Jour. Korea Inst. Mining Geol.
Vol. 15, No. 2 (1982), pp. 51-63

Uranium Mineralization and Its Potential in Bolivia

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Abstract: The uranium deposits of Bolivia are mainly found in the Altiplano and the Cordillera Oriental. In the Altiplano, many radioactive anomalies are detected in the Tertiary red beds and volcanic rocks. In the Cordillera Oriental, important anomalies are detected in the sedimentary rocks of Paleozoic, Mesozoic and Tertiary ages as well as in hydrothermal veins and syenitic rocks of Tertiary age. Classification of uranium deposits is attempted and their potentials are discussed. Widespread occurrence of various genetic types of uranium deposits in Bolivia draws attention of geologists on scientific and economic viewpoints. Mineralogical and genetic studies of important uranium deposits of Bolivia will be published in separate papers.

1. Introduction

This paper is the results of the field and laboratory studies on the important types of uranium deposits of Bolivia, with emphasis on the genesis and potential. The uranium deposits and anomalies have been visited during the period from 25 July to 15 September 1978.

This uranium investigation project has been undertaken as one of the Cooperation programs in Science and Technology between Korea and Bolivia on the governmental basis following the request from the Commision Boliviana de Energia Nuclear (COBOEN). The project has been carried out by the Korean Mission consisting of two geologists (Soo Jin Kim and Se Moon Chang) with the help by geologists from COBOEN.

The purpose of the project is to clarify the general modes of occurrence of radioactive minerals and their mineralogy and genesis. Such work is very important especially in the areas without extensive investigation as the basis for further detailed investigation. Its result can be used effectively not only for the investigation of known deposits or anomalies but also for exploration of unknown deposits in other areas.

The areas visited by the authors include Sevaruyo, Potosi, Cochabamba, Illimani and Charazani. The Chacarilla-Corocoro area has not been studied in detail. Tupiza, Lipez and Robore areas have not been visited. However, it is significant that nearly all types of uranium occurrences of Bolivia have been included in this study.

The field investigation was carried out by the financial support from the Ministry of Foreign Affairs and the Korea Mining Promotion Corporation, and the laboratory research was supported by the Korea Mining Promotion Corporation.

Sincere thanks are extended to Mr. Francisca Mariaca S., Director of COBOEN, Mr. Victor Virreira P., Chief of the Department de Materias Primas, and other geologists of COBOEN, who did not hesitate to help us in the field and the laboratory, and to Prof. U. Petersen of Harvard University for his kind suggestions.

2. Physiography

Physiographically, Bolivia is divided into four entirely different morphotectonic units (Fig. 1). From west to east they are 1) the Andes, 2) the Subandean foothill zone, 3) the eastern plains, and 4) the Brazilian shield. Each unit, except the Brazilian shield area in the northeastern part

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of the country, is developed in N45 W direction in the northern half and in the NS direction in the southern half of the country. Detailed description on the physiography of Bolivia has been made by Ahlfeld (1969).

2.1. The Andes

The Andes is the main high mountain range in the western part of the country. It is subdivided into a) the Cordillera Occidental, b) the Altiplano, and c) the Cordillera Oriental (Fig. 1). Three units are developed in parallel bands within the Andes.

The Cordillera Occidental is developed along the western border with Chile.

The Cordillera Oriental consists of many high cordilleras: Cordillera de Apolobamba with Chaupi Oroco Mt.(6040 m) and Cololo Mt. (5900 m); Cordillera de Munecas with Ayoncuno Mt. (5020 m); Cordillera Real with Illampu Mt. (6700 m) and Illimani Mt. (6480 m); Cordillera de Tres

