

LATERITIC ALTERATION OF METASEDIMENTARY ROCKS WITH COPPER SULFIDE MINERALIZATION IN
CENTRAL BRAZIL*

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ABSTRACT

In Central Brazil, a lateritic crust was formed on a Pleistocene peneplanation surface. In the central western part of the State of Goiás, this crust, which is being dismantled by recent weathering, occurs partially above metasedimentary rocks with copper sulfide mineralization. Some mineralogical and geochemical evidences show a close lithodependence with the immediately underlying rock.

Isovolumetric and isoaluminium analyses show that during the weathering there was a depletion of elements. This depletion is slight for iron and aluminium but total for the alkaline elements. Silica shows an intermediate behaviour. However, we observe in the crust an absolute accumulation of iron. Where the topography presents gentle slopes a secondary crust has been formed, with the rock structure preserved. In this case the absolute accumulation of iron is more abundant than in the primary crust. This seems to indicate a vertical but also a lateral mobility of iron.

Various analyses show a clear relationship between iron oxides and hydroxides and copper in the top part of the weathered mantle. However, in the studied profiles, this relationship seems to be closer in the deeper portions than in the superficial horizon.

The results obtained so far suggest that for geochemical prospection, analysis of the iron-oxide-rich phases, for example, nodules formed by crust destruction, may give a better geochemical picture than other classical procedures.

INTRODUCTION

A bibliographic review of metalogenesis in the tropical regions shows that few works are dedicated to the study and analyse of the dynamic behaviour of the metal elements inside the thick lateritic coverings which usually cover the intertropical region. Obviously this is not true for certain elements which, along with the lateritisation processes, can accumulate the elements on the Earth surface in economically exploitable concentrations. Because of this, numerous researches have been developed involving aluminium, iron, manganese, nickel, etc.

However, the knowledge of the behaviour and the distribution of the metal elements in the superficial coverings is of fundamental importance for the definition of models and the setting of rules for geochemical prospection, which are adapted to tropical

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weathering conditions.

It was with this objective that lateritic weathering was studied along with the behaviour of some of the major elements and of copper in a sulfide mineralized zone partially covered with a ferruginous crust.

THE CHARACTERIZATION OF THE AREA

Localization and Geology

The copper mineralization, discovered in 1975 (Silva, 1981), is located in the central part of the State of Goiás, about 250 km to the Northwest of Brasilia near the city of Chapada Grande.

It is embeded in a metasedimentary formation from either the Archean or Inferior Proterozoic. According to Ribeiro (1978), Dami and Ribeiro (1978), and Saboia and Teixeira (1980), this formation should be placed between the Greenstone Belt sequences ~~and the middle and superior units of the superior Proterozoic (Araça Group).~~ Alternatively, according to Machado (1981), it should be placed between the middle and superior units of the Greenstone Belt (Figure 1). These formations have suffered a metamorphism of the "green schist" facies, locally reaching the "amphibolite" facies.

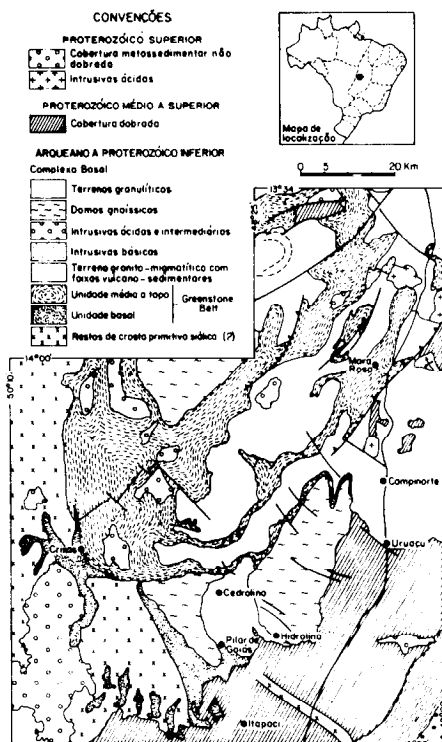


FIGURE 1
Location Map and Geological Map.

