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VILCABAMBA URANIUM DEPOSITS,
CUZCO DEPARTMENT, PERU

By
John W. Gabelman

October 1962

Division of Raw Materials, AEC
Washington, D. C.

Junta de Control de Energia Atomica,
Lima, Peru
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In 1957 uranium was discovered in the Vilcabamba district on the
north flank of the Cordillera Vilcabamba, part of the Cordillera Oriental.
This district contains principally small copper-nickel veins. Small
lenses of uraninite occur in calcite veins cutting Permian Copacabana
limestone. Uranium is most abundant marginal to centers of strongest
copper-nickel mineralization. Leaching and oxidation are virtually
absent because of Pleistocene glaciation. Four separate areas in which
uranium has been identified are Huamanayi, Calderón, Minasmayo, and
Negrillas. The Puntarayoc area, near Pampaconas, is considered a sepa-
rate district. The deposits have been tested by trenching, drilling,
and sampling concurrently with geologic reconnaissance mapping of the
surrounding region.

INTRODUCTION

In early November 1959 the writer visited for the third time the
uranium exploration project of the Junta de Control de Energía Atómica
del Perú (JCEA) at the head of the Vilcabamba valley, La Convención Prov-
ince, Cuzco Department, Perú (fig. 1). This report summarizes the unpub-
lished memoranda describing the earlier visits and also contains new data.

The route involved flying to Cuzco and travel by rail to Huadquiña
at the northern end of the Cuzco-Santa Ana Railroad. The writer was met
in Huadquiña by Ing. Julio Pizarro of the JCEA, who accompanied him to
the JCEA camp at Pacopata. Subsequently, the progress of exploration
was reviewed, and most of the deposits discovered since the writer's
last visit were examined. The writer returned to Cuzco November 13.

Accessibility to the Vilcabamba valley has been improved by construc-
tion of a single vehicle bridge across the Río Vilcanota (Urubamba) at
Chaulay and by placing a truck road into the Vilcabamba valley into
serviceable condition. Both these projects were completed by the Peruvian
Servicio de Caminos. The total truck route distance from Chaulay to the
JCEA camp is nearly 120 kilometers.

One factor impeding development of the Vilcabamba area is the paucity
of pack and saddle animals because of scant forage for animals near
Chaulay. In addition, there may be difficulties in renting these animals
from the local residents. Prior to completion of a vehicle road, any
further development of the area would require improved transportation,
which might be effected by purchasing the needed animals and maintaining
them in Chaulay with imported grain. Obtaining supplies also is diffi-
culty because of poor communication and liaison between Pacopata, Retamayoc,
Chaulay, Huadquiña, Cuzco, and Lima.
FIGURE 1
MAP OF PERU
SHOWING LOCATION OF AREA OF FIELD INVESTIGATION

SCALE

EXPLANATION

Capitals of Departments
Other Towns
Main Roads

VILCABAMBA DISTRICT

Figure 1: Map of Peru showing location of area of field investigation.
No ore has been sorted or stockpiled at Pacopata since shortly after the end of 1958, nor have any shipments been made from the area.

GENERAL GEOLOGY

The Huamanapi prospect area is about 1 kilometer east of the Minas-pata area examined in 1954 by Rogers and Coronado, and is new with no evidence of earlier development for any metal. It lies on the northeast flank of a large, broad northwest-trending anticline, and other than this fold the local area is relatively undisturbed. A small intrusive plug of diorite (?) or monzonite (?), about 100 meters in diameter, is within 500 meters of the prospect, and three basic dikes fill joints cutting the altered favorable bed of Permian Copacabana limestone. The small intrusive and dikes are unaltered. The nearest large intrusive is more than 5 kilometers distant. The immediate prospect area is devoid of important faults, but a fault of large displacement trends west-northwest within 800 meters east of the prospect. The strongest rock deformation has resulted from jointing.

