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ASPECTS OF THE DISTRIBUTION OF COPPER, ZINC, NICKEL AND CHROMIUM IN THE SOILS OVER AMPHIBOLITES AND GRANITES IN THE LOKO HILLS, SIERRA LEONE[1]

by

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(4 figures and 4 tables)

RESUME.- Les roches des "Loko hills" font partie d'un groupe de roches archéennes constituant le "Kambui group" (Mc FARLANE *et al.*, 1974). Les roches dominantes sont des amphibolites et des granites syncinématiques. Ces deux unités reposent apparemment en discordance sur des migmatites.

Un échantillonnage systématique et l'analyse des sols superficiels suivis du traitement statistique des résultats montrent que le Cu et le Zn ont une distribution très semblable de même que le Ni et le Cr.

L'analyse de régression montre que des quantités importantes de Cu, de Zn et de Ni peuvent être expliquées par la coprécipitation avec les sesquioxides pendant la pédogenèse. D'un autre côté, une grande partie de Cr est considérée comme localisée dans les minéraux primaires qui ont résisté à l'altération. Les faibles valeurs du Cu et de Zn échangeables mesurées peuvent être attribuées à la capacité d'échange de cations assez faible des sols. On a pu conclure que ce phénomène est principalement dû à la nature et à des modifications des particules colloïdales du sol découlant des changements dans l'environnement géochimique secondaire.

ABSTRACT.- The Loko hills schist belt is part of a wider group of archaean rocks which form the Kambui group (McFARLANE *et al.*, 1974). The dominant rocks are amphibolites and synkinematic granitoids. These two rock units rest apparently unconformably on a basement of acid migmatites.

Systematic sampling and analyses of near surface soils, and subsequent statistical treatment of the results indicate marked similarities in the distribution patterns between copper and zinc on the one hand, and between nickel and chromium on the other.

Regression analysis shows close associations between the members of the couples Cu-Zn and Ni-Cr. However, only nickel shows a strong positive correlation with the geology.

Partial extraction studies have shown that appreciable amounts of Cu, Zn and Ni can be accounted for in terms of coprecipitation with sesquioxides during pedogenesis. Chromium on the other hand is considered to be largely in primary minerals which have resisted weathering. The low values of exchangeable Cu and Zn have been attributed to an overall low base exchange capacity of the soils. It is concluded that this is principally due to the nature of and modifications to soil colloidal particles imposed by changes in the secondary geochemical environment.

INTRODUCTION

In tropical regions, the high degree of chemical weathering results in the removal or masking of all surface indications of mineralisation. This fact, combined with the thick and sometimes impenetrable vegetation are problems that beset the conventional prospector. To these, may be added the following local handicaps :

a. Most of the country remains virtually unmapped. There has been no systematic study of the soils within the country. Thus information that usually serves as a guide to prospectors is lacking.

b. Poor communication makes accessibility to potentially interesting areas almost impossible.

Previous investigations in tropical terrains have shown that ore metals and their associated indicator elements are generally to be found in the soils, sediments and waters in the vicinity of parent mineralisation. The factors that influence the dispersion of trace

