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Paleoclimate, Provenance and Weathering Studies of Clays in Parts of Isan-Ekiti, Southwestern Nigeria

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ABSTRACT

This work entailed the geochemical, mineralogical and weathering studies of clays in parts of Isan-Ekiti, Southwestern Nigeria. The average K_2O/Na_2O ratio (2.34) for the clay is much higher than that of the UCC (0.87), suggesting removal of plagioclase feldspar; the low K_2O/Al_2O_3 values (0.02-0.31) is attributed to the marked dominance of kaolinite and rarity of illite, K-feldspars and micas. CIA, CIW, PIA, MIA, WIP, SiO_2/Al_2O_3, the (A–CN–K); (A–CNK–FM) and (F–A–S) ternary diagrams) indicate moderate weathering intensity. The K_2O vs. Rb plot and the rich quartz content suggest that they are of felsic origin. The Orudi (B) clays may have been sourced from charnokites, while the rest of the clays may have originated from granites and migmatites. The MAP values range between 921 and 1370 ± 182 mm/year and an average of 1169 mm/year. The MAT values ranged from 12.2 to 15 °C, with an average of 13.9 °C. There is no correlation between MAT and CIA, suggesting that temperature was a minor factor in the formation of the clays. There is a strong correlation between MAP and CIA, implying that hydrolysis was a major factor in the formation of the clays. During the formation of Isan clays, the climate was considerably colder and dryer than the prevailing climate, implying that the Isan-Ekiti area may have once being a semi-arid environment.

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KEYWORDS: *Clay, Isan-Ekiti, provenance, weathering, minerals*

INTRODUCTION

Clay minerals are very common in fine grained sedimentary rocks such as shale, mudstone, siltstone and in fine grained metamorphic slate and phyllite. Clay minerals account for about 50-60 wt.% of most shales and are often responsible for many of the problems encountered when drilling through shales (Hillier, 2006). Clays may be composed of mixtures of fine-grained clay minerals and clay-sized crystals of other minerals such as quartz, carbonate, and metal oxides (Velde, 1995). Clay minerals are common weathering products (including weathering of feldspar) and low temperature hydrothermal alteration products. There are two main types of clays: primary and secondary clay. Primary clays are clays that have not moved from its place of formation, while secondary clays have moved from its place of formation either by the action of water or wind and erosion. Primary clays are the purest form of clay also known as kaolin. Primary clays that are fired at their highest temperature are white in colour; secondary clays fire at lower temperature and are not white. Weathering is the chemical decomposition and physical disintegration of rocks at/near the Earth's surface. The chemical weathering of rocks proceeds by water-rock interaction and some alkaline and alkali-earth elements are easily leached from rock, while the residual elements are redistributed to secondary minerals (Loughnan, 1969).

Nigeria lies approximately between latitudes 4° N and 15° N and longitudes 3° E and 14° E, within the Pan African mobile belt in between the West African and Congo cratons. The geology of Nigeria is dominated by crystalline and sedimentary rocks both occurring approximately in equal proportions (Woakes et al., 1987). The area covered by the southwestern Nigeria basement complex lies between latitudes 7° N and 10° N and longtitudes 3° E and 6° E right in the equatorial rain forest region of Africa. The main lithologies include the amphibolites, migmatite gneisses, granites and pegmatites (Fig. 1). Other important rock units are the schists, made up of biotite schist, quartzite schist, talc-tremolite schist and muscovite schists (Obaje, 2009). According to Talabi & Tijani (2011), Ekiti State is located between latitudes 7°15′ N to 8°5′ N and longitudes 4°44′ E to 5°45′ E covering an approximate area of about 6 353 km2 (Fig. 2). In Nigeria, clay is widely distributed though not always found in sufficient quantity or suitable quality for modern industrial purposes. More than 80 clay deposits have been reported from all parts of the country (Akhirevbulu et al., 2010). The aim of this work is to determine the mineralogy, provenance, weathering intensity and paleoclimate of some clays from Isan-Ekiti.

Geology of the Study Area

Isan-Ekiti is amongst the many towns located in Ekiti State, southwestern Nigeria. It is located on the Basement Complex between longitude 5.2° 11′ and 5.4° 30′ East and latitude 7.3° 10′ and 7.9° 59′ North with an altitude of 460m above sea level. Isan Ekiti is

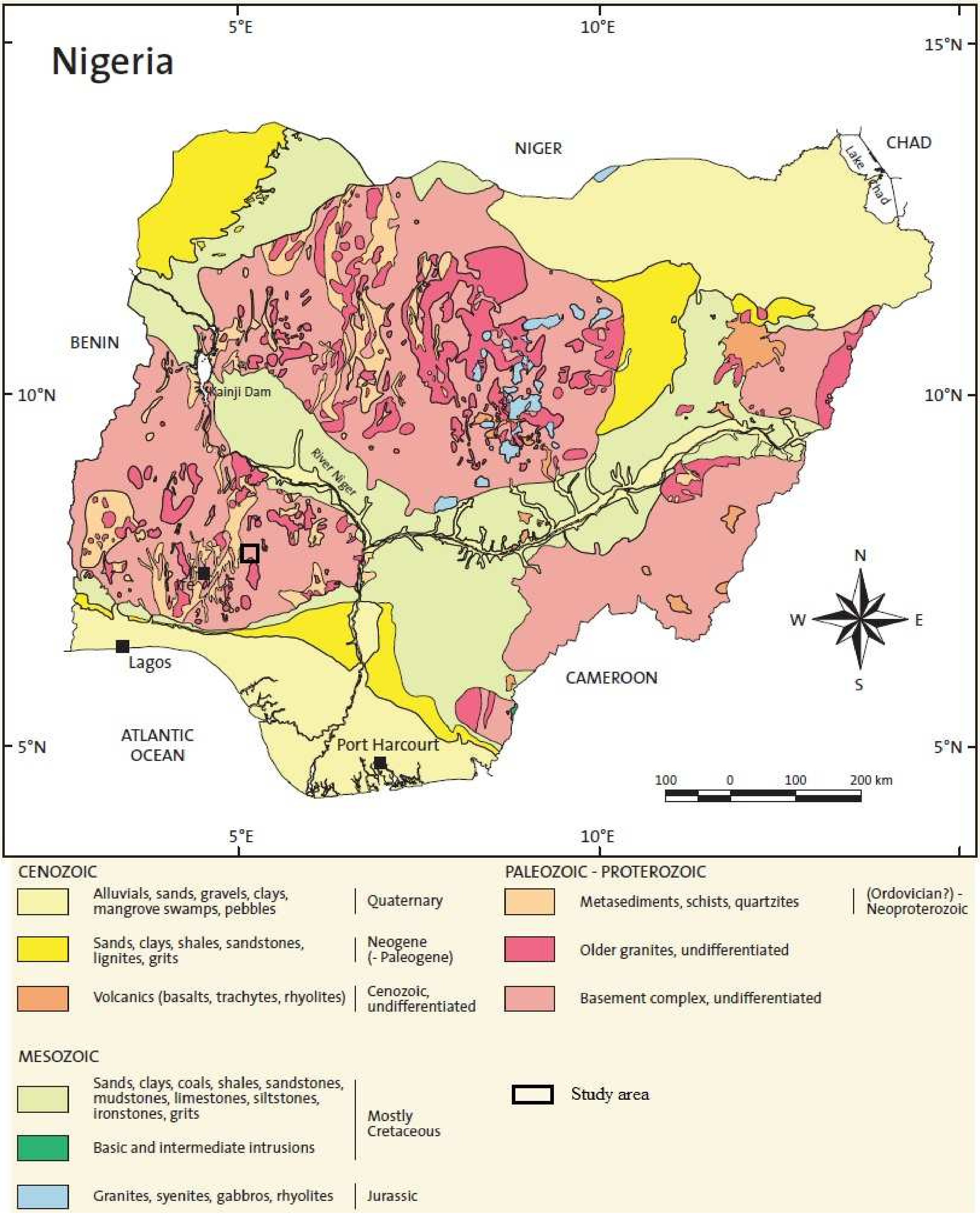

Figure 1. Geological map of Nigeria showing the major geological components: basement, younger granites and sedimentary basins (After Schlüter, 2008).

