have been produced by companies other than the Companhia Geral de Minas, the total production from the plateau through 1952 would be about 100,000 metric tons.

Not enough data are available to estimate the ore reserves precisely. Based on preliminary surface investigations, the writer estimates that an additional 50,000–75,000 metric tons of handpicked washed concentrate may be produced from the alluvial and eluvial deposits using primitive mining methods. By conducting a systematic exploration program in favorable areas and by improving the methods of mining and concentration, the ore reserves might be increased.

The zirconium ore is very heavy, having a specific gravity of 5–5.5 and may be separated from the other material by ordinary gravity concentration methods.

DESCRIPTION OF MINES AND PROSPECTS

All the deposits and prospects lie within a 30 kilometer radius of Poços de Caldas and are accessible by jeep in dry weather. (See pl. 1.) Most of the samples taken for analysis are zirconium ore concentrates. These samples furnish data on relative amounts of uranium at various localities in the plateau. Where feasible, channel samples were taken across mineralized zones. Table 3 gives the average equivalent uranium content of various types of samples from the radioactive deposits in the plateau.

The Taquarí (pls. 2, 3), Três Barras (pl. 3), and Tamanduá-Vilela-Moirões (pl. 3) areas were studied in detail. Taquarí was chosen for detailed study because considerable work had already been done on the eluvial zirconium deposits by the DNPM and because a topographic map of the area was available. The two other areas were studied in detail to obtain structural information and because they were accessible.

Individual deposits are described below under their respective geographic areas: The Pocinhos area, the Cascata area, and the south-central area. (See pl. 1.) The names of localities used in this report are local names in present use and are subject to change.

The deposits described in the Pocinhos area are Taquarí, Taquarí do Sul, Zotinho, Ponte Alta (Sebastião Ribeiro), Madama, Dona Rita, Irene, Pouso Alegre, Buso, Chapada, and Espingarda. All were visited and sampled except Chapada. In the Cascata area, the deposits are Serrote, Cocal, Quirinos, Rodrigues, Gigante, Brígidas, and Jorge.

Of these, only Jorge was not visited. In the south-central area the deposits are Três Barras, Itororó, Lobo, Lagôa Dourada, and São Filão, all east of the Andradas Road; and Tamanduá, Moirões, Vilela, Nesinho, and Cachoerinha, west of the Andradas Road. (See fig. 3.) All were visited except Lobo, Nesinho, and a few prospects near Lagôa Dourada.

Other radioactive deposits which were visited and sampled but which are different types from those listed in the preceding paragraph are Ozório sandstone deposit (zirconium-uranium), Morro do Ferro (iron), and Cercado (manganese). (See pl. 1.)

TABLE 3.—*Average equivalent uranium content of samples from the uraniferous zirconium deposits of the Poços de Caldas Plateau*

[Analyses by G. E. Tolbert and H. Bessa]

Deposit	Type of material tested	Number of samples	Average eU content (percent)
	Porinhos area		
Taquarí	Eluvial ore (handpicked concentrates).	13	0.39
	Eluvial ore (handpicked concentrates).	55	.37
	Eluvium (grab samples)	107	.07
	Vein ore (concentrates)	30	.60
	Ore concentrates (all types)	133	.40
Taquarí do Sul	Vein ore (concentrates)	6	.33
	Wallrock	1	.02
Zotinho	Vein ore (concentrates)	3	.50
Ponte Alta	Eluvial ore (handpicked concentrates).	3	.27
	Vein ore (concentrates)	10	.29
	Wallrock	2	.03
Dona Rita	Vein ore (concentrates)	8	.24
Irene	Eluvial ore (handpicked concentrates).	9	.20
	Vein ore (concentrates)	1	.20
Madama	Eluvial ore (handpicked concentrates).	3	.24
	Vein ore (concentrates)	1	.35
Órfãos	Eluvial ore (handpicked concentrates).	4	.35
Espingarda (western deposit).	Vein ore (concentrates)	4	.18
	Grab sample from ore pile	1	.11
	Vein ore (concentrates)	1	.13
Espingarda (eastern deposit).	Vein ore (concentrates)	6	.55
Buso (northern deposit)	Vein ore (concentrates)	2	.22
	Channel samples, 1 m long, across mineralized zone.	3	.09
Buso (southern deposit)	Vein ore (concentrates)	6	.40

TABLE 3.—*Average equivalent uranium content of samples from the uraniferous zirconium deposits of the Poços de Caldas Plateau*—Continued