Although higher temperature weak base metallization was associated with the large fault, low-temperature nickel-cobalt-uranium metallization appears to have occurred independently of the fault or intrusives. A dolomitic, silicic, and pyritic pipe of recrystallized limestone occurs near the top of a ridge at the contact of limestone and overlying Permian Mitu sandstone. The pipe, about 100 meters in diameter, does not appear to have resulted from deformation. Radioactive pyrite and minorchalcopyrite are the only notable metallic minerals in the pipe. Chalcopyrite, cobaltite, niccolite, tetrahedrite, and uraninite, however, are more common though still weak east of the pipe in a zone between 400 and 1,200 meters away. Metallic deposits have not been discovered on any other side of the pipe but may exist. Uraninite is most prominent where nickel, cobalt, and copper are weak, and it probably would be even more prominent in deposits still farther from the pipe. Mineralization was strongest in large joints that constitute the only apparent feeders although it spread manto-fashion into the limestone in a single known favorable stratigraphic interval of 10 to 15 meters.

The principal alteration was marmorization (recrystallization). The marble forms a matrix for small, irregular areas of silica, dolomite, hematite, talc, chlorite, and manganese oxide. Such areas are widespread though less than 1 meter in diameter. Marble encloses metallized joints in zones up to 5 meters wide, and has spread at least 25 meters from large joints in favorable beds up to 4 meters thick. Metals occur in thin joint veinlets and irregular pods up to tens of centimeters in length in the marmorite matrix; the veinlets and pods are of unpredictable continuity and concentration. Engineers state that uraninite pods have not been found outside the metallized joints they call "veins." However, evidence of metallization (not necessarily uraninite) was seen by the writer in pits as much as 5 meters from a joint vein. Except that permeability may decrease sharply away from the joint veins, there are no strong reasons why some uranium should not have occurred following altera-
tion and other associated metallization products in the favorable replaced beds. Marmorite away from the "vein" commonly is more radioactive than that in any other part of the vein other than the uraninite pods.

**URANIUM DEPOSITS**

**Exploration**

The greatest exploratory effort in 1959 was prospecting in new surrounding areas and the opening of as many surface pits as possible on isolated uranium occurrences.

**Sampling**

Seventeen channels were cut on Huamanapi joint veins and across the altered favorable limestone bed; some of these were carefully selected on the basis of channel orientation and length. The chief difficulty in wise selection of channel location apparently depends upon the definition of the controlling feature and the determination of its limits. Mineralization occurs either in a joint-vein structure or within a specific replaced stratigraphic interval, and it is desirable to orient the channel perpendicular to the plane of the structure or bedding. The limits of the channel should coincide with the limits of mineralization which, in this area, are more mineralogical than structural, or should extend to the width that would have to be mined if the latter is greater. Most of the channels were cut about 10 centimeters wide and 2 to 5 centimeters deep. Also, intervals between channels should be equal, regardless of the possibility of a channel's intersecting high-grade uraniferous pods.

The writer's original recommendation was to estimate the mineralization only of the bed by sampling the favorable limestone stratum adjacent to but outside the joint veins. Other channels were to be cut across the joint veins.

Of the 22 samples from 17 localities one contained 0.001 percent \( \text{U}_3\text{O}_8 \), four contained traces of uranium, and the remainder contained none. Consequently, the outcrop of the favorable bed, at least near the joint veins, and probably the entire bed, presumably has no economic uranium. This also appears to be true of the joint veins, but these had not been sampled to determine their average grade. However, regardless of grade the joint veins do not contain sufficient uranium ore to warrant expensive development.

In 1958 the writer estimated a handsorting ratio of 13:1 and an average grade of 0.15 percent \( \text{U}_3\text{O}_8 \) for the joint veins at Huamanapi. By November 1959 the JCEA had mined 2,702 metric tons of rock from these veins, and from the rock had handsorted 2.44 tons of ore, averaging 3.69 percent \( \text{U}_3\text{O}_8 \); the stockpile is located at Lima. This ore was recovered at a sorting ratio of 1126:1, indicating an in-place grade of 0.005 percent \( \text{U}_3\text{O}_8 \) for the rock. Thus, the highest grade uranium mineralization found at Vilcabamba through 1960 is uneconomic. No ore has been
mined since 1959 because of exhaustion of excavations to the limits of surface mining and the failure to discover other sizable mineralized outcrops.