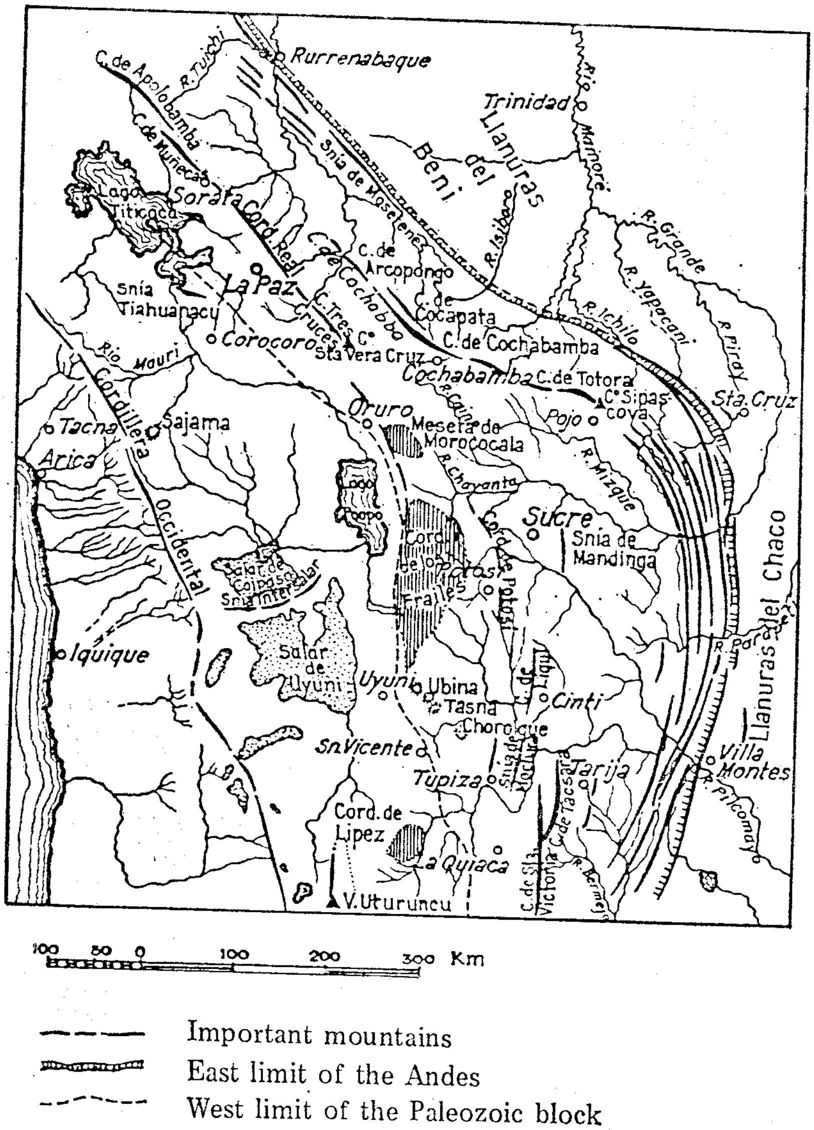

Fig. 1 Physigraphy of Bolivia (Troll, 1928).

Curces with Jachacunocollo Mt. (6480 m); Cordillera Santa Vera Cruz; Cordillera de Cochabamba; Cordillera de Arcopongo (4400 m); Cordillera de Potosi; Cordillera de Los Frailes with Ubina Mt. (5150 m), Tasna Mt. (5100 m), Chorolque Mt. (5600 m) and Iscaisca Mt. (4340 m); Cordillera de Lipez; Cordillera de Sta Victoria and Cordillera de Tacsara.

The Altiplano is an intramountaineous basin at the altitude of 3,500–4,000 meters. Large lakes such as Lago Titicaca, Lago Poopo, Sala de Cojpasa and Sala de Uyuni are present in the Altiplano.

2.2. The Subandean Foothill

This zone is relatively narrow eastern foothill of the high Andes. The altitude of this zone is between 1,000 and 2,500 meters. It consists of strongly folded Paleozoic and Neogene formations.

2.3. The Eastern Plains

The plains are distributed in the eastern and northern parts of the country at the altitude of 500 meters. It is subdivided into the Beni Plain in the northern part where the Precambrian shield is covered by the Quaternary formations, and the Chaco Plain in the eastern part where the Paleozoic formations are covered by Quaternary formations.

Nearly all rivers in plains as well as in mountains finally run toward north to join the Madeira River.

3. General Geology of Bolivia

The general geology of Bolivia is well compiled in the publication by Ahlfeld and Branisa (1960) and Ahlfeld (1946, 1972) and Schlatter and Nederlof (1966).

Geology of Bolivia consists of the Precambrian, Paleozoic, Mesozoic and Cenozoic formations, the Cenozoic volcanic rocks and the Mesozoic to Cenozoic granites (Fig.2). It is characteristic that Bolivia differs from other Andean countries like Chile, Peru and Ecuador, in that large areas of the eastern part of its territory consist of the Precambrian schists, gneisses, migmatites and granites. It is important to note that these rocks are probably early Precambrian in age, and contain banded iron and manganese formations.

The Ordovician, Silurian and Devonian sediments are well exposed from the border with Peru to the border with Argentina, along the Cordillera Oriental and Subandean zone, all showing curved distribution with convex side toward east. A narrow band of these rocks is also developed fringing the Precambrian shield in the eastern part of the country. All these sediments consist of grey, black or greenish marine shale, limestone and sandstone with some interbedded continental "red bed"

The Cambrian sediments contain purple, pink, white, and green quartzite with yellow-green shales. The Ordovician sediments overlying the Precambrian rocks contain thickly bedded arkose and red arkosic sandstones with red jasper and hematite in the upper part. They were deposited without interruption from Tremadocian to Caradocian. Glacial sediments of the Silurian (Gotlandian) transgressed with an angular unconformity.

The Permo-carboniferous sediments are distributed in patches along the Subandean belt. They are deeply folded. They correspond mostly to two continental glacial periods separated by red, yellow and green sandstones with dark grey and red shale. The Permian sediments are marine in the lower part and continental toward the top.

The Cretaceous sediments are mostly continental, and are found in the Cordillera Oriental and the Subandean zone as well as in the eastern area. They are preserved in cores of synclines. They consist of conglomerate and red sandstone with interbedded limestone and varigated marls. The Cretaceous rocks in the Subandean region consist of red cross-bedded sandstone with calcareous and limonitic cements.

The Tertiary rocks are widely distributed in many parts of Bolivia. Among these, the most important occurrences are found in the Subandean belt. In the western Altiplano, the Tertiary continental sediments and volcanic rocks are 0.3 to 12.0 Km thick. The lower part of the sequence consists of reddish brown and red sandstone, conglomerate and shale, whereas the upper part consists of pyroclastic rocks including tuffs and ignimbrites. The folded Tertiary rocks are covered unconformably by extensive lava flow and tuffs of Miocene to Pliocene Epoch.

