

LATERITIC WEATHERING OF GRANITE-GNEISS IN OBUDU PLATEAU, SOUTH EASTERN NIGERIA

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ABSTRACT

Obudu Plateau (Latitudes $6^{\circ} 30' N$, $6^{\circ} 45' N$ and Longitudes $9^{\circ} 15' E$, $10^{\circ} 00' E$) is a basement Horst bordered in the East by the Cameroun volcanic line, both of which form the Bamenda massif. This is a zone of migmatite-gneiss-schist complex with subordinate occurrence of amphibolites, charnockites and minor intrusive of granites, dolerites and Gabbros. Its tropical location pre-disposes it to climatic conditions (high temperature and pressures, heavy rainfall) that induce deep and severe weathering to form lateritic rocks.

This paper reports the chemical, mineralogical and textural changes involved in the lateritization of granite-gneiss in Obudu plateau and establishes that the susceptibility of constituent minerals to lateritic weathering is in the sequence; feldspar, Hornblende, Biotite, Quartz. Most of the chemical constituents of the basement rocks in these changes. Al_2O_3 and Fe_2O_3 are enriched in the upper horizons in preference to SiO_2 . Kaolinite is also abundant compared to other clays whereas Ba takes the opposite trend as it increases with severity of weathering.

KEY WORDS: Bamenda Massif, Tropical Location, weathering, Alumina, Kaolinite.

INTRODUCTION

Laterite is reddish to brown in colour and may be vesicular, concretionary, cellular, vermicular, slag-like pisolitic, concrete-like or gravely (conglomeratic) in texture. It is composed chiefly of ferric oxides with minor amount of alumina, manganese oxides, and variable quantities of quartz grains and rock fragments. Laterite also contain significant proportion of clay minerals. The composition of laterite varies according to the nature of the underlying rock and the amount of chemical decay that has occurred.

Lateritization is the process whereby rocks are converted to laterite by the enrichment of Iron oxide and the depletion of silica. Lateritization is favoured by low relief, a warm climate with alternating wet and dry seasons, and a fluctuating water table near the surface, which enables insoluble ferric oxides to be precipitated in the zone of aeration.

The percolation of very high amount of rainfall through the soil causes desilication. Soluble salts such as bases of calcium, sodium and potassium are completely removed from the tropical soil during lateritization, leaving behind highly stable oxides and hydroxides of iron and aluminium. Excessive accumulation of hydroxides of iron and aluminium lead to the formation of indurated rock-like

layer beneath the surface called laterite. Laterites are rapidly developed upon iron rich parent materials such as basalts, but thick laterites are also common in basement areas where they form on iron-deficient gneisses and schists.

The primary laterite forming factors include climate (precipitation, leaching, capillary rise and temperature), topography (drainage), vegetation, parent rock and time. A combination of the laterite - forming factors and the soil forming process of weathering produces the distinctive morphological properties, chemical and mineralogical composition of laterites.

LOCATION AND GEOLOGY

The study area (figure 1) is part of Obudu Plateau in Cross River State of Nigeria. It lies within the reactivated Precambrian Basement of Nigeria, which forms a portion of the pan-African Tectonothermal belt located between the West African Craton, to the west and the Gabon-Congo Craton, to the east.

It is bounded by longitudes $9^{\circ} 15' E$ to $10^{\circ} 00' E$ and latitudes $6^{\circ} 30' N$ to $6^{\circ} 45' N$ covering an area of about $75km^2$. The Obudu Plateau represents a terminal portion of the western Bamenda Massif of the Cameroons that wedges into eastern Nigeria (Orajaka, 1964; Umeji, 1988, Ekwueme, 1991.).