Diamond drilling

In December 1959 the writer concluded that the joint-vein system did not contain enough sufficiently high-grade ore to warrant exploration under very high development and transportation costs. It was recommended that the mineralized limestone bed be drilled to determine the possible existence of richer ore. Accordingly, four locations were selected for vertical holes that would penetrate the replaced bed as far from its intersection with the joint veins as the capacity of the JCEA drill would allow. Figure 2 is a profile at the site of hole no. 1.

The problem of continual water loss in the cavernous limestone was eventually solved by installing a 400-meter-long cane pipeline. Over 90-percent core recovery was attained in all holes.

Two holes were completed to 200 feet; a third stopped temporarily at 165 feet. The first hole probably penetrated the favorable limestone bed, which is indicated by a fairly abrupt change downward from silicated to silicified limestone; the favorable bed also is dolomitized. The core shows no anomalous radioactivity. The second and third holes did not reach the limestone, which should exist within 260 feet of the surface. By the middle of 1962 the JCEA had completed seven holes, three near Pacopata and four near Calderón. Almost all the holes reached 200 feet, but none showed indications of uranium.

Drilling substantiated the favorable and selectively altered character of the limestone bed at the surface. The limestone is strongly recrystallized, dolomitized, bleached, and pyritized. Small disseminations of chalcopyrite are present. Silicification occurred within and to an unknown distance below the bed; local lenses of silicated (serpentinite-amphibole skarn) limestone extend more than 30 meters above the bed.

The writer considers that further testing for replacement deposits in the limestone to be inadvisable.

Excavations

Huamanapi area: Few new pits were opened in this area since the writer's previous visit, and the surface development is roughly the same. Several trenches in the Trinchera sector were extended but not deepened. A 10-meter crosscut to a joint vein in the San Marcos sector was abandoned without being completed. Subsequent exploratory effort has been concentrated on surface prospecting and shallow trenching in new outlying areas.

Calderón area: The Quebrada Calderón area, about 3/4 kilometer north of the Huamanapi occurrences, is characterized by numerous mineralized faults, commonly over 1 kilometer long, cutting Copacabana limestone and
overlying diabasic volcanics. The area contains several old Spanish copper mines. The largest faults trend nearly east; second-order faults strike east-northeast and third-order faults trend northeast. Most of the mineralization occurs in the smaller faults which are largely gouge zones, up to 5 meters wide, containing veins at their contacts with the wall rock. Mineralization fills cavities along fault margins or more commonly replaces the limestone walls up to 2 meters from faults. Alterations are principally silicification, dolomitization, and red hematitization. Metallization products are pyrite, chalcopyrite, tetrahedrite, bornite, and niccolite.

Discovery of spots and lenses of strong uraninite disseminations in the veins caused a diversion of most surface excavation from Huamanapi to this area. Three large faults are known to contain uranium. The largest, of unknown name, is the east-west fault coincident with Quebrada Calderón. From this large fault branch three east-northeast faults containing all the known uraniferous lenses. There is one lens in the westernmost fault and three others in a small subsidiary vein. The middle fault, the Aurora vein, contains five lenses, with one lens in a subsidiary vein. The easternmost fault, the Calderón vein, contains five lenses.

Lenses vary greatly in size. The largest known lens of strong radioactivity, about half a meter wide, is in the southeast wall of the Aurora gouge zone and extends about 30 meters horizontally along the vein throughout a vertical relief of about 25 meters.

About twelve trenches and pits, averaging about 1 meter deep, have been excavated on the lenses. A gasoline-operated hammer drill was used in the largest pits on the Aurora and Calderón veins.

No lenses have been sampled, but JCEA geologists believe that these lenses are as rich or richer than those of Huamanapi. The writer estimated the average grade of the lenses to be less than 0.2 percent $U_3O_8$. If the number, distribution, size, and grade of lenses exposed on the surface throughout at least 350 meters of relief is representative of these same features below the outcrop, as should be the case because of negligible oxidation, the occurrences are not economic at the current market price of uranium.

