Provenance, Tectonic Setting and Source-Area Weathering of the Coastal Plain Sediments, South West, Nigeria

H.Y. Madukwe
Department of Geology
Ekiti State University
Ado-Ekiti, Ekiti State, Nigeria.
henrymadukwe@yahoo.co.uk

R.A. Obasi
Department of Geology
Ekiti State University
Ado-Ekiti, Ekiti State, Nigeria.
romanus914@yahoo.com

O.R. Fakolade
Department of Mineral Resources Engineering
Federal Polytechnic,
Ado-Ekiti, Ekiti State, Nigeria.
tosofakolade@yahoo.com

C.E. Bassey
Department of Geosciences
Akwa Ibom State University
Mkpat Enin, Akwa Ibom State, Nigeria
clembassey@yahoo.com

***Abstract*- Major oxide geochemical analysis was carried out on the Coastal Plain sediments in the Dahomey Basin, to infer their provenance, tectonic setting and source-area weathering. The depletion of highly mobile K and Ca elements is due to leaching during the formation of clay minerals during increased chemical weathering. Na is a highly mobile element that is enriched, this may be due to secondary enrichment. Si is a less mobile element and its enrichment suggests moderate chemical weathering. The immobile Fe and Ti and the less mobile Mg elements were depleted, this suggest that they may be from a common source with more felsic minerals and dearth of ferromagnesian minerals. The high Al_2O_3/TiO_2 ratio also suggests felsic source rock. The CIA values for the samples ranged between 9 and 30%, while CIW ranged from 10-32% indicating a very low degree of weathering of the source materials, suggestive of materials from reworked clastic sediments. The PIA values ranged from -43-28%, this also indicates very low weathering with the negative values suggesting rapid deposition of pre-existing clastic sediments with little or no weathering. MIA values for the samples indicates no weathering of the source material, which is not in agreement with the other weathering indices. The Coastal Plain sediments plotted in the plagioclase zone on the A–CN–K diagram, indicating little or no weathering for some samples. The weathering trend suggests that the sediments are rich in plagioclase feldspars without alteration to smectite. The ternary plot of SiO_2/Al_2O_3, MgO and Fe_2O_3 indicated that the studied samples were deposited in the non-marine and deltaic settings. This observed trend is supported by the binary plot of Fe_2O_3 versus MgO. Provenance discrimination diagram shows that plots appeared in three provenance fields except P4 (main igneous) indicating that they are derived from multiple environments. The tectonic setting plots shows most of the sediments appeared in the passive continental margin field and few samples in the active continental Margin and which may suggests sediments from multiple sources of igneous and gneissic origin plus reworked older clastic sediments**.

***Index Terms*—Felsic, weathering, chemical maturity, provenance, tectonic setting**

I. INTRODUCTION

Clastic sediments are loose, solid particles that originate from the weathering and erosion of pre-existing rocks. Siliciclastic sedimentary facies are very important parts of sedimentary basin analysis. The textural features of these siliciclastic facies are due to natural processes like of weathering, erosion, transportation and deposition. The compositions of clastic sediments are affected by several factors, such as hydraulic sizing, tectonic environment, diagenesis, weathering and transportation processes [1, 2, 3]. Their composition consecutively depends on the primary chemical composition of the source rock area and the tectonic setting of the depositional basins [4, 5, 6]. Therefore, composition of sandstones has been used as sensitive indicator for provenance and weathering conditions at the source of sediments [7, 8, 9]. The major assumption proposed for sandstone provenance studies is that each tectonic setting consist of its own rock type [10, 11]. Even though some geochemical ratios can be altered during

weathering during oxidation [1] or diagenesis [12, 13], as long as the bulk chemical composition is not totally altered, the geochemical composition of sediments is an important tool in the study of provenance [14, 1, 15].
The major oxide discrimination diagrams of [14] have been usually used to classify the tectonic settings of sedimentary basins [16] and according to [17] caution is required in their arbitrary use. The most essential clues for the tectonic setting of basins come from the relative depletion of the oxides like CaO and Na_2O (the most mobile elements), among others. The oxides are understood to show enrichment or depletion of quartz, K-feldspars, micas and plagioclase. The ratio of the most immobile elements to the mobile ones increases towards the passive margin to the relative tectonic stability [16] and therefore suggests prolonged weathering.
The Dahomey basin is an extensive sedimentary basin extending almost from south-Ghana to Nigeria (precisely the Benin hinge-line). The Dahomey basin (Fig.1) is a marginal pull-apart basin [18] or Margin sag basin [19], which was initiated during the early Cretaceous separation of African and South American lithospheric plates. A number of authors have identified and described the eight lithostratigraphic units in the Dahomey basin [20, 21, 22, 23, 24]. In most parts of the basin, the stratigraphy is dominated by sand and shale alternations with minor proportion of limestone [23].