The mineralized sequence in the study area presents three main lithologies: quartzites, mica-schists and amphibolites. The mica-schists the lithologic support of the copper mineralization, have been classified by Silva (1981) into five different facies according to their biotite, cyanite, sericite and feldspath contents.

From a genetic point of view, the mineralization is not yet perfectly defined, though presenting some characteristics of sedimentary beds. For example, the copper is disseminated over many kilometers with a relatively little thickness. The mineralization of the copper is concordant with the encased rock and the original sediment is of a pelitical to psammitical nature, deposited in coastal marine environments (Silva, 1981).

The principal copper mineral is chalcopyrite, followed by traces of bornite and chalcocite. However, the most abundant sulfide is pyrite. In the chalcopyrite crystalline structure there is some inclusion of gold and silver. The presence of either an oxidated copper mineral or of a cemented zone, has not been locally observed.

Relief and Geomorphology

By adapting and updating the works of King (1956), performed in Eastern Brazil, Braun (1970) has recognized in the central part of the Brazilian territory two erosion surfaces. The oldest and most important, from which the present relief has been sculptured, is the South American Surface, beginning in the Inferior Cretaceous, that has practically affected the whole of Brazil. The Cycle "Velhas" started at the end of the Oligocene, and its principal phase of aggradation is linked with the Inferior Pleistocene. King (1956) also defines a third cycle, the "Paraguaçu", that according to Braun (1979) should be considered as a sub-cycle of the "Velhas".

The South American Surface, in the study area, has been almost totally eroded, leaving only a few witnesses formed by rocks which were more resistant to weathering and to erosion. However, the "Velhas" surface is well marked on the landscape, forming extensive planes covered by a lateritic crust ("Chapada"), and cut out by the present drainage network.

Climate and Vegetation

The climate of the region is of the semi-humid tropical type, with four to five dry months. The mean annual temperature is 24°C, presenting a small thermal variation (22 to 26°C). The monthly precipitation ranges from 21.9 mm in the dry season (from May to September) to 210 mm in the moist season (from October to April), characterizing a climate with contrasting seasons.

The vegetation is of the type arboreal savannah ("cerrado"), with a lower herbaceous layer consisting of grassland and an upper arboreal layer. Locally, along drainage networks, a more dense vegetation of the gallery forest type has developed.

