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# Lower Paleozoic gold occurrences in the 'Eastern Cordillera' of Southern Peru and Northern Bolivia: A genetic model

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ABSTRACT: The mines and gold occurrences of the eastern cordillera of the South Peru and North Bolivia are generally hosted by lower Paleozoic (middle to upper Ordovician) shales and sandstones. Mineralizations consist in gold quartz veins, generally of reduced thickness (< 50 cm) and lengths from a few tens to several hundreds of meters. The veins are generally bedding parallel but also cut the beds. They consist mainly of quartz with small amount of chlorite, arsenopyrite, pyrite, pyrrhotite; Gold occurs principally as free flakes within the quartz, in small inclusions or filling small cracks in the sulfides. The gold contents are of about 10 to 20 g/t. Sulfide layers formed principally by arsenopyrite and pyrrhotite with variable but generally low gold content (about 1 g/t) are also present in the serie and form bedding parallel lens shaped outcrops. The gold is characterized by a high grade of fineness; in part, it corresponds to a locally remobilized gold whereas early gold is included in the sulfides (pyrrhotite) and associated with a paragenesis with Hg, Bi, Te.

In most cases the mineralizations are deformed by the Variscan tectonic, although in a few cases, the mineralizations may be younger.The observations, in particular in the Rinconada area, agree with a model where the gold is introduced in the sedimentary pile by submarine hydrothermal activity and sea floor sulfide accumulations.

## 1 INTRODUCTION

The gold mineralizations of the "Eastern Cordillera" extend on about 300 km from the north of the town of Cuzco in Peru, to the east of the town of La Paz in Bolivia (Figure 1). In the peruvian part of the belt, mines and gold occurrences are located in several groups, namely near Cuzco (Cordillera de Vilcabamba), near Ocongate (mina Manco Capac), as a more or less continuous zone along the rio Inambari (mines of Candelaria, Media Naranja, Benditani, Santo Domingo, Sandia) and in the area of Ananea near the frontier with Bolivia (Carabarcuna, La Rinconada, Tres Amigos, Gavilan de Oro, Untuca, Figure 2).

In Bolivia, gold mineralizations occur in the Cordillera de Apolobamba (area Suches-Cerro Palomani), in the headers of the rio Pelechuco (mines of Altarani, Turcos, Lavanderani) and in the headers of the rio Amalanta (mines of Liruni, Huarachani, Sunchuli. Figure 3). In the area of Yani, are known the occurrences and mines of Aucapata, Santa Barbara, Lacayani, Silusani, La Suerta, Fortaleza, Figure 4). Near La Paz, gold occurrences are located at Pacollo, Olla de Oro, Rosario.

In the southern part of Bolivia, gold quartz-veins with stibnite are known in the ordovician rocks near Tupiza (figure 1).

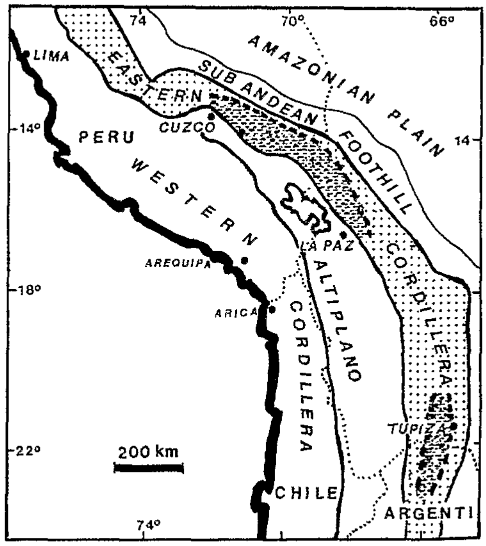


Fig. 1 Location of the Paleozoic gold province in the Eastern Cordillera of the central Andes (Southern Peru and Bolivia).

