RME - 4530 (Rev.)
GEOLOGY AND MINERALOGY
(TID - 4500, 46th. Ed.)

U. S. ATOMIC ENERGY COMMISSION
DIVISION OF RAW MATERIALS
IN COOPERATION WITH THE
JUNTA DE CONTROL DE ENERGIA ATOMICA DEL PERU

EXAMINATION OF SELECTED AREAS IN PERU

By

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July 1962
Washington, D. C.

EXAMINATION OF SELECTED AREAS IN PERU

CONTENTS

Page

ABSTRACT 5

INTRODUCTION 6

CCOLLPACCASA AREA 6
  Geology 6
  Radioactivity 9

PUNTARAYOC AREA 9
  Geology 9
  Mineralization 11

CHAULLAY-CUQUIPATA AREA 12
  Geology 12
    Structure 14
    Alteration 14
    Metallization 14
    Oxidation and leaching 15
  Radioactivity 15

VILCANOTA FAULT ZONE 16
  Geology 16
    Stratigraphy 18
    Structure 19
    Alteration 19
    Metallization 22
    Laguna de Langui fault 22
  Radioactivity 22

COASTAL ZONE 24
  Geology 24
    Structure and tectonics 25
    Lithology 26
    Oxidation 27
    Mineralization 28
  Radioactivity 30

REFERENCES 31

EXAMINATION OF SELECTED AREAS IN PERU

ILLUSTRATIONS

Page

Figure 1. Map of Perû showing location of area of field investigation 7

2. Ccollpaccasa area, Cuzco Department, Perû 8

3. Geologic sketch, Puntarayoc area, Cuzco Department . . . 10

4. Geologic sketch, Chaullay-Cuquipata area, Cuzco Department, Perû 13

5. Vilcanota fault zone, Cuzco Department, Perû 17

6. Tentative correlation chart, Vilcanota valley 20

EXAMINATION OF SELECTED AREAS IN PERU

ABSTRACT

In brief reconnaissance of parts of southern Perú anomalous radioactivity was noted in the altered red beds of the Ccollpaccasa area, which contains strong folds and faults parallel to and on the north side of the Cordillera Vilcanota. There may be a zonal gradation from strong mineralization centers at Minasmayo and Huamanapi several kilometers south to weaker mineralization at Ccollpaccasa, with the amount of other metals decreasing and uranium increasing outward from the centers.

Deposits of principally uranium minerals may occur in the Puntarayoc area marginal to the strongly altered Chancara pipe. They may be richer and more widespread than the known Ni-Co-Cu deposits from which extraction of the small amount of contained uranium seems unwarranted. Also favorable in this area is the low-temperature environment in which uranium commonly occurs.

In the lower Vilcabamba valley altered rock is associated with the Chaullay-Cuquipata fault zone. Although only small amounts of anomalous radioactivity have been noted to date, the surface rocks are strongly leached, and the area is otherwise favorable for uranium in veins.

In the Vilcanota fault zone several alteration pipes in fluvial sediments with local carbon concentrations are weakly anomalous. Moreover, the alteration belts enclosing the Vilcanota and Laguna de Langui faults registered a background of twice that outside the belts. Since low-temperature uranium tends to be associated with argillization, bleaching, and pyritization, economic uranium deposits may be found in the favorable low-temperature portion of the Vilcanota belt from Urcos to Ollantaytambo.

No anomalies were noted in low-level aerial examination of hematite-altered areas of southern Perú, although slight increases were detected over some chiefly argillic and pyritic pipes. Southern Perú may have some small deposits of uraninite or high-temperature complex uranium minerals associated with magnetite or specularite, and small quantities of uranium are known but not consistently present in the high-temperature environment, such as in Peruvian and Chilean copper deposits.

INTRODUCTION

In 1958 and 1960 the writer briefly reconnoitered the Ccollpaccasa, Puntarayoc, and Chaullay-Cuquipata areas in La Convención Province and the upper Vilcanota valley in Cuzco, Quispicanchis, and Canchis provinces, Cuzco Department, Perú, and the coastal portion of the country from Pisco south to Tacna (fig. 1). This report consolidates the original short reports on these areas of southern Perú.

CCOLLPACCASA AREA

Geology

Ccollpaccasa (fig. 2) is the pass between the heads of the Vilcabamba and Consebidayoc valleys and lies north of the uraniferous area near Vilcabamba pueblo. In this area the headwaters portion of both valleys is structurally controlled by a high-angle fault which trends west-northwest for a known length of 12 kilometers, with evidence for its termination only at the southeast near Vilcabamba. Exposures of parts of the fault indicate a central gouge zone, at least 20 meters wide, with numerous branches and sympathetic faults. A larger parallel fault, about 17 kilometers long, is about 1 kilometer to the southwest. The aggregate displacement of the faults is estimated to range from 300 to 1,000 meters.

On the southwest side of the larger fault are at least 500 meters of limestone of the Lower Permian Copacabana group. The beds dip 25° to 50° N. and strike parallel to the fault trace except at the northwest end where they swing to an east-west strike.

On the north side of the smaller fault red mudstone, sandstone, and conglomerate of the upper Mitu formation, a facies of the Copacabana group, trend generally parallel to the fault trace but are folded into a series of anticlines and synclines paralleling the fault; thus, the zone of strong deformation exceeds 2 kilometers in width. This middle or upper part of the Mitu is at least 200 meters thick.

The rocks between the faults are interbedded sandstone and volcanics of the lower Mitu formation. Southeast of the army encampment, in the Huamanapi valley, lower Mitu red beds are interbedded with limestone, indicating a gradational contact between the limestone and red beds. The coarse-grained sandstone, conglomerate, and andesite of the lower Mitu formation grade upward into fine-grained sandstones and mudstones. At Vilcabamba the lower clastic interval is at least 300 meters thick.

Valley fill largely conceals the northeastern fault, but at Ccollpaccasa locally strong bleaching and weak pyritization were noted in and near some sympathetic faults in the red beds. This alteration appears to be confined to a zone 100 to 200 meters wide and at least 500 meters long.