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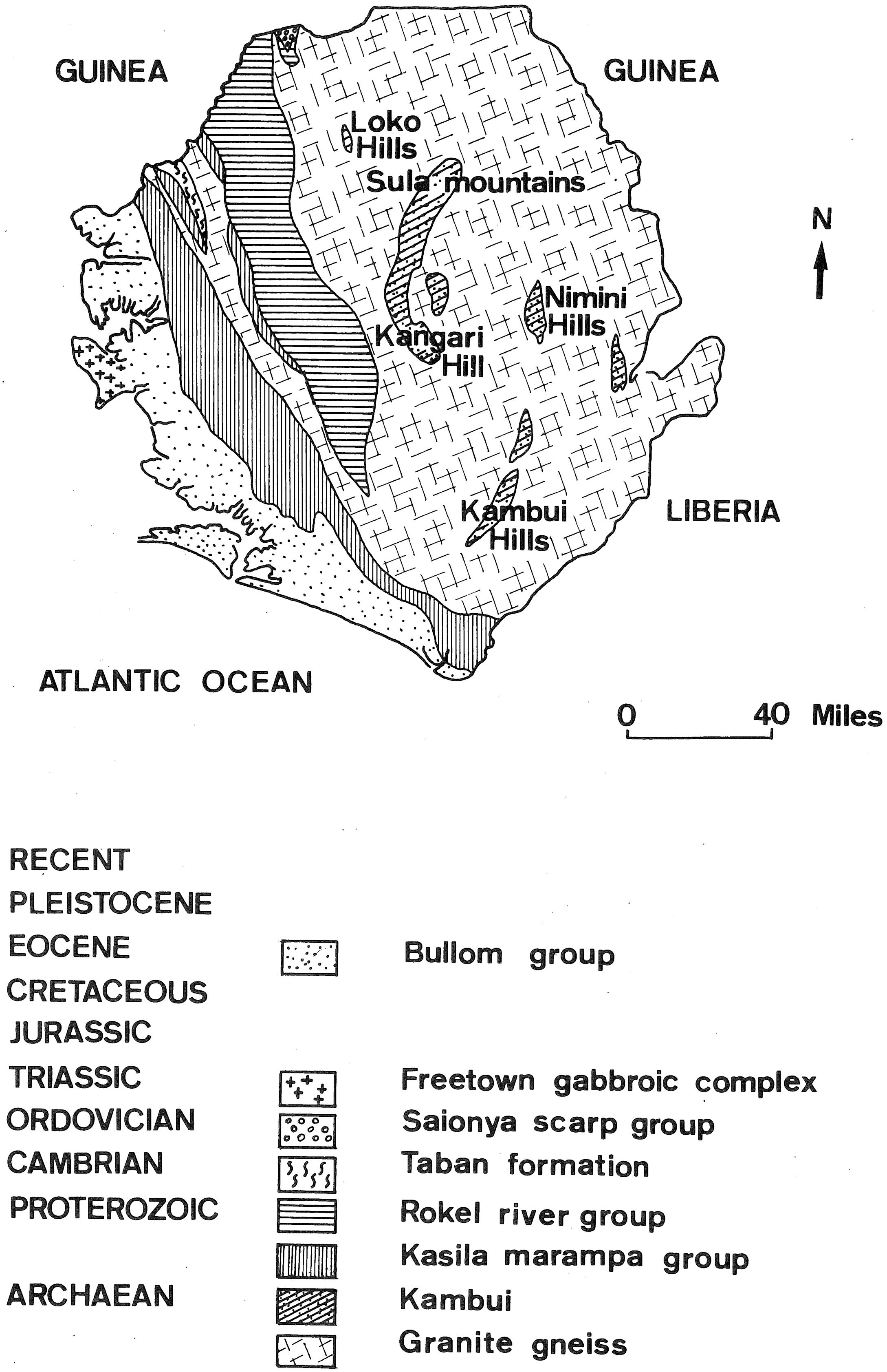

Figure 1.- A generalised geological map of Sierra Leone

elements within tropical environments have been reviewed in some detail by various authors; (WEBB & MILLMAN, 1950), (HAWKES, 1954), (WEBB, 1956), (HAWKES *et al.* 1956), (MATHER, 1959).

In this paper, it will be shown that in the Loko Hills area, the basic rocks (amphibolites) are richer in Cu, Zn, Ni and Cr than the surrounding granitoïds. During weathering, the elements go into solution and are redistributed leaving characteristic patterns within the resulting soils. The distribution pattern of Ni within the residual soils is such that is reflects the differences in the Ni concentration of the two rock types.

An attempt is also made to investigate the effectiveness of different extraction techniques and to interprete the results in terms of properties of the weathering environment.

DESCRIPTION OF STUDY AREA

The area investigated forms part of the Loko Hills in the northern province of Sierra Leone (fig. 1). Like the rest of the country, the area falls within the tropical rain forest belt. Rainfall, temperature and relative humidity show seasonal variations. Average yearly rainfall is about 125 inches, while temperature and relative humidity vary between 77°F. and 48 % minimum and 83° and 90 % maximum respectively. About three-fouths of the area is covered with tall cane grass which attain heights of about ten feet in certain areas. Elsewhere are open forest interspersed with thick undergrowths of shrubs.

TOPOGRAPHY AND SOILS

Sierra Leone can be divided into four NNW trending topographic units (ANDREW-JONES, 1966). These are from SW to SE :

1. The coastal plains (100-500 ft).
2. The upland areas (750-800 ft).
3. The dissected plateau area (1000-2000 ft).
4. The high plateau region (>6000 ft).