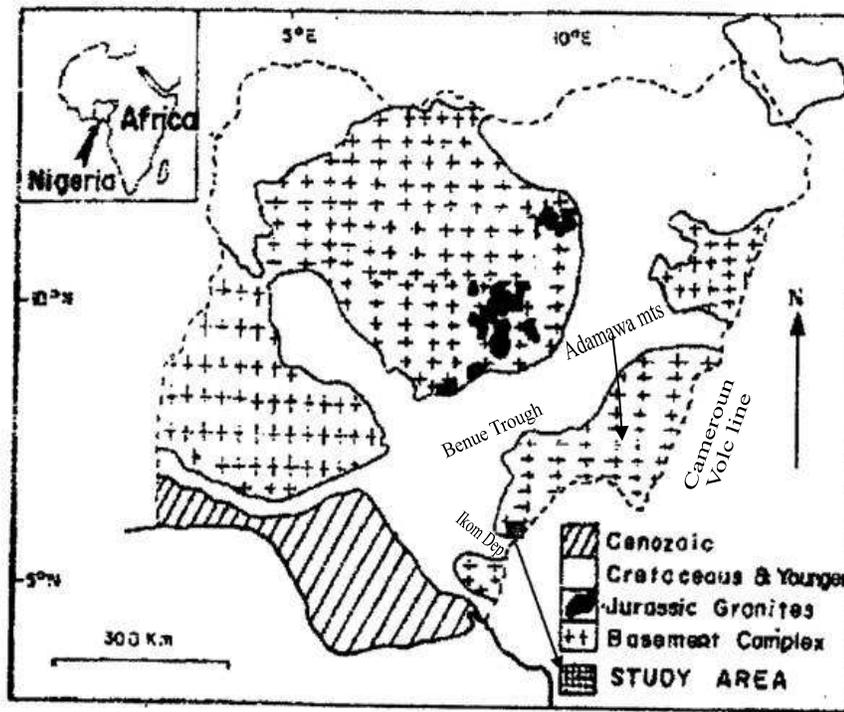


Fig. 1: Geological map of Nigeria showing location of study area

Generally the geology of Obudu Plateau can be classified into four units:

- (a) Migmatite - gneiss complex
- (b) Schists
- (c) Granitic, charnockitic and peridotitic intrusives
- (d) Unmetamorphosed dolerite dykes and dioritic intrusives .

The dominant rock unit in the Plateau is the migmatite-gneiss complex, while dioritic and peridotitic rocks are of minor occurrences (Orajaka, 1964, 1971 Umeji, 1991; Ekwueme, 1990a, 1994a, 1994b, 1998; Ekwueme *et al.* 1997). Generally, these metamorphic rocks are high grade migmatites, gneisses, schists, amphibolites and meta-peridotites.

Porphyroblastic paragneisses constitute a large part of the basement rocks of Obudu Plateau. The paragneisses in the eastern part of the Plateau are more quartzose than the western paragneisses, which are more aluminous. Prominent north-trending gneisses are abundant in Obanliku, Sankwala, Oloibi and Ishikpeche hills (Orajaka, 1964).

The gneisses can be subdivided into garnet-sillimanite gneisses, garnet-hornblende gneisses and pyroxene - bearing gneisses. They are coarse - grained and form prominent hills, which have been eroded in parts to expose dolerite dykes. (Ekwueme 1994).

Relying on the stable co-existence of garnet, kyanite and sillimanite in the garnet sillimanite gneiss, it can be inferred that metamorphism in Obudu Plateau attained at least intermediate pressures and reached the

highest grade of the amphibolite facies of the Barrovian type.

The Schist suite most of which are migmatized, are fairly distributed in Obudu Plateau. Amphibolites occur as lenses in the gneisses, and they are products of deformation and metamorphism.

Highly deformed high-grade migmatitic schists are frequently found in association with high-grade migmatitic gneisses, and both together form the basement units into which granites and pegmatite dykes intrude. Most of the schists contain garnet, except those that are sillimanite - bearing. Ekwueme (1990a) suggested that the sillimanite-bearing schists are products of the alteration of initial garnet-bearing schists.

Pegmatites are also common in Obudu Plateau, but are more frequent in the schists than in the gneisses. Muscovite-bearing pegmatites are also common; others are the biotite bearing and muscovite-biotite-bearing varieties.

Charnockites are abundant. They range from medium to coarse-grained to granulite textures (Ekwueme, 1990a). They crop out at River Metu, Busi, Bogene and Bebi (Ekwueme, 1990a). The structural disposition of the charnockites along fracture zones suggests emplacement due to faulting. They are associated with granite, pegmatites and granulites. The foliated variety trend N - S or NE - SW.

Dolerite dykes are common in the area. Some of the dolerites are finegrained, while others are medium-grained. The fine-grained dolerites are quantitatively

minor compared to the medium to coarse-grained variety.