[Analyses by G. E. Tolbert and H. Bessa]

Deposit	Type of material tested	Number of samples	Average eU content (percent)
Cascata area			
Serrote	Eluvial ore (handpicked shipping concentrates).	6	0.55
	Eluvial ore (handpicked concentrates).	7	.61
	Vein ore (concentrates)	10	.60
Cocal	Eluvial ore (handpicked shipping concentrates).	2	.64
Quirinos	Channel sample, 9 m long, across mineralized zone.	1	.10
Rodrigues (northern deposit).	Eluvial ore (handpicked concentrate).	1	.37
	Vein ore (concentrate)	1	.13
	Channel sample, 20 cm long, across mineralized zone.	1	.02
Rodrigues (southern deposit).	Disseminated ore (concentrates)	3	.17
	Vein ore (concentrates)	1	.51
	Grab sample from ore pile	1	.09
Brígidas	Eluvial ore (handpicked concentrates).	2	.40
	Vein ore (concentrate)	1	.57
	Vein ore (concentrate)	1	.75
Gigante	Channel sample, 2 m long, across ore zone.	1	.26
	Wallrock; channel samples, 2 m long, including ore zone.	2	.04
South-Central area			
Três Barras (eastern deposit).	Wallrock 8 m from ore zone	1	0.01
	Channel samples, 1 m long, across ore zone.	12	.18
	Channel samples across ore zone.	14	.51
Três Barras (western deposit).	Eluvial ore (grab samples)	10	.10
	Channel sample, 1 m long, across ore zone.	1	.21
Itororó	Channel samples across ore zone.	4	.46
Tamanduá-Vilela	Eluvial ore (handpicked concentrates from ore pile).	2	.51
	Vein ore (concentrates)	11	.49
	Vein material (from veins in fresh rock).	2	.20
	Wallrock	1	.08
	Channel sample across ore zone	1	.61
Moirões	Eluvial ore (handpicked concentrates from ore pile).	1	.55
Cachoeirinha	Eluvial ore (handpicked concentrates).	6	.55
São Filão	Channel samples across mineralized zone.	3	.06

POCINHOS AREA

TAQUARÍ

The Taquarí zirconium deposit is about 23 kilometers southeast of Poços de Caldas (pl. 1) on a large hill called Morro do Taquarí, which has an area of about 170 hectares (approximately 420 acres) and an altitude of 1,500 meters (pl. 2). Resk Frayha of DNPM made a topographic map of the area at a scale of 1:2,000 and tested the thickness of the eluvium and alluvium by digging 280 shallow prospect pits. This work was done in 1951 and is described in an unpublished report of the DNPM. About 95 percent of Frayha's prospect pits were resurveyed and 400 additional stations were surveyed during the present study to furnish control for a map showing the surface radioactivity (pl. 3).

Taquarí was traversed with a backpack counter at intervals of 20 to 30 meters. Three arbitrary scales of gamma-radiation intensity were established: high intensity, an increase of 15 or more scale divisions on scale 2 of the counter; medium intensity, an increase of 7–10 scale divisions on scale 2 of the counter; and background. In general, the areas of high radioactivity correspond to areas rich in zirconium ore.

The rocks exposed on Morro do Taquarí are mostly very decomposed so that accurate identification is very difficult in field investigations. A reconnaissance geologic map (pl. 2) outlining the areas of nepheline syenite, tinguaite, and phonolite was prepared while making radiometric traverses.

The phonolite and tinguaite commonly decompose to a soft white rock. Much of the rock may be hydrothermally altered, but it is difficult to distinguish hydrothermally altered zones from weathered zones. The syenite is generally medium to coarse grained, but on the southeast side of Morro do Taquarí near Córrego Filadelfia, the texture of the syenite becomes finer near the contact with phonolite. In this area, acmite and mauve-colored eudialyte(?) are in the syenite.

Alluvial deposits of zirconium ore are found in the valley of Pouso Alegre Creek in the Taquarí area (pl. 3) as semiconsolidated gravel deposits in pockets along old stream channels and in terrace gravel. These deposits are mined by pick and shovel, and the ore is concentrated by sluicing.

The eluvial deposits cover approximately one-fourth of Morro do Taquarí. The average thickness of the eluvium on the upper slopes is 10–20 centimeters; however, farther down the hillside the average thickness is 40–60 centimeters. These deposits are worked by women and children who pick out the heavier caldasite from the eluvium and carry it in baskets to the roadside where it is picked up by a truck and hauled to the washing station at the bottom of the hill.

