GEOLOGY AND EXPLORATION OF GOLD PLACER DEPOSITS OF THE PRECAMBRIAN SHIELD OF EASTERN BOLIVIA.

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ABSTRACT: The Precambrian shield of eastern Bolivia occupies some 220,000 km^2, consisting of granulite, gneiss, syn- and post-kynematic granitoids and a number of elongated low to medium grade schist belts. The latter are at least of lower Proterozoic age, cover 10% of the region and exhibit in places volcano-sedimentary and structural units of weak to high primary gold content. All gold placer deposits are spatially related to these schist belts. The different types developed during the geomorphological evolution of the shield since late-Miocene time. The combined effects of early lateritization, tectonical uplift and erosion under semi-arid climate and savanna vegetation have led to the formation of eluvial-lateritic, coluvial and different types of alluvial placer deposits. In the last 300 years principally small coluvial and headwater gulch placers were mined, yielding a total production of about 16 tons of gold. This quantity is relatively low in comparison with other Precambrian gold placer districts. Medium-size placer deposits of economic grade may have formed where several auriferous gulches join to form a higher order stream or in sediment traps of the larger rivers. These deposits are found near the shield border in paleo-channels which lie under argillaceous fluvio-lacustrine sediments. The region as a whole is considered as a minor gold placer province of Bolivia.

RESUMEN: El escudo Precambrico de Bolivia oriental abarca un area de 220.000 km^2. Consiste de granulita, gneiss, granitoides syn- y post-cinemáticos y varias fajas alongadas de esquistos de metamorfismo bajo a medio. Estos tienen una edad mínima de Proterozoico inferior, cubren 10% de la región y estan compuestos frecuentemente de unidades volcano-sedimentarias y estructuras con bajo a alto contenido de oro primario. Todos los placeres auríferos de la región estan relacionados a las fajas de esquistos. Los tipos diferentes fueron formados durante la evolución geomorfológica del escudo desde el Mioceno superior. La combinación de los efectos de una lateritización temprana, ascenso tectónico, erosión en clima semiarido y cobertura de savana resultó en la formación de placeres eluvio-lateriticos, coluviales y aluviales. En los ultimos 300 años se explotaron principalmente placeres coluviales y las cabeceras secas de quebradas. La producción total esta estimada en unas 16 toneladas de oro. Esa cantidad es considerada pequeña comparada con otros distritos de placeres de zonas Precámbricas. Placeres de dimensión media y tenor económico se formaron probablemente en sitios donde varias quebradas auríferas se juntaron en un canal de mayor orden, o en trampas sedimentarias de los ríos mayores. Esa situación se encuentra preferencialmente cerca del borde sudoeste del Precámbrico dentro de paleo-canales debajo de una cobertura de sedimentos fluvio-lacustres. La región es considerada según sus características como una província aurífera de menor importancia de Bolivia.

INTRODUCTION

The Precambrian shield of eastern Bolivia is a geotectonic extension of the Central Brazilian shield to SW covering an area of about 220,000 km^2 between latitude 13° 00' S and 19° 00' S (fig. 1). Although placer gold mining dates back to the early Jesuitan colonization in 1688-1767, historical and technical data are very sparse. Peiser (1944) contributed a description of ore fields and mineralization of the Ñuflo de Chávez province. The Precambrian project, a technical cooperation program of the British Geological Survey and Servicio Geologico Boliviano (GEOBOL) in the period 1976-83 produced geological 1:250,000 maps, a 22-element geochemical atlas of 1,000,000 scale and studies of the San Simón and San Ramón gold districts (Litherland et al., 1986).

