Morphological and chemical evolution of gold grains during the formation of a polygenic fluviatile placer : the Mio-Pleistocene Tipuani placer example (Andes, Bolivia)

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Évolution morphologique et chimique des grains d'or au cours de la formation d'un placer fluviatile polygénique : exemple du placer mio-pléistocène de Tipuani (Andes, Bolivie)

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Néogène, Quaternaire
Tipuani (Bolivie)

Abstract

This study of gold grains sampled in the basin of Tipuani shows how gold grains have evolved in a fluvial placer formed for the last 10 Ma during the structural development of the Eastern Andes.

Whatever the age and the sedimentological significance of the host sediments, the morphology of the gold grains changes progressively during their downstream transport. Changes include an increase in the flatness and in the roundness, appearance of specific morphological features such as striation marks, folding and « sandwich structures ».

Gold composition is not homogeneous ; some grains show silver depleted rims, and cores with the same composition as that of the primary mineralization known in the Cordillera. No correlation occurs between transport distance and the chemical characteristics of the gold grains. Chemical evolution is related to the supergene alteration suffered by the host material.

The study of the morphogenic change of the gold grains therefore provides evidence as to the mode of transport and estimates as to the distance from primary sources, whereas the study of chemical composition permits one to distinguish between gold grains directly derived from primary mineralization and gold grains of more complex history which stayed in materials submitted to weathering.

Résumé

L'étude des paillettes d'or échantillonnées dans le bassin de Tipuani permet de montrer comment se transforment les paillettes au cours de la formation de placers fluviatiles contrôlée par l'évolution de la Cordillère orientale des Andes du nord-ouest de la Bolivie au cours du Néogène et du Quaternaire.

Quels que soient l'âge et les caractéristiques sédimentologiques des sédiments aurifères, la forme des grains d'or évolue progressivement au cours de leur transport vers l'aval dans le lit des rivières. Cette évolution se marque par un accroissement de l'aplatissement des paillettes, de leur émoussé et par l'apparition de traits morphologiques spécifiques (stries, redoublements, structures en sandwich).

La composition des paillettes n'est pas homogène ; certaines présentent une auréole externe appauvrie en argent alors qu'au cœur la composition est identique à celle des grains d'or contenus dans les minéralisations primaires connues dans le Paléozoïque de la Cordillère. Il n'y a aucune corrélation entre la distance parcourue par les paillettes dans le lit des cours d'eau et leur composition chimique. Celle-ci est contrôlée par l'altération météorique subie par le sédiment dans lequel ont séjourné les paillettes.

L'observation des caractéristiques morphoscopiques des paillettes ainsi que l'évolution progressive de ces caractéristiques au cours du transport renseignent sur l'agent de transport et permettent d'estimer la distance parcourue depuis les zones primaires sources, tandis que l'étude de la composition permet de séparer les grains d'or provenant directement de l'érosion de minéralisations primaires de ceux qui ont eu une histoire plus

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complexe et qui, par exemple, ont séjourné dans des sédiments soumis à la météorisation.

Introduction

Placer gold grains show higher fineness than primary lodes gold grains (Pliny the Elder 79 A.D. ; McConnel, 1907 ; Fisher, 1945...). However, detailed analyses have shown (Ramdohr, 1965 ; Desborough, 1970) that the average fineness increase is due to the formation of a high fineness rim, while the core of the gold grains keeps a composition similar to of the primary mineralization sources. Consequently, some authors have concluded that the composition of the core of the gold particles (Desborough *et al.*, 1978 ; Giusti and Smith, 1984, for example) or the average composition of placer gold particles (Mosier *et al.*, 1989) could be considered as constituting the composition of primary mineralization sources.

Beyond composition, the morphology of particles evolves during transport, as a function of distance and of the agent of transport (Ramdohr, 1965 ; Yeend, 1975 ; Hérail, 1984, 1988). The analysis of the morphology of gold grains makes it then possible to separate, in placers, detrital particles from the ones that could have been neo-formed (Saager, 1969 ; Hallbauer and Utter, 1977 ; Utter, 1979 ; Hallbauer, 1981) or to recognize the sources that provided the detrital gold (Hallbauer and Utter, 1977 ; Hérail *et al.*, 1988, for example).

The separate study of the morphology and composition of the gold grains collected in a placer, however, only allows an approximation as to their evolution in relation to primary gold grains contained in source mineralization. The purpose of this paper is to show how the combined analysis of the morphological and chemical evolution of gold grains collected in a polygenic placer (the Tipuani-Mapiri gold placer, Andes of Bolivia) provides a definition of the different steps of evolution of the gold grains and a reconstruction of the history of gold grains contained in the placers of the river beds.

Gold-bearing mineralization of the Cordillera Real of Bolivia and associated placers

In the Cordillera Real of Northern Bolivia, gold is exploited from an altitude of over 4 000 m, near the glaciers of the Illampu, down to an altitude of around 500 m, in the tropical rain forest. Primary gold mineralization, located on the Northeastern side of the Cordillera (Yani district) occurs in concordant and cross-cutting gray-blue gold quartz veins within sandstones and pelitic sediments of the Upper Ordovician (Ahlfeld and Schneider-Scherbina, 1964) associated with sills of spilitised rocks defined as the product of a submarine syn-sedimentary magmatism (Tistl, 1985). Outside the Yani district, some gold veins are exploited in the Silurian slates and in the hornfels surrounding the Illampu batholite (Ahlfeld and Schneider-Scherbina, 1964). Showings within cross-cutting gold quartz veins have been discovered in the Llanvirnian pelites on the lower part of the NE slope of the Cordillera Real (Hérail *et al.*, 1988).

