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Geodynamic and Gold Distribution in the Tipuani-Mapiri Basin (Bolivia)

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ABSTRACT The Tipuani-Mapiri intermontane basin is filled up mainly by Tertiary conglomeratic deposits (Cangalli formation) which fossilize a steeped paleo-topography entrenched in lower Paleozoic schists. Sediments deposited after an important uplift of the SW part of the Cordillera Oriental and during the folding and uplifting of the Serrania de Carura. This morphotectonic evolution is related to the overriding of the NE margin of the Cordillera Oriental on the sub-Andean zone that in turn overrides the Brazilian foreland. Some sedimentological features and also some characteristics of gold distribution in the basin are explained by the morphotectonic framework.

INTRODUCTION

The gold placers of the Tipuani area are the richest in a region where gold is mined since the Spanish Colonial Epoch and the Incaïc period. Important amounts of gold were recovered from the rio Tipuani valley but precise data on the total production are not avaible; however some partial recorded productions may be used to emphasize the past production: for instance, between 1957 and 1967 the Banco Minero bought 16,782 kg gold in the town of Tipuani and between 1963 and 1969, 471 kg were mined from a single place in the meander of Cueva Playa (Ruiz, 1972). Gold was also extracted from Neogene conglomerates (Cangalli formation) e.g. in 1947 the Compañía Aramayo de Mines de Bolivia (CAMB) recovered 235,976 kg gold from the pit of "Tulujahuira". These data outline the importance of the Tipuani area where dozens of tons gold have been mined.

In spite of this intensive mining activity in the past, the area still has large amount of metal occurring in some hundred of millions of m^3 of alluvial deposit with economic grade (Ruiz, 1972, Heuschmidt, 1986). In addition to the area of Tipuani, gold is also present in other parts of the basin as the Consata-Mapiri valley, so that the Tipuani-Mapiri basin can be classified among the world most important district for recent alluvial gold placers.

