Geochemical Mass Balance of Gold Under Various Tropical Weathering Conditions: Application to Exploration

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ABSTRACT

Soil geochemical exploration is a very sensitive technique for mining exploration in weathered terrains. However, the gold signal in tropical environments is relatively complex due to the various dissolution-reprecipitation processes; thus, the evaluation of the soil anomalies' significance is rather difficult. A quantitative approach has been adopted for comparing the gold signal evolution in lateritic profiles from Africa, Amazonia and Australia to determine general trends in the significance of gold anomalies in soil in terms of various pedogenic contexts and in order to better assess the "potential" of soil anomalies for exploration follow-up. The comparison of gold signal variations was based on mass balance calculations (i) for the upper soil horizons commonly used as sampling media in geochemical surveys, with respect to the average saprolite, and (ii) for the saprolite with respect to the fresh rock in order to assess the evolution of gold grades from the primary ore to the oxidized zone. The selected mineralized sites range from savannah zones to rainforest systems, and present profiles with Fe-duricrusts, red gravelly latosols, yellow latosols and podzols.

The gold mass balance showed that for similar gold grades in the saprolite, the gold anomalies are relatively weak in duricrusts of savannah zones with an increase of contents with depth; and relatively strong in rainforest latosols due to surficial enrichments. Red gravelly latosols, which represent an intermediate stage between duricrust and the rainforest latosol, might develop little depleted to moderately enriched soil anomalies depending on the relative proportion of residual duricrust fragments.

Unlike the upper horizons of the profile, gold in the saprolite appears to be systematically leached in regard to the bedrock, mostly at the weathering front. The gold mass balance in the oxidized part of deposits with respect to the primary ore shows a relatively constant rate of -40 to -55% for most of the African, Amazonian and Australian deposits. This means that saprolitization processes have a uniform effect on gold remobilization at the base of the weathering profiles.

INTRODUCTION

The geochemical cycle of gold in tropical environments is relatively complex because it may be dissolved and sometimes reprecipitated in the weathering profiles (Mann, 1984; Freyssinet *et al.*, 1989a; Colin and Vieillard, 1991; Edou-Minko *et al.*, 1992; Bowell *et al.*, 1993a; Porto and Hale, 1996). It has been shown that the gold signal in intertropical zones varies greatly from site to site (Wilhelm and Essono-Biyogo, 1992; Bowell *et al.*, 1996). Considering West Australian lateritic deposits on the basis of conceptual models, it was suggested that the paleoclimatic history of weathering profiles controls the extent of supergene gold remobilization and probably the nature of gold complexation (Butt, 1987).

The purpose of this paper is to use a quantitative approach to determine general trends in the significance of gold anomalies in soils in terms of various lateritic weathering contexts in order to better assess the selection of soil geochemical anomalies of gold. The comparison of gold signal variations from well-characterized ore deposits of sub-Saharan Africa, Amazonia and Australia is based on a mass balance calculation of the gold, estimating the evolution of concentration in terms of residual enrichment and absolute gain or loss.

WEATHERING PROFILES IN INTER-TROPICAL ZONES

The major types of tropical weathering profiles can be considered in relation to the climatic zone in which they develop, such as savannah and rainforest.

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The ferruginous duricrust profile (savannah zone)

Lateritic profiles capped by ferruginous crusts (ferruginous duricrust, cuirasse, ferricrete) are mostly developed under tropical climates characterized by alternating wet and dry seasons (i.e., savannah climates). In Africa, the climatic stability field of extensive duricrusts corresponds to an E-W band in which the average annual temperature exceeds 22°C and annual rainfall ranges between 900 mm and 1400 mm. Ferruginous duricrusts tend to be less abundant in semi-arid areas such as in the Sahelian band and also in more humid areas such as Central Africa or Amazonia.

A typical well-preserved lateritic profile commonly consists of four superposed units that, from the base up (Figure 1), are parent rock, saprolite, mottled zone, and duricrust.