The major part of gold production in this region (estimated to about 2 tons/year) comes from river bed placers and Quaternary alluvial terraces of the Consata-Mapiri river, Tipuani river, Challana river and their tributaries as well as from the Middle Miocene conglomerates (Cangalli Formation), retained in the Tipuani-Mapiri basin (fig. 1). The Cangalli Formation (Frochot, 1901 ; Stoll, 1961 ; Freydank, 1965 ; Hérail *et al.*, 1986 ; Fornari *et al.*, 1987) corresponds to fluvio-torrential and fluviatile sediments that partially overly a fluviatile erosion paleotopography most probably between Upper Oligocene and Lower Miocene. It is mostly made up of fragments of Ordovician rocks and shows a maximum thickness of about 500 m.

After deposition, the weathering of these sediments, produced a thick (more than 50 m) rubefacted and slightly argillaceous zone (« el Cangalli Rojo »), which is underlain by not-weathered sediments that have retained their original grey-blue color (« el Cangalli azul »). During Quaternary entrenchment of the valleys, alluvial terraces were built which are weathered progressively with age. On the highest and oldest levels, the weathering profile is about twenty meters thick on average, and its upper part corresponds to a tropical ferruginous soil.

Sampling and analytical methods

Samples of about 100 kg were collected from natural outcrops and from mining faces. The samples are reduced in the field by sieving and the remaining materiel is carefully panned. In the laboratory the material is further concentrated using heavy liquids and a Frantz electromagnet. Gold grains are then obtained from this concentrate by hand-picking using a stereomicroscope. Sixty six samples have been treated, from which 1 287 gold grains have been extracted to provide study material for this work.

The grains are measured, weighted and their morphology described under optical microscope ; some grains are examined in SEM, according to criteria established in previous studies (Hérail, 1984) such as general shape, surface aspects (impacts, striations, corrosion marks, recrystallization features) and outlines (blunted edges, up-turnings, folds...). The general morphological evolution of the grains goes along with an increase in the flatness, that can be quantified by using one of the different indices calculated to describe the detrital grains. For the gold grains, the Corey factor (Corey, 1949 *in* Tourtelot and Riley, 1973) has been used by some authors, but we prefer the Cailleux flatness index (F.I.) (Cailleux and Tricart, 1959) because it gives a wider range of values. It is defined by the relation $(L + b)/(2\ t)$, where L is the length, b the breadth and t the thickness ; for a spherical or cubic particle, the value of F.I. is 1.

The analyses of the chemical composition of the gold grains is made using an electron microprobe (Camebax) on polished sections. The following elements Au, Ag, Cu, Fe, As, Hg, S, Co, Ni, Sb, Bi were tested operating with 25 kV accelerating voltage an a current of 15 nA and count of 40 sec per element. Only Au, Ag, Cu, Fe and As were frequently detected ; in this paper we will only refer to the gold and silver content expressed by the fineness (Au/Au + Ag × 1 000).

Results

Evolution of the morphology of the gold grains during their transport in the valleys of the Cordillera Real

The present evolution of the gold grains transported in the present rivers of the Amazonian side of the Cordillera Real has been characterized by the study of gold particles collected in the alluvia of the Consata-Mapiri and Mapiri rivers beds (fig. 1). The average discharge of the Tipuani river at Guanay is 110 m^3/s, and the one of the Mapiri river, upstream from Guanay is 450 m^3/s ; the median of the annual daily maxima is 520 m^3/s for the Tipuani river and 1 900 m^3/s for the Mapiri River (Guyot *et al.*, 1988 ; Bourges and Carrasco, personnal comm. 1989). The slope of these rivers is higher than 3 % until the Consata village for the one and until the Tipuani village for other. It decreases then, down to values of the order of 1 % ; between Mapiri and Guanay, the slope of the river is only about 0.3 %.

Gold liberated by erosion of the lodes is constituted by xenomorphous grains of highly variable size (fig. 2, photo 1). Within 10 km of the source, the original crystalline outlines have disappeared (fig. 2, photo 2). The evolution is then marked by a blunting of the grains and the acquisition of a subcircular or oval bladed morphology (fig. 2, photo 3). After transport over a distance of about 60 km the grains have been flattened so much by hammering that they are easily folded upon themselves (sandwiched grains) (fig. 2, photo 4). The mean flatness index of the population of gold grains increases in relation to the distance covered. For a population of gold grains of primary gold lodes, the average value of F.I. is between 2 and 4 ; it reaches 9 after a transport of about 30 km, and 15 after 60 km (fig. 3) ; this value does not increase significantly beyond 60 km.