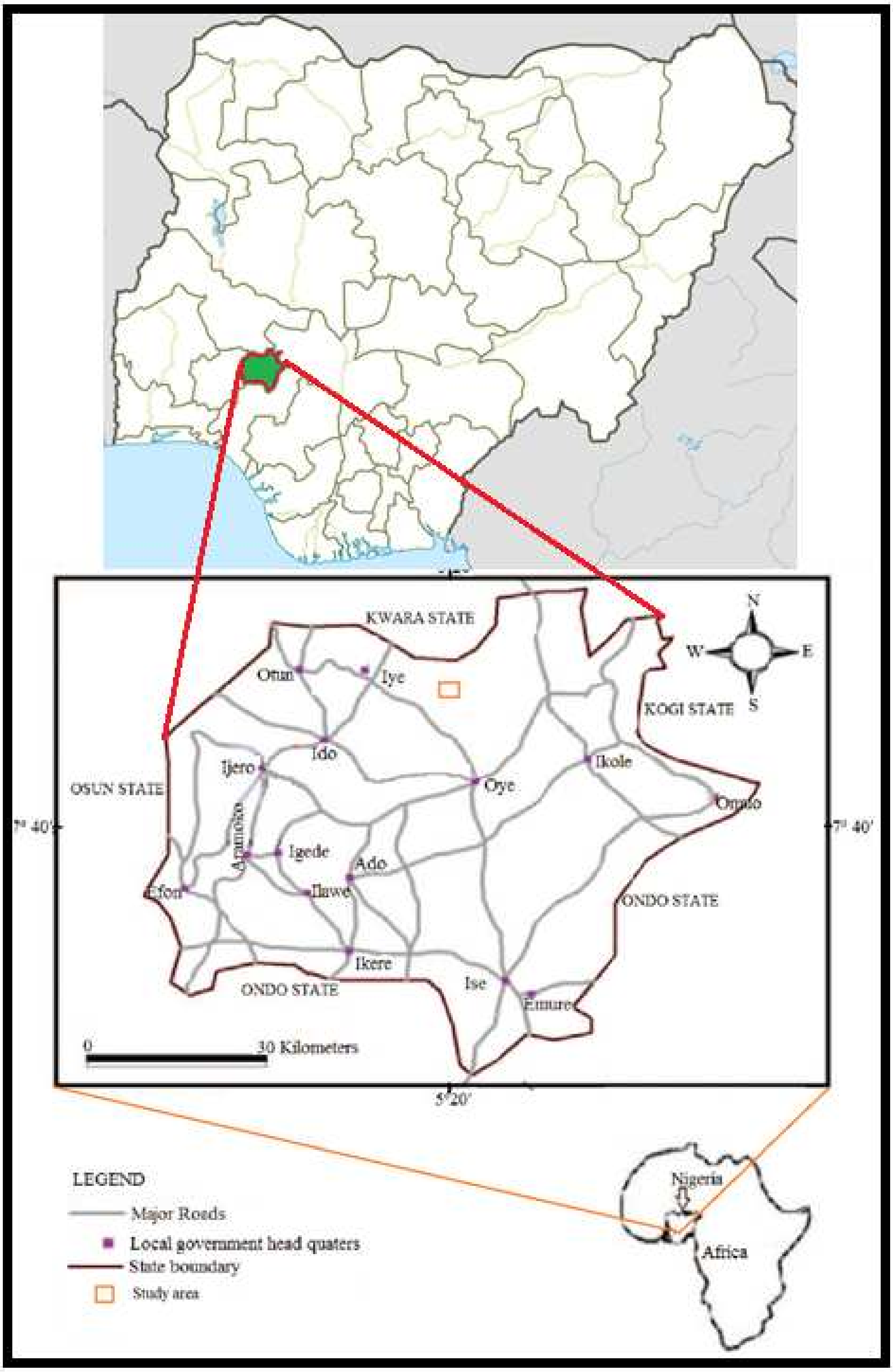

Figure 2. Map of Ekiti State showing the study area (modified from Talabi & Tijani, 2011).

accessible by major roads, minor roads and footpaths in highly vegetated areas; the climate (the rainy sand dry seasons). The temperature range is between 21° and 28°C with high humidity. The south westerly wind and the northeast trade winds blow in the rainy and dry (Harmattan) seasons respectively. Tropical forest exists in the south, while savannah occupies the northern peripheries (Oyawoye, 1972).

MATERIALS AND METHODS

Seven samples were collected from Aradie, Orudi, Iyaya and Turro areas in Isan Ekiti. The samples were oven dried to remove the moisture content. After which they sieved, grinded and packed for analysis.

Chemical Analysis

This analysis was carried out at National Steel and Raw Material Exploration Agency. The elements in the clay samples were determined using X-Ray Fluorescence analysis (XRF) and Atomic Absorption Spectrometry. It is based on the observation that atoms of an element can absorb electromagnetic radiation. This occurs when the element is atomized and the wavelength of light absorbed is specific to each element. Each sample was first pulverized and 0.5gm digested with 5ml HF and a mixture of prepared solution of nitric acid and perchloric acid (ratio 3:2). The sample was stirred and heated inside a fume cupboard. The digested sample was diluted with distilled water and made up to 20ml mark. About 1ml was taken from the solution and further diluted with distilled water to 10ml mark. This represents the stock solution, x 10-dilution factor. The elements were then determined from the digested samples using a Perkin Elmer 305 Atomic Absorption Spectrophotometer and using a Philip PW 1210 (TEFA ORTEC automatic X-ray F Model).

XRD Procedure

The analysis was carried out at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria (for Aradie and Orudi samples); and at the Center for Analysis and Test, Institute of Soil Test. Kaduna, Nigeria (for Iyaya and Turro samples). The measurements at the Centre for Energy Research and Development were taken with XRD (MD10) Monochromatic CuKα radiation (wavelength = 1.5406) produced by Radicon limited. The samples were exposed to the X-ray beam from an X-ray generator running 25kV and 20mA. The scanning regions of the diffraction were 16-72° on the 2 theta angle.

The measurements at the Center for Analysis and Test, Institute of Soil Test. Kaduna utilized the MiniFlex Rigaku Procedure for X-ray diffraction analysis and mineral identification. Powdered samples were pelletized and sieved to 0.074mm. These were later taken in an aluminum alloy grid (35mm x 50mm) on a flat glass plate and covered with a paper. Wearing hand gloves, the samples were compacted by gently pressing them with the hand. Each sample was run through the Rigaku D/Max-IIIC X-ray diffractometer developed by the Rigaku Int. Corp. Tokyo, Japan and set to produce diffractions at scanning rate of 2°/min in the 2 to 50° at room temperature with a CuKa radiation set at 40kv and 20mA. The diffraction data (d value and relative intensity) obtained was compared to that of the standard data of minerals from the mineral powder diffraction file from the International Centre for Diffraction Data (ICDD).

RESULTS AND DISCUSSION

Clay Mineralogy

The XRD patterns of the whole-rock samples show that the samples from Orudi and Aradee are mainly of kaolinite type (Fig. 3 and Fig. 4); the clay samples also contain quartz and dickite. The samples from Turoo and Iyaya are composed mainly of quartz, kaolinite minor feldspar and illite (Fig. 5 and Fig. 6). These compositions of the studied clay samples suggest a felsic source. Presence of feldspars in the Turoo and Iyaya samples suggests an incomplete alteration and formation of the clay from in situ weathering of the older crystalline rocks in the study area (Ekosse and Ngole, 2012).

Geochemistry and Weathering Intensity

Table 1 shows the geochemical composition of the samples studied in comparison with UCC, NASC, PAAS, Migmatite, Granite and Charnockite values. SiO_2 is the most abundant in all the samples. The Turoo and Iyaya samples have a higher SiO_2 content than Orudi and Aradee samples. Fe_2O_3 is more abundant compared to Al_2O_3 in Orudi and Aradee samples, but the reverse is the case for Turoo and Iyaya samples. The average SiO_2 value for the studied clay (50.73%) is lower than that of the UCC (66%);