The long narrow strip of rocks that form the Laminaia Schist belt forms a distinct surface at 750-800 ft. with isolated summits at over 900 ft. These are considered to represent remnants of the dissected plateau surface. These elevated areas are cut off by steep escarpments from low lying plains occupied by seasonal swamps.

The prevailing high rainfall and warm temperatures are conducive to rapid decomposition of mineral and organic matter, followed by intense leaching. During the wet season, soluble materials are leached out of the decomposing surficial zone. At the same time, iron and aluminium are oxidised into immobile sesquioxides which accumulate in situ to form laterites and their associated lateritic soils or "latosols".

In certain areas on the ridge crest are exposed indurated surfaces or "duricrust". According to WOOLNOUGH (1927), the duricrust represents an indurated B-horizon following the lowering of the water table. On the gently sloping lower slopes of the hills, soil character changes to typically grey coloured gleys, characteristic of impeded drainage conditions.

GENERAL GEOLOGICAL ASPECTS

The rocks that form the Laminaia Schist belt (fig. 1) form part of the Loko group, which is considered to be of Pre-Leonean age (>2700 m.y.) and to predate the main Kambui Schists in the eastern part of the country (McFARLANE *et al.,* 1974). The rocks form a narrow, continuous ridge, with an arcuate shape that extends for about sixteen kilometers in an approximately north-south direction.

The dominant rocks of the schist belt are amphibolites, considered to represent remnants of a deeply eroded greenstone belt (DIXEY, 1925). These are almost completely surrounded by granitic rocks with textures characteristic of synkinematic origin (MARMO, 1956). These two rock units rest unconformably on a basement of older migmatites and gneisses (fig. 2) which form part of the stable West African Craton. The rocks have an approximate north-south strike with near vertical dips.

The main interest in the area lies in its widespread gold mineralisation. There are records of active alluvial gold mining in the streams around laminaia and other areas within the schist belt. Other surface indications of mineralisation include sulphides, mainly pyrite and chalcopyrite which occur as disseminations within the amphibolites.

GEOCHEMICAL INVESTIGATIONS

SAMPLING

A geochemical soil survey was carried out over the amphibolites and granitoïds that form the Laminaia Schist belt. The initial sampling was carried out