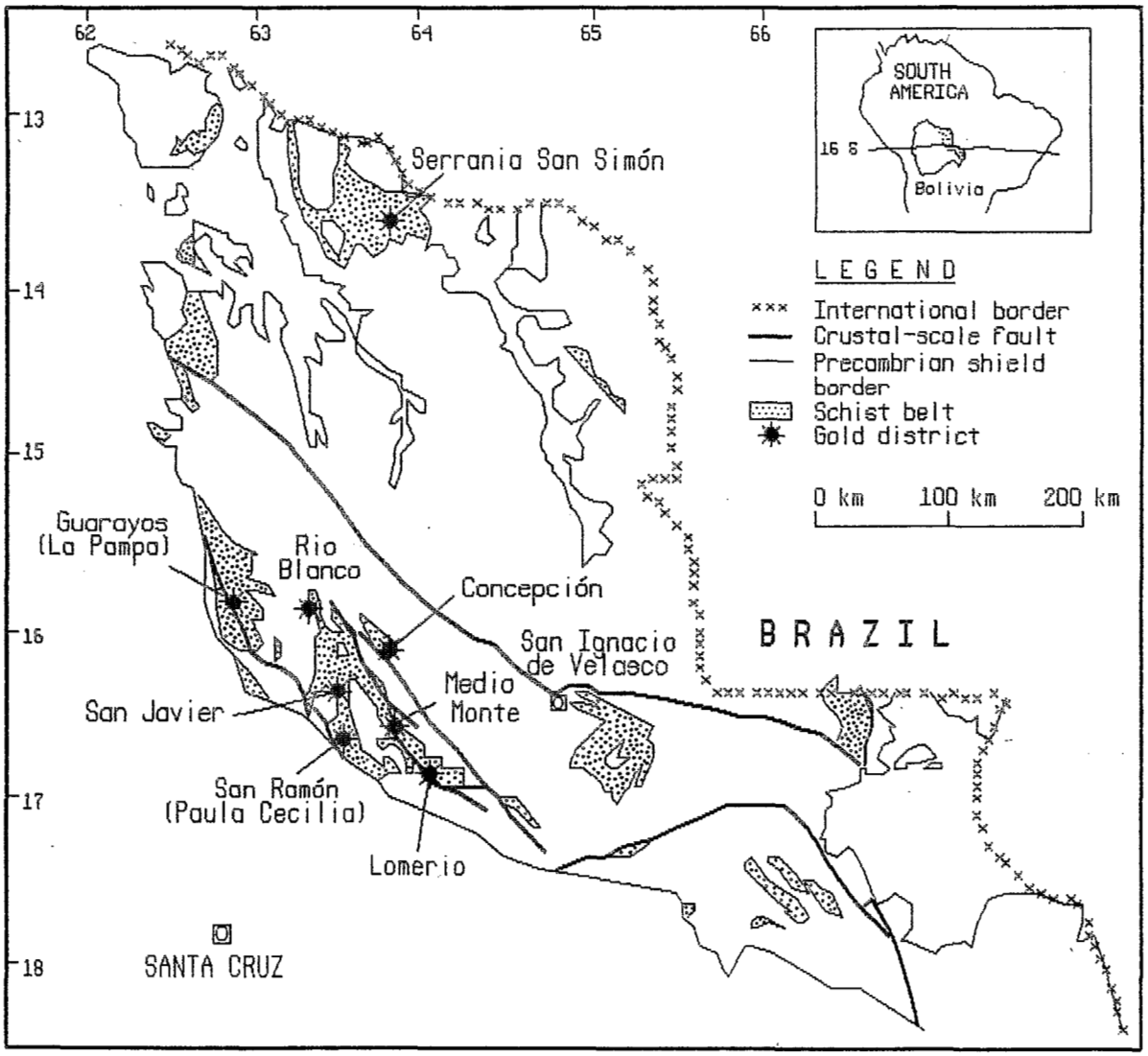

Fig. 1: Location map of gold placer districts. Precambrian shield of eastern Bolivia. Shieldborder, schist belts and crustal-scale shear zones from the Precambrian Project (Litherland et al., 1986).

The entire region was fiscal mining reserve prior to August 1986. After its annulment numerous mining claims were staked, principally on ground favorable for placer gold mineralizations. The objective of this study is to provide recent geoscientific data about their geological setting, geochemistry and formation, appraise some important economic parameters and evaluate the possibilities for future mining on industrial scale. The findings are based on exploration work of Empresa Minera Santa Maria (EMSA) S.A., a Santa Cruz based mining company, and studies carried out by researchers from the Institute of Mineralogy and Ore Deposit Investigation of the Technical University of Aachen (Germany).

PHYSIOGRAPHY, CLIMATE, VEGETATION

The shield conforms to an elongated north-west trending dome like laterite planation surface. It is buried by Quaternary alluvial basins at its margins and overlooked in places by inselbergs or ridges rising rarely more than 200 m above the plain. The late-Miocene San Ignacio surface can be traced over more than half of the shield area. It is at maximum height of 550 m near the community San Ignacio, falling to levels of 150 to 300 m towards the shield margins (Litherland et al., 1986).

The drainage pattern follows to the slope of the peneplain which is transected by the continental watershed between the Amazon to the north or the Plata river to the south-east. It was formed during the Plio-Pleistocene Santa Ana epeirogeny, which affected the entire region by uplift and faulting. Table 1 gives a general view of the different landforms, their distribution and influence on dispersion of gold.

Table 1: Distribution and characteristics of landforms. Precambrian shield of eastern Bolivia.

MORPHOLOGICAL ENVIRONMENT	*SPECIFICATION*	*TYPE OF Au DISPERSION*	*FRACTION OF TOT. AREA (%)*
Alluvial and lacustrine plains	Meandering and lateral erosion	M	13
Laterite plateau surfaces	Complete laterite section, no rock outcrops	M + H	50
	Partially dissected plateaus, coluvium	M > H	25
Inselbergs	Old laterite face preserved	M + H	5
	Irregularly eroded, laterite stripped	M > H	5
Piedmont terrace	Pediments at slope of inselbergs	M	2

M = mechanical dispersion, H = hydromorphic dispersion.

The climate is tropical. It varies from dry tropical in the south to very humid in the north. The region is covered by semideciduous hardwood forests in its drier southern part becoming more evergreen and high stratified jungle north of latitude 15 º S (monte alto).

