THE EASTERN BOLIVIA MINERAL EXPLORATION PROJECT "PROYECTO PRECÁMBRICO"

by Jevan P. Berrangé

The Precambrian of eastern Brazil is now the subject of a major program of technical cooperation carried out jointly by British and Bolivian scientists. In an area until now unknown, four orogenic cycles have been identified ranging from 2000 Ma to late Precambrian in age and a new Mesozoic alkaline province has been discovered. This article presents a geological overview of the region and an account of the mineral deposits and potential, including the first regional compilation map.

Introduction

Bolivia can conveniently be divided into three major geologic-physiographic provinces. The *Andean Mobile Belt*, with its sediments, volcanics and igneous intrusions of Phanerozoic age, forms the mountainous southwestern part of the country and towers above the flat *Quaternary Alluvial Beni-Chaco Lowlands*. These give way eastward to the more rugged terrain formed by rocks of the *Precambrian Shield*. Traditionally, the Andean Mobile Belt has been the source of Bolivia's mineral wealth, including tin, silver, lead, bismuth, copper, wolfram, zinc, antimony, cadmium and gold. However, as the reserves here are rapidly being depleted it is necessary to find other sources. The Precambrian across the border in Brazil has deposits of tin, iron, manganese, gold and diamonds, and the Bolivian Shield was therefore an obvious target for an ore-search program.

Organization of the Project

The Eastern Bolivia Mineral Exploration Project, usually referred to as "Proyecto Precámbrico", is an Anglo-Bolivian Technical Cooperation Project being carried out by the Institute of Geological Sciences (IGS) on behalf of the Overseas Development Administration (ODA) in collaboration with the Servicio Geológico de Bolivia (GEOBOL). The immediate aim of the Project is to make a rapid but systematic integrated survey of the geology and mineral potential of that part of the Precambrian Brazilian Shield lying within eastern Bolivia. The long term objective is to assist in the overall development of the region by identifying areas of potentially valuable minerals and rocks. Mining such deposits could increase Bolivia's exports and foreign exchange earnings, besides boosting the present rural economy by providing employment and encouraging the building of roads and other

Figure 1: Catarata Arco Iris discovered by Proyecto Precámbrico geologists while ascending the Rio Paucerna, Serrania Huanchaca.

infrastructural development, as well as by stimulating immigration to the "Oriente" of settlers from the highlands.

At the outset the Project was divided into two zones to be surveyed in two phases. During Phase I, which ran from 1976 to 1979, reconnaissance (at 1:1 000 000 and 1:250 000) geological mapping and geochemical surveys were carried out over the Southern Zone — that portion of the Precambrian shield lying south of latitude 16°. Phase II (1980-1983) involves detailed follow-up work on promising geochemical anomalies and mineralization discovered during Phase I, and also continues the reconnaissance mapping and geochemical exploration in the Northern Zone.

The Project area is approximately 220 000 km², i.e. a fifth of the total area of Bolivia and nearly the same size as Ghana or the United Kingdom. In terms of both the size of the area being surveyed and the number of U.K. specialists involved (10-11), Proyecto Precámbrico is the largest and most ambitious ODA/IGS geological and mineral exploration project ever mounted. One of the great strengths of the Project is that it has been able to draw on the specialist services available in the various IGS units, both in the U.K. and by working visits to the field as required.

As part of its contribution, ODA has provided essentially all the equipment needed. This includes 17 Land Rovers and spare parts, canoes and outboards, camp equipment, field survey instruments, radio transceivers, microscopes, stereoscopes, drawing office and laboratory equipment. At the start of the Project a complete geochemical laboratory was set up in the Santa Cruz headquarters and equipped with a rock crusher, an atomic absorption spectrophotometer, a portable X-ray fluorescence analyser and various other instruments for colorimetric and chromatographic analysis. By also making use of the GEOBOL optical emission spectrograph in La Paz, we can carry out quantitative analysis for about 25 different elements. As of September 1982 some 23 600 samples had been analysed, work which involved more than 276 000 element determinations. A complete petrographic laboratory was also set up in Santa Cruz and equipped with rock cutting, grinding and polishing machines, microscopes, an electromagnetic separator and other equipment for routine thin-sectioning and microscopic examination of rock samples, and separation of heavy minerals for microscopic and geochemical studies.