Physiography, climate and vegetation

The study area has a rugged topography comprising north-easterly trending ridges separated by lowlands, which form valleys and passes. Generally, the Obudu Plateau constitutes the highest elevated part of south-eastern Nigeria, with a maximum height of 1576m above sea level at the Obudu Cattle Ranch (Udo, 1978)

Most rivers are seasonal, overflowing their banks in the rainy seasons and reducing in water volume or even completely drying out in the dry seasons. The drainage is structurally controlled as almost all the rivers rise from the Northeastern part and flow toward the south west.

The present day climate is characterized by a high annual rainfall between 1000mm and 2500mm. The rainfall regime includes a long wet season of heavy rainfall (March-October) and a dry season (November-mid March, Iloje, 1972).

The vegetation cover in the study area is influenced by the climatic type, soil cover and human activities. The vegetation types include Guinea savanna and rain forests (Udo, 1978). The Guinea Savanna is characterized by very tall grasses interspersed with trees. Tall trees of the rainforest type abound around the river valleys. The common trees of the Guinea savanna are acacias, baobab and shea-butter.

The Obudu-Cattle Ranch road is the only major road that traverses the study area, running roughly East-West. Secondary roads include Sankwala-Bayasung road, running N-S in the western part of the Obudu area. Accessibility is highly limited by the preponderance of very high peaks. Thus, the roads and footpaths are

largely restricted to the plains or foot of hills or in few cases, along the Obudu-Cattle Ranch road.

METHOD OF STUDY

In Obudu as well as other parts of the stable Precambrian West African shield, deep weathering and planation processes have been operating for millions of years. As a result the highlands are characterized by extensive plateaus and plains which are punctuated in places by inselbergs. The precambrian crystalline basements consisting of different metamorphic and igneous rocks are, for the most part, blanketed by a thick cover of in-situ laterites. This provides an ideal setting and excellent natural laboratory for the study of lateritization process and products on suites of different parent rocks.

The present study focuses on the chemical and textural changes accompanying the lateritization of granite-gneiss, a rock type wide spread from Obudu toward Sankwala. It also seeks to document unique geochemical signatures and fingerprints together with characteristic micromorphological features in laterites that may perhaps be diagnostic for detecting the identity on the surface of the presence of various rock types in deeply weathered terrains and by implication, the mineral resources potential of such areas (Kronberg *et al.*, 1979; Matheis, 1980; Oti, 1987). Detailed logging of the laterite profile was conducted based on an augered hole, some 3km south-west of Sankwala market, along the Obudu cattle Ranch road. Some 7m of laterite together with underlying saprolite and fresh parent rock were sampled in a continuous section (fig. 2). Seven samples taken from the different horizons were then subsequently analysed in the laboratory for the various parameters.

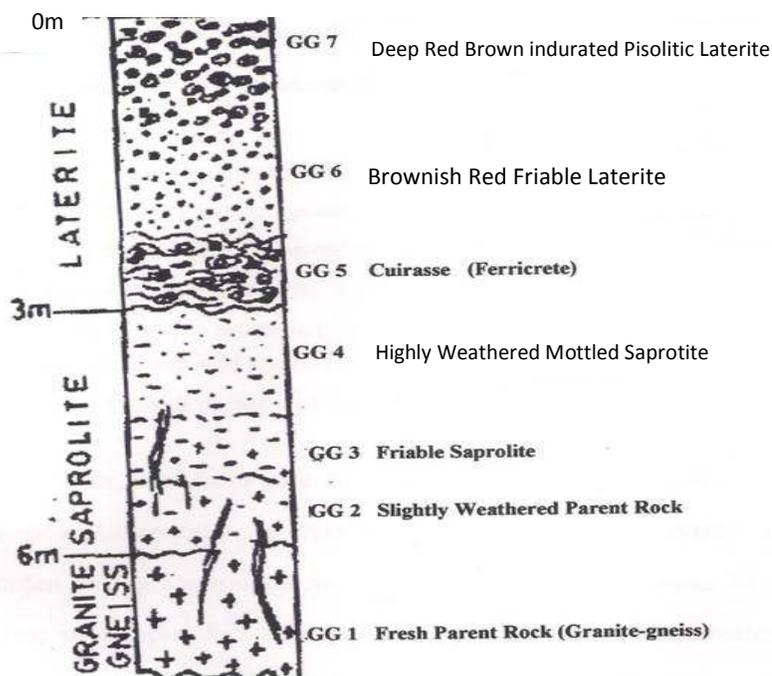


Fig. 2: Section showing lithological changes from fresh parent rock through saprolite and ferricrete to pisolitic laterite. (GG1-GG7 are sample designations of the sampling points.)