These mineralizations are in part source of the gold of the placers which extend in fluvio-glacial and flu-

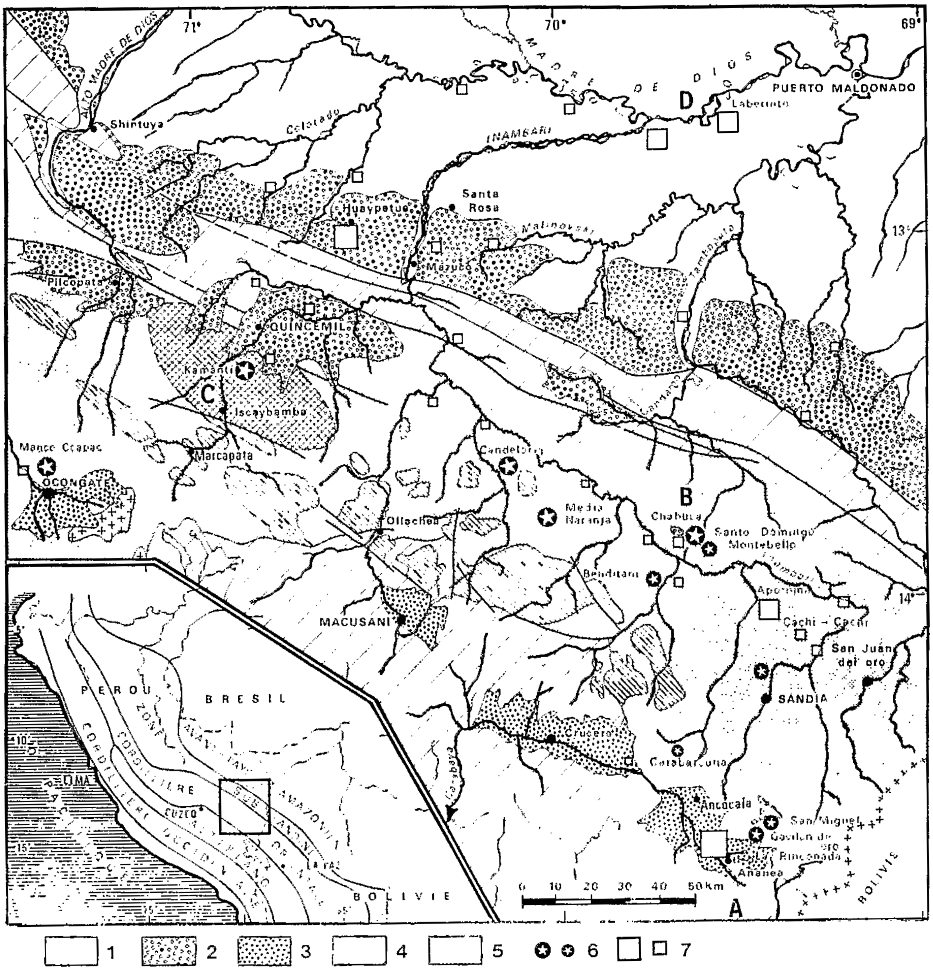


Fig.2 Location of gold occurrences in the Southeastern Peru; 1: alluvial plain of Madre de Dios; 2: Neogene detrital deposits from the intermontane basins and Amazonian piedmont; 3: Neogene basins of the Altiplano slope of the Eastern Cordillera; 4: post Devonian outcrops; 5: Ordovician to Devonian series; 6: Rock hosted gold occurrences; 7: main gold placers.

vial deposits in the SW slope of the cordillera (San Antonio de Poto in Peru, Suches in Bolivia) and in fluvial materials in the NE, Amazonian slope of the cordillera (Tipuani-Mapiri).

This brief review of the gold occurrences of the eastern Cordillera in the central Andes of Peru and Bolivia is principally based on informations from Soler et al., 1986, Ahlfeld et Scheider-Scherbina, 1964; if some of the mines are known since Incaic times, (Berthelot, 1978), it may be noted that most of the occurrences are located near the line of crest of the cordillera whereas in the amazonian slope, an important part of the area is the covered by the tropical rain-forest and is not accurately explored.

All this primary gold occurrences are hosted by lower Paleozoic rocks which consist of a thick (9000 m) serie of detrital sediments mainly shales and sandstones. They were deposited in an extensive intercontinental tough located between the Brazilian shield in the eastern side and the Arequipa massif in the western side. Incipient rifting appears to have accompanied the subsidence and the accumulation of the thick turbiditic sequence. Rifting may be accompanied by basic to intermediate volcanism. The rifting process no produced the development of oceanic crust and changed to a compressional regime, resulting in the closure of the aborted rift. Marine sedimentation continued during up to late Devonian when occurred an intense compressive deformation (Variscan o Eohercynian tectonic of Laubacher, 1978).