Granite intrusions are scattered as small masses throughout the Bolivian Andes. Their ages range from Triassic to present (Clark and Farrar, 1973). The extrusive igneous rocks consist mostly of rhyolites, dacites and andesites of Miocene in age.

The Quarternary sediments are widely developed in the Beni and Chaco Plains as well as in the Altiplano. They cover the Precambrian rocks in the Beni Plain and the Paleozoic rocks in the Chaco Plain.

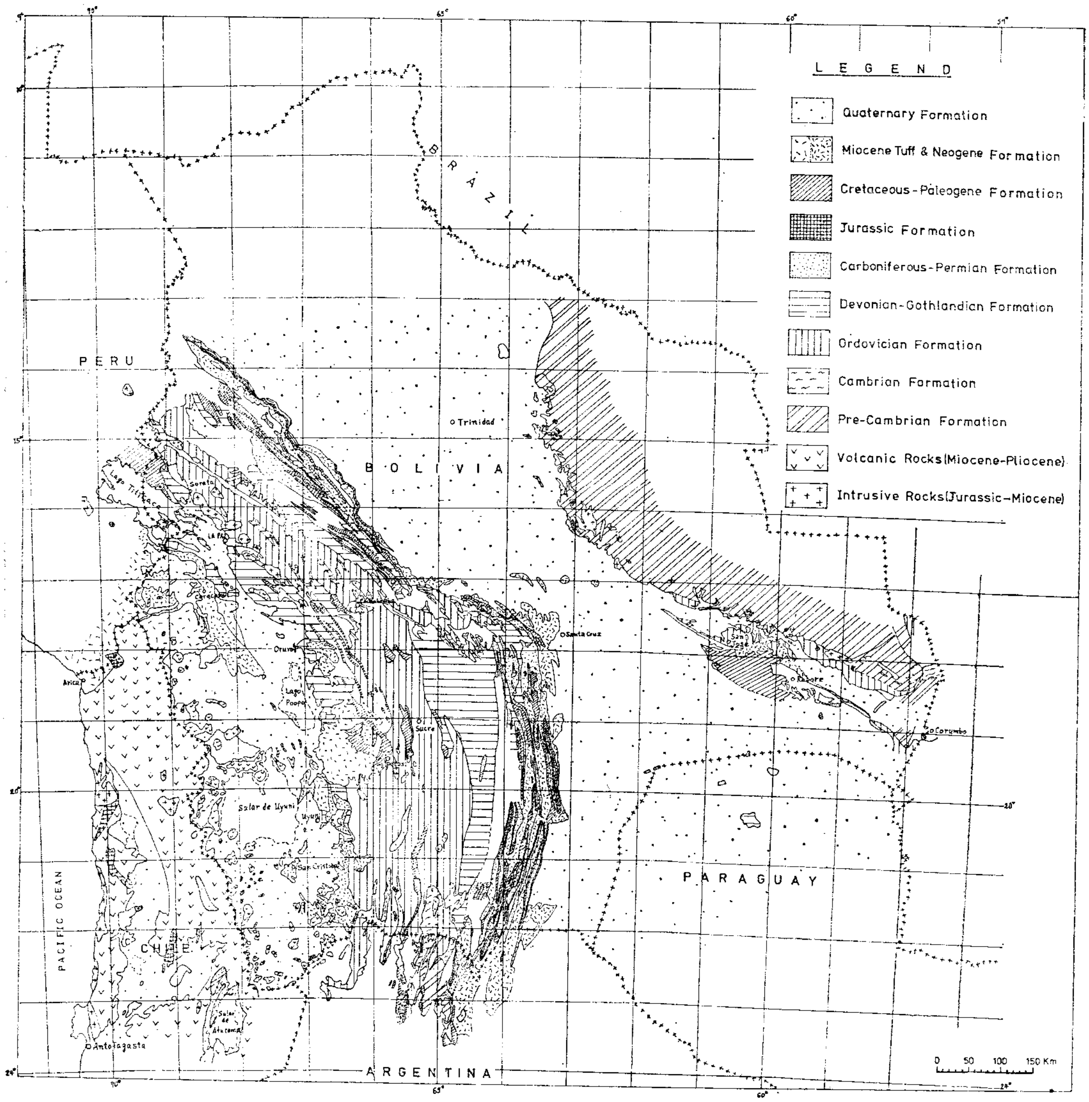

Fig. 2 Geological map of Bolivia (from Schlatter and Nederlof, 1966)

4. Structural Geology

Detailed study of the geology and tectonics of the central Andes in terms of plate tectonic theory has been made by James (1973). Interrelationship of mineralization and tectonics in the central Andes has been studied by Ahlfeld (1967), Sillitoe (1970), Turneaure (1971) and Petersen (1972). From these studies, the following outline of the tectonic and structural features of Bolivia have been compiled.

