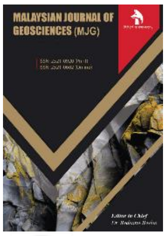
ZIBELINE INTERNATIONAL PUBLISHING

Malaysian Journal of Geosciences (MJG)

DOI: http://doi.org/10.26480/mjg.02.2020.59.64

ISSN: 2521-0920 (Print)
ISSN: 2521-0602 (Online)
CODEN: MJGAAN



RESEARCH ARTICLE

MOBILITY AND REDISTRIBUTION OF MAJOR ELEMENTS IN WEATHERED PROFILE DEVELOPED ON PEGMATITE AT KITIBI-IWOYE, SOUTHWESTERN NIGERIA

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ARTICLE DETAILS

Article History:

Received 11 February 2020
Accepted 13 March 2020
Available online 10 April 2020

ABSTRACT

Geochemical studies of weathering profiles around Kitibi-Iwoye revealed redistribution of elements from parental pegmatite to the regolith. Geological mapping showed that the pegmatite intrudes diorite and migmatite gneiss. Weathered samples from B-horizon were air-dried, pulverised and analysed using X-ray Fluorescence Spectrometry (XRF) in the Department of Geological Sciences, University of Cape Town, South Africa. Chemical Index of Alteration (CIA), Weathering Index of Parker (WIP), Mass balance calculation and Al_2O_3 – CaO+Na_2O – K_2O (A–CN–K) ternary plot were employed to determine elemental mobility and distribution caused by weathering. SiO_2 (74.2 and 43.4 wt %), CaO (0.43 and 0.03 wt. %), Na_2O (7.14 and 0.04 wt. %), K_2O (1.90 and 0.67 wt. %), MnO (0.11 and 0.03 wt. %) and P_2O_5 (0.20 and 0.05wt. %) displayed depletion from parent rock to the regolith respectively. But Al_2O_3 (15.5 wt. % and 33.5 wt. %), Fe_2O_3 (0.39 and 3.40 wt. %), TiO_2 (0.04 and 0.35 wt. %) and MgO (0.08 and 0.11 wt. %) showed enrichment from parent rock to the regolith respectively. Fe_2O_3 (3.19) is the most enriched whereas Na_2O (-99.8), CaO (-98.9), P_2O_5 (-95.3), K_2O (-89.5), SiO_2 (-81.9), MgO (-73.1), MnO (-64.5) and Al_2O_3 (-23.6) are progressively depleted. Mean CIA value of 97.8 revealed that weathering has almost reached its completion whereas CIA of 62.1 for the pegmatite suggested that the parent rock is at incipient stage of weathering. Pegmatite had a WIP of 110.5 whereas the weathered samples with WIP ranging from 2.66, 3.88, 6.03, 6.23, 6.92, 8.08, 9.08, 9.76 and 14.6 respectively showed decreasing trend of weathering. This study confirmed contrasting behaviour of CIA and WIP. A-CN-K diagram suggested strongly weathered samples plotted at the apex of Al_2O_3 field whereas pegmatite plots along the A-CN line.

KEYWORDS

Weathering profile, Pegmatite, B-horizon, Mass balance, Parent rock.

1. INTRODUCTION

Mobility of elements in a particular geological setting is mostly triggered by chemical reactions within a rock body after its crystallisation. These reactions often occur when the rock mass interacts with an invading fluid (Rollinson, 1993). There is direct relationship between mobility and redistribution of elements in rock alteration processes. Cramer and Nesbitt noted that redistribution of elements is dependent on the mobility of these elements during the interaction of rock with meteoric or connate water (Cramer and Nesbitt, 1983). Natural processes such as weathering, water-rock interaction, hydrothermal alteration, groundwater mixing, evolution and magmatic crystallisation can disrupt the pattern of mobility and fractionation of elements (Yusoff et al., 2013).

Such elemental mobility and fractionation (redistribution) provide a veritable tool for comprehending processes that lead to the formation of weathered products and their abundance. These processes are directly influenced by climatic and geomorphological conditions of tropical region (Voicu et al., 1997). The redistribution of elements in rock profile is strongly controlled by the interaction between water, minerals, oxidizing environments and organic acids, so weathering in the soil and unsaturated zone above the groundwater table may be faster than below the groundwater table. This interaction will be more influential on less stable and less resistant minerals, causing them to leach elements (Harnois, 1988).