FIGURE I

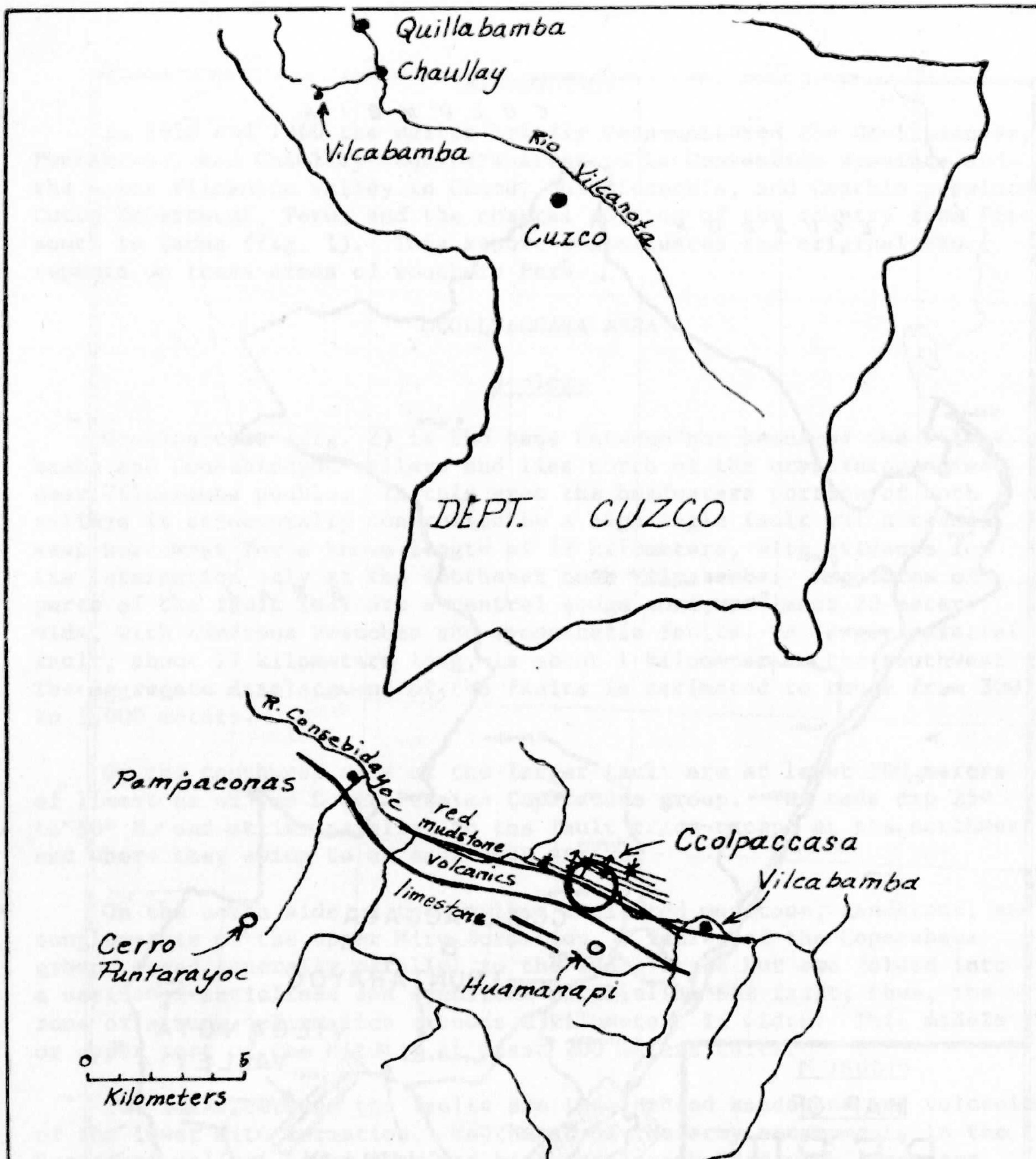
MAP OF

PERU

SHOWING LOCATION OF

AREA OF

FIELD INVESTIGATION



Location Map

CCOLPACCASA AREA

La Convención Province

Cuzco Department, Perú

J.W. Gabelman

Figure 2

Radioactivity

Radioactivity to 3 times background was noted at several places in this area in which mineralization was similar to that of many uraniferous areas on the Colorado Plateau, USA. The presence of limonite-after-pyrite and the lack of pyrite, even in dense mudstone nodules, indicate locally strong oxidation.

Although leaching is unimportant at Huamanapi and Cerro Puntarayoc, probably because of glacial scouring, it could be stronger here because of less glacial erosion and a more permeable fault zone; and uranium concentrations could increase with depth. Ccollpaccasa is 3 to 5 kilometers north of the Huamanapi uranium area and may represent a zonal gradation outward from stronger mineralization; therefore, it may be more favorable for uranium than Huamanapi, as uranium favors an outer zonal position.

Very little of the alteration was examined carefully, and the zone may have concealed extensions; also, other zones may exist on either side of the fault. The writer recommended that the area surrounding Ccollpaccasa for about 2 kilometers be examined radiometrically in conjunction with preparation of a reconnaissance geologic map to a suitable scale. In addition, in November 1958 a large area to the north of the pass was reconnoitered by Sosa and Goyburu (1958a), who detected several anomalies ranging to 4½ times background in red beds within 4 kilometers of the pass.

PUNTARAYOC AREA

Geology

The Puntarayoc area (fig. 3) is southwest of Vilcabamba at an elevation of about 4,200 meters. The vehicle road nearest Puntarayoc is at Chaullay, about 56 kilometers map distance and over 100 kilometers by horse to the east.

In the Vilcabamba-Pampaconas area (figs. 2 and 3) about 500 meters of limestone (Aguilar, Ocampo, Jordán, and Pizarro, 1957) of the Lower Permian (Newell, 1949, p. 38) Copacabana group underlie an unknown thickness of continental red beds of the Mitu formation, which Newell also assigns to the Copacabana group. The subjacent limestone in the area of the deposits strikes nearly east and dips 30° to 40° N. About 1 kilometer west of the deposit is the eastern edge of a small granite batholith.

The faulted north flank of a large anticline lies between Pampaconas and Vilcabamba; nothing is known of the south flank or the exact size of the fold. Faulting may have dropped a large block of unmetamorphosed sedimentary rocks into a matrix of metamorphosed lower Paleozoic sediments intruded by granite batholiths. In the Puntarayoc area the sediments dip north or northeast, and are divided by a large west-north-west-trending high-angle fault that separates limestone on the south from red beds on the north. Subsidiary faults and long, shallow folds parallel the large

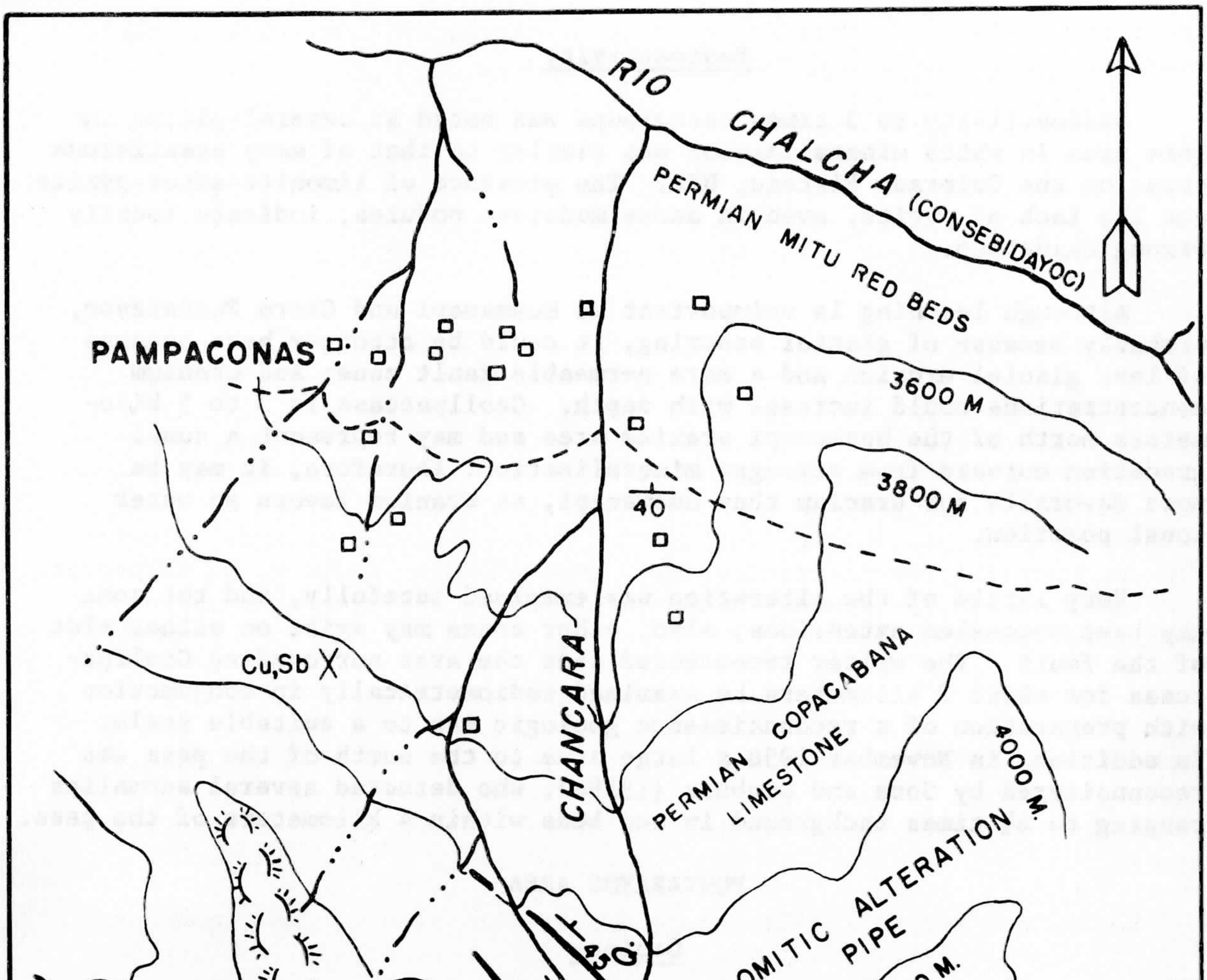

RIO CHALCHA (CONSEBIDAYOC)
PERMIAN MITU RED BEDS
PAMPACONAS
3600 M
3800 M
40
Cu,Sb
CHANCARA
PERMIAN COPACABANA LIMESTONE
4000 M.
DOLOMITIC ALTERATION PIPE
4200 M.
45
50
CERRO PUNTARAYOC
4521 M.
Cu
Ni,U
Cu
35
GEOLOGIC SKETCH
PUNTARAYOC AREA
LA CONVENCION PROVINCE
CUZCO DEPT., PERU
0
1/2
1
KILOMETERS
J. W. GABELMAN Jan., 1959

Figure 3

structure (fig. 3). Shorter folds trend northwest and northeast in the shear pattern across the flank of the anticline.