The GEOBOL contribution has included the provision of counterpart staff including a co-director, geologists, chemists, laboratory assistants, administrators, draftsmen, secretaries, drivers and field labourers. GEOBOL also provides offices and laboratories including use of their fully equipped OES laboratory in La Paz. In addition, they supply the topographic basemaps (where available), aerial photographs and enhanced LANDSAT imagery. GEOBOL also covers running expenses both in Santa Cruz and in the field, all local transport costs including charter flying (excluding helicopters which are paid for by ODA) and certain services for the IGS team.

The results of the Project are being incorporated in 21 comprehensive reports in both English and Spanish. Some describe the geology and mineral potential of the individual map areas shown on Figure 3, and others are devoted to the mineral prospects being studied in detail during Phase II. There are also overall summary reports and one detailing the results of the age determination program. All these reports are being put on open file for consultation at IGS (London and Keyworth) and GEOBOL (La Paz and Santa Cruz). A number of scientific papers have also been published.

Working in Eastern Bolivia

At the start of the project, the Proyecto Precámbrico area was *terra incognita*; it had neither been mapped geologically nor surveyed systematically for mineral deposits, and no topographic maps were available for the Northern Zone.

Figure 2: Helicopter with aluminium canoe tied underneath, being loaded up prior to lift-off from the basecamp near the Rio Verde, Serrania Huanchaca.

Thus before geological work could commence in this zone, basemaps showing the drainage, relief and other geographic features had to be prepared. These maps are based on interpretations of enhanced LANDSAT imagery including colour composites of LANDSAT bands 4/5/7, and black-and-white bands 5 and 7, with details added from conventional aerial photography. The preliminary maps are subsequently upgraded with additional information, including geographic names, gathered in the field. These topographic basemaps are themselves a very significant contribution to development of the region and are already in demand by settlers, ranchers, pilots, prospectors, lumber companies and the National Centre for Forestry.

The Northern Zone is an area of trackless forest and swamp, only sparsely inhabited and lacking in roads. Field work here is carried out by mapping brigades consisting of one British and one Bolivian geologist, and six to ten *peóns* who in addition to their other duties cut lines, back-pack food and equipment, hunt and fish and make camp. In order to gain access to and move about within their areas the brigades use DC3's and single engine planes, helicopters, Land Rovers, ox-carts and horses, wooden launches, dugouts and aluminum canoes. Each year individual brigades have cut many tens of kilometers of "road" through the forest to give access for the Land Rovers, while many hundreds of kilometers of jungle trail are cut and surveyed on foot. The statistics tell nothing about wading through swamps, the swarms of biting insects, the sicknesses and injuries that have to be coped with, the desertion of *peóns*, the diet of monkey meat and rice, and temperatures in the shade greater than 30°C!

The most difficult and hazardous field operations involved the mapping of the Serrania Huanchaca during 1980 and 1981. This was the area explored in 1908 at the request of the Bolivian government by English surveyor, Lt. Col. Percy Harrison Fawcett. The frontier between Bolivia and Brazil at that time was uncertain and Fawcett led an expedition up the Rio Verde to its source in the Serrania Huanchaca. On his return to London, his graphic descriptions to the Royal Geographic Society of the forested "Green Hell" along the Verde and especially of the mysterious Huanchaca tableland bounded on all sides by precipitous cliffs, stimulated Sir Arthur Conan Doyle to write his celebrated book "The Lost World" where Jurassic and Cretaceous fauna and flora, including dinosaurs, were supposed to be preserved.

Geological Relationships

The Precambrian rocks of eastern Bolivia developed during four orogenic cycles (Litherland and Bloomfield, 1981). The oldest rocks are assigned to the Trans-Amazonian Cycle

(± 2000 Ma) and are represented by the Lomas Maneches Granulite Group and the bulk of the Chiquitania Gneiss Complex. These units are composed essentially of high-grade granulites and paragneisses, mostly of metasedimentary origin but including basic hypersthene granulites and enderbite granulites considered to be igneous.

The ensialic San Ignacio Cycle (<1800 - 1300 Ma) began with the deposition of the sediments now forming the San Ignacio Schist Group that is mainly represented by discrete schist

belts forming synclinal depressions of local facies variations. These schist belts are mainly composed of metapelitic schists with a variable meta-psammitic fraction, and include thin layers of graphitic schists, calc-silicates, meta-ironstones and meta-volcanics. There is also a basic/ultramafic sill-forming phase. The cycle culminated in the San Ignacio Orogeny – a regional NW-trending tectono-metamorphic event that reworked the older granulite basement and generated extensive migmatites, synkinematic G1 and post-

Figure 3: Geological Compilation Map of Eastern Bolivia.

kinematic G2 granites. In the Northern Zone these form the very extensive Pensamiento Granitoid Complex.

