GENETIC-EXPLORATORY MODEL OF ALLUVIAL GOLD OF THE BRAZILIAN AMAZON

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ABSTRACT: Cratonic regions of the Brazilian Amazon contain one of the largest concentrations of alluvial gold in the world. The placers are characterized by immature, poorly sorted sediments, with highly variable ore grades. Such features indicate formation through mass movements - quick transportation under torrential conditions, and rapid deposition with little reworking - occurring under semi-arid climate and sparse vegetation.

The placers studied are widely distributed in the Brazilian Amazon and register the occurrence of at least two semi-arid depositional cycles, corresponding to the Pleistocenic glaciations in the high-latitude regions. Sediments transported to the valleys by mass movements preserve many features indicative of the nature, the size and the site of both primary and secondary source rocks, which are invariably located nearby. The study and evaluation of placers formed this way may demand specific procedures, with rigid control of representative data. The distribution pattern of gold grades and characterization of heavy minerals assemblages can be helpful in the search of alluvial placer sources.

RESUMEN: Las regiones cratonicas de la Amazonia brasilera contienen una de las mayores concentraciones de placeres aluviales auríferos del mundo. Estos placeres parecen haber sido formado por deslizamientos en masa, con transporte rapido en ambientes torrenciales, deposición rápida sin retrabajo importante, bajo un clima medio árido y con una escasa cubertura de vegetación.

Estos depósitos registran la ocurrencia de por lo menos dos ciclos deposicionales, correspondientes a las glaciaciones del Pleistoceno en las regiones de altas latitudes. Los sedimentos transportados en conjunto hacia los valles conservan rasgos característicos de la naturaleza, tamaño y ubicación de las rocas fuentes primarias y secundarias, que siempre son de localización cercana.

La pesquisa y la evaluación de estos placeres caracterizados por sedimentos inmaturos y mal seleccionados, con leyes de oro muy variables, requieren procedimientos específicos presentados en este trabajo.

INTRODUCTION

Amazonian cratonic regions correspond to the high lands totalling a surface area of over one million square kilometers in Brazilian territory, and extending to neighboring countries to the North and the West. They constitute one of the greatest concentrations of Quaternary gold placers in the world, distributed in provinces of great economic significance (fig. 1).