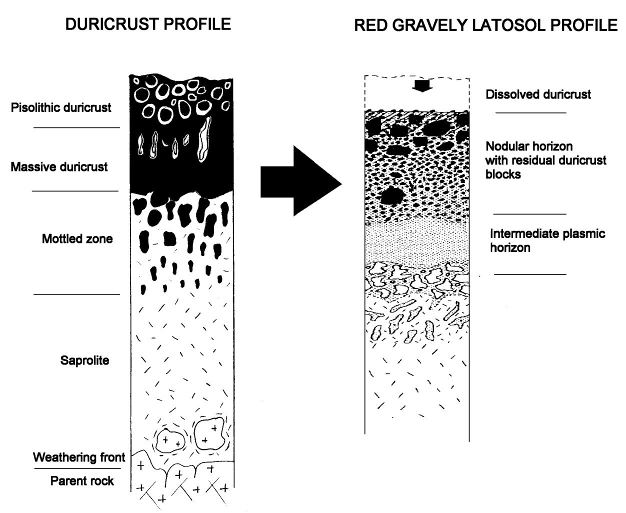

Figure 1: *Schematic ferruginous duricrust profiles and their transformation to red gravelly latosols.*

The saprolite overlying the fresh parent rock is generally a thick weathered horizon in which weathering is an isovolumetric process; i.e., the primary minerals are pseudomorphically replaced by weathering products, whilst retaining the structure of the parent rock. In the upper part of this horizon, most of the primary minerals have been weathered to kaolinite and goethite; only quartz and resistant minerals (zircon, tourmaline, chromite, etc.) remain unaffected.

The mottled zone overlying the saprolite, is marked by the progressive destruction the primary structure. The weathering in this horizon is marked by both a volume reduction and a strong textural reorganization. Absolute accumulation of iron starts in the mottled zone with the development of ferruginous spots (5–150 mm) that become more abundant and more indurated towards the top of the zone.

The ferruginous duricrust capping the lateritic profile develops a fairly homogeneous indurated matrix that imparts a massive aspect to the cuirasse whilst, towards the top of the layer, goethite rims and cutans develop along microcracks and microfissures through the purple-red matrix. These rims reflect the rehydration and replacement of hematite by goethite, giving rise to the formation of a pisolitic duricrust facies (Nahon, 1991).

The transformation of the ferruginous duricrust profile (rainforest system)

The humid zones of Central Africa and Amazonia commonly show the remnants of old duricrust alternating with reddish or yellowish clayey soils (latosols) containing ferruginous nodules. Red gravelly latosols result from the chemical weathering of duricrusts under rainforest conditions (Nahon *et al.*, 1989; Lucas and Chauvel, 1992; Tardy, 1993), with a progressive reduction to centimetre-size, then millimetre-size gravel and eventually to micro-aggregates as described by Lucas and Chauvel (1992). A clayey matrix composed mostly of goethite and kaolinite, sometimes gibbsite, develops at the expense of the old ferruginous horizon.

A common red gravelly latosol consists, from the base up (Figure 1), of: saprolite, an intermediate plasmic horizon, and a nodular (or gravelly) horizon.

The saprolite of humid tropical zones shows similar features to that of the savannah zone except that, at the top of the horizon, numerous channels of red or yellow clay matrix penetrate the saprolite matrix. The intermediate plasmic horizon (0.5–10 m thick) has a homogeneous aspect and is composed of the same red or yellow clay matrix as the underlying channels.

The nodular (or gravelly) horizon is composed of duricrust blocks and/or ferruginous nodules bound by a clay matrix with the same characteristics as the matrix of the intermediate plasmic horizon. The top of the nodular horizon is generally covered by a 0.2–0.5 m thick humic layer.

On truncated profiles, it is seen that red or yellow latosols develop at the expense of the underlying saprolite and, of course, do not contain nodular horizons. The red or yellow clayey matrix, however, is similar to that of the red gravelly latosols.

The processes of ferruginous duricrust transformation to a red gravelly latosol can be related to the average moisture content of the soil (Tardy, 1993). The indurated ferruginous structure of the savannah duricrusts is mostly composed of hematite. Transformation of this hematitic structure results from the combined process of (i) iron remobilization due to the rapid mineralization rate of organic matter in rainforest conditions, and (ii) rehydration of the indurated hematitic structure into powder-like goethite, the average rainforest soil moisture content being too high to maintain hematite as a stable soil component (Tardy and Nahon, 1985). In confined environments of rainforest areas, the latosols can even be transformed into podzols with a strong iron and alumina leaching leading to the formation of sandy surficial horizons (Lucas and Chauvel, 1992).

GOLD MASS BALANCES IN THE WEATHERING PROFILE

To compare the evolution of the gold signal in various lateritic profiles a mass balance approach was used to evaluate the relative percentage of depleted or enriched gold. The gold mass balance calculations thus provide a relative index permitting evaluation of the increase or decrease of the gold signal with depth.

In a first step, the mass balance calculations were applied on various soil geochemical anomalies using the average gold content in the saprolite horizon as reference in order to compare gold signal trends in various upper horizons commonly used as sampling media in soil geochemical surveys.