The project geologists were planning at least two angle drillholes on the Aurora and Calderón veins, apparently to locate richer uranium mineralization beneath the surface; however, it seems improbable that more information could be obtained from such drilling than from detailed mapping of the surface and prospect pits. Also, a more beneficial type of physical subsurface exploration would be a drift on the largest uraniferous lens because core recovery in the gouge zones and adjacent shattered walls probably will be very low. Furthermore, it is fairly certain that metallization is confined to gouge-zone walls, and a drill will allow only spot penetration thereof whereas a short drift will expose much more wall.

Most of the surficial uraninite is in sooty form. The quantity seems to decrease with depth, thus suggesting its probable secondary supergene origin. Because the highest grade surface occurrences of uranium are sub-
marginal, it is economically inadvisable to utilize drilling or drifting in determining their genesis.

Kenneth Rogers and other AEC geologists examined three old Spanish adits in this area and eliminated them as sources of uranium. The adits are about 250 meters east of the Calderón vein, and their lenses probably are very similar to those described in this report.

Minasmayo area: This area was not visited because of lack of time, the only slightly anomalous radioactivity, the presence of very strong silicification and pyritization, and the report of the best uranium mineralization being in dumps from old Spanish copper workings. Sosa and Goyburu (1959) noted six anomalies in the area; these ranged from \( \frac{1}{4} \) to \( \frac{1}{2} \) times the areal background radioactivity. The anomalies on Cerro Huaynahuarco and near the bottom of Quebrada Minasmayo are in localities previously examined by AEC geologists and probably are not new discoveries. No physical exploration has been done on these occurrences.

Negrilas area: While examining the satellite alteration pipes near the Huamanapi mineralization new uranium occurrences were discovered in Quebrada Negrialas, adjacent and parallel to the Río Huamanapi on the southeast (Aguilar, Sosa, and Goyburu, 1959). They have been visited by the writer.

Mineralization in this area is much weaker than that in the Minasmayo and Huamanapi drainages. Alteration is principally dolomitization and minor silicification (jasperoid), and metallization products are pyrite, chalcopyrite, tetrahedrite, galena, and uraninite in local disseminations near but rarely in sizable faults.

Three radioactive localities were discovered on the northwest side of Quebrada Negrialas, five on the southeast side near Lago Negrialas, and one on the east side about 1 kilometer north of Lago Negrialas. Anomalies range from 2 to 35 times background, averaging about 5 times background. Six localities are not spot anomalies but rather small areas completely anomalous or containing groups of anomalies. The largest area of 40 by 120 meters contains 32 individual anomalies, some of which can be attributed to sooty uraninite on the surface.

The critical geologic feature in Quebrada Negrialas is the large Negrialas east-west normal fault which passes through Lago Negrialas and has thrown Permian Copacabana limestone against slightly metamorphosed Permian Mitu red sandstones and shales. At least one parallel fault and several branch faults complicate the zone on the limestone (north) side. Most of the areas of anomalies occur within 500 meters of the Negrialas fault, implying some controlling influence over radioactivity; however, in only two areas does uranium occur in fault zones. In one area a gouge zone, 20 to 30 centimeters wide, is mineralized, and in the other areas anomalies are in dolomitized portions of apparently undeformed Copacabana limestone. Dolomitized
limestone is recognized by its yellow-brown color, whereas unaltered limestone is black or dark gray. In the former case mineralization resulted at least in part from cavity filling; in the latter case, principally from replacement dissemination.

Oxidation is uncommon to rare except along faults; pyrite, chalcopyrite, and tetrahedrite are fresh on the outcrop. The source mineral of uranium was not recognized in most areas but may be sooty uraninite, although hard black uraninite was found in a shallow prospect northwest of Lago Negrillas. Development is limited to very shallow trenching on several anomalies.

**Geological interpretation**

**Area as a whole**

The size of the area containing anomalies or small deposits has been expanded to about 100 square kilometers through JCEA exploration. Within this area there is clear evidence of lateral zoning of mineralization according to temperature-pressure environment. Further study of this zoning should make it possible to identify that portion of the area which should contain the richest uranium concentrations because uranium commonly is most abundant at the lowest temperatures and pressures of mineralization.