Vein deposits at Taquarí are well exposed on top of the hill where three large lenses are exposed in a trench (fig. 3 and pl. 3, sta. A). These lenses are mainly composed of oxidized caldasite that contains a high uranium content but is too low in zirconium dioxide to mine. Several smaller lenses and veins are exposed in two other prospect holes at the top of the hill (pl. 3, sta. B and C). These deposits generally strike north, but one lens and vein system appears to strike due east. A hole drilled to a depth of 75 meters by the DNPM near the trenches at the top of the hill penetrated 45 centimeters of caldasite at a depth of 5.5 meters. Several samples from this hole contained abundant fluorite.

Very strong surface radioactivity was detected in the area north of station D (pl. 3); this area is underlain by highly oxidized, manganiferous rock. An analyzed sample of this rock contained 1.36 percent eU which is the highest recorded radioactivity of any sample from this sector of the plateau. This area should be trenched to fully explore the radioactive rock. The manganiferous rock mixed with caldasite has no value as zirconium ore but is worth investigating as a possible source of uranium. A few hundred meters downslope from this outcrop, the eluvium contains a few small boulders having druses and vugs containing green and brown crystals of zircon.

Most of the samples collected at Taquarí are eluvial material of two types: (1) handpicked eluvial caldasite which has little or no gangue and (2) grab samples of eluvium. The diameter of the eluvial pebbles is 2–3 centimeters. The alluvial samples (favas) were handpicked alluvial ore concentrates from stream bottoms.

Taquarí do Sul.—A large prospect pit called Taquarí do Sul (a name given by the writer) is located approximately 1,500 meters south of Taquarí (pl. 1) and is parallel to the strike of the structures at stations B and C (pl. 3). The zirconium ore occurs in veinlets 1–2 centimeters wide, pods 3–7 centimeters wide, and a few lenses as much as 0.5 meter wide. Most veinlets strike N. 20°–30° E., and dip 55°–70° NW.

Zotinho.—Approximately 1,600 meters north of Taquarí, at a locality called Zotinho (pl. 1), an aeroradiometric anomaly was detected but was not investigated. This area lies along the strike of the veins at Taquarí and Taquarí do Sol.

Conclusion.—A series of inclined holes across the strike of the veins in the Taquarí area should be drilled to determine whether the veins continue at depth. Several east to west trenches should be dug on the north side of the hill in the area of radioactive manganiferous rock (pls. 2, 3) to obtain structural information and samples. If the veins are found to continue at depth, additional holes should be drilled on strike from Taquarí northward to Zotinho and southward to Taquarí do Sul. (See pl. 1.) A prospect tunnel near the base of Taquarí normal to the vein system would also provide valuable information on the extension of veins and their grade at depth.

POUSO ALEGRE

The Pouso Alegre deposit is on the north bank of Pouso Alegre Creek (p. 1) about 2 kilometers north of the base of Morro do Taquarí. At one time the Companhia Geral de Minas mined alluvial terrace deposits along this creek. The terrace deposits contain about 8 percent zirconium ore concentrate. No data are available on the uranium content.

PONTE ALTA (SEBASTIÃO RIBEIRO)

The Ponte Alta (Sebastião Ribeiro) area is 20 kilometers southwest of Poços de Caldas on the road to Pocinhos (pl. 1). The main vein in this area is about 1 kilometer north of the main road and is intermittently exposed for 375 meters along a line of shallow pits and trenches. The vein strikes approximately N. 70° E., dips 70° SE., and is 12–15 centimeters wide. Phonolite and phonolite porphyry wallrocks are altered to white clay. Slickensides and gouge along the walls indicate considerable movement along the vein. More than 100 metric tons of ore concentrate has been produced from this deposit.

DONA RITA

The Dona Rita deposit is on a hill on the south side of the road from Caldas to Pocinhos at kilometer 20 (pl. 1). Four parallel trenches are cut into the side of this hill. Three of these trenches are only a few meters long, whereas the fourth trench follows the main vein system, which is 20–110 centimeters wide, northward for about 300 meters. Most of the zirconium veinlets, which strike N. 10° E. and dip 70° W., are 2–3 centimeters in width, but locally swell into lenses 30 centimeters wide. The wallrock is altered to white clay next to the veins; slickensides and gouge are very common on the vein walls.

Further trenching and drilling on the north end of the Dona Rita deposit are necessary before the size of the deposit can be determined.