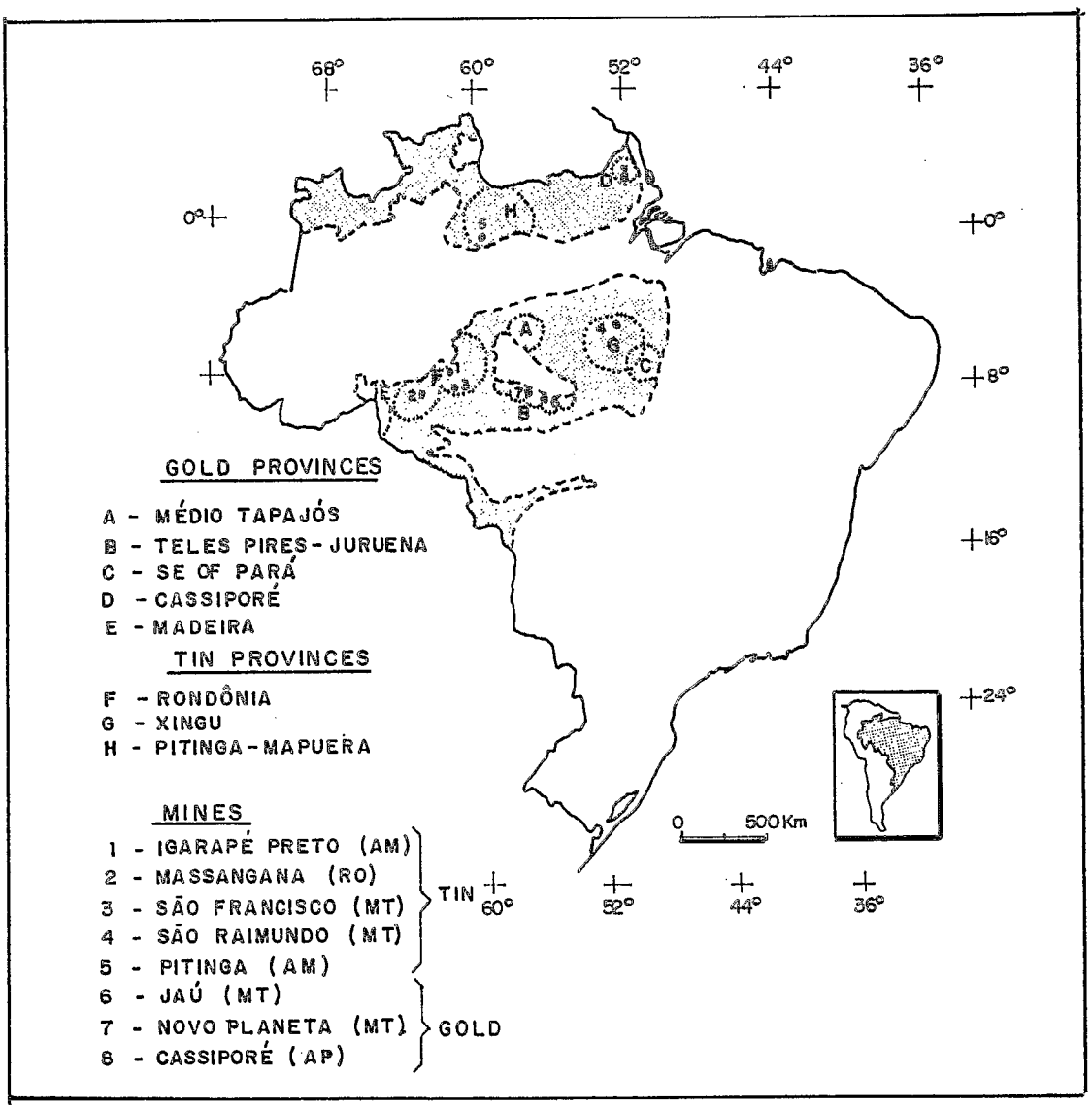


Fig.1: Location of the main studied areas.

The inadequate approach to work in these areas usually results in serious dearth of information, in addition to economic losses and environmental damages, that could be avoided by a comprehensive study of its peculiarities. In fact, the study of the Amazonian alluvium reveals many special characteristics, distinct from the classical alluvial model – adopted to

develop almost all methodology and technology available for exploration, mining and processing – leading to the formulation of a specific genetic exploratory model, also applicable to the tin placers of the region (Barros, 1987).

This new approach is the product of efforts of many experts and institutions – especially the Paranapanema Group and the University of Brasilia – to whom the authors extend their appreciation.

GEOLOGICAL CONTEXT

Most of the primary gold deposits known in the Brazilian Amazon have resulted from hydrothermal activity in high angle shear zones. Such conditioning is evident all over the craton, segmented by several shear belts reactivated in many episodes (Veiga, 1990). The resultant veins participate in distinct geological contexts, distributed in supracrustal sequences of low and high metamorphic grade, including typical greenstone belts, in plutonites and continental felsic volcanic, as well as tonalitic basement. Recorded primary bodies generally are relatively small, but can be considerably rich in gold. Repeated with certain frequency, they expand considerably the potentially mineralized areas.

The weathering of these sources in lateritic regime usually results in significant supergenic enrichment in eluvial and colluvial zones, important for definition of economic alluvial placers. Gold contained in veins or disseminated in host rocks tends to present fine to ultrafine grain size, and purity between 75 to 85% Au (Veiga et al., 1988). Lateritic enrichment may promote, in addition to an increase in grain size, considerable upgrading of the native blend, through preferential leaching of the more soluble metals associated, such as Ag, Cu and others (Mann, 1984). The existence of lateritic gold with purity of between 92 and 98%, as registered in Novo Planeta (Maraui & Veiga, 1985) and Cassipore mines (Veiga et al., 1988), is common.

PALEO-ENVIRONMENTAL EVOLUTION

The global changes which characterized the Cenozoic era resulted in repeated and profound paleoclimatic changes in the Amazon, with alternating phases of dry and humid climates. They are correlated, respectively, to glacial and interglacial periods occurring in high latitude regions. This would imply, in peripheral regions of the Amazon (cratonic terrains) in shifts in the limits of the forest, confined to ciliary forests surrounded by savannas during the dry periods (Sioli, 1985). In the central Amazon basin these fluctuations seem to have been less pronounced or even non existent.

Thus, Pre-Cambrian terrains and in particular their gold sources, have been subjected to deep weathering, marked by alternating periods of hot and humid climate favouring supergenic enrichment, and periods of drier climate favorable to erosion and concentration of resistates, in sediments transported torrentially to the valleys by mass movements (Veiga, 1990).

The drainages studied have restricted dimensions and low gradient, which limit their capacity for transport and selection. Thus, in periods of drier climate, their valleys would tend

to be rapidly filled up by immature and poorly sorted sediments, with poor gravimetric concentration, as recorded in the high grounds of the Amazon (fig. 2).

