GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL. 4 NO. 2 2006 : 183 - 191
 ISSN 1596 - 6798


# MINERALOGY AND GEOCHEMISTRY OF THE WEATHERING PROFILES ABOVE BASEMENT ROCKS IN IBADAN SOUTHWESTERN, NIGERIA.

A. T. BOLARINWA

(Received 19 May, 2004; Revision Accepted 27 January, 2006)

## ABSTRACT

The nature of the lateritic profiles above the Precambrian basement rocks in Ibadan area, southwestern Nigeria, was investigated using petrographic, X-ray diffraction and chemical techniques. The objective of the investigation was to determine the compositional variations within and between the residual profiles over the different rock types in the area with a view to know the trend of weathering.

Polished and thin sections of the fresh rocks, clay and laterite samples collected were prepared for petrographic studies. Powdered samples were also selected for routine mineralogical analyses using Philips-PW/1010/02 X-ray diffractometer. Major and trace elements compositions of representative samples of the rock and the overlying clay and laterite were determined using an Atomic Absorption Spectrophotometer (AAS), and a Philips PW 1480 automated X-ray fluorescence (XRF) spectrometer.

Mineralogical studies show that the weathering profiles are composed mainly of quartz, kaolinite, goethite and limonite. Petrographic studies of the polished sections of the clayey and laterite samples show that kaolinite is from the alteration of feldspars while the Fe-minerals are from the decomposition of biotite and hornblende present in the rocks. Other minor components include illite, halloysite and anatase.

Geochemical dispersion trends between the upper reddish lateritic horizon and the lower greyish kaolinite zone suggest leaching of $SiO_2$, $Na_2O$, CaO, MgO and $K_2O$ relative to $Al_2O_3$ and $Fe_2O_3$. The removal of mobile elements by meteoric water and subsequent concentration of stable weathering products results in lateritization. Also, bauxite minerals such as gibbsite, boehmite and diaspore are absent in the profiles. This shows that the trend of weathering is towards iron enrichment (ferralitization) rather than aluminium accumulation (bauxitization).

**KEYWORDS**: Basement rocks, weathering, geochemistry, laterite, clay minerals.

## INTRODUCTION

The Precambrian basement complex of southwestern Nigeria consists predominantly of gneisses, schists and quartzites, into which granitic and basic intrusives have been emplaced. These crystalline rocks have generally been weathered into ferralitic and ferruginous tropical soils (D'Hoore, 1964). Translocation and redistribution of the weathering products through groundwater and percolating rainwater under appropriate Eh and pH conditions result in lateritization or duricrust formation (Norton, 1973).

Geochemical investigations by Tietz (1983) indicated that laterite profiles over amphibolites and mica schists are commonly depleted in Al, Fe, Mn, Ti, Ni and Cr downwards, while Ca, Na, Mg and K increases in the same direction due to leaching. Onuogu and Ferrante (1986) suggested that soil analyses may assist in location of zones of nickel mineralization over amphibolitic complex. Emofurieta (1988) evaluated the economic potential of the residual profile over a pegmatite rock in Ibadan area using geochemical, mineralogical and physical properties as indices. Elueze and Bolarinwa (2001) appraised the industrial suitability of clay occurrences in the weathered profiles in Abeokuta area, southwestern Nigeria.

In Ibadan area of southwestern Nigeria, thickness of the weathering profiles over the basement rocks range between 5 and 30m. Exposures of vertical profiles in the area distinguish three major horizons, namely, the topsoil, iron-rich laterite and clayey zone. The variations in colour, texture and composition of the various zones within the profiles depend on the parent rock and the prevailing chemical environmental conditions. Transition between the zones is gradual, while in some cases the weathering products preserve the textural and structural features of the bedrock.

Aspects of the geology and geochemistry of rocks in Ibadan area have been studied by many workers including Jones and Hockey (1964), Grant (1970), Oyawoye (1972), Elueze, (1982), Bolarinwa, (2001) and Elueze and Bolarinwa (2004). The objectives of the present investigation are to identify the major rock types in the area and the characteristic features of the overlying profiles, and also to compare the mineralogical and geochemical patterns in the profiles overlying the various rock types.

## FIELD CHARACTERISTICS OF THE WEATHERING PROFILES

A 6m thick weathering profile over banded gneiss is exposed at about kilometer 58 along Ibadan - Lagos Express road and Ibadan-Abeokuta road (Fig. 1). Four distinct horizons are recognised based on the colour, texture and preservation of relic structures. The topsoil in this profile is about 0.5m thick, brownish in colour and rich in organic matter. The underlying laterite is yellowish brown, concretional and partially consolidated. This layer is about 1.5m thick. Below this layer is the compact, clay-accumulated zone that is brownish yellow in colour. The layer, which is about 2.5m thick, grades into the underlying saprolite.

Quartzite and quartz-muscovite schist are widespread around Ibadan (Fig. 2). They form prominent elongated ridges in the area. The characteristics and depth of weathering above this rock type vary considerably with the mica content. The coarse type with little mica are resistant to weathering, while the micaceous varieties characterised by schistose texture are easily decomposed.

A thick weathering profile exposed at Boluwaji area of Ibadan (Profile 11, Fig 2), consists of four major horizons. Thin, loose topsoil is underlain by a gravelly and reddish brown laterite. Angular quartz pebbles are scattered within this horizon. The thickness of the topsoil and the brownish laterite layer does not exceed 0.5m and 2.0m respectively. Immediately below the laterite horizon is an extensive zone of brownish yellow lateritic clay. The layer is dominantly composed of gritty clay of about 7.0m thick. Underlying the clayey zone is the whitish saprolite layer.

Pegmatite dykes cut across most of the gneisses and schists in Ibadan area (Fig. 2). They are pinkish in colour due to the presence of microcline. The plagioclase feldspar rich

A. T. Bolarinwa, Department of Geology, University of Ibadan, Ibadan, Nigeria.

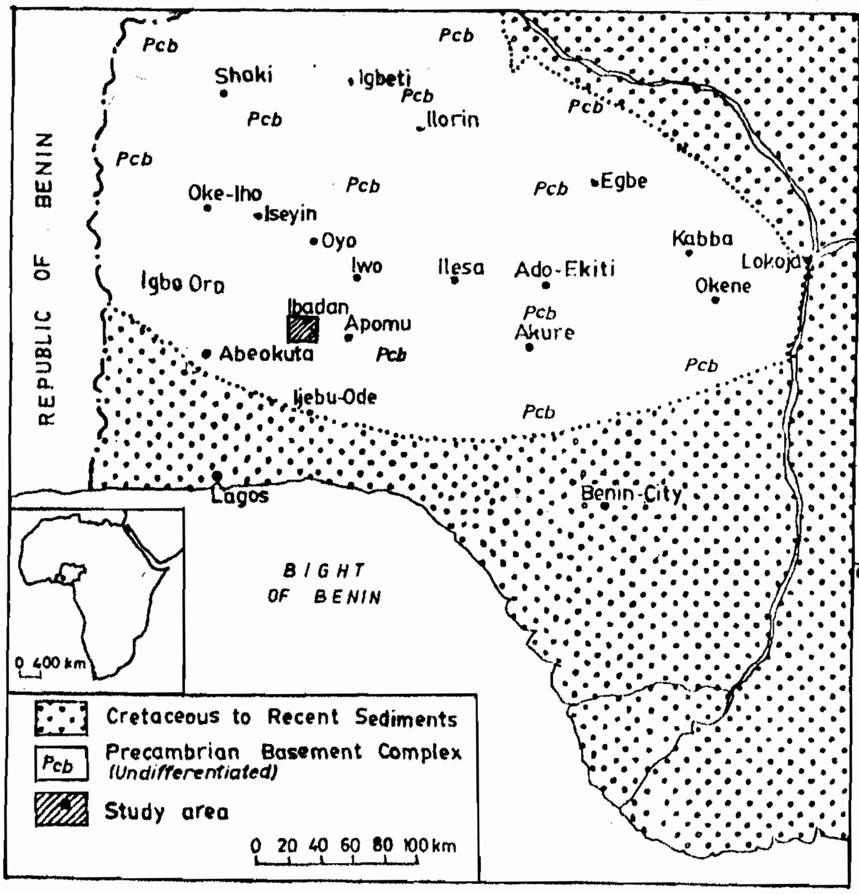


*Fig. 1: Location map of Ibadan area within the basement complex of southwestern Nigeria.*