PRECAMBRIAN SOURCE ROCKS

The Precambrian shield of eastern Bolivia consists principally of granulite and gneiss, intruded by syn- and post-kinematic granitoids. The north-eastern part was consolidated during the San Ignacio orogeny (>1.3 Ga) to the Paragua craton. Its south-west and west border was afterwards reworked and definetely cratonized during the Sunsas orogeny (1.0 Ga). About 10% of the shield comprises schist belt rocks of low to medium metamorphic grade. Their age is at least lower Proterozoic (Litherland et al., 1986).

All known gold districts are located in schist belt areas (fig. 1). These are concentrated in the southern Sunsas mobile belt where bimodal volcanic rocks and crustal-scale shear zones are developed. Possible primary sources for gold placer deposits may be mesothermal gold mineralizations of different geological settings, banded iron-formations and other rock units of anomalous gold content, and quartz-pebble conglomerates.

HISTORY OF GOLD PLACER MINING

The development of the gold resources of the region was hindered in the past by difficult or no access, unfavorable climatic conditions, disease and presence of hostile tribes over extensive areas. Thus until fifeteen years ago the Santa Cruz Department had remained geologically nearly unknown and, with respect to mineral resources, unexplored.

Table 2: Estimated production from gold placer deposits. Precambrian shield of Eastern Bolivia.

DISTRICT	*PERIOD*	*PAST PRODUCTION* ALLUVIAL. (tons)	HARD ROCK (tons)	*ACTUAL OUTPUT* (kg/year)
Serrania San Simón	1690 - today	2.5	1.0	20
San Ramón- San Javier	? - today	10.0	0.1	40
Medio Monte- Lomerio	? - today	1.5	---	4
Concepción- Rio Blanco	1690 - ?	0.5	---	0
Guarayos	? - today	0.5	---	10
Otros	1690 - ?	1.0	---	0
TOTAL		16.0	1.1	74

Gold was first worked by Jesuits in the San Simón range and the area of Concepción during colonization in the period 1688-1767. Mining activities recommenced in the late eighteenth century and reached peaks in 1882-1885 and 1905-1918. The first mining claim was adjudged in 1889 in the San Ramón area by the Bolivian authorities. It is documented that over 7,000 people were working in this district. Mining was concentrated principally on rich coluvial and alluvial placer deposits. In the San Simón area the Jesuits and later small companies also exploited gold bearing quartz reefs by primitive underground methods.

Since then mining has had a rapid decline. In the period 1982-84 the San Ramón area has seen a small gold rush due to a considerable increase in the gold quotation. At present some small-scale mechanized alluvial operations exist.

No official statistical data on gold production are available. The figures of Table 2 are estimations of the authors and may be biased. Total production from gold placers may reach 16 tons during the last 300 years. Governmental institutions and private companies may have spent about $US 15,000,000.-- (1991 American Dollar) or $US 68.-- per 1 km^2 in exploration work over the last fifeteen years.

GOLD PLACER DEPOSITS

DISTRIBUTION

Five important gold placer districts exist in the Precambrian shield of eastern Bolivia (fig. 1). The majority are located in the Sunsas mobile belt as the San Ramón-San Javier, Medio Monte-Lomerio, Concepción-Rio Blanco and Guarayos districts. The Serrania San Simón district is found as an exeception at the Paragua craton. In the following chapters some geological features are documented by the description of some typical examples (fig. 2, 3).

GUARAYOS

The gold placers occur about 12 km E of Ascensión de Guarayos where numerous creeks exhibit significant stream sediment anomalies of visible gold over an area of 7 km to 15 km. The presence of gold is also proven by old primitive placer workings.

The area is covered by thick laterite which shows an upward zonation from pale saprolite (<15.0 m), over mottled saprolite (<2.5 m) to the ferruginous zone. The latter is laterite in a strict sense, consisting of duricrust, pisolite rich layers and red-brown latosol (<3.5 m). Quartz stone line layers occur up to 2.5 m thick. The laterite surface is intersected by small creek valleys. At the valley flanks it is stripped and truncated in places up to the saprolite.

The different placer mineralizations are typically developed at the La Pampa prospect of EMSA S.A. (fig. 2a). Gold quartz veins are present at the contact between leucocratic gneiss-granofels and finely banded amphibolite. Deep geochemical weathering caused a mushroom shaped soil anomaly of visible gold over an area of 2,000 m to 200 m. The soil is not enriched in trace elements such as As, Cu, Zn and Pb, reflecting the low content of sulphide minerals of primary mineralization. High gold grades are related principally to quartz fragment rich sections both in the saprolite and the laterite on top. A superficial, flat lying gold resource of

650,000 tons and an in situ grade of 0.68 g Au/ton was delineated. About 50 % of the gold occurs in grain sizes between 100 and 10 mesh. The average quartz content of the 2 mm to 30 cm fraction is 1 ton/m^3. The mineralized layer is 2.5 m thick on average, considering a 0.23 g Au/ton cut off.