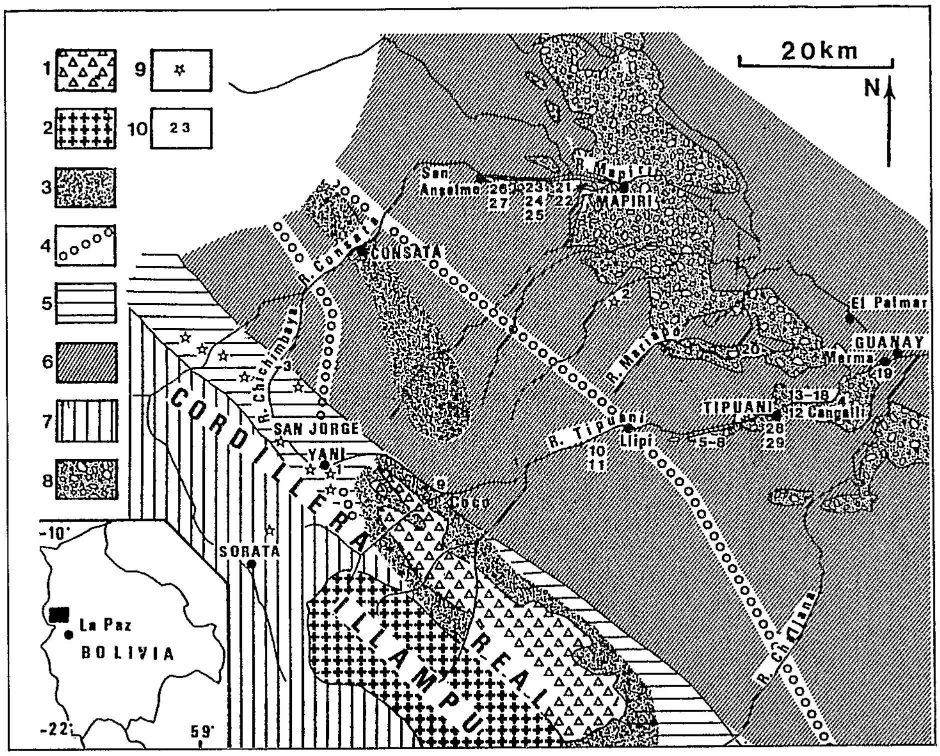


Fig. 1. — Geology and gold occurrences in the Cordillera Real (after Hérail *et al.*, 1988).
1 : syntectonic granite of Zongo-Yani (eo-Hercynian) ; 2 : Illampu granodiorite (Triassic) ; 3 : medium to high-grade thermal metamorphism ; 4 : biotite boundary ; 5 : shales and sandstones (Caradocian) ; 6 : black shales (Middle Ordovician, p.p. Llanvirnian) ; 7 : schists (Silurian-Devonian) ; 8 : Cangalli Formation (Neogene conglomerates) ; 9 : primary gold occurrences ; 10 : location of the samples of figure 6.

Fig. 1. — Schéma géologique de la Cordillera Real avec l'indication des indices d'or (d'après Hérail et al.*, 1988).*
1 : granite syntectonique éo-hercynien de Zongo-Yani ; 2 : granodiorite d'Illampu (Trias) ; 3 : métamorphisme thermique moyen à fort ; 4 : limite de la biotite ; 5 : shales et grès (Caradoc) ; 6 : black shales (Ordovicien moyen, Llanvirnien p.p.) ; 7 : schistes (Siluro-Dévonien) ; 8 : formation de Cangalli (conglomérats néogènes) ; 9 : indices d'or primaire ; 10 : localisation des échantillons de la figure 6.