Lithology of the weathered profile

The laterite profile averages 7 meters in thickness and its lithological composition and that of the underlying saprolite and parent rock are shown in Fig.2: and described as follows from top downwards.

- (a) (GG7) deep red brown pisolitic laterite, consolidated (2m)
- (b) (GG 6) brownish red pisolitic laterite less consolidated (1m)
- (c) p(GG 5) cuirasse (ferricrete) (60cm)
- (d) (GG 4) highly weathered saprolite, lateritic (80cm)
- (e) (GG 3) friable saprolite (50 cm)
- (f) GG 2) weathered but still coherent parent rock (15cm)
- (g) (GG 1) fresh parent rock - granite gneiss (bed rock)

Major oxides, minor and trace elements determinations were made by Lyell Campbel Laboratories, in Port Harcourt, under the supervision of Dr. Gordon Bishop. Determinations were carried out with a Siemens XRF after pellets of samples had been prepared by fusion with Lithumtetraaborate.

Together, 11 major and minor oxides, as well as 24 minor and trace elements were determined. Loss on ignition (LOI) was determined after heating in an oven for 15 minutes at 1200°C.

RESULTS AND DISCUSSIONS

The data obtained from the chemical and mineralogical analysis of the samples are presented in tables and graphs for interpretation.

Major oxides are in table 1 while trace element composition is in table 2

Table 5.1: Major and minor oxides composition in wt% of the laterite over granite gneiss in Obudu

Sample	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total
GG7	44.90	16.74	16.67	0.97	0.12	0.17	10.07	0.18	1.18	0.07	9.35	100.42
GG6	46.29	17.87	22.26	0.87	0.28	0.12	0.05	0.01	0.82	0.08	10.41	99.05
GG5	55.22	14.06	18.01	0.76	0.73	0.13	0.05	0.11	1.65	0.06	8.45	99.23
GG4	60.25	18.51	5.97	0.90	0.06	1.35	0.20	0.27	3.97	0.06	7.95	99.49
GG3	63.85	14.91	4.57	0.63	0.08	3.00	2.89	2.66	3.66	0.30	2.66	99.21
GG2	62.37	15.57	5.21	0.69	0.09	3.09	2.33	2.14	4.43	0.18	3.06	98.16
GG1	64.06	14.49	4.49	0.60	0.09	3.09	3.26	3.25	4.44	0.28	1.01	99.06

Table 2: Minor and trace elements data (in ppm) of laterite over granite gneiss.

	Ba	Ce	Co	Cr	La	Se	V	As	Bi	Cu	Mo	Nb	Ni	Pb	Rb	Sn	Sr	Ta	Th	U	W	Y	Zn	Zr
GG7	526	316	53	552	45	19	333	24	10	49	5	24	62	56	49	20	62	6	22	6	5	33	28	648
GG6	589	872	157	642	69	17	431	13	6	59	15	21	69	92	40	20	54	5	34	14	5	28	18	541
GG5	1595	468	196	463	51	11	298	22	10	54	11	20	61	62	57	20	76	5	15	6	5	26	24	551
GG4	1412	104	39	223	91	14	106	27	6	28	5	25	67	48	190	20	187	5	24	5	5	31	41	415
GG3	1684	141	26	328	48	14	90	21	6	51	3	13	68	48	217	20	491	5	34	7	5	26	63	227
GG2	1553	122	39	323	79	17	100	6	6	69	4	17	78	42	169	20	107	5	22	10	5	57	58	227
GG1	1575	118	33	395	30	14	190	18	6	18	8	16	60	53	170	20	492	5	24	6	5	16	59	197

MINERALOGICAL AND TEXTURAL CHANGES

In Figs. 3, 4, 5 and 6, the chemico-mineralogical development of the profile from parent rock through the saprolite to the laterite is summarized.

GG 1-Parent Rock

The parent rock consists essentially of quartz, orthoclase, microcline, albite-oligoclase plagioclases, biotite, biotite, green hornblende and arfvedsonite hornblende (Ekwueme, 1990). These components constitute more than 90% of the rock by weight and volume. Accessories are zircon, titanite, apatite and magnetite. The rock texture is granoblastic to gneissic with biotite and hornblende defining the lineations in the gneissic domains. Some of the mineralogical phases were confirmed by x-ray diffraction (fig. 6).