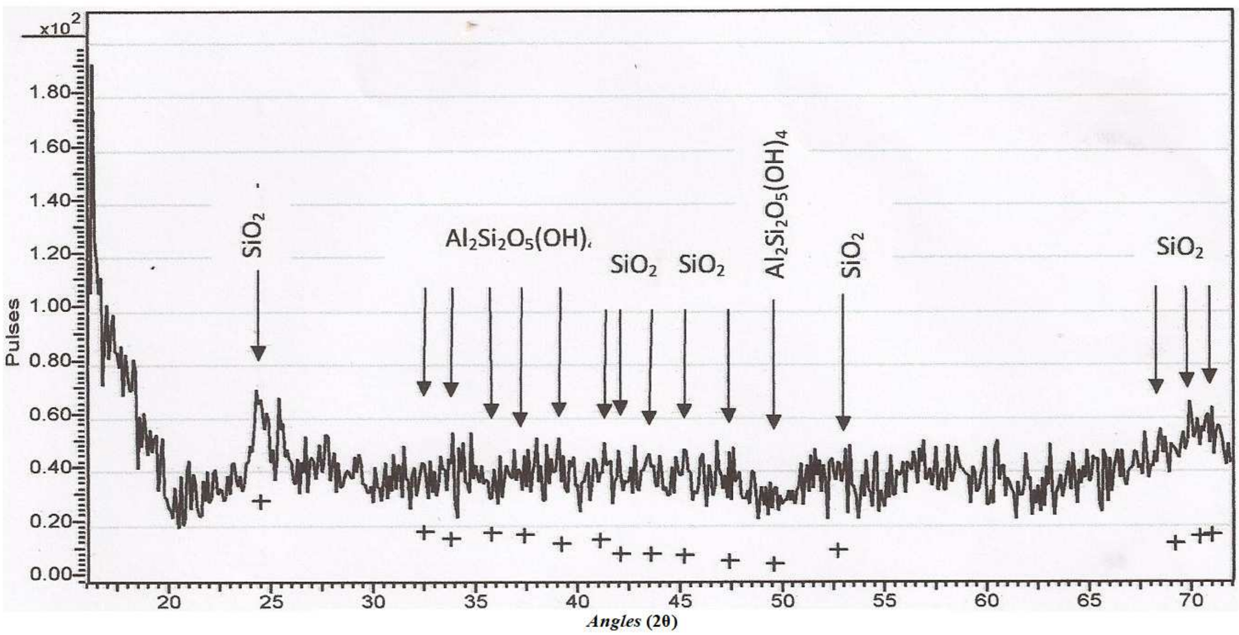

Figure 3. XRD analysis of Orudi sample.

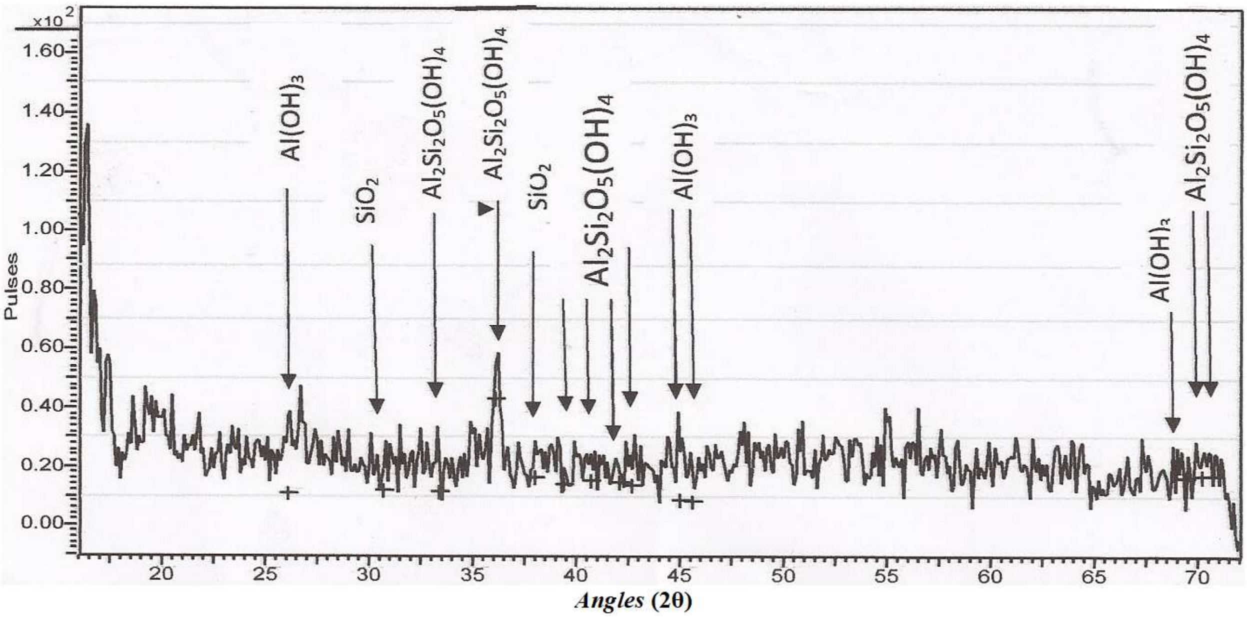

Figure 4. XRD analysis of Aradee sample.

NASC (64.8%); PAAS (62.8%), migmatite (68.60%); granite (73.30%) and charnockite (66.30%) which may be due to erosion. The SiO_2/ Al_2O_3 ratio of the clay samples range between 2.43 and 3.37, which is lower than NASC (3.83), UCC (4.34) and PAAS. The ratio of SiO_2/Al_2O_3 indicates presence of silica and is due to high quartz content.

Table 1 Data of geochemical analysis (Major Elements in %, Trace and Rare Earth Elements in ppm)

Oxides	Orudi A	Orudi B	Aradee A	Aradee B	Iyaya	Turro A	Turro B	Mean	NASC	PAAS	UCC	Migmatite	Granite	Charnockite
SiO_2	50.60	42.60	40.20	40.00	61.90	59.81	59.97	50.73	64.8	62.8	66	68.6	73.3	66.3
Al_2O_3	15	16	16.02	13.02	20.61	21.69	24.66	18.14	16.9	18.9	15.2	15.1	15.24	12.01
Fe_2O_3	22.96	32.41	14.46	18	5.06	3.07	3.36	14.19	5.65	7.22	5	2.78	2.34	3.34
TiO_2	3.9	2.75	0.07	0.03	3.81	0.92	2.02	1.93	0.7	1	0.5	0.08	0.04	1.05
CaO	0.74	0.74	1.69	2.69	0.02	0.47	0.46	0.97	3.63	1.3	4.2	2.3	0.92	3.98
Na_2O	1.12	0.74	0.95	0.89	0.14	0.47	1.75	0.87	1.14	1.2	3.9	3.88	1.58	3.14
K_2O	3.16	2.01	3.01	4	0.65	0.87	0.48	2.03	3.97	3.7	3.4	4.04	3.36	2.88
MnO	0.31	0.04	0.13	0.11	0.01	0.01	0.01	0.09	0.06	0.11	0.08	0.32	0.1	0.15
MgO	0.01	0.01	21.76	22.06	0.72	1.45	0.29	6.61	2.86	2,20	2.2	0.36	0.12	2.73
P_2O_5	0.02	0.02	0.01	0.01	0.09	0.03	0.38	0.08	0.13	nd	nd	0.05	0.11	0.62
Eu_2O_3	0.32	0.12	0.15	0.15	nd	nd	nd	nd	1.25	nd	0.88	nd	nd	nd
Re_2O_7	0.03	0.04	0.04	0.04	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
TRACE ELEMENTS														
Ba	nd	nd	nd	nd	671	512	687		636	650	550	nd	nd	nd
Cd	nd	nd	nd	nd	6	10	8		nd	nd	nd	nd	nd	nd
Co	nd	nd	nd	nd	14	26	22		26	23	10	nd	nd	nd
Sr	111.1	105	131.2	131.2	nd	nd	nd		142	200	350	nd	nd	nd
Cr	145.2	122.1	145.9	150	112	128	119		125	110	34	nd	nd	nd
Ni	150	140.1	250	222	33	30	10		58	55	20	nd	nd	nd
Nb	nd	nd	nd	nd	5	5	524		13	19	25	nd	nd	nd
Zn	239.1	252.4	594.4	563.1	310	296	nd		nd	nd	71	nd	nd	nd
Zr	23.6	54.4	78.1	110.2	nd	nd	nd		200	nd	190	nd	nd	nd
Cu	32.1	34.4	53.5	56.1	28	26	16		nd	nd	25	nd	nd	nd
Rb	33.3	33.3	112	132.3	10	191	250		125	nd	110.2	nd	nd	nd
Sc	nd	nd	nd	nd	90	10	158		nd	nd	nd	nd	nd	nd
Pb	73.1	76.4	146.2	150	nd	nd	nd		nd	nd	15	nd	nd	nd
V	19.76	16.49	20.09	20.09	nd	nd	nd		130	nd	60	nd	nd	nd

UCC = Upper Continental Crust (Adapted from, Taylor and McLennan, 1985)
NASC = Average North American Shale Composite (adapted from Gromet et al., 1984)
PAAS = Post Archean Australian Shales (Adapted from, Taylor and McLennan, 1985)
Migmatite = mean values from five localities in Ekiti State (After Talabi, 2013)
Granite = mean values from five localities in Ekiti State (After Talabi, 2013)
Charnockite = mean values from five localities in Ekiti State (After Talabi, 2013)

