BOLIVIA

Geography

Bolivia is a landlocked country located in central western South America. The western part of the country is dominated by two ranges of the Andes: the Cordillera Occidental on the western flank of the high plateau (Altiplano) and the Cordillera Real (or Oriental) on the eastern flank. The northern Andes average 5486 m in elevation with the highest point being the Illimani (6458 m) near-by La Paz. The Altiplano ranges in elevation from 3658 to 4267 m and is ~129 km wide. It forms the largest basin of inland drainage in South America and contains the renowned Lake Titicaca which straddles the border with Peru.

The eastern tropical lowlands or pampas (Oriente) comprise roughly two thirds of the country, with rainforest predominating in the northern portion. An intermediate zone of valleys and basins lies between the eastern Andes and the Oriente. The lowlands of Bolivia have a humid tropical climate.

Metals are Bolivia's most important mineral resources and include tin, zinc, tungsten, antimony, silver, iron, lead and gold. Other resources include natural gas, oil, timber and hydropower [1].

Geology

General

The geology of Bolivia is determined by two main features: the Precambrian Shield in the east and the younger orogenic system of the Andes in the west (Figure 1). These comprise rocks ranging in age from Proterozoic to Pleistocene.

The Bolivian Precambrian appears to be the south-western margin of the Central Brazilian Shield and is found mainly in eastern Bolivia, although two minor occurrences are described from western Bolivia, south of Tarija and SW of La Paz.

The epeirogenic uplift of the eastern Andes occurred in Neogene times and developed two basins: one in the Andean foreland, the other in the Altiplano. The Andean foreland basin is filled with oxidized molasse type sediments, 3000–4000 m thick, derived from the Andean block and which are stratigraphically further subdivided.

The eastern basin occupying the Altiplano area is the type locality for a refined Tertiary stratigraphy consisting of ten different units that lithologically comprise clastic and chemical sediments interbedded with acid to intermediate volcanics. Apparently, the stratigraphic equivalent to the Perez Formation is in the eastern Cordillera: the Los Frailes formation consists of acid–intermediate volcanics, which in the Cotaje area are known to host uranium mineralization. Quaternary deposits cover extensive areas of the Cordilleras, the Altiplano and the eastern plains and include glacial deposits, fluvial gravels, volcanics, lacustrine sediments and saline deposits.

Much of the country has not been mapped in detail. A high ranking official in Bolivia's mining industry stated in early 2009 that "Bolivia's geological map covers just 25 per cent of its territory" [2].