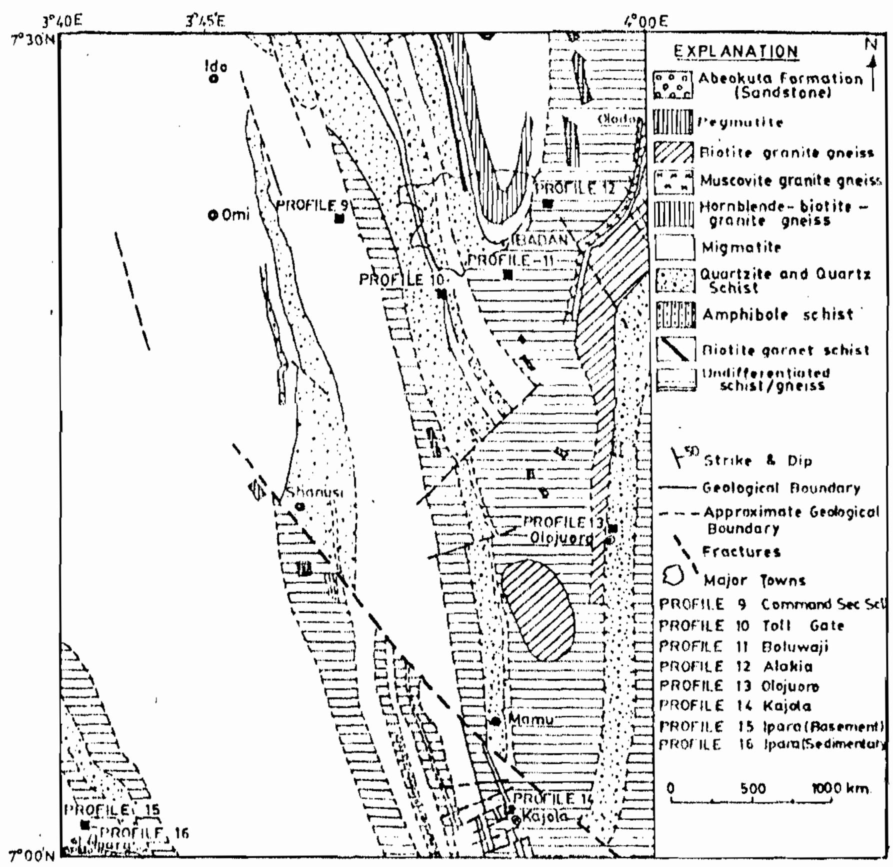


*Fig. 2: Geological map of Ibadan area (modified after Jones and Hockey, 1964), showing the weathered profile locations.*

varieties are whitish in colour. They are generally coarse grained with a graphic texture.

A weathering profile above pegmatite rock around Toll Gate (Fig. 2), near the Ibadan end of the Ibadan-Lagos express road, shows four gradational horizons. The first is the topsoil, which is brownish, loose and humic. The second horizon is brownish yellow and gravelly. The total thickness of these two horizons is not more than 2.5m. The third horizon is yellowish and clayey. It is about 5m thick. The fourth zone constitutes the saprolite.

## ANALYTICAL TECHNIQUES

Polished and thin sections of the fresh rocks, clay and laterite samples collected were prepared for petrographic studies. Some powdered representative samples were also selected for routine mineralogical analyses using Philips-PW/1010/02 X-ray diffractometer of the Department of Geology, Obafemi Awolowo University, Ile-Ife. Diffraction patterns were compared with established standards and interpreted using the JCPDS (1974) X-ray powder diffraction file.

Abundances of major and trace elements of representative samples of the rock and the overlying clay and laterite were determined using an Atomic Absorption Spectrophotometer (AAS) of the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife.

Powdered samples were digested with 5ml of 42% concentrated hydrofluoric acid (HF) and 38% concentrated hydrochloric acid (HCl) in a tightly covered digesting bottle. The digested samples were analyzed using an Alpha 4 Chem Tech Atomic Absorption Spectrometer (AAS). Determinations of the major elements Fe, Mn, Mg, Ca, Na, K, Ti, P and trace elements Co, Cr, Cu, Ni and Zn were achieved using four AAS standard solutions of known concentrations. Alphastar software was used for data acquisition and treatment. Al was determined using colorimetric method while Si was by subtraction. Results of the elemental concentrations in parts per million (ppm) were converted to percentage oxides using appropriate factors.

Duplicate samples in discs were analysed at the Geochemischen Institute, Georg-August-University, Goettingen, Germany, using a Philips PW 1480 automated X-ray fluorescence (XRF) spectrometer. Data processing was controlled by the Philips X40 software package. Discs for both major and trace elements determination were prepared at 1100°C using spectroflux 100 (Johnson Matthey GmbH® containing lithium tetraborate. Weight percent water was determined gravimetrically by loss on ignition (LOI). Details of the analytical procedure are presented in Bolarinwa (2001). Results of the whole rock geochemistry of the fresh rocks and the weathered materials are presented in Tables 1 and 3 - 7; and illustrated in Figs. 9, 10 and 11.

Measurements of pH values of prepared slurries were obtained with a standard meter. The pH value of each sample was measured using a pH meter standardized with a buffer solution. Results of the pH tests are presented in Table 2. pH value is a measure of the acidity of the weathering environment. The variations with depth of the pH values are discussed under the different rock types.

## MINERALOGY OF THE PROFILES

Petrographic study of the banded gneiss shows mafic bands composed of biotite and hornblende alternating with felsic bands of quartz and feldspars (Fig. 3). The X-ray diffractograms of the weathering profile illustrated in Figs. 4 a,b and c, show prominent peaks for plagioclase and microcline in the parent rock (Fig. 4a). Biotite and muscovite are also reflected. Notable quartz peaks occur at 4.26, 3.35, 2.46, 1.82, 1.67 and 1.54Å values. The clayey zone and the laterite diffractograms (Figs. 4b and c) display prominent peaks of quartz and kaolinite. Other minor peaks are those of plagioclase, goethite, and zircon.

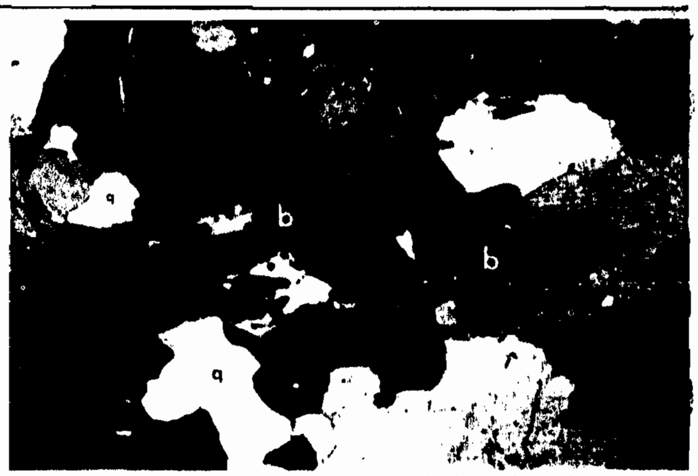


***Fig. 3: Photomicrograph of the banded gneiss showing mafic band of biotite (b), in between felsic bands of quartz (q) and plagioclase feldspars (pg), crossed polars, x 2.5mm.***

The X-ray diffractograms of the quartz-muscovite schist weathering profiles are shown in Figs. 5 a,b & c. Muscovite peaks are recorded at 3.35 and 1.98Å in the rock, while phlogopite and plagioclase peaks are recorded at 1.66 and 2.01 Å, respectively. Quartz peaks are recorded at 4.26, 2.46 and 2.28Å values. Prominent kaolinite peaks are reflected at 7.13, 3.56 and 2.34Å values in the clayey zone and the laterite. Other minerals present in the laterite zone include goethite and hematite. Although muscovite is usually resistant to incipient weathering, it is altered to kaolinite at advanced stage of weathering.

