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Dissolution Features of Gold Particles in a Lateritic Profile at Dondo Mobi, Gabon

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ABSTRACT

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This paper describes the morphological evolution of gold particles in a lateritic weathering profile under rain forest. Inherited from primary quartz veins associated with amphibolite, the gold particles can be recognized from the weathering front up through the saprolite and overlying regolith to the land surface in the central part of the supergene gold dispersion halo. Gold particles undergo some changes in the uppermost 10 m. Voids and corrosion pits appear on particle surfaces; their numbers and sizes increase toward the land surface. Edges of particles become progressively more blunt from the bottom to the top of the section. The morphological changes are attributed to dissolution of gold over time. Possible causes for such dissolution are discussed. Occurrence of gold particles in the soil could be helpful for gold explorations in the humid tropics.

INTRODUCTION

Because explorations for gold are given priority in many countries of the intertropical belt, the nature and distribution of gold particles within deeply weathered profiles should contribute to efficient prospecting. In tropical parts of Africa, for example, weathering profiles are thick (Bocquier et al., 1984) and thus conceal alterations in the bedrock. Hallbauer and Utter (1977) and Herail et al. (1988) used morphological features of gold particles in alluvium to establish relationships between the shapes of the particles and the distances over which they had been transported. Wilson (1983) described shapes of gold nuggets in lateritic weathering profiles in Australia and compared those with nuggets in gold-bearing bodies. He found the morphology of the gold particles

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useful in such comparisons. The possibility of relating gold particles within the weathering profile to those of an underlying gold deposit prompted the present investigation. A gold deposit has been found under a thick, weathered mantle at Dondo Mobi in the equatorial forest of southern Gabon. The morphology of gold particles visible to the naked eye has therefore been examined in samples representing several layers of the weathering profile overlying the gold deposit in the central part of the gold dispersion halo, the shape of which was determined on the basis of data from auger holes, drill holes and pits (Colin and Lecomte, 1986; Lecomte, 1988).

GEOGRAPHIC AND GEOLOGIC SETTING

The Dondo Mobi area is located in the gold district of Eteke (11°35′E, 1°17′S) in southern Gabon (Fig. 1). This region is formed of "half-orange" hills, 700 m high, covered by an equatorial rain forest. The climate is warm and humid, with a dry season from June to October. The mean annual rainfall is around 2,000 mm.

The gold deposit is located 100 m below the surface in a gneiss of the Birrimian series (Bassot, pers. commun., 1987) intruded by lenses of amphibolite. Gold is associated with pyrite and occurs in siliceous or silico-carbonaceous vein fillings. The veins are related to extensive fractures parallel to the schistosity of the rock. The structure of mineralized veins (Fig. 2) is preserved through the saprolite and the veins are close to the contact between the gneisses and a lower proterozoic formation of schists and quartzites.

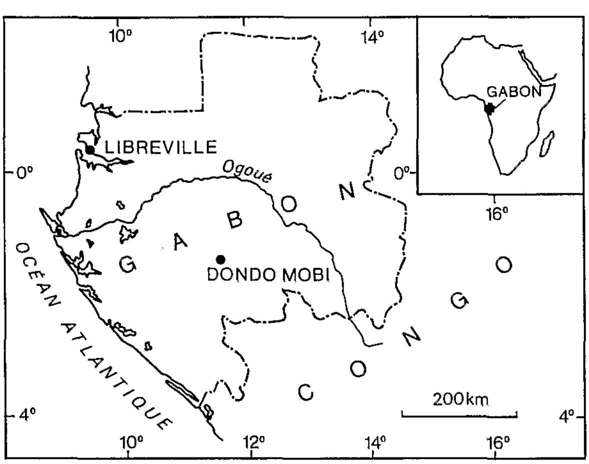

Fig. 1. Location of the Dondo Mobi gold deposit.

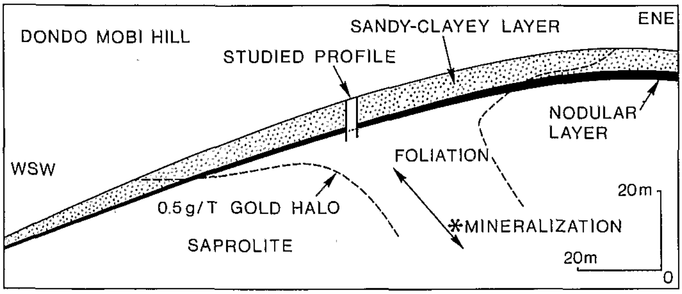

Fig. 2. Schematic cross-section of the weathering mantle of the Dondo Mobi hill.