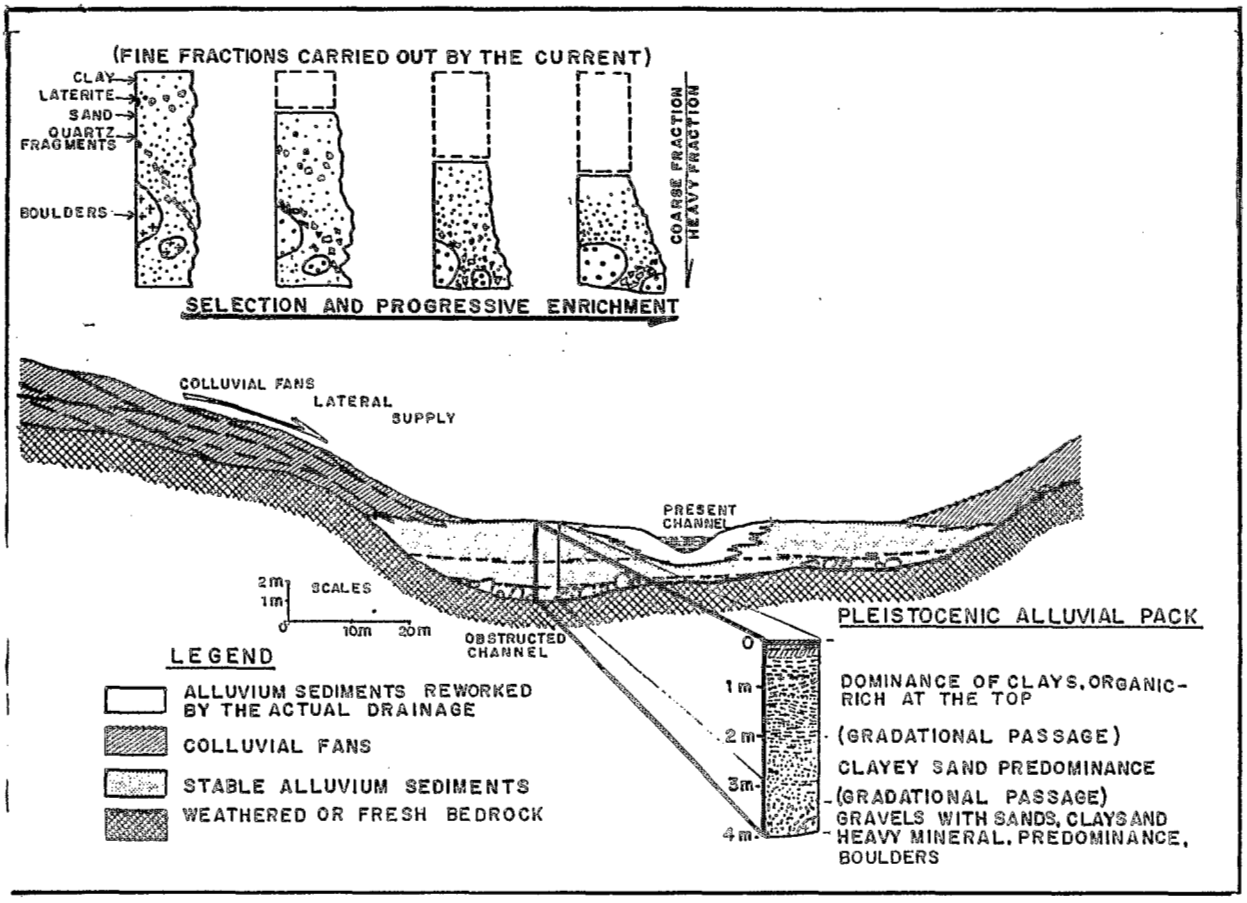


Fig. 2: Typical section of an Amazonian alluvium.

In many areas, two alluvial sequences are identified. They are separated by erosive discordance, where the young sequence occupies the present valleys. The old sequence occupies, in Rondonia, buried paleovalleys with little or no relation to the present drainage (Bettencourt et al., 1988). In Pitinga, the old sequence is preserved in marginal terraces covered by colluvium (Daoud & Veiga, 1986), and a similar situation is recently recorded for gold deposits in Tapajos province (fig. 3).

The position of these sequences in Pitinga and Tapajos reflects the natural entrenchment of the valleys due to the superposition of two erosive cycles, with partial reworking of the old alluvium and lateral shifting of the drainages.

Paleovalleys of Rondonia have a different evolution. In the Southern margin of the Madeira river, near Guajara Mirim, there are two gold "garimpos" recently installed in paleovalleys (fig. 4), similar to occurrences exploited in the Northern margin, in Bolivian territory.