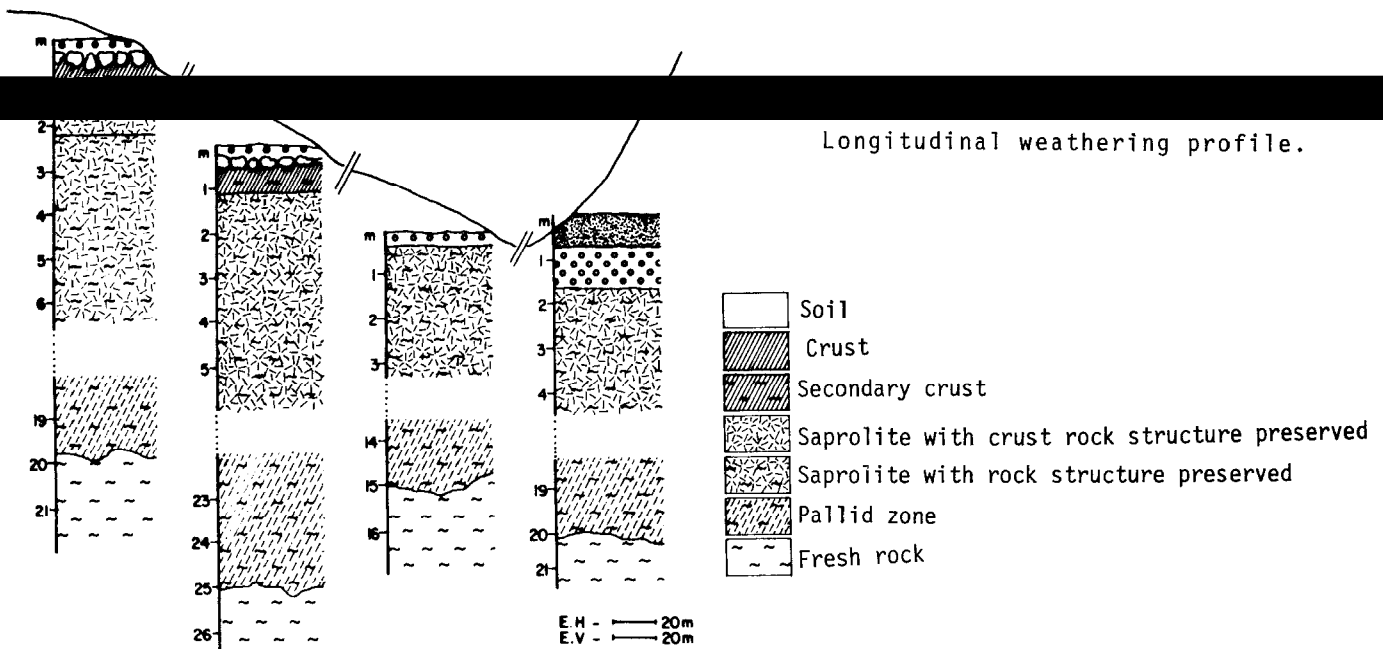
THE LATERITIC WEATHERING

The evolution of the lateritic weathering has been studied from profiles collected in different landscape compartments (plaining tops, gentle slopes and steep slopes). The situation of plaining tops prevails over practically the entire region, being less frequent in areas with steep slopes, and rare in those presenting gentle slopes.

Morphological and Mineralogical Evolution

The average thickness of the weathered mantle in the upper areas is about 20 m. Analytical studies have not been developed over the entire thickness. Only the first eight meters have received a detailed treatment. This is because wells of this depth are located in this region for mineral prospection.

Even though some small variations are present, a pattern profile can be seen (Figure 2), characterized by the presence of the following weathering facies:



- . A moderately thick horizon present at the contact with fresh rock, characterized by incipient schist-mica weathering. Feldspaths are the first minerals to be altered, giving origin to clayey minerals of the 2/1 type (smectites). The liberation of iron in the pallid zone is of small importance. This horizon can be correlated to the "horizont pistache" defined by Leprun (1979) on the Upper Volta.
- . Over this facie there is a very thick horizon (a thickness slightly greater than 10 m) with great morphological homogeneity. The structure of the original rock has been preserved although the primary minerals have been almost totally destroyed. Only the quartz, the cyanite and some rare mica crystals have survived the weathering. The smectite, developed on the preceding horizon, has disappeared, having turned into kaolinite, the dominate clay minerals (Figure 3). The iron is individualized into hematite and goethite, which are associated. It seems, however, that the hematite is more abundant than the goethite at the profile base, this situation being reversed towards the top. This horizon characterizes the saprolite facies with preserved structure.
- . The saprolite with preserved structure is covered by a horizon whose thickness varies from 0.5 to 1 m, presenting the same mineralogical characteristics. The major

progressive and is followed by both the disappearance of smectite and a strong decrease of the kaolinite.

Geochemical Evolution

~~The rapid faciological variations presented by mineralized schist-mica make it~~

setting of balances. However, since the paragenesis of the different facies is globally the same, varying only in proportion relative to the constituents, it is possible to think about establishing a global weathering balance.

The chemical analysis reveals that the concentrations of the alkaline elements decreases rapidly towards the top of the weathered profile while silicon, aluminium and iron remain nearly constant in the saprolite. Only iron shows a substantial larger concentration (2 to 4 times) in the saprolite-crust transformation.