In a second step, the gold mass balance at various depths within the saprolite horizon was determined using the average gold content in the fresh parent rock as reference in order to determine how gold is vertically distributed in the saprolitic horizon, which makes up most of the oxidized zone of lateritic deposits.

Finally, in the third step, the mass balance of the gold is considered for a series lateritic deposits. In each case, the average gold content of the fresh parent rock is the reference with respect to the the average gold content of the whole saprolite. This mass balance approach, that considers the overall deposit, permitted the assessment of the probable evolution of (the) gold grades from the oxidized zone to the bedrock.

Gold is generally concentrated in small amounts within the mineralized structures of the fresh parent rock or overlying saprolite, and is strongly dispersed in the upper ferruginous horizons. Moreover the gold distribution pattern is highly heterogeneous at mineralized structure scale, which is why the average gold content values used in the mass balance calculations need to take into account large volumes (several tens of cubic metres) that include not only the mineralized structures, but also part of the wall rocks and the dispersion haloes in the weathering horizons (see Figure 2).

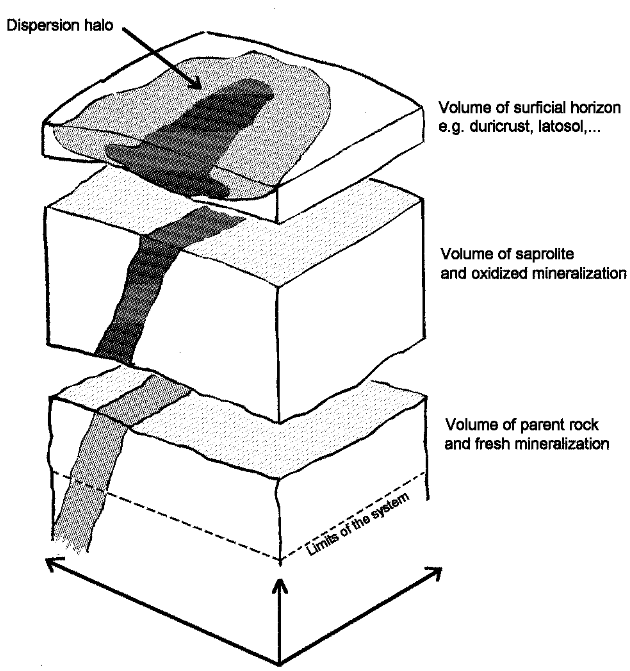

Figure 2: *Sketch of the system taking into account the volumes for the gold mass balance calculation.*

Mass balance calculation

The gold mass balances were estimated using models developed by Brimhall and Dietrich (1987) with reference to the variation of bulk density, porosity and the concentrations of an immobile element. The equations take into account variations in element content related to residual enrichment, collapse of primary fabric, and open-system transport. The mass balance model comprises three major parameters:

1. Residual enrichment

   Residual enrichment is related to increasing porosity with preservation of the primary texture, as in the saprolite. The enrichment/depletion factor is then a simple function of density:

$$\frac{C_{i,w}}{C_{i,p}} = \frac{\rho_p}{\rho_w} \qquad [1]$$

   ρ_w: Bulk density of the weathered material
   ρ_p: Bulk density of the primary rock
   $C_{i,w}$: Concentration of a given element i in the weathered rock
   $C_{i,p}$: Concentration of a given element i in the primary rock

   Saprolitization being an isovolumetric process, the gold mass balance in saprolitic oxidized ore in comparison to the underlying fresh ore, can be expressed using equation [1].

2. Volumetric change

   Collapse effects and mechanical strain develop generally in the upper part of weathered profiles. In this study, the amount of chemical enrichment due to collapse was determined considering Zr or Ti as immobile elements representative of stable heavy minerals. Any enrichment of Zr or Ti in excess of the residual enrichment is therefore considered as a volume reduction, as no or little evidence of zircon and Ti-oxide dissolution was observed in any of the examples. The collapse factor is calculated from the following equation:

$$\varepsilon_{j,w} = \frac{\rho_p C_{j,p}}{\rho_w C_{j,w}} - 1 \qquad [2]$$

   $\varepsilon_{j,w}$: Collapse factor calculated from the concentrations of an immobile element j (Zr or Ti) as reference.