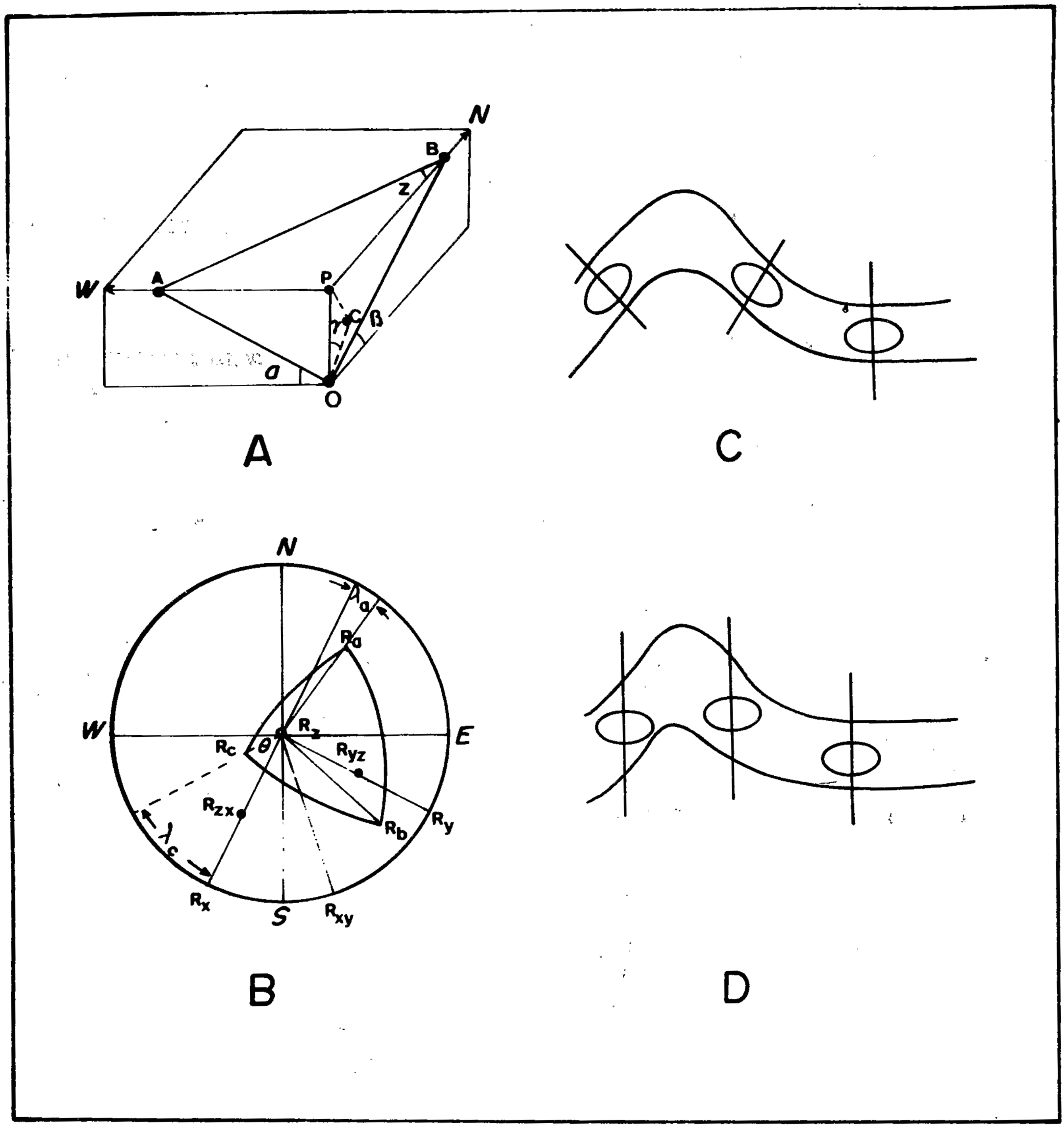

Figure 1. Schematic diagrams showing the orientation of optical axis (minimum reflectance) of vitrinite in uniaxial negative (A) and biaxial (B) models. The orientation of optical axis with reference to bedding plane can be used to indicate whether maturation predates (C) or postdates (D) tectonic structures.

THE TIPUANI-MAPIRI BASIN

Location and Geological Features

The Tipuani-Mapiri basin is an intermontane basin with an NW-SE elongate shape. To the SW it is bounded by the high ridge of the Cordillera Real (Mt Illampu = 6424 m) consisting of lower Paleozoic shales and quartzites intruded by large granitic plutons. To the NE, it is limited by the reliefs of the Serrania de Carura and by the sub-Andean foothills. Northwestward it continues in the Apolo depression and relicts of erosional surfaces. Southeastward it extends near Coroïco where erosional surfaces are covered by strongly weathered conglomerates. The total extension of the basin is more than 200 km long and only 10 to 30 km wide (fig. 1).