Pegmatites are important sources of economic minerals such as tourmaline, beryl, tantalite and kaolin which are extracted from weathered pegmatite during mining. In recent times there has been renewed interest in the study of pegmatites globally because of their attractive economic potentials (Adekeye and Akintola, 2007; Garba, 2003; Price and Velbel, 2003. Alteration of high temperature phyllosilicates such as muscovite and biotite into clay minerals follows a different pattern with that of plagioclase and alkali feldspar (Velde and Meunier, 2008). Transformation trend in phyllosilicates proceeds in steps because of strong similarity in the structure of unstable primary phase and newly formed secondary minerals. Major and trace elements hosted by rock forming minerals are mostly liberated during chemical weathering (Van der Weijden and Van der Weijden, 1995). Their mobilization and redistribution during weathering is particularly complicated because

Quick Response Code	Access this article online	
	Website: www.myjgeosc.com	**DOI:** 10.26480/mjg.02.2020.59.64

Cite the Article: Jimoh, M.T., Bolarinwa, A.T, T. O. Kolawole (2020). Mobility And Redistribution Of Major Elements In Weathered Profile Developed On Pegmatite At Kitibi-Iwoye, Southwestern Nigeria. *Malaysian Journal of Geosciences, 4(2): 59-64.*

these elements are affected by various processes such as dissolution of primary minerals, formation of secondary phases, redox processes, transportation of materials, co-precipitation and ion exchange of various minerals (Islam et al., 2002; White et al., 2000). Direct evidence of past weathering conditions can be obtained from weathered soil through combination of field observation, petrography, X-ray Diffractometry and whole rock (Bahlburg and Dobrzingki, 2009). Saprolite retained original composition and texture of the pegmatite in some parts of the profiles. It was noted that saprolites are open system as they are easily affected by vegetation, rainfall, soil processes and oxygen (Nesbitt and Young, 1982). This research is targeted at studying geochemistry of weathered profile developed on pegmatites at Kitibi-Iwoye and Awo mining sites. Proportion of each major element present in the profile will be revealed. Issues pertaining to mobilization and redistribution of the elements in the source rock and overlying regolith caused by weathering are also addressed. Various indices such as mass balance model, chemical index of alteration, weathering index of parker and Al2O3 – CaO+Na2O – K2O (A–CN–K) ternary diagrams were employed to interpret rate of weathering processes. The Chemical Index of Alteration (CIA) proposed and the Weathering Index of Parker (WIP) which was first introduced and developed are the two most commonly applied indices (Nesbitt and Young, 1982; Parker, 1970; Hamdan and Burnham, 1996).

1.1 Local Geology and Description of Weathering Profiles

The study areas (Kitibi-Iwoye and Awo) are located within the Precambrian basement complex of southwestern Nigeria. Vegetation of the study area shows a transition from humid tropical forest to savannah woodland. The geomorphological and topographical features revealed that the study area had suffered various degrees of weathering which had transformed the underlying bedrock into weathered saprolites of varying depth and thickness.Various rock types identified in the area are migmatite gneiss, biotite gneiss, banded gneiss, diorite, granodiorite, granite, and pegmatite (Figure 1).

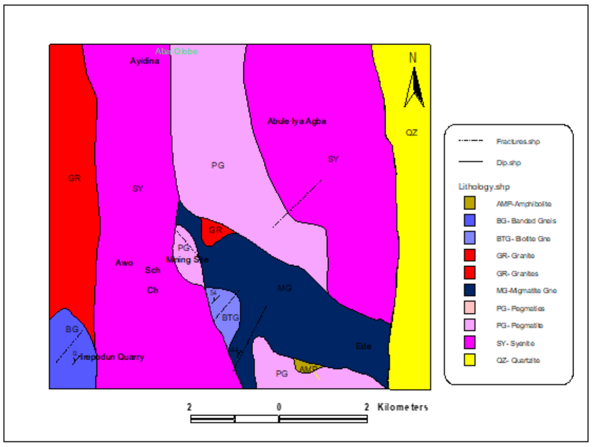

Figure 1: Geological Map of the study area

Pegmatite is the predominant rock type which intrudes older lithology such as migmatite gneiss. In some places, their veins occur as cross-cutting discordant dykes in rock units such as migmatite, banded gneisses and diorite. These dykes and veins range from few centimeters to tens of meters. Most of the pegmatite bodies seldom exceed 200-300 m in length, 1-2 m wide and suffer varying degree of tropical weathering. Hand specimen examination of un-weathered samples showed coarse grained microcline and plagioclase, quartz, muscovite and biotite as the major constituent minerals whereas accessory minerals such as zircon, apatite, magnetite, tourmaline and beryl occur in varying proportion (Figure 2).