An outcrop of pegmatitic nepheline syenite that contains crystals of hornblende as much as 4 centimeters long and abundant purple fluorite is about 30 meters west of the Dona Rita trenches. Fluorite is a common accessory mineral in nepheline syenite in the Pocinhos area.

IRENE

The Irene deposit is on the south side of the road to Pocinhos at kilometer 21 (pl. 1). All production at this site has been from eluvium. Two vertical veins, 10–12 centimeters thick, that strike N. 15° E. are exposed in shallow pits.

MADAMA AND ÓRFÃOS DEPOSITS

These deposits are small, and only a few tons of eluvial ore concentrate has been produced from each. Their locations are shown on plate 1; sample analyses are given in table 3.

ESPINGARDA

The Espingarda deposits, owned and worked by the Companhia Geral de Minas, are 6 kilometers south of Pocinhos (pl. 1) and are about half a kilometer apart. The western deposit was developed by trenching along several parallel veins that range from 2 to 6 centimeters in width, strike N. 70° W., and dip 55°–85° SW. The soft clay wallrock is dangerous to work because of its tendency to slump, particularly if wet.

The company developed the eastern deposit, which is 1–2 meters wide, by driving an adit on a mineralized zone that strikes N. 20° W.

BUSO

The Buso deposits are 25 kilometers south of Poços de Caldas and 2 kilometers southwest of Taquarí; they are accessible by the Taquarí road (pl. 1). Development on the northern deposit consists of a series of prospect pits and tunnels, one above the other on the side of a hill, along a system of parallel veinlets 3–7 centimeters wide in a mineralized zone 30 centimeters wide. The veins strike east and dip 55° N. They contain manganiferous material and are radioactive, but very little caldasite is present.

The southern deposit contains a few scattered prospect pits and an adit that was driven on a 6-centimeter vein striking N. 15° E. and dipping 60° NW.

CASCATA AREA

SERROTE

Serrote is about 2 kilometers south of the town of Cascata (pl. 1) in the State of São Paulo. Serrote is the oldest zirconium mine in the Poços de Caldas area, and most of the zirconium ore has been produced from this mine (fig. 4). The surface at Serrote is crisscrossed by old trenches, caved tunnels, mine dumps, and roads; consequently most of the veins and lenses are now obscured. A few large blocks of nearly pure caldasite were observed in a stream bottom at Serrote (fig. 2). These boulders are described in the section on radiometric analyses.

The miners report that some of the lenses were more than a meter wide. Mining operations were discontinued when unsupported walls of the trenches made the work hazardous (fig. 4). Alluvial, eluvial, and vein deposits have been mined at Serrote, but all the production comes from eluvium that contains 5–10 percent caldasite. The ore is hauled by truck to a central washing station for concentration. Further work at Serrote will require the removal of dump piles and the reopening of trenches in order to locate the ore bodies.

Nepheline syenite, phonolite, and phonolite porphyry crop out in the area. A mauve mineral, probably eudialyte, was observed at one syenite outcrop.

COCAL

Cocal (Triangulo) is an alluvial deposit located on the boundary between Minas Gerais and São Paulo, about 1 kilometer northeast of Cascata (pl. 1). The alluvial ore is in irregular-shaped lenses a few meters below the surface. Cocal has been extensively explored by auger drilling to a depth of 15 meters by the DNPM, but no radiometric data are yet available.

QUIRINOS

The Quirinos deposits, 26 kilometers southwest of Poços de Caldas and 6 kilometers south of Cascata (pl. 1), include prospects and stripped areas in an area of several square kilometers. The main deposit, which strikes about N. 20° W., was developed by a large open pit and several adits and trenches. The two largest adits are now full of water, and most of the other workings are caved.

RODRIGUES

The Rodrigues deposits are 26 kilometers from Poços de Caldas and 6 kilometers from Cascata, on the north side of the road opposite Quirinos (pl. 1). For simplicity, they are referred to as the northern and the southern deposits.

The northern deposit has produced some eluvial ore. The prospect pits are all caved with the exception of one large pit which contains a small vertical caldasite vein. This vein, which cuts fresh phonolite, strikes due east and is 2–6 centimeters wide. The soft altered wallrock zone is 15–20 centimeters wide.