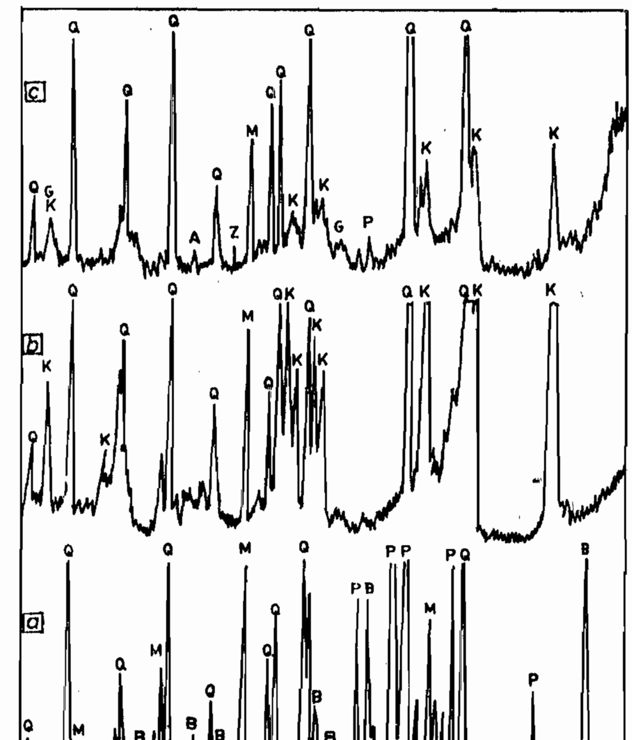


***Fig. 4: X-ray diffraction analysis of the banded gneiss profile in Ibadan area. a – rock, b – clay, c – laterite, Q – quartz, M – microcline, P – plagioclase, I – illite, B – biotite, K – kaolinite, G – goethite, Z – zircon.***

Petrographic study of the pegmatite rock shows large crystals of quartz, albite and microcline (Fig. 6). In thin section, the laterite and the clayey horizons are composed of fractured quartz, limonite, goethite and clay minerals (Fig. 7). In the X-ray chart for rock presented in Fig. 8a, conspicuous peaks of microcline and plagioclase are recorded at 3.24 and 3.17 Å, respectively. The clayey zone is composed of kaolinite, halloysite and quartz. The muscovite flakes in the rock persist in the clay zone (Fig 8b), while goethite is recorded in the laterite horizon (Fig. 8c).

## GEOCHEMICAL TRENDS

### Weathering Profile above Banded Gneiss

The average and range of chemical compositions of the banded gneiss, the clayey zone and the laterite of the weathering profile along Lagos-Ibadan express road are as shown in Table 1. The variation of the major oxides is presented in Table 5 and Fig. 9. The data and the illustration show a general decrease in $SiO_2$ contents from the bedrock to the clayey zone. Mean concentrations of $SiO_2$ are 66.06 and 54.41% in the rock and clayey zone respectively. This value increases from 54.41% in the clayey zone to 56.50% in the laterite (Table 5). Most of the primary minerals present in the rock, such as hornblende, feldspar and biotite have been altered to secondary minerals such as kaolinite and other clay minerals, which are prominently reflected in the X-ray charts (Figs. 4b and c). These result in the enhancement of $Al_2O_3$ from 12.82% in the parent rock to 21.79 and 19.81% in the clayey and laterite zones, respectively. $Fe_2O_3$ on the other hand increases from 2.91% in the rock to 5.32% in the clayey zone and 6.71% in the laterite (Fig. 9). The higher value of $Fe_2O_3$ in the laterite zones compared to the bedrock is due to the presence of concretionary pisolitic iron nodules in the laterite horizons. The relative enrichment of $Fe_2O_3$ and $Al_2O_3$ in the weathering profile can be explained by the leaching of MgO and $SiO_2$ (Zeissink, 1969 and Schellmann, 1989). MnO, MgO and $P_2O_5$ are depleted in the clayey zone, which is a zone of leaching and reformation (Aleva, 1994). The oxides are however enhanced in the laterite, which is a zone of accumulation of materials leached from the topsoil.

The average pH in the laterite is 6.7 while that of the clayey zone is 6.2, and that of the parent rock is 8.5 (Table 2). Dissolution and leaching of MgO, CaO, $Na_2O$ and $K_2O$ is enhanced by the low pH of the clayey zone. $TiO_2$ appreciates significantly from 0.28% in the rock to 0.38 and 0.60% in the clayey zone and the laterite, respectively.

Trace element abundance shows greater enrichment of Co, Cr, Cu, Ni, and Zn in the laterite zone than the soil horizon (Tables 1 and 5). Co (20ppm, 49ppm, 25ppm); Cr (18ppm, 51ppm, 34ppm); Cu (20ppm, 49ppm, 26ppm); Ni (22ppm, 77ppm, 34ppm), and Zn (39ppm, 68ppm, 38ppm) corresponding values (Table 1) in the rock, laterite and soil are generally below values that could be considered for possible mineralization.

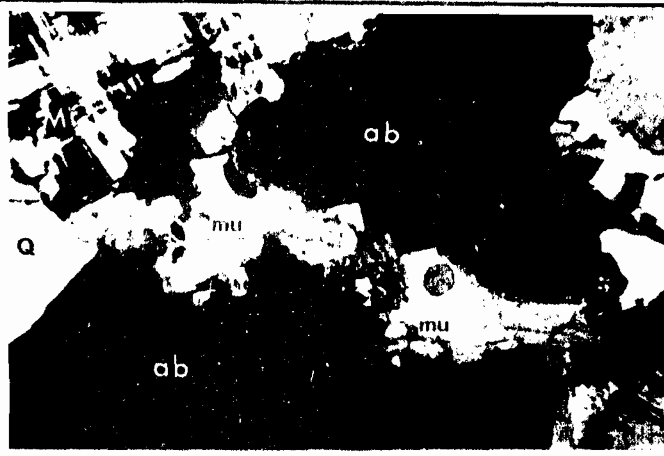


***Fig. 6: Photomicrograph of the pegmatite showing muscovite (mu), sandwiched between albite (ab), microcline (Mr) and quartz (Q). Crossed polars, x2.5mm.***

***Fig. 7: Photomicrograph of the weathered pegmatite showing insitu ferruginization of quartz and feldspars. L – limonite, G – Goethite. Reflected light, oil immersion, crossed polar, longer edge of photo is 420µm.***

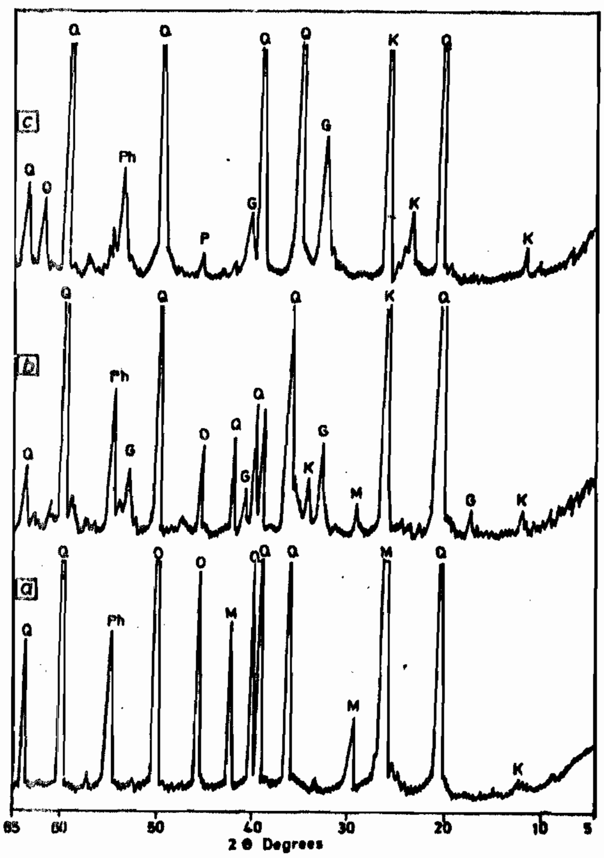


***Fig. 5: X-ray diffraction analysis of the quartz-muscovite schist profile in Ibadan area. a – rock, b –clay, c- laterite, Q – quartz, K – kaolinite, M – Muscovite, P – plagioclase, Ph – phlogopite, G – goethite.***