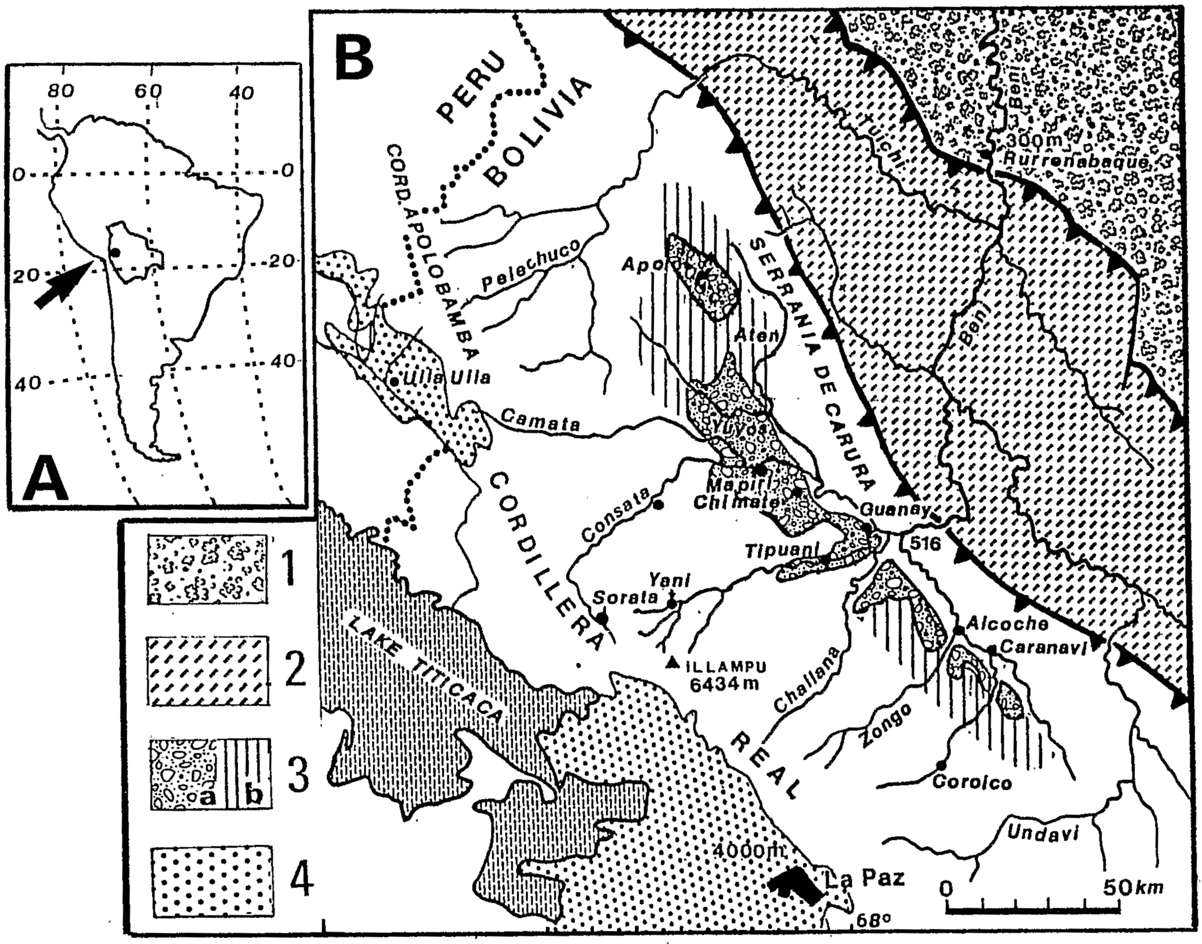

Fig. 1: Location maps. a) South America; b) location of the study area 1: Amazonian plain, 2: sub-Andean zone, 3: Tipuani-Mapiri Basin: a = Cangalli formation, b = main remnants of the erosional surfaces associated with the infill of the basin, 4) Plio-Quaternary basins of the Altiplano facing slope of the Cordillera Oriental.

The sedimentary fill consists of thick fluvial conglomerates, called the Cangalli formation (Frochot 1901, Stoll 1961, Freydanck, 1965, Hérail and others, 1986). This formation rests on Middle to Lower Paleozoic schists and quartzites and fossilizes a steeped paleotopography. This fact explains the important changes in the thickness of deposits which may reach about 500 m. In the center of the basin the top of the infill is about 1000 m above sea level and it reaches 1200 m in the upstream part of the principal valleys (e.g. rio Tipuani). It is deeply dissected by entrenched rivers: the present stream bed is about 500-600 m above sea level, and so, about 400 to 500 m lower than the top of the infill; this entrechment of the rivers was accompanied by a strong erosion of the alluvial deposits.

The age of the formation has been attributed, without serious chronological evidences, to Upper Pliocene or Pleistocene (Freydanck, 1965, Bamin, 1977); radiometric data (K/Ar on biotite of an interbedded cineritic level, Fornari and others, 1987) indicate a Middle to Upper Miocene age.

Sedimentological Evolution

The sedimentary evolution of the Tipuani-Mapiri basin is characterized by an important stage of accumulation (sedimentation of the Cangalli conglomerates) followed by an erosional stage (formation of the present drainage pattern and Quaternary terraces).

The Cangalli formation shows several facies and their sedimentological characteristics allow to identify the main paleo-valleys coming from the cordillera and the secondary paleo-valleys of local reduced watersheds.

In the upper part of the main paleo-valleys (as the paleo-Tipuani and the paleo-Challana, fig. 2), the deposit consists of torrential conglomerates with blocks up to several m in diameter but the majority of the clasts is only about 30 cm. They are organized in fining upward, narrow and deep channels. The petrographic and mineralogic composition of the deposit changes from the bottom to the top of the paleo-cañon. At the bottom, abundant granitic blocks coming from batholiths located near the crestline of the Cordillera (Zongo-Yani, Illampu) and high-grade metamorphic rocks are mixed with Ordovician slates and quartzites which come from near outcrops. In the upper part of the infill the slates and quartzites become more and more abundant. Downstream, the size of the blocks decreases and the deposit changes over a distance of about 2 km to fluvial conglomerates with large and shallow channels showing clear figures of lateral accretion. The clasts are rounded and well imbricated; they are mainly derived from the Ordovician outcrops, and elements derived from the high Cordillera become rare.

In the NW part of the basin, between Chimate and Mapiri (fig. 1) wide alluvial fans appear.

At the border of the paleo-valleys, silts, laminated clays and locally thin beds of lignite, are locally present on both sides of the streams axis; they can reach several dozens of m in thickness. Toward the axis of the paleovalley, these deposits are interbedded with the fluvial conglomerates, while toward the borders they are interbedded with colluvium and slope deposits. The presence of very fine deposits at the borders of encased valleys reflects the damming of lateral hollows by rapid alluviation in the center of the valley in a high depositional rate environment.

In the paleo-valleys coming only from the reliefs surrounding the basin (e.g. the paleo-Mariapo, fig. 2) also fluvial conglomerates exist, but they consist of proximal deposits characterized by angular clasts in a poorly sorted matrix (Hérail and others, 1986). All the components are derived from local Ordovician outcrops.