This study was carried out in different localities in Lagos State, south-western Nigeria lying between longitude 3^o 04' and 3^o 35' East and latitude 6^o 22' and 6^o 41' North. They extend from the western end of Agbara to Ajah locality (Fig. 2). This present research is aimed at interpreting the sediment source-area weathering, provenance, tectonic setting of the coastal plain sediments based on major oxides geochemical data.

II. Stratigraphy of Dahomey Basin

Previous work on the Cretaceous stratigraphy (Fig.3) of the Dahomey basin has recognized three formations belonging to the Abeokuta group [22] as follows; (1) The Ise Formation which is Neocomian to Albian in age consist essentially of continental sands, grits and siltstones. This is directly overlying the south western Precambrian Basement Complex. (2) The Afowo Formation which overlay Ise Formation consists of coarse to medium-grained sandstones with

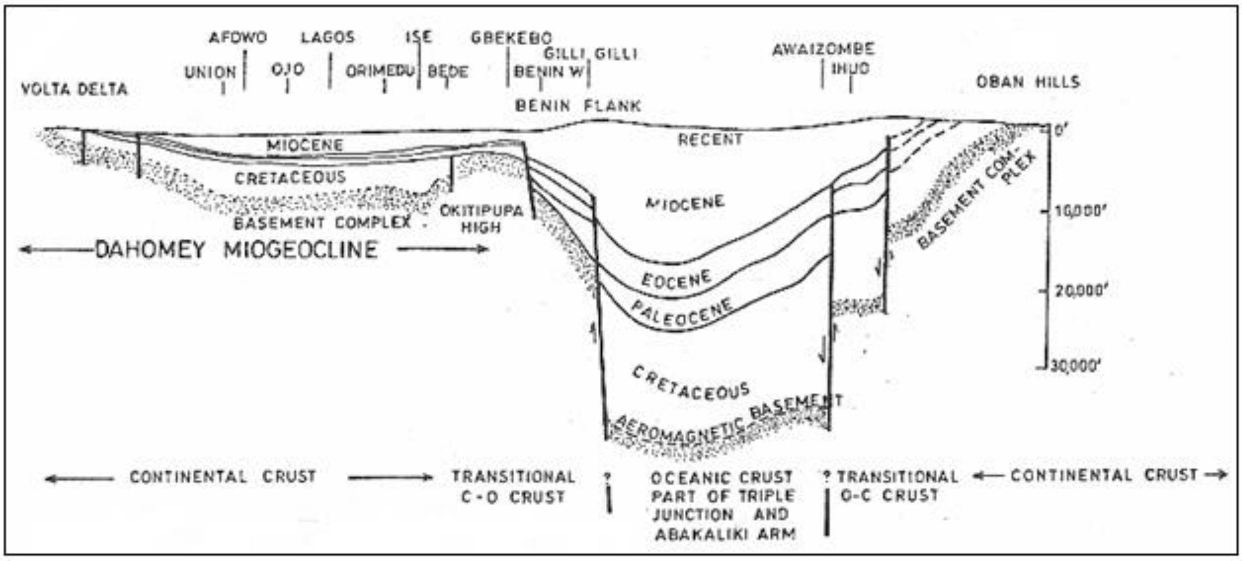

Figure 1: East-West geological section showing the Dahomey Basin and Upper part of the Niger Delta [25].