Figure 2: Garnet-bearing pegmatite at Kitibi-Iwoye showing extremely coarse crystal of feldspar

Pegmatites within the vicinity of the mining site have been deeply weathered revealing the resistant, fractured quartz. Evidence of weathering is noticeable as the less resistant feldspars display variegated colours which is between red and off-white. The weathering profiles are located on a gently sloping hill of about 300 m above the sea level, the depth of the profiles ranges from about 12m at the center of the hilltop to 3m at the edge of the hill. There are numerous drilling pits where various economic minerals have been worked. The top soil (20-50 cm deep) which consists of unconsolidated humic and soil materials have been grossly disturbed by farming and indiscriminate piling up of mine tailings. This layer is directly underlain by gravelly lateritic layer of about 40-65 cm. The gravelly materials have sharp abraded edges with sizes ranging from 1-5 cm. Saprolite developed over the bedrock consists of disoriented mixture of white to light gray weathered materials which are soft, wet and friable. The samples are gritty to touch due to presence of detrital quartz. Relicts of primary constituent minerals such as quartz, feldspar and muscovite are conspicuous at the boundary between the regolith and underlain bedrock (Figure 3). The weathering profile of the study area which is directly underlain by pegmatite has been considerably altered through interaction between solution, rock and their weathering residues.

Figure 3: Weathered profile at a road section along Iwo-Oshogbo road

1.2 Mineralogical Composition of the Pegmatite and weathered materials

Detailed information on the mineralogy of pegmatite and weathered materials around Kitibi-Iwoye was provided (Jimoh et al., 2016). The pegmatite consists of quartz, feldspar, muscovite, biotite, opaques and accessory minerals such as tourmaline and beryl. X-ray diffraction patterns of quartz- feldspar- muscovite-rich pegmatite further identified albite, anorthite, microcline, quartz, muscovite ± biotite and accessory minerals (Figure 4). Phases such as kaolinite, illite, quartz, phlogopite, muscovite and goethite were present in the weathered mass.

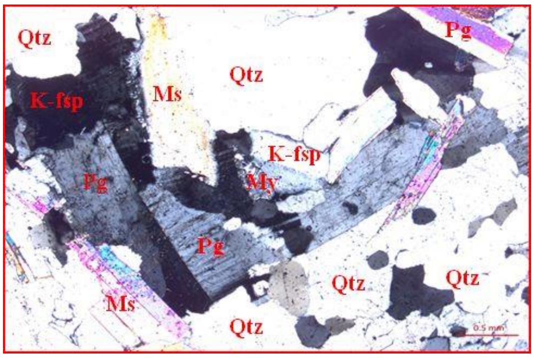

Figure 4: Photomicrograph of pegmatite showing quartz (Qtz), muscovite (Ms), myrmekite (My) wrapped within K-feldspar (K-fsp) and plagioclase (Pg), and Cross polars, x2.5

2. METHODOLOGY

2.1 Sampling and Sample Preparation

Pegmatite within the precincts of the mining site were sampled and studied for its geological and textural features. In the laboratory, representative samples were crushed in a jaw- crusher with tungsten carbide jaw blades and subsequently pulverised in a tungsten carbide ball-mill. Samples of the pulverised rock were thoroughly mixed in a Turbula mixer and aliquots of these samples were used for chemical analyses.

Weathered materials developed as regolith on the pegmatite were preferably collected at designated depths of horizons B (3.5-5.0 m) and C (6.0-6.5 m) using hand auger. Samples were collected from these horizons because they contain chemically altered rock materials with identifiable textural features of its parental pegmatitic protolith. The weathered profiles are derived from the same parental source but at different topographic positions of the study area. Changes in depth, structure, textural distribution, colour, grain types and arrangements of the dried samples were examined. The feldspathic components of the horizons have suffered certain degrees of weathering whereas muscovite and quartz components are relatively resistant. The samples were packed into various cellophane bags and air dried at the base camp. The samples were also pulverized prior to chemical analyses.

