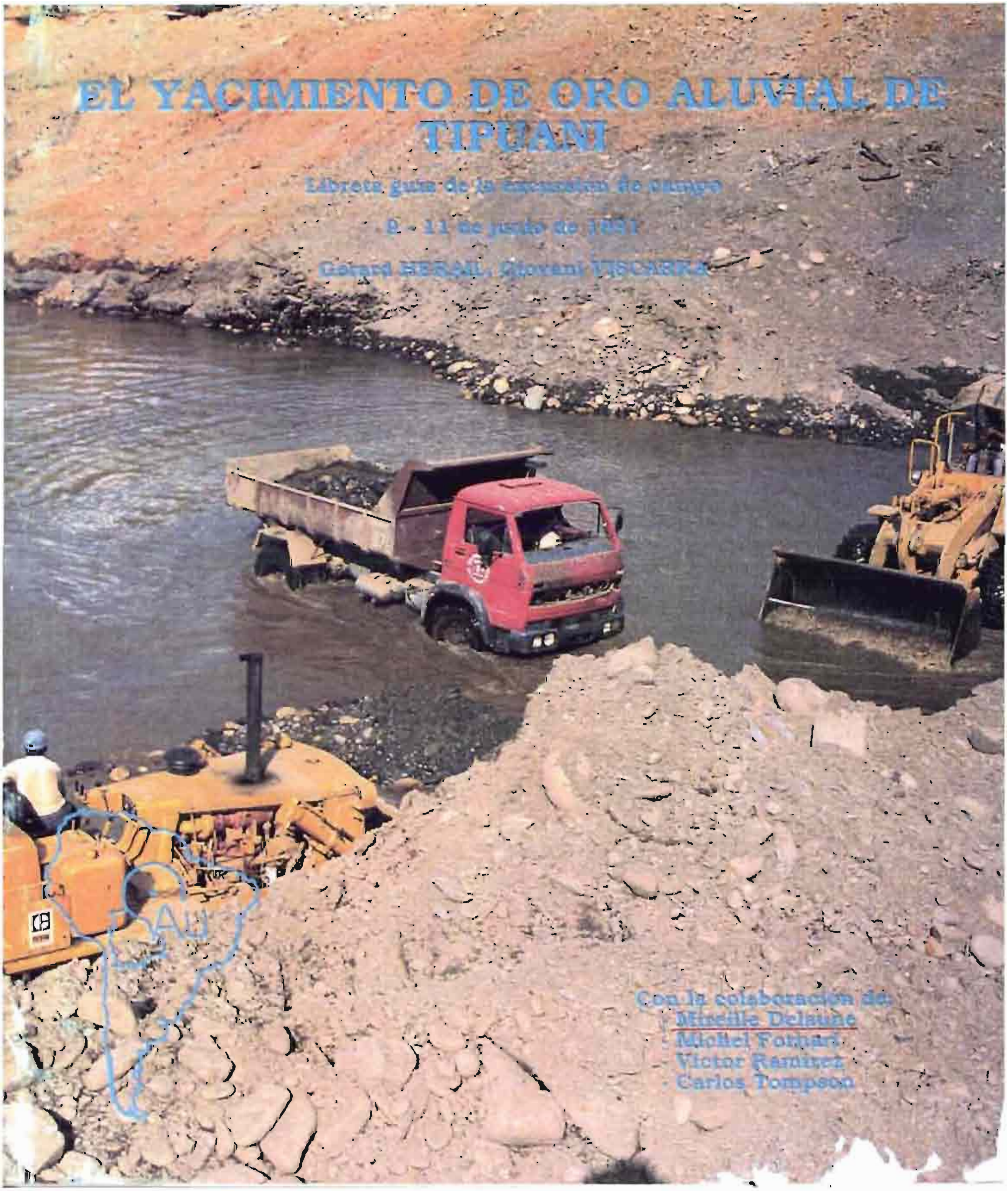

EL YACIMIENTO DE ORO ALUVIAL DE TIPUANI

Libreta guía de la excursión de campo

9 - 11 de junio de 1991

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- Michel Fornari
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SYMPOSIUM INTERNATIONAL SUR LES GISEMENTS ALLUVIAUX D'OR

INTERNATIONAL SYMPOSIUM ON ALLUVIAL GOLD PLACERS

SIMPOSIO INTERNACIONAL SOBRE YACIMIENTOS ALUVIALES DE ORO

THE GOLD PLACER OF TIPUANI

Field guidebook, june, 9 to 11, 1991

by Gérard HERAIL & Giovanni VISCARRA

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During the trip to the Tipuani River Valley, different types of fluviatil placer deposits, (active river beds, alluvial terraces, paleo channels), will be shown in the area between Guanay and Unutuluni.

This region is well known for the quantity of gold it has produced and still is producing as well as for the characteristics of the deposit. Records of gold mining in the area go back as far as into the period of the Incas. In 1562, the first colonial expedition led by Juan de Roda arrived at Román Playa. In 1580, exploitation reached upstream until Chuquini and in 1602 until Tipuani (Revilla 1988).

Early in the 19th century, first attempts in big scale mining were made by Ildefonso Villamil, who produced more than 150,000 ounces of gold from several areas upstream of Tipuani, from 1813 to 1833 and 1850 to 1866 (Revilla 1988). In those times, alluvial terraces were exploited by means of a method called "banquería" (a vertical shaft was driven to the bedrock and the productive gravel excavated from there lateraly) or in open air from the river banks.

Whereas the first attempts of mechanization were made in 1840 with the use of water-pumps by J. Wheathey, an Irishman, heavy equipment was introduced only towards the end of the 19th century.

In 1898, the Incahuira Dredging Company brought machinery and a dredge to the Kaka River. But it was the "Compañía Aramayo de Minas" which conducted major mining activities between 1936 and 1949, putting the main emphasis in the exploration and exploitation of the "old channel" of the Paleotipuani.

Since 1952 (following the nationalization of the mines and the forced return of all gold concessions held by Aramayo to the State on November 7) and until 1961, the gold placers of the Tipuani valley were exploited by groups controlled by the Banco Minero, which bought the gold. In 1961, the government anulled all previous licences and granted juridical personality to cooperatives, which in 1963 formed the "Federación Regional de Cooperativas Auríferas" (FERRECO), which is actually exploiting the Tipuani Valley placer deposits. In the beginning, the efforts of the cooperatives were concentrated on terraces and active river beds, whereas, since a few years, the exploitation of the "Old Channel" predominates.

1. THE ITINERARY LA PAZ - TIPUANI (FIG. 1)

The distance of 259 km is travelled in about 10 hours. Nevertheless, a stop-over is made in Guanay (228 km), where we spend the night. The trip takes us from the Altiplano (3500 - 4000 m) over the pass of La Paz ("La Cumbre", 4636 m) down into the hot areas of the Yungas (2000 - 500 m).

Leaving La Paz in a NNE direction, we pass through extensive fluvioglacial deposits of the La Paz Formation, consisting of grey to ochre silty clayed sediments of lacustrine origin, interbedded with fluviolacustrine sands and conglomerates.

The base of this formation has been dated at 5.5 ± 0,2 M. y. in Cota Cota (Lavenu et al. 1988). The upper part of this formation conserves a layer of tuff, the Chijini Tuff, dated at 2.8 M. y. (Lavenu et al. 1988). This tuff outcrops on the right of the road, deformed by a normal fault. Overlaying the La Paz Formation appear morainic and fluvioglacial sediments of the Quaternary, and furthermore well conserved moraines at the bottom of the Chuquiaguillo Valley and its slopes (beginning at km 8).

At the road stop of Chuquiaguillo, one observes on the right, at the bottom of the Chuquiaguillo River, some minor mining operations for alluvial gold. This gold originates in displaced material of the La Paz Formation as well as in moraines coming down from the water parting. One of the reasons for the foundation of city of La Paz on October 20, 1548 by Alonso de Mendoza was the discovery of gold in the high valleys of the La Paz drainage basin.

Higher up towards the pass, outcrops of Devonian and Silurian slates (Lehman 1979, Martinez 1980) are crossed and once the pass is reached, one observes good outcrops of black slates belonging to the Uncía Formation (Silurian). Beginning our descent (km 23), we cross more sandy sediments of the Llallagua Formation which overlays the Cancañiri Formation (Ashghillian) and is characterized by the presence of allochton blocks and gravel and by big slope slidings. Afterwards we enter into a series of light-colored quartzite of the Upper Ordovician. Throughout the rest of the itinerary right down to the placers of Tipuani, following a pretty narrow road, Ordovician terrains are traversed, like quartzites of the Upper Ordovician or lutites of the Middle Ordovician. An exception is the orthogranite of the Zongo-Yani batholite (of Eohercynian age), outcropping near the tunnel of Unduavi at km 39.

After the Unduavi tunnel, the road to Chuspipata (km 52) is less steep and follows through an area made up predominantly of Ordovician slates. From Chuspipata on and following a narrow road down to the Yungas, we cross massive outcrops of quartzites (Upper Ordovician). Approaching Yolosa (fig. 1), after having travelled 81 km, the relief becomes less sharp and the valleys open up. Some 250 to 300 metres above the actual Coroico River are remnants of old valley fillings showing thick red alterations. These horizons could carry auriferous alluvial deposits, as one observes beyond the bridge of Santa Bárbara (km 92) on the left side of the road.