The *Sunsas Orogenic Cycle* (<1300-950 Ma) began with the erosion of pre-existing rocks and deposition of the molasse-like sediments assigned to the Sunsas, Vibosi and Huanchaca Groups. Subsequent deformation of these and older rocks was essentially confined to the NW-trending curvilinear Sunsas Orogenic Belt now forming the southwestern portion of the shield outcrop. Deformation was accompanied by a major phase of granitoid (G2, G3) development. The outcrop pattern of the San Ignacio Group schist belts in this Sunsas Orogenic Belt is due to overprinting by the Sunsas Orogeny. The northeastern margin of the Sunsas Orogenic Belt is formed by the tectonic Concepción and San Diablo Fronts or "straightening zones" between it and a quasi-cratonic *Marginal Zone* that only underwent moderate and localized deformation. Further toward the NE this semi-stable zone passes into the *Paraguá Craton*, a rigid stable block on which the Sunsas sediments are essentially undeformed. The close of the Sunsas Cycle marked the cratonization of the shield.

The *Rincón del Tigre Layered Igneous Complex* (± 992 Ma) is a layered sill-like pluton estimated to be between 3000 and 4600 m thick, measuring some 62 x 27 km and exposed over an area of about 720 km². It comprises a basal Ultramafic Unit (max. 3000 m) of alternating cyclic units including serpentized dunites, bronzitites, picrite, melanorite and harzburgite; a median Mafic Unit (max. 1550 m) of norite, magnetite gabbro and tholeiitic gabbro; and a topmost Felsic Unit (750 m) of granophyre. The pluton was intruded into the Marginal Zone, differentiated and then open-folded with limb dips of up to 45°.

The *Brazilian Orogenic Cycle* (<950-500 Ma) is represented in Bolivia by unmetamorphosed sequences on the eastern and southern margins of the shield. In the east, geosynclinal sediments of the *Boqui Group* that is an extension of the Paraguay-Araguaia belt in Brazil (Almeida et al., 1976), comprise conglomerates arkoses, shales, limestones, greywackes, banded ironstones and cherts. These were locally folded about N-trending axes, and are unconformably overlain by the *Murciélagos Group* of reef and non-reef limestones of probable Cambrian age. On the southern flank of the shield the miogeosynclinal dolomitic limestones, sandstones and shales of *Tucavaca Group* are confined to a WNW-trending fault-controlled basin (aulacogen). The unconformably overlies rocks of the Sunsas Cycle in the west and the Boqui Group in the east.

Mesozoic igneous activity in eastern Bolivia is represented by three separate alkaline complexes. These line up along a meganelement that is a continuation of the Paraguay Belt regarded as a failed arm of a triple point related to the break-up of the South America-Africa plate (Fletcher and Litherland, 1981).

The volcano-plutonic *Candelaria Alkaline Complex* (116-90 Ma) occurs alongside the E-trending Mercedes Rift. It comprises a nepheline syenite pluton and a separate body formed mainly of nordmarkite and trachyte with minor foyaite and phonolite phases. Outliers of red continental-type Cretaceous sandstones outcrop nearby. The *El Tigre Alkaline Complex* is a coarse-grained nordmarkite pluton, some 42 km in diameter, showing prominent cumulate layering and current bedding.

The *Velasco Alkaline Complex* (146-134 Ma) is by far the largest of the three complexes. It consists of an early volcanic suite of agglomerates, welded and brecciated tuffs and porphyritic trachyte flows, and a series of 14 interfering circular, ring and elliptical plutons including foyaite, pulaskite, nordmarkite, quartz syenite, riebeckite granite and biotite granite as the main rock types (Fletcher and Litherland, 1981). These plutons cover some 440 km² and occur on a NE-trending lineament, at the NE end of which lies a carbonatitic complex – Cerro Manomó – originally

described by Fletcher et al. (1981). More recent detailed mapping shows that Cerro Manomó is formed of a highly brecciated and intensely silicified paragneiss core surrounded by a less highly altered aureole. These are all cut by an irregular network of carbonatitic dykes and sheets that have also undergone pervasive multiphase hydrothermal alteration causing destruction of all the carbonate minerals, intense silicification, and accompanying liberation and deposition of a range of minerals described below. Minor amounts of apatite rock, agglomerates and lavas also occur.