METHODS

A pit was dug from the surface into the saprolite (10 m depth) in the central part of the 0.5 g/t gold halo above the mineralized veins (Fig. 2). This halo is a supergene dispersion pattern of gold (Lecomte and Colin, 1987). For study of the weathering profile, the layers were identified, described and sampled. Five samples were collected (32 l per sample = 50 kg) from the weathering profile with the following distribution (Fig. 3): three samples of the sandy–clayey layer (at depths of 0.5, 3.5 and 5.5 m), one sample of the nodular layer (7 m deep) and one sample of the saprolite (9 m deep). The samples were carefully washed by means of a California pan. Gold was separated from the other heavy minerals by heavy liquids and magnetic techniques; 1817 gold particles were collected, ranging from 40 μ to 2,000 μ in size. The morphology of

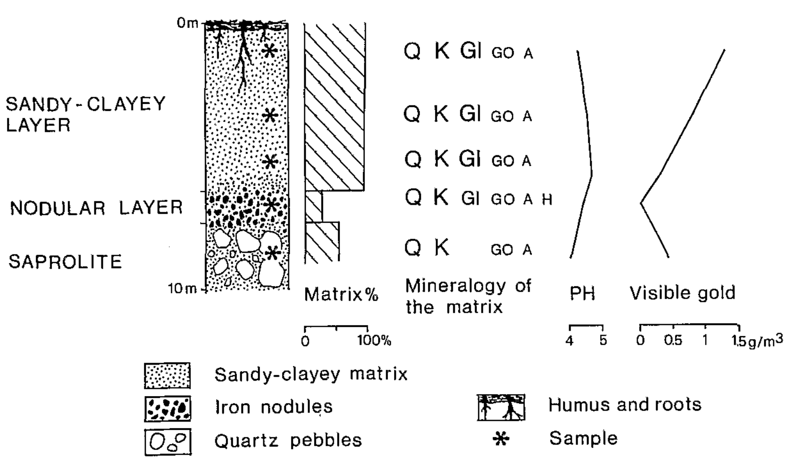

Fig. 3. Sketch showing principal features of the profile studied: Q=quartz; K=kaolinite; Gl=gibbsite; GO=goethite; A=amphibole; H=hematite; the sizes of the letters are proportional to the abundance of the minerals (X-ray diffraction).

gold particles was examined by optical microscopy and scanning electron microscopy (SEM).

THE WEATHERING PROFILE

The profile (Fig. 3) can be divided into three main layers from the base (10 m deep) to the surface as follows:

(1) The saprolite, 2.40 m thick, is made up of angular quartz fragments or blocks (50% by weight) embedded in a red–brown sandy–clayey matrix (which also represents 50% by weight) and consists mainly of quartz and kaolinite with subordinate amounts of goethite and amphibole.

(2) The nodular layer, 1.60 m thick, consists of red–brown sandy–clayey matrix (25% of the total weight) rich in scattered nodules and quartz pebbles. Quartz, kaolinite and gibbsite are the main minerals of the matrix; goethite and amphibole are less abundant and hematite is present. At the base of this layer, iron nodules form centimetric plates with layered textures whereas at the top are numerous centimetric and millimetric rounded ferruginous nodules. These nodules have a massive texture and sometimes a thin peripheral cortex; their grain sizes progressively decrease upward.

(3) The sandy–clayey layer, 6.00 m thick, is composed of a yellow–brown sandy–clayey matrix with rare rounded ferruginous nodules at the base. At the contact with the nodular layer, the matrix comprises 90% of the total weight and the sizes of iron nodules rapidly decrease upward from 5 to 2 mm in diameter. From the bottom of the layer to the surface, the relative weight percent of the matrix increases (92% at the top). The mineralogical composition of the matrix remains uniform, consisting of quartz, kaolinite and gibbsite with minor goethite and amphibole. Such matrices are typical of ferralitic soils under primary forest in Gabon (Beaudou et al., 1977; Muller, 1978) and have fine microaggregate texture with polyhedric or granular elements which are less pronounced in the three uppermost metres. A few roots may appear in this uppermost part. The sandy–clayey layer is covered by a light pale–greenish humic layer, 0.10 m thick, with indications of strong biologic activity.

The pH values range from 4.1 to 4.7. The maximum value occurs at the base of the sandy–clayey layer and regularly decrease upward (Fig. 3).