GG2 – Slightly Weathered Parent Rock

Megascopic observation of this weathered but still coherent granite-gneiss shows the incipient stages of weathering. Grain boundaries and cleave planes are the most vulnerable site of alteration. Transmineral fissures are common. These run across minerals with no preferred cleavage planes (quartz) through and into those with good cleavages such as biotite and hornblende. In these latter minerals, alteration starts within these cleavage planes (Oti, 2007).

GG3 – Friable Saprolite

This horizon represents the main saprolite zone. Although still texturally coherent, that is with original parent rock textures still intact, hydrolytic weathering reactions have advanced. Evidences are the incongruent dissolution of many silicate phases, particularly feldspars, biotite and amphiboles.

GG4-Highly Weathered Saprolite

This horizon lying directly under the ferricrete seems to be the most critical horizon separating bedrock from laterite proper. Feldspars have almost completely disappeared, in their place kaolinite has come to stay. Hornblende has disappeared, as well as apatite and magnetic, releasing much ferrous iron which is immediately oxidized and reprecipitated as ferric iron in goethite and haematite.

GG5 – Ferricrete

This is by far the most important horizon showing the most dramatic changes. Feldspars and hornblende are now completely absent. Iron oxides, in the form of goethite and hematite are now the most important mineralogical phases, anatase precipitates and is concentrated in small discrete domains or pouches. Kaolinite is now the dominant and only clay mineral present. Pisolite-sized concretions appear, showing fine-grained embayed and angular quartz set in hematite matrix. These concretions show a thin veneer of goethite coating.

GG6 – Pisolitic laterite, Less consolidated

In this horizon abundant pisolites – ranging in size from less than 1mm to over 1cm occur. Their constitution is as described for GG5. The only minerals present are quartz, abundant goethite, hematite and kaolinite, and some anatase.

GG7 – Pisolitic laterite, Consolidated

The mineralogy is much similar to that of the underlying horizon (GG6) except that much allochthonous quartz is present.

CHEMICAL CHANGES

Tables 1 and 2 respectively show the values of 10 major oxides, plus loss-on-ignition (LOI) and 24 minor and trace element determined in the various horizons from the fresh parent rock through saprolite to the laterite – so also are figs. 3, 4 and 5

Major Oxides

From a cursory examination of Tables 1 and 2 and Figs. 3, 4 and 5, it is evident that some constituents have suffered losses whereas others are enriched. According to Krauskopf (1979) these losses and gains may be real provided the total mass of the rock has remained essentially constant, or may merely be apparent if some constituents are affected while others are not at all or only slightly. The trend may signify a real decrease in all components, but with those with the least decrease showing the highest apparent abundance. Consequently, therefore, results of chemical analysis only show the relative amounts of components or elements present. However, these problems may be

overcome by adopting several procedures in monitoring the direction of element mobilities and determining what quantities are involved at any given time during the course of chemical weathering (Schellmann, 1980, Eggleton *et al*, 1987).

If parent rock is not available as is often the case in deeply weathered terrains then recourse must be made to the isoalumina (Krauskopf, 1979) or isotania methods in which Al_2O_3 or TiO_2 are presumed immobile because these oxides in all weathered materials, generally show the greatest apparent increase despite the fact that Al and Ti, of all common rock components are the least abundant in surface waters (Kromberg *et al*, 1979).

Minor and Trace Elements

Of the 24 minor and trace elements analysed, it is found that those present in the parent rock (GG 1) and in the pisolitic laterite (GG 6) show marked difference in concentrations.

There is a definite behaviour of these minor and trace elements in the weathering profile from the parent rock through the saprolite to the laterite. The concentration of the individual trace and minor elements in the laterite (and saprolite) and in the parent rock clearly discriminate the elements into those enriched and those depleted. Of these Ce, Co, Cr, La, Cu, Y and Zr are enriched in various degrees, whereas Ba, Rb, Sr, and Zn are depleted some strongly to very strongly. Essentially unaffected are Sc, As, Bi, Mo, Ni, Nb, Pb, Sn, Ta, Th, and U. Figs. 4 and 5 explain the enrichment and depletion trends in ppm.