Going on, carrying on towards Caranavi more Middle Ordovician terrain is passed and near Chorro (km 121) the presence of quartzites is marked by narrow gorges. Not until km 133 has been passed, the valley of the Coroico River opens, the relief smoothes out and reddish soils developing over paleozoic rocks become frequent. From here on, we enter into the proper Cangalli Basin (fig. 2). Passed San Silverio (km 143), one observes (ahead to the left) at the horizon, pyramid shaped reliefs made up by conglomerates of the Cangalli Formation which rest on more rounded ground made up of slates.

The basin with the Cangalli Formation is bounded at its northeastern end by an important overthrust (the Main Andean Overthrust, Sempere et al. 1988), which caused the rising of

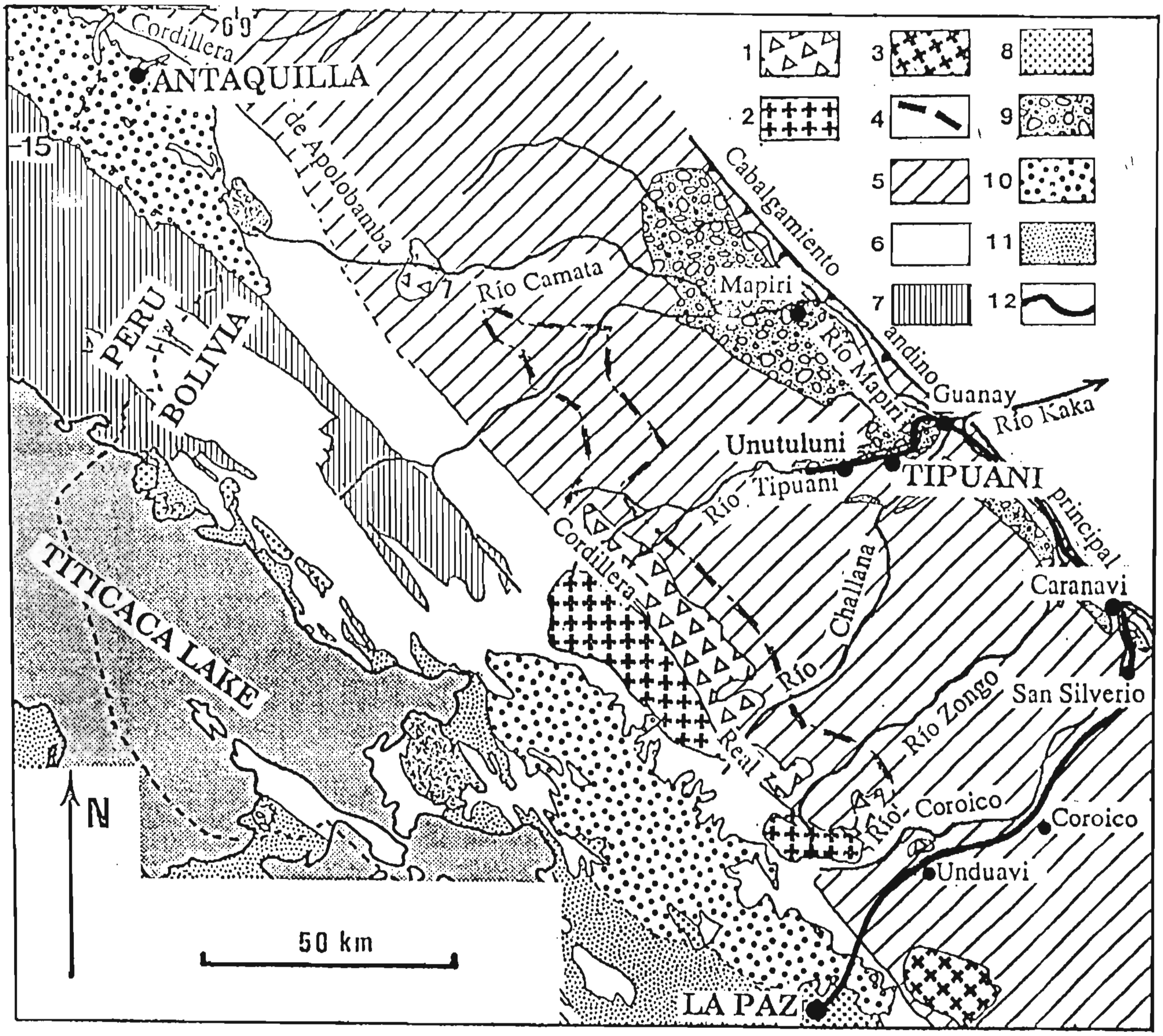
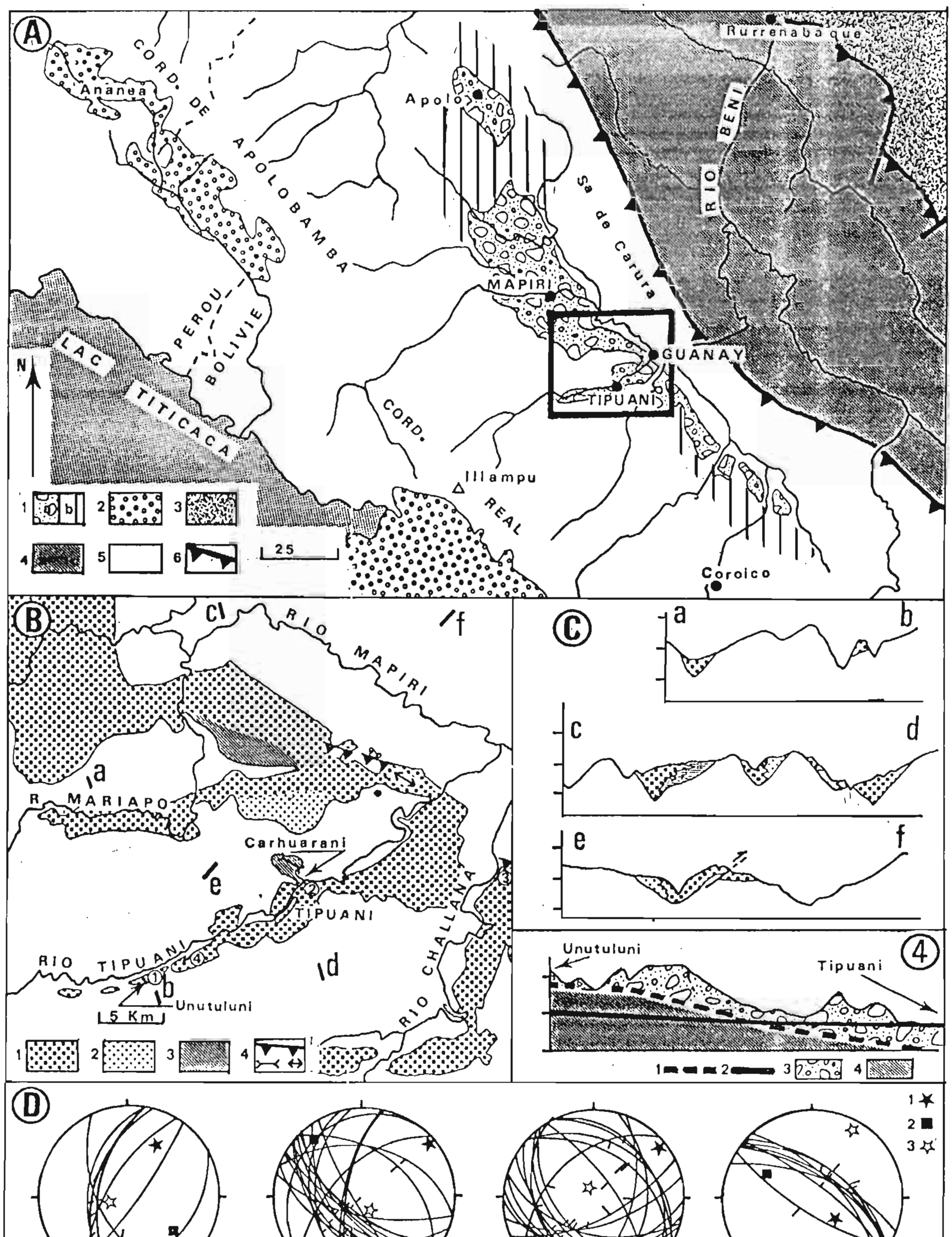


Fig. 1. Simplified geological map of the area located between La Paz and Tipuani (Compiled from Martinez 1980, Tistl 1985, Hérail et al. 1988, Sempere et al. 1990).

1 - Eohercynian syntectonic orthogranite of Zongo, 2 - Triassic granodiorite of Illampu - Huayna Potosi, 3 - Miocene granite, 4 - High and middle metamorphism zone boundary, 5 -Ordovician, 6 - Silurian to Permian, 7 - Undifferentiated Cenozoic strata, 8 - Oligocene to Pliocene (La Paz Formation, Aranjuez Formation...), 9 - Cangalli Formation, 10 - Glacial and fluvioglacial sediments (Quaternary), 11- Fluvial and lacustrine sediments (Quaternary). 12 - Itinerary of the fieldtrip

notable reliefs at the northeast and the isolation of the Tipuani Basin which developed to a "piggy-back basin" during Cenozoic times (Fornari et al. 1989).