The average value of SiO_2 in the clays under investigation is > 50 %; this suggests that quartz is the major component. The high mean value of Al_2O_3 (18.14) could be attributed to feldspar and clay minerals in the deposit. The average K_2O/Na_2O ratio (2.34) for the clay sample is much higher than that of the UCC (0.87), suggesting removal of plagioclase feldspar. The Isan clays have low K_2O/Al_2O_3 ratio values (0.02-0.31); the low values of K_2O/Al_2O_3 ratio are attributed to the

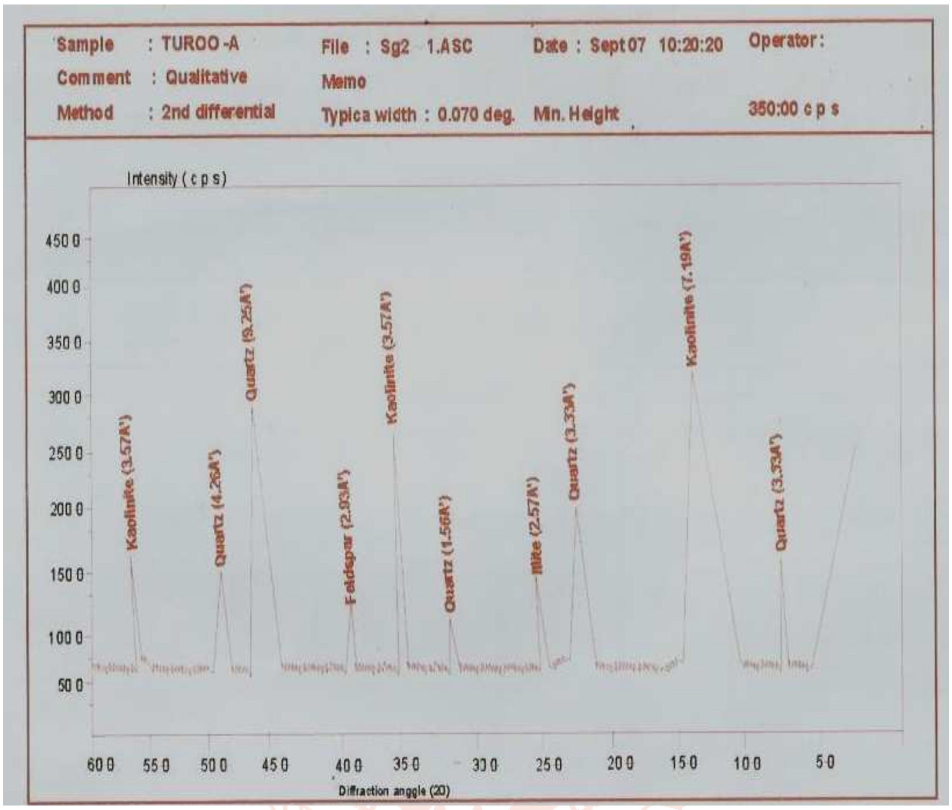

Figure 5 XRD analysis of Turro A Sample

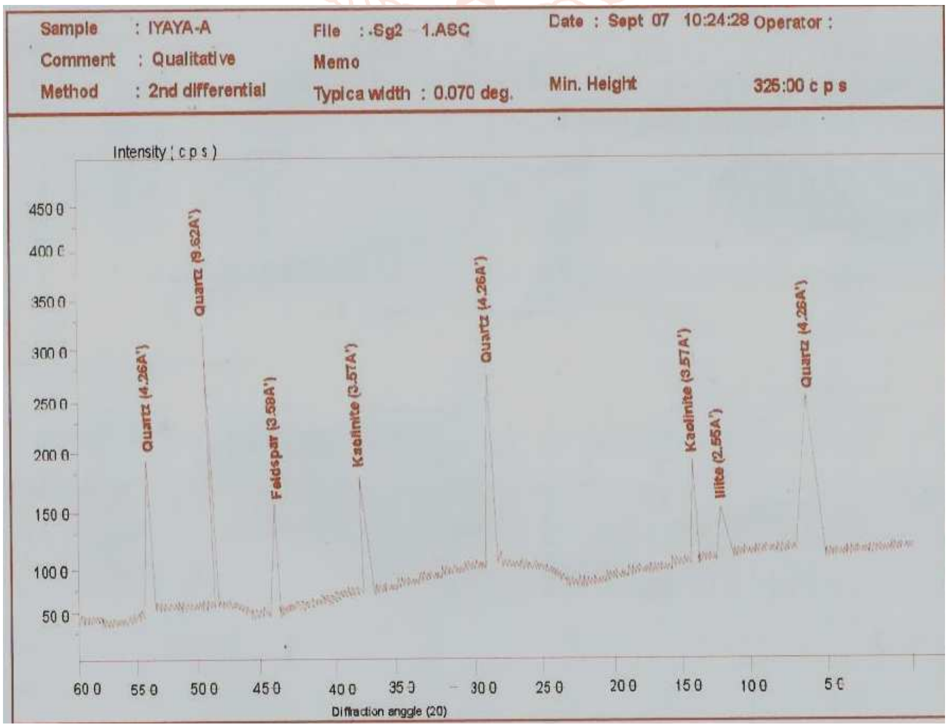

Figure 6 XRD analysis of Iyaya Sample

marked dominance of kaolinite and rarity of illite, K-feldspars and micas (EL-Wekeil and Abou El-Anwar, 2013). The K_2O/Al_2O_3 ratios for clay minerals range from 0.0 to 0.3 and 0.3 to 0.9 for feldspars. K_2O/Al_2O_3 ratio greater than 0.5, suggests the dominance of alkali feldspars compared to other minerals, while K_2O/Al_2O_3 ratios less than 0.3 suggest minimal alkali feldspar content (EL-Wekeil and Abou El-Anwar, 2013). The studied clays have K_2O/Al_2O_3 values less than 0.3 suggesting dominance of clay minerals over other minerals.

Rocks exposed to and sediments transported on the Earth's surface are subjected to alteration processes with chemical weathering being one of the most important, the process of weathering trends to produce progressively fine-grained particles, especially clay minerals, at the expense of the coarse-grained material (Kovács, 2007). Feldspar dominates on average in crustal rocks, their transformation to clay minerals and Al-hydroxides is essential to chemical weathering (Eynatten, 2004). Several weathering indices can be used to study the degree of weathering that has occurred to a sediment or rock. The degree of silicate weathering can be estimated by the Chemical Index of Alteration (CIA) proposed by Nesbitt and Young (1982); CIA = $A1_2O_3/(A1_2O_3 + CaO + Na_2O + K_2O)] \times 100$. CIA values for the clay samples ranged between 61.25% and 95.58% with an average of 79.63%, indicating moderate to intense degree of weathering. The Chemical Index of Weathering (CIW) proposed by Harnois (1988) is similar to the CIA except for the exclusion of K_2O in the equation: CIW = molar $(Al_2O_3/(Al_2O_3+ CaO + Na_2O))$.