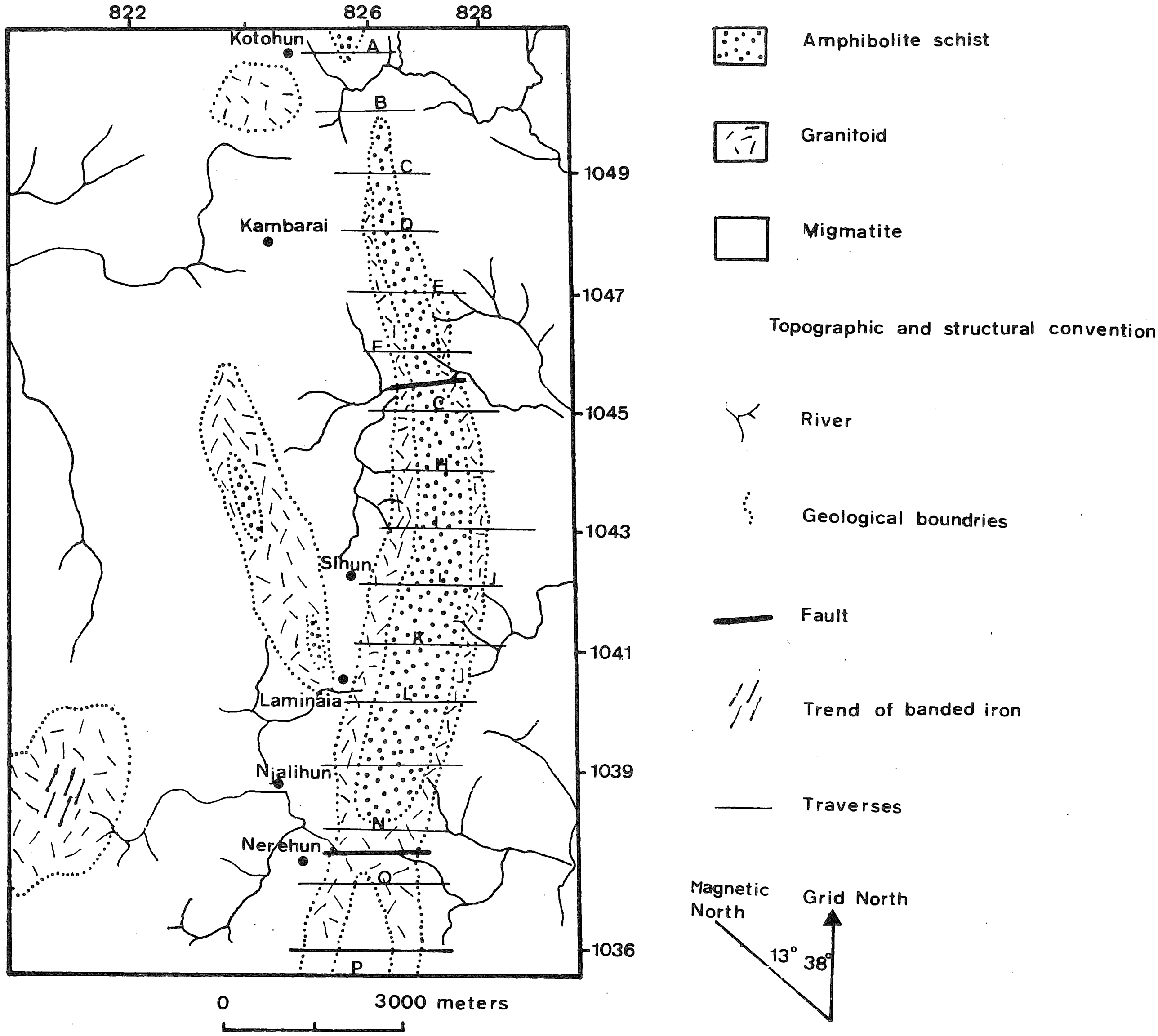

Figure 2.- General geology of the Laminaia Schist belt with superimposed traverse (A–P).

at 100 meter intervals along traverses (A–P) coinciding with the east-west map grids (fig. 2). More detailed sampling was carried out between traverses D and F at 300 ft. intervals along lines about 600 ft. apart. All samples were collected from a depth of about nine inches which falls within the B-horizon in the area.

Owing to the scarcity of rock outcrops, and the intense state of weathering in which they usually exist, only a few fresh rock samples could be collected.

ANALYSES

All samples were analysed by atomic absorption spectrophotometry using the Shandon Southern model A 3400 for total Cu, Zn, Ni and Cr, after digestion with a mixture of concentrate hydrofluoric and perchloric acids. On selected soil samples, the amounts of the metals released in standard partial extraction techniques by aqua regia and neutral ammonium acetate solution were also determined.

PRESENTATION OF DATA

ROCKS

The analytical results for five rock samples collected from widely separated areas are shown in table I together with their macroscopic mineralogical descriptions.

Table I.- Results of rock analyses

Sample nº	Description	Cu ppm	Zn ppm	Ni ppm	Cr ppm
F 1	Fine grained laminated amphibolite with hornblende and subordinate andesine.	190	160	250	600
F 5	Coarse grained porphyroblastic amphibolite with disseminations of pyrite and chalcopyrite	190	150	300	650
F 45	Coarse grained diopside-rich amphibolite.	200	160	300	650
F 30	Medium grained amphibolite gneiss with dark amphibolite bands and leucocratic feldspathic bands.	180	180	260	800
F 83	Porphyroblastic granitoid containing microcline, oligoclase quartz and biotite.	60	60	45	80

It is evident from this table that the granitoids are poorer in the elements considered than the amphibolites with which they are associated. The differences in trace metal concentration between the two rock types are greater for chromium and nickel than for copper and zinc.

SOILS

1. Geochemical profiles

The analytical results for the reconnaissance survey are presented as individual profiles together with a sketch geological section for each traverse (fig. 3). The interesting feature of these graphs is in their dome-like nature. The pattern is consistent for all the elements considered and appears to be more striking for Cr and Ni. Comparison with the adjacent geological sections indicates an apparent relationship between this tendency and the distribution of the different rock units. The peaks of the domes roughly coincide with the amphibolitic rocks, which are bounded on either side by granitic rocks. This observation gives a first indication that the difference in the metal contents between the two rock types is mentained in the residual soils derived from weathering of these rocks.

2. Moving average maps

Small scale variations in the geochemical relief caused by geological features, sampling and analytical errors may make the interpretation of geochemical data difficult. Taking this into account, and with the aim of demonstrating broard tendencies in the metal distribution patterns, a moving average smoothing was carried out on the data on soils sampled during the detailed survey. The resulting moving average maps are shown in fig. 4.