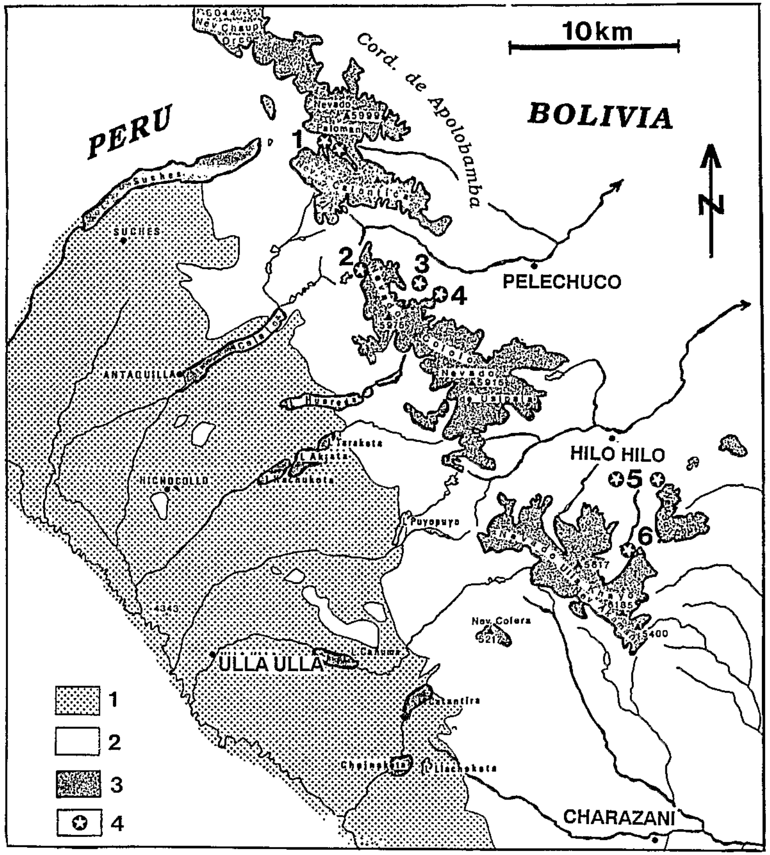


Fig. 3 Location of gold occurrences in northern Bolivia; 1: Plio-Quaternary outcrops; 2: Mesozoic and Paleozoic outcrops; 3: Snow caps. Stars = in rock gold occurrences of 1: Suches, 2: Altarani, 3: Turcos, 4: Lavandarani; 5: Hilo Hilo, 6: Liruni.