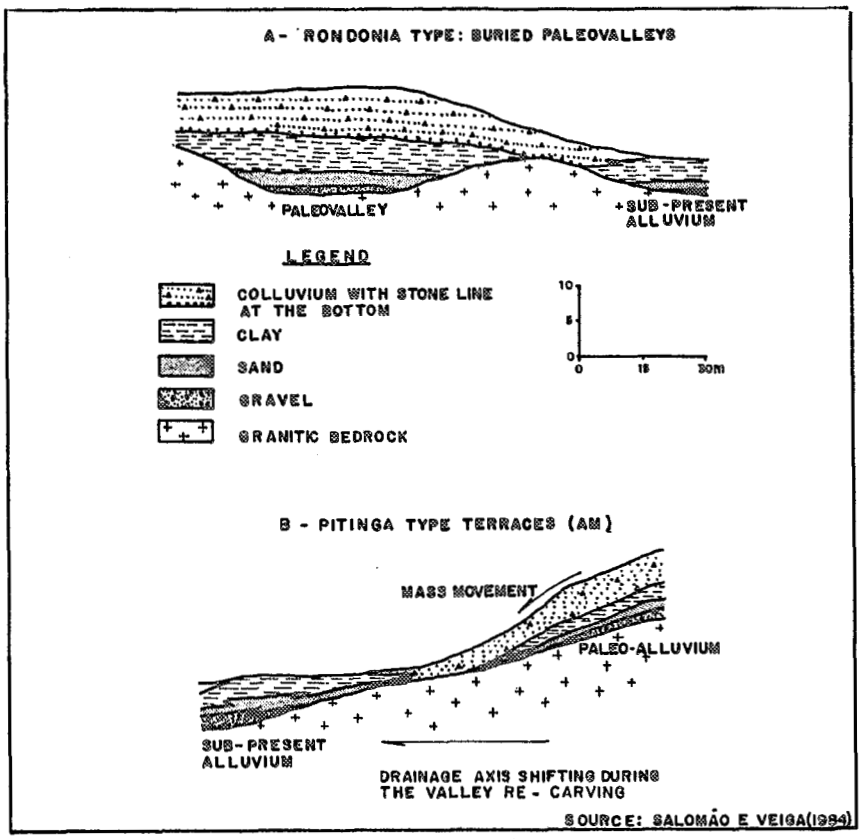


Fig. 3: Schematic representation in transversal section. Policyclic alluvium.

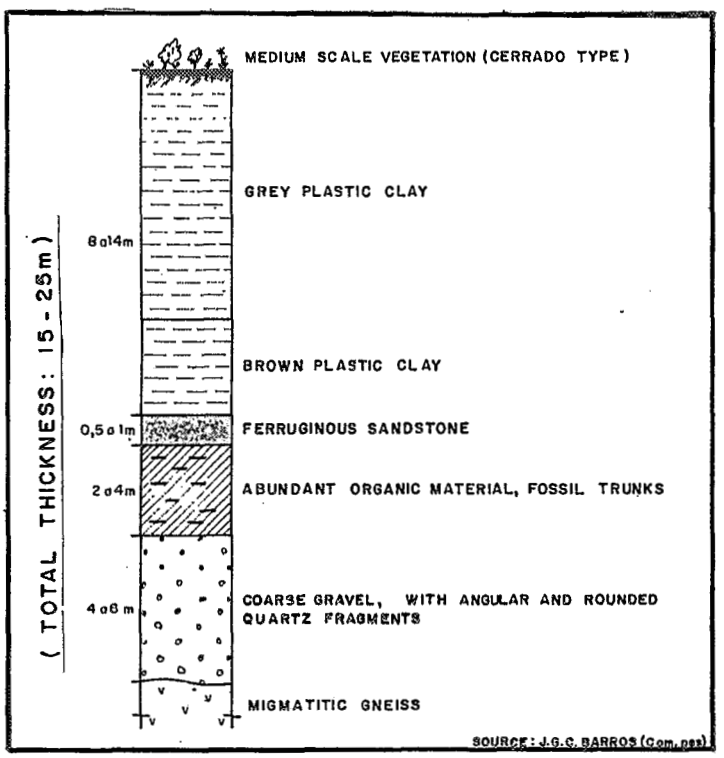


Fig. 4: Covered paleovalley in Madeira river, RO. Stratigraphic column in Periquito garimpo.

The burying of the paleo-alluvium indicates the subsidence of the Northern portion of Rondonia after their deposition, in response to the tectonic uplifting of the neighboring Andean block, followed by extensive flooding which deposited plastic clays and sealed the paleovalleys (Veiga, 1990). The neotectonic influence in the evolution of the landscape is also registered in Peru (Dumont, 1989).

In fact, the alluviums studied present a comprehensive record of the paleoclimatic changes which occurred in the Amazon during the Quaternary. At the present stage of knowledge, Veiga (1990) suggests the following alluvial sequences in the high grounds of the Brazilian Amazon:

a) Ancient sequences: located in reworked areas, they occupy buried paleovalleys or terraces. They have ages of around 35,000 years B.P. (before present), and are correlated to the Upper and Middle Pleistocene.

b) Sub-present sequences: they occupy the present valleys, developed before the last expansion of the rain forest, and are occasionally covered by colluvium. Their ages vary between 20,000 and 13,000 years B.P., corresponding to the second subcycle of the Wisconsin glaciation, of the Upper Pleistocene.

c) Present sequences: these represent the localized reworking of sub-present sequences, restricted to the streams, beginning from the last expansion of the forest cover of the lower Holocene.