variable interbeds of shales, siltstones and clay. The sediments of this formation were deposited in a transitional to marginal marine environment during turonian to Maastritchtian age. (3) The Araromi Formation consists basically of sand, overlain by dark-grey shales and interbedded limestone and marls occasional lignite bands. The formation conformably overlies the Afowo Formation and Maastrichtian to Paleocene age has been assigned [22]. The Abeokuta Formation was conformably overlaid by Imo group which comprises of shale limestone and marls.
The two-lithosratigraphic units under this group are: Ewekoro formation which consists of thick fossiliferous limestone. [26] described the Formation as consisting of shaly limestone 12.5m thick which tends to be sandy and divided it into three microfacies. [27] further modified this and proposed a fourth unit. It is Paleocene in age and associated with shallow marine environment due to abundance of coralline algae, gastropods, pelecypods, echinoid fragments and other skeletal debris. The Akinbo Formation overlies Ewekoro Formation and it consists of shale, glauconitic rock bank, and gritty sand to pure grey and with little clay. Limestone lenses from Ewekoro formation grades literally into the Akinbo shale towards the base. The base is characterized by the presence of a glauconitic rock.

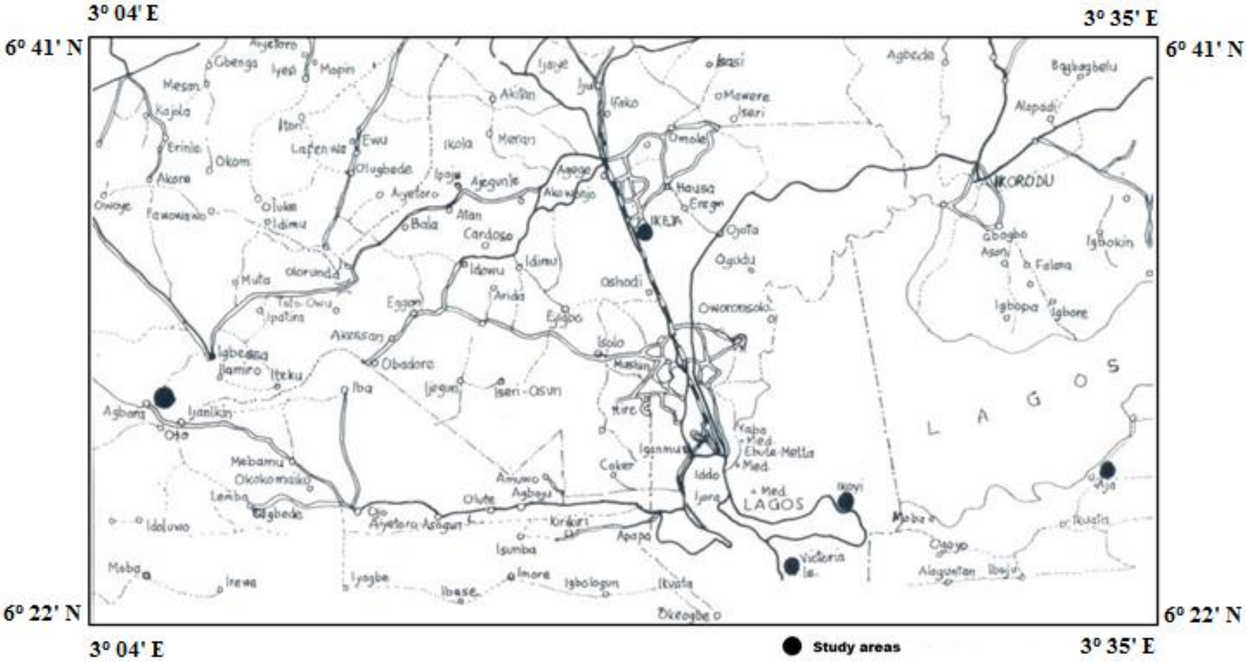

Figure 2: Map showing the location of the study area (Adapted from Lagos Sheet 68, 1st Edition Fed. Surveys Nigeria, 1966).

The age of the formation is Paleocene to Eocene. The Oshoshun Formation overlies the Imo group which is a sequence of mostly pale greenish-grey laminated phosphatic marls, light grey white-purple clay with interbeds of sandstones. It also consists of claystone underlain by argillaceous limestone of phosphatic and glauconitic materials in the lower part of the formation and were deposited during Eocene [23]. The sedimentation of the Oshoshun Formation was followed by a regression phase which deposited the sandstone unit of Ilaro Formation [28]. The sequence represents mainly coarse sandy estuarine deltaic and continental beds which show rapid lateral facies change. The coastal plain sands are the youngest sedimentary unit in the eastern Dahomey basin. It conceivably unconformably overlay the Ilaro Formation but lack convincing evidence [20]. It consists of soft, poorly sorted clayey sand and pebbly sands deposited during Oligocene to Recent.