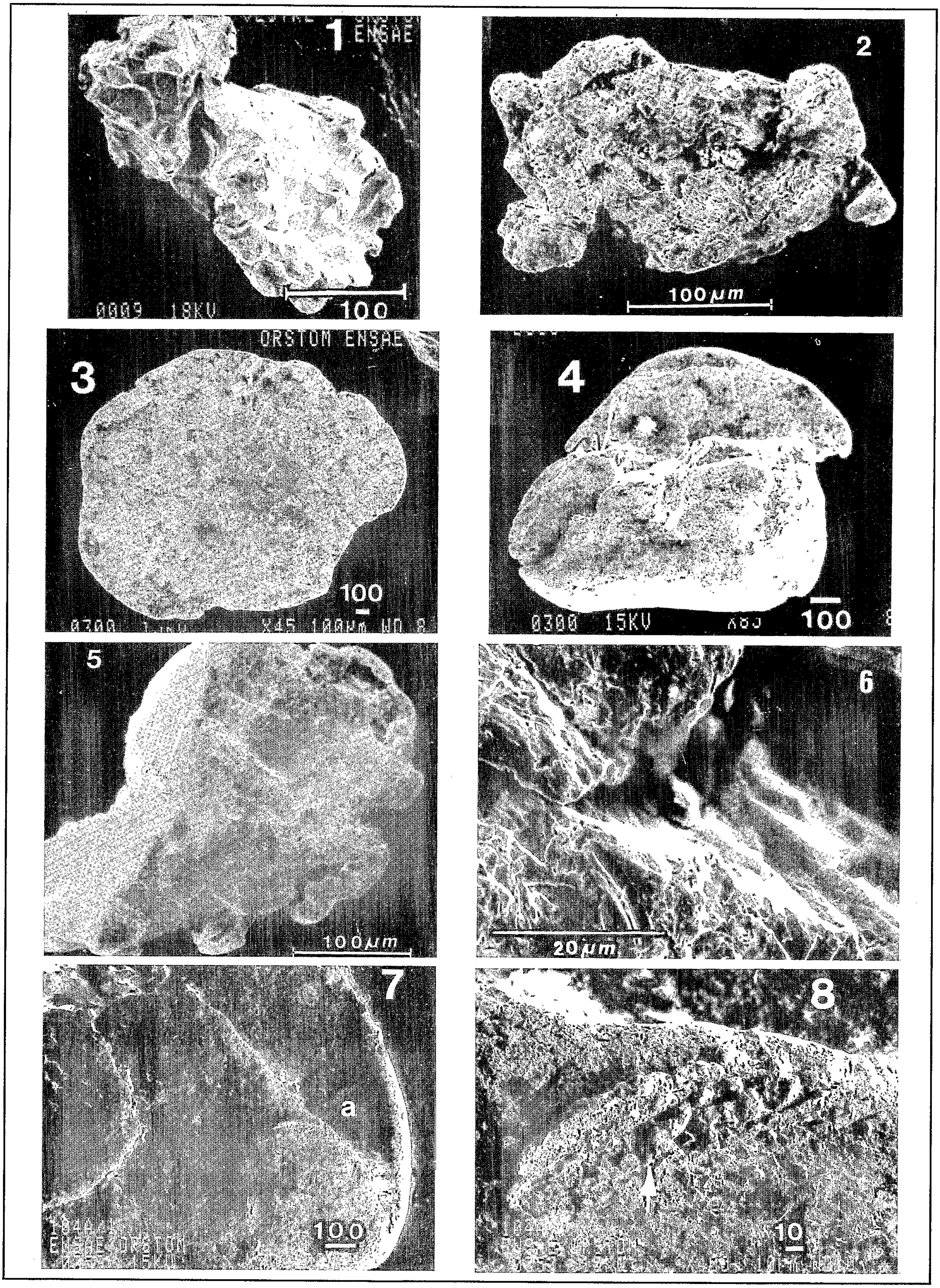
This increase in flatness index with the distance of transport is a general facture which varies with the size of the grains involved (fig. 4). A case in point is that of the Tipuani River where the increase in flatness index is very slight in grains with lengths less than 0.5 mm but is pronounced in grains with lengths greater than 1 mm (fig. 3). It is within the grain size range of 0.5 to 1 mm that the rate of increase of flatness index during transport in Tipuani River corresponds most closely to the average change in flatness index.

Nevertheless it should be noted that :

— Although the value of F.I. for particles less than 0.5 mm does not increase significantly with transport (fig. 3 and 4), the form of these particles does change, and it is the process of folding which acts to mantain low F.I. values.

— During the transport the thickness and the size of the gold particles tend to stabilize downstream with the evolution of the hydrodynamic conditions and granulometric selection. This explains that after a certain distance the F.I. does not increase or may even decrease due to the effects of folding. For particles of length about 1.5 to 4 mm the thickness stabilizes to values of about 0.1 to 0.2 mm after about 15 km of transport which means that the value of F.I. is mainly controlled, for the biggest particles, by variations in length.

For all these reasons, the shape analysis of particles deforming within the fluvial environment is preferentially carried out on particles with lengths from 0.5 mm to 1.25 mm al-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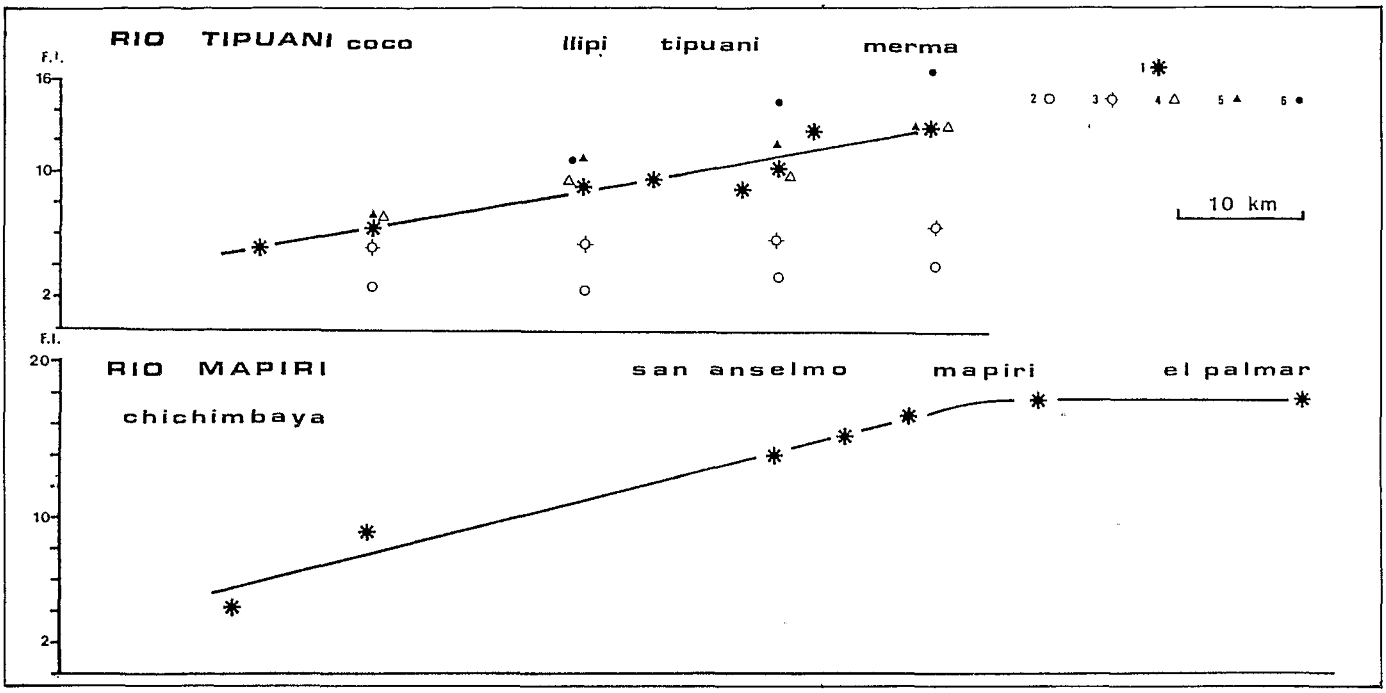