3. Absolute gain and loss

   Absolute gain and loss occur in open systems, which is the case in most weathering processes. This parameter is defined as the mass added to the unweathered closed system by estimating the excess enrichment after correction for residual enrichment and the collapse factor. The absolute enrichment can be expressed by the following equation:

$$\tau_{i,w} = \frac{\rho_w C_{i,w}}{\rho_p C_{i,p}}(\varepsilon_{j,w} + 1) - 1 \qquad [3]$$

   $\tau_{i,w}$: Mass of element i added to the unweathered closed system

   The $\tau_{Au,w}$ parameter representing the absolute gain or loss of gold of a weathering horizon with respect to a reference horizon was used as a comparison index of the gold signal between the saprolite and various types of overlying ferruginous horizon.

Origin of data

The gold mass balance estimations presented below are based on well-documented exploration databases with several hundreds to tens of thousands of samples for each site. The sites at which the gold signal was compared between the saprolite and the overlying ferruginous horizon are based on a systematic grid of pits or trenches, completed with auger and/or drill holes in the saprolite. The gold mass balance in the saprolite could be detailed at two sites (Yaou and Mount Percy) due to reserve estimation databases composed of RC drill-hole grids. The gold mass balance at the deposit scale is based on the average gold contents and average densities of fresh and weathered rock quoted in the literature. The exploration datasets were completed by chemical bulk analysis (ICP-AES and/or FX) of major and trace elements of representative profiles in order to calculate the collapse factor and the mass balance of the major elements.

RESULTS

Gold mass balance between the saprolite and ferruginous horizons

The sites for estimating the gold mass balance between the saprolite and ferruginous horizons were selected according to their pedogenic and paleoclimatic location (Table 1) and include cases with duricrust profiles, red gravelly latosols, yellow latosols and podzols on truncated profiles. The absolute gold gain or loss varies strongly between the different sites (Table 1).

In ancient laterite profiles of the savannah zone (e.g., Banankoro), the ferruginous duricrust is well developed over a thickness of 3 to 8 m with an important absolute accumulation of iron (τ_{Fe} > 450% in Banankoro). Gold is strongly leached (τ_{Au} = –75%) at the top in the ferruginous duricrust with respect to the gold content in the saprolite.

At the Lafarella deposit, under similar weathering conditions as the Banankoro area, the gold mass balance in the duricrust above the mineralized body is strongly negative (τ_{Au} = –90 %), (Bamba, 1996). This mass balance probably overstimates the net loss of gold because the calculation only considers the average gold content above the primary structure and do not integrate the gold stock present in the dispersion halo.

In the humid tropics, where the duricrust has been degraded to a red gravelly latosol, the gold mass balance shows contrasting results. The red gravelly latosols (3–18 m thick), are generally composed of nodular fragments from the ancient ferruginous duricrust and recent red clayey matrix. The gold mass balance may be slightly negative as in Posse deposit, or positive as in the Mborguéné and Ity deposits.

The profiles with the highest gold accumulation are the yellow latosols of equatorial climates. At Yaou, for example, where the yellow latosol develops on a truncated profile at the expense of the saprolite (a com-

Table 1: ***Principal characteristics of the studied sites.***

	Banankoro (South Mali)	Larafella (Burkina Faso)	Posse (Bahia st., Brazil)	Mborguene (Cameroun)	Ity Mine (Côte d'Ivoire)	Esperance (F. Guiana)	Yaou (F. Guiana)
Morpho-climatic parameters							
Climate	Contrasted tropical	Contrasted tropical	Humid tropical	Humid tropical	Humid tropical	Equatorial	Equatorial
Annual rainfall (mm/y)	900	850	1800	1800	2000	2500	2500
Profile	Complete	—	Complete	Complete	Complete	Truncated	Truncated
Ferruginous horizon	Fe- duricrust	Fe- duricrust	Gravelly latosol	Gravelly latosol	Gravelly latosol	Semi-podzol	Yellow latosol
Thickness (m)	(4–5)	(2.5)	—	(3–4)	(3–18)	(<1)	(2–4)
Mineralization type	Shear zone. Quartz veins in volcano-sedimentary schists	Mineralized albitite stockwork in volcano-sedimentary series	Fine stockwork with hydrothermal alteration in volcano-sed. rocks	Quartz lodes in volcano-sedimentary series	Skarn type in carbonate – diorite and mafic schists	Quartz stockwork in volcano-sedimentary series	Quartz-carbonate stockwork in tonalite (Yaou-A orebody)
Mass balance parameters							
Immobile element	Zr	Zr	Zr	Zr	Zr	Zr	TiO_2
$\varepsilon_{i,w}$ *(%)*	–49	–25 [1]	–50	–25	–59	–27	–10
$C_{Au,saprolite}$ *(ppb)*	410	7350 [1]	720	501	2200	1855	4780
$C_{Au,Fe\ hor.}$ *(ppb)*	120	800 [1]	1120	773	5900	1162	9060
τ_{Au} *(%) Ferruginous horizon*	–75	–90	–11	+37	+47	–54	+61
τ_{Au} *(%) top horizon–soil*	—	—	–30	—	—	—	—
τ_{Fe} *(%)*	+434	+990	+35	+151	+11	–43	+37
References	BRGM (1984) unpubl. report; Freyssinet (1993)	Bamba (1996) 1. mineralized body without halo	Porto (1991) Porto and Hale (1996)	BRGM (1986) unpubl. report; Freyssinet *et al.* (1989)	Vitali (1965); S.M.I. (1992) unpubl. report.	Zeegers *et al.* (1985) Lecomte and Zeegers (1992)	BRGM—BHP-UTAH (1991) unpubl. report; Freyssinet (1994)