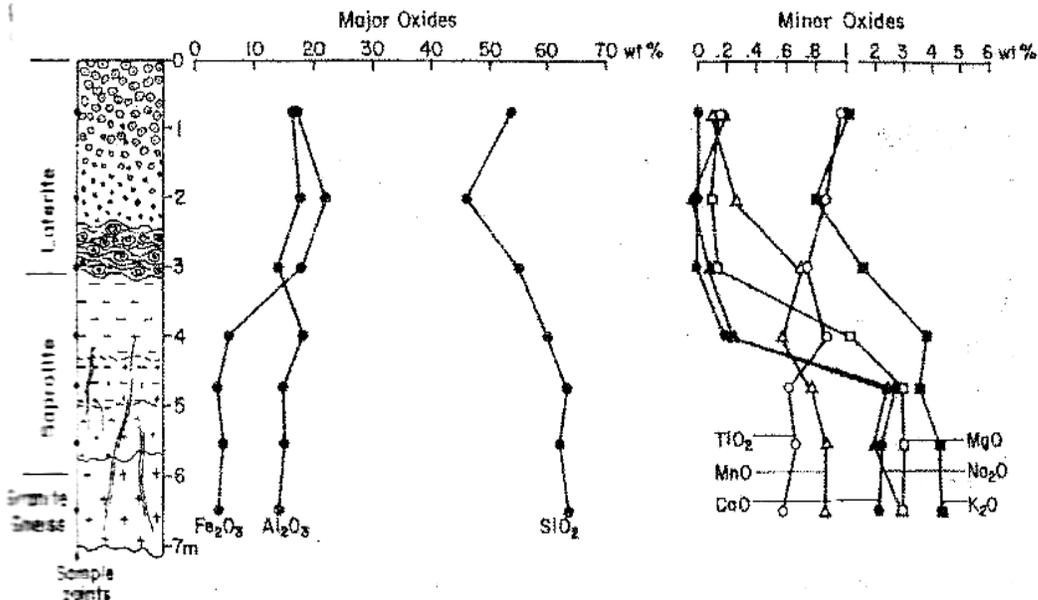


Fig. 3: Major and minor oxide content from parent rock (granite-gneiss) up through saprolite to laterite (iron oxide, Alunina and titania show increase in the weathering profile, whereas silica, lime, magnesia, soda, potash and MnO show rapid and intense losses). This trend is expected because of their mobility.

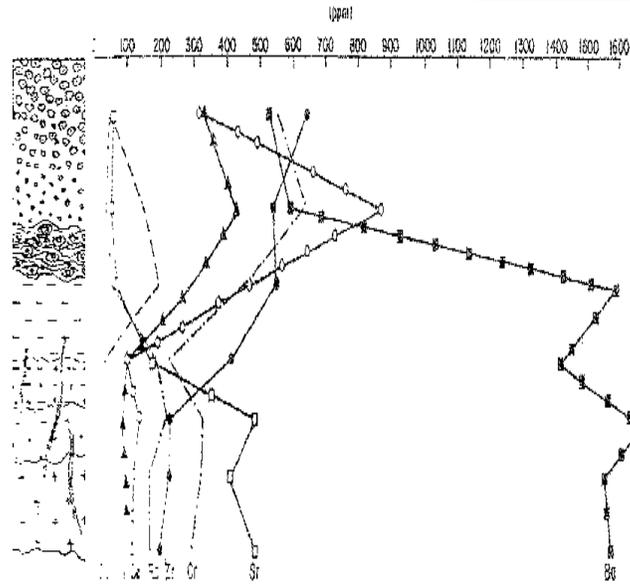


Fig. 4: Minor and trace elements (Co, V, Ca, Rb, Zr, Cr, Sr and Ba) distribution in lateritic profile of granite-gneiss. Ba, Sr and Rb are rapidly lost, whereas others show slight to strong enrichment in the upper parts of the profile.