The visible gold content is 0.45 g/m^3 in the saprolite, 0.16 g/m^3 in the nodular layer and increases from 0.41 g/m^3 to 1.42 g/m^3 upward in the sandy–clayey layer (Fig. 3).

MORPHOLOGY OF GOLD PARTICLES

The gold particles present in the saprolite (Fig. 4.1) have very jagged rims with numerous indentations. They are made up of gold crystals with sharp edges. Quartz crystals, locally associated with a poorly crystallized Si–Al–Fe

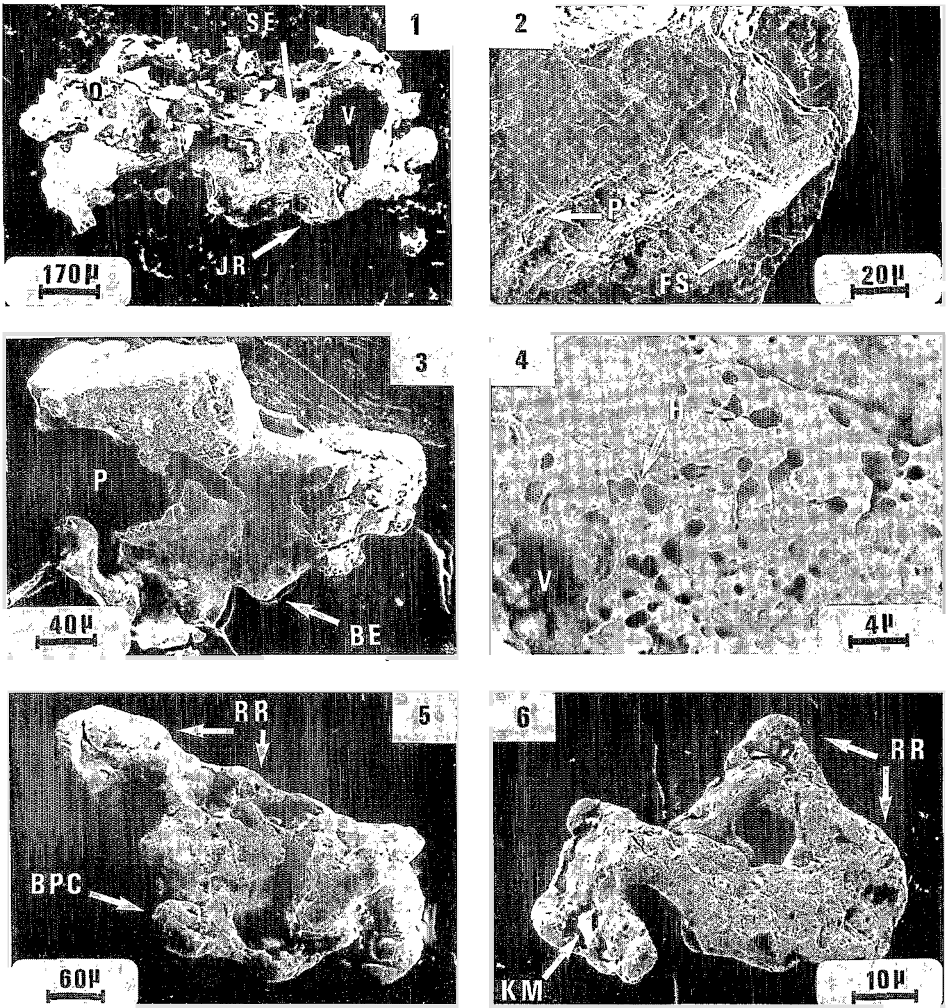

Fig. 4. Scanning electron micrographs of gold particles: 1 = gold particles extracted from the saprolite, *JR* = jagged rim, *Q* = quartz, *SE* = sharp edge, *V* = void; 2 = details of 4.1; note the non porous surface; *FS* = flaky structures, *PS* = puckered structures; 3 = gold particles extracted from the nodular layer, *BE* = blunt edge, *P* = dissolution pit; 4 = details of 4.3; the surface is covered by numerous dissolution features; *H* = dissolution pit, *V* = void; 5 and 6 = gold particles extracted from the sandy–clayey layer; note the porosity and the marked roundness; *KM* = kaolinitic matrix, *RR* = rounded rim, *BPC* = blunt primary crystal.

kaolinitic matrix, are present within the gold particles. Most often, relatively large voids are observed in or between these phases and the gold. The non-porous surfaces currently consist of flaky and puckered structures (Fig. 4.2).