Fig. 3. — Variation of the flatness index (F.I.) with the down river transport distance along the Tipuani and Mapiri rivers.
1 : mean values ; 2 : F.I. value for gold grains < 0.25 mm length ; 3 : F.I. value for gold grains of 0.25 to 0.5 mm length ; 4 : F.I. value for gold grains of 0.5 to 0.75 mm length ; 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.

Fig. 3. — Variations de l'indice d'aplatissement (F.I.) en fonction de la distance de transport le long des rivières Tipuani et Mapiri.
1 : valeurs moyennes ; 2 : valeur de F.I. pour les grains d'or de longueur < 2,5 mm ; 3, 4, 5, 6 : valeur de F.I. pour une longueur de grain comprise entre 0,25 et 0,5 mm ; 0,5 et 0,75 mm ; 0,75 et 1 mm ; 1 et 1,25 mm.

though the morphological analysis of particles of less than 0.5 mm length provide much information. On the other hand particles of greater than 2 mm length are of little interest.

The same change of morphology and the same rate of variation of the flatness index characterize the gold grains that come from the Quaternary terraces of the Consata and Tipuani rivers. However on the surfaces of the grains from the alluvia of the terraces, structures formed during weathering of the alluvia can be superimposed on the structures acquired during transport (fig. 2, photos 7 et 8). Corroded shapes are the most common, whereas recrystallization features are scarce.

A detailed examination of the particles collected along the rivers Tipuani and Consata-Mapiri, and along secondary rivers (fig. 5) shows that the regular increase of the mean F.I. of the populations in relation to the distance of transport goes along with the persistence, over considerable distances along the valleys, of a low proportion (2 to 8 %) of grains with a F.I. comparable to that of gold grains that are contained in the primary mineralization. Beyond their low flatness, these grains show very irregular outlines and little or no folding. Primary crystalline outlines are conserved in cavities that are protected from erosion (fig. 2, photos 5 and 6). This suggests that these grains have been transported over less than a few kilometers, and that primary gold mineralization is also present in the Paleozoic outcrops along the lower part of the Tipuani basin (Hérail *et al.*, 1988).

Composition of the gold particles contained in the alluvia of the valleys of the rivers Tipuani and Consata-Mapiri

The average fineness of gold grains coming from primary mineralization is lower than that of the alluvia on the eastern side of the Cordillera Real. However, these differences conceal an important heterogeneity of fineness values, either at the populations level or at the individuals level (fig. 5).

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Fig. 2. — Morphology of gold particles of the Amazonian slope of the Cordillera Real.
1 : xenomorphous gold grains of quartz veins of Yani district ; 2 : very little flattened and blunted gold grain ; upstream of the Tipuani river ; less than 10 km of transport ; 3 : flattened and blunted gold grain, bending in the left ; Tipuani valley, near Tipuani village ; 4 : « sandwiched » gold grain. 70 to 80 km of transport, Mapiri river, between Mapiri and Guanay ; 5 : immature, poor flattened and blunted, gold grain with very irregular topography ; Mariapo river ; 6 : detail of 5, original crystalline outlines preserved in the cavities. (This indicates very short distance) ; 7 : detail from a blunted gold grain with a sandwich structure and stries (a) which indicates a transport distance of about 60 km : gold grain from the weathered upper terrasse of rio Tipuani ; 8 : detail a of # 7 : 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 cristals are present on the surface of the primary cristals revealed by the corrosion. (Scale is in micrometers).