The CIA and CIW are interpreted in similar way with values of 50 for unweathered upper continental crust and roughly 100 for highly weathered materials, with complete removal of alkali and alkaline-earth elements (McLennan, 1993). The CIW for the studied clay ranged between 76.90 and 98.80% (Average = 88.22%), indicating moderate to intense degree of weathering. The intensity of the chemical weathering can also be estimated using the Plagioclase Index of Alteration (Fedo et al., 1995); in molecular proportions: PIA = $[(Al_2O_3-K_2O)/ (Al_2O_3 + CaO + Na_2O-K_2O)] \times 100$; unweathered plagioclase has PIA value of 50. The PIA values for the Isan clays ranged from 68.97% to 98.76% (Average = 85.83%) indicating moderate to intense degree of weathering. The Mineralogical Index of Alteration (MIA) proposed by Voicu et al. (1997) is a weathering parameter calculated as: MIA = 2*(CIA-50). MIA values between 0 and 20% are designated as incipient, i.e. just starting; 20%-40% (weak); 40%-60% (moderate) and 60%-100% as intense to extreme degree of weathering. MIA values are between 22.49% and 91.16% (Average = 59.25%), which indicate moderate weathering conditions. The silica-to-alumina (SiO_2/Al_2O_3) mole ratio also known as Ruxton's ratio is hinged on silica-loss during weathering and used as a parameter to measure weathering intensity. The reliability of this index depends on the consistency of the Al_2O_3 content during weathering and should only be utilized when SiO_2/Al_2O_3 mole ratios were less than 3 (Ruxton, 1968). Optimum weathered value is zero while the optimum unweathered value is > 10. The clays being examined have SiO_2/Al_2O_3 ratios between 2.06 and 2.86 (average = 2.40); this suggests moderate weathering intensity. Parker (1970) proposed a weathering index based on element-oxygen bond strength, referred to as the Weathering Index of Parker (WIP). The WIP is the appropriate index for the assessment of weathering of rocks where hydrolysis is the main weathering process (Gupta and Rao, 2001). The WIP value classification range from 0 to > 100; 0 being the optimum weathering and its maxima correspond to the least weathering. The studied clay has WIP values ranging from 15.66 to 152 with an average value of 71.09, which implies moderate weathering intensity. In the (A–CN–K) ternary diagram (Fig. 7), some samples occur close to the point A (kaolinite), while others plotted at the top half center close to the average shale, this may suggest the removal of Ca, Na and K from the source rocks and moderate weathering intensity. The molar proportions of Al_2O_3 (A) = Al_2O_3, $CaO + Na_2O + K_2O$ (CNK) and $FeO_{tot} + MgO$ (FM) is shown in Figure 8. Some samples plotted within the feldspar–kaolinite–gibbsite compositional triangle but closer to the clay zone, indicating that kaolinite is more abundant than feldspar; it also shows that the clay contains iron. The diagram shows virtually all of the samples lying parallel with the A–FM line, implying that there is Al and iron enrichment and alteration of feldspars. Figure 9 can be used to identify the degree of weathering, it shows the kaolinisation of the samples. The Isan clays are in the kaolinic zone of the diagram, which indicates that the samples are altered to kaolinic degree indicating moderate weathering intensity. Figure 10 also suggests moderate weathering intensity of the clays. The SiO_2/Al_2O_3 ratios in the samples are less variable (2.06–2.86), but their K_2O/Na_2O ratios vary considerably in the range of 0.18–3.07 (Fig. 11). The above ratios are different from those of the average UCC, NASC and PAAS. In a plot of Na_2O/Al_2O_3 vs. K_2O/Al_2O_3, depletion of Na and K is evident in the clay samples, compared to UCC (Fig. 12).

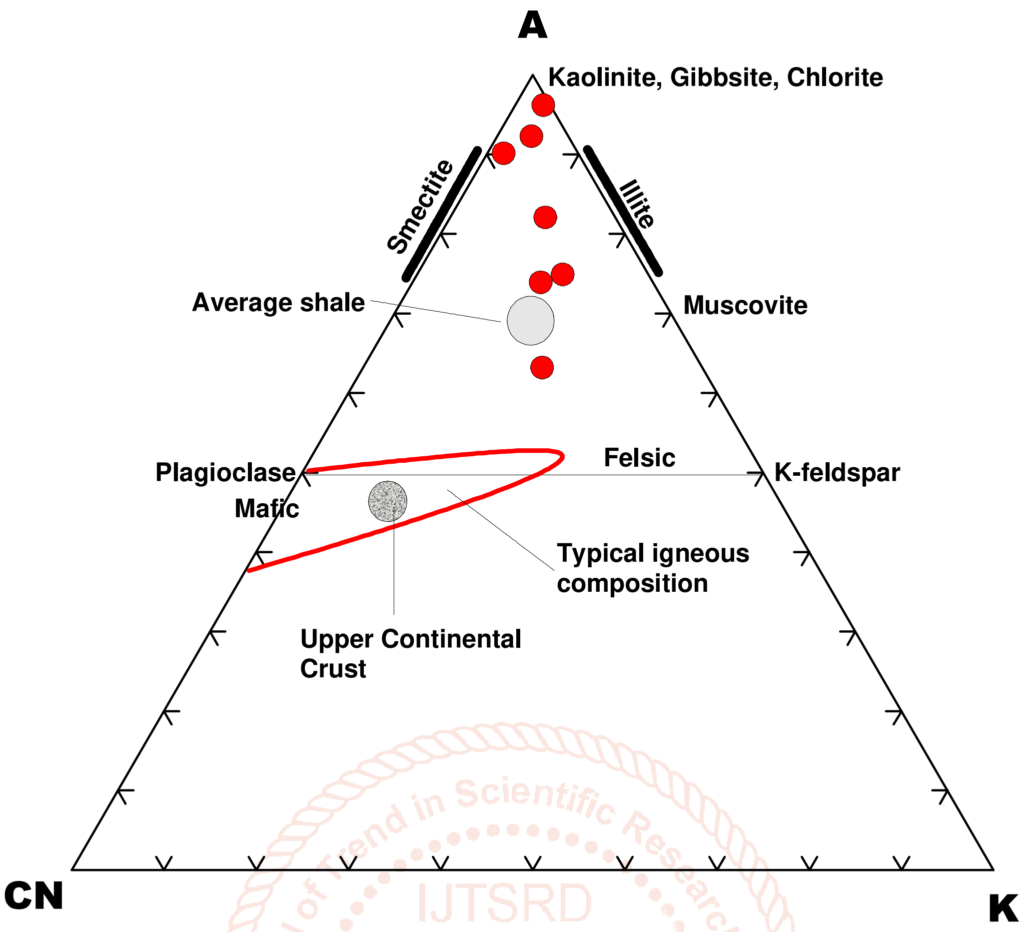

Figure 7. A-CN-K ternary plot for the Isan clays. Fields from Gu et al. (2002).

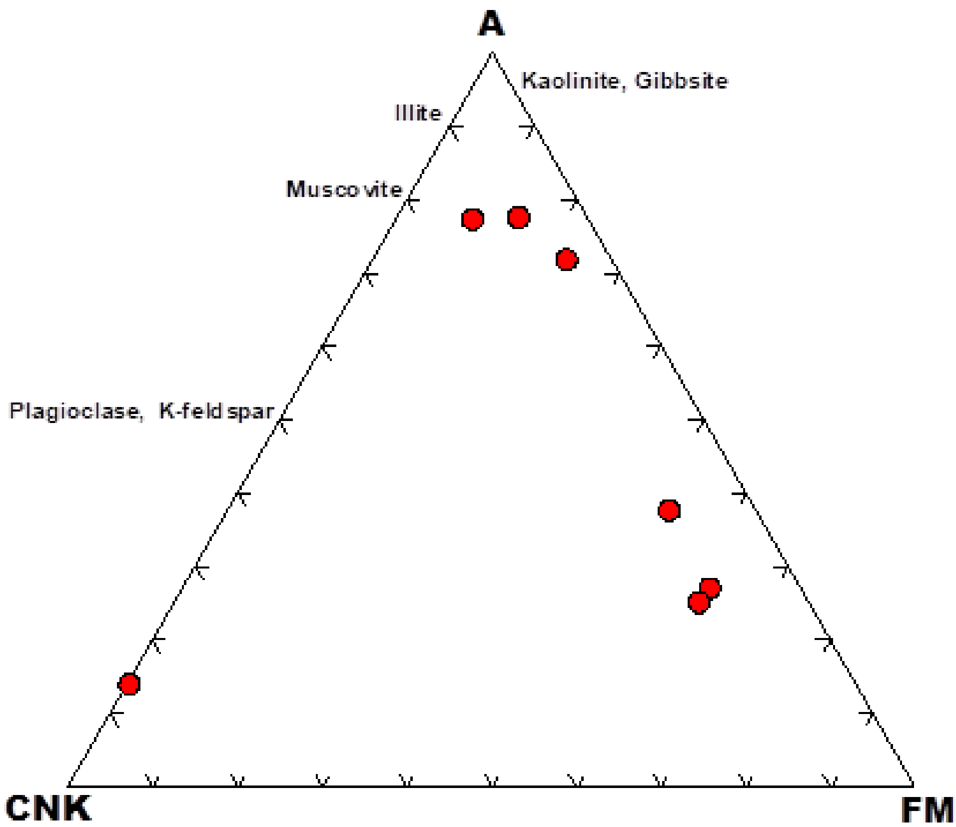

Figure 8. A–CNK–FM (Al_2O_3—$CaO+Na_2+K_2O$—Fe_2O_3+MgO) Ternary diagram of the bulk chemical composition of the Isan clays.