Prominent areas of mineralization at Huamanapi and Cerro Puntarayoc (R. Vidal, personal communication) contain the only strongly altered rocks. The Puntarayoc mineralization, believed to be the stronger, consists of Ni, Co, Cu, Pb, Ag, and Fe minerals in veins near an area of colorful oxidized pyritic and argillic alteration which was not seen by the writer.

About 2 kilometers north-northeast of the Puntarayoc deposit the Chancara alteration pipe occupies the trough of a northwest-trending syncline in the Chancara valley. This dolomitic, silicic, and slightly pyritic pipe is crossed by the trail from Pampaconas to the deposit. Its most strongly altered central part is about 200 meters long and 100 meters wide, with subsidiary pipes and bedding-controlled alteration extending southeast along the synclinal trough for as much as 500 meters. Alteration, and possibly metallization, away from the pipe seems to be strongest in this direction, presumably because of visibly stronger deformation along this trend.

Mineralization

The rocks of this area have been altered only for limited distances at isolated stratigraphic positions. The lack of noticeable faults causes the writer to suspect less mineralization here than farther to the east. Leaching and oxidation are relatively unimportant, as at Vilcabamba.

Rogers and Freyre (1955) reported silicification of two limestone beds stratigraphically below the deposits and the recrystallization of a 12-meter stratigraphic interval containing several small occurrences. The writer noted moderately strong dolomitization of the recrystallized interval, which is only 3 or 4 meters thick at the site of the strongest metallization.

Six claims called the Atômica group, covering 6,000 hectares, have been denounced for uranium by Srs. José Pancorvo and Angel Luglio. The principal mineralization is on the Atômica No. 1 claim. The balance of La Convención Province has been withdrawn from uranium locations by the JCEA.

Six prospect pits, 50 to 70 meters apart and covering a topographic relief of about 40 meters, have been excavated in one stratigraphic interval in a small east-west gully tributary to the Río Chancara. Mineralization apparently is discontinuous between the prospects.

The lowest prospect is a 4-meter-wide adit driven along a small east-west vein that is enclosed by a 1-meter-wide recrystallized and silicified zone. The vein, 25 centimeters wide, is a gouge zone between shattered walls filled with calcite, quartz, and scattered specks of chalcopyrite; metallization is negligible. Radioactivity is less than twice background.

The second pit up the gully is in a 1-meter-thick bed of recrystallized and dolomitized limestone between limestone walls. Small specks of chalcopyrite constitute the unimportant metallization.

The third prospect is a crosscut driven from the gully bottom to intersect, about 8 meters below the outcrop, a small breccia chimney at the intersection of two small faults. The fault walls and chimney are relatively unaltered. The chimney, at one dihedral angle of the intersection, is about 5 meters in diameter at the outcrop, becoming larger in diameter downward. An unaltered limestone bed capping the chimney forms a third wall, contributing to the downward enlargement which should not persist to great depth. The capping bed indicates some control by favorable lithology.

The breccia contains unaltered limestone fragments in a coarse-grained white calcite matrix that is metallized with nodules, specks, and thin seams of chalcopyrite, niccolite, gersdorffite (Rogers and Freyre, 1955), uraninite, pyrite, barite, and rhodochrosite. Selected samples have assayed as high as 2 percent U_3O_8 and others as high as 30 percent Ni. Between 200 and 300 kilograms of sorted ore was stockpiled at the time of examination. Tonnage in place, indicated by development to January 1959, is about 5 metric tons. This prospect might be developed into a small ore body of probably less than 100 tons.

All the remaining pits up the gully are excavated in thin limestone beds with no evidence of strong fracturing. Metallization is limited to very weak chalcopyrite disseminations, and radioactivity is 3 to 4 times background. The westernmost pit contains slightly stronger metallization of niccolite, tetrahedrite, and uraninite in a few scattered lenses.

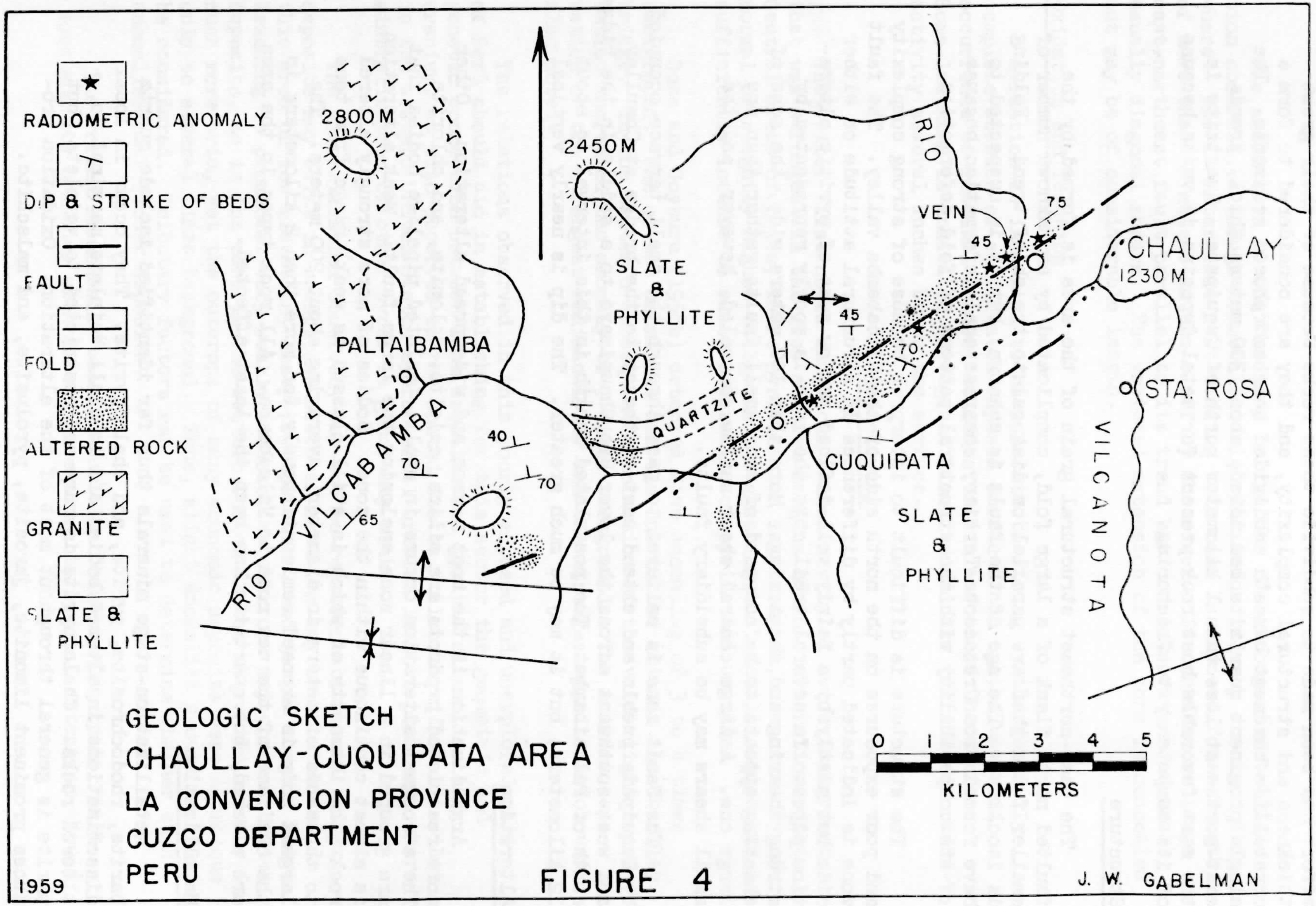
In view of the difficulties of transportation and because the known deposits contain chiefly nickel, cobalt, and copper, extraction of the small amount of uranium does not seem to be warranted. Deposits chiefly of uranium minerals may exist, however, marginal to the strongly altered Chancara pipe and may be richer and more extensive than those observed to date. The low-temperature alteration also is favorable because uranium occurs most commonly in a low-temperature environment and should be more prominent here than at Vilcabamba where high-temperature silication is the predominant alteration.

The writer recommends preparation of a geologic and alteration map of the area enclosing the alteration map to a distance outward of at least 3 kilometers, with particular attention accorded to the southeastward extension of mineralization in the synclinal trough. The mineralogy of all deposits should be noted to determine variations in the temperature environment, and the lowest temperature sectors should receive most attention. An isorad map of the area also should be made.