The possible amount of mineralization in the Vilcabamba area is estimated in the light of structures that might have transported or received products, the intensity of mineralization indicating the total quantity of products, and zoning that fostered the separation of types of products.

**Lithology:** The Vilcabamba-Pampaconas area lies between at least three granite batholiths or large stocks which have no surface connections and whose margins commonly are faults. In detail the position and elongation of these intrusives are not related to the structural grain of deformed sediments, which was imparted to the area earlier than intrusion and only slightly modified thereby. Latitic(?) and mafic dikes, sills, and small plugs are uncommon and were intruded after granite emplacement and most of the deformation. The diabasic(?) (termed trachytic by JCEA geologists) volcanics of cerros Simacocha, San Cristobal, and Chanjanticra, south and southwest of Vilcabamba, are considered contemporaneous with the Mitu continental clastics because their well-developed flow-layering and jointing completely parallel the bedding and jointing of the deformed sediments lying above and below Mitu beds.

Schists, gneisses, phyllites, and slates were produced by mild regional metamorphism from compressional deformation at the end of the early Paleozoic and are not related to granitic intrusion. Most of the limestone adjacent to granite contacts has been unaffected by contact metamorphism related to granite intrusion. The writer considers pyrometasomatic deposits as resulting from moderate- to high-temperature ferromagnesian silication; these are more related to structure than to intrusion. Alteration generally is fissure-controlled and occurs both in red beds and limestone.
Structure: The structural grain of the area usually is west-northwest, varying locally to northwest or west. A wide zone of high-angle normal and reverse faults, with hundreds of meters displacement, passes through Vilcabamba and Quebrada Minasmayo and divides the area longitudinally into a Mitu red-bed matrix on the north and a Copacabana limestone matrix on the south. To the north the red beds typically are deformed into many closely spaced, moderately tight folds with few related small faults trending parallel to the principal faults of the zone. To the south the moderate deformation is characterized by a north- to northeast-dipping homocline on which the only significant modification is the east-west Negrillas fault zone at the southern side of the area. This zone separates limestone on the north from indurated red shale (almost slate) on the south. Anomalies in red beds north of the fault zone have not been investigated in detail although most of the known uranium deposits (including Huamanapi, Calderón, Negrillas, Minasmayo, and Puntarayoc) are in limestone on the south side of or within this fault zone.

The largest faults in the zone trend parallel thereto and are wide gouge zones poorly prepared for mineralization. The next largest subsidiary faults, trending east-northeast, are smaller gouge zones, 2 to 4 meters in width, that also are poorly prepared for cavity-filling mineralization. Subsidiary northeast faults in the walls of east-northeast faults reflect shattering and tension jointing and are well prepared to receive mineralization, but they generally are small and unlikely to yield large tonnages of ore.

The gradational decrease in deformation from the fault zone southward to Quebrada Negrillas and a subsequent slight increase to Lago Negrillas is most important in that the fault zone, 1 to 2 kilometers wide, is excellently prepared to receive the greatest mineralization both in numerous cavities and as replacements in adjacent shattered limestone. The Minasmayo and Calderón areas lie within this zone, and Huamanapi is about 3/4 kilometer outside the zone in a sector of poor ground preparation because of insufficient joint shattering.

The best possibilities of mineralization are replacements of the most permeable limestone beds near joint shatter lenses. Fracturing between Huamanapi and the Negrillas fault is unimportant, and solutions are able to flow only in poorly connected joint networks and bedding planes. Thus, the possibilities for mineralization replacement of limestone are poor. In a half-kilometer-wide zone enclosing the Negrillas fault subsidiary deformation (small faults and shatter stockworks) is uncommon and very moderate, and the Negrillas fault appears to be a clean straight break. Shattering and replacement possibilities here are slightly less than at Huamanapi.