Several large trenches in the southern deposit trend approximately east to west. At the end of an old haulage road, a large trench 39 meters long follows a zone of gray disseminated ore 40–70 centimeters wide. Blebs and pods of gray caldasite are disseminated in soft decomposed phonolite(?). In the southernmost trench, an ore zone 30 centimeters wide, which contains several narrow caldasite veinlets, trends N. 10° E. and dips 55° NW.

BRÍGIDAS

The Brígidas deposit, 30 kilometers from Poços de Caldas and 9 kilometers from Cascata (pl. 1), is south of the Quirinos and Rodrigues deposits. A trench 170 meters long and 7–10 meters deep follows a series of veins and large lenses that strike N. 10° W. The surface radioactivity in the area is generally strong.

The extent of the main ore zone at Brígidas and its relationship to the Quirinos and Rodrigues deposits are not known but might be determined by several trenches across the ore zone.

GIGANTE

The Gigante deposits, 31 kilometers from Poços de Caldas, occupy a large area southwest of Brígidas. At one time both eluvial and vein deposits were mined but now nearly all the trenches and prospect pits are caved and little information about the size and occurrence of the deposits is available. A few small zirconium-bearing veinlets that strike N. 45° W. and dip 55° SE. were observed in the southern part of the area.

SOUTH-CENTRAL AREA

TRÊS BARRAS

The Três Barras deposits are 18 kilometers south of Poços de Caldas and may be reached by turning east at kilometer 14 on the road to Andradas and following an oxcart road for 4 kilometers (pl. 1). The ore zones, called the eastern and western deposits in this report, were mapped by planetable on a scale of 1:1,500 (pl. 3). The eastern deposit has been prospected by a line of trenches and two short adits, the western deposit by a few shallow pits. Three arbitrary scales of gamma-radiation intensity (similar to those at Taquarí) were established: (1) high intensity, (2) medium intensity, (3) background. Appropriate stations for delimiting the areas of different intensities were established during radiometric traversing and subsequently were tied to a plane table survey.

The vein zone in the eastern deposit is 20–30 centimeters wide. A shaft was sunk by DNPM in the vein zone to a depth of 11 meters. The wallrock is highly decomposed and is altered to green, yellow, and white clay. Relic texture in the wallrock adjacent to the veins appears to be coarser than the texture of fresh phonolite exposed 30 meters away from the ore zone; the wallrock probably is altered nepheline syenite.

The ore zone of the western deposit is poorly exposed in a few shallow pits. The veins and blebs of caldasite less than 1 centimeter in diameter are in decomposed rock that probably was phonolite.

ITORORÓ

The Itororó deposit is about half a kilometer north of Três Barras (pl. 1). An excavation 40 by 30 meters marks the site of a large lens of caldasite, now mostly mined out. This lens was probably one of the largest concentrations of zirconium ore in the plateau. Several adits have been driven farther up the hill in an effort to find the extension of the ore zone.

The aeroradiometic survey shows a large radioactivity anomaly trending northward from the Três Barras–Itororó deposits (see pl. 1). This anomaly was checked in the field about 3 kilometers north of Itororó, and several small zirconium-bearing veinlets were discovered in an old prospect pit.

The probability that north-striking structures controlled the deposition of the ore and the large radioactivity anomaly extending north of Itororó suggests that the area north of the Três Barras-Itororó deposits should be investigated for new deposits.

TAMANDUÁ-VILELA-MOIRÕES

The Tamanduá-Vilela-Moirões area is approximately 16 kilometers south and 2 kilometers west of Poços de Caldas on the road to Andradas (pl. 1). Vilela, 2 kilometers northwest of Tamanduá, is reached by an oxcart trail. At least two parallel zones of radioactivity trending N. 20° W. extend from Tamanduá to Vilela. Radiometric traverses were made at 50- to 75-meter intervals, using the same three scales of radioactive intensity that were used at Taquarí (pl. 3). The Tamanduá deposit was prospected by excavating a line of small trenches. Several adits were driven into the hill just south of Vilela, and the mineralized zones in these adits were sampled.

In the northern part of the Tamanduá area a prospect adit was driven in a zone of disseminated ore that trends N. 20° W. Small blebs and pods of gray caldasite as much as 4 centimeters in diameter are scattered through decomposed nepheline syenite(?) apparently at its contact with phonolite; the syenite appears to be more decomposed than the phonolite.

In the southern part of the area, two small caldasite veinlets 1–4 centimeters wide fill fractures in fresh phonolite(?) (pl. 3). This is one of the few places in the plateau where veins have been found in unweathered rock. One veinlet strikes north and dips 65° W.; the other strikes N. 50° E. and dips 65° NW. Both veinlets appear to die out in about 30 meters. Two samples of the vein material averaged 0.20 percent eU, but the bleached wallrock is not radioactive.