From Caranavi to Guanay, the road stays in the Coroico Valley until its junction with the Mapiri, Challana and Tipuani Rivers. All along this part of the road, we follow the strike of the andean structures, observing to the left, on the riverbank, pyramid-like reliefs of conglomerates of the Cangalli Formation, resting on Ordovician slates. Locally, along the river, one observes small-size gold workings, but intense mining activity begins only from the confluence of the Coroico River with the Mapiri River (km 224). The workings of gold washers ("barranquilleros") along the riverbanks as well as open pit operations of mining cooperatives on alluvial terraces are especially dense from the confluence of the Challana with the Mapiri on until Guanay (km 228). In the same area, the stretch partly covered with vegetation between the road and the Mapiri River is filled with waste from dredging the river bed and low terraces of the Mapiri. These dredging operations were run in the entire zone of Teoponte and Guanay from 1959 until 1990, first by SAPI (Southamerican Placer Inc.), later by CODEMA (Cooperativas del Mapiri).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Ananea
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2. THE CANGALLI FORMATION: GENERAL SEDIMENTOLOGICAL FEATURES AND CONTEXT OF SEDIMENTATION

The Cangallí Formation outcrops in the Tipuani-Mapiri basin (fig. 1) which covers some 100 km in an SE-NW direction parallel to the andean structures. Towards the Northwest, this basin extends beyond Apolo, although without any sediments conserved, and towards the Southeast beyond Coroico, thus reaching a total length of over 200 km. At the Northwest, it is limited by the Serranía of Carura, which is made up by Paleozoic series overthrusting the subandean zone. In the Southeast, the Cangallí Formation, discordantly overlaying the Ordovician, extends into the principal valleys descending from the Cordillera Real (from South to North: Challana, Tipuani and Mapiri rivers).

2.1. Sedimentological characteristics.

The Cangallí Formation is detritic, consisting mainly of conglomerates deposited in a fluviatil environment (Frochot 1901, Ahlfeld 1946, Stoll 1961, Freydanck 1965). However there are numerous changes of facies (Hérail et al. 1986, Viscarra 1986, Hérail et al. 1989). These sediments fill a paleo-drainage system, which caused important variations in the sedimentation thickness (from 0 to 500 metres) and in the facies (fig. 2). Above the gorges of the paleo-valleys coming from the Cordillera, we find fluviotorrential conglomerates with individual blocks up to several m^3. Downstream, better-sorted fluviatil conglomerates change slowly into distal facies of flood plain, as for example downstream the Paleo-Mariapo (fig. 2). Nevertheless, no lacustrine facies have been found in the Tipuani-Mapiri basin downstream, trapped behind the relief closing the basin at the north, which means that this basin never has been an endoreic one (Fornari et al. 1987).

The main part of the sediments belonging to the Cangallí Formation has been preserved at the bottom of the paleo-valleys (Challana, Tipuani, Mariapo and part of the Chimate-Mapiri zone). This paleo-morphology controls the geometry and the structure of the sedimentary filling. At the bottom of a paleo-valley, the sedimentation begins with very coarse and well-rounded conglomerates (blocks with 0,8 to 1 m in diameter are frequent). This conglomerate rests directly on the Ordovician substratum; the rocks are polished and one observes quite often pot-holes. The

⬅Fig. 2. The Tipuani basin: sedimentological and structural features

A - Geographical location. 1 - Tipuani-Mapiri basin (a: Cangallí Formation, b: erosional surface associated to the filling of the basin), 2 - Plio-Quaternary basins of the south-occidental piedmont, 3 - Amazonian plain, 4 - Subandean belt., 5 - Cordillera Oriental, 6 - Main thrust of the Andean Front (the heavy rectangle indicates the location of the map of the Figure B).

B - The Cangallí Formation in the central part of the Tipuani-Mapiri basin. 1 - Boulder and cobble conglomerates, 2 - Gravels and sands, 3 - Silts and clays of flood plains, 4 - Main folds and reverse faults. White, Ordovician bedrock.

C - Sections a-b, c-d, e-f (location and legend: see B).

D - Grades of the present talweg and of the paleotalweg of the Tipuani River. 1 - Paleotalweg, 2 - Present talweg, 3- Cangallí Formation, 4 - Ordovician.

E - Microfracturation and stress analysis in the Cangallí conglomerates (stereo nets 1, 2 and 3) and in the Quaternary high terrace of Paniagua (stereo net 4). Location of station: see figure B. Cyclographic projection of the striated fault planes with their slip vector. Orientation of the calculated tensor: 1 - major principal stress axis σ_1; 2 - intermediate principal stress axis σ_2; 3 - minor principal stress axis σ_3; Schmidt projection in the lower hemisphere.

sediment, in which trunks of trees have been preserved, contains clasts of the Ordovician series as well as intrusive rocks from the high parts of the Cordillera (fig. 1). The structure of the sediment changes towards the top of the series because of the widening of the valley which permits the river to deviate and to reduce its speed and its transport capacity. The sediment is structurally characterized by channels filled with decreasing grain-size and well-imbricated conglomerates. In vertical cross-sections, the individual channels are separated by layers of poorly-sorted conglomerates. They have a thickness of several metres to several tens of metres and form massive layers without signs of erosion at the basis and no remarkable granulometric changes from bottom to top. These sediments are the result of the superposition of flows, one over the other, without any aquatic remobilization after deposition.

In summary, the serie consists of a succession of more or less complete decreasing grain-size sequences. Towards its top, the proportion of coarse conglomerates decreases with regard to that of smaller gravel and sand. Nevertheless, the most important change is the decrease of the number and of the continuity of the high energy channels filled with blocks ranging from several centimeters up to one metre in diameter and which constitute the pay-streaks ("veneros").

Laterally, towards the margins of the paleo-valley, characteristic facies appear (fig. 3).

- Colluvial facies ("falderío"): they consist of poorly rounded blocks and gravels of Ordovician slates in a red sandy-clayed matrix. These deposits are the result of a local transport by gravity (for example slope slidings) or superficial wash-off. They have formed in a low energy environment independent from the waters of the river.

- Swampy facies: they consist of layers of sand and clay (sometimes with floating gravels) of a bluish grey color, which contain plant fragments (sometimes in live position). Small layers of lignite can be observed. On the riverbank, these clays are interbedded with conglomerate layers, whereas at steep rocky riverbanks they are mixed with colluvial material ("falderíos"). The thickness of these facies can be of various tens of metres. In the Tipuani Valley, they are particularly well developed around Uanani and Carhuarani as well as in the lower parts of the Iscua River (fig. 4). The reconstitution of flow directions (for example in the area of the Iscua River), clearly shows (fig. 4) that the sediment and the transporting waters came mainly from the Paleotipuani and not from the slopes. These sediments were deposited in swampy areas caused by inundations of the Paleotipuani. Near Carhuarani, outcrop clayed and silty-clayed sediments which could have been deposited in a permanent lake.

The distribution of the different facies described above occurs under the specific arrangement of the valley at a certain time of its geological history and is subject to constant changes as time goes on. At later stages of the infilling, more fine grained facies become important and particularly the channels appear more apart one from another due to the increased width of the valley opened to the running water. In particular, some inherited geomorphological structures of the Paleovalley may interfere with the surface of the rising new valley and may cause some local and momentaneous changes to the tracing of the riverbed. Thus (fig. 3C), when the level of the sedimentary filling reaches the lowest point of the surrounding slopes of the paleo-valley, the waters may deviate and change the course of the river. A clear example of such an event exists in the area of Molleterio-Chima (fig. 4).

The present top of the Cangallí basin filling which can be seen, corresponds to an erosion surface cutting the Paleozoic substratum in the surroundings of the basin. In the basin itself, this erosion surface is covered by alluvial terraces of the Challana, Tipuani, Mapiri rivers, or by wide spread alluvial fans (Chimate Formation) in areas not drained by rivers abundant in water and coming from the high parts of the Cordillera. An example for such an area is extending to the