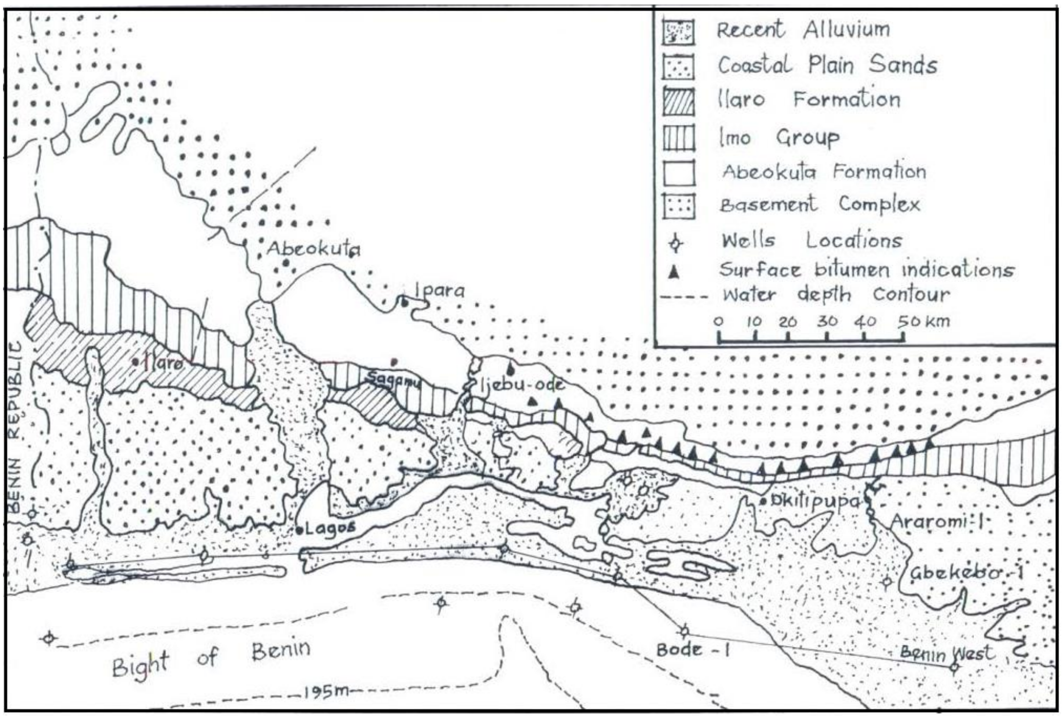

Figure 3. Geological Map of the Eastern Dahomey Basin [23].

III. MATERIALS AND METHODS

There was no outcrop within this study area; samples were collected from five borehole at 3.0 meters interval. Boreholes investigated are located at Agbara, Victoria Island, Ikoyi, Ikeja and Ajah. Three hundred and twenty four subsurface samples (324) were collected while an average of 30 samples, based on the sub-units established was selected for laboratory analysis. Precaution was taken during the sample collection to avoid contamination. The Atomic Absorption Spectrophotometer (AAS UNICAM 969 MODEL) was used for the geochemical analysis. Dilute hydrochloric acid was used on the sample for possible gas presence. Hand lens and Binocular microscope were also used for mineralogical identification codes.

A. Geochemical Analysis

Thirty samples were selected for geochemical analysis. The samples were air-dried, crushed using a jaw crasher, and pulverized with the ball milling machine. 10 grams of each sample was weighed and put in a clean digestion bottle. With the aid of a calibrated plastic syringe, 15mls of 40% Hydrochloric acid was added with the help of an automatic pipette, and 10mls of Hydrofluoric acid was also added. In the process of mixing the two acids, the bottle was tightly closed in order to avoid the escape of silicon=fluoride [SiF4] gas. The digestion bottle was later put on a water bath and warmed up to 70 degree centigrade for about two hours and allowed to cool down to 25- 30 degree centigrade. A 100 mls saturated boric acid was added to the solution and the bottle was closed tightened. The bottle was put on a water bath up to 70ₒc until the milky solution became clear. Distilled water was added to it after cooling to make a solution of 250 mls; part of distilled sample was put in a sample container which was then analyzed with a dilution factor of 25. Major elemental oxides such as SiO_2, Al_2O_3, K_2O, Na_2O, CaO, MgO, FeO, Fe_2O_3 and TiO_2 were obtained using Atomic Absorption Spectrophotometer [UNICAM 969 model] with a precision of +0.5.