Geometry of mineralization: At Vilcabamba there is a large amount of barren ground within the fault zone, and mineralization extends southward into poorly prepared ground. Nevertheless, the most intensely mineralized ground is within the zone, and mineralization decreases in strength toward the sides.
All mineralized ground occurs as isolated alteration pipes with marginal or contained metal deposits. The size of the pipe, the density of mineralization, and the mineralogy of its products reflect the intensity and environment of mineralization. The largest and most intensely mineralized pipe known is in Quebrada Minasmayo, and the next strongest is on Cerro Yunquiyoc. There may also be a third on Cerro Puntarayoc near Pampaconas. At least twenty smaller, less mineralized pipes are considered satellitic to these large centers; they are randomly distributed throughout the area but maintain a gradual decrease in size and intensity outward from the Minasmayo centers.

The amount of rock alteration greatly exceeds the quantity of metallization; therefore, interpretation of alteration provides a guide to the intensity of metallization even when related metalliferous deposits are unavailable for study.

Project geologists report the average diameter of the pervasively altered Minasmayo pipe to be about 400 meters. Fissure-controlled pervasive alteration extends at least a kilometer from the pipe. This outer zone is relatively unknown except for the old Spanish copper workings, but there may be significant veins of copper in the vast quantity of altered rock.

The pervasive alteration pipe on Cerro Yunquiyoc has an average diameter of about 250 meters. Marginal to this pipe alteration is selective in favorable limestone beds and is locally pervasive in bodies of up to 200 meters in diameter. However, the total quantity of altered rock is small, and the amount of metallization is essentially negligible.

Pervasive alteration pipes near Lago Negrillas average less than 50 meters in diameter, and marginal alteration occurs only in selected beds or in fissure walls. The average diameter of altered portions of selected limestone beds is 50 to 100 meters, and the quantity of associated metallization is very small.

Mineralogy: A very wide range of temperature-pressure environments is indicated by the radical changes in mineralogy outward from the Minasmayo center. Clay may be present in the Minasmayo alteration pipe but apparently is rare or absent in the remainder of the area although a clay lacking visible undeformed textures is difficult to differentiate from gouge.

The highest temperature alteration, and that most prevalent in the Minasmayo and Calderón areas, is ferromagnesian silicification with magnetite skarn. Skarn fills many fissures in various rock types and replaces very large volumes of limestone in the Vilcabamba fault zone. It is composed of recrystallized limestone, giant-grained calcite, quartz, amphibole (hornblende or actinolite), serpentine, garnet, and magnetite. Although silication occurs very rarely elsewhere in the area, skarn ceases to be common at a sharp east-west boundary occasioned by the favorable limestone bed at Huamanapi. South of and stratigraphically below this boundary alteration consists of lower temperature forms of silicification, dolomitization,
and hematitization or pyritization. Dolomitization is the most abundant, and hematitization is more common than silicification; pyrite is least common. Sparse chloritization of red beds and volcanics is considered the equivalent of dolomitization of a calcareous environment. The smaller amount of chlorite presumably is indicative of a selectively stronger mineralization of calcareous rocks, not of a smaller quantity of solution in siliceous rocks. Dolomite is uncommon in silicated areas, is most abundant near Cerro Yunquiyoc and Huamanapi, and diminishes but persists to the limits of the area.

Earthy red hematite is common outside wall zones of fissures in the Calderón sector but is restricted to shatter joint-vein lenses at Huamanapi and to the largest faults at Lago Negrillas. Hematite is indicated to be earlier and of higher temperature environment than dolomite but lower than that of silication. Silicification is most common at Huamanapi but generally absent near Lago Negrillas.

Red hematite is an unusual alteration product and normally would be suspected of having oxidized from magnetite. However, it is concluded to be primary because of extremely little oxidation and the great quantity of hematite under fracture control and replaced by dolomite. The paragenesis of alterations is interpreted to be: recrystallization, ferromagnesian silication, magnetite, red hematite, dolomite-chlorite, and silicification.

Metallization of pyrite, chalcopyrite, bornite, argentiferous tetrahedrite, niccolite, galena, uraninite, calcite, barite, and quartz reflects lateral temperature zoning.