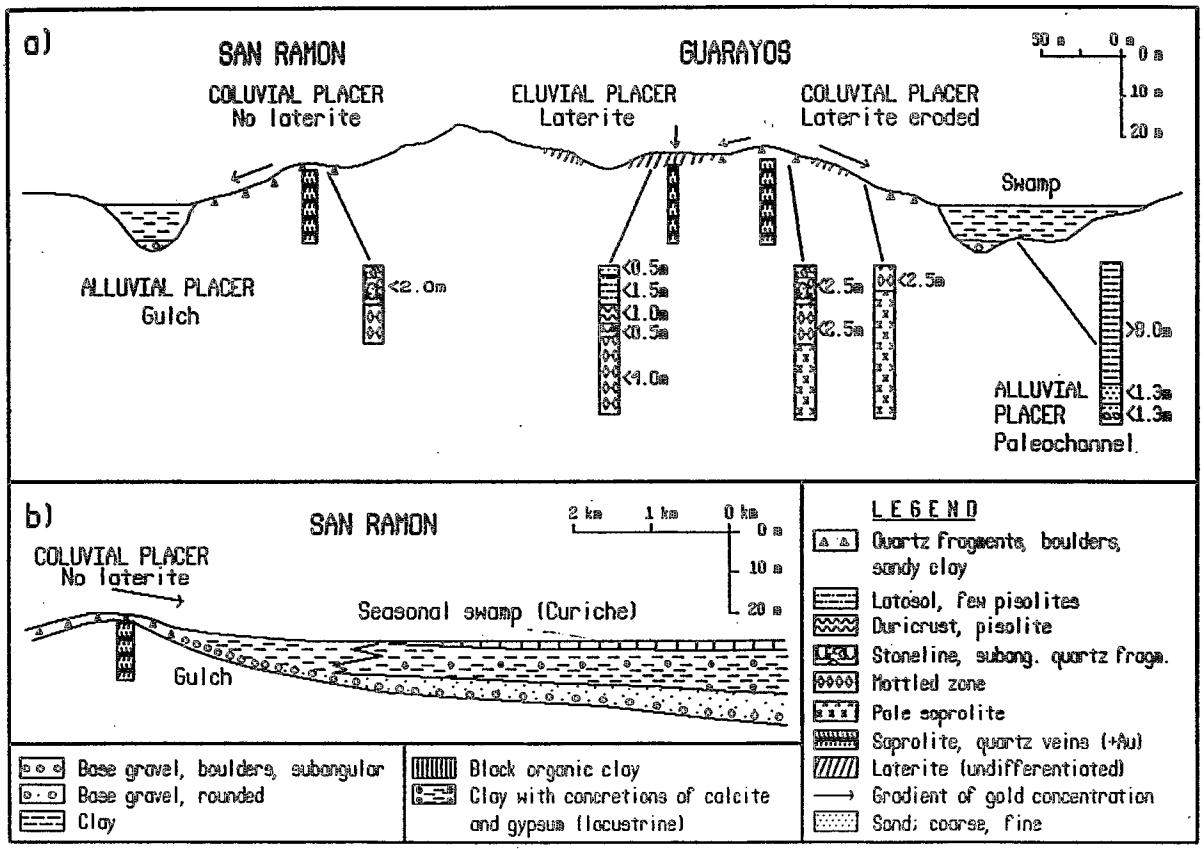

Fig. 2: Geological setting of different gold placer deposits. Precambrian shield of eastern Bolivia.

The gold is also enriched in the headwaters of gulches due to gravitational transport. The mineralized base gravels are up to 1.3 m thick, and 1.5 km downstream overlain by washed sand (<1.3 m), and a 6 to 10 m thick layer of fluvio-lacustrine clay. The base gravels consist principally of subrounded quartz and less metamorphic rock fragments as granofels, gneiss and amphibolite. The headwaters of the gulches form small high grade placer deposits and are mined out. Downstream the overall grade drops to less than 0.15 g Au/m^3.

SAN RAMON - SAN JAVIER

This placer district is restricted to volcano-sedimentary rock outcrops which form an elongated schist-greenstone belt of 40 km length between the communities San Ramón and San Javier. Numerous small placer deposits are known whose gold was mined long time ago. At present the belt is being intensively explored for primary gold deposits by several mining groups.

Geomorphologically the area belongs to the La Cruz Range which overlooks the neighbouring plain from a height of nearly 300 m. The hills are considered as relics of pre-Miocene erosion cycles. No San Ignacio surface related laterite is developed and in places fresh rocks crop out. The style of placer mineralization is well documented east of San Ramón within and around the Paula Cecilia claim of EMSA S.A. (fig. 2).

Gold is disseminated in quartz veins, shear zones and gossan, the latter being the product of the weathering of banded iron-formations. The small-scale gold workings are concentrated on small coluvial deposits and gulch sediments. The gold of the latter occurs in <1.5 m thick base gravels of narrow channels, being overlain by a sandy clay layer and pure clay on top, similar to Guarayos. In many places the gulches are nearly dry and permit drift mining.