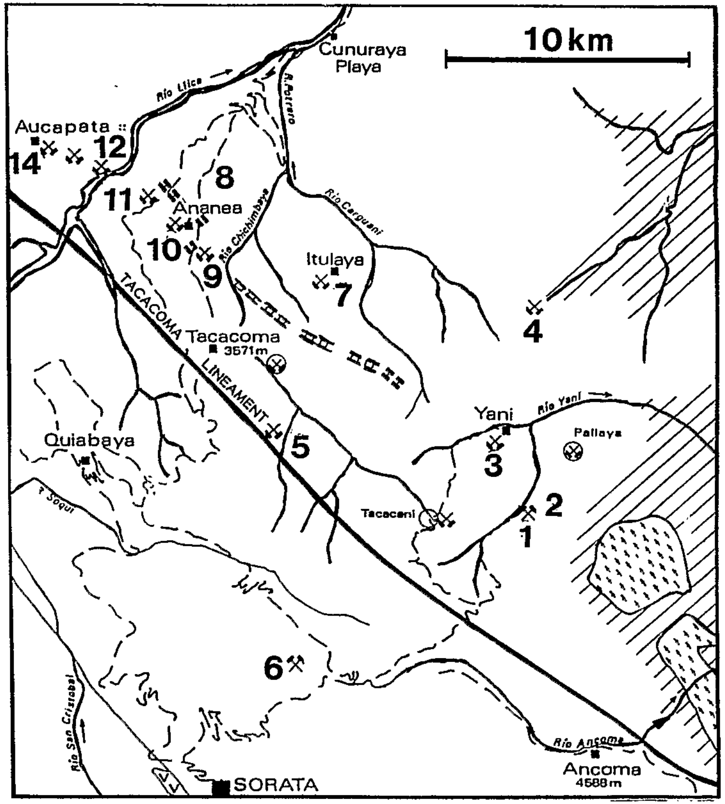


Fig. 4 Gold mineralizations of the area of Yani; 1: mine La Suerte, 2: Fortaleza, 3: Trinidad, 4: Santo Domingo, 5: San Jorge, 6: Progresiva, 7: Itulaya, 8: Collabamba, 9: Sillusani, 10: Ananea, 11: Lacayani, 12: mina Maria, 13: Santa Barbara, 14: Aucapata. Heavy hatched line = outcrops of stratiform sulfide layers. Tacacoma lineament limits lower Paleozoic (NE) from Silurian outcrops. Crossed = Yani-Zongo granite. (from Tilst, 1985)

## 2 GOLD MINERALIZATIONS

Two main types are presents: 1 gold quartz veins, which are known since incaic times and are the only one presently worked and, 2 massive sulfides layers (mainly pyrrhotite and arsenopyrite) with minor contain of gold.

### 2.1 La Rinconada area

In the area of La Rinconada both types are present. The mineralizations are located in a detrital sequence of about 1000 m thick, with shales and sandstones, which corresponds to distal input from a mature continent located in the west (Arequipa massif). Some anoxic conditions are shown by the presence of graphitic matter. The sandstones which are fine grained (200-400 µm), consist mainly of quartz with rare fragments of plagioclases and muscovites; trace minerals are small rounded zircon (50 µm), green and black tourmaline; also are present monazite, anatase and sphene. Beds of shale consist of muscovite (40 µm) sometimes chloritized in a fine matrix of quartz and sericite. A few white to grey layers of 30 cm to 1 m thick, of fine grained reworked cinerites are interbedded in low proportion and may represent a distal volcanic activity during the sedimentation.

Tectonic: the area was intensely deformed by big recumbent isoclinal folds with penetrative cleavage and thrusting; The main deformation occurred in the lower Carboniferous. Two tectonics units are distinguished (Figure 5): In the first one (normal thrusted unit) the beds are in normal position, and strike E-W with dips of 15-20°S whereas the main cleavage is oriented E-W with a dip ranging from 10 to 30°N. This unit suffered a lateral displacement toward the south, which amplitude is not presently known, but which passes several kilometers; it is limited by a thrust fault with tectonic breccias more than ten meters thick. The second tectonic unit (imbricated and inverted unit, UEFI) consists of groups of beds, in normal o inverted stratigraphic position, separated by low dipping thrust faults; frequently the contacts are injected by white brecciaous quartz. This unit forms a tectonic sole below the thrusted unit.

This major tectonic episode was followed by a minor deformation with E-W folding which locally in accompanied by a crenulation cleavage super imposed on the first major cleavage. Late normal and wrench faults cut all the folded structures.

The rocks show low grade metamorphism and the sandstones are crystalized to quartzites.

The gold quartz veins

The gold quartz veins which are called "mantos" when they are low dipping, are generally parallel to the bedding planes of the shales. The thickness is generally between a 2 to 25 cm and they extend from several meters to several hundred of meters. They show a laminated aspect by the presence of fine (millimetric) intercalations of mica (chlorite) and sometimes they include fragments of the wall rock, whose orientation is not modified. Also are observed veins, that cut the