B. Mineralogical Analysis

A selective staining technique was utilized to separate quartz, feldspar and rock fragments. The lighter mineral fraction of 2mg were collected and placed in a lead and bath in warm concentrated Hydrochloric acid [HCl] for a minute. After washing, the sample was immersed in one percentage aqueous solution of malachite green for five minutes rinsed and dried. The sample was again mounted on a slide with Canada balsam, and studied under the microscope. Quartz remains unchanged in colour while feldspars stain yellowish and rock fragment stain brown. The relative proportion of different detritus minerals were determined by point counting and results recorded in percentage.

IV. RESULTS AND DISCUSSION

A. Geochemical Composition

Table 1 shows the major oxides component of the coastal plain sediments. The samples are dominated by SiO_2, which ranges from 73.6-85% (Average = 81.14%). The limited range of SiO_2 content may be due to poor sorting and rapid deposition. Al_2O_3 ranges from 4.70-12.9% (Average = 8.19%), this may be attributed to composition of lithic fragments while the low concentrations of Fe_2O_3 (Average = 1.462%) MgO (Average = 0.22%); FeO (Average = 0.58%); K_2O (Average = 1.05%), TiO_2 (Average = 0.01%) and CaO (Average = 0.02%) may be ascribed to chemical destruction under oxidizing conditions during weathering and diagenesis or source-area composition. Lack of MnO is probably due to dissimilatory manganese reduction by microbes or source-area composition.

Chemical alteration of rocks during weathering led to the depletion of alkalis and alkaline earth elements and preferential enrichment of Al_2O_3 [29]. The high Al_2O_3/TiO_2 ratio of 69 - 478 (Average = 222) indicates felsic source rock.

B. Source-area Weathering

According to [12], the evaluation of the degree of chemical weathering of the sediments' source rocks can be determined by calculating the Chemical Index of Alteration (CIA), where CIA = molar ($Al_2O_3/[Al_2O_3+CaO+Na_2O+K_2O]$).This index works correctly when Ca, Na, and K decrease as the intensity of weathering increases [30]. The Chemical Index of Weathering (CIW) proposed by [31] 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 value of 50 for unweathered upper continental crust and roughly 100 for highly weathered materials, with complete removal of alkali and alkaline-earth elements [32, 33, 34]. Low CIA values (i.e. 50 or less) also might reflect cool and / or arid conditions [35]. The intensity of the chemical weathering can also be estimated using the Plagioclase Index of Alteration [35]; in molecular proportions: $PIA = [(Al_2O_3-K_2O)/ (Al_2O_3 + CaO^* + Na_2O-K_2O)] \times 100$ where CaO* is the CaO residing only in the silicate fraction. Unweathered plagioclase has PIA value of 50 while Phanerozoic shales have PIA value of 79. [36] Voicu et al. (1997) also proposed the Mineralogical Index of Alteration (MIA) as 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. The extreme value of 100% indicates complete weathering of a primary material into its equivalent weathered product [37].

The CIA values for the samples ranged between 9 and 30% (Av. 17%), while CIW ranged from 10-32% (Av. 19%) indicating a very low degree of weathering of the source materials, suggestive of materials from reworked clastic sediments. The PIA values ranged from -43-28% (Av. 3%), this also indicates very low weathering with the negative values suggesting rapid deposition of pre-existing clastic sediments with little or no weathering.

MIA values for the samples ranged between -83 and 40% with an average value of -66%, which indicates no weathering of the source material, this is not in agreement with the CIA, CIW PIA.