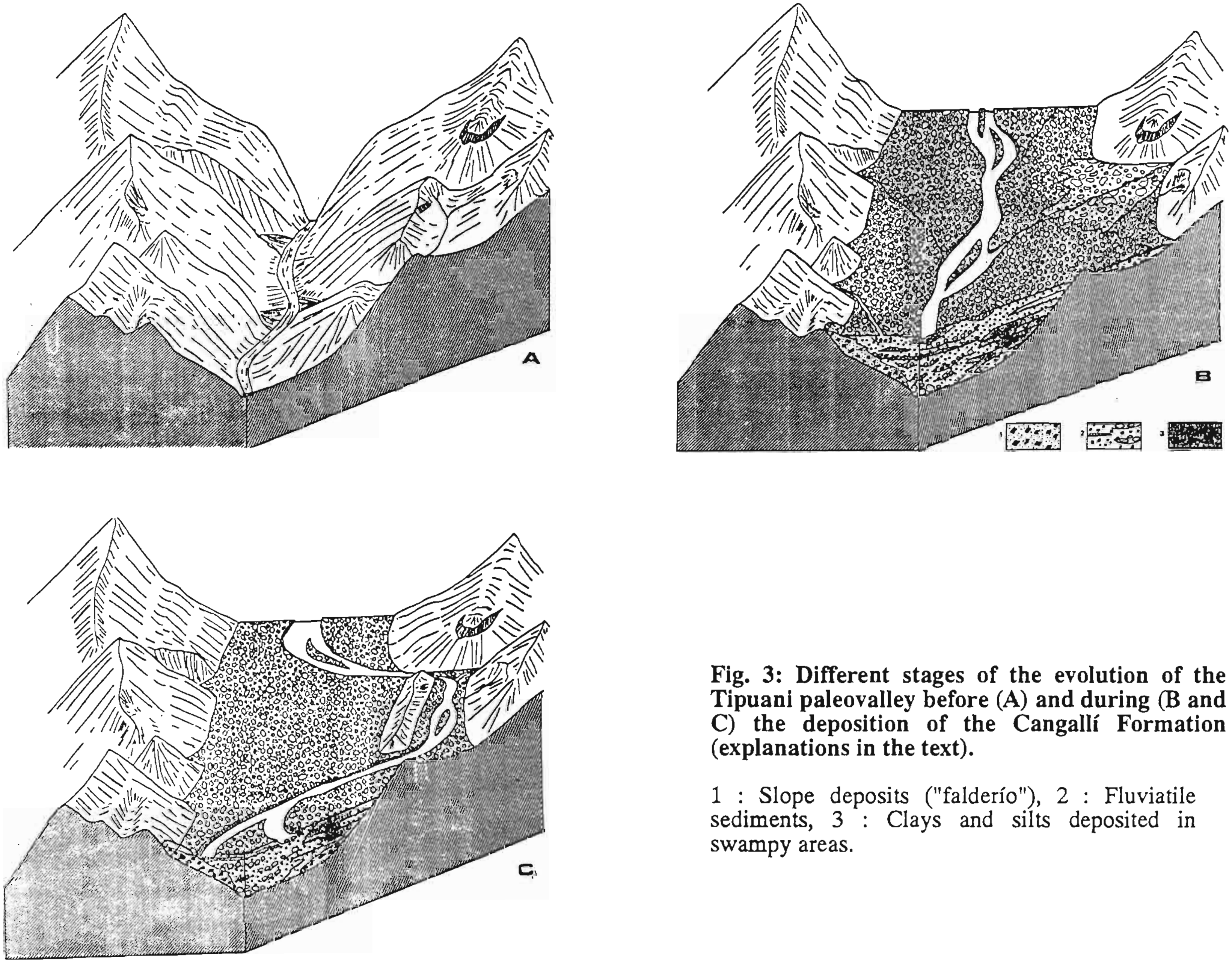


Fig. 3: Different stages of the evolution of the Tipuani paleovalley before (A) and during (B and C) the deposition of the Cangallí Formation (explanations in the text).

1 : Slope deposits ("falderío"), 2 : Fluviatile sediments, 3 : Clays and silts deposited in swampy areas.

NW of the Mariapo river until the Mapiri river (Hérail et al. 1986, 1988). Undoubtedly, (althrough the problem has not been studied in detail) it is from this surface, ending the filling of the basin, that a thick horizon of weathering develops, resulting in the superposition of the so-called "Blue Cangalli" by the so-called "Red Cangalli".

2.2. The deformation of the Cangalli Formation.

The respective sediments were deposited in a system of paleovalleys which came into existence following the rise of the Eastern Cordillera. Deposition and capturing of the sediments took place after the rise of the Serranía de Carura and the structuring of the Subandean, which caused the collapse of the drainage system.

The Serranía de Carura closed the basin in the Northeast and trapped the sediments now known as Cangalli.

Throughout the basin, surface and underground observations at the basin scale enable us to reconstruct the tectonical deformation and to interpret its development. Thus we know that in its actual position, the gradient of the paleo-valleys is steeper than the present valleys. The bed of the Tipuani river (fig. 2), upstreams of Unutuluni, lays some 300 metres lower than the bottom of the paleochannel filled with the Cangalli Formation as to be seen in the mines of Unutuluni. Further downstream, in the area actually occupied by the big sandbanks of Tipuani, the bottom of the paleochannel is found at about 190 m of depth and in Cangalli at about 210 m of depth (ORSTOM-UMSA ined.). Compared with the gradient of the present Tipuani, which is in the order of 0,3%, the gradient of the paleochannel is in the order of 4.5%, that does not correspond to an inclination for depositing sediments. The difference of gradients between the paleochannel and the present channel is the proof of orogenetic movements.

Deformation can be seen also in folding with strikes N120 - N130E, inverted faults striking in the same direction, as well as corridors where the conglomerate has been heavily tectonized. This is evident through the visible fracturing of pebbles. The evaluation of the microtectonical data reveals that the conglomerates suffered a subhorizontal compression with an orientation of about N050E (fig. 2). The folds and inverted faults observed in the basin belong to the same event (Lavenu 1986, Hérail et al. 1987, 1988, Fornari et al. 1987).

The oldest alluvial levels, younger than the Cangallí Formation (high terraces of the Tipuani River and the Chimate Formation) have not been affected by this deformation.

3. THE TIPUANI RIVER PALEOCHANNEL AND THE CANGALLI FORMATION BETWEEN GUANAY AND UNUTULUNI (FIG. 2 AND 4)

Between Guanay and Unutuluni, the Cangallí Formation outcrops along the Tipuani valley; at many places, good outcrops are easly accessed.

At many places, between Guanay and Tipuani, following the road, besides the Paleozoic which is part of the paleorelief that separates the Tipuani and Mariapo paleovalleys (fig. 2), "distal" sedimentary facies of the Cangallí Formation are also observed. These facies were deposited, downstream, where the water had low energy, between two main rivers. In the Aguada and Polopata area, these facies consist of fluviatile sediments which comprise conglomerate and interbedded clayish sands; the rocks dip gently to the SW.

The conglomerates - which have been deposited in the axis of the paleovalley - outcrop in the left (S to SW) side of the road; they form pyramidal shaped reliefs with red cliffs, characteristic of the Cangallí Formation. In the landscape, the position of the sediments filling a deep (almost 1,000 m in this place) paleovalley, excavated in the Ordovician bedrock, is clearly observed. From the Cerro Pilón (1,425 m) the paleogeomorphology of the Tipuani valley can be observed; also the present valley with mining workings.

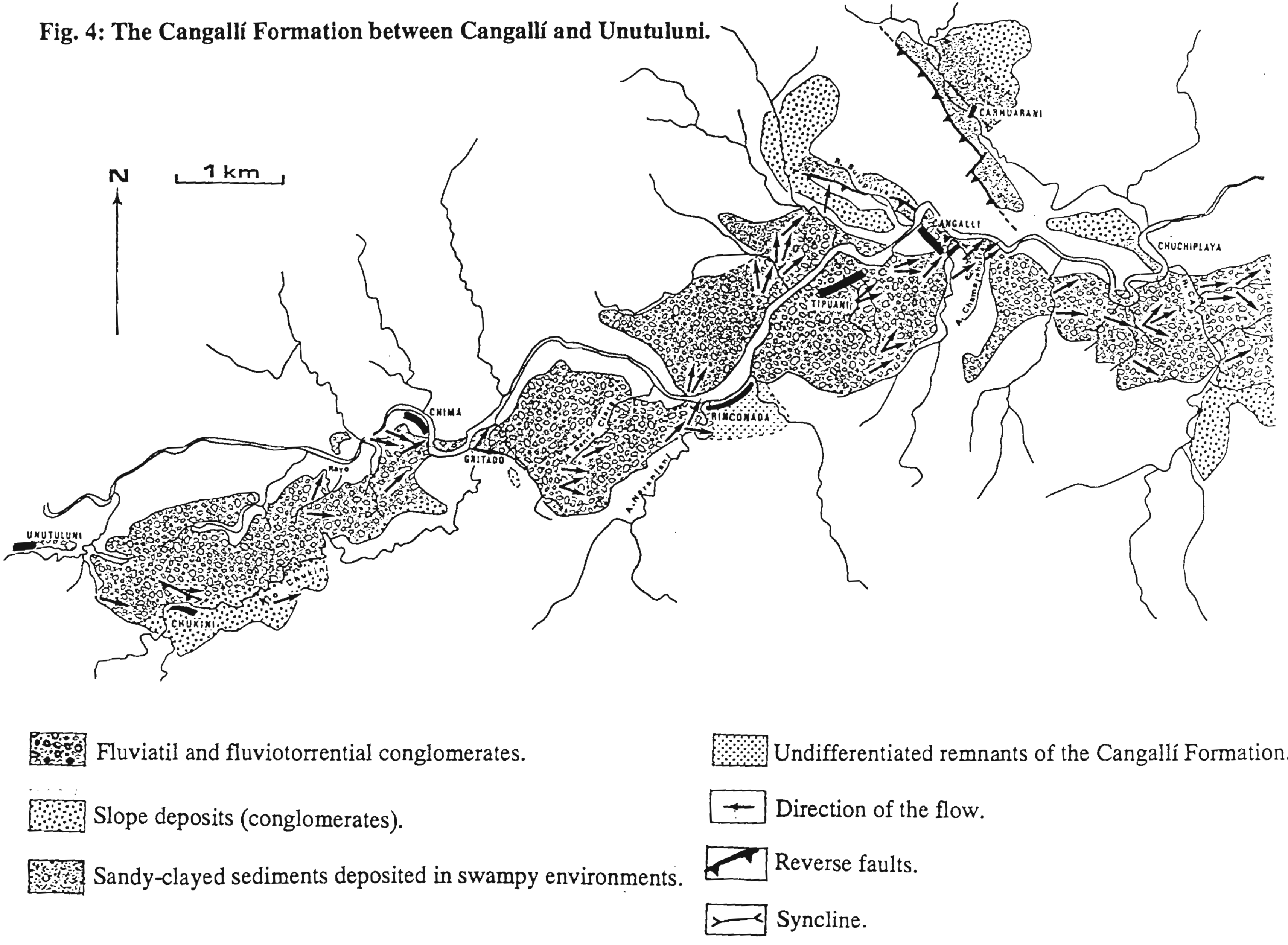
On the descend towards Carhuarani (728 m) one can appreciate the importance of the dissection, which took place before and after the Cangallí Formation deposition. Along this stretch, specific facies of the Cangalli Formation outcrop, here represented by sediments deposited in a low-energy environment. The sediments consist of conglomerates composed of small, well-rounded clasts, locally interbedded with conglomerates, composed of very slightly blunted clasts. The conglomerates overlay a suite of grey sands and silt, partly clayed and, locally, containing "lignites". These facies can be oberved when crossing the Carhuarani River. The sediments are folded and form an assymetric syncline which trends N130E; the southwestern limb is vertical, at places overturned or overthrusted by Ordovician slates.