The gold particles extracted from the nodular layer (Fig. 4.3) are readily recognizable crystals. They have blunt edges and are marked by corrosion pits.

For example, the particle shown in Fig. 4.3 consists of relicts of a cubic crystal and an octahedral crystal. The surface morphology is irregular and displays numerous subcircular micrometric holes (Fig. 4.4). These holes may be connected to each other, creating bigger voids. Locally, within the particles is a honey-yellow poorly crystallized clay matrix similar to the one described earlier.

At the base of the sandy–clayey layer, gold particles are characterized by more rounded shapes (Fig. 4.5). The crystal faces are still visible but the edges are distinctly blunt. From the base of that layer to the soil surface, the crystal faces of the gold particles are less and less recognizable. They disappear completely at the top of the layer (Fig. 4.6). The roundness of particles is especially marked in the surface layer of the soil.

Cavities or corrosion pits increase in size upward in the weathering profile, reaching 10 μ in their maximum dimensions in the surface layer of the soil. The cavities contain an Si–Al–Fe matrix, often separated from the gold by a void.

DISCUSSION

Morphological differences in gold particles in the various parts of the weathering profile are as follows:

(1) Quartz disappears and is replaced by an Si–Al–Fe kaolinitic matrix in cavities in gold particles within the transition from the saprolite to the overlying nodular layer.

(2) Porosity of the gold particles is increased because of more corrosion pits in the nodular and sandy–clayey layers as compared to the saprolite.

(3) Roundness of particles is increased markedly from the saprolite to the soil surface.

In the saprolite, the quartz grains within the gold particles are bordered by voids or by an Si–Al–Fe matrix. In the upper parts of the profile, only the Si–Al–Fe matrix is found in the pits. The disappearance of the quartz and the persistence of the Si–Al–Fe matrix is taken as evidence for epigenetic replacement of primary quartz by that matrix.

The sizes and shapes of the cavities or pits in the gold particles suggest that they are the result of dissolution. Deep in the profile, the pits are round and small (1 μ). The sizes gradually increase upward in the weathering profile. Those in particles in the uppermost part of the sandy–clayey layer are as large as 10 μ in diameter. Furthermore, the pits follow the crystal faces of the primary gold.

An additional change in gold particles within the weathering profile consists of marked rounding upward from the saprolite to the soil surface. Most obvious in the sandy–clayey layer, the rounding is progressive upward in the profile. This roundness, especially in the uppermost meter of the profile, is very similar to that described by Herail et al. (1988) for gold particles in alluvium. Those particles were, however, marked by striations and impact marks, lacking from the gold particles at Dondo Mobi. The absence of striations and impact marks indicates that no sedimentary accumulation (gold placers) occurred at the study site. The roundness is therefore attributed entirely to dissolution.

The several characteristics of the gold particles within the profile provide one line of evidence for the formation of the weathering profile in situ. Additional lines of evidence support this interpretation. Thus, for example, gold particles are embedded in the sandy–clayey matrix from the bottom to the top of the profile. Also in the matrix in the saprolite at the bottom of the profile are pebbles and blocks of quartz which match those of the underlying hard rock. Beyond that, Lecomte and Colin (1987) found significant amounts of Ni and Cr throughout the matrix and interpreted those as signatures of the underlying primary amphibolites. Present also in the matrix are grains of amphibole (Fig. 3).

The several lines of evidence strongly indicate that the profile was formed by lateritic weathering (in the meaning of Lacroix, 1914) from gold-bearing rocks. The gold particles are thus considered to be residual. Similar behavior of gold particles under tropical conditions has been reported earlier by Mossman and Harron (1983) and Sutherland (1985).

Origin of a nodular layer such as the one at Dondo Mobi has been a subject of discussion for a long time. Formation of such a layer, called a "stone line", has been attributed to erosion of lateritic plateaus or to deposition of younger sediments over an older land surface by Segalen (1969) and Riquier (1969) in Gabon and by Folster (1969) in Nigeria. More recent studies in Congo (Muller et al., 1981), Cameroon (Muller and Bocquier, 1987) and northern Gabon (Colin and Lecomte, 1988) have demonstrated close textural and mineralogical relationships within and among the component layers of weathering profiles. Those investigators therefore concluded that the ferruginous nodules of the nodular layer of "stone line" were relicts of an earlier iron crust that was destroyed by partial dissolution under equatorial forest. Such a crust would not have been completely massive.