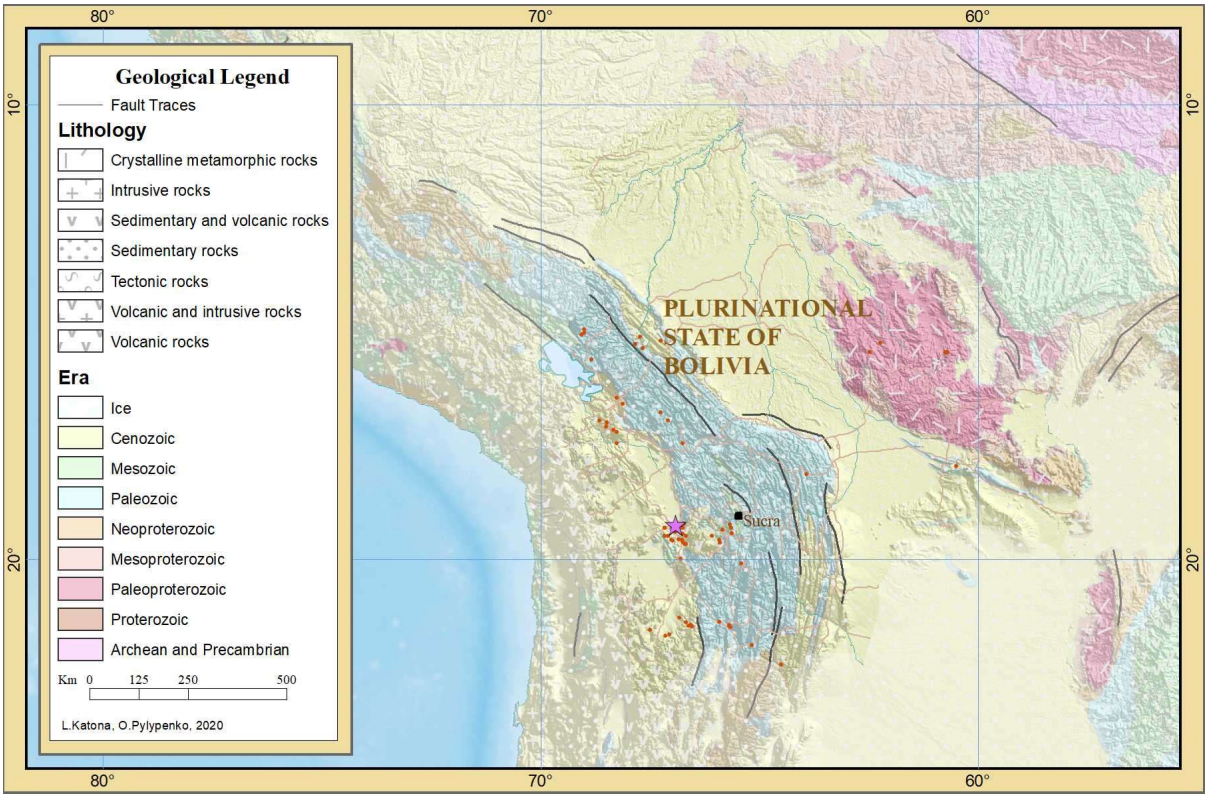

FIG. 1. Regional geological setting of Bolivia showing the distribution of selected uranium deposits and occurrences. For the general uranium deposit and uranium occurrence legend see World Uranium Geology, Exploration, Resources and Production, IAEA, 2020. A general global geological legend is shown although not all geological units necessarily occur on this particular map.

Potentially favourable uranium-bearing areas

Along with 20 other countries, Bolivia was one of the countries selected by the International Uranium Resources Evaluation Project (IUREP) for the conduct of an orientation phase. These were countries with a relatively unknown, but promising resource position.

Although Bolivia does not have identified resources of uranium, a large number of occurrences are known, several of which were noted in IUREP reports (1980 and 1985) as being potentially economically viable deposits [3, 4].

There are no known occurrences of quartz pebble conglomerates or of Proterozoic unconformity related uranium mineralization. Bolivia does, however, have large areas underlain by the Precambrian rock of the Guaporé Shield, including schists, gneisses, migmatites and granites. These rocks, which crop out in the eastern part of the country, are probably of Archaean or Lower Proterozoic age.

Disseminated deposits in igneous and metamorphic rocks

Radioactive anomalies have been found at several locations in the Cordillera de Los Frailes area, which consist of a series of sheets of volcanic material such as rhyolites, lavas, tuffs and other types of Tertiary pyroclastic rocks. The mineralization occurs in fractures or is disseminated in the host rock. The uranium is in the form of pitchblende, torbernite, coffinite and autunite and is associated with iron, manganese, arsenic and molybdenum minerals together with smoky quartz and baryte and is related to a nearby dacitic intrusive. Surface leaching and re-precipitation appear to have played a part in the formation of these occurrences. The grade is around 0.09% U_3O_8.

Locations where granitic intrusives, ranging in age from Triassic to Recent, intersect Precambrian metamorphic or Lower Palaeozoic sediments (mainly dark marine shales and sandstones) are of particular interest. The Bolivian Andes, for instance, could be investigated for mineralization, especially if it can be shown that the granites are of the 'fertile' type.

Vein occurrences are found in the central Cordillera. In the northern part of the Cordillera, several vein occurences have been found containing pitchblende and autunite associated with copper and iron mineralization. The most important finds appear to be the Charazani anomalies and the Urania mine, a former producer of tin and tungsten, located 70 km SE of La Paz. More details are available in the IUREP reports for 1980 and 1985 [3, 4].

Sandstone deposits

In the Altiplano, many radioactive anomalies have been detected within the Tertiary succession. This basin is filled with continental sediments and volcanics. The rocks are folded and covered by extensive lava flows and ignimbrites.

In the northern sector of the Altiplano, between Peru and latitude 18° S, a high frequency of radiometric anomalies was recorded around Chacarilla and Corocoro. This area contains sedimentary copper deposits of the red bed type. Uraniferous occurrences are linked to palaeochannels where the presence of organic matter played an important role in the precipitation of the uranium.