Because the structure of the saprolite is preserved, it is possible to use the isovolumetric method of Millot and Bonifas (1955). With this method, it is possible to show that there is almost a total elimination of the alkalines and a small elimination of aluminium. Silicon and iron show an intermediary behaviour (Table 1).

TABLE 1. VARIATION OF THE AVERAGE ISOVOLUMETRIC CONTENT IN THE ALTERATION FACIES AS COMPARED TO THE FRESH ROCK.

| | | | Fe ₂ O ₃ | Al ₂ O ₃ | SiO ₂ | MnO | MgO | CaO | K ₂ O | Na ₂ O | CuO |
|---------------|-----------------|-----|--------------------------------|--------------------------------|------------------|-------|------|------|------------------|-------------------|------|
| Top Area | Crust | m | 34.13 | 26.48 | 99.35 | 0.046 | 0.23 | 0.05 | 0.68 | 0.26 | 0.22 |
| | | Δ % | +84 | -26 | -30 | -50 | -98 | -99 | -91 | -79 | -80 |
| | Saprolite | m | 12.36 | 29.33 | 75.70 | 0.026 | 0.61 | 0.03 | 0.42 | 0.24 | 0.15 |
| | | Δ % | -33 | -18 | -47 | -71 | -94 | -99 | -94 | -81 | -87 |
| Gentle Slopes | Secondary Crust | m | 65.92 | 31.77 | 86.26 | 0.029 | 0.67 | 0.16 | 1.47 | 0.25 | 0.22 |
| | | Δ % | +255 | -12 | -39 | -68 | -93 | -96 | -80 | -81 | -80 |
| | Saprolite | m | 9.07 | 21.86 | 89.47 | 0.025 | 1.98 | 0.17 | 1.97 | 0.19 | 0.20 |
| | | Δ % | -51 | -39 | -37 | -73 | -80 | -96 | -74 | -85 | -82 |
| Fresh Rock | | m | 18.56 | 35.90 | 142.52 | 0.091 | 9.98 | 4.39 | 7.48 | 1.28 | 1.12 |

It is not easy to make a geochemical balance of the crust since there is no morphological argument for us to affirm whether or not volume has been conserved. Nevertheless, since aluminium leaching was of little importance towards the top of the saprolite, it is possible as a first approximation to think that the aluminium would present the same behaviour in the crust. It is thus possible to calculate the variation in the volume between the saprolite and the crust.

For 100 g of Al₂O₃ we have:

$$t_i = \frac{100}{P_i} = \frac{100}{d_i V_i}$$

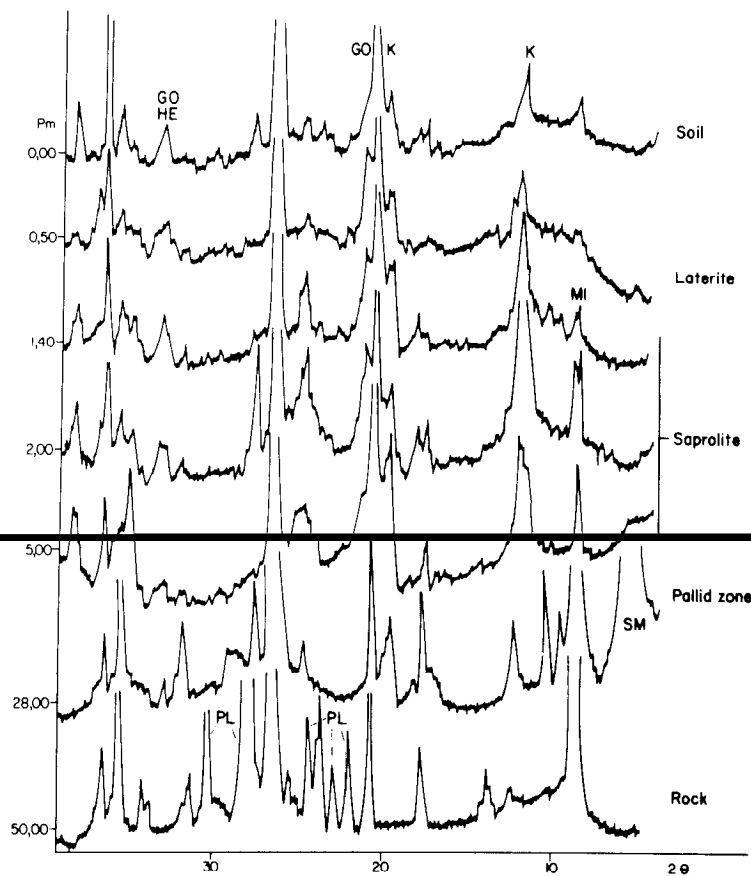


FIG. 3. XRD patterns of a typical weathering profile.

difference is that the rock structure in this horizons is not visible anymore. It is the saprolite facies without preserved structure.

. The crust occurs over the saprolite. Its thickness is quite variable but it seldom exceeds 2 m. It is massive at the base and fractured with individualized ferruginous nodules on top. The kaolinite proportion quickly decreases upwards while the goethite becomes better crystallized. Minerals inherited from the original rock, such as quartz and cyanite, are still visible in very variable concentrations and are proportional to the concentrations found in the original rock.

. A fairly thin (10 to 20 cm) quartz-rich and clay-poor (kaolinite) soil is located over the crust. This soil contains many ferruginous nodules from crust dismantling.

The lateritized surface, in general, is carved by the present drainage network. Two types of valleys have been formed, the most frequent one showing an open-V shape, with relatively steep slopes. The alteration profiles are truncated, the soils being in direct contact with the saprolite presenting preserved structure (Figure 2). The other type, being rare, presents asymmetric slopes. Over the gentle slopes, the weathered profile is characterized by the presence of a secondary crust in which the structure of the original rock has been preserved. The transformation of the saprolite-crust is

where t_i = the concentration of Al_2O_3 in sample i
 P_i = the weight of sample i
 d_i = the density of sample i
 V_i = the volume of sample i

The respective volumes of crust and of saprolite are then:

$$V_c = \frac{100}{t_c d_c} \quad \text{and} \quad V_s = \frac{100}{t_a d_a}$$

$$\frac{V_c}{V_s} = \frac{t_a d_a}{t_c d_c}$$

$t_i d_i$ = isovolumetric concentration

The application of the above formula leads to an average value of $V_c/V_s = 1.11$.

This means that there has only been a small depletion of aluminium, because it would be difficult to imagine an increase in the volume. Therefore the calculation shows that the isovolumetric method can be used in the crusts without a large error.

Thus Table 1 shows the existence of an absolute iron accumulation of over 84% in relation to the original rock (when applying the isoaluminium method this value goes to over 131%). Taking into account the absence of relief in the region, the increase of iron can be explained by the liberation of iron at the base of the profile during the dismantling of the crust. The migration of aluminium would be caused by the mechanical transport of kaolinite type clays.

The isovolumetric method is also applicable to gentle slopes, since the conservation of the structures is observed along the entire profile, including the crust. The distribution of the elements in the saprolite is the same (Table 1) as that observed in the upper profiles with a more accentuated loss of iron and aluminium. A significant accumulation of iron (over 250% in relation to the original rock) was observed in the crust and there was an elimination of aluminium (far smaller than that found in the saprolite). This fact suggests the existence of a lateral migration of iron and aluminium, particularly in profiles located along gentle slopes.

When the slopes become steeper, a more common condition in this area, there is no iron accumulation.

Crust Authochthony

Several lightly weathered minerals, directly inherited from the underlying rock, have been observed in the crust. By this mechanism, for example, samples of the crust collected under cyanite-rich facies show an enrichment of this mineral. Furthermore, it was also found that the copper concentrations located in the crust over the mineralized area, are clearly anomalous. There exist, in so far as the crust and its

mineralogical and geochemical inheritance of the underlying rock, is an irrefutable proof of its authochthonous origin.