The following general features are evident from these maps :

a. The distributions of Cu and Zn appear to be related to an approximately north-south oriented zone of high metal values in the eastern part of the area.

b. Nickel and chromium show marked similarities in both the repartition and the trend of the contours. This trend roughly coincides with the approximate north-south strike direction of the amphibolites and their surrounding granitoids.

These observations point to associations in the residual soils between Cu and Zn on the one hand and between Ni and Cr on the other. It is also apparent that while the distribution patterns of Cu and Zn tend to be related to a zone of high metal values, probably mineralisation, the patterns of Ni and Cr indicate a relationship to the two rock units (amphibolites and granitoids).

3. Correlation studies

Correlation coefficients (r) were calculated for all possible pairs of the elements considered. Also included among the variables, is a geological factor described by giving each sample an index (1 or 2) depending on whetter the sample was collected over granitoids or over amphibolites.

Also calculated is the parameter r_0 which gives a measure of the statistical significance of r. These calculations were effected with logarithmic convertions of the data to account for a probable lognormal distribution of the elements (SINCLAIR, 1972). The correlation matrix is presented in Table II.

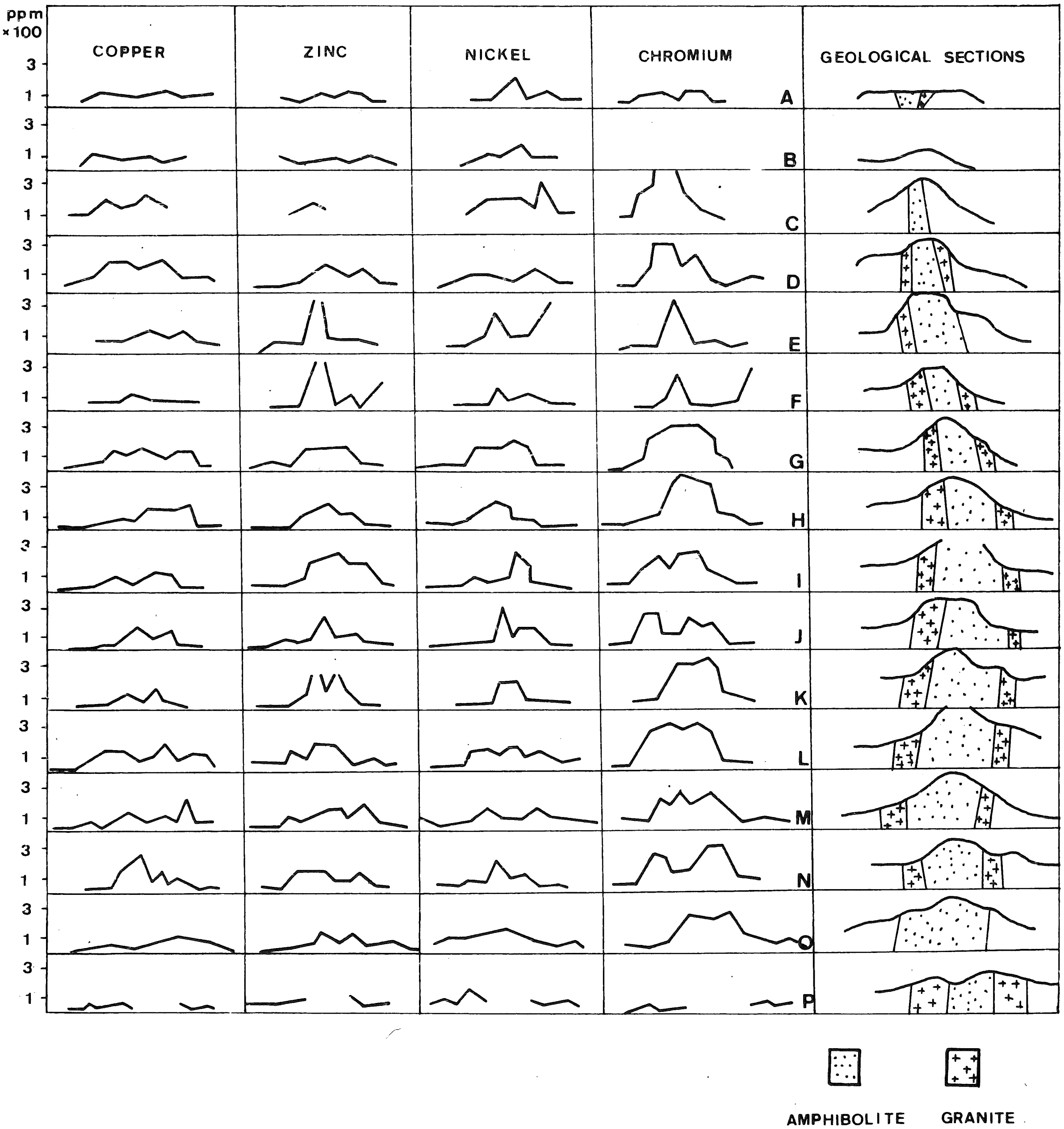

Figure 3.- Geochemical profiles for Cu, Zn, Ni and Cr along traverses A-P.

Table II. Correlation coefficients for trace metals and geology

	Cu	Zn	Ni	Cr	Geology
Cu					
Zn	0,511				
Ni	0,291	0,200			