These interpretations about the paleoenvironmental evolution of the Amazon are highlighted by the discovery in their alluvial placers, of abundant archaeological records, as polished stone tools and polishing shops buried by alluvium (fig. 5). The records indicate an important Pleistocenic cultural tradition, widely disseminated in the Brazilian Amazon. Thus, the human occupation of the region occurred much earlier than it was formerly believed, based on studies in the Holocenic plains named "varzeas" (Veiga, 1989).

In many areas, the alluvium is masked by expressive colluvial coverage, attributed to periods of lesser humidity during the Holocene, and possibly favoured by the occurrence of natural or human fires (fig. 6).

GEOLOGY OF ALLUVIAL DEPOSITS

The morphological characterization of the Amazon high ground alluviums (Veiga et al., 1988) is as follows:

a) Deposits evolved over flat to moderately rough relief filling up the present valleys and the Pleistocenic paleodrainage, buried like in Rondonia, or suspended, like in Pitinga and in Tapajos (fig. 3).

b) They are well developed along the drainage axis, generally characterized by wide and flat troughs, forming relatively narrow deposits connected with lateral colluviums (fig. 2).

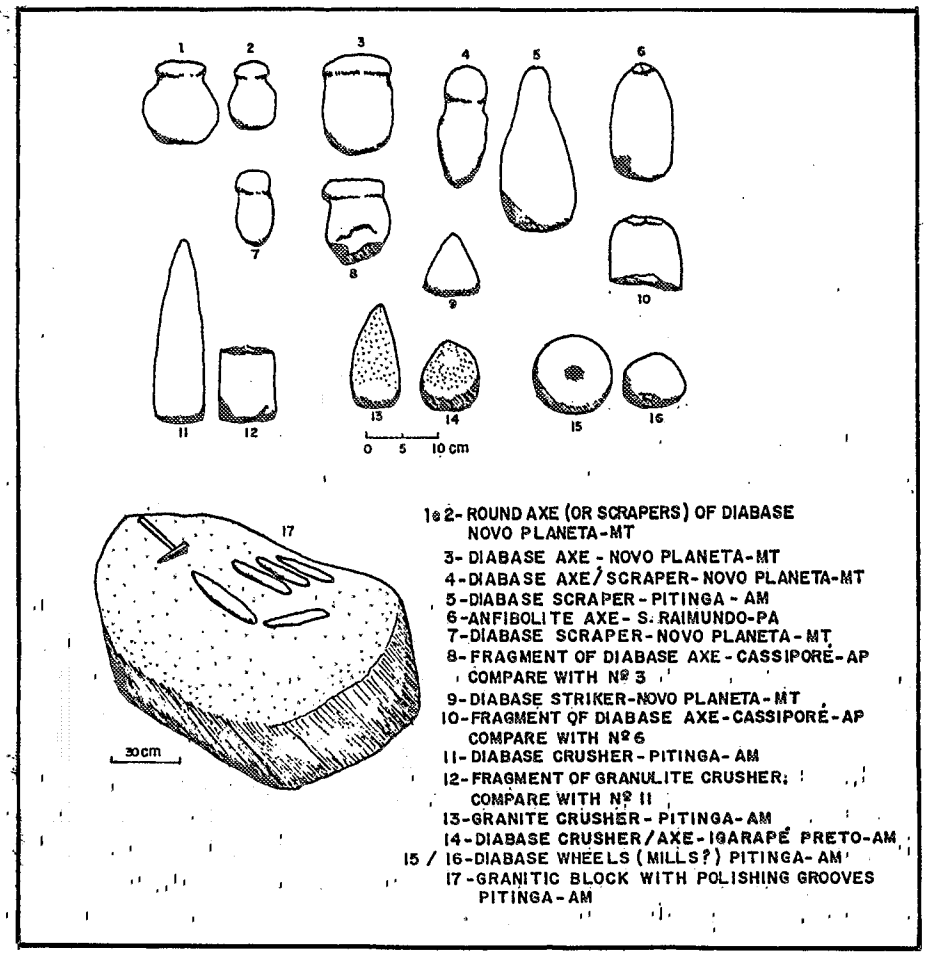


Fig 5: Example of stone artifacts and rocks with polishing grooves found in Pleistocenic alluvium.