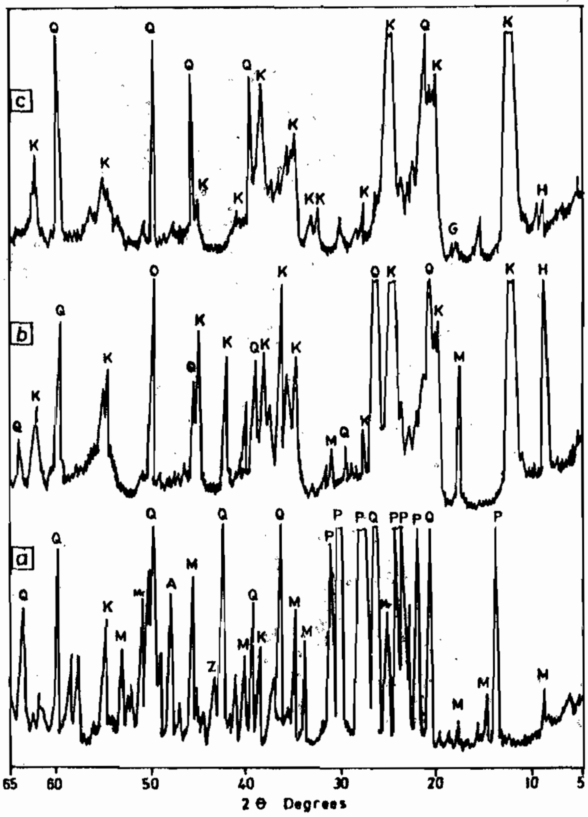


***Fig. 8: X-ray diffraction analysis of the pegmatite profile in Ibadan area. a – rock, b – clay, c – laterite, P – plagioclase, Q – quartz, M – mica, Z – zircon, A – anatase, K – kaolinite, H – halloysite, G – goethite, Mr – microcline.***

Table 1 Average chemical compositions (%) of residual profile over banded gneiss in Ibadan area

| | ROCK | | CLAYEY ZONE | | LATERITE | |
|---|---|---|---|---|---|---|
| OXIDES | Mean | Range n=5 | Mean | Range n=5 | Mean | Range n=5 |
| $SiO_2$ | 66.06 | 64.82-67.38 | 54.41 | 52.02-58.77 | 56.50 | 54.18-58.40 |
| $TiO_2$ | 0.28 | 0.25-0.35 | 0.38 | 0.31-0.46 | 0.60 | 0.51-0.74 |
| $Al_2O_3$ | 12.38 | 11.88-14.26 | 21.79 | 18.62-25.11 | 19.81 | 18.33-21.98 |
| $Fe_2O_{3(t)}$ | 2.91 | 2.53-3.68 | 5.32 | 4.92-6.25 | 6.71 | 5.39-8.31 |
| MnO | 0.10 | 0.04-0.13 | 0.06 | 0.04-0.08 | 0.18 | 0.15-0.20 |
| MgO | 1.11 | 1.05-1.18 | 0.15 | 0.10-0.019 | 0.31 | 0.20-0.46 |
| CaO | 5.33 | 4.42-6.30 | 0.65 | 0.48-0.92 | 0.54 | 0.36-0.68 |
| $Na_2O$ | 5.29 | 4.01-6.10 | 2.14 | 2.13-2.16 | 0.48 | 0.20-0.74 |
| $K_2O$ | 4.42 | 3.33-5.23 | 5.14 | 4.21-5.78 | 3.81 | 3.24-4.76 |
| $P_2O_5$ | 0.29 | 0.20-0.40 | 0.13 | 0.08-0.24 | 0.26 | 0.20-0.38 |
| LOI | 0.56 | 0.46-0.63 | 9.20 | 6.58-11.07 | 10.57 | 9.46-12.6 |
| **Total** | **99.17** | | **99.37** | | **99.77** | |
| Trace elements (ppm) | | | | | | |
| Co | 20 | 15-23 | 49 | 38-66 | 25 | 18-39 |
| Cr | 18 | 14-22 | 51 | 33-61 | 25 | 26-42 |
| Cu | 20 | 13-35 | 49 | 44-52 | 26 | 16-38 |
| Ni | 22 | 16-32 | 77 | 54-110 | 34 | 25-44 |
| Zn | 39 | 29-48 | 68 | 45-87 | 39 | 29-52 |
| Silica and alumina ratios (%) | | | | | | |
| S.R | 4.20 | 4.01-4.50 | 2.00 | 1.75-2.50 | 2.13 | 1.96-2.48 |
| A.R | 4.41 | 3.30-5.61 | 4.10 | 3.64-4.80 | 2.95 | 2.26-3.84 |
| MgO+CaO | 6.44 | 5.60-7.35 | 0.80 | 0.65-1.10 | 0.85 | 0.71-0.98 |
| $Na_2O+K_2O$ | 9.70 | 7.34-11.17 | 7.28 | 6.35-7.94 | 4.29 | 0.71-0.98 |

S.R. – Silica ratio
A.R. – Alumina ratio

*Table 2: Average and range of pH data of analysed samples*

| | ROCK | | CLAYEY ZONE | | LATERITE | |
|---|---|---|---|---|---|---|
| PARENT ROCK TYPE | Mean | Range n=5 | Mean | Range n=5 | Mean | Range n=5 |
| Banded Gneiss | 8.5 | 8.4-8.5 | 6.2 | 6.0-6.4 | 6.7 | 6.5-6.8 |
| Quartz-muscovite schist | 7.5 | 7.1-7.8 | 5.9 | 5.6-6.5 | 6.9 | 6.7-7.1 |
| Pegmatite | 8.4 | 8.2-8.5 | 6.1 | 5.9-6.3 | 6.8 | 6.5-7.0 |

Table 3. Average chemical composition (wt.%) of quartz- muscovite schist weathering *profile in Ibadan area*

| | ROCK | | CLAYEY ZONE | | LATERITE | |
|---|---|---|---|---|---|---|
| OXIDES | Mean | Range n=5 | Mean | Range n=5 | Mean | Range n=5 |
| $SiO_2$ | 66.47 | 64.21-68.47 | 63.30 | 59.76-66.38 | 70.53 | 68.78-72.41 |
| $TiO_2$ | 1.26 | 1.07-1.65 | 1.55 | 1.32-1.72 | 1.67 | 1.54-1.82 |
| $Al_2O_3$ | 15.29 | 13.33-16.83 | 18.96 | 16.92-20.38 | 13.99 | 13.33-14.61 |
| $Fe_2O_{3(t)}$ | 4.88 | 3.01-6.75 | 5.49 | 16.92-20.38 | 5.17 | 4.76-5.90 |
| MnO | 0.17 | 0.09-0.24 | 0.06 | 3.62-7.76 | 0.07 | 0.04-0.09 |
| MgO | 1.46 | 1.20-1.82 | 0.30 | 0.19-0.38 | 0.30 | 0.14-0.43 |
| CaO | 2.31 | 1.78-2.68 | 0.07 | 0.05-0.09 | 0.04 | 0.03-0.05 |
| $Na_2O$ | 2.81 | 2.31-3.74 | 0.72 | 0.55-0.92 | 0.34 | 0.24-0.42 |
| $K_2O$ | 2.95 | 2.17-4.56 | 3.95 | 3.29-4.36 | 1.64 | 1.18-2.16 |
| $P_2O_5$ | 0.40 | 0.16-0.62 | 0.04 | 0.02-0.06 | 0.04 | 0.02-0.05 |
| LOI | 0.88 | 0.78-0.96 | 5.08 | 4.64-5.68 | 5.40 | 4.55-6.08 |
| **Total** | **98.88** | | **99.52** | | **99.19** | |
| Trace elements (ppm) | | | | | | |
| Co | 43 | 33-48 | 35 | 28-44 | 27 | 18-36 |
| Cr | 33 | 28-42 | 68 | 49-87 | 48 | 34-59 |
| Cu | 28 | 16-45 | 81 | 65-96 | 54 | 38-88 |
| Ni | 21 | 16-27 | 61 | 36-81 | 38 | 18-67 |
| Zn | 28 | 21-36 | 57 | 50-66 | 34 | 24-45 |
| Silica and alumina ratios (%) | | | | | | |
| S.R | 3.30 | 2.72-4.19 | 2.58 | 2.12-3.23 | 3.68 | 3.46-3.96 |
| A.R. | 3.13 | 2.50-4.43 | 3.45 | 2.63-4.67 | 2.70 | 2.4-2.84 |
| MgO+CaO | 3.77 | 2.98-4.14 | 0.37 | 0.25-0.45 | 0.35 | 0.18-0.46 |
| $Na_2O+K_2O$ | 5.76 | 4.82-6.87 | 4.67 | 3.96-4.76 | 1.98 | 1.53-2.58 |