COPPER BEHAVIOUR

The dynamic behaviour of copper has been determined from chemical analysis using both total samples and separate granulometric fractions.

The total analysis shows a pronounced drop of the copper concentrations in soils located above the crust or secondary crust. This behaviour is not found in profiles located on slopes where the crust does not occur (Figure 4). In general, it has been observed that in anomalous zones the concentrations of copper in the soil are two or three times lower than those found in the underlying crust and these values, as a whole, increase with depth.

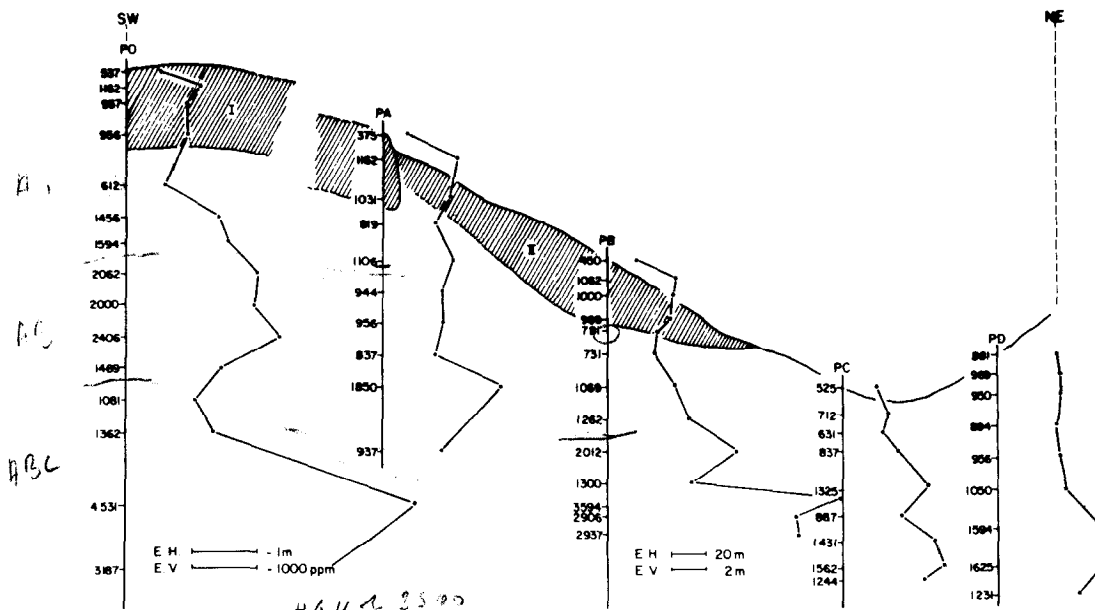


FIG. 4. Vertical variation of the copper concentration. I. Crust; II. Secondary crust.
Copper Supporting Phases APC 1%

The chemical analysis shows an increase of the copper concentration in the fine fractions (Table 2). These values are very significant for the soils and saprolite samples, but not for the crust samples (PA-3), which were both crushed and ground. In the friable samples, 30% or more of the total copper is found in the fraction smaller than 2μ . This fraction is essentially made up of kaolinite and iron oxides.

The cumulative curves of successive iron oxide extractions show a clear relationship between copper and iron (Figure 5). In the saprolite samples with a remaining structure (PA-5), most of the copper is extracted with the iron. In the crust, the two extraction curves show a similar behaviour. Nevertheless, in this case, only 45% of the copper is extracted compared to 90% of the iron. The residue of the extractions,

TABLE 2. CHEMICAL CHARACTERISTICS OF THE GRANULOMETRIC FRACTIONS OF THE DIFFERENT HORIZONS OF THE UPPER PROFILES.