CHAULLAY-CUQUIPATA AREA

Geology

The entire lower Vilcabamba valley between Chaullay and Paltaibamba (about 8 kilometers' map distance above Cuquipata) (fig. 4) is underlain by lower Paleozoic metamorphic schists, phyllites, and quartzites. No



GEOLOGIC SKETCH
CHAULLAY-CUQUIPATA AREA
LA CONVENCION PROVINCE
CUZCO DEPARTMENT
PERU

1959

FIGURE 4

J. W. GABELMAN

effort has been made to subdivide these rocks because of their great thickness and structural complexity, and they are considered to form a crystalline basement beneath subdivided unmetamorphosed sediments. The single prominent quartzite bed noted, about 300 meters thick, trends east-northeast less than 1 kilometer north of Cuquipata. Quartzite is the most favorable host rock present for metal deposits in veins because of its competency to fracturing.

Structure

The east-northeast structural grain of the area is formed by the faulted north flank of a large fold, complicated by an unknown number of smaller folds that are parallel or diagnoal to the chief trend. Folding is isoclinal. The age of the fault is unknown, but it is suspected to have formed from Cretaceous-Tertiary compressional deformation because of its compatibility with the structural pattern of fold deformation.

The structure is difficult to interpret because of strong complexity and poor exposures on the north side of the Vilcabamba valley. The fault zone is indicated partly by differences in structural attitude on either side but mostly by a fairly well-defined narrow zone of pyritic alteration pipes. In several trail cuts the zone is poorly represented by strong shearing and shattering. More than 100 meters wide, the zone of shearing appears to be composed of many small faults rather than one large one. A large central shear may be concealed, however, and the small shears may be subsidiary faults.

The fault zone is believed to pass through the small terrace occupied by Cuquipata pueblo and extend east-northeast to the bridge at Chaullay, and west-southwest across the lower Río Chaupimayo to a saddle in the ridge south of Paltaibamba. The postulated length in this interval is about 12 kilometers, but it may be much greater. The dip is nearly vertical.

Alteration

Argillization is the most common and widespread alteration. Other more restricted products are silica, calcite, dolomite, and chlorite. The strongest alteration occurs in small, isolated pipelike bodies that are grouped in a linear zone enclosing the large fault. Weak alteration is almost continuous within the zone. Bodies of more strongly altered rock (the intensity of which is still classed as weak) range from tens to thousands of meters in diameter, averaging about 200 meters. The largest body is exposed semicontinuously for more than 2 kilometers in the cut face of the new road to Vilcabamba. All rock types in the area are altered, but quartzite has been the least affected.

Metallization

Metallization-stage minerals thus far identified include quartz barite, rhodochrosite, pyrite, and chalcopyrite. They occur in local disseminations in altered bodies and in small veinlets marginal to altered rocks. Chalcopyrite is rare and restricted to veinlets, but pyrite is general throughout most of the alteration. Oxidation produces prominent limonite, jarosite, pyrolusite, and malachite.

The small vein at the Chaullay bridge has the strongest metallization observed, although nonmetallic mineralization is much stronger elsewhere. The 10-meter-wide west-tending vein zone is exposed for a length of more than 30 meters in the cliff by the river. It contains no large east-northeast fault parallel to its trend but consists rather of small, usually diagonal shears. The westward extension of the zone is concealed but may be of considerable length.

Oxidation and leaching

Oxidation is indicated to be moderate to strong by the generally complete absence of sulfides on exposed surfaces and by the uncommon occurrence of residual armored sulfides within a foot of the surface. Some leaching is indicated by vagrant limonite and the increase in radioactivity several inches below the surface.

Radioactivity

The writer first noted anomalous radioactivity of twice background that was strongest in the less altered margins of most alteration pipes. Central areas of pipes, where pyritization is strongest, are commonly of normal or slightly higher background, suggesting that metallization was sufficiently intense to allow separation of pyrite and uranium.

Sosa and Goyburu (1958b) detected five anomalies of 3 to 4 times background. One of the anomalies was the one in the vein at the Chaullay bridge. In the writer's subsequent examination of the vein slight excavation increased the anomaly to 9 times background. The evident separation of the strongest radioactivity and the strongest pyritization was also noted.

The relations observed in this poorly exposed and unexplored part of Perú should aid in establishing for this sector the geometric and genetic connection between weak argillic and pyritic alteration and uranium, as also observed in the United States. Also significant is that in the western United States hydrothermal uranium is most prominent where mineralization of other types is generally weak.

The mineralization observed, may not be representative, and better deposits may exist in unexplored sectors. Leaching may be substantial in this area of low elevation, heavy precipitation, and jungle cover. Where leaching is prominent very weakly radioactive outcrops may conceal better deposits, as is the case in the western United States where the climate is much more arid, yet the outcrops of many economic deposits were anomalous only to several times background. Thus, slight anomalies should at least be considered. Tributary factors can be used to determine whether such anomalies mask richer deposits.

The writer recommends "walking-out" the Chaullay-Cuquipata fault zone and its branches with detection equipment; special attention should be accorded to the marginal zones of pyritic alteration pipes. Isorad maps should be prepared for the most important small areas.

Also, the westward extension of the vein at the Chaullay bridge should be examined meticulously; this is feasible because of less jungle cover in that area. It is advisable to learn whether the anomaly increases with a little additional excavation, i. e., to determine the amount of leaching.

If significant uranium mineralization is found in the lower Vilcabamba valley, it will be desirable to learn the distribution of schist and quartzite therein because of the greater favorability of quartzite as a host rock for mineralization.

VILCANOTA FAULT ZONE

Geology

The Vilcanota fault zone, in the Vilcanota valley, apparently extends from Ollantaytambo to Abra (pass) La Raya (fig. 5). A large fault at Ollantaytambo separates a relatively low-lying sedimentary area from the high massif of metamorphosed basement in the Cordillera Vilcabamba. In 1958 work in the Cuzco-Anta area (Gabelman and Jordán, 1959) led to the suspicion that this fault extended up the Vilcanota valley past Cuzco; however, the upper part of the valley had not yet been visited.

A trip from Cuzco to La Raya in December 1958 and subsequent trips up the valley led to the interpretation of a fault zone in the upper valley and afforded an opportunity for limited investigation. It is tentatively concluded that the Vilcanota valley from Ollantaytambo to La Raya is structurally controlled by one complex fault zone.

In most of the Cuzco region southwest of the Vilcabamba and Vilcanota cordilleras the late mature Puna erosion surface truncates broad thrust-faulted folds involving Mesozoic and early Tertiary sediments. Local youthful dissection of this surface and its present average elevation of about 4,000 meters indicate strong late Tertiary uplift of the Andean block in Perú. The principal drainage pattern seems to have been established prior to the latest uplift.

Superimposed on this regional uplift are long west-northwest segments that were uplifted differentially above the Puna surface to form the present spectacular Vilcabamba and Vilcanota cordilleras. The age of this local strong uplifting is suggested by the transection of the Cordillera Vilcabamba by the Vilcanota canyon of extreme depth and narrowness.

The Río Vilcanota enters its canyon at Ollantaytambo where a fault is indicated by Permian Mitu red beds on the southwest side of the valley and Devonian schists on the northeast side. Schistose "nevados" rise to