There are also anomalies in the southern sector, associated with copper and with organic material. The most important anomalies in this area occur at the Kollpani copper mine and at Ague de Castillo.

Other types of deposit in the central part of the Cordillera Oriental

Radioactive anomalies associated with phosphates, organic matter and sulphides have been detected in the Tapacari zone, hosted in Ordovician black shales [3–5].

Uranium exploration

Historical review

In 1953–1955, the Government of Bolivia, in cooperation with the US Atomic Energy Commission, conducted radiometric surveys in 70 metalliferous mining districts, as well as undertaking airborne traverses across the Brazilian Shield. Uranium mineralization was discovered at several mines, including the Siglo XX tin mine.

In 1963, the National Department of Geology, supported by the United Nations Development Programme, conducted an aerial survey across 15 000 km² of the Cordillera de los Frailes and this resulted in the identification of radiometric anomalies.

In 1974, the Bolivian Nuclear Energy Commission (COBOEN) signed a production sharing contract with AGIP of Italy to explore 50 000 km² within the main area of Tertiary red beds. COBOEN was assisted in its work by the IAEA and by France's Commissariat à l'Energie Atomique (CEA).

In the period 1970–1982, COBOEN conducted exploration which was partly supported by the IAEA (1979–1981). In 1970, uranium mineralization was discovered at Cotaje, Cordillera de los Frailes. Subsequently, exploration activities were concentrated on the Cordillera de los Frailes and within the Eastern Cordillera.

Other occurrences were found, including Tholapalca I-III, Los Diques, La Calera and Torko in the Cordillera de los Frailes, and at Yauricoya, Tollojchi, Cohuila and Cerro Sapo in the Eastern

Cordillera. Mine development at Cotaje included carrying out heap leach tests (at a pilot plant) on ~12 000 t of mineralized material. COBOEN terminated its active work in 1982.

AGIP, under a production sharing contract with COBOEN, explored four areas in Tarija, Lipez, Corocoro and San Jose de Chiquitos, covering an area totalling 48 778 km². Methods used included airborne and ground radiometrics, geological mapping and drilling. Owing to unfavourable results, the contract was terminated in late 1978.

A geological and multielement geochemical project known as the Precambrian Project was carried out jointly by the Geological Survey of Bolivia (GEOBOL) and the British Geological Survey. The project covered ~220 000 km², corresponding to nearly the entire surface exposure of the Precambrian Brazilian Shield, and included the determination of uranium in several sample media.

An IUREP Orientation Phase Mission was carried out in 1982.

In June 1983, COBOEN was dissolved and the raw material activities were divided between GEOBOL, responsible for activities from uranium exploration through to evaluation, and Bolivia's Research Institute of Mining and Metallurgy, which is responsible for mining and metallurgical activities with respect to uranium. No activities took place between 1983 and 2009.

Expenditures

Between 1974 and 1978, AGIP spent US $8 400 000 on exploration and the Government spent US $967 788 in 1977–1982. These expenditures covered airborne radiometric and other surveys as well as surface drilling programmes.

Drilling effort

AGIP drilled 18 026 m (113 holes) between 1974 and 1978, while the Government drilled another 2674 m (57 holes) in 1977–1982. The costs of these drilling programmes are included in the total exploration expenditures already noted and are not detailed separately.

Including the planned exploration for 1979, a total area of 49 600 km² was surveyed by airborne spectrometry and 40 000 km² by other methods. In addition, 22 600 m of drilling was completed. Exploration costs between 1972 and 1979 exceeded US $11 million (including US $2.5 million planned for 1979).

Drilling in the Los Frailes sector up to January 1979 indicated an estimated 50 tU resource at an average grade of 0.08% U, as reported in the 1983 Red Book [6, 7].

Recent and ongoing uranium exploration and mine development activities

The Government has confirmed plans to restart uranium exploration at the Cotaje mine in Potosí Department, according to an EFE news agency report in May 2009. The article noted that Bolivia is currently not producing or exporting uranium.

The Government is considering restarting a mine at Cotaje to produce uranium by 2010 if uranium reserves are confirmed. The Government is reportedly not directly involved in the project at the Cotaje deposit.