S.R. – Silica ratio
A.R. – Alumina ratio

## Weathering Profile above Quartz-muscovite Schist

Results of the major and trace element contents of the quartz - muscovite schist and the overlying weathering profile at Boluwaji, Ibadan, are presented in Tables 3 and 6. The variation trends of the major oxides are illustrated in Fig. 10. The result shows that the laterite is enhanced in $SiO_2$ (70.53%) relative to the clayey zone (63.30%) and the rock (66.47%). $Fe_2O_3$ is slightly enriched in the clayey zone (5.49%) and the laterite (5.17%) compared to a mean value of 4.88% in the rock. Notable peaks of goethite are reflected on the X-ray traces (Figs. 5b and c). $Al_2O_3$ increases from 15.29% in the bedrock to 18.96% in the clayey zone due to the presence of kaolinite. A slight decrease of $Al_2O_3$ to 13.99% is noticed in the laterite zone. Average MgO contents are 1.46, 0.30 and 0.30% in the rock, the clayey zone and the laterite respectively. Corresponding values for CaO are 2.31, 0.07 and 0.04; while $Na_2O$ concentrations are 2.81, 0.72 and 0.34% (Table 3). These values indicate leaching of MgO, CaO and $Na_2O$. $TiO_2$ contents increase slightly from the parent rock to the laterite. $P_2O_5$ on the other hand diminishes from 0.40% in the rock to 0.04 in both the clayey and laterite zones (Table 6, Fig. 10).

The silica- sequioxide ratios (S.R) of the clayey and laterite, over quartz-muscovite schist, range from 2.58 to 3.68. The alumina-iron oxide ratios (A.R) range from 3.45 to 2.70 respectively. The relatively high S.R. and A.R. values suggest that true laterites are not produced by the weathering of quartzite and quartz-rich rocks (Aleva, 1994).

The concentrations of trace elements do not show any significant enrichment that could be attributed to mineralization. Co diminishes from the bedrock to the laterite zone. Though other trace elements, such as, Cr,Cu,Ni and Zn are enhanced in the clayey zone, they are, however, reduced in the laterite. Average Co contents in the rock, clayey zone and laterite are 43, 35 and 27ppm; Cr (33, 68 and 48ppm); Cu (28,81 and 54ppm); Ni (21, 61 and 38ppm); and Zn (28, 57 and 34ppm) (Table 3).

## Weathering Profile above Pegmatite

Tables 4, 7 and Fig. 11 give the average values and variation trends of elements along a pegmatite weathering profile at Toll Gate, Ibadan. $SiO_2$ shows a gradual decrease in concentration from the bedrock (68.55%) to the clayey zone (61.02%). The laterite horizon is however enriched in $SiO_2$ to about 70.30%. $Fe_2O_3$ also follows the same pattern, with the bedrock value of 1.06%; 0.60% for the clayey zone and 1.65%

Table 4: Average chemical compositions (wt%) of weathering profile above pegmatite in Ibadan area

| | ROCK | | CLAYEY ZONE | | LATERITE | |
|---|---|---|---|---|---|---|
| OXIDES | Mean | Range n=5 | Mean | Range n=5 | Mean | Range n=5 |
| $SiO_2$ | 68.55 | 67.34-69.48 | 61.02 | 60.00-63-23 | 70.30 | 68.91-72.12 |
| $TiO_2$ | 0.10 | 0.06-0.14 | 0.39 | 0.19-0.67 | 0.27 | 0.22-0.34 |
| $Al_2O_3$ | 18.24 | 16.62-19.66 | 21.27 | 20.31-23.14 | 17.52 | 15.85-19.69 |
| $Fe_2O_{3(t)}$ | 1.06 | 0.33-1.58 | 0.60 | 0.35-0.86 | 1.65 | 1.16-1.82 |
| MnO | 0.36 | 0.24-0.50 | 0.12 | 0.08-0.23 | 0.08 | 0.06-0.09 |
| MgO | 0.13 | 0.06-0.21 | 0.05 | 0.02-0.09 | 0.05 | 0.04-0.06 |
| CaO | 0.44 | 0.21-0.62 | 0.08 | 0.07-0.09 | 0.06 | 0.04-0.08 |
| $Na_2O$ | 2.46 | 2.04-2.78 | 0.51 | 0.27-0.72 | 0.23 | 0.15-0.42 |
| $K_2O$ | 7.15 | 6.26-8.30 | 3.04 | 1.21-5.21 | 0.44 | 0.20-0.62 |
| $P_2O_5$ | 0.34 | 0.18-0.44 | 0.14 | 0.09-0.26 | 0.05 | 0.03.0.07 |
| LOI | 0.36 | 0.20-0.51 | 12.49 | 10.76-14.66 | 9.07 | 8.21-9.98 |
| **Total** | **99.19** | | **99.71** | | **99.72** | |
| Trace elements (ppm) | | | | | | |
| Co | 36 | 33-39 | 46 | 40-55 | 20 | 8-34 |
| Cr | 38 | 26-62 | 37 | 21-56 | 49 | 30-70 |
| Cu | 41 | 30-56 | 45 | 29-62 | 43 | 25-66 |
| Ni | 46 | 33-62 | 51 | 39-68 | 40 | 22-50 |
| Zn | 19 | 20-31 | 36 | 20-49 | 28 | 21-39 |
| Silica and alumina ratios (%) | | | | | | |
| S.R | 3.55 | 3.41-3.80 | 2.79 | 2.53-3.04 | 3.67 | 3.20-4.08 |
| A.R. | 17.21 | 10.52-59.58 | 35.45 | 24.19-58.86 | 10.62 | 8.71-15.87 |
| MgO+CaO | 0.57 | 0.34-0.77 | 0.13 | 0.10-0.16 | 0.11 | 0.08-0.13 |
| $Na_2O+K_2O$ | 9.61 | 8.80-10.70 | 3.55 | 1.48-5.93 | 0.67 | 0.35-1.04 |

S.R. – Silica ratio
A.R. – Alumina ratio

Table 5: Detailed chemical compositions (%) of weathering profile over banded gneiss in Ibadan area.