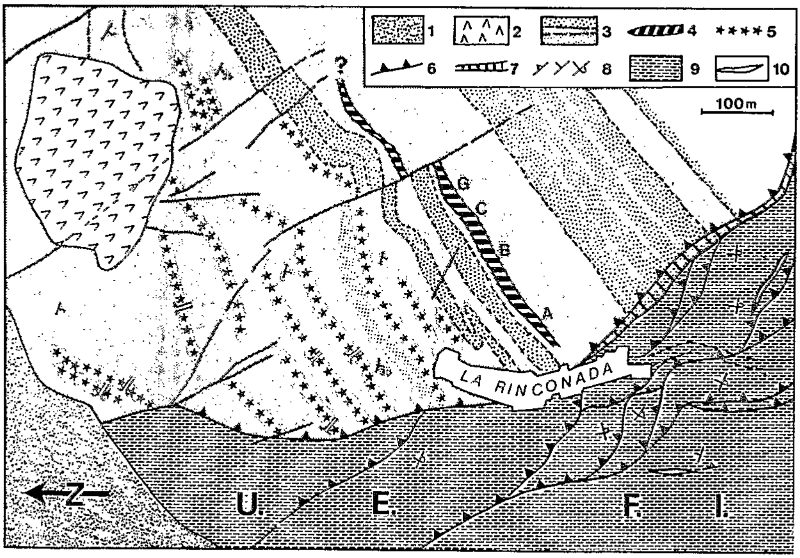


Fig. 5 Geological map of la Rinconada area; 1: glacier, 2: scree; 3: shales and quartzites of the overthrusting unit; 4: massive sulfide layer; 5: main gold quartz veins (mantos); 6: thrust; 7 tectonic breccia; 8: shales and quartzites of the imbricated and inverted unit (UEFI).

beds and may connect two mantos.

All the mantos are located in the thrusted unit (Figure 5) and the majority is located in the lower part of the stratigraphic column in relation with the sulfide layer. Structural observations indicate that the mantos suffered the major folding event.

The quartz of the gold veins shows a specific aspect which permits to distinguish it from others type of quartz such as tectonic exsudation or late tensional gashes filling.

The gold veins consist mostly of quartz with a greyblue color and of minor amounts of chlorite, pyrite, pyrrhotite and arsenopyrite; galena and chalcopyrite form dispersed small grains (30-40 µm). Elsewhere within the veins minor amounts of epidote are occasionally present.

Gold occurs as coarse (up to several millimeters) free patches filling microfractures between the quartz grains, as isolated flakes at the border of the sulfides grains or in inclusions in the sulfides.

Massive sulfides mineralization

This type of mineralization is not so known than the quartz vein type. In the Rinconada area (Figure 5), the sulfide layer crops out on about 300 m along strike. It forms a layer of about 2 m thick within the shales, oriented E-W and with an average dipping of 30° S; it consists essentially in a central arsenopyrite rich facies sandwiched by two pyrrhotite rich facies; these in turn grade into black "chloritites" facies with abundant pyrrhotite. These different facies are organized in flat shaped lenses which lay parallel to the general bedding of the shales (figure 6).

The central arsenopyrite facies consists of crystals of arsenopyrite up to 2 mm, cimented by chlorite with a part of about 15% of detrital quartz and muscovite. In a few tens of centimeters, the facies changes from very abundant crystals in few matrix to parts with needle shaped arsenopyrite crystals dispersed within the matrix; in this case the content of As decreases from 30% to 17%; locally in the lower part, some centimetric flat lenses of chloritic shale are present that contain fine laminations of arsenopyrite.

The lower sulfide facies contains essentially pyrrhotite, sometimes transformed in pyrite, and minor amount of chalcopyrite. The pyrrhotite, even when forming large stretch shows an aggregate structure with engrained crystals of about 400 µm; it includes relicts of detrital quartz and, sporadically muscovites. Isolated millimetric crystals of arsenopyrite appear to develop at the expense of the pyrrhotite.

The lower sulfide facies present a complex organization with several "sub-facies" which differ one another by the distribution and the amount of sulfides. In its lower part, black shales dominate with abundant disseminated pyrrhotite which grade upward to chloritites always with pyrrhotite. The presence of small ovoidal pieces of schist included by fine lamination of pyrrhotite suggest sedimentary reworking.

The upper sulfide facies (hanging wall) is characterized by the same abundance of pyrrhotite as in the lower sulfide facies. However crystals of arsenopyrite are more abundant. The change to the shales of hanging wall rocks is transitional with an intermediate level of fine sandstone with abundant dessiminated pyrite and pyrrhotite. In turn, the amount of sulfides decreases rapidly upward.