mon feature in Amazonia, especially on hill slopes), the absolute accumulation rate exceeds 60% with gold being the most enriched element in this horizon (Freyssinet, 1994).

At the Espérance deposit, the weathering profile is truncated and the pedogenic process is characterized by an early stage of podzolization with most of the elements, such as Fe ($\tau_{Fe} < -40\%$) and Al ($\tau_{Al} < -45\%$), beginning to be leached. The soil is reduced to a relatively thin (< 1 m) sandy-clayey horizon capping the saprolite (Lecomte and Zeegers, 1992). This podzolization process, developed at the expense of a truncated mineralized saprolite, is accompanied by a strong leaching of gold.

Gold mass balance in saprolites

At the Yaou deposit (orebody A) in French Guiana, the large amount of data obtained from grid (25 × 25 m) of vertical drill holes, with regular sampling at 1 m intervals through the weathering profile, enabled a statistically well-established calculation of the gold mass balance in the saprolite (Freyssinet, 1994). The gold mass balance in terms of depth was calculated for superimposed 2-m-thick saprolite layers (Figure 3a) with respect to the average gold content in the primary ore. The leaching process occurs mostly at the weathering front where the net loss is –55%. The gold mass balance then decreases gently upwards in the profile to reach –70% at the top of the saprolite. However, it is noted that at specific depths (6 m and 14–16 m) the absolute gold loss is reduced to –30%. This corresponds to scattered enrichment of Mn oxides, with the linear relationship between Au and Mn concentrations probably being due to adsorption of Au by Mn-oxides and to the accumulation processes in relation to the actual water table levels (Freyssinet, 1994).

At the Mount Percy deposit in Western Australia, the gold mass balance in the saprolite was estimated from a database compiled from a grid (50 × 50 m) of 459 RC drill holes with a total of about 25 000 samples. Density measurements were determined by CSIRO on two representative cross-sections (Butt *et al.*, 1995). The mass balance, calculated for 5-m-thick saprolite layers (Figure 1b), shows that about 35% of the initial gold stock is leached close to the weathering front. The leaching process increases progressively from the base to the top of the saprolite to reach a net loss of –67% at 10 m depth. Between 20 and 35 m depth, the gold loss is less important and ranges from –48 to –30%. Butt *et al.* (1995) showed that this depth corresponds to the development of a large lateral dispersion halo of Fe and As associated with scattered secondary gold reprecipitation.

Gold mass balance of lateritic deposits

As with the saprolites, the estimation of the gold mass balance at the scale of entire lateritic deposits needs well-established average gold contents and rock densities for both the primary and the oxidized ore. Mining data from various lateritic deposits were therefore compiled in order to estimate the gold mass balance in the oxidized part of each deposit. Only the saprolitic part of the deposits was considered—the upper ferruginous layers were not taken into account in the mass balance estimation. Figure 4 illustrates the relationships between the mass contents of gold per cubic meter in both the fresh ore of the parent rock and the oxidized ore of the saprolite in various regoliths of Côte d'Ivoire (Angovia), Mali (Syama), French Guiana (Espérance, Yaou), Brazil (Posse), Western Australia (Big Bell, Copperhead, Harbor Lights, Mount Percy, Nevoria, Wiluna) and the Northern Territories (Cosmo Howley, Moline, Woolwonga).

Despite the primary ore being of various types, all the deposits show a negative gold mass balance of between –22 and –55% in the saprolitic ore with respect to the parent rock ore. The average gold loss in the oxidized ore for entire lateritic deposits is around –43%, with about 70% of the deposits presenting a mass balance between –40 and –55%.