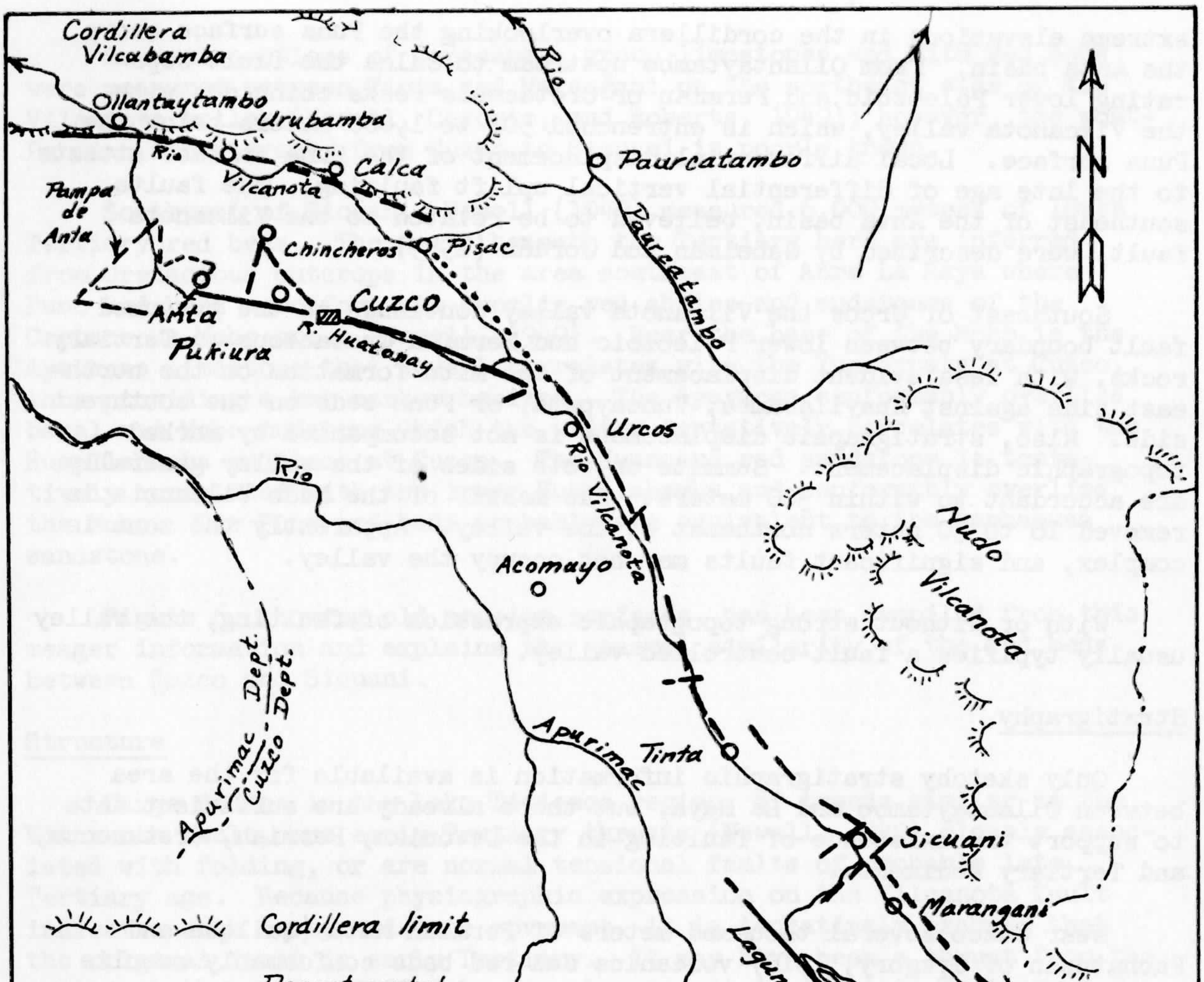

Cordillera Vilcabamba
Ollantaytambo
Urubamba
Rio Vilcanota
Calca
Paurcatambo
Rio Paurcatambo
Pampa de Anta
Chincheros
Pisac
Anta
Cuzco
R. Huatanay
Pukiura
Urcos
Rio Vilcanota
Rio Apurimac
Nudo Vilcanota
Acomayo
Apurimac Dept.
Cuzco Dept.
Tinta
Sicuani
Marangani
Laguna de Langui
La Raya Pass
Cordillera limit
Departmental boundary
Fault
Inferred fault
Espinar
0
50
Kilometers
Cuzco Dept.
Puno Dept.
N
Vilcanota Fault Zone
Cuzco Department, Peru
January, 1959
J. W. Gabelman

Figure 5

extreme elevations in the cordillera overlooking the Puna surface above the Anta basin. From Ollantaytambo upstream to Calca the fault separating lower Paleozoic and Permian or Cretaceous rocks coincides with the Vilcanota valley, which is entrenched 500 to 1,000 meters below the Puna surface. Local differential displacement of the Puna surface attests to the late age of differential vertical uplift faulting. The faults southeast of the Anta basin, believed to be related to the Vilcanota fault, were described by Gabelman and Jordán (1959).

Southeast of Urcos the Vilcanota valley continues as the presumed fault boundary between lower Paleozoic and Permian Cretaceous or Tertiary rocks, with less evident displacement of the Mitu formation on the northeast side against Huayllabamba, Yuncaypata, or Puno beds on the southwest side. Also, stratigraphic displacement is not accompanied by marked topographic displacement. Summits on both sides of the valley generally are accordant to within 300 meters. The massif of the Nudo Vilcanota is removed 16 to 30 meters northeast of the valley. Apparently the zone is complex, and significant faults may not occupy the valley.

With or without strong topographic expression of faulting, the valley usually typifies a fault-controlled valley.

Stratigraphy

Only sketchy stratigraphic information is available for the area between Ollantaytambo and La Raya, but there already are sufficient data to support the existence of faulting in the Devonian, Permian, Cretaceous, and Tertiary sediments.

Near Cuzco several thousand meters of Permian Mitu (Quilque and Pachatusan of Gregory, 1916) volcanics and red beds conformably overlie Permian Copacabana limestone, which is believed to exist but is not exposed between Ollantaytambo and Pisac. The limestone would disconformably overlie the Devonian metamorphics. The Mitu is disconformably overlain by the Huayllabamba red beds (Gregory, 1916). The Huayllabamba consists of a lower section of about 1,000 meters (writer's estimate) of maroon sandstone with some interbedded shale, and an upper section of 850 meters (Kalafatovich, 1957) of red mudstone and shale with minor interbedded sandstone and gypsum. The stratigraphic nomenclature is being currently revised for a report on the Cuzco-Anta-Urubamba area.

The Cretaceous Yuncaypata formation of Kalafatovich (1957), the Yucay of Gregory (1916), was renamed by Kalafatovich to resolve confusion over the name of the type locality. It conformably overlies the Huayllabamba and is about 25 meters thick. An unconformity is believed to separate the limestone from more than 1,000 meters of Tertiary gray sandstones and minor interbedded shales; this is the Bambanusa sandstone of Gregory (1916).

Several sections of Copacabana group limestones and Mitu red beds were measured between Tinta and Marangani on the northeast side of the Vilcanota valley (Newell, Chronic, and Roberts, 1949); however, the post-Permian stratigraphy from Cuzco to Sicuani is poorly known.

Southwest of Sicuani, Newell (1949) measured 6,000 meters of lower Tertiary red beds. The rocks beneath the Tertiary here are inferred from Cretaceous outcrops in the area southeast of Abra La Raya where Puno red beds unconformably overlie red shales and mudstones of the Cretaceous Moho group (Newell, 1949). Near the base of the Moho is the Ayavacas limestone that Newell correlates with the Yuncaypata at Cuzco, thus providing a key marker horizon. The Ayavacas conformably overlies basal red Moho mudstone which the writer tentatively correlates with the Huayllabamba mudstone at Cuzco. The Huancané red sandstone is tentatively correlated with the lower Huayllabamba and conformably overlies the Moho. The Puno red beds probably are equivalent to the Bambanusa sandstone.

Figure 6, showing old erosion surfaces, has been compiled from this meager information and explains the general similarity of the red beds between Cuzco and Sicuani.

Structure

Large faults in the Lake Titicaca region, of trends similar to the Vilcanota fault, are early Tertiary thrusts (Newell, 1949) closely associated with folding, or are normal tensional faults of probable late Tertiary age. Because physiographic expression on the Vilcanota fault indicates both early and late movement, it is tentatively assumed that the original fault is early Tertiary. It may have been a thrust from the northeast that was modified by normal movement in the late Tertiary and physiographically expressed along its northwestern part.

Apart from its remarkable continuity the zone is more characteristic of differential uplift than of thrust movement. It is composed of many faults, most of which are relatively short and terminate at, or are offset by, cross faults expressed by offsets in the faultline scarp. Some cross faults also may be tears paralleling the thrust movement.

Notably near Tinta and in the lower Huatanay valley Pleistocene or Recent volcanic cones are localized in the fault zone. The Huatanay (Cuzco) and the Laguna de Langui valleys also are structurally controlled by faults that branch from and parallel the Vilcanota fault.