The central Andes including Bolivia, Peru, Chile and Argentina is a volcano-plutonic orogen

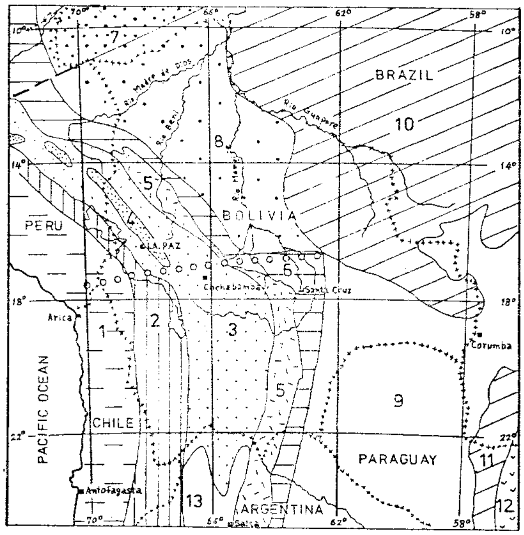

Fig. 3. Tectonic sketch map of Bolivia and surroundings (after Schlatter and Nederlof, 1966).

Mobile Belt
1 Cordillera Occidental
2 Altiplano-Puna (intramountain basin)
3 Cordillera Oriental
4 Cordillera Real (Mesozoic intrusive)
5 Subandean Foothills
Perimontane Foreland Belt (partly folded)
o o o o Arica-Elbow Line
Craton
7 Amazonas Graben
8 Beni Plain (shallow shield covered by Quaternary)
9 Chaco Plain (Paleozoic platform covered by Quaternary)
10 Brazilian Shield
11 Central Paraguay Arch
12 Parana Basin (intracratonic)
13 Pampean Ranges

constructed along a convergent or consuming plate. Descent into the mantle of the Nazca plate eastward from the Peru-Chile trench is presently active at a rate of some 6 cm/yr, and consumption of eastern Pacific plates appear to have taken place since at least Permo-Triassic times (Sillitoe, 1976).

During the Paleozoic a 10–15 Km thick sedimentary succession of flysch type was deposited on the continental margin of western South America at least partly overlying a Precambrian basement (Megard et al., 1971). They crop out in the Cordillera Oriental. Much of the 50–70 Km thick continental crust beneath the central Andes consist of Precambrian-Paleozoic basement (Cobling and pitcher, 1972)

The Mesozoic-Cenozoic orogen may be considered to have become active in the Permo-Triassic when calc-alkaline intrusive and extrusive rocks were emplaced and at the same time as continental red bed sedimentation. From that time until the present the formation of calc-alkaline intrusive and extrusives has dominated the geological record in the central Andes. The development of a convergent plate margin along western South America in Permo-Triassic times was probably due to the inception of a predecessor of the basement. East Pacific Rise is a by-product of the incipient disruption of the super-continent of pangaea (Sillitoe, 1973).

In the early post-Permian stages of construction of the magmatic arc, especially in the Jurassic, andesitic volcanism was submarine in coastal Peru and northern Chile, and shallow water marine sediments, both calcareous and clastic, were deposited within and east of the coastal volcanic arc during the Jurassic and Lower Cretaceous. From the middle or upper Cretaceous onward, however, volcanism and associated clastic sediments were dominantly subaerial, although local deposition in land-locked lagoons undoubtedly occurred. Once the magmatic arc was appreciably above the sea level, from the Upper Cretaceous onward, continental molasse-type sediments were deposited in the eastern part of the Andes in tectonic graben, particularly in the Altiplano and its extension, the Puna and further east in the Subandean Ranges. About 20 Km of molasse was accumulated on the Bolivian Altiplano in late Mesozoic and Cenozoic times. Lesser amounts of coarse, clastic sediments were also deposited in the late Cenozoic in the central and longitudinal valleys (grabens) of western Chile within arc-trench gap.

The post-paleozoic structures throughout the central Andes is dominated by a longitudinal, tensional fault system giving rise to horsts and grabens with many of the faults of high-angle, reverse type (Ahlfeld, 1972; Schwab, 1970; Thomas, 1970). The overall structural regime, including the folding of Meso-Cenozoic and Paleozoic formations, and the vast uplift of the Andes, particularly in the Cenozoic, can be understood in terms of the distension of the continental crust produced by the injection of enormous volumes of calc-alkaline magam (James, 1971; Gough, 1973). Other styles of dislocation play a part in the structural makeup of the central Andes. On the eastern border of the Andes a belt of eastward-directed intracontinental, high-angle thrusting is present which may reflect the incipient development of an subduction zone at the rear of the magmatic arc.

The Brazilian shield stretches from NW of Santa Cruz to almost the foot of the Andean mountain system (Schlatter, 1966; Ahlfeld, 1967). Because of this, the conspicuous change in directions of the strike of the Andean mountain chains from a NW-SE to N-S direction in the region of the "Coda" NW from Santa Cruz becomes comprehensible. The "Arica Elbow Line" a zone of weakness of the regional extent was formed in Precambrian times and up till recent time it has frequently reactivated. The northern narrow part has been strongly uplifted against its southern counterpart.

The east Andean block consists of monotonous psammitic-pelitic, marine sediments of early Paleozoic age followed by mainly continental sediments of Carboniferous, Permian, Cretaceous, and Miocene. The maximum thickness of the Ordovician sediments amounts to about 10,000 meters, that of the Silurian to 1,200 meters, and that of the Devonian to 3,000 meters (Ahlfeld, 1967).