All creeks east and south-east of San Ramón flow into a depression called Palmar. It covers an area of 16 km^2, is filled by a thick pile of fluvio-lacustrine sediments and is separated from the Rio Grande Quaternary plain by a bar of Precambrian rocks. At present only a few small permanent swamp areas (curiche) testify to the former existence of a large lake (fig. 2b).

The gradient of the creeks is high in the headwaters and decreases to nearly zero in the Palmar depression. The upper courses are steeply cut in the bedrock and exhibit only sparse sediment accumulations. On the other hand a system of paleo-channels is developed in the Palmar at depths of >8 m.

QUISER RIVER

The catchment area of the Quiser river is about 1,400 km^2 in size, draining the schist belts of the San Ramón-San Javier and Medio Monte-Lomerio gold districts. It is an active stream, which exhibits variable gradients along its 75 km long course (fig. 3). The first 50 km are characterized by steep gradients and strong erosion. Small terraces are developed, which testify older stages of stillstand and deposition (Biste, 1985). They are auriferous in the Medio Monte and San Ramón districts. Similar conditions are encountered in the tributaries Uruguaytu, San Antonio and numerous minor creeks, and in the northern Blanco and Zapocoz Norte rivers. The terraces attracted early prospectors, and are nearly mined out.

The lower course is close to the base level of erosion, which is at above 240 m a.s.l. at the shield border. The gradient is reduced, so that stream meandering and lateral erosion are dominant. An up to several kilometer-wide flood plain is developed downstream to the turning-point of steep to low gradient. It is filled with fluvio-lacustrine sediments covering a system of gold bearing paleo-channels (fig. 3).

SERRANIA SAN SIMON

The Serrania San Simón forms an inselberg massif which extends 40 km by 20 km and rises up to 370 m over the laterite plain. It is covered by dry savanna with sparse low semi-deciduous woodland which changes abruptly to evergreen forest in the plain.

The primary gold mineralization occurs in discordant quartz veins and saddle reefs, which are hosted in low metamorphic clastic sediments of lower Proterozoic age. Ancient workings on veins are scattered over an area of 2,250 m to 40 m (Litherland et al., 1986).

The erosion of the veins produced gold concentrations in small sediment fillings in the headwater of gulches. At the base of the massif thin piedmont pediments are developed. Some gulches join together and form an open valley at the border of the massive. The bedrock deepens quickly to more than 9.0 m forming narrow paleo-channels similar to the San Ramón area. Their course differs in places from the present creeks. The gold is concentrated in <1.5 m thick base gravel beds.