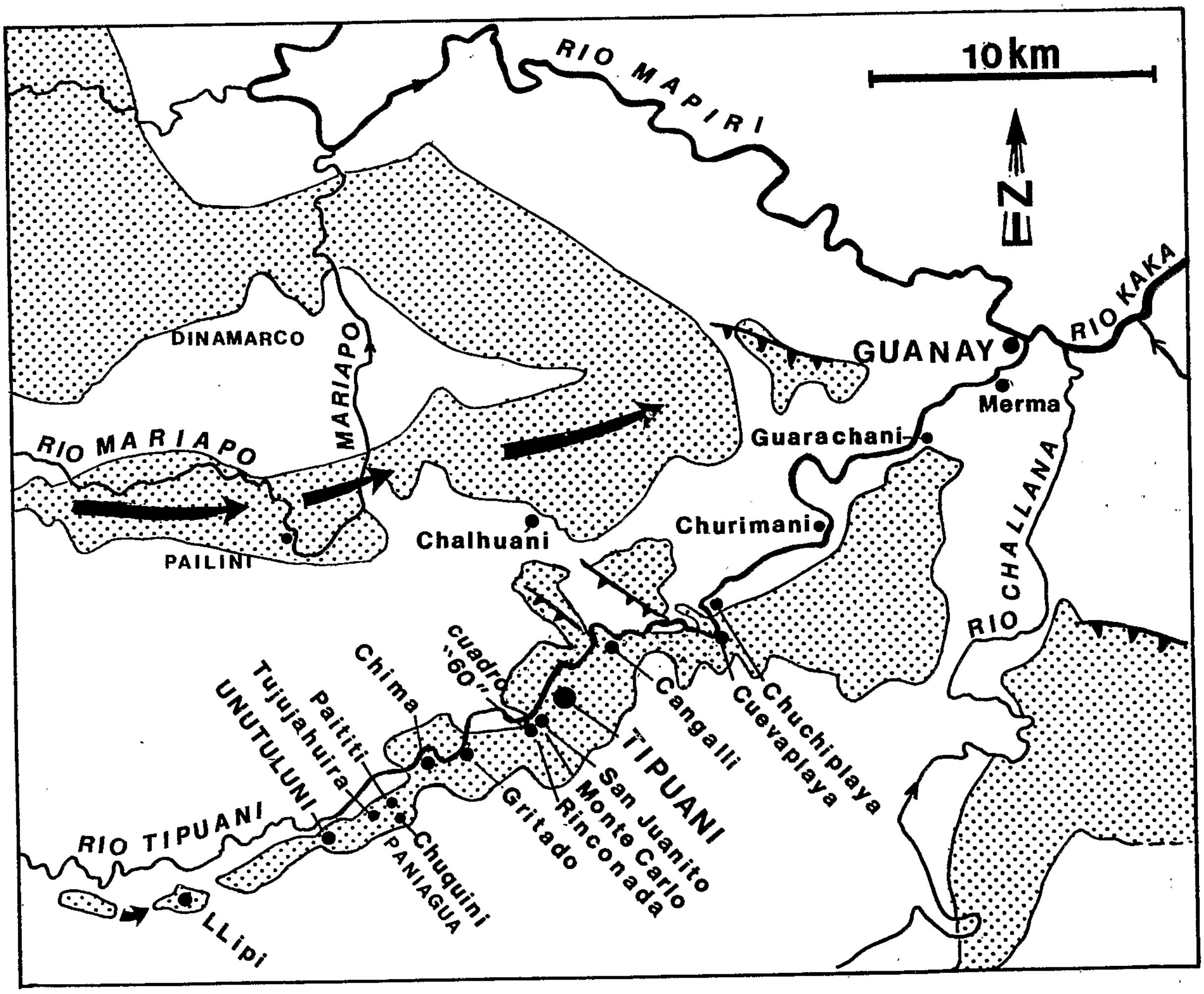

Fig. 2: The Cangalli outcrops in the area of Tipuani, with location of some sites of gold exploitation. (arrows indicate the stream of the paleo-Mariapo).

Farther downstream, where the paleo-valleys become wider, the facies change to silt and clays of flood plain, with gravels and sands deposited by local tributaries. Temporary emersions permitted some pedogenesis to develop.

The location of the main streams in the Tipuani-Mapiri basin at the time of the deposition of the Cangalli formation was roughly the same as today (rio Mapiri, Tipuani, Challana and Zongo). The rivers flowed to the NE and joined in a confluent area oriented parallel to the Serrania de Carura (fig. 1). In this area the grain size of the deposit decreases toward the top of the series where the conglomerates form more and more sinuous and wide channels. The paleo-flows are oriented to the NE, and only in local place are parallel to the NW-SE trending reliefs which bound the basin northeastward. In the SE part of the basin (region of Alcoche, fig. 1) flow directions are toward the NW. The lack of lacustrine facies dowstream from the fluvial facies indicates that the basin never was endoreïc. Locally, the reliefs of the Serrania de Carura may have deviated the flows but they have never made a barrier. Several flows outlet existed, one of them located near the present confluence of the rio Zongo and rio Coroïco as indicated by the convergence of the paleo-flow directions in this area.

The infill of the Cangalli stopped with the deposition of an alluvial level which correlates laterally with an erosional surface. Remnants of this surface are well preserved in the main interfluves of the rio Tipuani and in the NE area between the rio Chimate and the rio Mapiri. An important weathering profile (several dozens of m thick) developed, starting from this surface. It explains the superposition of an altered red deposit ("Cangalli rojo") on an unaltered grey deposit ("Cangalli azul").

It is also from this terminal surface that the Quaternary drainage developed and that the rivers dissected the basin. The main present rivers follow roughly the same valleys than the paleo-rivers, but important local differences exist. Differences between the stream directions can be important for the local rivers as the rio Mariapo (see fig. 2). Several terraces, and alluvial fans in the Chimate area, were built. In the main valleys (e.g. Tipuani, Challana) the deposit results from the removal of Cangalli formation and from river drifts whose source areas are the whole Cordilleran slope, while in the local valleys (e.g. Mariapo) the terraces contain only clasts of the Cangalli formation or from local Ordovician outcrops.