TABLE I. MAJOR OXIDES COMPONENT (WT %) OF THE COASTAL PLAIN SEDIMENTS AND THEIR WEATHERING INDICES

Oxides (%)	**AGB /30-48**	**AGB /54-60**	**AGB /78-84**	**AGB /144--156**	**KJA/ 33-51**	**KJA/ 66-72**	**KJA/1 17-123**	**KJA/ 132-141**	**VI/8-21**	**VI/3 3-64**	**VI/60-90**	**IKY/ 54-66**	**IKY/6 6-87**	**IKY/ 150-207**	**AJ/4 2-54**	**AJ/90 -102**	**AJ/14 4-180**
SiO2	82.09	80.95	73.6	80.5	81.2	81.5	79.7	82.6	83.7	85	81.1	84.6	82.8	80.8	75.5	79.9	83.9
Al2O3	4.78	8.09	8.8	8.2	9.4	7.9	6.7	6.1	6.7	8.1	9.5	6.5	7.4	9.5	11.8	12.9	6.9
Fe2O3	2.03	2.92	2.8	1.2	0.9	1.1	0.6	1.5	1.3	1.7	1.1	1.3	1.1	0.9	1.8	1.1	1.4
FeO	0.92	0.35	0.6	0.4	0.5	0.3	0.4	0.6	0.8	0.5	1	0.6	0.5	0.4	0.8	0.5	0.7
MgO	0.33	0.29	0.2	0.2	0.3	0.2	0.2	0.4	0.2	0.3	0.2	0.1	0.1	0.2	0.1	0.1	0.3
K2O	0.52	0.38	1.1	1.2	2.5	2.4	1.9	2.3	0.7	0.6	0.35	0.7	1.3	0.3	0.3	0.3	1
CaO	0	1.21	1.4	0.2	0	0.7	1	0.5	4	0.07	0	1.2	1.6	0	0	0	0.1
Na2O	6.45	5.2	4.6	6.8	5.9	8.8	3.3	4.7	8	6	6.4	3.6	4.7	5.3	5.7	4.7	4.1
TIO2	0.01	0	0	0	0	0	0	0	0	0	0		0	0	0.1	0	0.1
TOTAL	97.23	100	97.7	100	100	99.3	96.6	99.7	100	99.7	100	98.4	99.5	97.5	96	98.6	98.5
PIA	19	28	22	0	-37	-16	-43	-18	5	15	10	11	-3	10	21	15	9
CIA	22.56	30.07	28.28	12.77	9.68	8.46	8.82	16.67	9.29	20.31	14.01	19.12	12.64	13.85	23.08	18.03	21.21
CIW	23.94	31.30	31.82	14.63	13.24	10.38	12.24	22.39	9.77	21.88	14.67	21.31	14.86	14.52	24.00	18.97	25.00
MIA	-54.9	-39.9	-43.4	-74.5	-80.6	-83.1	-82.4	-66.7	-81.4	-59.4	-72.0	-61.8	-74.7	-72.3	-53.8	-63.9	-57.6

CIA: Chemical Index of Alteration
CIW: Chemical Index of Weathering
PIA: Plagioclase Index of Alteration
MIA: Mineralogical Index of Alteration

From the A–CN–K Ternary diagram (Fig.4), the Coastal Plain sediments plotted in the plagioclase zone, showing little or no weathering for some samples. The weathering trend suggests that the sediments are rich in plagioclase feldspars without alteration to smectite. The chemical composition of weathering products in a river basin is expected to exhibit entrenched concepts on mobility of various elements during weathering [39, 40], and therefore to assess the state of chemical and physical weathering [41, 40, 42]. Elemental ratios calculated with respect to Al are used to identify and evaluate the major element mobility. According to [40], the ratio of the content of element X and Al_2O_3 in rivers divided by the ratio of the same element content of upper continental crust (UCC) gives the elemental ratio.