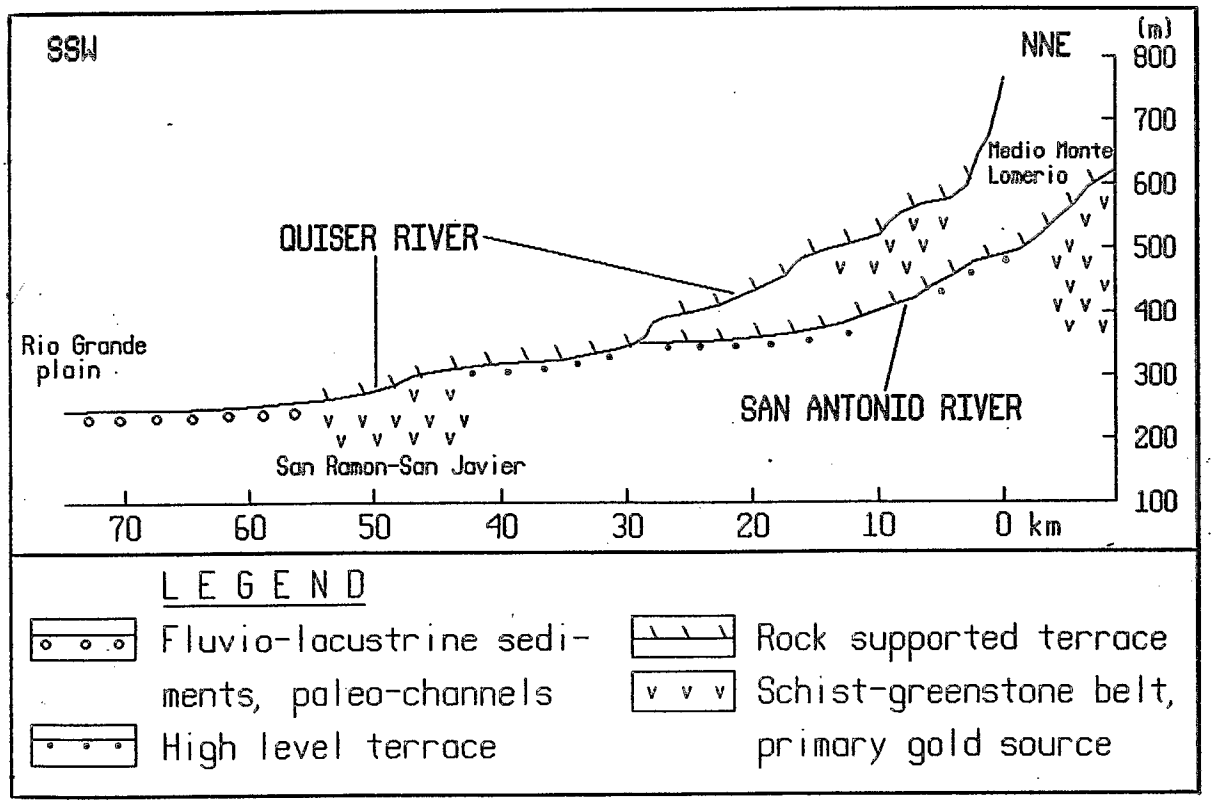

Fig. 3: Longitudinal section of the Quiser river.

PLACER CHARACTERISTICS

TYPES

The region exhibits a wide spectrum of placer types. Most frequent and mined are coluvial and headwater gulch placers, which occur in all districts (table 3). They are characterized by low watertable, small ore volumes, high ore grades and erratic gold distribution. Buried gulches and paleochannels are developed principally close to the south-west border of the shield where the tributaries of the San Julian river are flowing into the wide Quaternary Rio Grande plain. Eluvial-lateritic gold concentrations occur where the San Ignacio planation surface is developed over primary gold enrichments.

Table 3: Distribution of gold placer types. Precambrian shield of eastern Bolivia.

DISTRICT	ELUVIAL - LATERITIC	COLUVIAL	ALLUVIAL			
			HEADW. GULCH	BURIED GULCH	PALEO-CHANNEL	RIVER VALLEY
Serrania San Simón	L	X	L	L	X	O
San Ramón-San Javier	O	X	X	X	X	X
Medio Monte-Lomerio	O	X	X	O	O	O
Concepción-Rio Blanco	O	X	X	O	O	O
Guarayos	X	X	X	X	O	O
Otros	O	X	X	O	O	O

X = very frequent, L = less frequent, O = not developed

MINERALIZATION

Grain size decreases as a rule with distance from the primary source. With the exception of the Quiser river the alluvial transport is rarely more than 5.0 km. The gulches form narrow channels of <100 m width. The gold is concentrated in base gravels of <1.5 m thickness. The depth of the bedrock varies considerably between the different alluvial placer types. Thus, the ratio between barren and mineralized sediments decreases from the headwater gulches (2:1) to paleo-channels of wide river valleys (5:1). Observations on this are given in table 4 and 5.

Table 4: Geological characteristics of gold placer deposits. Precambrian shield of eastern Bolivia.

TYPE	GRAIN SIZE Au (mesh)	DEPTH BEDROCK (m)	THICKNESS MINERALIZED (m)	BARREN / MINERALIZED
ELUVIAL.-LATERITIC	<< - 10	4	2	< 1 : 1
COLUVIAL	<< - 10*	2	2	---
ALLUVIAL:				
Headwater gulch	100 - 10*	6	2	< 2 : 1
Buried gulch	100 - 20	6 - 12	2	< 5 : 1
Paleochannel	< 35	8 - 16	2	< 7 : 1
River valley	< 35	6 - 12	2	< 5 : 1

NOTE: * Large gold nuggets of >10 mesh are present only in San Ramón.

GOLD COMPOSITION

Detailed studies of shape, geochemistry and fineness are available only for the Guarayos district (Bufler et al., 1990; Bufler, 1991). The gold of the La Pampa prospect is extremely pure. The fineness varies from >988 of saprolite to 992 of duricrust/pisolite and reaches >999 in the gulch deposits (table 5). Gold grains from buried gulches of the San Ramón area (Litherland et al., 1986) show finenesses >930.

The concentration of trace elements such as Cu, Bi, Te and Fe in gold from the La Pampa prospect is very low. Grains from duricrust and pisolitic layers exhibit depletion rims with values of 0.36-0.95 wt% Ag and 0.15 wt% Cu in the core, and values of 0.23 wt% Ag and 0.02 wt% Cu at the outer zone.

Table 5: Economic parameters of gold placer deposits. Precambrian shield of eastern Bolivia.

TYPE	VOLUME (m^3)	IN SITU GOLD GRADE (g/m^3)	IN SITU METAL CONTENT (kg)	FINENESS (‰)
ELUVIAL.-LATERITIC	>200,000	1.5	>300	>992
COLUVIAL	100,000	1.0	100	>988
ALLUVIAL:				
Headwater gulch	100,000	0.6	60	>997
Buried gulch	200,000	0.3	60	999
Paleochannel	>400,000	0.2 ?	> 80	---
River valley	>800,000	0.25 ?	>200	---

NOTE: ? = inferred figures, no exploration data available.

GOLD MORPHOLOGY

Grains from the La Pampa prospect show no striation, are generally round edged and show negative prints of quartz crystals (fig. 4). Corrosion features are often developed showing that some dissolution had taken place during their formation. The gold of the San Ramón area occurs frequently in nuggets of several 10 g weight. Nuggets of irregular shape with at least two generations of gold were found, weighing up to 640 g.