2.2 Laboratory Techniques and Chemical Analyses

Chemical analyses of major elements such as Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K and P were done by X-ray Fluorescence Spectrometry (XRF) in the laboratory of Department of Geological Sciences, University of Cape Town, South Africa. 2 g of pulverized rock and weathered samples were weighed and put in the oven at 110˚C for at least 4 hours. Upon cooling, the samples were weighed and roasted in a furnace overnight at 850˚C to drive off excess moisture content and to convert all Fe in the samples to Fe_2O_3, hence Fe does not occur as total Fe but as Fe_2O_3. The samples were homogenized by measuring 0.7 g of the samples from 2 g of dried samples into glass discs and 6 g of X-ray flux was added to reduce the temperature at which the samples melt for homogenization to complete. The samples were thereafter fused in a gas fusion chamber (Model: CLAISSE-M4 GAS FUSION) which contains platinum crucibles. The X-ray flux contains 35.3% lithium tetraborate ($Li_2B_4O_7$) and 64.7% lithium metaborate ($LiBO_2$). Lithium bromide (LiBr) was also added to release the fused discs from the platinum crucible in the gas fusion chamber. The operational settings for the XRF spectrometry was set at 4 kW, 60 kV (160 mA).

2.3 Data Evaluation and Assessment

Data obtained were evaluated using mass balance evaluation, chemical index of alteration (CIA), Weathering index of Parker (WIP) and A-CN-K ternary plot.

2.3.1 *Mass Balance Model*

Mass balance model is the percentage loss or gain in the concentration of weathered samples in each element compared with its concentration in the parent rock. In order to determine the extent of weathering, values of weathered samples and the parent rock were compared using mass balance equation (Cramer and Nesbitt, 1983). Mass balance equation was used to evaluate distribution of elements during supergene weathering. The equation is represented by:

$$\textbf{\% (loss or gain)} = \left(\left(\frac{X_A}{X_B}\right) \Big/ \left(\frac{Y_A}{Y_B}\right)\right) - 1 * 100 \text{ Eqn 1}$$

Where X_A is concentration of element X in weathered sample and X_B is concentration of element X in parent rock.

Y_A is concentration of immobile element Y in weathered sample and Y_B is concentration of immobile element Y in parent rock.

A group researchers observed that immobile elements are either accumulated within the residual phases or adsorbed by newly formed secondary minerals (Eggleton and Buseck, 1980). It was further noted that Ca, Na, P, K, Si, Ba, Rb, Mg, Pb, Ni, Zn, Cr and Co are mobile elements that are products of minerals such as feldspars, micas and apatite that are susceptible to weathering. Mobile and immobile elements are geochemically distributed throughout the regolith during weathering (Tijani et al., 2006).

Low concentration of elements or concentration below detection limits in parent rocks posed difficulties in choosing the immobile element to be used in the calculation of percentage loss or gain. Following the approach, Ti was the preferred immobile element because of its availability in all igneous rocks in concentrations at wt. % levels (Cramer and Nesbitt, 1983). Other elements are present at concentration (ppm or ppb levels) near to their detection limits in the parent materials.

2.3.2 *Chemical Index of Alteration*

Chemical Index of Alteration (CIA) is a measure of the extent of feldspars alteration to clays it is the most widely applied and most indicative of the available weathering indices (Rollinson, 1993; Nesbitt and Young, 1984; Nesbitt and Young, 1989). It represents a ratio of predominantly immobile Al_2O_3 to the mobile cations Na^+, K^+ and Ca^{2+} given as oxides (Bahlburg and Dobrzinski, 2009). According to a study, CIA is represented by the molecular proportions of (Nesbitt and Young, 1989).

$$\text{CIA} = \left({}^{A}\!/_{A + C + N + K}\right) * 100 \ldots \text{Eqn 2}$$

Where A = Al_2O_3, C = CaO, N = Na_2O and K = K_2O

2.3.3 *Weathering Index of Parker*

Weathering index of Parker (WIP) for silicate rocks such as acid, intermediate and basic igneous rock was introduced (Parker, 1970). The proportions of mobile elements such as Na^+, K^+, Mg^{2+} and Ca^{2+} were considered, this is because of their high mobility among the major elements. In WIP, the value of Ca^{2+} is implicitly assumed to be contained in silicate minerals (Bahlburg and Dobrzinski, 2009; Price and Velbel, 2003). WIP is represented by:

$$(100)[(2Na_2O/0.35) +](MgO/0.9) + (2K_2O/0.25) + (CaO/0.7) \ldots \text{Eqn 3}$$

2.3.4 *Ternary plot*

Ternary plot consists of a triangle whose three apices represent a composition such as Al_2O_3, CaO + Na_2O and K_2O. Ternary diagram of Al_2O_3-CaO+Na_2O-K_2O (A-CN-K) was employed to show the trend and the degree of silicate weathering. It also plays a vital role in evaluating composition of the parent rock (Nesbitt and Young, 1989; Fedo et al., 1995; Li and Yang, 2010).