The footwall of the sulfide layer is marked by a

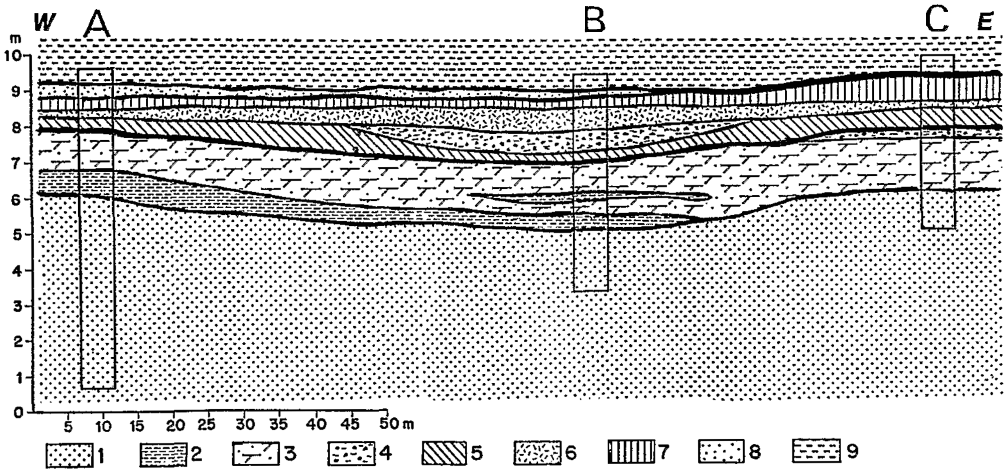


Fig. 6 Lens shaped aspect of the massive sulfide mineralization. 1: footwall quartzite, 2: shales, 3: chloritites, 4: black shales with pyrrhotite, 5: pyrrhotite layer, 6: massive arsenopyrite layer, 7: pyrrhotite layer (hanging wall), 8: fine sandstone, 9 : hanging wall host rock (shales).

quartzitic level of about 6 m thick. Locally, a strong alteration occurs in the footwall rocks; the transformed zone extends on about 30 m and affects particularly a quartzitic level of about 6 m thick interstratified within the shales. In the quartzite, numerous connected veinlets of quartz form a stockwork; also irregular pockets of several tens of centimeters of grey-bluish quartz (the same as the gold vein quartz) with chlorite and sulfides are present . From place to place, the original rock is transformed to quartz, chlorite, pyrrhotite and arsenopyrite. We interpret these modifications as the indication of a channelway zone where hydrothermal solution flowed upward.

In the whole normal thrust unit (figure 5) veinlets with quartz, chlorite, pyrite, pyrrhotite and arsenopyrite are present. At the border of some of these veinlets, crystals of arsenopyrite up to 1 cm are disseminated in the shales. Infra-millimetric to millimetric crystals of arsenopyrite and pyrrhotite can also be widely disseminated in some level of shales. They indicate diffuse circulation within permeable levels.

2.2 Yani area

In the Yani area, (figure 4) the gold mineralization are hosted in rocks of middle to upper Ordovician age which consist of fine black shales, locally rich in graptolitic fauna. In the lower part of the sequence, sills and flows of spillitic lavas are present. The spillitized rocks, essentially composed of albite (about 80%) and chlorite (10-20%), show pillow shapes with white altered borders and black-green inner part. Associated with the lava is note worthy the presence