Pyrite is the most common mineral in all these metal deposits and also the only very common metallic mineral in replacement disseminations in most of the large alteration pipes. Other metallic minerals are most common in deposits marginal to or removed from the largest pipes but coinciding with small outlying pipes.

Replacement disseminations of chalcopyrite and bornite occur in the largest alteration pipes but are most common in the Minasmayo and Calderón veins which may contain workable copper deposits. Chalcopyrite, one of the most abundant minerals in the Negrillas deposits, is rare between the Negrillas and Huamanapi areas and is repeated as impregnations in red beds in the most remote zone.

Tetrahedrite and niccolite, though widely distributed, are restricted in abundance to areas nearest the alteration centers. Galena is rare, but its distribution is essentially limited to the most weakly mineralized area between Huamanapi and the Negrillas fault where it is one of the most important metallization products. The abundances of barite, calcite, and quartz are unknown.

Uranium has been found in all environments but apparently is most common in close association with chalcopyrite, tetrahedrite, and niccolite. The trend of exploration seems to indicate the greatest abundance of uranium
at Calderón; however, its occurrence in small isolated lenses in that area and at Huamanapi may possibly have been overemphasized. The least uranium may be expected at Minasmayo, and further investigation should prove the Huamanapi deposits to be better than those at Calderón.

The deposit northwest of Lago Negrillas, in particular, contains only calcite, dolomite, quartz, and an extremely small amount of pyrite in association with hard pitchblende. The quantity of uranium is expected to increase with distance from the strongest mineralization center even though other metallization diminishes and may be nearly negligible where uranium is most abundant; thus, a profitable uranium deposit may exist in areas worthless for any other metal. Of the known areas the Negrillas seems to be the most favorable for additional investigation; however, prospecting should be extended from all the areas.

Metallization paragenesis appears to be: pyrite, chalcopyrite, bornite, tetrahedrite, niccolite, galena, and uraninite.

Oxidation and enrichment: Surficial oxidation is essentially negligible, which is unusual in view of the heavy rainfall. Sooty uraninite apparently decreases in abundance below the surface, indicating possible secondary enrichment although most of the uranium is in equilibrium. The lack of oxidation is attributed to the excellent protection offered by limestone and to the newness of the topography following late or post-Pleistocene glaciation.

The lack of oxidation, the frequency of outcrop, and the prominent topographic relief combine to offer unusually favorable conditions for interpretation and valuation of primary mineralization with a minimum of physical development. Project geologists correctly maintain that only excavation or drilling can disclose the subsurface, but the valuation of a district should be based on the average size, grade, and controls of uranium deposits that might be encountered, and these factors can be determined from the surface.

Areas favorable for exploration: Most of the introduced uranium presumably will be concentrated in those mineralized portions of the Vilcabamba area having a very low temperature-pressure environment. These small areas will be farthest removed from strong alteration centers. Because open prepared ground is required for substantial metallization, investigation should be directed specifically to the most faulted or fractured portions of the mineralized areas. The mineralization environment seems to be more favorable toward the Negrillas area than toward other portions of the Vilcabamba region, yet mineralization of that area seems limited by a deficiency of suitable ground preparation. The writer, however, noticed several long faults with weakly altered walls in Quebrada Negrillas, and it is suggested that these be checked for vein possibilities. The environment southeast of Lago Negrillas may be even more favorable.

Huamanapi area

Structure: The Huamanapi joint veins are actually near-vertical lenses of joint stockworks in which the joints and intervening limestone have been
mineralized. The increased number of joints within lenses indicates that the stockworks probably resulted from shattering. Most of the lenses have similar attitudes but are en echelon; they occur in a 30-meter-wide zone that trends essentially west, paralleling the largest Calderón faults. The diminishing deformation from Calderón toward Huamanapi, plus the geometrical similarity, suggests that the Huamanapi zone is an incipient fault in which stresses similarly oriented to those at Calderón were sufficient to shatter but not to break or displace the sediments. Strain consisted of shattering by increased jointing that was localized in specific lenses, resulting in a poorly interconnected solution-channel network of low capacity.