3. RESULT AND DISCUSSION

Result of major oxide mobilization and redistribution in pegmatite and weathered samples of Kitibi-Iwoye is presented in table 1. The geochemical data showed that SiO_2 displayed steady depletion from the bedrock to the regolith, 74.2 wt % and mean value of 43.4 wt % were recorded for SiO_2 in pegmatitic bedrock and weathered samples respectively. The values compared relatively with what was reported for similar geological unit (72.2 wt %) but higher for the mean value obtained for the regolith (69.4 wt %) (Tijani et al., 2006). Oxides such as CaO (0.43 and 0.03 wt. %), Na_2O (7.14 and 0.04 wt. %), K_2O (1.90 and 0.67 wt. %), MnO (0.11 and 0.03 wt. %) and P_2O_5 (0.20 and 0.05wt. %) showed decreasing trends for the parent rock and regolith respectively. The amount of Al_2O_3 increases from 15.5 wt. % to a mean value of 33.5 wt. % in the weathered samples. This clearly show alumina enrichment within the regolith compared to the parent rock. In other words, during weathering, more of Al_2O_3 accumulated as the rock disintegrates.

Oxides such as Fe_2O_3 (0.39 and 3.40 wt. %), TiO_2 (0.04 and 0.35 wt. %), MgO (0.08 and 0.11 wt. %) followed trends similar to that of alumina (Table.1) and Loss on Ignition (LOI) which represents the weight (wt%) of volatiles and oxides (H_2O^+, CO_2, F, Cl and S) lost upon heating the sample to 850˚C for more than four hours revealed parent rock and regolith values of 0.52 and 18.24 wt. % respectively. Fe_2O_3 showed general increase from the pegmatites to the regolith. The pegmatites had concentration of about 0.39 wt. % and mean concentration of 3.39 wt. % in the weathered samples. WS_7 showed more reddish brown colouration compared to what was observed in other weathered samples, this was due to high content of Fe_2O_3 (7.00 wt. %). It also showed that during weathering, more of Fe_2O_3 accumulates in the Saprolite. It is suggestive of haematite abundance towards the upper part of the weathering profile. Information obtained from the data showed mobilization pattern in the major oxides. Some oxides are significantly mobilized while some sparingly mobilized or immobilized during the weathering of pegmatitic bedrock. It is observed that individual oxide increases in concentration with depth which is a clear indication of leaching from surface and accumulation towards the bedrock. TiO_2 and Zr are universally used for quantifying mass losses for major and trace elements in soils and other residual weathering products by assuming that they are immobile during weathering processes (Nesbitt, 1979). A group researchers preferred to use TiO_2 instead of Zr, on the basis that the latter is not always evenly distributed in samples, and TiO_2 is more abundant (Nesbitt, 1979; Nesbitt and Markovics, 1997).

3.1 Mass balance Model

Mass balance which represents percentage (%) loss or gain was calculated using equation 1 and presented in table. 3. Physical and chemical weathering of bedrock led to the formation of Saprolite. Extensive leaching of the primary constituent minerals is mostly restricted to the major elements whose depletion occurred in the parent rock towards the B-horizon. Positive and negative values obtained for the major elements considered are indication of enrichment and depletion respectively.

According to some researcher, stability of Ti has been proved in studies relating to soil genesis and continuity of soil profile (Kabata-Pendia and Pendias, 2001). Using these criteria, and according to a study, Ti was the immobile element used to calculate the mass balance in this study (Nesbitt and Wilson, 1992). Data obtained from calculating the mass balance (table 3), shows that most of the major elements have been highly depleted except for Fe_2O_3 (3.19) whose depletion was not as much as other major elements. Na_2O with an average mass balance value of -99.8 is the most depleted or least enriched while Fe_2O_3 with mean mass balance 3.19 is the most enriched and least depleted (Table 3). CaO (-98.9), K_2O (-89.5), P_2O_5 (-95.3) and SiO_2 (-81.9) are significantly depleted whereas MgO (-73.1) and MnO (-64.5) are moderately depleted while Al_2O_3 (-23.6) is barely depleted.