In the stretch between Carhuarani, Suluplaya and Cangallí, facies of the same character are observed; towards Cangallí the conglomerates progressively predominate. These materials also are deformed: small inverse faults trending N120E-N130E and dipping more than 20° to the southwest, are seen; antithetic fractures generally dip steeper (about 45° to the NE). The deformation is also marked by intense fracturing of the clasts. Such microtectonic facies are clearly observed on the right bank of the Tipuani River, just in the entrance of the gorge, downstream from Cangallí.

Before going down to the Tipuani River and before reaching the Cangallí village, in the slope that dominates the latter, one can see some features of the paleovalley's physiography, where the Cangallí Formation was deposited (fig. 5). At the village's level, the paleovalley is 600 m wide and the paleoslopes have a rather steep gradient (almos 45°) similar to the gradient of present slopes. The data obtained by VES (ORSTOM-UMSA) indicate that in this area the bottom of the paleovalley probably reaches its highest depth, about 225 m under the present level of the river.

At many places between Cangallí and Unutuluni, for example in La Rinconada and in Gritado-Chima (fig. 4), similar situations are observed. In the Unutuluni region the uplifting and the post-Cangallí dissection were very important and we can observe the paleogeomorphology of the pre-Cangallí valley and the structure of the sedimentary filling. In the Tujojahuira section (fig. 6), detailed observations show the geometry of the paleovalley which is rather narrow (not more than some tenths of metres wide); it is also observed how the river could wander and enter into other openings (such as Copacabana) when the filling moved forward.

Fig. 4: The Cangallí Formation between Cangallí and Unutuluni.



These structures are filled with conglomerates consisting of coarse boulders towards the bottom (up to several cubic metres in volume) and less coarse boulders towards the top. The structure of the sediments changes drastically. In the bottom of the paleocanyon, pay-streaks are superimposed; they correspond to bottom of channels of torrential regime, whereas towards the top the channels are wider, with the width/depth ratio considerably increased, and poor in gold.

In the hanging paleocanyon of Copacabana, this type of structure is repeated, though less clearly and more difficult to observe.

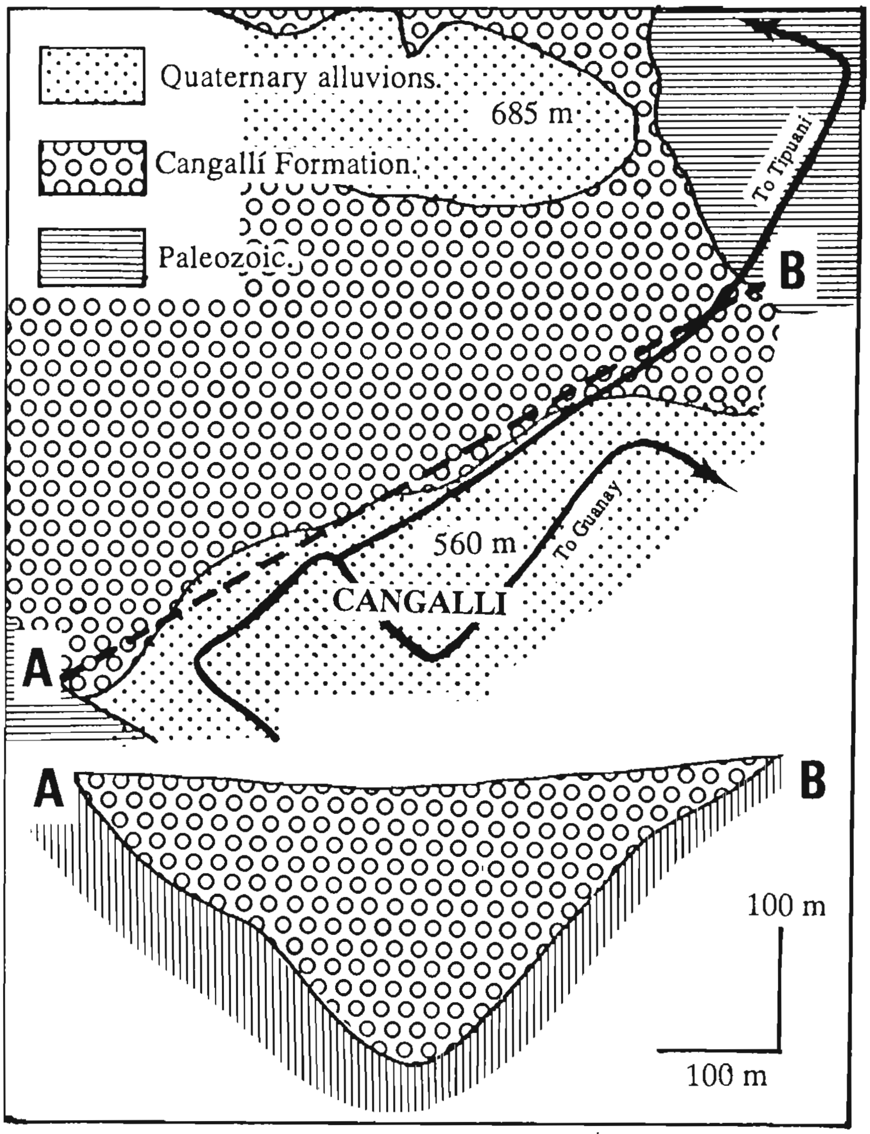


Fig. 5: The paleovalley of the Tipuani River in Cangallí.

Geological simplified map and transversal section. For this section, VES are used.

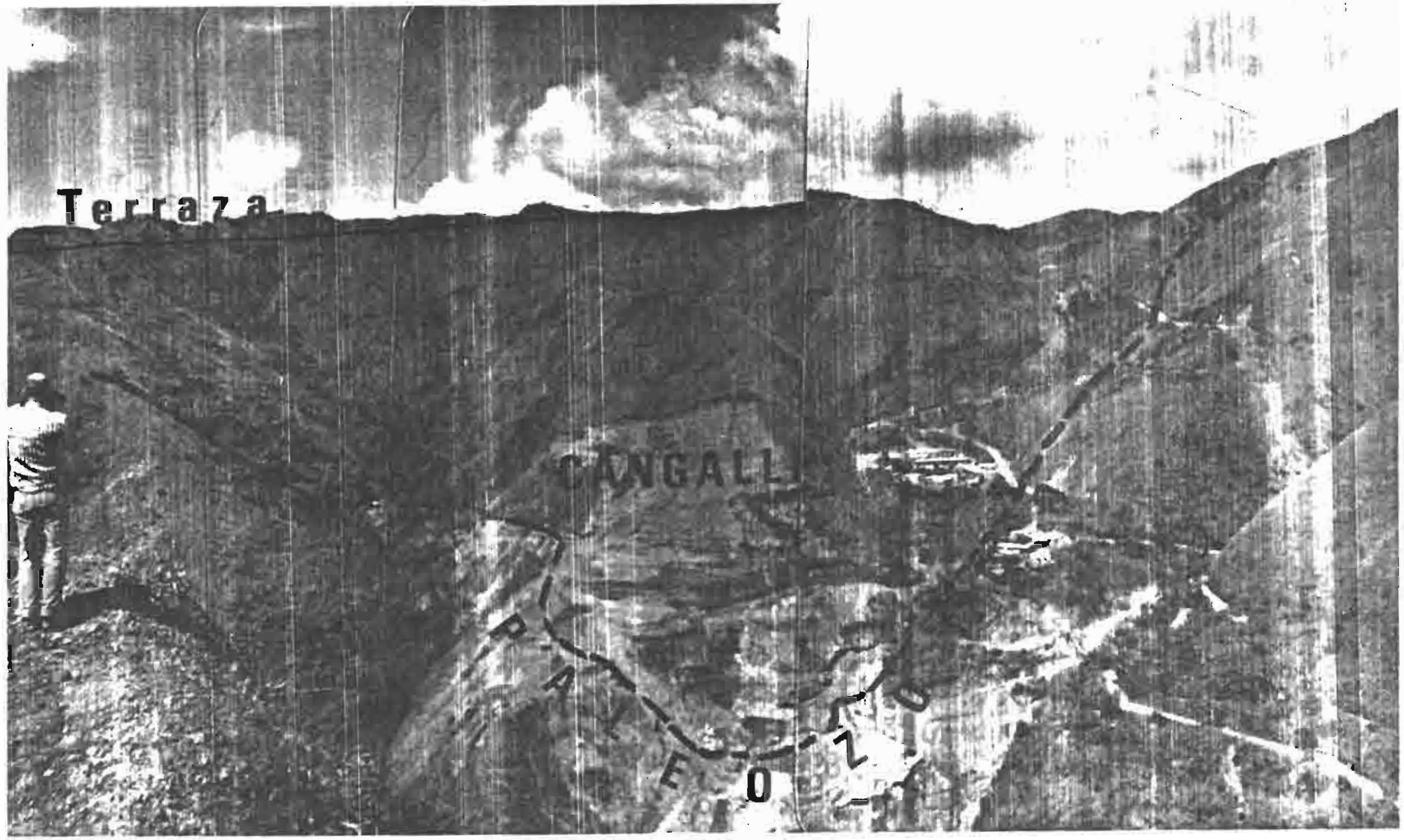


Fig. 6: The paleovalley of the Tipuani River in Tujojahuira seen from Unutuluni.