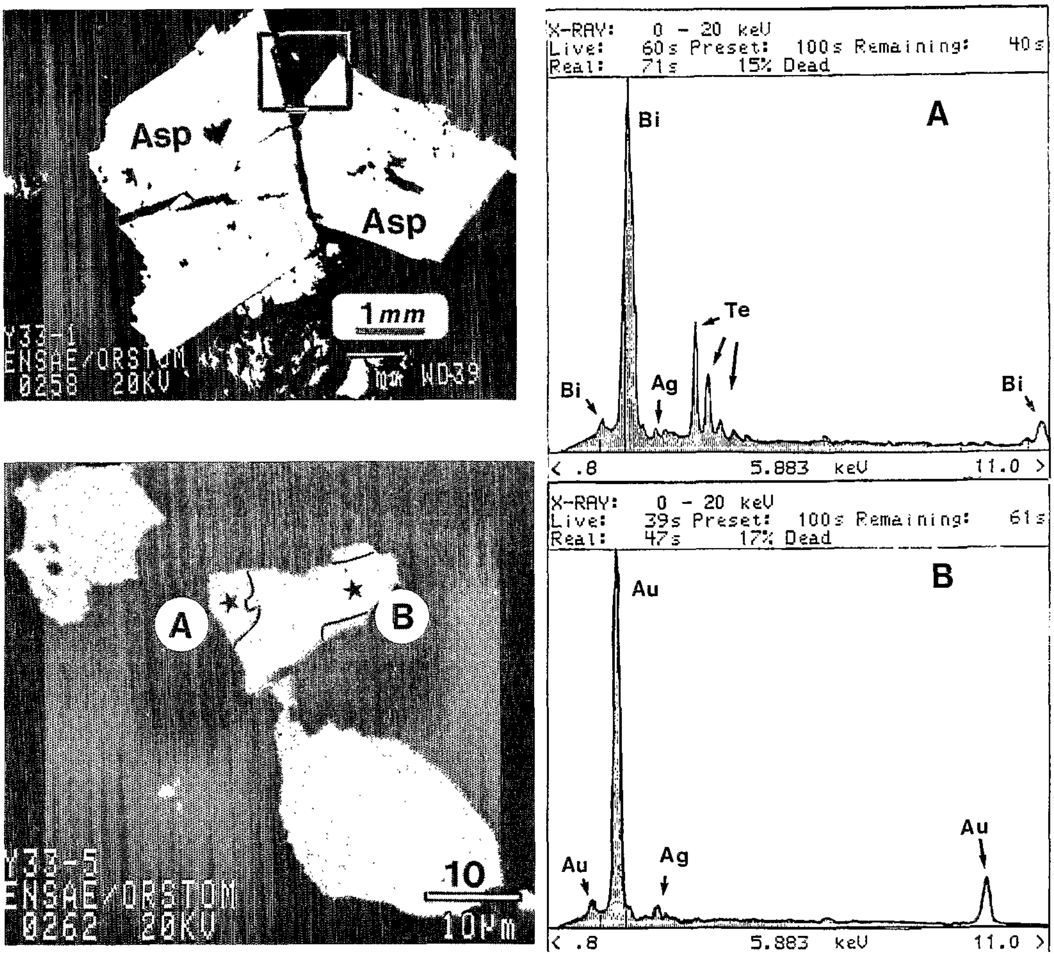


Fig. 7 Gold inclusions in and at the border of large crystals of arsenopyrite (Asp, photo 1). Gold (white) is associated with Bi and Te minerals (grey, photo 2). A & B stars: location of the analysis.

of disseminated pyrite in the neighbouring black shales. In the SE part of the Yani area, the Zongo leucogranite produced a thermal metamorphism with presence of sillimanite, K-feldspath, muscovite, andalusite and biotite.

The gold mineralizations in the area of Yani consist in veins of some centimeters to 1 m thick and several hundreds meters long. They follow the bedding planes or cut them as in the other parts of the Cordillera. They appear to be preferentially located in the low grade metamorphic rocks and absent in the high grade aureole.

The veins consist mostly of quartz with minor amounts of chlorite, albite, arsenopyrite and pyrite, pyrrhotite. Traces of scheelite, chalcopyrite, galena are present . Gold appears as isolated grains from several microns to several millimeters in the quartz or in small cracks in the sulfides. Part of the gold may be included in the sulfides as suggested by content of up to 2 g/t in separated grains of pyrite and arsenopyrite indicated by NA analysis. Microprobe analysis indicate also the presence of "invisible" gold up to 100 ppm in the sulfides, mostly in the pyrrhotites of the sulfide layers.

The gold is very pure with fineness of more than 880‰. The minor changes in Au and Ag contents (fineness up to 975‰) which exist between the gold grains from rock slabs sometimes located a few cm one another, do not appear to be related to any chronological or textural differences. The fact that the gold grains are included in sulfides or free in the quartz is not related to a systematic change of composition.

Microprobe analysis for trace elements in gold show the presence of small amount of Cu (0.01 to 0.5%), Fe (0.01 to 0.2%). As is detected, but is not systematically present; grade may by up to 0.24%, but is mostly between 0.01 and 0.03%. Bi is detected punctually in some spots and appears to correspond to inclusions smaller than the beam of the microprobe. The presence of small grains with bismuth and tellure close to small grains of gold (Figure 7), as, also, the presence of traces of Hg in the gold from the sulfide layers may traduce the influence of volcanic influence in the hydrothermal solutions in the early stages of the mineralization wheareas the coarse (and pure) gold in the quartz veins reflects local reworking.