Leaching of the major elements is mainly restricted to Mg, Ca, Na, K and Si. These elements show considerable depletion in the soil when mass balance was calculated. Significant leaching and depletion of the elements are due to weathering of primary minerals such as plagioclase, alkali feldspars, biotite and muscovite. It also depicts that the major elements are being gradually reduced from the bedrock towards the topsoil in the B-horizon. Mobility characteristics of the major elements around the study area showed that weathering profile has definitely been disturbed by erosion and mass movement.

Some researcher noticed a similar trend in the distribution of elements in the soil which showed that the bedrock was obliterated to some extent by redistribution of the elements in the soil by weathering, erosion and different rates of dissolution and mobility of the elements in the secondary environment (Adekeye and Akintola, 2007). The result shows that elements in the bedrock tend to be of lower concentration compared to the soil samples which indicates that there is high elemental mobility. Although these elements are been worked on, they tend to be of higher concentration to what is found in the bedrock.

3.2 Chemical Index of Alteration

Chemical Index of Alteration (CIA) of the rock and weathered samples were calculated using equation 2, the result is presented in Table 2. An average value of 97.8 % was obtained for the weathered samples which obviously showed that the feldspar has been extensively weathered. A group researchers stated that kaolinite with CIA of 100 has reached the highest degree of weathering (Nesbitt and Young, 1982; Fedo et al., 1995; Bahlburg and Dobrzinski, 2009). Illite is between 75 and 90, muscovite at 75, the feldspars at 50. Fresh basalts have values between 30 and 45, fresh granites and granodiorites of 45 to 55 (Bahlburg and Dobrzinski, 2009). The value of 97.8 obtained for the study area revealed that the weathering has almost reached its completion stage and the product is kaolinite (Jimoh et al., 2016). Whereas CIA of 62.1 obtained for the pegmatite parent rock indicated a value close to that obtained for fresh granite and granodiorite but suggested that the parent rock has just commenced its alteration processes which accounts for its slightly higher value.

The behavioural pattern of the values implied that the higher the CIA the more the intensity of weathering. The values obtained for pegmatite (58.3) and weathered mass (73.4) was compared with the CIA calculated in this study for pegmatite (62.1) and weathered mass (97.8), it shows that weathering is almost completed in this study due to the relatively high CIA but the values of unaltered pegmatite are almost similar in this study and that obtained (Tijani et al., 2006). The proposition was also supported the CIA values of approximately 45–55 indicate no weathering, while a value of 100 indicates intense weathering after the complete removal of alkali and alkaline earth elements from the parent rocks (Taylor and Eggleton, 2001; Tijani et al., 2006; Mclennen, 1993). Generally, the larger CIA values mean stronger silicate weathering.

3.3 Weathering Index of Parker

Weathering Index of Parker (WIP) was calculated using equation 3 and the result was presented in Table 2. The more weathered rocks have the least values of WIP. Its value ranges commonly between ≥100 and 0. Fresh and unweathered pegmatite (RS) had a WIP value of 110.5 which shows that RS has not suffered from much weathering. The least values of WIP for the study area are WS6 (2.66) and WS9 (3.88) while moderately high values were reported for WS7 (6.03), WS8 (6.23), WS3 (6.92), WS1 (8.08), WS2 (9.08) and WS5 (9.76) whereas WS4 (14.6) had the highest WIP value. It is implied from these values that the most weathered sample is WS6 while the least weathered is WS4.

Comparative analysis was drawn from the results obtained for CIA and WIP as shown in Table 2. Both models showed contrasting behavioural pattern in which the values of CIA are increasing as weathering is progressing whereas the values of WIP were correspondingly decreasing (Kingsley and Ekwuene, 2009). Their values were also plotted on a binary plot (Figure 5). The rate of weathering is increasing as CIA increases while the rate is increasing as WIP decreases. Fresh and unweathered pegmatite plots at the top left corner of Figure 5 whereas the mostly weathered samples plot at the bottom right corner.

3.4 Ternary plot

The concentration (wt. %) of Al_2O_3, CaO, Na_2O and K_2O (A-CN-K) in fresh pegmatite and weathered samples are presented in Tables 1 and 2. All values plotted fell into the apical portion of Al_2O_3 field (Figure 6). Using the approach of the samples have been strongly weathered whereas a value plotted at the middle along the A-CN line showed weak weathering which suggests that the rock sample is at the incipient stage of weathering (Figure 6) (Shao et al., 2012). According to a study, fresh and unaltered granitic rock such as pegmatite has a CIA value of 50 but the CIA of unaltered pegmatite in this study is 62.1 which indicate that the pegmatite has been weakly weathered (Tijani et al., 2006). Other CIA values which plotted within the apex of Al_2O_3 field revealed that those samples had been strongly weathered into kaolinite (Jimoh et al., 2016). This observation is corroborated in Figure 6 which also confirms that most of the samples have been intensely weathered.