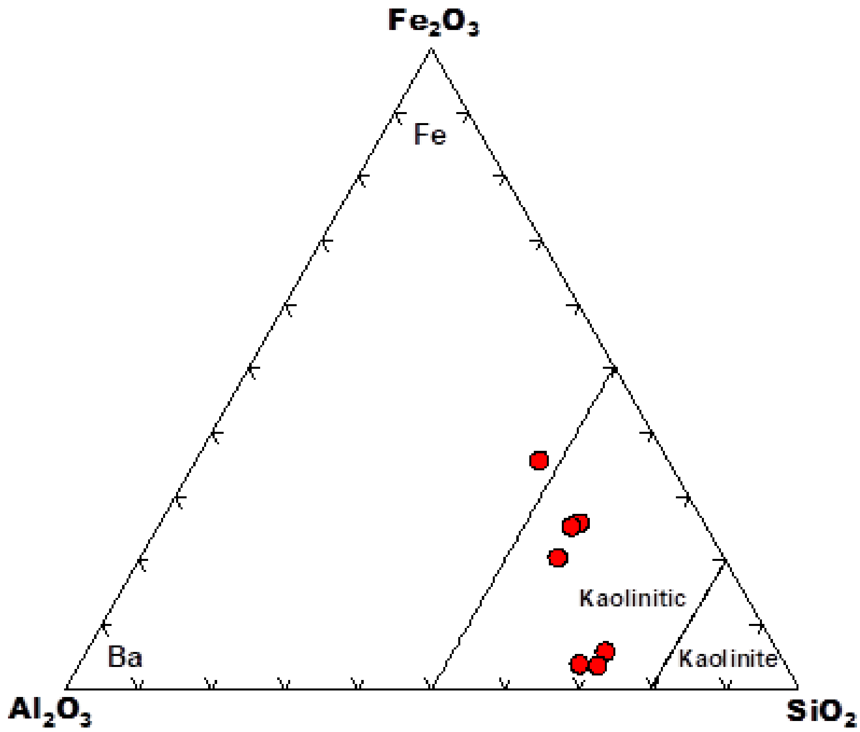

Figure 9. F–A–S (Fe_2O_3, Al_2O_3, SiO_2) ternary diagram, Ba = bauxitic, Fe = ferritic, Ka = kaolinite (after Schellmann, 1983).

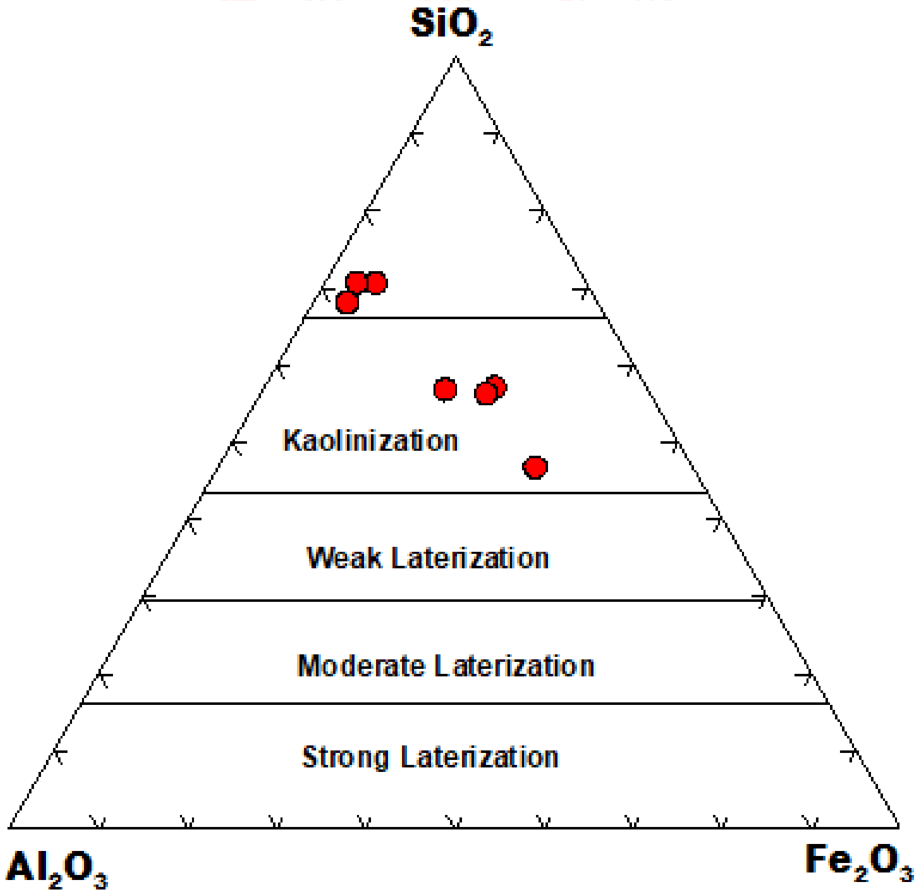

Figure 10. SiO_2–Al_2O_3–Fe_2O_3 triangular plot indicating extent of lateritization (Modified after Schellmann, 1986).

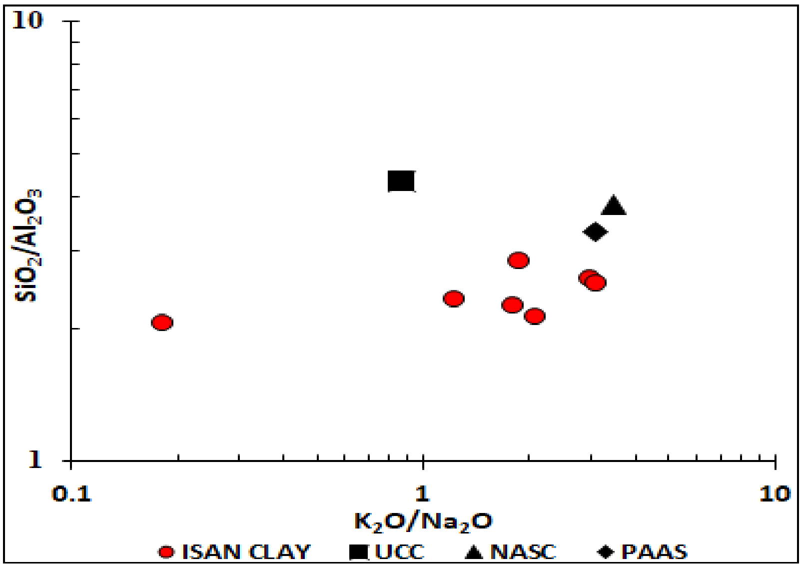

Figure 11. Variations in molar ratios of SiO_2/Al_2O_3 vs. K_2O/ Na_2O for the clay samples.

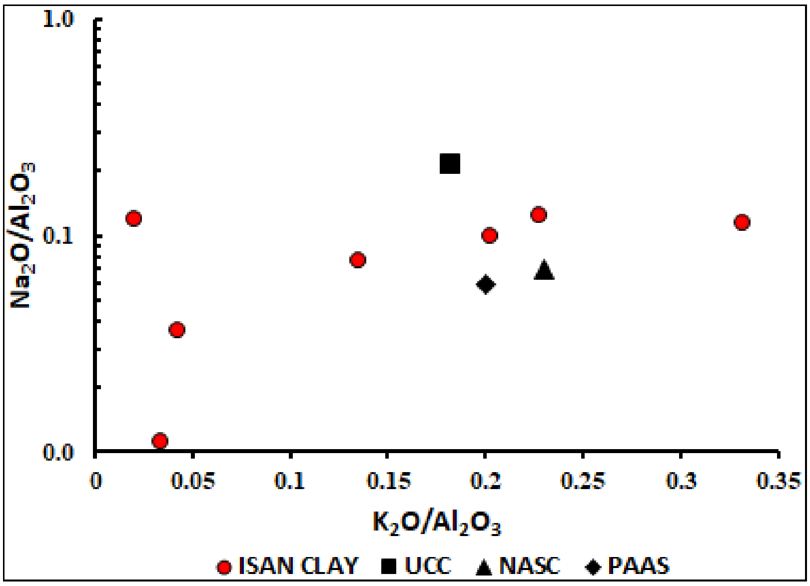

Figure 12. Variations in molar ratios of Na_2O/Al_2O_3 vs. K_2O/Al_2O_3 for the clay samples (after Garrels and Mackenzie, 1971).

Chemical index of alteration (CIA) and elemental ratios such as K/Na, Al/Na can be utilized to evaluate the degree of chemical weathering with respect to their mobility during weathering (Nesbitt and Young, 1982). The Al/Na vs. CIA diagram (Fig. 13) shows moderate Al/Na values for the clay compared with the UCC, NASC and PAAS. Figure 14 also alludes to increased silicate weathering in the Isan clays analysed.