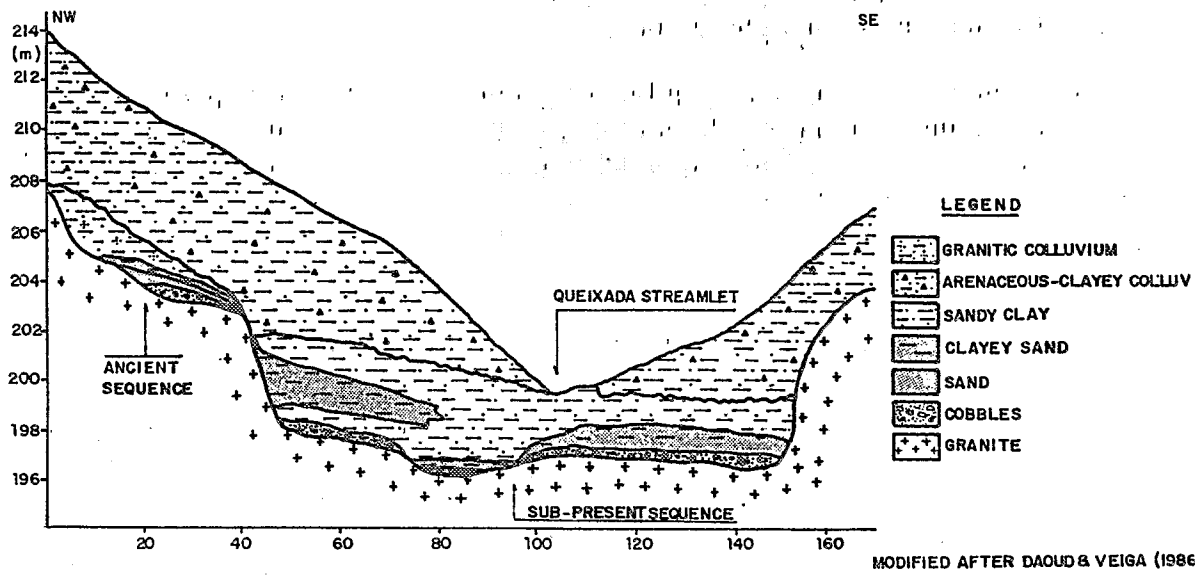


Fig. 6: Colluvial occlusion of placers; cross section of Queixeda streamlet L-131, in Pitanga Mine AM.

c) Alluvial sequences generally present a diffuse stratigraphy, often forming a single unit of immature sediments with graded layering (fig. 2).

d) Subsequent slices of colluvium may partially cover the alluvium, radically changing the profile of valleys and masking underlying sediments.

Alluvial mining activities, in Brazil, in organized operations or in "garimpos", concentrate in alluviums with width between 100 and 1000 m, and thickness between 2 and 10m, approximately, which are in the Amazon context small to medium size deposits. These orebodies have a few kilometers in length and volumes of 200,000 to 1,000,000 m^3, and can reach in some cases 10,000,000 m^3 of ore, with an average gold content between 0.1 and 1 g/m^3. In large size alluviums, mining activities concentrate in the river bottom sediments: for example gold mining in the Madeira River, in Rondonia. However, knowledge of these deposits is still scarce, as a consequence of difficulties for research in drainages of this magnitude.

Larger size drainages tend to develop sequences with sharper stratigraphy than those related to small drainages, as a result of the better scope of reworking and sediment sorting. In both cases, the gravel layers show a clear evidence between sub-actual alluviums and their sources.

The granulometry is typically bimodal, generally with rough gravel 1 to 4cm diameter, buried in sandy-clayish matrix. Well rounded pebbles normally represent a heritage of older sediments which have contributed to the formation of the alluvium. They are usually of quartz, laterite fragments, and fresh or weathered rocks. Presence of laterite indicates an occurrence of humid climate prior to its deposition, in line with the paleo-environmental evolution recognized in the region.

In a general way, heavy minerals less than 2mm in grain occur in the gravel matrix. In gold placers, however, the appearance of gold nuggets of several centimeters, or even gold aggregated to vein quartz fragments, is not rare.

Coarse grain sediments settled at the bottom of the valleys often appear cemented by limonite and/or silica, forming blocks or compact layers, leading to difficulties in mining and recovery. This indicates the intensity of weathering processes in the Amazon during periods of humid climate, active even today.

CARACTERIZATION OF ALLUVIAL MINERALIZATIONS

Amazon alluvial placers, formed by mass movements, represent the present stage of gold accumulation previously concentrated in eluvium and colluvium, or directly eroded from primary sources located in the substratum. The pattern of distribution and the characteristics of heavy minerals assemblage, under these conditions, reveal information about the nature and location of their primary and/or secondary sources, invariably located in relative proximity (Veiga et al., 1988).

The alluviums studied rarely present economic concentrations at more than 5 km away from their sources. In general, recoverable reserves are limited to a dispersion radius of 2 to 2 km of their source, extending from there as discontinued and/or low concentrations. Gold concentrates with coarse sediments, at the base of the deposit, with increasing grade and thickness from the edges to the alluvium axis, not necessarily coincident with the present drainage bed.