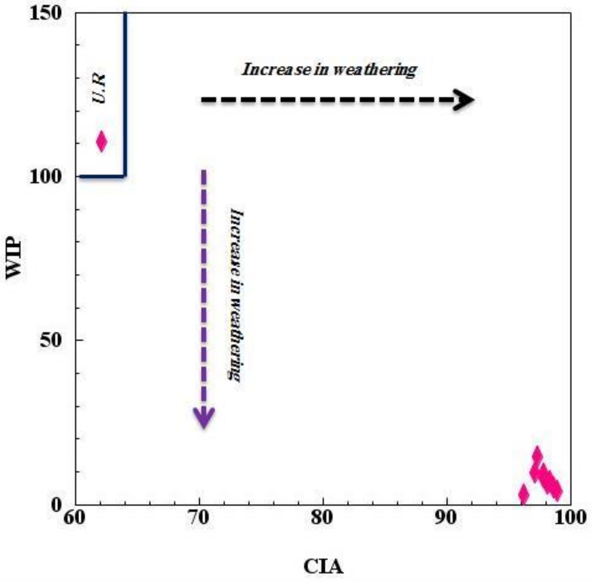

Figure 5: Relationship between CIA and WIP (Bahlburg and Dobrzinski, 2009). Where U.R is unweathered rock

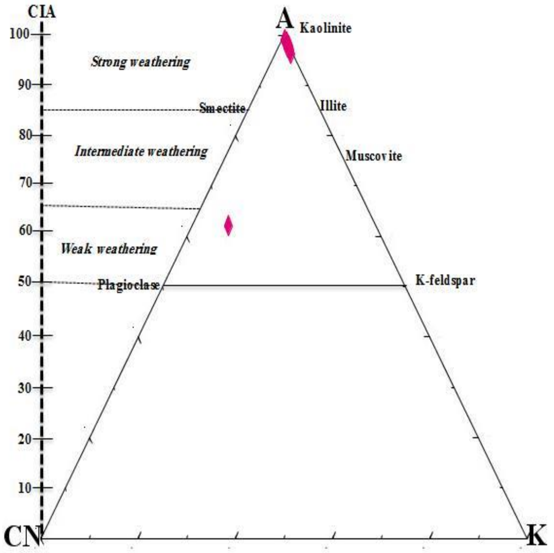

Figure 6: The Al_2O_3-CaO+Na_2O-K_2O diagram of fresh and weathered samples around the study area (Bahlburg and Dobrzinski, 2009; Shao et al., 2012).

Table 1: Major oxides concentration (wt. %) of analysed samples at Kitibi-Iwoye

	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	Mean	RS
SiO_2	42.1	46.8	44.9	45.5	43.6	44.6	38.7	43.2	41.4	**43.4**	74.2
Al_2O_3	33.21	37.68	36.92	29.54	29.05	34.69	29.37	35.82	35.44	**33.50**	15.50
Fe_2O_3	2.62	0.27	2.27	5.14	5.92	2.28	7.00	2.80	2.21	**3.39**	0.39
CaO	0.02	0.01	0.01	0.07	0.02	0.02	0.02	0.02	0.06	**0.03**	0.43
MgO	0.11	0.06	0.11	0.14	0.16	0.08	0.18	0.08	0.09	**0.11**	0.08
Na_2O	0.03	0.03	0.03	0.07	0.06	0.11	0.02	0.02	0.02	**0.04**	7.14
K_2O	0.70	0.82	0.58	0.67	0.80	1.24	0.38	0.54	0.29	**0.67**	1.90
MnO	0.01	-	-	0.06	0.03	0.06	0.03	0.01	-	**0.03**	0.11
TiO_2	0.22	0.03	0.18	0.48	0.69	0.24	0.73	0.26	0.28	**0.35**	0.04
P_2O_5	0.01	0.03	0.03	0.06	0.07	0.04	0.06	0.05	0.07	**0.05**	0.20
LOI	21.48	14.35	15.34	17.51	18.66	15.54	23.29	17.35	20.60	**18.24**	0.52
SUM	**100.6**	**100.1**	**100.5**	**99.24**	**99.06**	**98.9**	**99.78**	**100.2**	**100.5**	**99.85**	**100.5**