Orientation of the longer lens axis, probably in the plane of the incipient fault, depends on the orientation and intensity of formative stresses. If the strongest fractures resulted from subsidiary tension, the longer dimensions of tension fractures will be perpendicular to the direction of greatest shear movement in the plane of shearing, and the intermediate dimension will be oriented at an angle to the plane of the structure. If the greatest shear movement is vertical or horizontal the longest tension dimension will parallel the strike or dip; but if movement is compounded of horizontal and vertical components, this dimension will be at an angle to the strike and dip. The Huamanapi joints thus appear to be tensional, but the persistence of stockwork lenses parallel to the plane of shearing suggests that the lenses actually resulted from shear stresses and that their larger dimension should pitch in the plane of the vein. The fault borders on being an actual shear rupture. However, the greater dimension of the structural lenses probably does not coincide with that of the mineralized lens.

The east-west Huamanapi shatter zone was cleanly broken and displaced by later, but premineral, small faults trending nearly north-south. These faults were more open and formed better solution channels than the joint stockwork lenses because they were preferentially filled by mafic dikes or early alteration products.

Mineralization: Most features of mineralization have already been described. A significant indication of mineralogical temperature zoning is the occurrence of uranium in radioactive pyrite within the Yunquiyoc alteration pipe and as uraninite marginal to the pipe.

Mineralization occurred in decreasing intensity in the most open cross faults, in the joint stockwork lenses, and in limestone enclosing the Huamanapi shear zone. The faults and stockworks are specific features with well-defined structural boundaries which limit the types of mineralization, but the limits of replaced or altered limestone are more indefinite and less predictable. Although silication and recrystallization seem to occur in a zone crosscutting the beds and enclosing the shear zone, dolomitization and silicification generally are selective within specific stratigraphic units in the form of replacement lenses projecting from the shear zone or as isolated lenses. There are small lenses within a large stratigraphic interval, but the bulk of dolomitization and silicification, as well as some hematitization, occur in two stratigraphic units. The lower is the 5- to 10-meter
favorable bed that intersects the incipient fault at the surface and is being explored. The other, 5 to 10 meters thick, is 15 to 20 meters higher and is altered but not known to be metallized. The mineralized portions of these two beds project 500 to 1,000 meters from the Yunqueyoc alteration pipe. Most of the hematite and virtually all metallization are confined to the stockwork lenses. One mineralized cross fault contains a 1-meter-wide vein of jasperoid silica, but the others contain the same minerals as those found in the stockwork lenses.

It is now believed that only alteration products have the aforementioned distribution, and that except for pyrite and minor disseminations of other metallic minerals, metallization products normally are confined to the joint stockworks. Further, it is suggested that only those portions of the stockwork lenses within the most favorable bed are metallized although other mineralized beds may lie within the stockwork lenses. The easternmost lens in the San Marcos sector, about 25 meters long on the surface, was observed to bottom near the base of the bed. Hematite and silica are most common within the joint stockwork lenses within the bed.

It is implied that dolomite, hematite, and jasperoid silica, the early alteration products, pre-empted most of the open spaces in faults, stockworks, and favorable limestone beds, and that channel sealing allowed access of only limited quantities of later metallization products which consequently were forced into the reduced porosity of the joint stockworks.

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Plate 1. Topographic map of Vilcabamba-Río Chalca area, Cuzco Department, Perú.
Plate 3. Geologic and radiometric reconnaissance map of Minaspata area, Cuzco Department, Perú.
Plate 4. Geologic and radiometric reconnaissance map of Quebrada Negrillas area, Cuzco Department, Peru.

RECONOCIMIENTO GEOLOGICO-RADIO METRICO DE LA ZONA QUEBRADA NEGRILLAS

DISTRITO DE VILCBAMBA - PROVINCIA DE LA CONVENCION - DPTO. DEL CUZCO

Escala: 1/20,000

Mayo-Junio de 1959

Junta de Control de Energía Atómica del Perú, O. Aguilar M., J.E. Sosa B. and E. Goyburu de la C.

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