Alteration

A belt of hydrothermal alteration pipes encloses the Vilcanota fault zone from Ollantaytambo southeast to and beyond La Raya, a distance of nearly 200 kilometers. Shorter belts enclose the Huatanay valley and Laguna de Langui faults. The fault-bounded triangular Pampa de Anta is

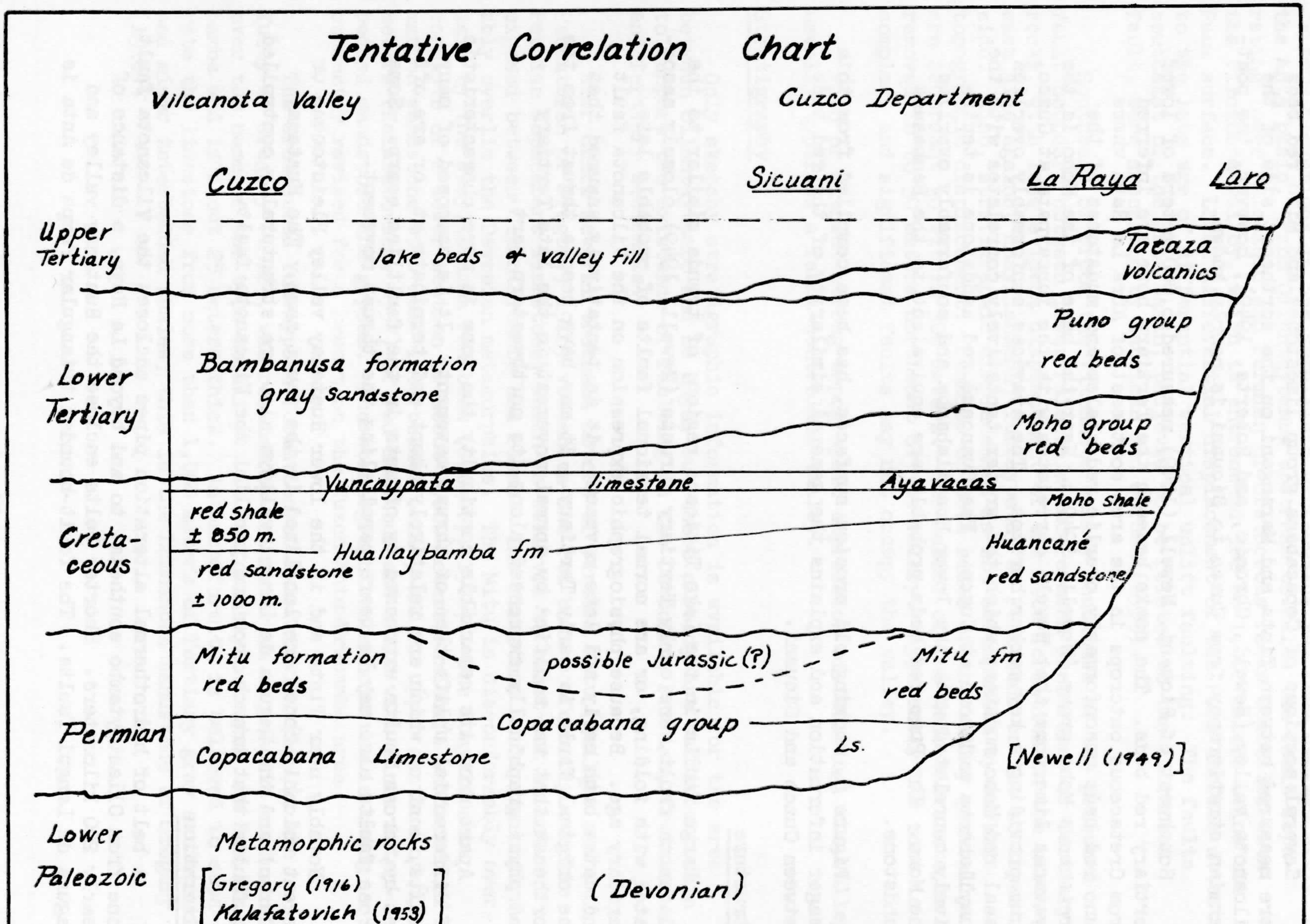

Tentative Correlation Chart
Vilcanota Valley
Cuzco Department
Cuzco
Sicuani
La Raya
Laro
Upper Tertiary
lake beds & valley fill
Tacaza volcanics
Lower Tertiary
Bambanusa formation
gray sandstone
Puno group
red beds
Moho group
red beds
Yuncaypata
limestone
Ayavacas
Moho shale
Cretaceous
red shale
± 850 m.
Huallaybamba fm
red sandstone
± 1000 m.
Huancané
red sandstone
Mitu formation
red beds
possible Jurassic (?)
Mitu fm
red beds
Permian
Copacabana group
Copacabana Limestone
Ls.
[Newell (1949)]
Lower Paleozoic
Metamorphic rocks
[Gregory (1916)
Kalafatovich (1953)]
(Devonian)
J.W. Gabelman.
1959

Figure 6

related to the Vilcanota fault and also in bordered by alteration belts that are known to contain small amounts of uranium.

There are virtually no alteration pipes outside narrow zones enclosing the faults that range up to several kilometers in width. Distant concentrations of pipes, visible from the Vilcanota valley, probably are related to unrecognized subsidiary structures.

Alteration pipes are erratically distributed along the Vilcanota zone. Consistently greater pipe concentrations at cross faults that displace or terminate individual longitudinal faults indicate locally increased concentrations of conflicting stresses. The volume, strength, and temperature environment of alteration in the belt are directly proportional to the concentration of alteration pipes. Marked zoning also is apparent, however, from southeast to northwest, with the number, size, strength, and variety of pipes being greatest near Abra La Raya and possibly still greater farther southeast. These factors decrease northwestward to a minimum near the junction of the Huatanay and Vilcanota valleys; they increase moderately near Ollantaytambo but are not as important as at La Raya.

The number and size of Tertiary intrusives varies in the same manner as for alteration pipes. Intrusives are important only near La Raya and northwest of Ollantaytambo. Volcanic cones in the belt generally decrease in prominence to the northwest.

In the Cuzco-Anta area an attempt to determine the distribution of selenium-bearing <u>Astragalus garvancillo</u> and hydrothermal alteration was largely inconclusive because of the great amount and widespread distribution of altered rock and the almost universal prevalence of <u>Astragalus</u> g., regardless of lithology (Gabelman and Jordán, 1959). However, a more distinct relation is apparent in the Sicuani-Laguna de Langui area where alteration is weaker and less extensive. The conclusion here is believed to be applicable to both areas.

<u>Astragalus</u> g. is prominent in many rock types in the Vilcanota alteration belt from Ollantaytambo to Sicuani. Near Cuzco the dominance of Huayllabamba red beds led to the possible conclusion that the selenium is indigenous to this formation and is being spread to other rocks by leaching and erosion. Actually, the entire interval between Sicuani and Laguna de Langui is underlain by Tertiary Puno red beds. The density of <u>Astragalus</u> g. visibly decreases southwest of Sicuani until the plant is absent in the large unaltered area between the Vilcanota and Laguna de Langui faults. <u>Astragalus</u> g. again becomes prominent in Puno beds in the alteration belt enclosing the Laguna de Langui fault.

Thus, it is concluded with considerable assurance that: (1) the selenium probably was introduced in epigenetic solutions; (2) its distribution and concentration generally appear related to that of alteration pipes although it is more extensive than the latter; and (3) it can be used as an indicator of uranium.

Metallization

As expected, the number and variety of related hydrothermal metal deposits closely follow the strength, volume, and variety of alteration pipes although the size and strength of deposits depend largely on zonal position with respect to alteration pipes. From the meager information available on metallization in the alteration belt it is apparent that mines exist only near La Raya, where base metals are most prominent. To the northwest, gold, silver, and antimony become more important but not necessarily of commercial quality. No deposits of these metals are known in the belt northwest of Sicuani. Small copper deposits were found in sandstone in the Cuzco-Anta area.

Probably any uranium or selenium present in the solutions metallizing the belt would seek a zonal position in the lowest temperature environment, near that of low-temperature copper and distant from base or precious metals.

Laguna de Langui fault

Because the existence and characteristics of the Vilcanota alteration belt were determined principally by driving the length of the belt, it was considered necessary to verify the restriction of alteration pipes to the belt through a cross traverse along the Sicuani-Laguna de Langui road. This road follows a cross-fault-controlled valley normal to and between the Vilcanota valley and the Laguna de Langui depression controlled by the Laguna de Langui fault.

Alteration pipes decrease in number southwestward from the Vilcanota valley to a wide barren interval between the two longitudinal faults. Pipes increase to a maximum at the Laguna de Langui fault, then decrease on the southwest side; this variation is accompanied by a similar variation in radioactivity. Thus, although alteration pipes seldom occur on either fault, their control by the faults is apparent.

Radioactivity

Very low-temperature uranium commonly is associated with weak argillization or bleaching, and pyritization, types of alteration prevalent in the Vilcanota fault zone between Urcos and Sicuani. Weak anomalies were detected in several alteration pipes in the Cretaceous Huayllabamba formation (lower sandstone and upper mudstone) and the Tertiary Bambanusa-Puno sandstone; both formations appear to be fluvial sediments with local carbon concentrations. The background in the alteration pipes enclosing the Vilcanota and Laguna de Langui faults is about twice that outside the belts.