Gold distribution along the placer is generally irregular, reflecting the conditions of deposit formation and its spatial position with regard to the source. In addition to the usual location of placers formed down stream or beside primary sources, in the Amazon the existence of placers enclosed in mineralized zones covering their own vein sources, is relatively frequent (fig. 7).

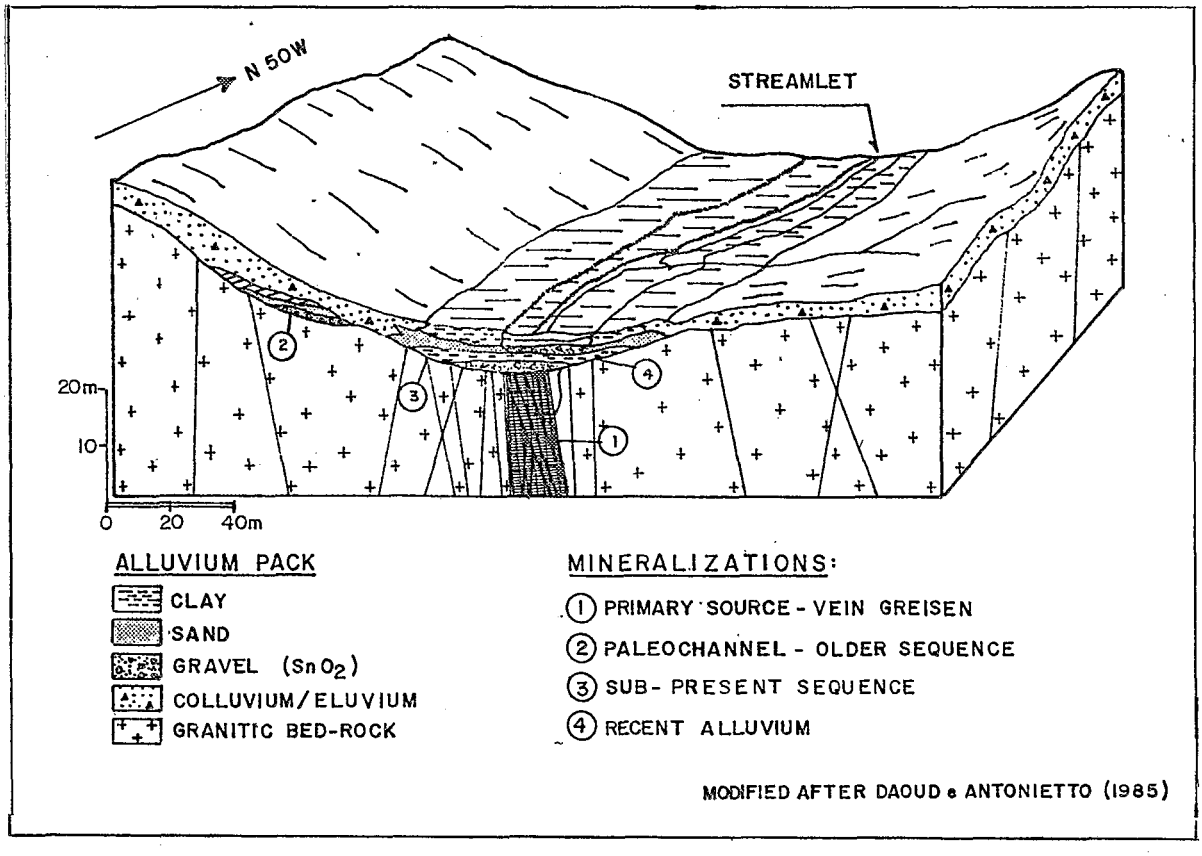


Fig. 7: Queixada Creek alluvium style, covering their vein sources in Pitanga, AM.

Among the inherited characteristics, the mineralogical transformations occurred due to lateritic weathering prior to the deposition of resistates in alluvium are important. Typical hydrothermal paragenesis – sulphides, albite, epidote, sericite, carbonates and others – generally degrades, while gold is released and concentrates in grains in the mantle of weathering. Further, supergenic action on the alluvium can result in a certain chemical mobility of gold after its deposition, favoured by humid acids which characterizes the Amazonian dark water drainages.

The combination of these factors results in diversified placers, where grade variability seems to be the most important characteristic. Instead of a regular and symmetrical distribution, a sharp asymmetry is seen, defining a wide range of variation adjusted to the lognormal distribution model, as demonstrate by Salomao & Falleiros (1986) and shown in table 1.

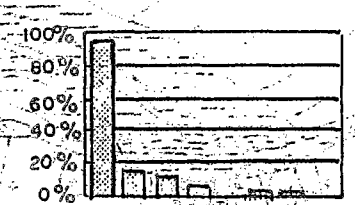
Table 1: Distribution pattern of values in Amazonian alluvium.