The morphology of the paleovalley filled by the Cangallí Formation can be seen. On the left (black arrow), the valley of Copacabana. Thick Quaternary terraces overlay the Cangallí Formation; on the photograph, the Paniagua level corresponds to the oldest level of the terraces system of the Tipuani River.

4. QUATERNARY ALLUVIAL DEPOSITS IN THE TIPUANI RIVER BETWEEN UNUTULUNI AND GUANAY; THEIR GOLD CONTENTS.

In this stretch of the river, the Quaternary deposits - if we exclude different types of colluvium - belong to fluviatile alluvium either in terraces or in the present bed of the river.

1) Terraces of the Tipuani river.

Due to a deep dissection (more than three hundred metres in altitude difference between the Paniagua apex and the present bed of the river), none of the terraces is continuous but there are remnants of several hectares in extension. These terraces are thick but not extensive, with an alluvium stratum commonly exceeding 30 m in thickness. This stratum includes a colluvium cover and small-sized, clayed sediments on the oldest horizons; the cover is barren and a few to ten meters thick. Under this stratum, the conglomerate is organized in a classical way, comprising various superimposed systems of channel filling with clasts which are progressively coarser towards the bottom. Unlike the sediments of the Cangallí Formation, which is usually overlain by the Quaternary alluvium, the Quaternary terraces contain clasts of granitic rocks coming from high parts of the Cordillera.

In the terraces, whatever their age may be, the vertical gold distribution follows the same model illustrated by the mineralized structure of terraces in the Montecarlo-La Rinconada region (Azevedo 1985). The 3,5-5.5 m thick cover contains less than 0.1 g/m^3; in the underlying, 5-7 m thick, conglomeratic horizon, the gold content is of the order of 0.2 g/m^3 whereas the 1.0-1.5 m thick basal conglomerate contains 0.6 g/m^3. However, the lateral distribution of gold and its contents vary according to the position in the bed of the river; consequently, the terraces are not equally mineralized.

2) The alluvial deposits of the present bed of Tipuani river.

The reputation of Tipuani proceeds from the extraction of gold in this type of alluvium. In the eighties, these deposits were mined by means of shafts and pits, and have given a large quantity of gold.

They exhibit obviously similar features to those in the terraces. But in this material certain investigations are easier, for instance, dating of observed phenomena.

Dowmstream from La Rinconada, the Tipuani river traverses two unbeached zones, in Tipuani and in Cangallí. The alluvial cover overlying either the Cangallí Formation or the Ordovician bedrock has a thickness of about ten metres. Taking as an example the alluvial deposits mined in Cangallí, we observe that this material is composed of two main sequences (fig. 7):

- a lower sequence, which is about 5 m thick, consists of a conglomerate deposited in channels of several metres in depth. In the sediment, boulders (50-60 cm in diameter) are preserved and more numerous towards the bottom; there are also some gigantic (2-3 m in diameter) granitic boulders. The latter are generally present in the contact with the bedrock though, locally, higher up, but always in the bottom of the channels. In Cangallí, wood fragments collected in the basal sequence yield a C14 age of 9,810 ± 190 years BP (fig. 7).

- one or some upper sequences which discordantly overlay the described sedimentary structures. In the bottom, they consist of a conglomerate with well-imbricated pebbles, whereas towards the top they go over to sand and silt which contain isolated pebbles. Wood fragments sampled in the base of this sequence (fig. 7) yield a C^{14} age of 340 year BP.

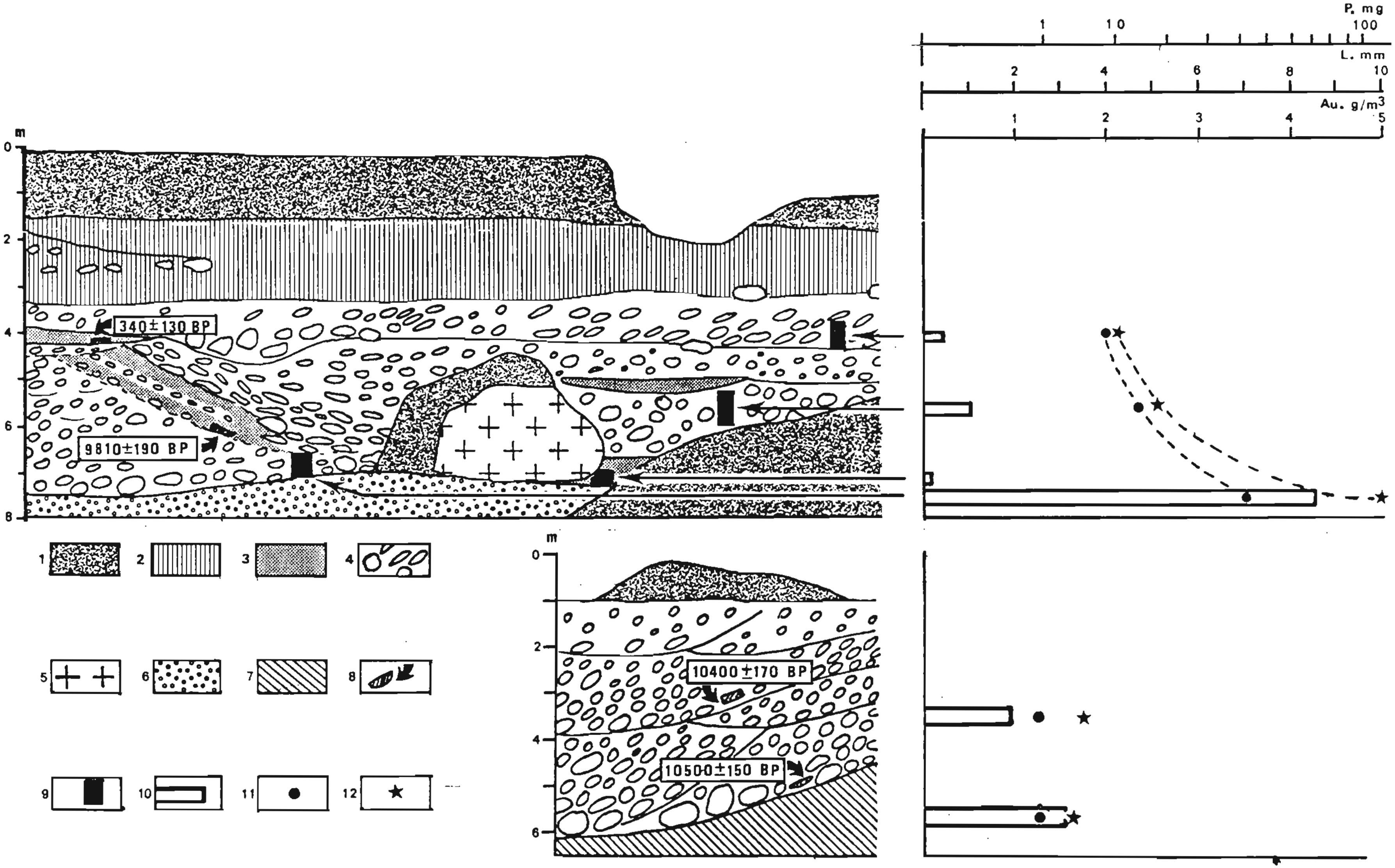


Fig. 7: Sedimentology, gold contents and gold grain granulometry of the auriferous alluvium of the Tipuani river bed and lower terraces in Tipuani (A) and Guanay (B).

1 : Terrains removed during the placers exploration, 2 : Silty cover, 3 : Silts and sands, 4 : Pebbles and boulders, 5 : Cyclopean leucogranitic block, 6 : Cangallí Formation, 7 : Ordovician, 8 : Sample of C^{14} dating location, 9 : Location of samples for determining gold values, 10: Gold content, 11: Length of the bigger gold grain of each sample, 12: Weight of the bigger gold grain of each sample.

The distribution and the features of gold reflect this dynamic change. The basal sediments of the lower sequence exhibit the highest gold contents (up to several grams per cubic meter) as well as the largest and heaviest particles (fig. 7); towards the top, the gold content decreases (hundreds of milligrams per cubic meter) and the particles are smaller.

This pattern of sedimentary structure and of gold distribution persists downstream. In the neighbourhood of Guanay, the alluvial deposits, mined by the Merma Ltda. cooperative, constitute an example: one can observe that the basal sequence is also made up of a superposition of channels (fig. 7). Those in contact with bedrock contain coarse pebbles and boulders. Wood fragments, dated by the C^{14} method yield 10,500 ± 150 years BP and 10,400 ± 150 years BP; there is no marked difference in age between basal channels and those which cover them in condition that the observations are made in the inferior ensemble. In the described case, the upper sediments were removed to allow mining of the rich lower alluvium.

So it appears that the auriferous alluvial deposits, mined in the present bed of Tipuani river, and the lower terraces, at least downstream from Tipuani, were deposited about 10,000 years ago, and quite rapidly. The more recent sediments are poorer in gold. Obviously, gold particles may come down from upper to lower levels; however, the most compact horizons, that outcrop in this alluvium do not play a clear role of false bedrock. This fact suggests that gold was deposited during different alluvial comings.