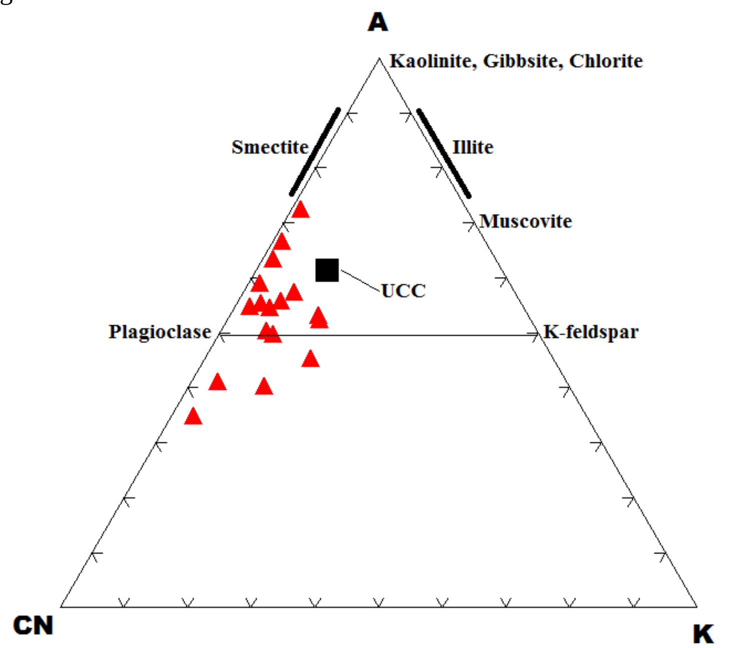

Figure 4. Ternary diagram showing the weathering trend of the Coastal Plain sediments (all in molar proportions); Al_2O_3–CaO +Na_2O−K_2O (A–CN–K). Average UCC value from [38].

The elemental ratio refers to the relative enrichment or depletion of the element, i.e., >1 indicates enrichment, <1 indicates depletion, and =1 indicates no change in the relative abundance of the element. The Coastal Plain sediments have, CaO, K_2O,

TiO_2, Fe_2O_3, MgO values less than 1, while SiO_2, and Na_2O have values greater than 1. The depletion of highly mobile K and Ca elements is due to leaching during the formation of clay minerals during increased chemical weathering. Na is a highly mobile element that is enriched, this may be due to secondary enrichment. Si is a less mobile element and its enrichment suggests moderate chemical weathering; the immobile Fe and Ti and the less mobile Mg elements were depleted, this suggest that they may be from a common source with more felsic minerals and dearth of ferromagnesian minerals. The plot of Na_2O/Al_2O_3 vs. K_2O/Al_2O_3 introduced by [43], shows that depletion of Na and K is not evident in the samples, compared to UCC (Fig. 5).

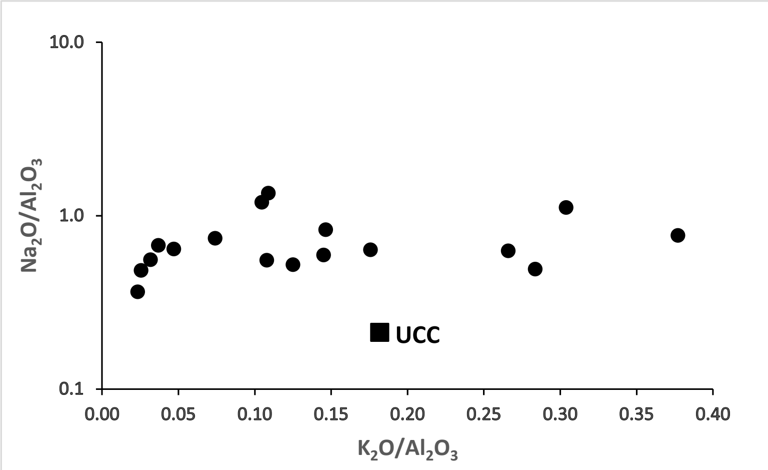

Figure 5. Diagram showing variations in Na_2O/Al_2O_3 vs. K_2O/Al_2O_3 (all molar ratios) for all of the samples and UCC, after [43].

C. Provenance and tectonic settings

In the QFL ternary diagram, the samples plotted in the craton interior field (Fig. 6), according to [44], sandstones plotting in the craton field are mature sandstones derived from relatively low-lying granitoid and gneissic sources, supplemented by recycled sands from associated platform or passive margin basins. We are of the opinion that recycled sands are the main source. Several authors [45, 14, 4, 7, 8] have related sandstone geochemistry to specific tectonic environment. The discriminant function plot of [8] defined four (4) main provenances: mafic igneous provenance; intermediate igneous provenance; felsic igneous provenance; and quartzose sedimentary provenance (Fig. 7). The Coastal Plain sediments plots appeared in three provenance fields except P4 (main igneous) indicating that they are derived from multiple environments.