FREQUENCY DISTRIBUTION OF ACCUMULATIONS
(GRADES x THICKNESS) - mg. Au/m^2

Pinta no Leito Stream, - Mine of Novo Planeta - MT

INTERVAL			FREQUENCY
12	—	676	97
677	—	1.340	17
1.341	—	2.004	14
2.005	—	2.668	5
2.669	—	3.332	0
3.333	—	3.996	3
3.997	—	4 660	0
4.661	—	5.324	2
TOTAL Nº OF SAMPLES:			138

Arithmetical Average: 680.865 — Arithmetical Variance: 859046
Geometrical Average: 297.050 — Logarithmic Variance: 2,0534

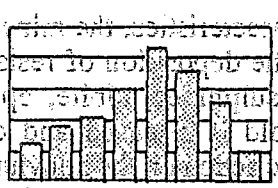


FREQUENCY DISTRIBUTION OF LOGARITHMS
- ACCUMULATIONS (mg. Au/m^2)

INTERVAL			FREQUENCY
2,485	—	3,247	9
3,248	—	4,009	13
4,010	—	4,771	15
4,772	—	5,532	21
5,533	—	6,294	30
6,295	—	7,056	25
7,057	—	8,818	18
7,819	—	8,580	7
TOTAL Nº OF SAMPLES			138

Arithmetical Average: 5,693 — Arithmetical Variance: 2,0534
Geometrical Average: 5,491 — Logarithmic Variance ,0796
Lower Limit: 2,485 — Upper Limit: 8,580

Confidence Interval
(90%) = AA ± 2,364
(95%) = AA ± 2,809
(99%) = AA ± 3,690



SOURCE: SALOMÃO – FALEIROS (1986)

GUIDELINES FOR MINERAL EXPLORATION

Geological characteristics of gold placers in Brazilian Amazon high grounds suggest the following guidelines for an exploratory approach:

a) The deposits are of immature and irregular placers, generated by mass movements typical of semi-arid climate, therefore prior to the last expansion of the rain forest, at the beginning of the Holocene.
b) They are characterized by low transportation capacity, poor grain size selection and gravimetric concentration, thus preserving many inherited features of their primary and/or secondary sources, invariably located in relative proximity.

c) The persistence of structural controls results frequently in the development of placers exactly over their vein sources, causing difficulties in the search for primary ore bodies through conventional geochemical methods such as: active sediments sampling in tributary streams and soil sampling at interfluvial areas. Detection of these ore bodies requires a good understanding of the geological environmental and a careful follow-up of the alluvial mining.

d) Deposits which fill the valleys may be masked by thick colluvial overburden, preventing the identification of their potential by a simple cross-section examination of the valley shape. A reliable evaluation of its economic potential is only possible with comprehensive knowledge of the regional geological evolution, supported by drilling.

e) Relics of early sequences could occur as terraces covered by colluvial material or as buried paleovalleys, forming rich deposits not easily noticeable in the present landscape, and hardly detectable through normal exploration work. However, with existing knowledge, it is possible to detect them with geophysical (electric and magnetic) methods, in previously selected areas using remote sensing.

f) Evaluation of ore bodies of complex structure, presenting a great variation in grade, like the Amazon placer deposits, must be supported by exploration procedures that assure a careful study through banka drilling, with asymmetric grids and control of significant data.

Due to this reason, the use of correlation and regression analysis for evaluation of data obtained in drilling, in each area under study, was proposed (Salomao & Falleiros, 1986). Based on considerable experience in exploration and mining of Amazonian alluvial placers, it is seen that the DOVC (Drilling Operational Variables Control) method provides criteria for data treatment before reserve calculations. This overcomes the usual indefinition resulting from the theoretical application of formulae and of correction factors not pertinent to the reality of the deposit type.

Once the reliability of samples is assured, adjustment to the lognormal distribution model permits identification of statistically anomalous grades present in the alluvium, whose indiscriminate use could yield disastrous results in reserve estimations. The consistence thus provided to research data establishes the basis for utilization of geostatistical methods to evaluate alluvial placers with obvious benefits for the planning and implementation of mining operations.

Some myths are thus abolished, many of which are used as rules, contrary to observed facts. Amazonian alluvial placers are not simple deposits, and require a specific treatment, consistent with their geological conditions. Non observance of these facts can cause failure of mining activities and the loss of invaluable information about the area's potential.

In addition to their intrinsic meaning, the alluvial parameters, whether assessed in ordinary operations of exploration and mining, or in monitoring of "garimpos", could constitute an efficient exploration tool in the search for their primary and secondary generating sources. In this way, it is possible to overcome the limitation of conventional geochemical sampling, commonly adopted in the region without support of other techniques, even in flat areas with deficient drainage of low transportation capacity. It is possible, through this method, to enlarge quickly the knowledge of mineral potential of the Amazon cratonic terrains.

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