Fig. 2. — Morphologie des particules d'or du versant amazonien de la Cordillera Real.
1 : grain d'or xénomorphe des filons de quartz du district de Yani ; 2 : grain d'or très légèrement aplati et émoussé ; cours supérieur de la rivière Tipuani (transport inférieur à 10 km) ; 3 : grain d'or aplati et émoussé, recourbé vers la gauche ; vallée de Tipuani, près du village de Tipuani ; 4 : grain d'or « en sandwich » ; rivière Mapiri, entre Mapiri et Guyanay (70 à 80 km de transport) ; 5 : grain d'or immature, à émoussé et aplatissement faible, présentant une surface très irrégulière ; rivière Mariapo ; 6 : détail de ce dernier grain où l'on peut observer les limites originelles des cristaux, préservés dans des cavités, ceci indique un transport sur une très petite distance ; 7 : détail d'un grain d'or émoussé avec une structure « en sandwich » et des stries (a) qui indiquent un transport sur une distance d'environ 60 km ; grain d'or provenant de la terrasse supérieure altérée du Rio Tipuani ; 8 : détail de a du grain ci-dessus : dans la partie interne des stries dues au transport, les limites cristallines sont mises en évidence par la corrosion pendant le séjour dans le profil d'altération ; de petits cristaux sont observés à la surface des cristaux primaires révélés par la corrosion. (Échelle en microns).

Composition of gold grains of the primary mineralizations of the Cordillera

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. The gold of the primary mineralization of the Middle Ordovician, outcropping in the Tipuani-Mapiri basin contains up to 8 % Ag. Nevertheless, the gold mineralization of the San Jorge mine (fig. 1) contains two populations of gold grains of very different composition : one is similar to the mineralization of the Yani district, the other contains 15 to 22 % of Ag (Tistl, 1985). This is reflected in the detrital grains that have been sampled in alluvia in the valley of the river Chichimbaya, where we found gold grains that contained up to 18 % Ag.

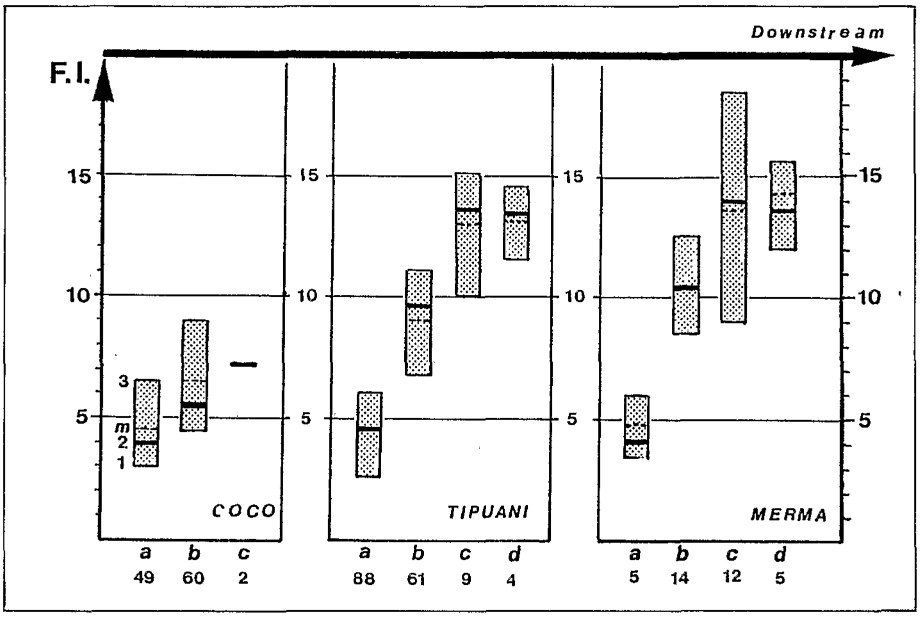

Fig. 4. — Flatness index (F.I.) variation related to the size of the gold grains.
a : 0 to 0.5 mm lenght class ; b : 0.5 to 1 mm ; c : 1 to 1.5 mm ; d : 1.5 to 2 mm ; (1, 2, 3 : first, second and third quartile, m : mean).

Fig. 4. — Variations de l'indice d'aplatissement (F.I.) en fonction de la taille des grains d'or. a, b, c, d : classes, en mm de longueur : 0-0,5 ; 0,5-1 ; 1-1,5 ; 1,5-2 ; (1, 2, 3 : premier, second et troisième quartiles ; m : moyenne).

Composition of gold grains of the Cangalli Formation

The population of the gold particles contained in the Cangalli Formation is made of two groups of individuals. One group of particles has an average composition similar to the one of particles contained in primary mineralization (fig. 6 : 5, 7 and 8). The other group, much more important, consists of Ag depleted grains that present differences in composition from one point to another (fig. 6 : 4 and 6).