The width and depth of the radioactive zones at Tamanduá-Vilela are not known but might be determined by trenching or drilling.

A lenticular vein deposit at Moirões is 1.5 kilometers west of Tamanduá (see pls. 1 and 3). This deposit, now obscured by slumping clay, was mined by washing away the soft clay wallrock with a small hydraulic giant (monitor) after the clay was broken by pick and shovel; the zirconium ore was then concentrated in a sluice box. This mining method worked satisfactorily, but it proved to be more expensive than ordinary trenching or pitting.

CACHOEIRINHA

Zirconium-bearing veins are reported at Cachoeirinha, approximately 2 kilometers west of Moirões (pl. 1). This area was not visited, but samples of eluvium were obtained from a prospector.

LAGÔA DOURADO-SÃO FILAO

The Lagôa Dourada-São Filão area is approximately 20 kilometers south of Poços de Caldas on the east side of the Andradas road (pl. 1). The name Lagôa Dourada is given to a large area that is reported to contain several zirconiferous deposits. The São Filão deposit consists of disseminated caldasite in a highly altered white clay wallrock. One small vein was observed that strikes N. 10° E. and dips 30° NW.

OTHER RADIOACTIVE DEPOSITS

MORRO DO FERRO

Morro do Ferro (Iron Hill) (Wedow, 1961) is about 17 kilometers south of Poços de Caldas, midway between Tamanduá and Taquarí (pl. 1), and is the highest point (1,541 m) within the Poços de Caldas Plateau. A magnetite dike 10 meters wide that strikes N. 50°–60° W. and dips 70° NE., forms the backbone of the hill. The area between the main dike and a smaller one 70–80 meters north is highly radioactive and marks the position of a very strong anomaly detected by the airborne scintillometer survey. The zone of high radioactivity continues for several hundred meters down the southeast side of the hill. When this zone was traversed on the ground with a 2- by 20-inch traverse tube, the rate-meter readings exceeded the scale on the least sensitive range of the counter. The radioactivity over this zone at an altitude of 100 meters was also greater than could be recorded on the least sensitive setting of the airborne scintillation counter.

The radioactive zone is a mixture of clay and highly decomposed nepheline syenite, limonite, and magnetite. In 1954, DNPM explored the area by drilling several diamond-drill and hand auger holes, and it was determined that the decomposed material extends downward to about 100 meters. The strong radioactivity measured in the field is apparently due to a large volume of disseminated radioactive material, and samples analyzed in the laboratory indicated a low uranium content. Chemical and spectrographic analyses made by the Instituto de Pesquizas Technológicas of São Paulo and the U.S. Geological Survey laboratory in Washington, D.C., show the presence of 0.011–0.012 percent U, 1.44–2.36 percent Th, and 3–12 percent rare-earth elements.

CERCADO

A large radioactivity anomaly located by the aeroradiometric survey is associated with a manganese deposit at Cercado, about 6 kilometers south of Morro do Ferro (p. 1). Preliminary results of analyses from a few samples indicate the presence of thorium and rare earths, but very little uranium, a fact that suggests that this deposit may be similar to Morro do Ferro.

OZÓRIO

The Ozório area is 7 kilometers west of Poços de Caldas on the road to Aguas da Prata (pl. 1). The radioactive zone is more than 100 meters long and trends about due north. The zone is poorly exposed and appears to be narrow. The radioactive rock is sandstone and is thought to be the Botucatú Sandstone of Triassic age (Barbosa, 1948). Samples of the radioactive sandstone contain 0.01–0.16 percent eU. Chemical and spectroscopic analyses made at the Instituto de Pesquizas Technológicas in São Paulo (table 4) indicate that the radioactivity is due to uranium. Analyses disclosed that zirconium is present, although in amounts considerably less than in the productive zirconium deposits, and that thorium and rare earths are absent. These data support the theory that the uranium in the Poços de Caldas Plateau is always associated with zirconium.

TABLE 4.—*Chemical and spectroscopic analyses, in percent, of radioactive sandstone of Ozório area*

[Analyses by Instituto de Pesquizas Technológicas]

Sample No.	eU	Chemical U_3O_8	ZrO_2
To 903	0. 13	0. 13	25. 5
904	. 07	. 056	18. 4
905	. 03	. 034	11. 9

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