The most notable anomaly was observed in a small alteration pipe in shattered Puno sandstone near a small fault at the Yauri-Vilcanota valley road junction at Sicuani. The pipe is anomalous to $3\frac{1}{2}$ times background;

mineralization products are sericite, siderite, manganosiderite, quartz, and bleached rock. This radioactivity demonstrates some relation between low-temperature alteration and uranium mineralization.

Weak uranium mineralization is known in the Cuzco-Anta area and is suspected northwest of Sicuani. The low-temperature portion of the Vilcanota belt from Urcos to Ollantaytambo has not been examined but is favorable for uranium deposits.

The writer suggests that the following work be done in the area:

(1) Measuring enough stratigraphic sections between Cuzco and Abra La Raya to interpret satisfactorily the Vilcanota fault;

(2) Reconnaissance mapping of the general features of the fault zone between Ollantaytambo and La Raya (the use of vertial aerial photographs will be valuable);

(3) Plotting on maps the position, size, and type of all alteration pipes;

(4) Plotting the position and mineralization of all known metal deposits;

(5) Determining the zonal position most favorable for uranium from the above information;

(6) Geologic and radiometric mapping of the most favorable small area to determine the economic uranium possibilities of the belt; and

(7) Using oblique aerial color photography to map structure, stratigraphy, and alteration quickly and effectively.

COASTAL ZONE

Geology

West of the crest of the Cordillera Occidental southwestern Perú is characterized by a steep mountain slope on the west side of the Andean cordillera, the coastal plain, and a narrow strip of small block mountains that coincides with and shapes the coastline. All have been modified by uplift and erosion, and resulted from intermittent differential vertical uplift dating from the late Tertiary and continuing to the present.

In the northwestern part of the region the mountain slope is about 50 kilometers wide and is very abrupt between the highland remnants of the Miocene Puna erosion surface and the coastal plain. It trends S. 50° E. near Pisco and S. 70° E. east of Arequipa. In the latter sector superimposed volcanoes complicate the separation of the slope from the uplifted coastal plain.

Just south of Arequipa the slope is physiographically, and perhaps structurally, offset to the west-southwest along a linear escarpment slope striking about N. 60° E. South of this offset the slope trends about S. 55° E. through Moquegua and northeast of Tacna, maintaining a low gradient. Throughout its length the slope is deeply dissected by consequent cross drainage and suggests a fault zone along or near its toe that parallels the coast from Pisco southeastward, swinging to nearly east in the Arequipa embayment. A second zone, en echelon to the southwest, reestablishes the original southeast trend.

The coastal plain parallels the mountain slope and actually is a rock-cut pediment sloping upward toward the toe of the mountain flank. Although broken locally by small fault-block mountains and dissected by major drainages, it is essentially one erosion surface, possibly partly residual from Puna erosion but developed principally after uplift of the mountain slope. Sides of the plain are linear in short segments and reflect the reticulate pattern of marginal faults.

Near Ica the plain is of low elevation. It trends north-northwest into the sea at Pisco; southeastward it gradually swings more eastward and rises in elevation. East of Camanã it averages 1,300 meters in elevation. West of Arequipa the elevation of its southwestern side averages 1,000 meters and that of its northeastern side 1,600 meters.

The plain narrows past the offset in the mountain slope and terminates in the hills southeast of the lower Río Tambo, which has deeply dissected it. At Tacna the plain slopes from the sea to about 900 meters over a width of 50 kilometers. Throughout its length it had been modified by tilting and dislocations along high-angle faults attendant to Pliocene to Recent uplift.

Except where it slopes to the sea, the western side of the plain is a steep escarpment, an abrupt cliff, or isolated block mountains with youthful topography exceeding 1,000 meters in elevation; all represent stages of rapid uplift. Mountain blocks formed an aggregate pattern like that in northern Perũ, i. e., concentrated at the coast, separated by flat plains, and commonly en echelon to the north-northwest with individual west-northwest trends. The frequency and promimity of blocks increase southeastward. In southern Perũ they may be said to constitute a coastal mountain range bordering the plain, which then becomes an interior coastal valley with cross drainage.

Structure and tectonics

The narrow bands of distinctive physiography and the shape and trend of the coastline, all of which are parallel, broadly define the late Tertiary deformation pattern of the region. Long, linear, steep slopes probably are faultline scarps resulting from displacement of the Puna and later erosion surfaces; the degree of scarp destruction indicates the relative age of faulting.

Faults appear to be successively younger westward, and those on the coast are Pleistocene of Recent, with continuing uplift from the sea. The westward progression of small, isolated fault blocks from mountains separated by the flat coastal plain to islands in the sea suggests that continually younger fault-block strips have been added to the coast. A flat shelf is indicated to extend west of the coast at least to the limit of the islands and probably 70 to 100 kilometers offshore to the margins of the great trenches, which in depth match the height of the Andes.

The abrupt displacements physiographically indicate largely vertical movement on the high-angle fault blocks; however, a strong horizontal component is suggested by the tendency of individual fault blocks to appear from the sea and trend obliquely inland at increasing elevations. Large segments of the coastal plain itself emerge from the sea in northwest-facing bays and rise to elevations of over 1,000 meters before being abruptly terminated by faults. The effect is that of narrow fault slices shoved obliquely upward from the shelf between the Andean cordillera and marginal deeps into the continental block to which they become welded; thus, the seaward extension of the coastline progresses from southwest to northeast.

Evidence for the above interpretation is striking. The coast southeast of Pisco generally appears curved but actually is composed of many short, straight segments. The segment south of Pisco to the Paracas peninsula actually trends south-southwest. The trend to San Juan Bay near Marcona is southeast, and from San Juan to Punta de Bombon (Mollendo) it is east-southeast. The smooth curve on to Ilo is essentially a large, northwest-facing bay, similar to the smaller bays to the northwest. The segments from Ilo to Arica is nearly southeast, almost reestablishing the trend between Paracas and San Juan. At Arica the coastline abruptly trends south to form an area of tectonic importance equaling that at Punta Negra in northern Perú where the coast and the Andean chain swing suddenly from northwest to northeast.

Although the short segments consist largely of straight sea cliffs reminiscent of wave-modified fault scarps parallel to the main segment trend, short sections and small, isolated, uplifted coastal fault blocks are oriented more westerly and disgonal to the main segment. The segment trend is carried northwestward from section to section through a series of northwest-facing bays. Thus, at San Juan and San Nicolas, scarps and small raised blocks individually trend nearly west, but en echelon they form a northwest trend.

Cross faults perpendicular or at a large angle to principal segment trends are suggested by scarps or terminations of erosion surfaces of similar orientation. Both large and small faults commonly swing eastward into the interior mountains, as in the retreat of the mountain slope east of Arequipa.

Lithology

There was little opportunity to determine relations between different lithologies. Aided somewhat by color, rocks could be recognized only as massive stratified volcanics or sediments. The geologic map of Perú (Bellido, Narvaez, and Simons, 1956) shows an intricate distribution of upper Paleozoic unmetamorphosed sediments, pre-Cretaceous granitic intrusives, Mesozoic marine sediments, portions of the Andean batholith, Tertiary sediments, and late Tertiary volcanics.

On the map longitudinal folding, thrusting, and intrusion generally parallel the average cordilleran trend. Except for the latest Tertiary and Quaternary sediments and volcanics, this pattern is completely independent of present physiography. The lithologic pattern, therefore, resulted from deformations earlier than those presently expressed in the landscape and probably was produced in Late Cretaceous to early Tertiary time. Lithology also is largely independent of original mineralization patterns.

Oxidation

Because of recent exposure and the aridity, most outcrops are remarkably fresh. Presumably the oxidized rocks were first selectively prepared by mineralization, and mostly mineralization products are oxidized. In areas of substantial relief oxidation occurs only in linear zones, suggesting mineralized faults, or in isolated areas in patterns that match the mineralization patterns noted elsewhere in the Andes.

Oxidation of mineralization products chiefly produces iron oxides. Dark-yellowish-brown limonite in altered rock was interpreted as after ferromagnesian minerals; orange-red to orange-yellow limonite, as after sulfides; and several shades of hematite red, as after magnetite or specularite; local examinations have verified these interpretations.

Primary alteration colors not markedly affected by oxidation are green, from chloritization or epidotization, and white, from argillization or bleaching. By far the most common oxidation color is hematite red, which stains a considerable percentage of the area seen. As confirmed on the ground, large areas weakly stained red may be merely joint stockworks of sparsely distributed magnetite or specularite. Numerous strongly stained dark-red fault zones and isolated areas, however, suggest magnetite veins and pervasive replacements similar to those being mined at Marcona and Acari. The veins are very common.