EXPLORATION APPROACH

The exploration of the different placer types requires the combination of various techniques. Gold-bearing areas are frequently indicated by old gold workings covered by dense vegetation. The gold potential in general of an unkown area is quickly tested by panning of large stream sediment samples for visible gold. Lateritic gold mineralization may also be localized by soil panning. But more effective is the assay of duricrust/pisolite samples for gold and pathfinder elements such as As, Ba, Mo, Sb and W (Butt, 1989).

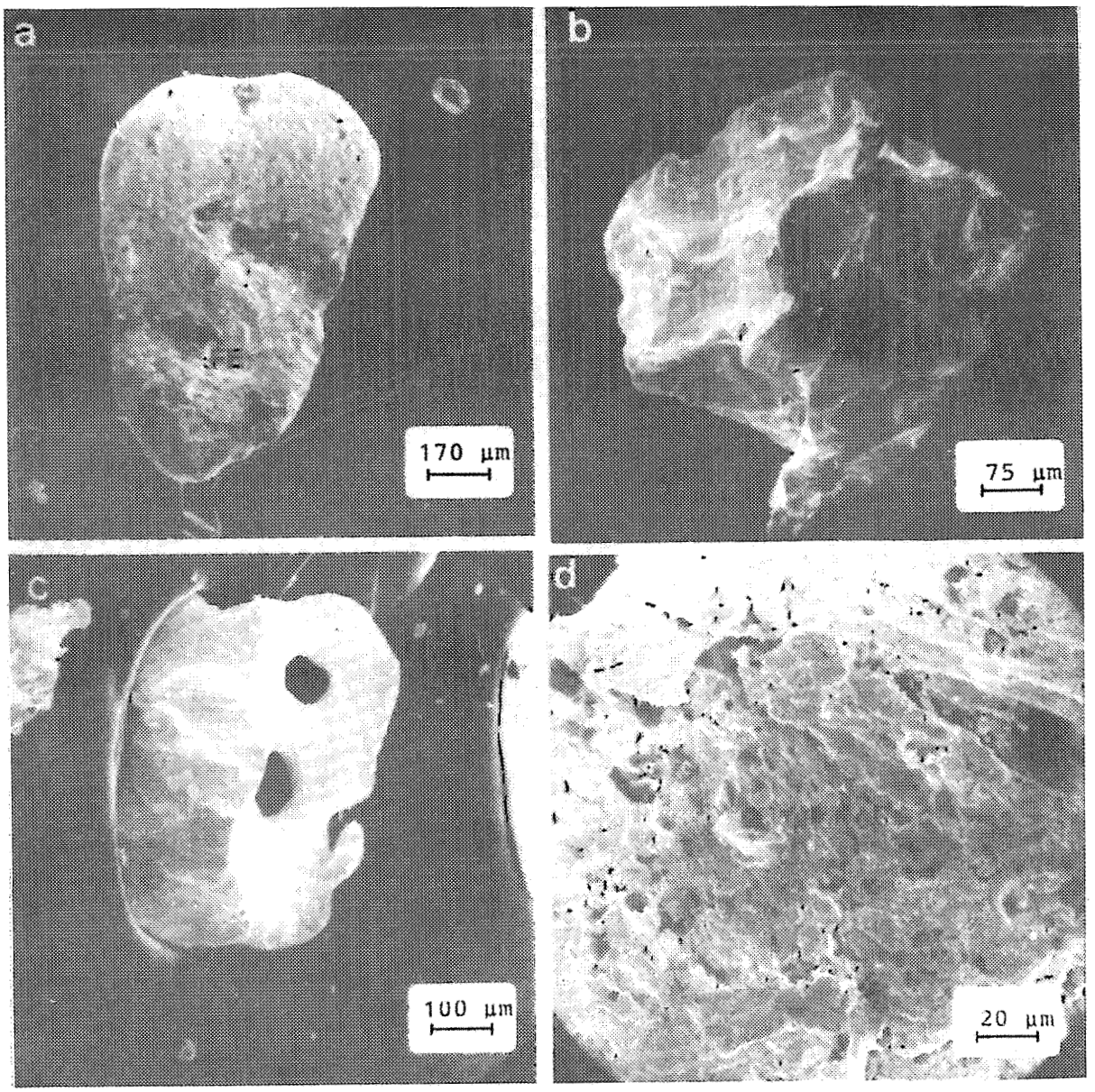

Fig. 4: Morphology of gold grains of the La Pampa prospect. a) Grain from a limonitic layer, b) idem, with triangular prints of quartz crystals, c-d) grains from a coluvial layer.

Inferred placer deposits in areas of visible gold anomalies can be delineated by using high quality satellite images, aerial photographs and careful ground examination. A problem is the location of buried paleo-channels. They are not detected by remote sensing methods.