| Granulometric Fractions mm | | > 1000 | 1000-500 | 500-210 | 210-105 | 105-62 | 62-20 | 20-2 | < 2 |
|-------------------------------|----------------------------------|--------|----------|---------|---------|--------|-------|-------|-------|
| PA-1 Soil | Fe ₂ O ₃ % | 25.74 | 22.19 | 9.23 | 4.00 | 3.37 | 5.40 | 14.2 | 11.36 |
| | Al ₂ O ₃ % | 11.10 | 9.55 | 5.01 | 2.50 | 1.70 | 2.60 | 14.65 | 33.55 |
| | Cu ppm | 1125 | 856 | 381 | 392 | 169 | 303 | 669 | 938 |
| | % P (1) | 7.98 | 7.17 | 17.23 | 19.02 | 7.77 | 14.81 | 5.44 | 18.12 |
| | % CuO (2) | 17.27 | 11.82 | 12.65 | 13.42 | 2.53 | 8.64 | 7.01 | 32.74 |
| PA-3 Crust | Fe ₂ O ₃ % | 25.21 | 2.96 | 21.48 | 15.19 | 12.07 | 18.77 | 23.61 | 13.85 |
| | Al ₂ O ₃ % | 7.42 | 18.43 | 8.22 | 6.71 | 7.56 | 9.45 | 23.06 | 28.82 |
| | Cu ppm | 1688 | 81 | 1281 | 1946 | 833 | 1344 | 1794 | 1169 |
| | % P (1) | 19.25 | 13.77 | 10.96 | 7.96 | 5.79 | 22.86 | 6.97 | 10.52 |
| | % CuO (2) | 28.40 | 0.97 | 12.26 | 12.53 | 4.21 | 26.82 | 10.92 | 10.84 |
| PA-4 SSE (3) | Fe ₂ O ₃ % | 23.96 | 18.28 | 13.31 | 5.9 | 5.11 | 11.62 | 10.83 | 12.25 |
| | Al ₂ O ₃ % | 9.97 | 9.83 | 7.66 | 5.43 | 5.10 | 10.21 | 27.12 | 34.02 |
| | Cu ppm | 1375 | 1125 | 850 | 910 | 500 | 1075 | 1200 | 1169 |
| | % P (1) | 11.82 | 8.58 | 10.26 | 12.02 | 5.62 | 15.89 | 12.03 | 25.00 |
| | % CuO (2) | 15.42 | 9.16 | 8.27 | 10.02 | 2.67 | 16.21 | 13.70 | 27.73 |
| PA-6 SEC (4) | Fe ₂ O ₃ % | 15.80 | 8.88 | 4.81 | 4.36 | 4.30 | 8.94 | 5.75 | 14.20 |
| | Al ₂ O ₃ % | 8.60 | 9.07 | 4.73 | 4.91 | 5.67 | 13.61 | 31.19 | 30.24 |
| | Cu ppm | 725 | 669 | 581 | 791 | 469 | 1138 | 669 | 1781 |
| | % P (1) | 4.23 | 4.01 | 12.30 | 13.06 | 8.29 | 10.34 | 23.94 | 24.05 |
| | % CuO (2) | 3.25 | 2.84 | 7.57 | 10.57 | 4.12 | 12.47 | 16.97 | 45.37 |

- (1) = Weight percentage of the granulometric fraction
- (2) = Copper percentage referent to the total sample
- (3) = Saprolite with no preserved structure
- (4) = Saprolite with preserved structure

analyzed by X-rays, consists of kaolinite and goethite. Mosser (1980) has shown that in clay fractions the copper preferentially accompanies iron oxide. It is possible to imagine, consequently, that the non-extracted copper is attached to the remaining goethite. But the quantity of copper present in the non-attacked residue corresponds to 3.5 meq of Cu²⁺/100 gr of kaolinite, this value being compatible with the exchange capacity of kaolinite. Therefore, it is not possible to totally eliminate the possibility of an attachment, even a partial one, of copper-kaolinite in the crust.