Upstream, in the gorge of Tipuani river, which drains the basin between Llipi and Unutuluni, it is much more difficult to observe the structure of the alluvial filling in the present bed. However, punctual observations of the alluvial deposits directly overlying the bedrock can be done in existing shafts. Here, the filling exceeds 30 m in thickness. The sediment consists of a conglomerate with very coarse boulders (at many places more than one cubic meter in volume) supported by pebbles and sand. In this sediment, tree trunks (a few to, locally, 30 m long) were trapped up. This fact suggests that the sediment was deposited during a period of huge floods. Three C^{14} ages were determined in the tree trunks: 33,800 years BP in the neighbourhood of Llipi (750 m a.s.l.), 31990^{+2250}_{-1760} years BP in Saiyuani (700 m a.s.l.) and 28,000 ± 600 years BP near Unutuluni (610 m a.s.l.).

It is no possible to carry out detailed observations, especially on the thickness of the alluvial cover, in the deposit preserved in the gorge of Tipuani river. It appears that a contribution of an older - than that observed in Tipuani - mineralization existed. We can certainly relate these different sediments to the main paleoclimatic changes that took place in the Cordillera for the last thirty millenaries.

5. GENERAL CHARACTERISTICS OF THE DETRITAL GOLD MINERALIZATION IN THE TIPUANI BASIN.

In the deposits of the Tipuani basins, whatever their age may be, the gold appears as free gold grains with variable shape and size. The composition of the heavy minerals suite varies along the Tipuani River.

1) The heavy minerals suite.

Opaque minerals (magnetite, ilmenite and pyrite) are prevailing among the heavy minerals in the deposits sampled along the Tipuani River. Only the transparent fraction has been systematically studied (fig. 8). Downstream, the Ordovician formations which contain mineralized quartz veins, supply espacially tourmaline, zircon (both detrital in the Ordovician),

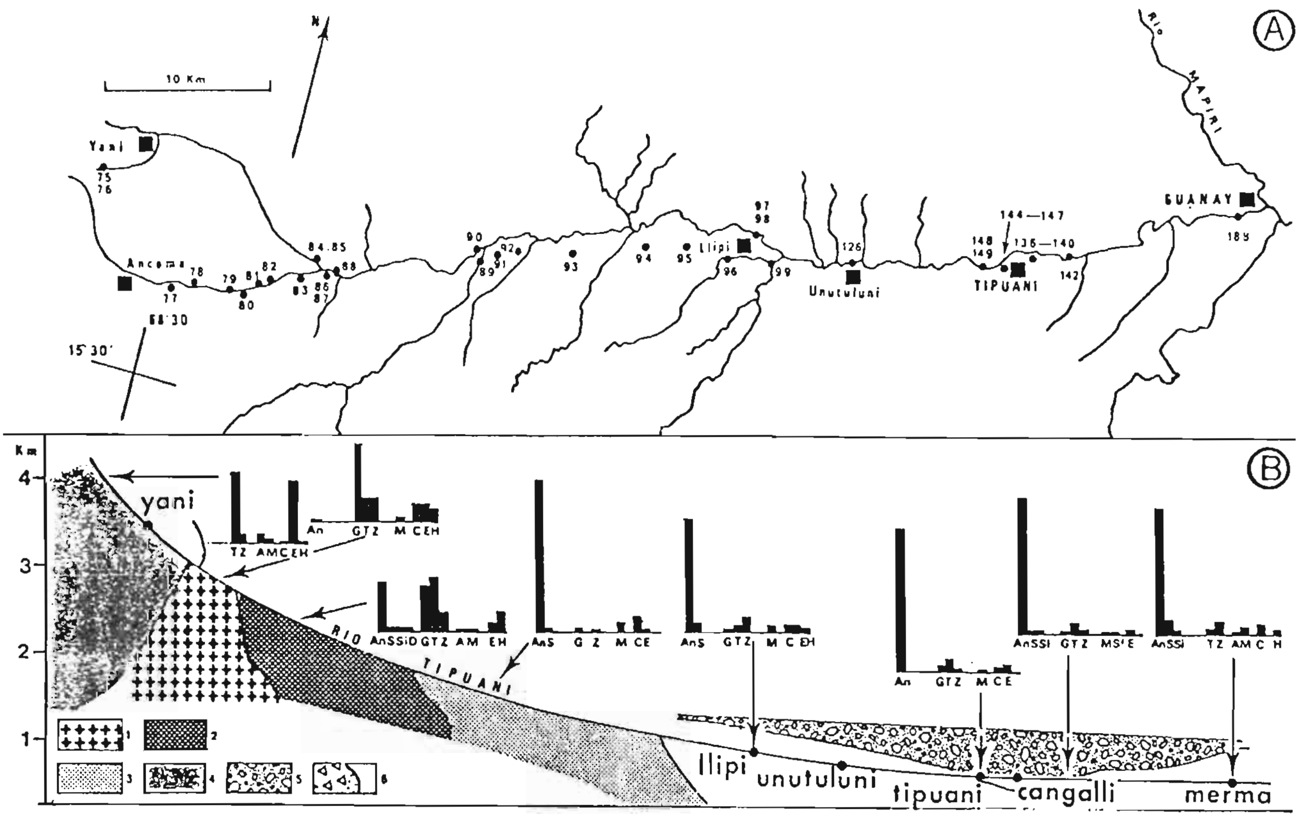


Fig. 8: Simplified section along the Tipuani valley and heavy minerals suite evolution in the Tipuani river bed. In A: location of the samples.

1 : Zongo granite, 2 : High and medium metamorphism zone, 3 : Low metamorphism zone, 4 : Paleozoic schists and sandstones, 5 : Neogene conglomerates (Cangallí Formation), 6 : Quaternary moraine.

Abreviations used in heavy minerals histograms :

An: Andalousite, S : Staurotide, Si: Sillimanite, D : Kyanite, G : Garnet, T : Tourmalin, Z : Zircon, A : Anatase, M : Monazite, C : Cassiterite, E : Epidote, H : Hornblende

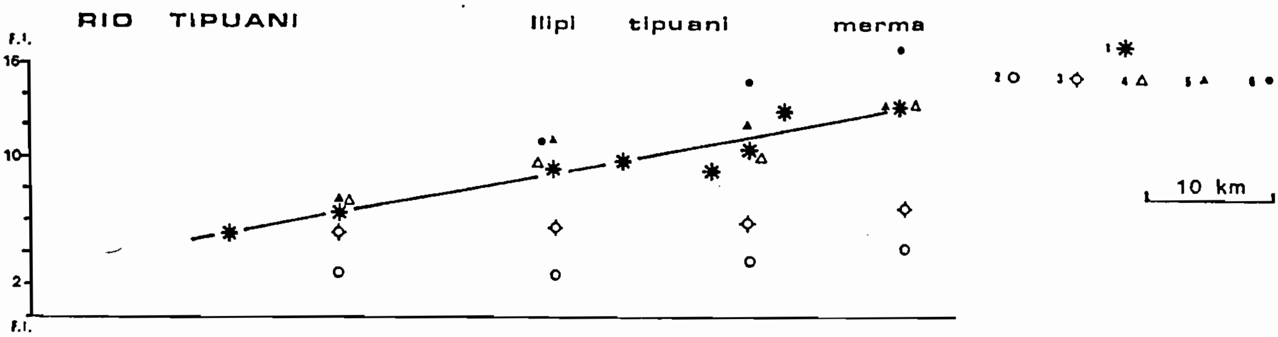


Fig. 9: Variation of the flatness index (F.I.) with the down river transport distance along the Tipuani river.

1: Mean values, 2: F.I. value for gold grains <0.25 mm length, 3: F.I. value for gold grains of 0.25 to 0.5 mm length, 4: F.I. value for gold grains of 0.5 to 0.75 mm length, 5: F.I. value for gold grains of 0.75 to 1 mm length, 6: F.I. value for gold grains of 1 to 1.25 mm length.

epidote, anatase... On crossing the Zongo leuco-granitic massif, garnet is added to these minerals and the cassiterite proportion increases. Further downstream, the erosion of the metamorphized outcrops (fig. 8) yields some sillimanite and very abundant andalusite. This latter is the prevailing mineral found downstream in Llipi as well in the Tipuani River (Delaune et al. 1991) as well as in the Kaka River (Morteani 1991).

2) The gold grains: morphology and composition.

The morphological evolution is characterized by an increase in the flatness index (fig. 9). Gold liberated by erosion of the lodes is constitued by xenomorphous grains of highly variable size. During the first 10 km from the source the original crystalline outlines have desappeared (fig. 10). The evolution is then marked by a blunting of the grains and the acquisition of a subcircular or oval bladed morphology (fig. 10). After been transported over a distance of 60 km the grains have been flattened so much by hammering that they are easily folded upon themselves (sandwiched grains) (fig. 10).

The increase in flatness index with the distance of transportion is a general feature which varies with the size of the grains involved. In the Tipuani River, the increase in flatness index is very low in grains with length less than 0.5 mm but it is pronounced in grains with length greater than 1 mm (fig. 9). It is within the grain size range of 0.5 to 1 mm that the rate of increase of flatness index during transportion in the Tipuani River corresponds most closely to the average change in flatness index.

The composition of the gold grains varies with the environment of deposition (fig. 11). The gold grains of the Yani lodes region contain from 4.5 to 6% of Ag, and less than 0.05% of Cu, as and Fe (Tistl 1985, Hérail et al. 1988, 1990). The gold of the primary mineralization of the Middle Ordovician, outcropping in the Tipuani-Mapiri basin contains up to 8% Ag (Hérail et al. 1988). The population of the gold particles contained in the Cangallí Formation is made of two groups of individuals. One group of particles has an average composition similar to the one in the primary mineralization (fig. 11: 5, 7 and 8). The other group much more important, consists of Ag depleted grains that present differences in composition from one point of analysis to another (fig. 11: 4 and 6).