There is apparently no major difference of gold mass balance between lateritic deposits according to their paleoclimatic situation. The gold mass balance in the saprolite of the Amazonian regolith (Espérance, Yaou) seems to be similar to that of deposits in African savannah zones (Syama, Angovia) and even of deposits in semi-arid zones such as Western Australia (Big Bell, Copperhead, Harbor Lights, Mount Percy, Nevoria, Wiluna).

DISCUSSION

In the cases described above, scientific studies show that gold is remobilized under tropical conditions, regardless of the type of horizon overlying the saprolite, be it ferricrete (Freyssinet *et al.*, 1989a; Bamba, 1996), red gravelly latosol (Porto and Hale, 1996), yellow latosol (Freyssinet, 1994) or tropical podzol (Lecomte and Zeegers, 1992). The remobilization process of gold leads to highly contrasted situations ranging from leaching in the duricrust of savannah zones to surface enrichment in the yellow latosols of rainforest systems.

It has been schown that gold remobilization in savannah zones, gold remobilization is contemporaneous with the duricrust formation (Freyssinet, 1993). As the duricrust development is a non-saturated zone process (Tardy and Nahon, 1985), this upper part of the weathering profile is a well-oxygenated layer with strongly oxidizing conditions that can favor gold dissolution. The Fe-duricrust acts as a leaching zone from which gold is mobilized to migrate downwards through the pore system. As the ferricrete formation rate is around 1–2 m/Ma as estimated by Nahon (1986), gold leaching in the duricrusts of West Africa could have developed over very long periods, thus explaining the strong negative gold mass balance observed in ferricretes. Part of the remobilized gold can sometimes develop absolute enrichment in the mottled zone (Freyssinet, 1994; Bamba, 1996).

Where the ferruginous duricrust has been degraded to a red gravelly latosol, the gold mass balance is less negative (e.g., the Posse deposit) and may even be positive (e.g., the Mborguéné and Ity deposits). It has been shown that the gold content in red gravelly latosols is preferentially concentrated in the fine clayey matrix rather than in the coarse fraction of duricrust nodules, which are generally depleted (Lecomte and Zeegers, 1992; Porto and Hale, 1996; Costa *et al.*, 1993). The enrichment factor of gold in the red gravelly latosol can probably be related to the progressive dissolution of the duricrust and the accumulation of residual gold in the fine neoformed matrix. The gold mass balance in these latosols would thus depend on the amount of dissolved duricrust and on the relative proportions of Au-enriched fine matrix and of Au-depleted ferruginous nodules. The upper part of the ancient duricrust being generally dissolved, the red gravelly latosol develops at the expense of the lower part of the duricrust and the mottled zone. The gold enrichment sometimes observed in the mottled zone can favor the absolute gain observed in red gravely latosols.