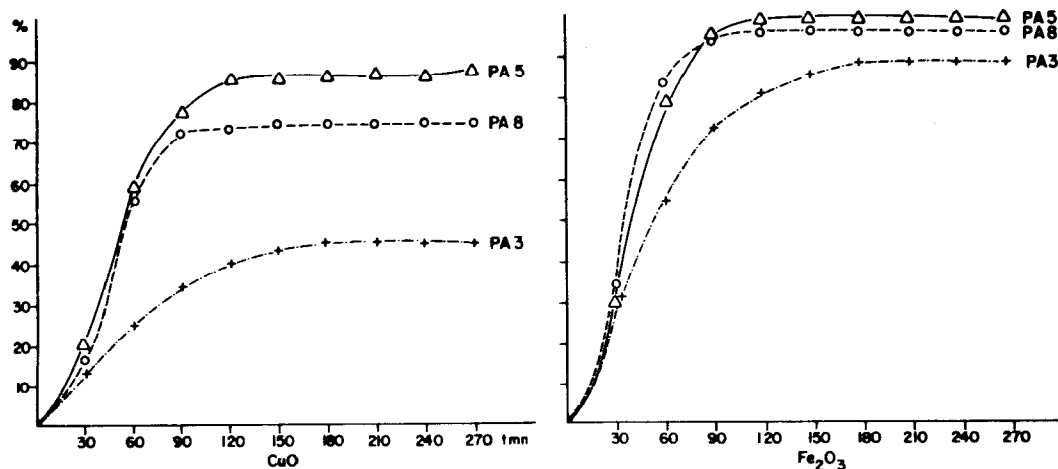


FIG. 5. Cumulative curves of successive iron oxide extraction on the fraction smaller than 2µ.

The behaviour of copper in deep horizons in contact with the fresh rock is still being studied. However, the absence of oxidized or cemented minerals indicates that, since

the beginning of the weathering, the copper has been connected with a supporting phase and is not yet mineralogically individualized.

Application to Geochemical Prospection

The soil formed over the ferruginous crust is constituted of a fine fraction (smaller than 2 mm), where quartz and kaolinite are the dominant minerals, and a coarse fraction, constituted essentially of iron oxide nodules originated from the dismantling of the underlying crust. Due to the existing lithodependence between the crust and the saprolite, and considering that the copper is preferably associated with the iron oxides, it is obvious that the nodules in the soils will be by far more representative of the underlying rock than the fine fraction (80 mesh), commonly used in geochemical prospection. Table 3 shows the effect of the dilution of the fine fraction and indicates how screening may give a better geochemical picture. Zeegers and Leprun (1979) have reached the same conclusions in Eastern Africa.

TABLE 3. VARIATION OF COPPER CONTENT IN THE GRANULOMETRIC FRACTION > 2 mm, < 2 mm.

| | | > 2 mm | < 2 mm | Total |
|---------------------------------|------|----------|----------|-------|
| Soil under the crust | PA-1 | 1030 | 475 | 519 |
| | PB-1 | 1025 | 413 | 450 |
| Soil without subjacent crust | PO-1 | 550 | 500 | 537 |
| | PC-1 | 663 | 513 | 525 |
| | PD-1 | 833 | 758 | 790 |

CONCLUSIONS

The lithodependence between the lateritic crust and the underlying rock has been verified in the study area.

Crust dismantling, as observed in superficial regions is accompanied by the formation of ferruginous nodules, directly inherited from the crust, which accumulate in the soil and over the slopes. Furthermore, crust weathering also promotes a certain lateral and vertical mobility of the iron.

The copper is preferentially linked with iron oxides in the top horizons. Because of this, the ferruginous nodules that originated from the crust dismantling are of special interest for geochemical prospection.

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LATERITISATION PROCESSES

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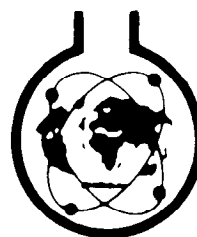
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