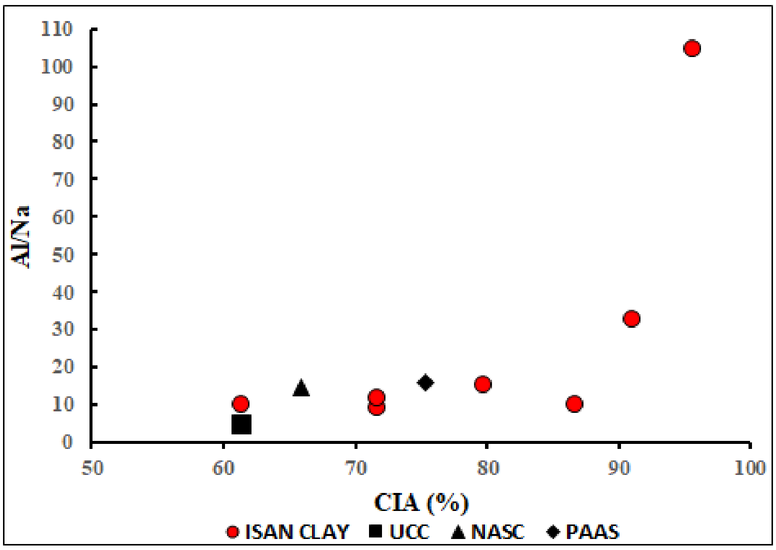

Figure 13. Connections of chemical index of alteration (CIA) with Al/Na ratio of the Isan clay.

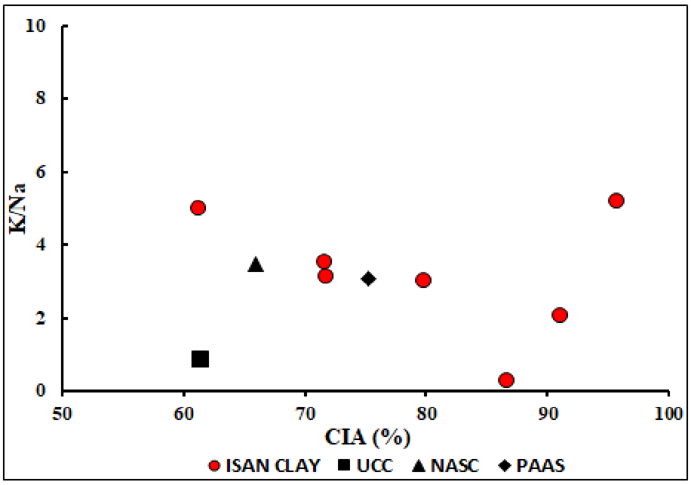

Figure 14. Connections of chemical index of alteration (CIA) with K/Na ratio in the clay samples.

Inorganic geochemical data and their applications are important for provenance studies (Taylor and McLennan, 1985; Condie et al., 1992; Cullers, 1995). According to McLennan et al. (1993), major elements provide information on both the rock composition of the provenance and the effects of sedimentary processes, such as weathering and sorting. The bivariate plot of Na_2O-K_2O shows that all but one (Turro B) of the samples are quartz-rich, which suggests that they are of felsic origin (Fig. 15). The ternary diagram in Figure 16 shows most of the samples plotting around the granite area, this suggests derivation from felsic igneous source.

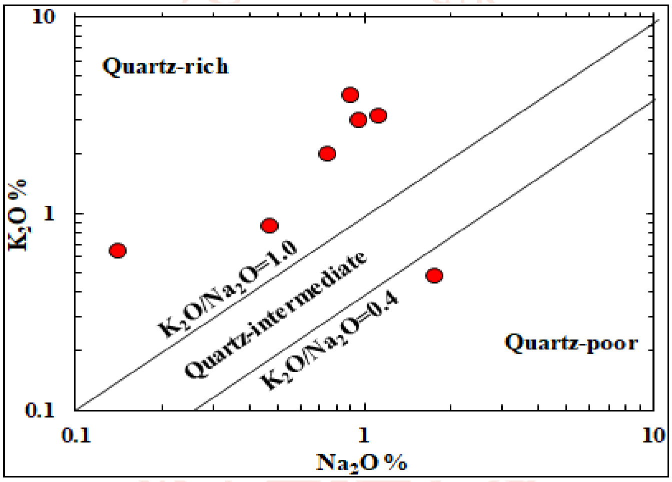

Figure 15. Bivariate Plot of Na_2O versus K_2O of the studied sediments showing quartz content, after (Crook, 1974).

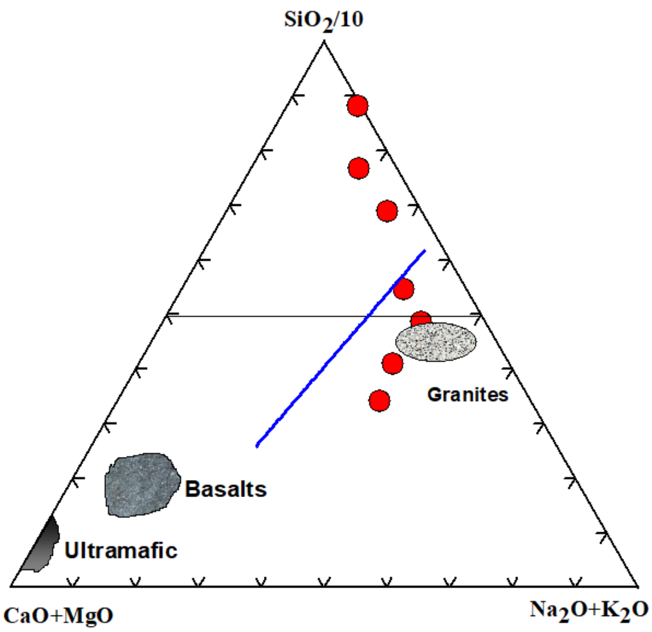

Figure 16. Plot of $Na_2O + K_2O$, $SiO_2/10$ and $CaO + MgO$ to illustrate possible affinities of the samples to felsic, mafic or ultramafic rocks (after Taylor and McLennan, 1985).

The provenance discriminant function plots (Fig. 17) show the clay samples appearing in multiple zones. Of particular note is the Orudi B samples plotting in the mafic igneous provenance zone, this suggests that the Orudi B clays may have been sourced from charnokites, while the rest of the clays may have originated from granites and migmatites. The provenance of a sedimentary formation can be determined via the use of K versus Rb ratios that are generally comparable to standard continental crust values (Floyd and Leveridge, 1987). The clay samples being examined plotted mainly in the acidic/intermediate composition zone with only one in the basic zone (Figure 18).

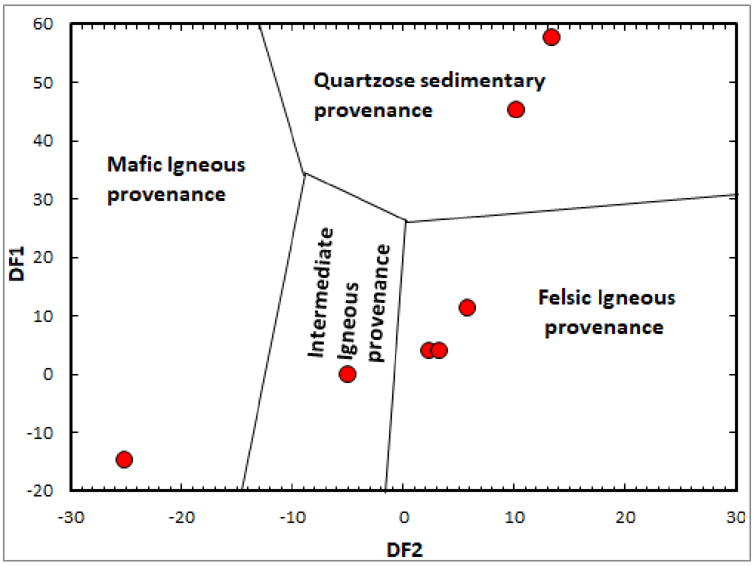

Figure 17. Discriminant function diagrams using major elements for the provenance signatures of the samples (After Roser & Korsch, 1988)

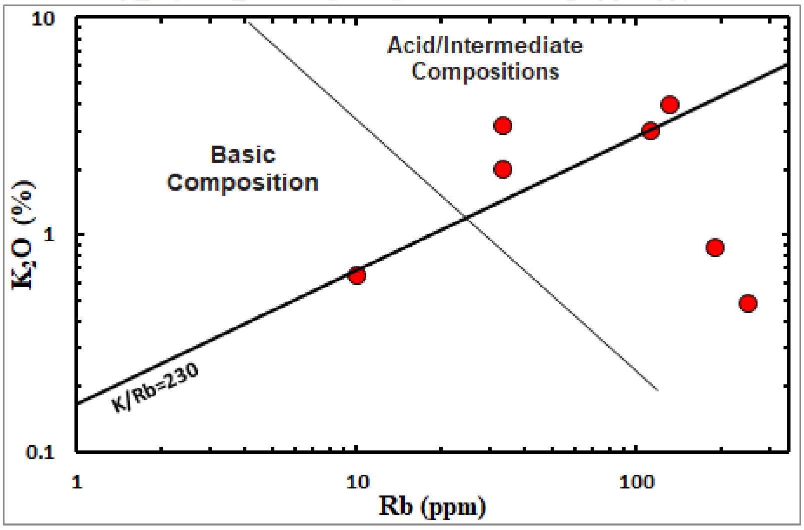

Figure 18. K_2O vs. Rb plot. Fields after Floyd and Leveridge (1987).