| | ROCK (OUTCROP) | | | | | CLAYEY ZONE | | | | | LATERITE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH | | | | | | 5.0m | 4.5m | 4.0m | 3.5m | 3.0m | 2.5m | 2.0m | 1.5m | 1.0m | 0.5m |
| Sample | BG/15 | BG/14 | BG/13 | BG/12 | BG/11 | BG/10 | BG/9 | BG/8 | BG/7 | BG/6 | BG/5 | BG/4 | BG/3 | BG/2 | BG/1 |
| $SiO_2$ | 66.56 | 64.82 | 65.36 | 66.19 | 67.38 | 52.02 | 55.50 | 53.64 | 52.10 | 53.77 | 56.92 | 58.79 | 57.40 | 54.18 | 55.21 |
| $TiO_2$ | 0.26 | 0.35 | 0.28 | 0.27 | 0.25 | 0.34 | 0.31 | 0.39 | 0.38 | 0.46 | 0.51 | 0.74 | 0.57 | 0.55 | 0.64 |
| $Al_2O_3$ | 12.34 | 13.46 | 12.15 | 11.88 | 14.26 | 23.51 | 25.11 | 19.26 | 22.46 | 13.62 | 20.50 | 18.33 | 19.46 | 21.98 | 18.77 |
| $Fe_2O_{3(t)}$ | 3.06 | 2.53 | 3.68 | 2.73 | 2.54 | 6.25 | 5.23 | 5.28 | 4.93 | 4.92 | 7.46 | 5.39 | 6.68 | 5.72 | 8.31 |
| MnO | 0.13 | 0.04 | 0.12 | 0.12 | 0.11 | 0.05 | 0.06 | 0.08 | 0.04 | 0.07 | 0.15 | 0.18 | 0.20 | 0.16 | 0.19 |
| MgO | 1.18 | 1.05 | 1.08 | 1.07 | 1.16 | 0.18 | 0.19 | 0.16 | 0.12 | 0.10 | 0.24 | 0.20 | 0.31 | 0.46 | 0.35 |
| CaO | 4.42 | 6.30 | 5.87 | 4.91 | 5.15 | 0.92 | 0.48 | 0.74 | 0.56 | 0.55 | 0.65 | 0.68 | 0.47 | 0.52 | 0.36 |
| $Na_2O$ | 6.10 | 5.36 | 4.92 | 6.05 | 4.01 | 2.14 | 2.14 | 2.16 | 2.15 | 2.13 | 0.20 | 0.29 | 0.74 | 0.73 | 0.46 |
| $K_2O$ | 4.66 | 3.74 | 5.23 | 5.12 | 3.33 | 5.06 | 4.21 | 5.78 | 5.65 | 5.00 | 3.25 | 4.76 | 3.24 | 3.29 | 4.52 |
| $P_2O_5$ | 0.26 | 0.30 | 0.30 | 0.20 | 0.40 | 0.24 | 0.12 | 0.10 | 0.13 | 0.08 | 0.21 | 0.24 | 0.38 | 0.25 | 0.20 |
| LOI | 0.62 | 0.57 | 0.46 | 0.63 | 0.51 | 9.23 | 6.58 | 11.37 | 10.52 | 8.32 | 9.46 | 10.25 | 10.55 | 12.16 | 10.44 |
| Total | **99.59** | **98.52** | **99.45** | **99.17** | **99.10** | **99.94** | **99.93** | **98.96** | **99.04** | **99.02** | **99.55** | **99.85** | **100.00** | **100.00** | **99.45** |
| Trace elements (ppm) | | | | | | | | | | | | | | | |
| Co | 15 | 19 | 21 | 23 | 20 | 54 | 66 | 42 | 38 | 45 | 22 | 39 | 27 | 18 | 20 |
| Cr | 20 | 16 | 14 | 19 | 22 | 57 | 48 | 61 | 55 | 33 | 31 | 42 | 39 | 26 | 32 |
| Cu | 21 | 18 | 15 | 13 | 35 | 48 | 52 | 44 | 49 | 51 | 38 | 36 | 24 | 18 | 16 |
| Ni | 18 | 20 | 16 | 25 | 32 | 60 | 85 | 100 | 76 | 54 | 42 | 33 | 25 | 44 | 27 |
| Zn | 43 | 35 | 48 | 40 | 29 | 73 | 68 | 87 | 45 | 63 | 29 | 52 | 48 | 31 | 33 |

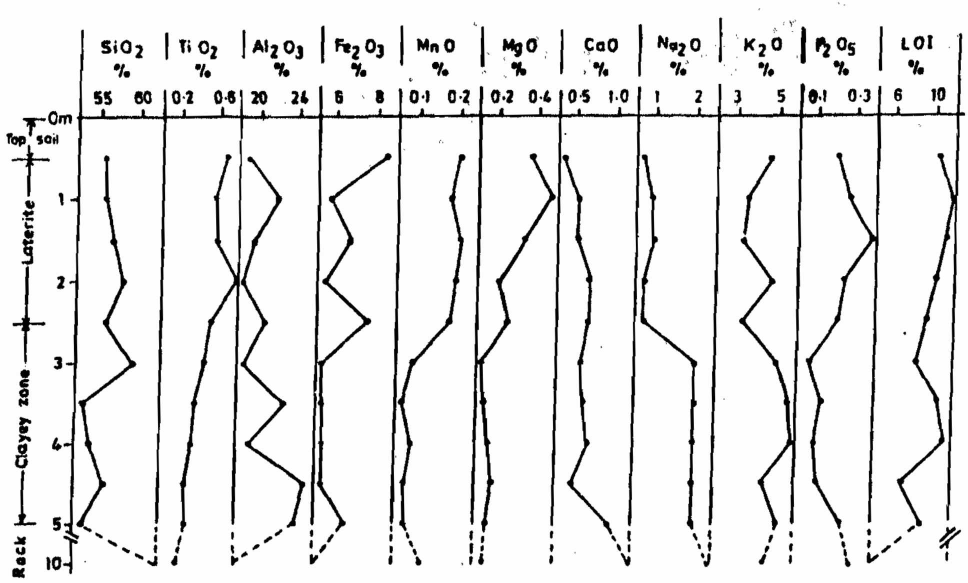


***Fig. 9: Chemical variation along the weathering profile over banded gneiss of Ibadan area.***

Table 6: Detailed chemical composition (%) of weathering profile over quartz-muscovite schist in Ibadan area.

| | ROCK | | | | | CLAYEY ZONE | | | | | LATERITE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH | 10.0m | 9.5m | 9.0m | 8.5m | 8.0m | 7.0m | 6.0m | 5.0m | 4.5m | 3.0m | 2.5m | 2.0m | 1.5m | 1.0m | 0.5m |
| Sample | QS/15 | QS/14 | QS/13 | QS/12 | QS/11 | QS/10 | QS/9 | QS/8 | QS/7 | QS/6 | QS/5 | QS/4 | QS/3 | QS/2 | QS/1 |
| $SiO_2$ | 67.68 | 64.21 | 65.83 | 68.47 | 66.15 | 66.38 | 65.21 | 59.76 | 63.31 | 61.82 | 70.23 | 71.74 | 72.41 | 68.78 | 69.50 |
| $TiO_2$ | 1.07 | 1.19 | 1.32 | 1.65 | 1.08 | 1.47 | 1.32 | 1.72 | 1.69 | 1.53 | 1.65 | 1.82 | 1.54 | 1.70 | 1.63 |
| $Al_2O_3$ | 15.62 | 16.83 | 15.94 | 13.33 | 14.75 | 16.92 | 18.39 | 20.38 | 19.67 | 19.45 | 14.21 | 13.33 | 13.54 | 14.61 | 14.24 |
| $Fe_2O_{3(t)}$ | 4.28 | 6.75 | 4.68 | 3.01 | 5.67 | 3.62 | 4.23 | 7.76 | 5.56 | 6.29 | 5.06 | 4.69 | 4.76 | 5.24 | 5.90 |
| MnO | 0.13 | 0.9 | 0.21 | 0.19 | 0.24 | 0.06 | 0.08 | 0.05 | 0.07 | 0.04 | 0.08 | 0.06 | 0.04 | 0.09 | 0.07 |
| MgO | 1.46 | 1.23 | 1.57 | 1.82 | 1.20 | 0.29 | 0.36 | 0.28 | 0.38 | 0.19 | 0.26 | 0.38 | 0.14 | 0.29 | 0.43 |
| CaO | 2.68 | 2.63 | 2.38 | 2.10 | 1.78 | 0.09 | 0.06 | 0.05 | 0.07 | 0.06 | 0.05 | 0.05 | 0.04 | 0.04 | 0.03 |
| $Na_2O$ | 2.45 | 2.65 | 2.89 | 3.74 | 2.31 | 0.80 | 0.64 | 0.92 | 0.67 | 0.55 | 0.42 | 0.35 | 0.24 | 0.40 | 0.29 |
| $K_2O$ | 2.43 | 2.17 | 3.10 | 2.48 | 4.56 | 3.96 | 4.28 | 3.84 | 3.29 | 4.36 | 2.16 | 1.18 | 1.74 | 1.50 | 1.62 |
| $P_2O_5$ | 0.57 | 0.16 | 0.29 | 0.62 | 0.37 | 0.05 | 0.06 | 0.04 | 0.02 | 0.03 | 0.03 | 0.04 | 0.05 | 0.02 | 0.04 |
| LOI | 0.92 | 0.84 | 0.96 | 0.78 | 0.39 | 5.68 | 5.05 | 4.72 | 4.64 | 5.29 | 6.08 | 4.32 | 4.55 | 6.21 | 5.35 |
| **Total** | **99.29** | **98.75** | **99.17** | **98.19** | **99.00** | **99.32** | **99.68** | **99.52** | **99.37** | **99.61** | **100.23** | **98.68** | **99.05** | **98.87** | **99.10** |
| Trace elements (ppm) | | | | | | | | | | | | | | | |
| Co | 42 | 45 | 48 | 33 | 45 | 32 | 38 | 31 | 44 | 28 | 34 | 36 | 23 | 18 | 26 |
| Cr | 28 | 30 | 36 | 42 | [illegible] | 76 | 49 | 87 | 68 | 60 | 55 | 59 | 47 | 34 | 45 |
| Cu | 16 | 24 | 32 | 23 | 45 | 65 | 72 | 76 | 94 | 96 | 88 | 64 | 38 | 41 | 39 |
| Ni | 21 | 27 | 18 | 25 | 15 | 36 | 81 | 49 | 67 | 74 | 67 | 52 | 26 | 25 | 18 |
| Zn | 36 | 31 | 22 | 21 | 30 | 51 | 66 | 50 | 55 | 62 | 29 | 38 | 45 | 33 | 24 |