Table 2: CIA and WIP values calculated for selected elements

	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	Mean	RS
Al_2O_3	33.21	37.68	36.92	29.54	29.05	34.69	29.37	35.82	35.44	**33.50**	15.50
CaO	0.02	0.01	0.01	0.07	0.02	0.02	0.02	0.02	0.06	**0.03**	0.43
MgO	0.11	0.06	0.11	0.14	0.16	0.08	0.18	0.08	0.09	**0.11**	0.08
Na_2O	0.03	0.03	0.03	0.07	0.06	0.11	0.02	0.02	0.02	**0.04**	7.14
K_2O	0.70	0.82	0.58	0.67	0.80	1.24	0.38	0.54	0.29	**0.67**	1.90
CIA%	97.8	97.8	98.3	97.3	97.1	96.2	98.6	98.1	98.9	**97.8**	62.1
WIP%	8.08	9.08	6.92	14.6	9.76	2.66	5.05	6.23	3.88	**7.36**	110.5

Table 3: Mass Balance Calculation of Major Elements at Kitibi-Iwoye

Major Elements	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	Mean
SiO_2	-89.7	-0.16	-86.5	-94.9	-96.6	-90.0	-97.1	-91.0	-92.0	**-81.9**
Al_2O_3	-61.0	224.1	-47.1	-84.1	-89.1	-62.7	-89.6	64.5	-67.3	**-23.6**
Fe_2O_3	22.2	-7.73	29.3	9.83	-12.0	-2.57	-1.64	10.5	-19.1	**3.19**
CaO	-99.2	-96.9	-99.5	-98.7	-99.7	-99.2	-99.8	-99.3	-98.0	**-98.9**
MgO	-75.0	0.00	-69.5	-85.4	-88.4	-83.3	-87.7	-84.6	-83.9	**-73.1**
Na_2O	-99.9	-99.5	-99.9	-99.9	-99.9	-99.8	-99.9	-99.9	-99.9	**-99.8**
K_2O	-93.3	-42.5	-93.2	-97.1	-97.6	-89.1	-98.9	-95.6	-97.9	**-89.5**
MnO	-98.4	0.00	0.00	-95.5	-98.4	-90.9	-98.5	-98.6	0.00	**-64.5**
P_2O_5	-99.1	-80.0	-96.7	-97.5	-98.0	-96.7	-98.4	-96.2	-95.0	**-95.3**

4. CONCLUSION

This investigation shows how major elements of Kitibi-Iwoye are released and redistributed during weathering. Al, Fe and Na are strongly mobilized and redistributed in weathering profile. Al and Fe showed up-profile enrichment whereas Na displayed up-profile depletion. Mass balance assessment obtained from the major elements showed that elements such as Na_2O, CaO, K_2O, P_2O_5, SiO_2, MgO and MnO have been depleted in concentration compared to what was observed in the parent rock. Therefore, these element decreases towards the top soil. The mean CIA value of 97.8 revealed that weathering has almost reached its completion and the product is kaolinite whereas CIA of 62.1 obtained for the pegmatite parent rock suggested that the parent rock has just commenced its alteration processes which accounts for its slightly higher value.

Fresh pegmatite with a WIP value of 110.5 had not suffered much from weathering. The WIP ranged from weakly weathered body through moderate weathering up to strongly weathered body. Comparative analysis of CIA and WIP showed contrasting behaviour in which the values of CIA are increasing as weathering is progressing whereas the values of WIP were correspondingly decreasing. The mass balance calculations are categorized into three on the basis of depletion/enrichment factor. (i) strong depletion but poor enrichment for Na, Ca, K and P (ii) moderate depletion profiles for Si, Mg and Mn (iii) poor depletion but strong enrichment for Al and Fe. The Al_2O_3-CaO+Na_2O-K_2O diagram of fresh pegmatite and weathered samples corroborated CIA, WIP and mass balance model that most of the samples have been intensely weathered and that the weathering product is kaolinite.

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Cite the Article: Jimoh, M.T., Bolarinwa, A.T, T. O. Kolawole (2020). Mobility And Redistribution Of Major Elements In Weathered Profile Developed On Pegmatite At Kitibi-Iwoye, Southwestern Nigeria. *Malaysian Journal of Geosciences, 4(2): 59-64.*