Numerous upstanding quartz breccia reefs cut the basement complex and the rocks of the Velasco Alkaline Complex around which they are particularly common. They are probably of Tertiary age and consanguineous with the silicification of Cerro Manomó. The Tertiary history is also marked by three to four successive cycles of lateritization

Mineralization

Numerous mineral showings and geochemical anomalies have been found during the course of Proyecto Precámbrico, and although only a small fraction of these can be expected to eventually develop into economic mineral deposits, a number of them look very promising and warrant further work. In addition to the mineral prospects actually discovered by Proyecto Precámbrico there are other important mineral fields that have been known for some time and which in the past few years have begun to be worked on a small scale. This renewed interest is largely a direct result of the interest in the mineral potential of the Precambrian shield generated by the Project. The most important mineralized areas in the region are shown on the map and are described in the following.

Cerro Manomó was first identified on satellite imagery by IGS geologists in 1976 prior to the start of the Project and was a target for investigations early in Phase I. Anomalous concentrations of niobium, vanadium, rare earth elements, scandium, thorium, uranium, barium and phosphate were found in its soils and rocks. This stimulated detailed follow-up work in Phase II that included the construction of a contoured 1:10000 scale topographic basemap of the mountain, detailed geological mapping, geochemical sampling of soils and rocks, pitting, ratemeter and spectrometer surveys, and thousands of chemical analyses of the samples collected.

This work has proved the existence, on the Eastern Spur, of a body of radioactive apatite rock. This measures some 20 x 115 m at the surface with a minimum measured reserve, based on pitting, of 58000 metric tons. It has an average grade of 3.5% P₂O₅ (range 1.5-22%); 0.1% U (range 0.01-0.57%) and 0.2% Th (range 0.05-0.84%). The three-dimensional form of the apatite rock body is not known and drilling is now required to determine this and the total tonnage and grade of the ore. Although too high in iron to be

Figure 4: Rio Verde basecamp on the Serrania Huanchaca.

suitable for the manufacture of superphosphate, the rock could be used as a small-scale source of fused soda phosphate fertilizer. Elsewhere on Cerro Manomó enrichment in niobium and rare earth elements has been confirmed but at levels too low to be of economic interest.

The *Rincón del Tigre Igneous Complex* was recognized early on as a potentially favourable target for asbestos, nickel, copper, and platinum mineralization and was therefore studied in some detail during Phase I. The results of the geochemical surveys were sufficiently encouraging to warrant follow-up work during Phase II, and detailed mapping, trenching and pitting, geochemical and geophysical surveys were carried out on surveyed grids cut across the anomalous areas.

Although chromite and asbestos have been found in the Rincón rocks, results to date suggest that these minerals do not occur in sufficient concentrations to be of economic interest. However, pitting and sampling in the Cerro Pelon sector of the complex has led to the first documented discovery of garnieritic nickel in Bolivia. The nickel deposits average 1.0% over a meter thickness, totalling approximately 50 000 tonnes of metallic nickel. This is insufficient to mine, but as only 7 km² of approximately 550 km² underlain by ultramafic rocks in the Rincón complex have been systematically prospected, the potential for the discovery of further nickel is considered to be relatively high.

Detailed studies of the reconnaissance geochemical anomalies have resulted in the discovery of widespread disseminated copper mineralization in the magnetite gabbros forming part of the mafic unit of the complex, with local concentrations of between 1.5% and 2.0% copper. Loose blocks of massive chalcocite-cuprite-malachite-native copper have also been found. The results are very encouraging, and drilling may be carried out in 1983.

The *Ascensión de Guarayos Tinfield* was found by geochemical prospecting techniques during Phase II and is the first discovery of tin mineralization in Precambrian rocks of eastern Bolivia. The cassiterite is derived from the weathering of pegmatite dykes and is concentrated in the gravel fraction of the alluvium within nearby canyons. Three shallow drill holes have been put down in the canyons and in one of them a mean of 600 g of SnO₂ per m³ has been found, with up to almost 4 000 g of SnO₂ per m³ in the basal two meters of sandy gravel. These are very interesting values comparable with grades of alluvial cassiterite mined in Brazil and Malaysia. Accordingly, a drilling program designed to evaluate the tinfield has been drawn up and may be carried out during 1983.