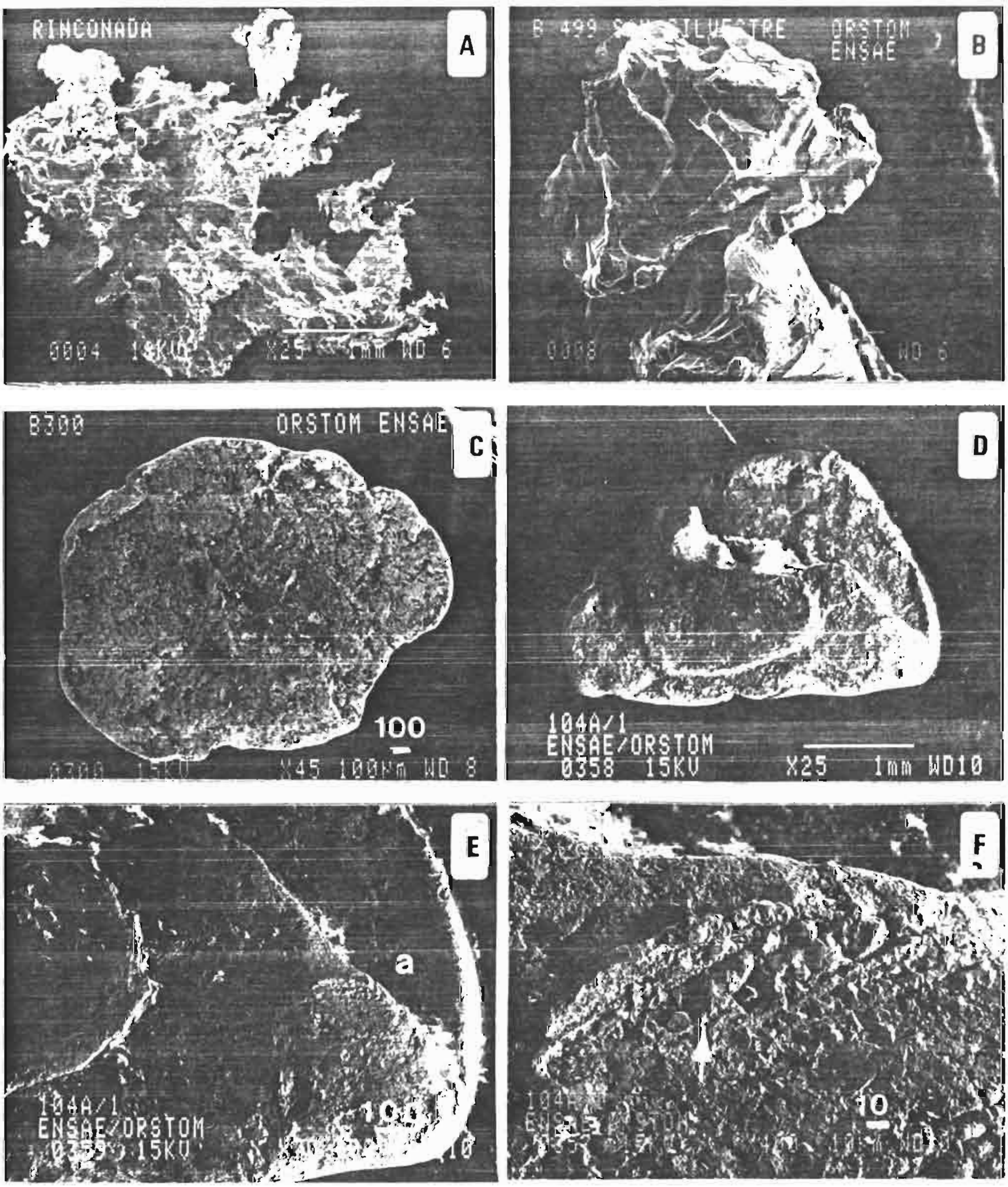

RINCONADA
A
ORSTOM
ENSAE
B
B300
ORSTOM ENSAE
C
100
X45 100µm WD 8
D
104A/1
ENSAE/ORSTOM
0358 15KV
X25 1mm WD10
E
a
104A/1
ENSAE/ORSTOM
F
10

Fig. 10: Morphology of the gold grains of the Tipuani valley.

A and B: Gold grains from the quartz veins of the upper Ordovician. C: Flattened and blunted gold grains from the aluvium of Tipuani area. D: Sandwiched gold grain from the weathered terrace of Paniagua (about 60 km of transport). E: Detail from D, in a: striae which indicate a fluviatil transport. F: Detail from E; in the inner part of the striation marks created during transport crystalline outlines are revealed by corrosion during the stay in the weathered profile. Small neoformed crystals are present on the surface of the primary crystals revealed by the corrosion.

(Scale in micrometers).

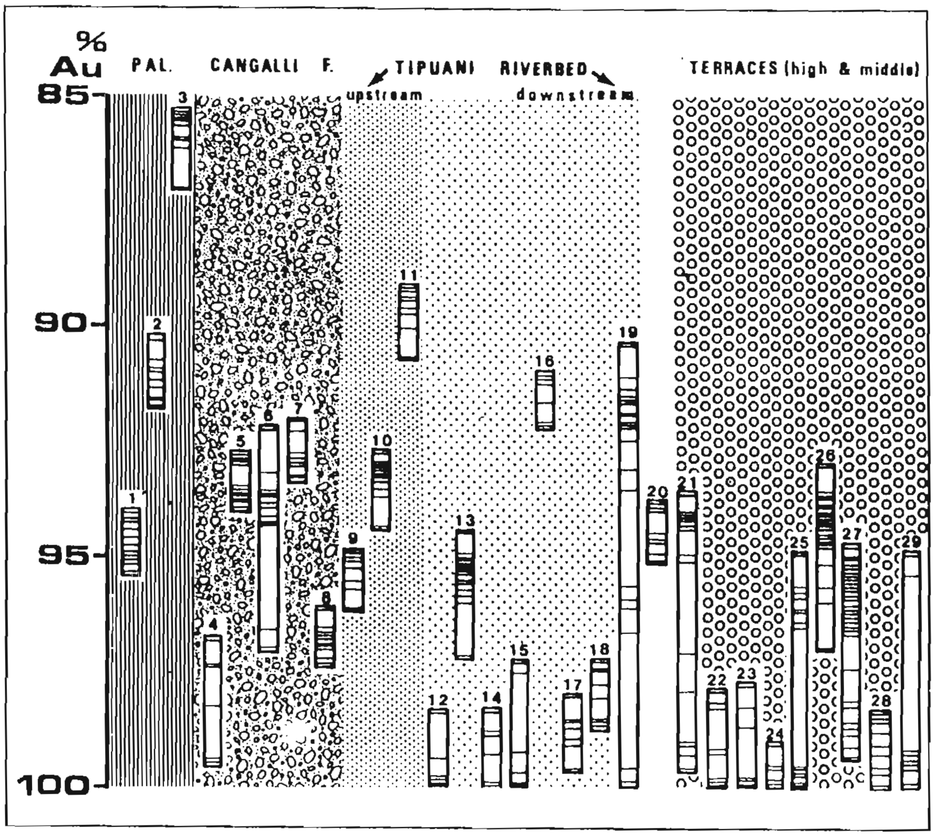


Fig. 11: Composition of the gold grains of lodes of the Cordillera Real and of the placers of the Tipuani basin. Explanations in the text.

The gold grains, that are contained in the alluvia of the terraces of the Tipuani river, show varying composition according to their position in the weathering profile. The grains 21 and 22 (fig. 11) come from the bottom of a middle terrace of the Consata-Mapiri river, below the weathering profile. The composition of the core of grain 21 is comparable to that of the gold grains of primary mineralizations of the Cordillera, whereas gold enriched rim is developed at the periphery; grains 22 is much richer in gold and shows a marked zonation. Grains 23 and 24, coming from the most weathered alluvial of the same terrace level, have an average fineness of more than 990, without clear spatial composition differences, contrary to grain 25, collected in a similar environment. Grains 26 and 27 come from the bottom of the oldest terrace and have been collected below the weathering front; both grains have a high average fineness and show a clear rim effect, event when the composition of the core is very close to those of the gold grains collected in the primary mineralization.

It appears that the most weathered alluvia of the terraces contain gold particles which show the greatest depletion in silver as well as the clearest marks of corrosion (fig. 10). On the other hand, below the level of weathering within the alluvials and also within the material of the present river beds, one observes gold grains with a great variety of Ag content.

An examination of gold grains collected from the present bed of Tipuani River shows the following:

- The particles that have been collected upstream from outcrops of the Cangallí Formation and old terraces have the same composition as the gold grains of the primary mineralization (fig. 11: 9, 10, 11). These particles do not show a silver depleted peripheral rim.

- The populations of particles that have been collected downstream from outcrops of the Cangallí Formation and Quaternary alluvial terraces are very heterogeneous; they are formed by a mixture of individuals of different composition:

. Particles very poor in Ag, which present either a notable difference in composition between the rim and the core (fig. 11: 15), or no marked difference in composition between the periphery and the core (fig. 11: 14, 17 and 18).

. Particles (fig. 11: 19) that show strong variations of the Ag content, the core bearing a composition similar to that of the primary mineralization, when the periphery is very rich in gold (fineness of about 999). This heterogeneity is also found on the scale of a sample such as those that have been collected in the Tipuani riverbed near Cangallí (fig. 11: 13 to 18).

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