Tectonic

A compressive tectonic deforms the Cangalli formation. The deformation is outlined by the presence of tilted beds, open folds with N120°E axis, reverse faults and large bands where the clasts are microfractured and punched (Hérail and others, 1986, Fornari and others, 1987). Computation of the structural data collected in several sites indicates a sub-horizontal compression with a maximum stress axis oriented about N050°E. Compilation of the surface and underground working observations (Stoll, 1961, Bamin, 1977) show that the present gradient of the paleo-valleys is steeper than that of the corresponding present valleys (Hérail and others, 1986). For the rio Tipuani it appears that between Untuluni and the village of Tipuani (fig. 2) the gradient of the present river is about 0.3% while the gradient of the paleo-valley filled by the Cangalli formation is about 4%. Similar differences between the present gradient and the paleo-valley gradient exist also along the rio Challana. These different gradients reflect a tectonic uplift.

In the old Quaternary terraces only extensional deformation was observed; in this case the minimum stress axis trend N030°E. Although landslide effects can be discarded the sites where faults were observed are too isolated to allow any regional geodynamic interpretation.

DISTRIBUTION AND CHARACTERISTICS OF THE GOLD GRAINS.

In the Tipuani-Mapiri Basin gold is present in the conglomerates of the Cangalli formation., as in the Quaternary terraces and in the deposits of the stream beds.

Gold in the Cangalli Formation.

In this formation the highest grade (between several g/m^3 and several dozens of g/m^3) occurs in the fluvio-torrential facies of the cañon, and particularly at the contact with the bedrock and at the bottom of some channels ("veneros" or pay gravels) which do not show peculiar location within the formation.

Upstream, in the fluvio-torrential deposits of the region of Untuluni, the mean grade is high because numerous high grade "veneros" exist in the formation. At Untuluni prospections made between 1945 and 1948 resulted in mean grade of 21.3 g/m^3. Deposits mined near Tulujahuira and Chuquini presented a mean grade of 32 g/m^3 (Urquidi and others, 1948) and a 12 m^2 exceptionally rich lens furnished a mean grade of 112 g/m^3

Downstream, in the fluvial facies, the grade decreases rapidly because the pay gravels are poorer and scarcer: e.g. in a pit ("cuadro 60") located 10 km downstream from Unutuluni and drilled to -177 m only 3 pay gravels were intersected at -35, -95 and -118 m. In this area the grade is about 3 g/m^3 and between the mineralized beds the grade of the deposit is very low. The flood plain and palustrine facies are generally barren.

Gold forms generally flattened particles ("laminado") with rounded outline. and the grain size decreases downstreamward. In the Cañon facies, particles of several dozens of g are encountered while downstream of Tipuani generaly only fine (<1 cm length) particles are recovered (Freydanck, 1965, Hérail and others, 1986).

Gold in the Terraces and the Stream Beds

In the terraces, as in the bed deposits of the main rivers of the basin (Challana, Tipuani, Mapiri), grade is generally high but shows important variations.

In the alluvial deposits of the terraces, 3 parts are distinguished (fig.3).
a) The upper part, which is very poor or barren, consist of silty and sandy sediment of flood plain and locally of colluvial deposits. b) In the middle part fluvial conglomerates are organized in channels, forming mainly all the deposit. The grade is generally of economic interest but very variable in the pay gravels located at the bottom of the channels. c) The basal part does not differ from b) but the grain size is generally coarser. It overlies the bedrock ("plan de peña") which consists of Paleozoic schists or of Cangalli conglomerates and is the richest in gold at the contact with the bedrock.

In the terrace of San Juanito de Monte Carlo the upper part (3.5 to 5.5 m thick) contains less than 0.1 g/m^3. In the middle part (5 to 7 m thick) the grade is about 0.2 g/m^3 while in the basal part (1 to 1.5 m thick) the grade reaches 0.6 g/m^3. Generally grade is up to several g/m^3 in the basal part.

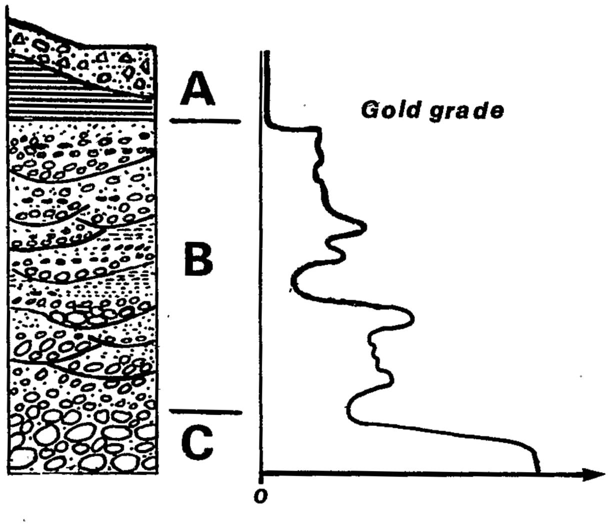

Fig. 3: Vertical variation of the gold grade in the terrace deposits. A = "overburden" with slope deposits and /or silts and clays; B = middle part conglomerates, C = lower part, coarse conglomerates with boulders, resting on the bed rock. (no scaled, see text).