Geoelectrical sounding methods are only partly succesful because the bedrock is often deeply weathered. The interface between sand and gravel layers is not reflected in the obtained graphs.

Sampling by pitting and processing of bulk samples gives satisfactory results in the evaluation of eluvial-lateritic, coluvial and shallow alluvial placer deposits above the water table. Alluvial placer ground beneath the water table has to be investigated by mobile engine-driven six inch churn drilling. The gold grades are erratically distributed. Thus, evaluation by drilling is a difficult task.

The access to most placer sites is complicated because of dense vegetation. The ground is generally swampy in the rainy season, so that the work has to be done by mobile equipment during the dry months May-November.

MINING ACTIVITIES

At present only small placer operations exist, producing about 75 kg gold per year (table 2). They are situated close to San Ramón, in Guarayos, Medio Monte and Serrania San Simón. Mining is concentrated on coluvial and headwater gulch placers containing typically some 10,000 m^3 of auriferous sediments (table 5). Mining is semi-mechanised using small gravel pumps, monitor and sluice boxes. Recently small Knelson concentraters were introduced to recover also the finer gold fraction.

Some buried dry gulches are also developed by shafts dug down to the bedrock and dangerous drift mining following the pay gravel. This type of mining stops when bedrock is deeper than 12 m because of presence of water, difficulties in ventilation or uneconomic gold grades. The gold is concentrated only by panning. At present there is no use of mercury.

Mining is done mostly without technical orientation. The main problem is the shortage of water during the dry season in May-October. No special environmental measures are taken, i.e. the mined out areas are left open without any reclamation. The gulches near Santa Rosa de la Mina are said to contain a strong mercury contamination due to the intensive exploitation in the rush of the last century.

DISCUSSION

The different placer deposits of the region are the product of the geomorphological and climatical history of the shield area since late-Miocene time. They are classified as jungle placers of low relief (Milner, 1991). In the Guarayos district the formation of a late-Miocene laterite planation surface favoured the preconcentration of gold in sheet-like eluvial-lateritic layers. The characteristics of the gold grains indicate that it was principally concentrated by mechanical release, and less by solution and reprecipitation. During the lateritization silver and copper were partially leached from primary gold grains. During the late Tertiary and Plio-Pleistocene the climate became drier. The regional scale deforestation and epeirogenic uplift caused partial stripping of the lateritic planation surface by headward stream erosion. The products of erosion and gold have been deposited as coluvial layers, gulch fillings and fluvio-lacustrine sediments.

On the other hand the San Ignacio laterite surface had not been developed in the San Ramón-San Javier, Medio Monte-Lomerio and Concepción-Rio Blanco districts. The terrain is

dominated by mountainous landforms and inselbergs which are relics of pre-Miocene planation phases. The formation of gossan and deep oxidation of lower Proterozoic Banded Iron-Formations is related to these older weathering cycles.

The headwaters of the major streams such as the Quiser, Blanco, Zapocos Norte etc. are developed over rock-defended terraces. Since the late Tertiary the shield border has submerged, causing the transgression of lacustrine sediments over older topography, river valleys and gulches. This has produced buried paleo-channels similar to those of the Rondonia region of Brazil (Veiga et al., 1991).

The different types of placer deposits were formed during semi-arid climate and sparse savanna vegetation. Coarse sediments and gold were transported over short distances probably as sheet washes under torrential conditions. This process of rapid deposition and little reworking produced thin layers of coarse poorly sorted sediments, which were overlain later by argillaceous lacustrine sediments. As a consequence the dispersion of gold rarely exceeds 5 km from its primary source.

The Quiser river as an exception comprises a large catchment area, steep to low gradients and derives its gold content from several minor auriferous tributaries and older terraces. A geological trap for sedimentation and a major gold accumulation exist in its lower course close to the shield border.

Large gold nuggets are found only in the San Ramón district, where source rocks contain sufficient pyrite to form thiosulfate-complexes which may have dissolved some of the free primary gold (Butt, 1989).

CONCLUSIONS

The gold placer deposits of the Precambrian shield of eastern Bolivia are related to outcrops of lower Proterozoic schist belts, where primary gold mineralizations and rocks of significant gold content exist in a volcano-sedimentary setting.

The different placer types are the product of the geomorphological evolution of the shield since the late-Miocene. The combined effects of early lateritization, tectonical uplift and erosion under semi-arid climate and savanna vegetation have led to the formation of eluvial-lateritic, coluvial and different alluvial placer deposits. During the last 300 years principally small coluvial and headwater gulch placers were mined yielding a total production of 16 tons. This quantity is relatively low in comparison with other Precambrian gold placer districts.

Economic-medium scale placer deposits may have formed where several auriferous gulches joined to form a higher order stream or in sediment traps of the larger rivers. These settings are preferentially found near the shield border in paleo-channels which lie under fluvio-lacustrine sediments.

The potential for eluvial-lateritic and low-grade medium-size paleo-channel placer deposits is uncertain because of sparse investigations. Nevertheless the region as a whole is considered as a minor gold placer province of Bolivia.

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