Pediment remnants, and accordant summits suggesting old remnants, are strongly stained hematite red, particularly from Nacza southeastward to Arequipa. Although patchy in places and locally suggesting underlying mineralization centers, the unusually extensive red stain seems to be confined largely to the gravel veneer.

There is no oxidation of the slopes underlying the red-gravel veneer in canyons dissecting pediments or in sea cliffs beneath raised coastal pediments. In some areas the red veneer probably results from the oxidation of magnetite in volcanic ash and tuff, but the greater part presumably is derived from veins and large replacement disseminations of magnetite. During surface reduction the magnetite is fed to the gravels and is widespread down-slope, becoming oxidized en route.

Oxidation to hematite occurred chiefly during pedimentation and essentially ceased during vigorous renewed uplift, as indicated by the lack of hematite stain in valley slopes, valley gravels, and beach deposits. Hematite derived from old pediment gravels apparently is removed selectively to the sea in advance of cobbles. Magnetite liberated to modern gravels since the start of pediment destruction has not had the time or environment to oxidize.

The Acari magnetite mine is on the steep south slope of a mountain, about 1,500 meters high, that is capped by a gravel-veneered pediment remnant. Several wide magnetite veins cut the slope at a high angle to the topographic contours. The entire slope, including the vein outcrops, is unoxidized, whereas the gravel veneer is strongly hematite-stained.

Locating the magnetite deposits supplying hematite to the gravel veneer is pertinent to the present exploration of the Peruvian coast for magnetite.

Mineralization

Soft rocks, strongly white in color usually indicate argillization; soft, pale- to dark-green rocks, chloritization; hematite red, original magnetite or specularite; orange red to orange yellow, indigenous or vagrant sulfides, principally pyrite; deep-brown to dark-red limonites (rare), chalcocite; and bold jet-black outcrops, silicification.

Except for the hematitic pediment gravels of physiographic origin, most mineralization patterns in rocks of this region are indeterminate because of broadly distributed mineralization centers in all the physiographic units. There is, however, slight linearity and some fault control. Most significant are the lack of relation to tectonic units modern enough to be indicated by the present physiography, and the prevalence of ferromagnesian limonite and hematite after magnetite and specularite, suggesting hypothermal mineralization. These features support the interpretation that the magnetite-specularite mineralization is early and controlled by early folding, thrusting, and possibly batholithic emplacement.

Regionally, magnetite is distributed along the west margin of the batholith and reflects the same tectonic control that guided batholith emplacement. Magnetite veins in the batholith preclude iron metallization before or directly with emplacement of the batholith. More likely, this metallization was a postmagmatic hypothermal phase controlled by final adjustment structures. A hypothermal origin of the magnetite is compatible with its fairly deep-seated emplacement shortly after intrusion of the batholith.

All mineralization, however, is controlled locally by the late Tertiary faults along which individual coastal blocks rose or sank. In such cases pyritization is more common than magnetitization, but there is more magnetite than pyrite. The general lack of lower than hypothermal mineralization along the coast suggests that any middle to late Tertiary mineralization would have occurred closer to the surface, and the high temperature of solutions was maintained even near the surface. If there was only one stage of mineralization, the late controlling structures must have existed earlier as weak zones.

In alteration pipes on the mountain slope east of the coastal plain the yellow and orange of diluted pyrite (and probably a minor amount of other sulfides), the white of strong argillization, and locally the deep reds suggesting copper minerals predominate over the hematite-after-magnetite and specularite common to the coast. Except east and southeast of Arequipa, where volcanics predominate, pipe distribution is more related to compressional deformation and intrusion than to differential vertical uplift.

Particularly south of Arequipa the strongest alteration centers, and those containing the most limonite-after-copper minerals, occur in volcanic areas of subdued or no volcanic physiography, indicating mid-Tertiary volcanism. Such geology characterizes many "porphyry" coppers in which explosive volcanic vents also were solution feeders at some deposits.

The coincidence of alteration pipes with Recent volcanic vents is striking. This latter alteration is fumarolic, late, and probably epithermal. Local geologists consider it valueless; however, the writer believes it is similar to that which introduced valuable copper minerals deeper in the explosive vents seen as eroded stumps today. Also, if a sufficiently high-temperature environment were carried by solutions to the surface, xenothermal mineralization could occur near the surface in modern vents. Thus, the fumarolic pipes may be surface expressions of very late Tertiary or Recent metallization deeper in the vent. The same altered appearance in an eroded vent would warrant investigation, as in any mineralized volcanic pile.

Regionally, these mineralization patterns illustrate zoning on a gigantic space and time scale. The relations commonly can be verified in detail at many mines and prospects. Hypothermal iron mineralization, possibly predating mid-Tertiary volcanism, predominates in a belt west of and underlying the coastal plain. The metallic replacement disseminations and concentrations contain magnetite or specularite but seldom copper minerals.

Less common copper minerals, pyrite, and gold, however, occur in veins marginal to but somewhat distant from iron disseminations. Eastward on the mountain slope magnetite and specularite are more rare until pyrite and chalcopyrite with tourmaline become the common replacement dissemination, and marginal veins are of copper and gold. Near the top of the slope lead and zinc veins gain in prominence but are virtually absent to the west.

Although pre-mid-Tertiary volcanic mineralization may have occurred on the slope, it evidently did not introduce much magnetite or specularite. Most of the slope was mineralized after volcanism, and mineralization possibly is younger to the east. Weak, late Tertiary epithermal mineralization is superimposed. Thus, the region discussed can be considered to contain a coastal iron belt and a mountain slope copper belt.

Radioactivity

Hematite-altered areas examined from the air at a low altitude were not anomalous, but although slight increases were noted over several predominantly argillic and pyritic pipes, these areas of high-temperature mineralization are not believed to be significantly radioactive.

There may be occurrences, however, of uraninite or high-temperature complex uraniferous silicates with magnetite or specularite. Most of the known uranium occurrences on the mountain slope are in granite pegmatites cutting the batholith. Also, one occurrence of radioactive magnetite near the coast was reported to the writer (Sam Mold, personal communication), and would not be unusual because of the occasional presence of small amounts of uranium in the high-temperature environment, particularly in Peruvian and Chilean copper deposits. Uranium minerals occur in the chalcopyrite veins of the Ica area in the northern part of the mountain slope discussed here and would not be surprising in some of the "porphyry" copper deposits, but such occurrences are unlikely to be of commercial importance.

The possibility of economic uranium deposits associated with Tertiary to Recent epithermal mineralization of volcanic vents is better than that of copper deposits because of the more favorable environment, but this has not yet been investigated.

REFERENCES

Aguilar M., Oscar, Ocampo A., Adolfo, Jordán O., Victor, and Pizarro F., Julio, 1957, Estudio geológico y de radioactividad, Distrito de Vilcabamba, Provincia del Cuzco: Perú, Junta de Control de Energía Atómica Rept. 26A.

Bellido B., E., Narvaez L., S., and Simons, F., 1958, Mapa geológica del Perú; 1:2,000,000: Soc. Geol. del Perú.

Gabelman, John W. and Jordán O., Victor, 1959, Reconnaissance for uranium in the Cuzco-Anta area, Department of Cuzco, Perú: U. S. Atomic Energy Comm. RME-4538.

Gregory, H. E., 1916, A geological reconnaissance of the Cuzco valley, Perú: Am. Jour. Science, v. 41, p. 1-100.

Kalafatovich V., Carlos, 1957, Edad de las calizas de la formación Yuncaypata, Cuzco: Soc. Geol. del Perú Bol., v. 32, p. 127-139.

Newell, Norman D., 1949, Geology of the Lake Titicaca region, Perú and Bolivia: Geol. Soc. America Mem. 36.

________________, Chronic, B. J. and Roberts, T. G., 1949, The upper Paleozoic of Perú: New York, Univ. Serv. Bur., Columbia Univ., 241 p.

Rogers, K. J. and Freyre V., A., 1955, U. S. Atomic Energy Comm. unpublished report.

Sosa B., Juan and Goyburu de la C., Eduardo, 1958a, Reconocimiento geológico-radiométrico del triángulo Pampaconas-Yupancca-Tincoc, Provincia de La Convención, Departamento del Cuzco: Perú, Junta de Control de Energía Atómica Rept. 36.

____, 1958b, Reconocimiento geológico-radiométrico preliminar de la zona Chaullay-Cuquipata, Provincia de La Convención, Departamento del Cuzco: Perú, Junta de Control de Energía Atómica Rept. 34B.