Physico-chemical conditions required for the dissolution of gold have been studied intensively (Boyle, 1979). The most common ionic species are Au^{+} and Au^{3+}. Ions in those oxidation states are unstable in solution. To remain in solution the ions need appropriate ligands as well as suitable pH and Eh conditions. Possible ligand donor ions are OH^-, I^-, Br^-, Cl^-, HS^-, SO_3^{2-}, $S_2O_3^{2-}$, SO_4^{2-}, CN^- and CNS^- (Boyle, 1979), but few of these anions occur in percolating solutions under humid equatorial conditions.

Krauskopf (1951) and Cloke and Kelly (1964) demonstrated on theoretical grounds and under laboratory conditions that gold could be dissolved at low pH (<5.5) and high Eh (>0.9) in solutions containing Cl^- with concentrations greater than $10^{-3.2}$ m/l according to the reaction:

$$Au + 4Cl^- = AuCl_4^- + 3e$$

At Dondo Mobi the pH is low and Eh high near the soil surface. Those conditions would allow dissolution of gold to accompany additions of chlorides in rainfall. The study area is 200 km from the Atlantic Ocean. According to Meybeck (1979) high chloride activities may follow from small-scale reactions during alternating wet and dry periods. Such reactions could involve gold in precipitation–dissolution mechanisms.

Under dense tropical forest, organic matter, humic substances and bacteria could play roles in dissolution of gold (Lakin et al., 1974; Baker, 1986; Ertel et al., 1986). Baker (1978) reported formation of complexes of gold with humic acids resulting from decomposition of organic matter by bacteria. The reaction between humic acid and gold is given by Steelink (1966) as follows:

$$Au + H^+ + \text{humic acid} + O_2 = \text{Au humate}^{3+} + H_2O$$

Moreover, Boyle (1979) noted the presence of $Au(CN)_2^-$, $Au(CN)_4^-$ and $Au(CNS)_4^-$ in oxidized zones below soils in which organic matter was present. Lakin et al. (1974) showed that these cyanide and thiocyanate complexes as well as sulfide complexes such as $Au(HS)^-$ are stable over a pH range of 5 to 8. The range of pH in the weathering profile at Dondo Mobi is 4 to 5, barely extending into the stability field for these complexes.

Processes operating during formation of the nodular layer could also have contributed to dissolution of gold particles. Mann (1984) has shown that during lateritization in the Yilgarn block of Western Australia, the oxidation of Fe^{2+} reduced the pH enough to allow dissolution of gold in chloride solutions. Ambrosi et al. (1986) demonstrated epigenetic replacement of kaolinite by hematite with a large release of protons. We have therefore inferred that the formation of iron nodules contributed to dissolution of gold particles.

Necessary conditions for the dissolution of gold, as observed by other investigators, could thus have prevailed during much or all of the lateritic weathering of the profile at Dondo Mobi.

CONCLUSIONS

Despite some differences among the gold particles in the several layers of the weathering profile, they are enough alike to be used as an index of mineralogical continuity in the central part of the dispersion halo from the rock to the soil surface. Identification of gold particles in soils could thus be useful in explorations for gold deposits in the humid equatorial belt.

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REFERENCES

Ambrosi, J.P., Nahon, D. and Herbillon, A., 1986. The epigenetic replacement of kaolinite by hematite in laterite – Petrographic evidence and the mechanisms involved. Geoderma, 37: 283–293.

Baker, W.E., 1978. The role of humic acid in the transport of gold. Geochim. Cosmochim. Acta, 42: 645–649.

Baker, W.E., 1986. Humic substances and their role in the solubilization and transport of metals. In: D. Carlisle, W.L. Berry, I.R. Kaplan and J.R. Watterson (Editors), Mineral Exploration, Biological systems and organic matter. Prentice-Hall, Englewood Cliffs, N.J.

Beaudou, A., Chatelin, Y., Collinet, J. and Martin, D., 1977. Note sur la micromorphologie de certains sols ferralitiques jaunes de régions équatoriales d'Afrique. Cah. ORSTOM, Sér. Pédol., 15: 361–379.

Bocquier, G., Muller, J.P. and Boulangé, B., 1984. Les latérites. Connaissance et perspectives actuelles sur les mécanismes de leur différenciation. In: Livre Jubilaire du Cinquantenaire, A.F.E.S., Paris, pp. 123–138.

Boyle, R.W., 1979. The geochemistry of gold and its deposits. Geol. Surv. Can., Bull. 280, 584 pp.

Cloke, P.L. and Kelly, W.C., 1964. Solubility of gold under inorganic supergene conditions. Econ. Geol., 59: 259–270.