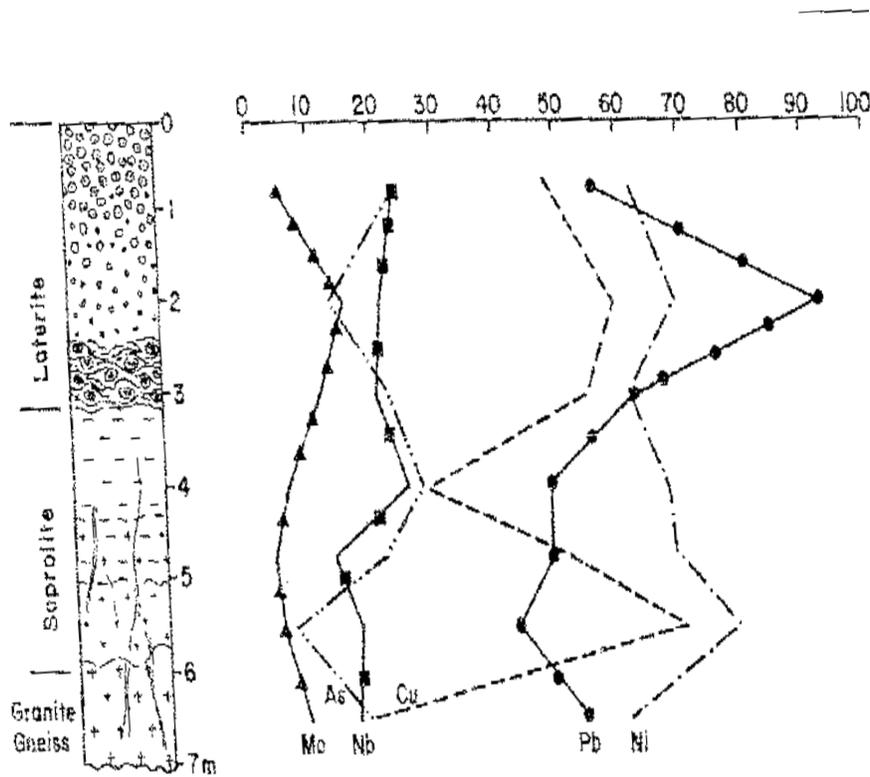


Fig. 5: Trace element (Mo, Nb, As, Ca, Pb, Ni) distribution in ppm in lateritic weathering profile over Granite-Gneiss, in Obudu.

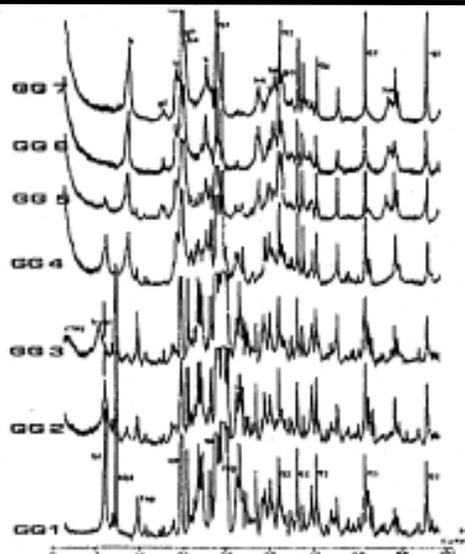


Fig. 6: X-ray powder patterns of lateritic weathering profile over Granite-Gneiss from parent rock (GG 1) through saprolite (GG 2, GG 3 and GG 4) to laterite (GG 5, GG 6 and GG7) bi = biotite; hbi = hornblende; fsp = feldspar, qz = quartz; he = hematite; go = goethite, gi = gibbsite; k = kaolinite, hybi = hydrobiotite.

CONCLUSIONS

Chemical study of the weathered profiles shows that there are marked physio-chemical deterioration from the surface down ward.

From the complex, multi-component system, $\text{SiO}_2 - \text{Al}_2\text{O}_3 - \text{Fe}_2\text{O}_3 - \text{K}_2\text{O} - \text{Na}_2\text{O} - \text{CaO} - \text{MgO}$ in the granite gneiss, the mineralogical evolution results in a simpler four-component system $\text{SiO}_2 - \text{Al}_2\text{O}_3 - \text{Fe}_2\text{O}_3 - \text{H}_2\text{O}$ (Kronberg, *et al*, 1979) which is more in equilibrium with earth surface conditions.

Accompanying the chemical breakdown of the constituent minerals, the alkali and earth alkali elements are rapidly lost as they represent the most mobile elements in the system. With attendant loss in volume, the less mobile elements (Al, Fe, Ti) become progressively enriched together with combined water. Silica which is usually more resistant to weathering also diminishes through dissolution.

The chemical data for the weathered profiles reveals a development trend from Silica rich parent-rock to Silica-depleted, Alumina and iron enriched and products. The effect of leaching is seen in the large deviation of the composition of the parent rock from the weathered profile.

The extensive depletion of silica is matched by the equally extensive increase in alumina, iron and LOI-water, plus the emergence of gibbsite as the main mineralogical phase.

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