The IAEA announced, on 27 March 2009, its intention to collaborate with Bolivia in the exploration for, and exploitation of, uranium deposits. Uranium deposits exist in Bolivia; however, the information has been classified by the Government as 'reserved'.

In the meantime, the National Service of Geology and Mining recognized 11 sites with uranium mineralization in the Cotaje district, between the towns of Huari in Oruro and Sevaruyo in the border area between both departments and the Mulato River in Potosí. However, technical reports indicate that these deposits of uranium are not extensive, but are rather minor discrete concentrations of mineralization. The resources are unknown owing to absence of investment in the quantification work. The Servicio Nacional de Geología y Técnico de Minas, part of Bolivia's Ministry of Mines and Metallurgy, announced plans to begin work in Oruro in May 2009 [8–10].

Uranium resources

In the 1985 Red Book [7], there were no entries in the reasonably assured resource and estimated additional resource categories. However, ~50 uranium occurrences are reported as having been discovered in the geological–topographical environments of the Precambrian Shield, the Eastern Cordillera and the Altiplano, where a number of deposit types may occur. These include unconformity-related deposits, disseminated magmatic, pegmatitic and contact deposits in igneous and metamorphic rocks (related to both Precambrian and Palaeozoic intrusives and veins associated with Ni, Co, W and Sn mineralization) and sandstone hosted deposits.

Speculative resources, as reported in the 1983 Red Book [6], were estimated, according to host strata, as: Precambrian rocks (80 000 tU), Palaeozoic rocks (15 000 tU), Mesozoic rocks (7500 tU) and Tertiary rocks (5000 tU). The distribution of these speculative resources by deposit type is shown in Table 1.

TABLE 1. SPECULATIVE RESOURCES BY DEPOSIT TYPE (tU) [6]

Deposit	Speculative resource (tU)
Unconformity related	0–50 000
Disseminated (magmatite)	0–30 000
Vein (metamorphite)	50–10 000
Sandstone	0–15 000
Others (Tertiary acid volcanics)	50–15 000
Total	100–120 000

As of 1 January 2017, Bolivia reports 1 718 tU of speculative conventional resources [11].

Potential for new discoveries

The areas underlain by the Precambrian rocks of the Guaporé Massif could be investigated to ascertain their potential for hosting quartz pebble conglomerate type deposits and possibly for deposits of the unconformity-related type.

The Cretaceous and Tertiary red beds along the sub-Andean zone, as well as Palaeozoic strata and those close to the Precambrian Shield in eastern Bolivia, are also favourable targets. The Lower and Middle Palaeozoic continental sediments are probably lower priority targets.

The large expanse covered by the Tertiary volcanic sheets in the Cordillera de Los Frailes is the most prospective for mineralization of the disseminated type. In addition to this area, there are many other localities in the Bolivian Andes where granitic intrusives, ranging in age from Triassic to Recent, intersect Precambrian metamorphic and Lower Palaeozoic dark marine shales and sandstones.

Areas of Bolivia that are prospective for the existence of sandstone-hosted uranium deposits comprise the Tertiary continental sediments of the Altiplano, which are associated with extensive lava flows

and ignimbrites. Other areas of particular interest are those with known occurrences and radioactive anomalies and where the sediments are intruded by granitic stocks or associated with rhyolites, such as the western margin of the Alta Meseta de Los Frailes.

The occurrences of Carboniferous, Permian and Cretaceous red beds preserved within the Palaeozoic rocks along the eastern Altiplano and in the Cordillera Oriental (extending from the border with Peru to Argentina) are also attractive targets [5].

Uranium production

News reports in 2009 mentioned that heap leach tests had been conducted in 1974 on 12 000 t of mineralized material from the volcanic-type deposit at the Cotaje mine.

In 2009, the Government announced that the Potosí authorities' would consider restarting operations at the Cotaje mine in 2009–2010 if sufficient resources were confirmed [12].

National policies related to uranium

COBOEN (now ABEN) was established in 1969 to control the exploration for radioactive mineralization and its exploitation, treatment and marketing. Foreign agencies are allowed to operate in Bolivia by agreement with COBOEN. In 1983, COBOEN was dissolved and its responsibilities were divided between the GEOBOL and the Research Institute of Mining and Metallurgy.

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