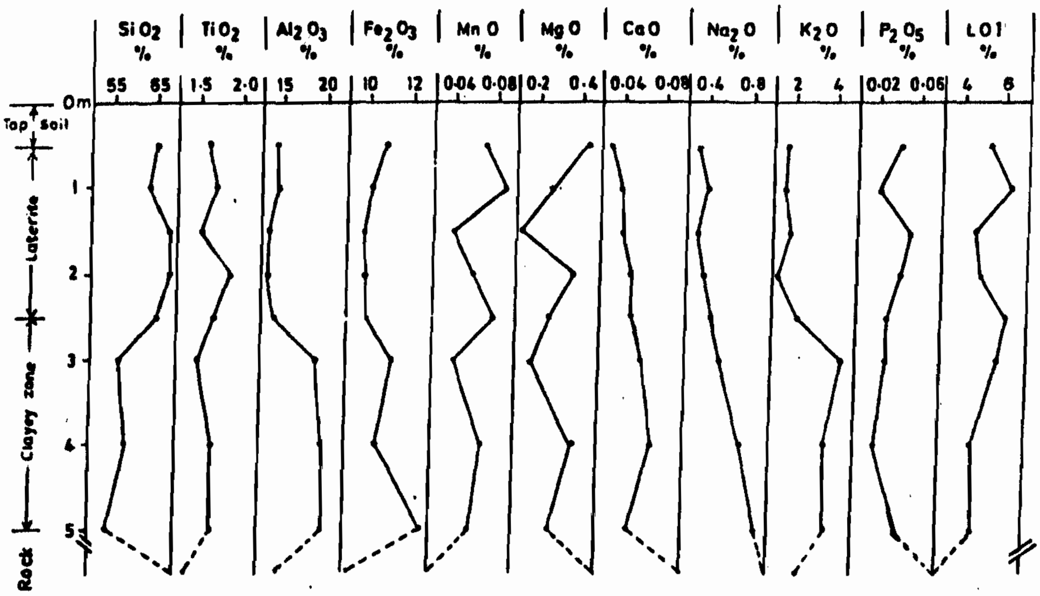


***Fig. 10: Chemical variation along the weathering profile over quartz-muscovite schist of Ibadan area.***

for the laterite. Enhancement in the value of $Al_2O_3$ from 18.24% in the parent rock to 21.27% in the clayey zone is diminished to 17.52% in the laterite. $TiO_2$ and the loss on ignition show a similar trend. The $TiO_2$ contents of the parent rock increase from 0.10% in the parent rock, to 0.39% in the clayey zone and 0.27% in the laterite. MnO, CaO, $Na_2O$, $K_2O$ and $P_2O_5$ show very strong reduction from the bedrock to the topsoil (Fig. 11). The corresponding concentrations in the rock, clayey zone and laterite for these elements are MnO, 0.36, 0.12 and 0.08; CaO, 0.44, 0.08 and 0.06%; $Na_2O$, 2.46, 0.51 and 0.23%; $K_2O$, 7.15, 3.04 and 0.44%; and $P_2O_5$, 0.34, 0.14 and 0.05% (Table 4). Co, Cr, Cu, Ni and Zn concentrations are generally less than 52ppm in the weathering profile. The pH of the rock is about 8.4, the clayey zone 6.8 and the laterite 6.1 (Table 2). This shows a consistent increase in acidity and intensity of weathering from the bedrock to the laterite.

## DISCUSSION

Chemical decomposition of the rock forming minerals in the basement rocks of Ibadan area produces mainly kaolinite. Illite and halloysite components are in small amounts. The kaolinite is from the alteration of feldspars, which is a major mineral in the banded gneiss, quartz-muscovite schist and pegmatite. Fe-minerals, notably goethite, hematite and limonite are from the decomposition of biotite and hornblende in the banded gneiss. The presence of biotite in the laterite may be attributed to the incipient stage of chemical weathering since biotite is altered to vermiculite, smectite or kaolinite at advanced stage of weathering (Norton, 1973). The quartz-rich muscovite schists and pegmatite weathering profiles possess simpler mineralogy compared to the profiles on the banded gneiss.

On the basis of the chemical data, the weathering

Table 7: Detailed chemical composition (%) of residual profile over pegmatite in Ibadan area.