Composition of gold grains of actual Tipuani riverbed

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

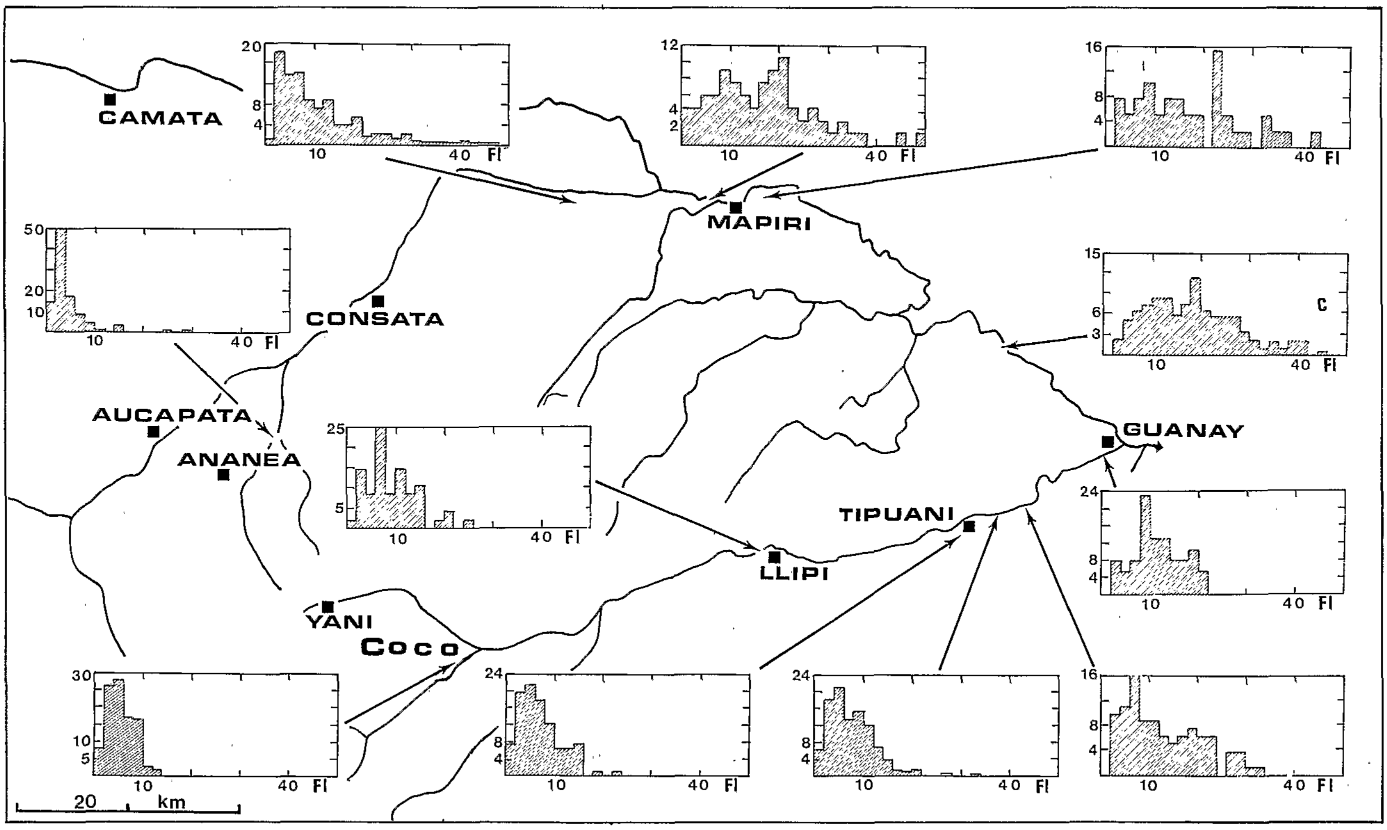

Fig. 5. — Histograms of the gold grains flatness along the Tipuani and Mapiri rivers.

Fig. 5. — Histogramme de l'aplatissement des grains d'or le long des rivières Tipuani et Mapiri.

— The particles that have been collected upstream from outcrops of the Cangalli Formation and old terraces have the same composition as the gold grains contained in primary mineralization (fig. 6 : 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 Cangalli 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. 6 : 15), or no marked difference in composition between the periphery and the core (fig. 6 : 14, 17 and 18).
- Particles (fig. 6 : 19) that show strong variations of the Ag content, the core bearing a composition similar to that of 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 Cangalli (fig. 6 : 13 to 18).