5. Outline of Ore Deposits

The ore deposits of Bolivia show different characters in the northern and southern parts which are separated by the Arica Elbow line. In the Cordillera Oriental, the northern block has been more highly uplifted than the southern block. The zonal distribution of Fe, Cu-(Mo-Au), Pb-Zn-Ag, and Sn-(W-Ag-Mo) from west to east is explained by the mineralization at the submerging plate (Sillitoe, 1976). Following is the summary from Ahlfeld (1967).

The mineralization is closely connected with the intrusion of granitic rocks. The intrusion of granitic rocks took place in close connection with block faulting and folding of Mesozoic time. Au and Sb mineralization took place during this tectonic movement. W, Sn, Bi, Zn and Pb mineralization took place at the late stage of this epeirogenic movement.

Ljungren (1962) distinguishes two types of granites in the Cordillera Real. They are microcline-rich metasomatic type and a younger K_2O-rich aplitic granite. Au. W. Sb. Sn, Bi. Zn and Pb mineralizations are associated with both types of granites. The old gold-quartz veins crop out along the deeply eroded eastern flank of the Cordillera Real mostly at distances considerably removed from magma. Scheelite-bearing quartz veins of young area grades into the next younger group of W deposits. The Sb veins widely distributed far to the east or west from the granite are connected with old faults which extend down to considerable depth and form lenticular shaped bodies in non-metamorphosed Paleozoic shales (Ahlfeld, 1967). W and Sn occur together in many places, but it is common that W (and Mo in places) is near the granite, and Sn far away from it.

Younger K_2O-rich aplitic granite shows close connection with the post-orogenic cassiterite veins which are found in greater numbers in the metamorphic Ordovician slates in the deeply eroded eastern flank of the Cordillera Real. It also includes the Li-bearing pegmatitic veins of the Fabulosa deposit and the pneumatolytic Au- and W-bearing quartz veins of the Chojlla type. W and Sn mineralization is abundant in the large Quimasa Cruz batholith. Ni and Co deposits diminish toward depth (Ahlfeld, 1967).

In the southern part, two mineralization epochs are recognized; one is the Tertiary mineralization connected with the intrusion of Miocene granite and another one is the mineralization connected with subvolcanism in the Pliocene Epoch.

Sn deposits in the Early Paleozoic rocks have been formed through three stages of mineralization from Miocene to Pliocene. Low-grade Sn-W-Bi-Pb-Zn deposits have been formed in Miocene Epoch in connection with the intrusion of granodiorite. Pliocene ore deposits have been formed in connection with the subvolcanic stocks of rhyolite and latite. They usually show distinct vertical and horizontal zonality of ore minerals.

The Tertiary mineralization is found as veins in various kinds of rocks. It is associated with quartz porphyry, adamelite, granodiorite, dacite, or rhyolite. The Sn-Ag deposits in the southern area are thought to have been formed through the contamination of older Sn-rich solution by Ag-rich ores (Schneider-Scherbina, 1962). The Ag-rich solutions are thought to have been derived from the "Circum-Pacific Silver Belt", whose mineral deposits are well manifested in Peru showing a continuation to the Altiplano in Bolivia.

The copper mineralization is found in the Tertiary formations which reach a thickness of more than 15,000 meters in the Altiplano synclinorium. It is assumed that the copper has come from the west, when connection between the Altiplano and the coastal geosyncline existed in the Lower Tertiary time (Ahlfeld, 1967). Since Miocene time, the strongly uplifted northeastern part of basin underwent erosion. The copper went into solution and was precipitated again in deeper horizons. Some of the copper deposits are associated with basalt (Ahlfeld, 1967).

Pb, Zn, Ag, Cu and Sb deposits in the Altiplano were formed in connection with volcanic activity in the Pliocene Epoch. Hydrocarbon was formed in the Tertiary formation at Beni and Chaco plains. Recent Hg, S, Sb, Mn, and Ba mineralization is also found around the hot spring in volcanic terrains.

It is generally recognized that from north toward south, successively younger phases of mineralization from Permian-Triassic to Pliocene-Plistocene in age are developed.

6. Uranium Mineralization

6.1. Regional Occurrences

The uranium deposits of Bolivia are mainly found in the Altiplano and the Cordillera Oriental, except in several other places.

In the Altiplano, many radioactive anomalies have been detected within the Tertiary red beds and within the volcanic rocks. The principal anomalies in the northern Altiplano are found in the vicinity of Corocoro and Chacarilla areas. The most important anomalies in the southern Altiplano are found in the boundary area between the Altiplano and the Cordillera Oriental in the Los Frailes areas.

In the Cordillera Oriental, the radioactive anomalies have been detected in the sedimentary rocks of the Paleozoic, Mesozoic and Tertiary ages, and in the veins of Tertiary age. In the northern part of the Cordillera Oriental, the radioactive anomalies are found in the volcanic rocks in the Charazani area and in the hydrothermal veins in the Millipaya and Bolsa Negra areas, and in sedimentary rocks in the Urania area. In the central part of the country, the radioactive anomalies have been detected in the Ordovician black shale, sandstone and syenitic rocks in the Cochabamba area, and in the Ordovician and Cretaceous sandstone as well as in hydrothermal veins in the Potosi area. In the southern part, the uranium is found in veins within the strongly fractured Tertiary rhyodacitic lava.