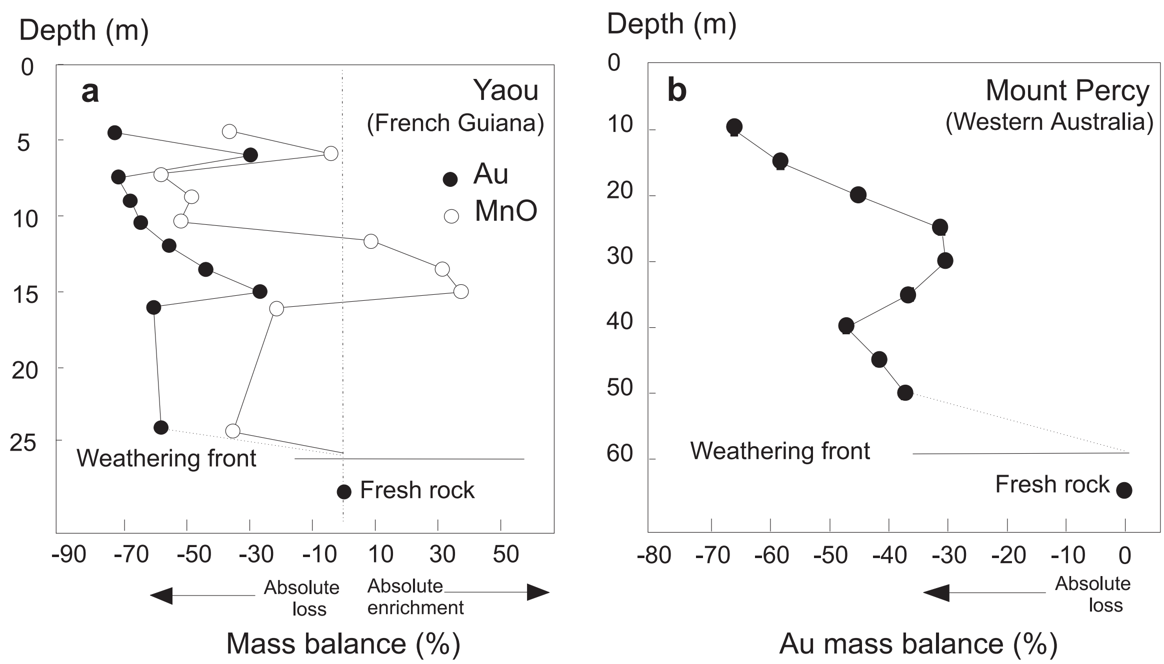

Figure 3: *Gold mass balance in the saprolite profile of the Yaou (a) and the Mount Percy deposits (b). The reference is the average gold content in the parent rock.*

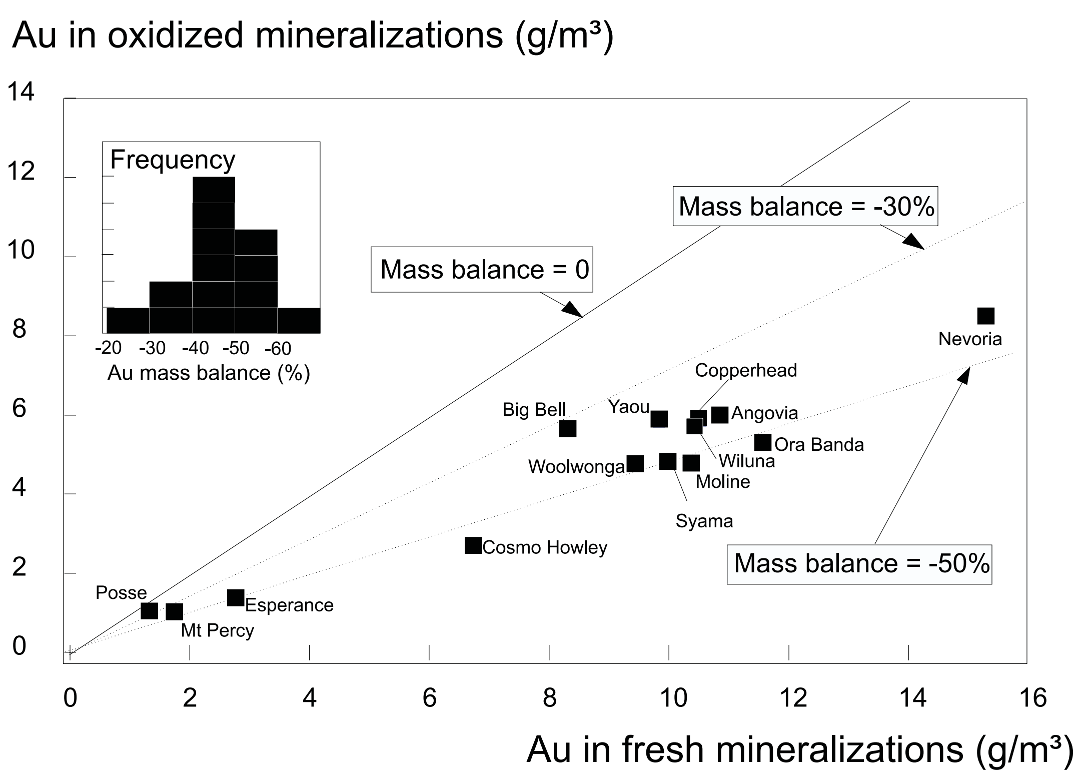

Figure 4: *Distribution of the average Au mass content in the oxidized saprolite versus that in the fresh parent rock for various mineralized lateritic deposits (including a bar chart of the gold mass balances).*

The Yaou deposit presents the highest gold accumulation in a recent yellow latosol developed on a truncated profile. Little gold dispersion occurs in the latosol and that most of the remobilization process is vertically controlled (Freyssinet, 1995). Gold is strongly leached within the humic layer in the top 50 cm, but reprecipitates below the ferruginous horizons, under less-oxidizing conditions, to develop spectacular absolute enrichment.

In Amazonia, however, both laterite and podzol systems can coexist. The podzolization process develops mostly on lower slopes at the expense of a previous yellow latosol (Lucas and Chauvel, 1992). Espérance deposit shows the opposite situation to Yaou. Here, the shallow sandy clay soil above the mineralized saprolite represents an intermediate stage of yellow latosol replacement by podzolization, which induces a strong deferrugenization process ($\tau_{Fe} = -43\%$) through organic acid complexation and leads to a residual enrichment of silica. As in the humic layer of yellow latosols, Au is strongly leached, probably in relationship with the important concentration of humic acids, but without reprecipitation in the underlying horizon (Bowell *et al.*, 1993b). This transformation of yellow latosols to podzols can thus strongly modify the soil gold signal from one of surface enrichment to one of strong leaching, resulting in strong lateral changes in the gold signal in rainforest systems depending on the soil process.