Cr	0,292	0,300	0,501		
Geology	0,271	0,321	0,513	0,389	

$N = 120$; $r_o = 0{,}212$

It is evident from this table that there are within the area surveyed, two groups of metal associations : Cu and Zn on the one hand ($r = 0{,}511$) and Ni and Cr on the other ($r = 0{,}501$). Also Ni has the best positive correlation with geology. There thus appears to be an agreement between the conclusions drawn from the moving average smoothing of the data and the regression analysis.

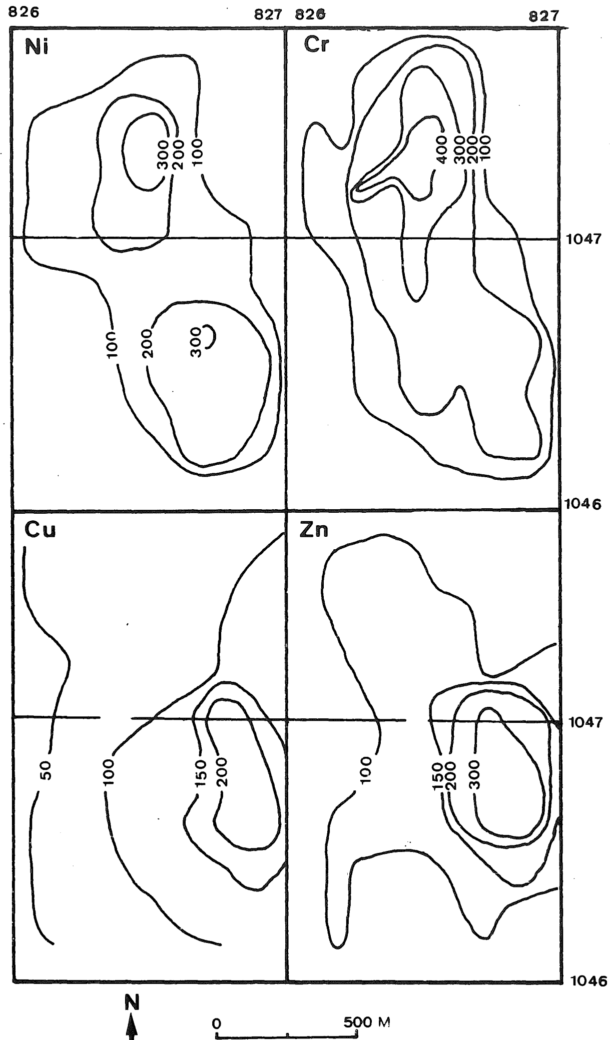

Figure 4.- Moving average maps showing tendencies in the distributions of Cu, Zn, Ni and Cr in the region between traverses D and F.

PARTIAL EXTRACTION STUDIES

AQUA REGIA ESTRACTABLE METAL

The percentages of total metal extracted by aqua regia are presented in Table III. This table shows that 71 o/o Cu, 86 o/o Zn and 79 o/o Ni are extracted by aqua regia. This would mean that in the soils, appreciable amounts of these three elements occur in phases such as, iron and manganese oxides, clay minerals and sulphides, which are dissolved by the hot acide mixture. (FOSTER, 1971) shows that aqua regia can extract over 70o/o of trace elements from ferromagnesian minerals such as biotite and amphibole. However, considering the prevailing tropical climatic conditions, one would expect almost negligeable amounts of these primary silicates within the soils. It is more likely that the Cu, Zn and Ni contents of the hot acid extracts represent metal associated with various forms of iron and manganese oxides and clay minerals. All these phases are products of the soil forming process. Their formation has therefore been influenced by features of the secondary geochemical environment.