Some radioactive anomalies are also detected

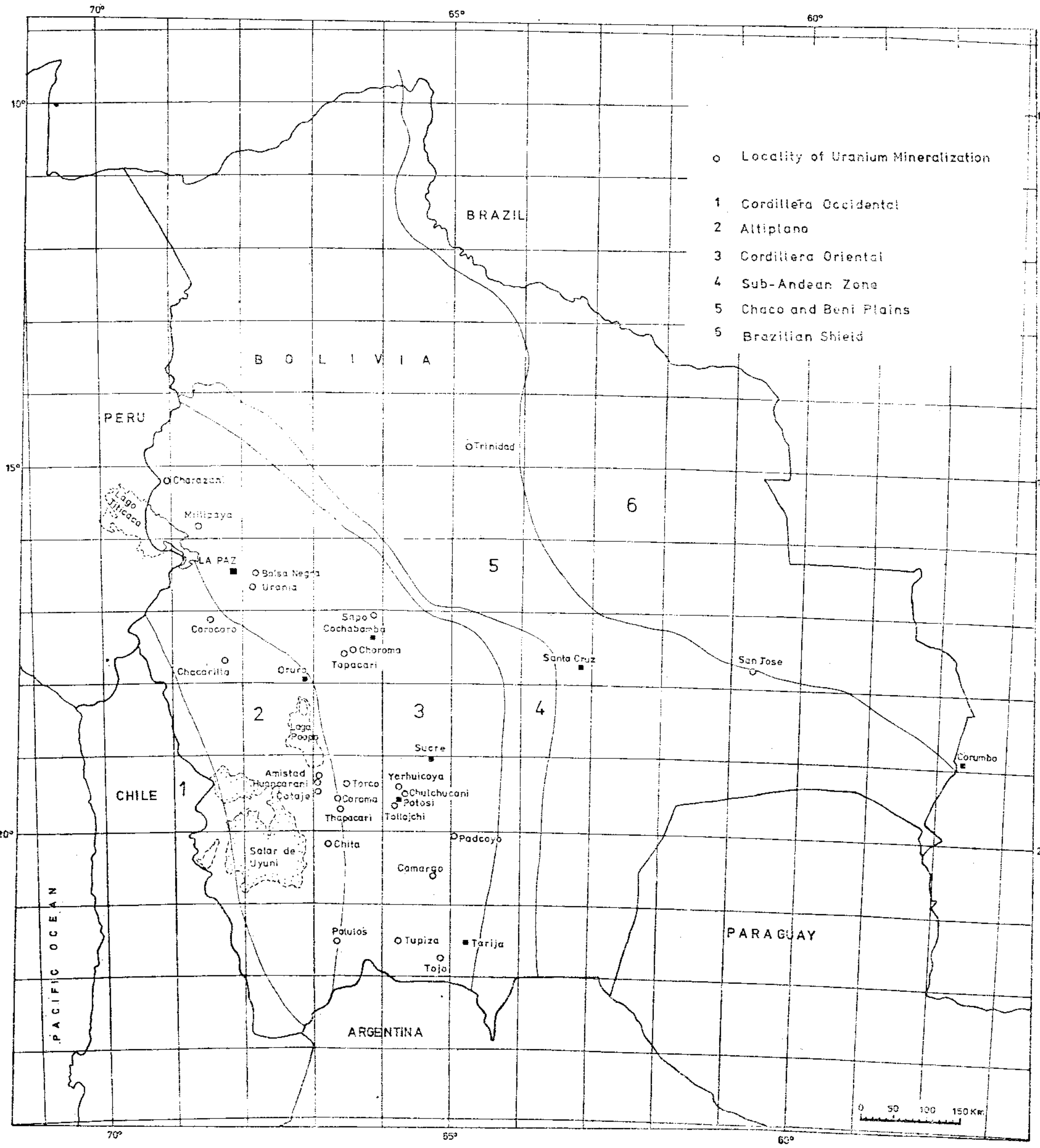

Fig. 4 Map showing the location of uranium mineralization

in the Ordovician formations in the Robore-San Jose area.

6.2. Distribution of Uranium Deposits and Anomalies

The localities of uranium occurrences are shown in the map (Fig. 4), and the names of areas and deposits or anomalies are given in the following.

A) Altiplano Zone
- 1) Sevaruyo area
  - (1) Cotaje Mine
  - (2) Corpus Cristi anomaly
  - (3) Huancarani anomaly
  - (4) Amistad Mine
  - (5) Tholapalca anomaly
  - (6) Los Diques anomaly
  - (7) Asuncion anomaly
  - (8) Coroma anomaly.
  - (9) Calera anomaly
  - (10) Larco anomaly
- 2) Chacarilla-Corocoro area
  - (1) Chacarilla anomaly*
  - (2) Corocoro anomaly
- 3) Lipez area
  - (1) Cerillos anomaly*

B) Cordillera Oriental Zone
- 1) Potosi area
  - (1) Yarhuicoya Mine
  - (2) Esperanza anomaly
  - (3) Chulchucani anomaly
  - (4) Padcoyo anomaly
  - (5) Tollojchi anomaly
- 2) Cochabamba area
  - (1) Sapo anomaly
  - (2) Choroma anomaly
  - (3) Independencia anomaly
  - (4) La Vina anomaly
- 3) Illimani area
  - (1) Urania Mine
  - (2) Bolsa Negra Mine
- 4) Charazani-Millipaya area
  - (1) Lunlaya anomaly
  - (2) Kohuila anomaly
  - (3) Incognita anomaly
  - (4) Nuevo anomaly
- 5) Tupiza area
  - (1) Tupiza anomaly*

C) Eastern Plain Area
  - (1) Robore-San Jose anomaly*

6.3. Relation to Other Metallic Ore Deposits

Considerable number of uranium deposits or anomalies in Bolivia have been formed in close connection with the formation of other metallic ore deposits.