In the present bed stream deposits, the gold grade distribution shows the same pattern as in the terraces (Ruiz, 1972, Hérail and others, 1986). Grade variations correspond to gold grain size variations; the biggest and the heaviest gold particles accumulate in the basal part of the deposit (fig. 4).

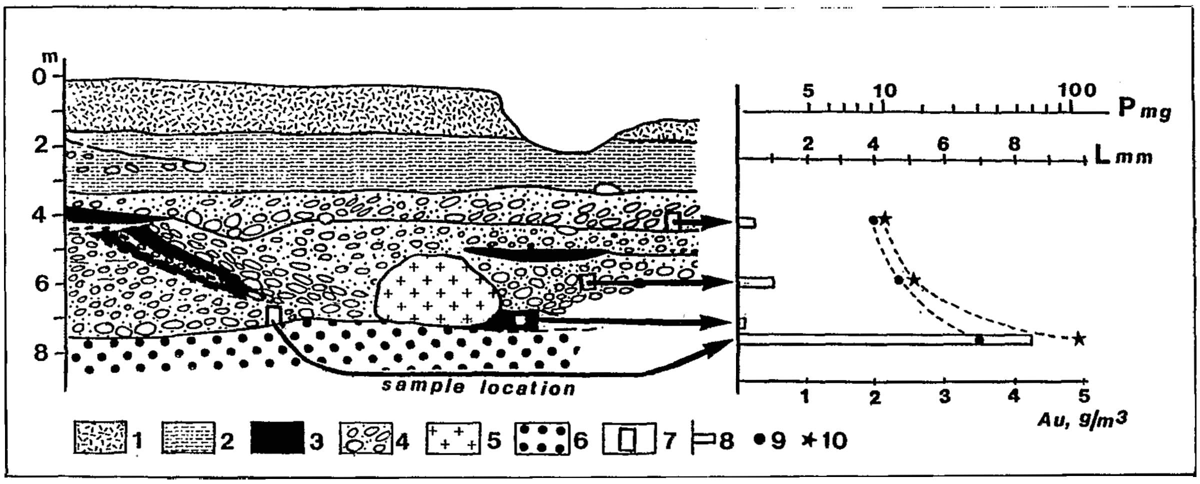

Fig. 4: Sedimentological organisation and gold characteristics in the river bed deposits ("playas"). 1 = rehandling 2 = silts and clays (overburden), 3 = silts and sands, 4 = clasts and blocks, 5 = boulder of leucogranite; 6 = conglomerates of the Cangalli formation (bedrock), 7 = location of the samples, 8 = gold grade, 9 length of the biggest gold particle (L mm), 10 = weigth of the biggest particle (P mg, log scale).

In the streams and the terraces of the rivers which drain only the lower part of the Cordillera, the barren overburden is very thick. Generally it overlies low grade (about some hundred of mg/m^3) deposit and will not pay the costs of an extensive exploitation.

In the terraces and the deposits of the present streams, gold appears mainly as flattenned and worn particles. Study of the particles sampled along the rio Tipuani and rio Mapiri show downstreamward changes in the grain size and morphoscopic features of the gold particles. The gold, which is furnished by the erosion of the primary mineralizations of the Cordillera Real, consists of xenomorph particles with very diverse shapes and sizes. Morphologic transformations occur during the transport: e.g. changes in the general outline, in the surface aspect, disappearance of primary crystalline shapes, appearance of neoformed crystalline shapes and structures such as striation marks, impacts, "sandwich" parts with superimposed metal plates (Hérail, 1988, Hérail and others, 1988).

Gold particle evolution is also shown by an increase of the flattening. Several index have been defined to characterize it, as the Correy factor (Correy, 1949 in Tourtelot and Riley, 1973) or the Cailleux indices. Cailleux and Tricart, 1959, proposed the ratio: $L + w / 2t$ where L is the length, w the width and t the thickness of the grain, which is used in this study. The flatness index (F.I.) is measured over all (or a large number of) gold particles of a sample and histograms permit to present sample variations (fig. 5); then the mean values are also calculated for all the deposits sampled along a river.

For the Tipuani as for the Mapiri river the mean value of the F.I. increases with the transport distance from the primary sources (fig. 5 and fig. 6). The gold particles derived from the erosion of the quartz veins of the lower Paleozoic schists have an F.I. of about 2 or 3; after a transport distance of about 30 km the mean value of the F.I. is about 9 and it reaches about 15 after a transport distance of about 60 km. Farther downstream the mean F.I. does not show any noticeable increase with the distance; this is partly because the gold particles are so thin that they fold several times on themselves. So, along a river, the morphology of the gold particles changes and the mean value of the F. I. increases regularly, at least during the first 80 km.