Palaeoclimate

According to Kovács et al (2013), the degree of chemical weathering in soils increases with mean annual precipitation and mean annual temperature. Sheldon et al. (2002) and Nordt and Driese (2010) developed expressions to deduce palaeo-precipitation and palaeo-temperature based on database of major-element analyses of modern soils from Marbut (1935). This is based on the spatial extent and continuity of coverage on a continental scale to ensure representation of a large range of climate regimes (Kovács et al., 2013). Mean annual precipitation (MAP) can be related to the chemical index of alteration without potassium (CIA–K) and is calibrated for precipitation values between 200 and 1600 mm/year (Sheldon et al. (2002):

MAP (mm/year) = 14.265(CIA-K) – 37.632 1

where CIA–K = 100 × [Al_2O_3/(Al_2O_3 + CaO + Na_2O)]. Sheldon and Retallack (2004) affirm that results obtained with this method are consistent with independent estimates from other proxies, such as plant fossils. According to Kovács et al (2013), a climofunction by Sheldon (2006) applied to inceptisols allows mean annual temperature (MAT) to be calculated using the expression:

MAT (°C) = 46.94C + 3.99 2

where C = mAl/mSi (m is the molar ratio). The results of the palaeo-precipitation and palaeo-temperature are shown in the Table 2. Recreated palaeoclimate results based on the climofunctions indicate that during the formation of Isan clays, the climate was considerably colder and dryer than the prevailing climate (Table 2). The MAP values obtained from Equation 1 range between 921 and 1370 ± 182 mm/year and an average of 1169 mm/year. The MAT values from Equation 1 ranged from 12.2 to 15 °C, with an average of 13.9 °C. In Isan-Ekiti the climate is classified as Aw (Tropical Savanna, wet) by the Köppen-Geiger system. The average annual temperature is 24.5 °C and the rainfall averages 1298 mm (Climate-data.org). The driest month is January; there is 9 mm of precipitation in January. With an average of 238 mm, the most precipitation falls in September. The precipitation varies 229 mm between the driest month and the wettest month. March is the warmest month with an average of 26.7 °C, while August has the lowest average temperature of the year (22.4 °C.) During the year, the average temperatures vary by 4.3 °C (Climate-data.org). Figure 19(a) reveals that there is no correlation between MAT and CIA, suggesting that temperature was a minor factor in the formation of the clays. In contrast, there is a strong correlation between MAP and CIA (fig. 19b), implying that hydrolysis was a major factor in the formation of the clays. The paleoclimate data suggests that the Isan-Ekiti area might have once being a semi-arid environment. A bivariate plot by Suttner and Dutta (1986) to discriminate paleoclimatic condition (Fig. 20), shows the Isan clays plotting in the semi-arid zone with less chemical maturity.

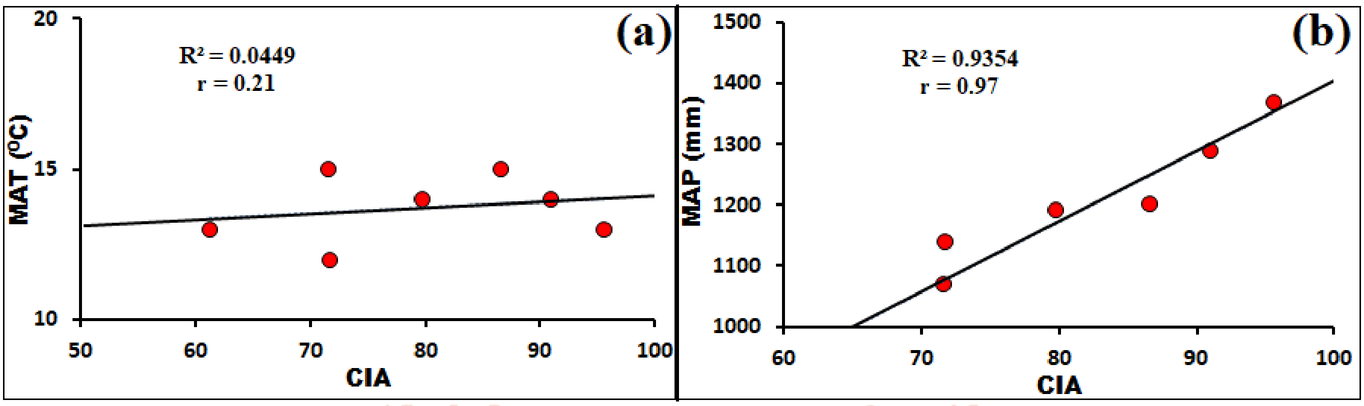

Figure 19. Relationship between (a) mean annual temperature (MAT) and CIA and (b) mean annual precipitation (MAP) and CIA of the Isan clays.

It is pertinent to take cognizance of the fact that kaolinitic palaeo-profiles may have not all formed in tropical to subtropical climates, and some may even not have formed under wet conditions (Chamley, 1989; Thiry, 2000). According to workers like Kuhlemann et al. (2008), Varga et al. (2011), we must take into consideration the impact of other effects (e.g., tectonic rejuvenation and the role of surface uplift) on the mineralogy and the CIA values.

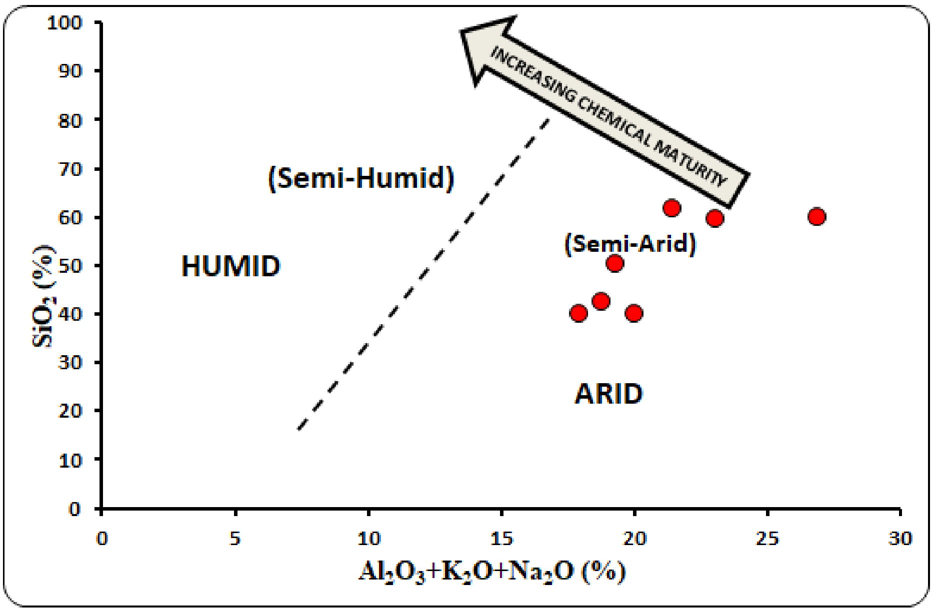

Figure 20. Bivariate plot of SiO_2 vs. (Al_2O_3 + K_2O + Na_2O) to discriminate paleoclimatic condition during the deposition of the Eocene sediments (after Suttner and Dutta, 1986).

CONCLUSION

Orudi and Aradee clays are mainly kaolinite with quartz and dickite present, while the samples from Turoo and Iyaya is composed mainly of quartz, kaolinite, minor feldspar and illite. SiO_2 is the most abundant in all the samples; the Turoo and Iyaya samples have a higher SiO_2 content than Orudi and Aradee samples. Analysis of the weathering state using several quantitative and qualitative indices indicates moderate weathering intensity. The clay samples are quartz-rich, which suggests that they are of felsic origin. The Orudi (B) clays may have been sourced from charnokites, while the rest of the clays may have originated from granites and migmatites.

Recreated palaeoclimate results based on the climofunctions indicate that during the formation of Isan clays, the climate was considerably colder and dryer than the prevailing climate; implying that the Isan-Ekiti area may have once being a semi-arid environment.

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