The uranium was deposited contemporaneously with cobalt and copper in the Cretaceous sandstone, and with copper in the Tertiary red beds. Similar association of elements is also found in the deposits which were formed by supergene weathering of these deposits.

In the hydrothermal deposits, the uranium minerals are associated with Ni, Co, Cu sulfides in the Yarhuicoya mine, with W, Sn, Zn minerals in the Urania and the Bolsa Negra mines, with Co and Au minerals in Millipaya, and with Cu, Pb sulfides in Cohuila.

Majority of uranium deposits in the Sevaruyo area were formed by reprecipitation of uranium which has been leached from the original uraniferous acidic volcanic tuffs and ignimbrites. Primary uranium mineralization is associated with sulfides such as pyrite and galena. But most of primary ores have been leached and remineralized under the supergene environment.

6.4. Classification of Uranium Deposits

A) Chronological Classification

(1) Paleozoic	Ex. Choroma
(2) Mesozoic	Ex. Amistad
(3) Tertiary	Ex. Chacarilla
(4) Quaternary	Ex. Asuncion

B) Genetic Classification

(1) Liquid magmatic

a) Syenitic	Ex. Sapo

*Not visited locality

b) Pegmatitic Ex. Sapo
c) Alaskitic Ex. Padcoyo
(2) Hydrothermal
a) Co-Ni-Cu-U type Ex. Yarhuicoya
b) Cu-Pb-U type Ex. Charazani
c) W-Sn-U type Ex. Urania
d) Au-Cu-U type Ex. Milipaya
e) Sb-Ag-U type Ex. Tollojchi
(3) Sedimentary
a) Cu-U red bed type Ex. Chacarilla
b) Black shale type Ex. Choroma
c) Sandstone type Ex. Amistad
d) Limestone type Ex. La Vina
(4) Supegene weathering
a) Sandstone type Ex. Corocoro
b) Vein type Ex. Coroma
c) Encrustation type Ex. Asuncion
d) Calcrete type Ex. Calera

6.5. Mineralogy of Uranium Ores

Uranium and associated minerals in the uranium ores which have been identified in this study, are shown in Table 1.

Table 1. Uranium and associated minerals in uranium ores from Bolivia

Tpyes of ore deposits	Uranium minerals	Associated minerals
Liquid magmatic	pyrochlore	sodalite, barite apatite
Hydrothermal	uraninite metauranospinite zeunerite	Cu-sulfides, maltite
		Fe, Pb-sulfides
		Sb, Pb-sulfides
		wolframite+scheelite
Sedimentary	uranophane	Co-hydroxides Cu-carbonates calcite
Supergene weathering	uranophane torbernite metatorbernite betauranophane boltwoodite autunite	Cu-carbonates Cu-hydrosilicate calcite

7. Potential of Uranium Resources in Bolivia

7.1. Cordillera-Altiplano Area

Most of so far reported uranium deposits and anomalies of Bolivia are distributed in this area. Excluding the hypogene deposits, the uranium mineralization is generally confined to the shallow depth. The uranium mineralization is found in the Tertiary volcanic rocks, sedimentary rocks of Paleozoic, Mesozoic and Tertiary ages, and hydrothermal veins.

Uranium mineralization in Tertiary volcanic Rocks:

In the volcanic rocks of Tertiary age, the uranium mineralization is generally developed along fissures such as faults or joints in the form of veins or dissemination throughout the wall rocks. Although the tuffs and ignimbrites in the area are the suitable rock types for the precipitation of uranium minerals, the fact that the impermeable rocks such as shale are not intercalated in these rocks on ideal ratio, accounts for the numerous sporadic small-scaled mineralization in shallow depth in the weathered and porous rocks.

The disseminated mineralization on the relatively wide area suggests the nature of "porphyry uranium" type. But the disseminated mineralization in the shallow depth near the surface is different from that in depth in mineralogy and ore textures. The mineralization near the surface is a supergene weathering product of the hypogene syngenetic mineralization. On the genetic viewpoint, therefore, the uranium mineralization in volcanic rocks can be classified into two types: the hypogene vein or porphyry type and the supergene vein or dissemination type. The supergene vein or dissemination deposits occur independently or in association with hypogene vein or dissemination type. Independent occurrence of supergene type of uranium deposit suggests that the uranium has been probably derived from the weakly uraniferous volcanic rock through leaching by groundwater.

Above two types of deposits will be the target of uranium mineralization in this area. Discovery of the superimposition of two processes of mineralization will make sure the potentially economic uranium mineralization. Area of the hypogene mineralization even if it is very weak, will be the potential target for further prospecting.