Colin, F. and Lecomte, P., 1986. Le cycle supergène de l'or en milieu équatorial dans les profils d'altération de Dondo Mobi, Gabon. Int. Sympos. Geochim. Earth Surf. Processes Miner. Form., Granada, March 1986 (Abstract).

Colin, F. and Lecomte, P., 1988. Etude minérologique et chimique du profil d'altération du prospect aurifère de Mébaga Mvomo (Gabon). Chron. Rech. Min., 491: 55–65.

Ertel, J.R., Hedges, J.I., Devol, A.H., Richey, J.E. and Ribeiro, M.N., 1986. Dissolved humic substances of the Amazon River system. Limnol. Oceanogr., 31 (4): 739–754.

Folster, H., 1969. Slope development in SW Nigeria during late Pleistocene and Holocene. Göttinger Bodenkd. Ber., 10: 3–56.

Hallbauer, D.K. and Utter, T., 1977. Geochemical and morphological characteristics of gold particles from recent rivers and the fossil placer of Witwatersrand. Miner. Deposita, 12: 293–306.

Herail, G., Fornari, M., Miranda, V. and Viscarra, G., 1988. Découverte de nouvelle minéralisations primaires d'or dans la Cordillère Royale de Bolivie à partir de l'analyse morphoscopique de paillettes d'or prélevées en alluvions. C.R. Acad. Sci. Paris, 307 (II): 63–69.

Krauskopf, K., 1951. The solubility of gold. Econ. Geol., 46: 858–870.

Lacroix, A., 1914. Les latérites de la Guinée et les produits d'altération qui leur sont associés. Nouv. Arch. Mus. 5ème Sér. V, 356 pp.

Lakin, H.W., Curtin, G.C., Hubert, A.E., Shacklette, H.T. and Doxtader, G., 1974. Geochemistry of gold in the weathering cycle. U.S. Geol. Surv. Bull., 1330, 80 pp.

Lecomte, P. and Colin, F., 1987. Gold dispersion and size fraction distribution in a tropical rain forest weathering profile at Dondo Mobi, Gabon. J. Geochem. Explor., 26 pp (in press). (12th Int. Geochem. Explor. Symp., April 1987, Orléans, Abstr., p. 74.)

Lecomte, P., 1988. Stone line profiles: Importance in geochemical exploration. J. Geochem. Explor., 30: 35–61.

Mann, A.W., 1984. Mobility of gold and silver in lateritic weathering profiles: some observations from Western Australia. Econ. Geol., 79: 38–49.

Meybeck, M., 1979. Concentrations des eaux fluviales en éléments majeurs et apports en solution aux océans. Rev. Géogr. Dynam. Géol. Phys., 21: 215–246.

Mossman, D.J. and Harron, G.A., 1983. Origin and distribution of gold in the huronian supergroup, Canada. The case for Witwatersrand-type paleoplacers. Precamb. Res., 20: 543–583.

Muller, D., Bocquier, G., Nahon, D. and Paquet, H., 1981. Analyse des différenciations minéralogiques et structurales d'un sol ferralitique à horizons nodulaires du Congo. Cah. ORSTOM, Sér. Pédol., 18(2): 87–110.

Muller, J.P., 1978. La séquence verticale d'organisation des horizons meubles des sols ferralitiques camerounais. Variation en latitude en fonction du pédoclimat et de l'afage du sol. Cah. ORSTOM, Sér. Pédol., 16(1): 73–82.

Muller, J.P. and Bocquier, G., 1987. Textural and mineralogical relationships between ferruginous nodules and surrounding clayey matrices in a laterite from Cameroon. Proc. Int. Clay Conf., Denver, 1985. Clay Miner. Soc., Bloomington, Indiana, pp. 186–194.

Riquier, J., 1969. Contribution à l'étude des stone lines en régions tropicales et équatoriales. Cah. ORSTOM, Sér. Pédol., 7(1): 72–110.

Segalen, P., 1969. Le remaniement des sols et la mise en place de la stone line en Afrique. Cah. ORSTOM, Sér. Pédol., 7(1): 113–127.

Steelink, C., 1966. What is humid acid? J. Chem. Educ., 40(7): 379–384.

Sutherland, D.G., 1985. Geomorphological controls on the distribution of placers deposits. J. Geol. Soc., London, 142: 727–737.

Wilson, A.F., 1983. The economic significance of non hydrothermal transport of gold, and the accretion of large gold nuggets in laterite and other weathering profiles in Australia. Soc. S. Afr., Spec. Publ., 7: 229–234.