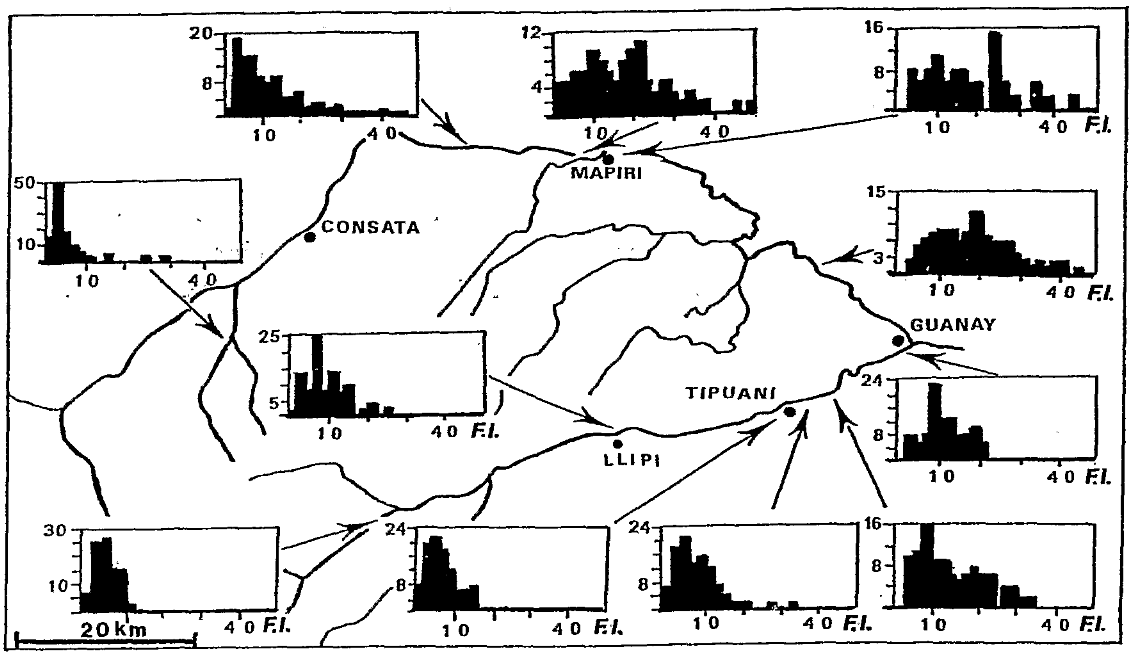

Fig. 5: Histograms of the gold particle flatness along the Tipuani and Mapiri rivers.

In some cases, examination of the gold particles shows the particles (2 to 8 % of the total) with F.I. less than 4. The morphological characteristics of these particles reveal a transport over very short distances, leading to discovery of additional primary mineralizations located in the Paleozoic substratum of the basin (Hérail and others, 1988).

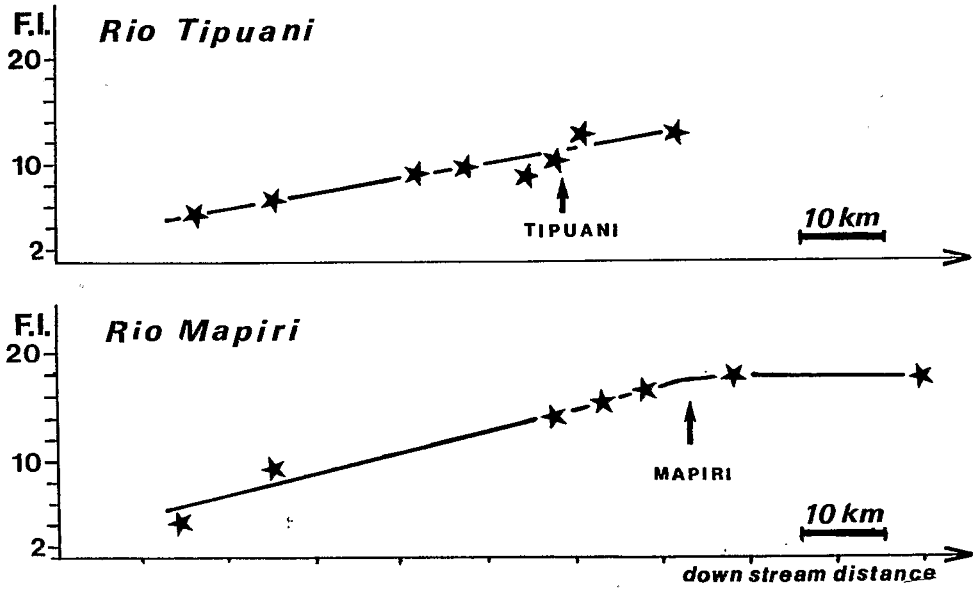

Fig. 6: Variation of the mean flatness index (F.I.) with the down river transport distance along the Tipuani and Mapiri rivers.