The gold mass balance in the saprolite with respect to the fresh parent rock does not present contrasted results according to the different situations. Both at Yaou in Amazonia and at Mount Percy in West Australian, the gold mass balance systematically shows an important loss occurring at the weathering front, as indicated on Figure 3.

The paleoclimatic history of Northern Amazonia having oscillated between tropical to equatorial climates since the Late Cretaceous (Tardy *et al.*, 1991), the saprolitization in the Yaou deposit can probably be considered as having been a continuous process since the weathering began up to the present time. As most of the gold loss occurs at the weathering front, the gold leaching process can probably be related to saprolitization reactions. Saprolite development is based on a progressive lowering of the weathering front, above which the saprolite shows little leaching of the residual gold. Gold dissolution is, however, reactivated in the top five meters of the saprolite close to the *latosol*, but the net loss only affects 15% of the initial gold stock in this part of the horizon.

The gold mass balance of the Mount Percy deposit, like that of the Yaou deposit, shows an important loss of gold at the base of the weathering profile. Here, however, the leaching process increases progressively from the base (–30%) to the top (–70%) of the saprolite, except at around 30 m depth (Figure 3) where secondary reprecipitation, as described by Butt *et al.* (1995), moderates the net loss. This progressive upward leaching in the saprolite constitutes a characteristic of the West Australian deposits, where the top part of the saprolite is commonly strongly leached. The phenomenon is not observed to such an extent in African and Amazonian deposits and is probably related to the post-lateritic gold remobilization processes that occurred since the Late Tertiary when the climate evolved to arid conditions (Butt, 1992).

The gold mass balances estimated for various types of lateritic deposit in Africa, Amazonia and Australia confirm that the saprolitization process induces a net loss of gold at a relatively constant rate of between –30 and –50% for most of the deposits. This suggests that gold remobilization at the weathering front under lateritic weathering conditions could have occured under similar physico-chemical conditions. The fact that the West Australian deposits do not show any greater loss in comparison to the African and Amazonian deposits tends to indicate that the Quaternary gold remobilization phase under arid climate had a dissolution-reconcentration effect with no major leaching out of the system.

CONCLUSIONS

The conclusion from this comparative study of the gold mass balance in different lateritic contexts, is that the potential of a soil geochemical gold anomaly and the possible evolution of gold grade with depth to the saprolite can be assessed from a detailed knowledge of the pedological environment. The estimation of the gold signal in soils is strongly dependent of the type of lateritic weathering, and thus of the morpho-climatic history.

In savannah zones, the formation of a duricrust induces a leaching in the upper horizons and thus develops strongly depleted gold anomalies. As duricrust formation is a very long process, the dispersion of gold is generally well extended but show a low signal in surface. On the contrary, in rainforest zones and for similar gold contents in the saprolite, gold tends to be enriched in the recent yellow latosol pedogenesis. Gold anomalies in soil are thus relatively strong, and the gold content tends to decrease from the latosol to the underlying saprolite. Thus gold anomalies in yellow latosols tend to overestimate the potential of the underlying oxidized mineralizations. In rainforest zone, the progressive lateral change from a yellow latosol to a podzol might induce a drastic change in the gold signal intensity from a strong anomaly to a very low one because of intense gold leaching in podzols.

Red gravelly latosols, due to their combined origin from both savannah and rainforest processes, show a depleted gold signal in the ferruginous nodular fraction and an enriched gold content in the clayey matrix. The sampling procedures should be adapted to this strong difference of gold content in term of granulometry. The use of the fine fraction (e.g., <125 μm) might induce strong gold anomalies with widely extended haloes, whereas the use of the coarse fraction (e.g., > 2–3 mm) might produce a low gold signal, but relatively well focused on the mineralized structures.

The strong variations in gold signal according to the soil type require careful regolith mapping and adapted sampling procedures for each exploration phase.

In the saprolite, unlike the soils, gold is systematically leached, mostly at the weathering front, at a relatively constant rate of –40 to –55%. As saprolites in general show a porosity of 30 to 40%, the change of density might compensate the gold loss, which is why the gold content in the oxidized ore may be roughly similar, or slightly higher than the average gold content of the fresh ore.

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