| | ROCK (OUTCROP) | | | | | CLAYEY ZONE | | | | | LATERITE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH | | | | | | 6.0m | 5.0m | 4.0m | 3.0m | 2.0m | 1.0m | 0.8m | 0.6m | 0.4m | 0.2m |
| Sample | P/15 | P/14 | P/13 | P/12 | P/11 | P/10 | P/9 | P/8 | P/7 | P/6 | P/5 | P/4 | P/3 | P/2 | P/1 |
| $SiO_2$ | 68.85 | 67.34 | 69.16 | 69.48 | 67.90 | 60.48 | 61.04 | 60.00 | 60.34 | 63.23 | 69.15 | 68.91 | 70.00 | 72.12 | 71.31 |
| $TiO_2$ | 0.13 | 0.06 | 0.09 | 0.14 | 0.03 | 0.38 | 0.32 | 0.19 | 0.41 | 0.67 | 0.24 | 0.34 | 0.22 | 0.28 | 0.28 |
| $Al_2O_3$ | 18.24 | 18.38 | 16.62 | 18.29 | 19.56 | 20.80 | 21.51 | 23.14 | 20.60 | 20.31 | 18.41 | 19.69 | 17.34 | 15.85 | 16.21 |
| $Fe_2O_{3(t)}$ | 1.07 | 1.37 | 1.58 | 0.94 | 0.33 | 0.86 | 0.79 | 0.55 | 0.35 | 0.46 | 1.16 | 1.82 | 1.67 | 1.28 | 1.79 |
| MnO | 0.24 | 0.35 | 0.46 | 0.50 | 0.25 | 0.23 | 0.12 | 0.09 | 0.08 | 0.10 | 0.07 | 0.09 | 0.10 | 0.08 | 0.06 |
| MgO | 0.21 | 0.08 | 0.06 | 0.13 | 0.15 | 0.05 | 0.04 | 0.02 | 0.09 | 0.06 | 0.05 | 0.05 | 0.04 | 0.06 | 0.04 |
| CaO | 0.55 | 0.43 | 0.38 | 0.21 | 0.62 | 0.08 | 0.09 | 0.08 | 0.07 | 0.09 | 0.07 | 0.08 | 0.06 | 0.05 | 0.04 |
| $Na_2O$ | 2.18 | 2.04 | 2.78 | 2.54 | 2.77 | 0.72 | 0.64 | 0.55 | 0.38 | 0.27 | 0.18 | 0.42 | 0.16 | 0.23 | 0.15 |
| $K_2O$ | 6.93 | 8.30 | 7.92 | 6.26 | 6.35 | 5.21 | 3.65 | 3.14 | 2.00 | 1.21 | 0.55 | 0.62 | 0.38 | 0.45 | 0.20 |
| $P_2O_5$ | 0.42 | 0.18 | 0.26 | 0.38 | 0.44 | 0.12 | 0.26 | 0.10 | 0.14 | 0.09 | 0.06 | 0.05 | 0.07 | 0.03 | 0.04 |
| LOI | 0.38 | 0.47 | 0.25 | 0.51 | 0.20 | 10.75 | 11.44 | 12.08 | 14.66 | 13.50 | 9.24 | 8.21 | 9.98 | 8.58 | 9.36 |
| **Total** | **99.20** | **99.00** | **99.56** | **99.38** | **99.76** | **99.70** | **99.90** | **99.94** | **99.93** | **99.99** | **99.18** | **100.28** | **100.02** | **99.55** | **99.56** |
| Trace elements (ppm) | | | | | | | | | | | | | | | |
| Co | 33 | 35 | 38 | 36 | 39 | 42 | 40 | 55 | 43 | 44 | 34 | 28 | 16 | 8 | 12 |
| Cr | 34 | 42 | 26 | 52 | 27 | 56 | 32 | 49 | 21 | 26 | 70 | 61 | 38 | 46 | 30 |
| Cu | 30 | 44 | 33 | 40 | 56 | 35 | 54 | 62 | 46 | 29 | 28 | 39 | 66 | 58 | 25 |
| Ni | 62 | 40 | 54 | 33 | 41 | 68 | 50 | 39 | 52 | 44 | 35 | 50 | 22 | 48 | 46 |
| Zn | 22 | 31 | 30 | 24 | 20 | 33 | 49 | 35 | 42 | 20 | 26 | 31 | 39 | 25 | 21 |

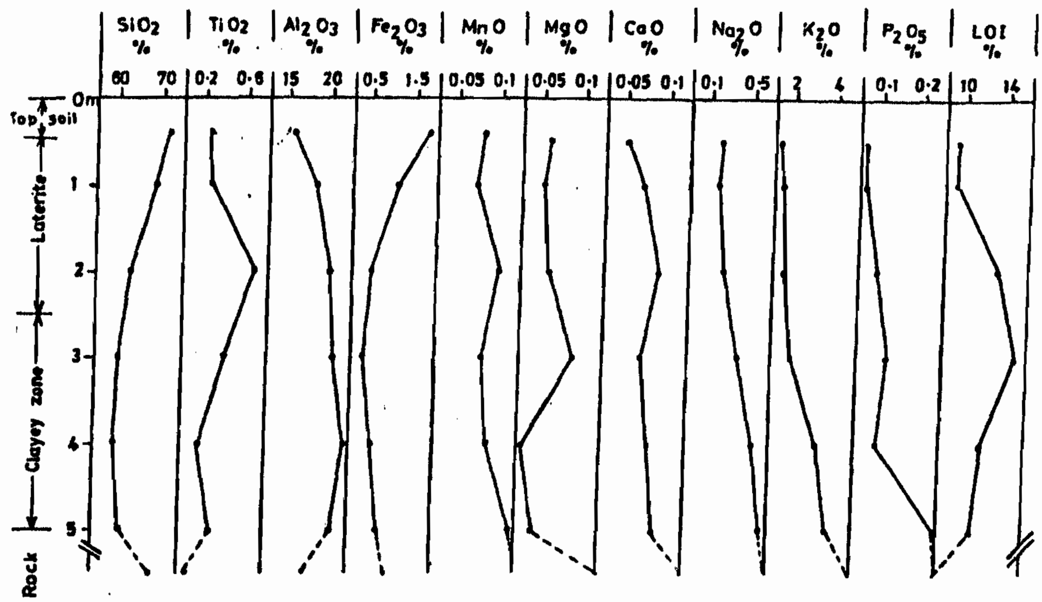


*Fig. 11: Chemical variation along the weathering profile over pegmatite of Ibadan area.*

profiles could be distinguished into three major zones, namely, the $Fe_2O_3$-rich laterite zone below the topsoil, the $Al_2O_3$-rich clayey zone below the laterite and the parent rock. The transitional horizon (saprolite), between the clayey-zone and the bedrock was not encountered in any of the profiles, due to deep weathering of rocks in the area.

The $Fe_2O_3$ rich laterite is low in $Na_2O$, $K_2O$, CaO and MgO, due to the removal of the alkaline and the alkaline earth elements through leaching of the topsoil and the laterite. $Al_2O_3$ is strongly enriched in the clayey zone below the laterite. $TiO_2$ increases from the bedrock upward to the laterite zone. Studies by Bolarinwa and Elueze (2005) have shown that $TiO_2$ is mainly present as leucoxene and anatase in the weathered profiles of gneisses, around Abeokuta.

The concentrations of the major elements correspond with the mineralogical data. Al is present mainly in kaolinite and muscovite. Fe occurs in goethite and hematite. Si occurs abundantly in quartz. It is also present in kaolinite. K occurs mainly in muscovite, particularly, at the incipient state of weathering of rocks. The laterite horizons of the weathered quartz-muscovite schist and pegmatite are dominated by about 70% $SiO_2$. This is probably due to the dissolution of kaolinite from the laterite, leaving behind quartz grains, which are subsequently cemented together by amorphous silica and aluminosilicates.

## CONCLUSIONS

In Ibadan area of southwestern Nigeria, the average thickness of weathering profiles over the basement rocks range between 5 and 30m. Exposures of vertical profiles along road cuts in the area distinguish three major horizons in the profiles over the basement rocks. The variations in colour, texture and composition of the various zones within the profiles depend on the parent rock and the prevailing chemical environmental conditions. Transition between the zones is gradual, while in some cases the weathering products preserve the textural and structural features of the bedrock.

Petrographic and X-ray diffraction studies of lateritic profiles over banded gneiss, quartz-muscovite schist and pegmatite of Ibadan area, have shown that the main mineral phase in the clayey zone and the overlying laterite above these rock bodies is kaolinite. Other clay minerals present include illite and halloysite. Minor components are zircon and titanium minerals such as anatase, rutile, ilmenite and leucoxene.

Chemical studies of lateritic profiles over banded gneiss, quartz-muscovite schist and pegmatite of Ibadan area show that $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ constitute the major oxides of the residual weathering products. Iron oxides, mainly goethite with subordinate hematite and limonite are present in the laterite horizon, whereas bauxite minerals such as gibbsite, boehmite and diaspore are absent in the profile. This shows that the trend of weathering is towards iron enrichment (ferralitization) rather than aluminium accumulation (bauxitization) (Aleva, 1994).

**ACKNOWLEDGEMENTS**

The author is grateful to Professors T.R. Ajayi and V.O. Olarewaju for permission to use their Departmental laboratory facilities. He is also indebted to Dr. A.A. Oladipo and Prof. (Dr.) Arno Mucke for technical support. The comments and suggestions of the anonymous reviewers, which helped immensely in making the views of the author clearer, are highly appreciated. Aspects of this investigation were financially supported by the University of Ibadan Senate Research Grant No. SRG/FSC/2000/11A.

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