San José de Chiquitos: Regional geological mapping and geochemical prospecting in this area during Phase I resulted in the discovery of copper-lead-zinc anomalies in soils and stream sediments. The geological environment in which these anomalies occur is very favourable and is analogous to other Precambrian sedimentary and volcano-sedimentary stratiform ores such as the copper and lead-zinc deposits of the Katangide-Damaride Belt of central and southwestern Africa. Follow-up surveys in the San José area during Phase II verified these interesting base-metal anomalies and located zones of alteration and sulphide mineralization. Further detailed work has been recommended.

San Javier/San Ramón goldfield: Alluvial gold, discovered in the Santa Rosa de la Mina area to the south of San Javier, was mined sporadically from 1888 to the mid-1950s. At one time over 7 000 people were employed. Interest has again been kindled by Proyecto Precámbrico and the relatively high price of gold. A small gold rush started early in 1982 with the rediscovery of good placer gold values in a creek east of San Ramón. During the first three weeks of the rush about 13 ounces of gold were won by local cooperatives using very primitive techniques. The gold originates in quartz veins and occurs in all sizes from minute flakes to nuggets weighing up

Figure 5: Manhandling heavily laden aluminium canoe up rapids on the Rio Negro.

to 53.5 g. A lot of gold remains to be won from the area which is suitable for small placer operations. Given good values these could help finance a search for economic concentrations of bedrock gold in the area, which also has base metal possibilities.

Serrania San Simón goldfield: Gold is rumoured to have been mined in Serrania San Simón by the Incas, but the first authenticated mining was by the Jesuits over a period of 30-40 years in the 18th Century. Relics of their workings suggest that they won a great deal of gold, both from placers and from the 'mother lode'. Then from 1905-1920 Saturnino Saucedo, the local baron of the area who commanded about 80 slaves, and his associate Juan Boyd supervised both alluvial and hardrock mining operations. The operation came to a halt when Boyd journeyed to the USA on the pretext of buying extra mining equipment and absconded with a liter bottle of gold.

Two separate small operations were conducted 1944 to 1945 and 1962 to 1964, and as always there are numerous tales of the discovery and loss of great riches. A detailed field assessment in 1974 concluded that the auriferous quartz veins

Figure 6: Bolivian geologist collecting a geochemical stream sediment sample from the Rio Tarvo.

in one sector constitute an exploitable zone over 3 x 1 500 m carrying an average of two to three grams per tonne, which assuming a minimum depth of 100 m was estimated to represent a reserve of 57 870 troy ounces of gold. The San Simón goldfield is being studied in detail by Proyecto Precámbrico geologists and there seems little doubt that much gold still remains to be won.

The San Ignacio and Concepción pegmatite fields: The complex pegmatites south of San Ignacio and Concepción were originally mined for muscovite and beryl but production had ceased by 1968. However, in 1980 interest in these pegmatite fields was renewed and several of the mines were reopened by local small miners in order to extract tantalite (price in 1981 around \$85/lb) and columbite. Project geologists have helped the local miners by providing encouragement and advice and have themselves carried out detailed surveys aimed at finding tantalite-columbite pegmatites in the area. Four discrete geochemical tantalite anomalies (range 130-560 ppm Ta) not associated with known pegmatites have been found in the San Ignacio area. Further detailed prospecting for tantalite-bearing pegmatites is indicated by these encouraging results.

La Gaiba-Anai rock crystal and amethyst field: In the eastern extremity of the Project area, near the border with Brazil, extensive deposits of quartz, amethyst and citrine occur in silicified north-trending fault zones cutting Cambrian limestones. This semiprecious gemfield is said to have been first discovered in about 1960 and has yielded unknown quantities of gem material over the past 20 years, though it is only since 1980 that the deposits have been exploited on a large scale. Amethyst samples are of very high quality, and given the right conditions it should be possible to develop this gemfield and start a local cutting and polishing industry.

Training

Not all our effort has been put into bush-bashing and looking for mineral deposits: the training of Bolivian counterpart staff has been another important aspect of our work. At the start of the Project formal courses were given by the IGS experts on a wide range of geological subjects. As part of our training program two illustrated booklets on structural geology and metamorphic petrology were prepared in Spanish for publication and issue to GEOBOL geologists.

English language training has also been provided in Santa Cruz, and four GEOBOL geologists with sufficient command of English have been sent to the UK to take specialist courses. Perhaps most valuable of all is the in-service training all GEOBOL staff have received while working alongside their ODA colleagues, both in the field and in the laboratories and drawing office. In ODA, where training is considered to be a very important part of technical cooperation projects, the philosophy is: "Give a man a fish and you feed him for a day. Teach him to fish and you feed him for a lifetime".

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