CONCLUSIONS

An active compressive tectonic acted since the Miocene in the NE slope of the Cordillera Oriental and in the Sub-Andean Zone. This tectonic setting originated the formation of the Tipuani-Mapiri basin. The trapping of the thick conglomeratic deposits of the Cangalli formation results from the uplift of the Serrania de Carrura which breaks the continuity of cordilleran slope. In this context, the basin can be interpreted as a piggy-back basin.

At the scale of the whole basin, the gold grade of the Neogene deposits is strictly related to the sedimentological features. In addition to their richness, these deposits form also intermediary collectors for the gold. During the stages of erosion and removal following the entrenchment of the rivers, entrenchment which is controlled by the continuous uplift, these collectors furnish gold particles. In turn, this gold is trapped in the terraces and river deposits; the grade becomes higher than in the source sediments and poor formations changes by successive reworkings to economic deposits. So the placers of the Tipuani-Mapiri intermontane basin, as those of the Amazonian piedmont, are directly controlled by the geodynamic evolution which is characterized by migration toward the NE of the tectonic, sedimentologic and orogenic activity.

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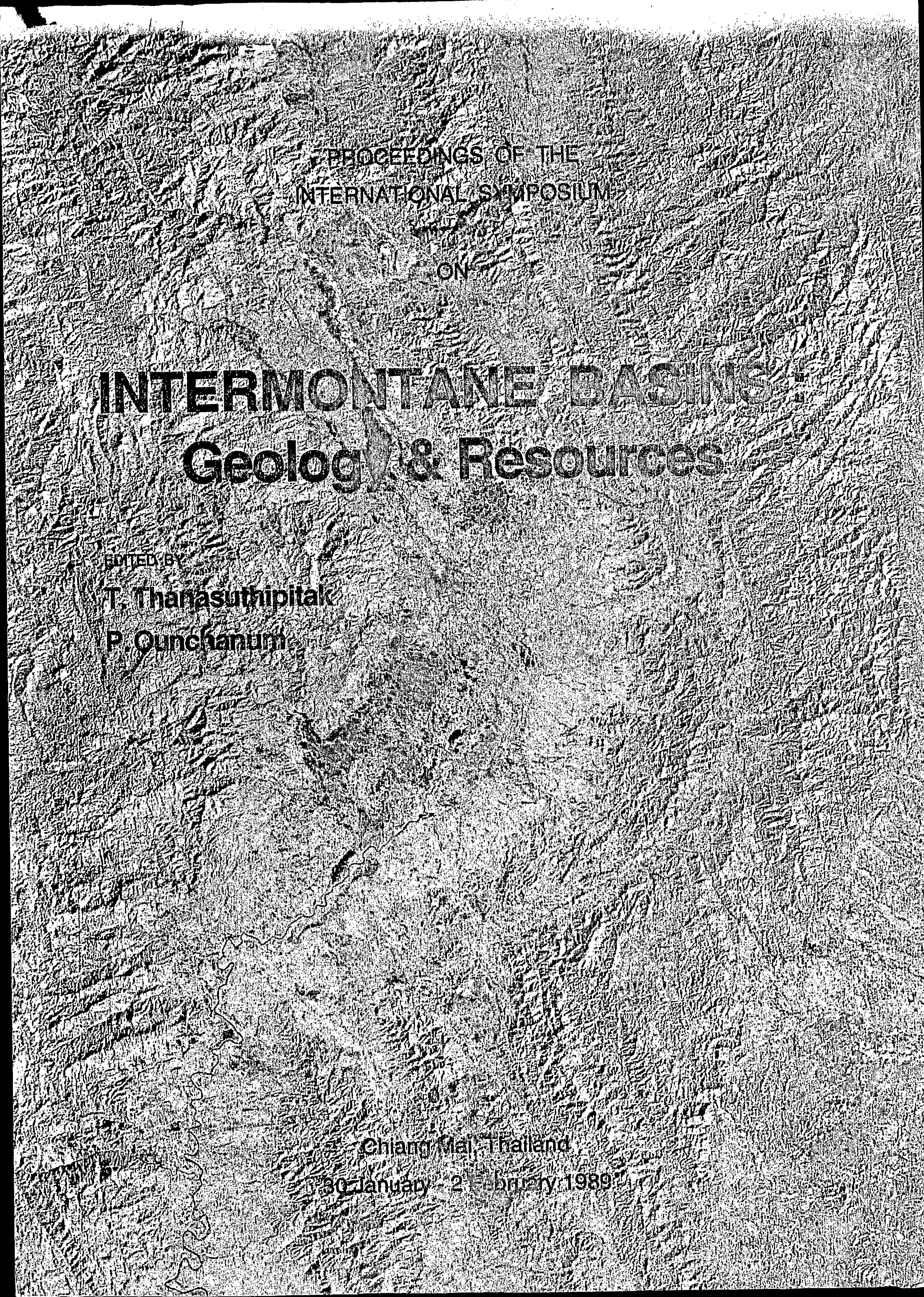

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