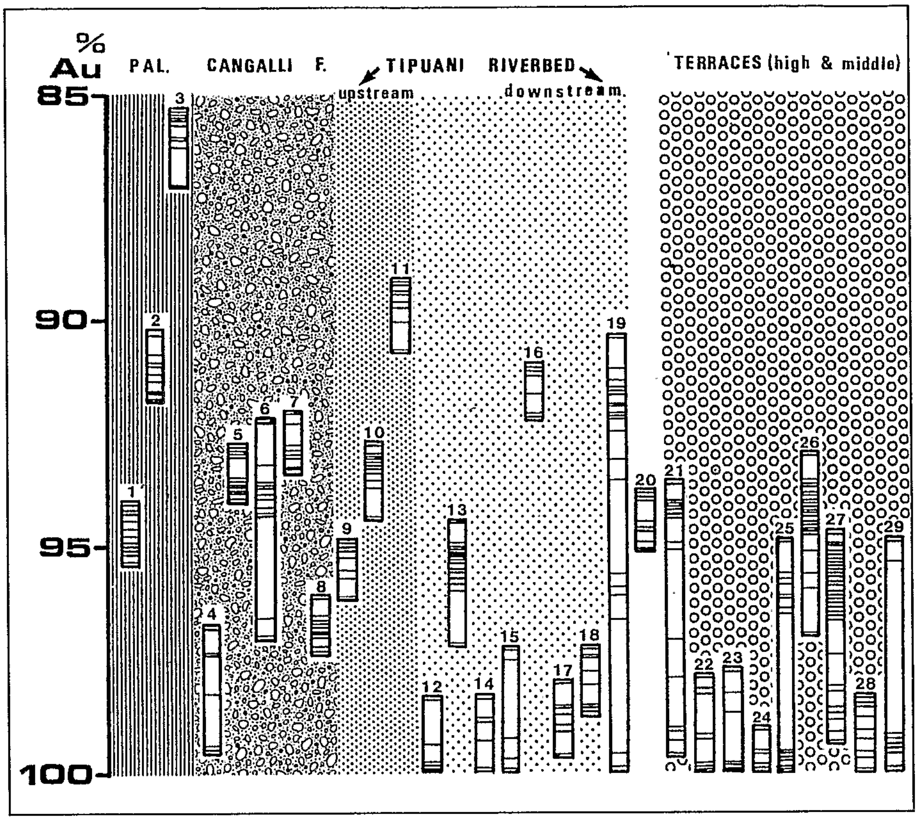

Fig. 6. — Composition of the gold grains of lodes and placers of the Cordillera Real. Location of the sample see fig. 1. Explanation in the text.

Fig. 6. — Composition des grains d'or provenant de filons et placers de la Cordillera Real. Voir figure 1 pour la localisation des échantillons. Explications dans le texte.

Composition of gold grains of the terraces of Consata-Mapiri and Tipuani river

The gold grains, that are contained in the alluvia of the terraces of the Consata-Mapiri river and the Tipuani river, show varying composition according to their position in the weathering profile. The grains 21 and 22 (fig. 6) 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 alluvia 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, even when the composition of the core is very close to those of the gold grains collected in 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. 2, photo 7). On the other hand below the level of weathering within the alluvials and also within the material of present river beds one observes gold grains with a great variety of Ag content.

Composition of gold grains of present bed of a secondary river : the Mariapo river example

The populations of gold grains that come from the present bed of a secondary river, whose drainage basin is totally included in the Tipuani-Mapiri basin and does not reach the Cordillera, are also very heterogeneous. Highly transformed gold particles are found together with individuals of a composition (fig. 6 : 20) and morphology very close to that of known primary mineralization (fig. 2, photos 5 and 6).

Discussion and conclusion

The analysis of the morphology and composition of the gold grains sampled in fluviatile placers developed on the amazonian slope of the Cordillera Real between the Middle Miocene and the present times, show that :

— In a fluviatile system developed in a zone of important orographic gradient, there is a clear correlation between the change of morphology of the gold grains and the distance traveled : disappearance of primary crystalline outlines, and neo-formation of distinctive structures (striations, bends, redoublings). During the first tenth of total distance (70 to 80 km in the case studied) these modifications go along with a regular increase of the F.I. However, studies on the placers of the Amazonian piedmont of the Peruvian Andes (Lankneus, 1987) and our work on the piedmont of the Bolivian Andes show that this rule does not apply for grains that are transported downstream over a distance beyond the sub-andean front of the Andes.

— Changes in the composition of gold particles are not related to the distance covered from the primary mineralization sources to the place of deposit, but to the followed route. Indeed, upstream from the outcrops of old gold-bearing sediments the grains collected in the river beds are derived directly from the erosion of gold-bearing veins and all show a composition similar to that of the gold contained in primary mineralization. On the other hand gold grains contained in the alluvia of the fluviatile terraces of the same rivers have a distinctive composition ; their average fineness is higher and they show an Ag depleted rim. This high fineness rim can be discontinous. Its width is a few tens of microns and the break between this Ag depleted rim and the core of the grains is sharp. In the case of gold grains collected in the oldest terraces, the ones that come from alluvia below the weathering front show a very clear Ag depleted rim, whereas the gold grains that come from intensively weathered horizons have a high average fineness, and the decrease of silver content also very often affects the core of the grains.

The gold grains with high fineness and well developed silver depleted rim have been found both in old sediments (Cangalli Formation), even when they have not been weathered, and in the alluvia of Quaternary terraces that have suffered meteorization.

The appearance of a low Ag content rim can be interpreted as a preferential leaching of silver (Stoffregen, 1986 ; Colin *et al.,* 1989 a, i.e.). In the alluvial terraces, the formation of high fineness grains goes along with the evolution of a weathering profile that gets more developed towards the oldest terraces. This phenomenon has been described in alluvial terraces from other regions (Hérail, 1984). The mechanisms of this natural refinement of gold are the same as those which have been described in profiles weathered under tropical conditions (Wilson, 1984 ; Webster and Mann, 1984 ; Freyssinet *et al.,* 1987, 1989 ; Colin *et al.,* 1989 b). Nevertheless although we have frequently observed the effects of corrosion within altered zones of terraces, recrystallized forms are very rare and newly formed grains have never been observed.

— The joint analysis of the morphology and composition of the gold grains contained in a placer allows, on one hand, the characterization of the transport agent and the distance covered from the primary mineralization sources, and, on the other hand, the separation of the gold grains that are a direct consequence of the erosion of the primary mineralizations from the ones that stayed in old placers that played the role of intermediate collectors.

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