## CONLUSION

A genetic model for the gold mineralizations of the eastern Cordillera can be suggested which will refers to the hydrothermal systems and sulfide accumulations present at modern submarine sea-floor spreading centers. Although several types exist in relation

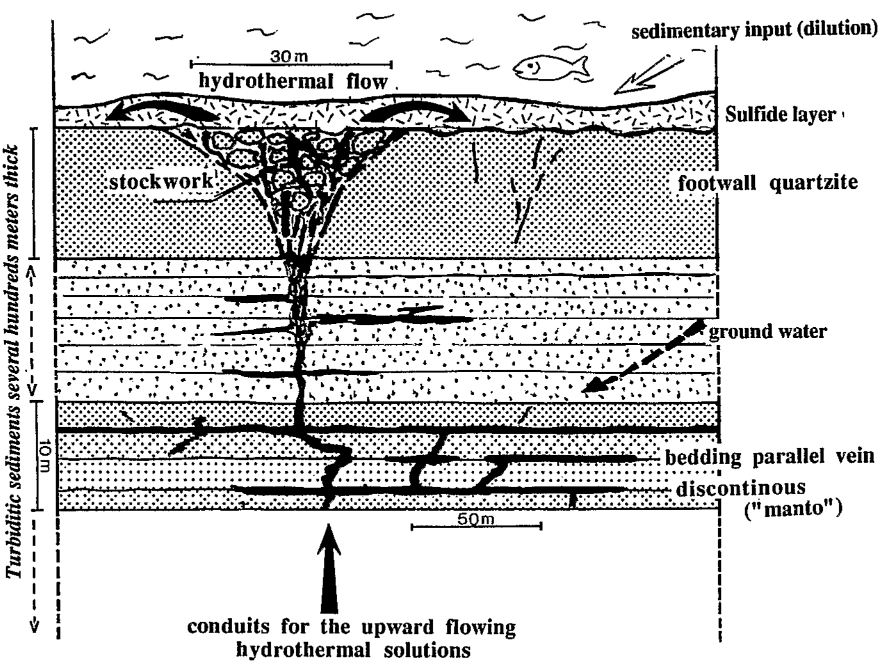


Fig. 8 Schematic representation of the interpretative genetic model for the gold mineralizations (not to scale, from Fornari & Bonnemaison, 1984).

with different geotectonic sites (Rona, 1984) the main characteristics are the local concentration of sulfide and metal rich muds and brines during the deposition of the detrital sediments. Before their emergence at sea floor, the upward travelling hydrothermal flows cross the sedimentary column in process of compaction. The bedding planes and the permeable levels can form conduits improving the formation of the veins and sulfide impregnation (Figure 8).

The single hydrothermal origin applies to the sulfide layers and the quartz veins mineralizations. The later events and, in particular, the deformation by the Variscan tectonic may modify and remobilize the syngenetic mineralization (Fornari et al., 1988).

Although the common characteristics shared by most of the gold mineralizations of the eastern Cordillera, some particular cases occur such as the mine of Santo Domingo in Peru, which was worked between 1890 and 1930 and was famous for the presence of columns of locally high grade ore (up to 2 kg/t). It consists of a N120°E striking quartz vein of several kilometers long,and about 1 m thick, with lenses of more than 5 m wide. Free gold is dispersed in the quartz and forms also locally ribbons up to 2 cm thick; the gold was accompanied by important amount of pyrite and stibnite.

In Bolivia, the mine of San Silvestre distinguishes by the Silurian age of the host rocks and by a K/Ar age of 227 Ma on muscovite from the vein. So part of the gold mineralizations appears to be related to younger events.

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PROCEEDINGS OF THE SYMPOSIUM BRAZIL GOLD'91
BELO HORIZONTE / MG / 13 - 17 MAY 1991

# BRAZIL GOLD '91

## The Economics, Geology, Geochemistry and Genesis of Gold Deposits

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*Published for the Associação Organizadora do Brazil Gold, Belo Horizonte, Brazil by*

A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1991