Only 43 o/o of Cr is extracted by aqua regia. It may therefore be concluded that an important amount of this element occurs in the soils within resistant primary minerals of the Spinel group. (Magnetite and chromite occur widely in the surrounding streams and also as trace mineral in the amphibolites). Mechanical processes would therefore be expected to play an important role in the dispersion of this element.

Table III. Results of Aqua regia extraction

Sample nº	o/o Metal extracted			
	Cu	Zn	Ni	Cr
AG 1**	60	100	83	100
AG 2**	67	83	67	100
AG 3	53	100	83	42
AG 4**	50	100	90	100
AG 5	83	93	91	37
AG 6	100	100	93	38
AG 7*	75	100	38	33
AG 8	89	62	83	24
AG 9	83	50	83	31
AG 10	75	67	100	29
AG 11	67	100	90	30
AG 12	80	100	79	40
KE 1	68	83	75	40
KE 2	75	68	77	64
KE 3	75	75	71	50
KE 4*	82	92	47	50
KE 5	88	88	71	47
KE 6	70	100	90	50
KE 7	72	94	100	40
KW 1	80	84	90	71
KW 2	92	70	60	20
KW 3	69	65	80	20
Average	71 o/o	86 o/o	79 o/o	43 o/o

* Samples with more than 1000 ppm nickel.
** Samples with between 20 and 50 ppm chromium.

AMMONIUM ACETATE EXTRACTABLE Cu AND Zn

Table IV shows the percentages of total Cu and Zn extracted by neutral ammonium acetate. For both elements the proportions are low (even lower for Zn) and appear to have no relationship with the corresponding total metal values.

Table IV. Proportion of Cu and Zn extracted by neutral amonium acetate

Sample nº	o/o of total metal extracted	
	Cu	Zn
AG 1	2	1
AG 2*	3	1
AG 3	5	1
AG 4	5	1
AG 5**	3	1
AG 6	3	1
AG 7	1	1
AG 8	3	1
AG 9	2	1
AG 10	3	1
AG 11	2	1
AG 12	2	1
AF 1	1.5	0.4
AF 2	2	1
AF 3	2	1
AF 4	2.5	2
AF 5	1	0.1
AF 6	2	0.5
AF 7	3	2
AE 1	2	1.5
AE 2	1	1
AE 3***	1	0.4
AE 4***	3	1
AE 5	3	1.5
AE 6	1	nd
AE 7	2.5	2.5
AE 8	2.5	nd
AE 9	3	1
Average	2.6 o/o	1 o/o

* Sample anomalous in Cu
** Sample anomalous in Zn
*** Samples anomalous in Zn and Cu

Ammonium acetate extracts metals loosely adsorbed unto soil colloidal particles such as clay minerals, amorphous iron and manganese oxides and organic matter. However, changes in environmental conditions may be such that,

a. ageing and recrystallisation of iron and manganese oxides takes place resulting in stronger bonds with their associated trace metals and a loss of their colloidal properties;

b. trace metals are strongly fixed by soil colloids in the form of coprecipitates, stable complexes and the so called potential determining ions (ROSE,1974);

c. kaolinite provides the dominant adsorbing surface. Under the prevailing climatic conditions, the formation of this mineral is favoured.

The dominance of one or any combination of the above will result in an overall low base exchange capacity of the soils which may explain the low values of exchangeable Cu and Zn.

CONCLUSIONS

In the Laminaia schist belt, the basic rocks are distinct in their contents of Cu, Zn, Ni and Cr from the granitic rocks. A combination of moving average smoothing, correlation studies and the examination of single profiles along traverses shows that for nickel, these differences are mentained in the residual soils derived from weathering of the parent rocks. This feature shows promise in the use of geochemistry as a geological mapping tool.

Partial extraction studies have shown that while mechanical processes play an important role in the dispersion of chromium, the distributions of Cu, Zn and Ni in the soils are to a large extent influenced by properties of the secondary geochemical environment.

The low values of exchangeable Cu and Zn have been attributed to an overall low base exchange capacity of the soils. It is concluded that this is principally due to the nature of and modifications to soil colloidal particles, imposed by changes in the geochemical environment.

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