In addition, the detailed study on the volcano-stratigraphy in Los Frailes will give significant data for the possibility of roll-type uranium mineralization in depth and the theoretical position of mineralization for further detailed exploration.

Uranium Mineralization in Tertiary Sedimentary Rocks: The Cu-U mineralization in the Tertiary red bed have been studied by AGIP and COBOEN. This type of uranium deposits has been unfortunately excluded in this study. Therefore, the opinion about the potential of this type of deposits in the Corocoro-Chacarilla can not be proposed. However, from the general features of the uranium mineralization in the red bed through the works by AGIP-COBOEN and the present authors' short observation at the Corcoro area, we want to mention a short comment on the genesis of uranium deposits in this area.

The uranium deposits are generally stratabound and restricted to the shallow depth. These features suggest that the uranium in the original very low-grade uranium formations has been leached and migrated along the beds and accumulated in certain depth as roll-type. The absence of significant uranium mineralizatization in deeper part of the formations along the same horizons is assumed to be closely related to the topography of the area and the mode of groundwater circulation.

The most obvious targets for uranium exploration in the Tertiary formations are the red bed which are assoiated with rhyolitic volcanic rocks, especially in the vicinity of granite stocks, and the area where the shale and sandstone are alternated on the ideal ratio. In addition, it is highly expected that uranium has been precipitated in the Tertiary sediments in the vicinity of the Brazilian shield.

Uranium Mineralization in Cretaceous Formations: The uranium mineralization in the Cretaceous formations is associated with copper and cobalt in sandstone. The Cretaceous formation consists nearly entirely of sandstone with the intercalation of several thin limestone beds. Supergene concentration of uranium took place just above the limestone beds. Although geological environments are not favorable for the secondary mineralization because of no intercalation of considerable number of shale beds, the presence of several limestone beds gives the opportunity for precipitation of uranium. Secondary uranium minerals are precipitated along the contact of limestone and the overlying sandstone. Therefore, the sandstone beds just above the limestone intercalations having the synclinal structure will be the most obvious target for uranium prospecting. In additon, Cretaceous sediments with intercalation of shale in sandstone which are closely associated with rhyolitic volcanic rocks will be another target for uranium exploration. The area showing the oxidizing and reducing facies is also a good target. It is also expected that the Cretaceous sediments in certain area contain uranium derived from weathering of Precambrian shield.

Uranium Mineralization in Paleozoic Formations: The Paleozoic sediments from Cambrian to Devonian consist of marine shale and sandstone with intercalation of continental red bed. They are generally less attractive target for sandstone type uranium deposits, because they contain less organic materials. But as examplified in the Esperanza deposit, the alternation of slate and quartzite, or only quartzite in shear zone are favorable place for precipitation of dissolved uranium transported by groundwater. Particularly attactive would be the areas where the uranium-bearing igneous rocks or hydrothermal veins are developed. It is also possible that uranium derived from Brazilian shield has been precipitated in the Paleozoic sediments.

Uranium Mineralization of Hydrothermal Origin: Uranium minerals and anomalies have been reported from Yarhuicoya, Millipaya, Urania, Llallaua-Catavy, and Sorpress. They are Ag-U-Co-Ni-Bi-As or Sn-W-U association. They occur in veins. It is highly expected that large number of ore deposits of this type can be found in Bolivia. As-Sb-Bi-Ag-U association recently found by us at Tollojchi is another type of hydrothermal deposits.

7.2. Other Areas

Uranium Mineralization in Sedimentary Formations: As mentioned in the previous section already, there is a high possibility that the uranium derived from the Brazilian shield has been precipitated in the sediments of Paleozoic, Mesozoic and Tertiary ages in the Subandean and the Eastern Plains.

Uranium Mineralization in Precambrian Shield: Large area of Precambrian schists and gneisses in the eastern Bolivia is a good target for regional uranium exploration. It is because there are high possibilities that the Precambrian rocks contain uraniferous conglomerates like in Witwatersrand in South Africa and Blind River in Canada. But it is questionable that heavy rainfall in the area might have leached uranium from the surface. It is also expected that uranium-bearing pegmatites are found in the area.

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볼리비아國의 우라늄鑛床과 그 潛在性

金洙鎭 · 張世文

요약 : 볼리비아國의 우라늄鑛床은 主로 Altiplano와 Cordillera Oriental에서 發見된다. Altiplano 에서는 主로 第三紀 赤色層과 火山岩에서 많은 放射能 異常帶가 發見되고 있으며 Cordillera Oriental에서는 古生代, 中生代 및 第三紀의 堆積岩類와 그리고 第三紀의 熱水鑛脈 및 閃長岩質岩에 重要한 異常帶가 나타난다. 볼리비아國에서 産出되는 우라늄鑛床에 對한 體系的인 分類가 施圖되었으며 同時에 이들 鑛床의 潛在性에 關하여 檢討되었다. 볼리비아國에서의 우라늄鑛床의 廣範한 分布와 함께 成因的 多樣性은 學術的 및 經濟的인 見地에서 地質學者들의 關心을 끌고 있다. 重要한 우라늄鑛床에 對한 硏究는 別途論文으로 發表될 豫定이다.