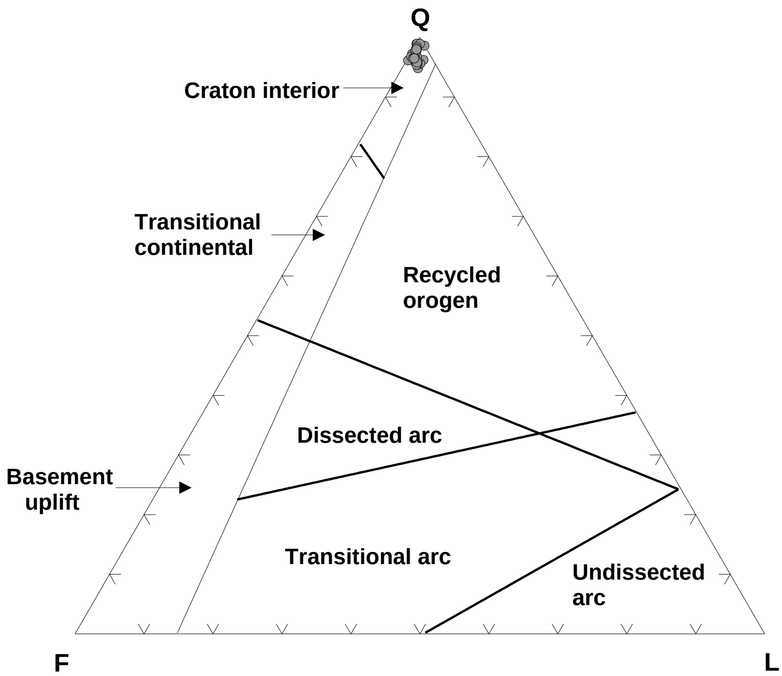

Figure 6. QFL plot showing framework modes for the Coastal Plain sediments: Q is total quartz grains, including monocrystalline and polycrystalline types; F is total feldspar grains; L is total unstable lithic fragments. Provenance fields from [44].

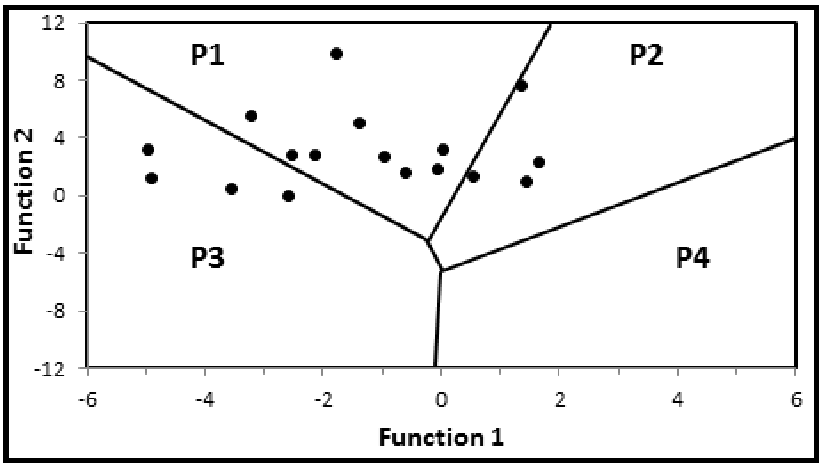

Figure 7. Discriminant function diagram using major elements for the provenance signatures of the Coastal Plain sediments, after [8]. P1= felsic igneous provenance; P2= intermediate igneous provenance; P3= quartzose sedimentary provenance and P4= mafic igneous provenance.

[7] created a tectonic discrimination diagram using K_2O/Na_2O ratio versus SiO_2 (Fig. 8) to determine the tectonic setting of clastic terrigenous sedimentary rocks. The cross plot is used to discriminate between sediments deposited in the Passive Continental Margin (PM), Active Continental Margin (ACM) and the Oceanic Island Arc (OIA). Most of the studied samples plotted in the Passive Margin and few in the Active Continental Margin tectonic settings suggesting a syn-rift faulting setting of a transform margin; it also suggests that the sediments may have come from multiple sources.

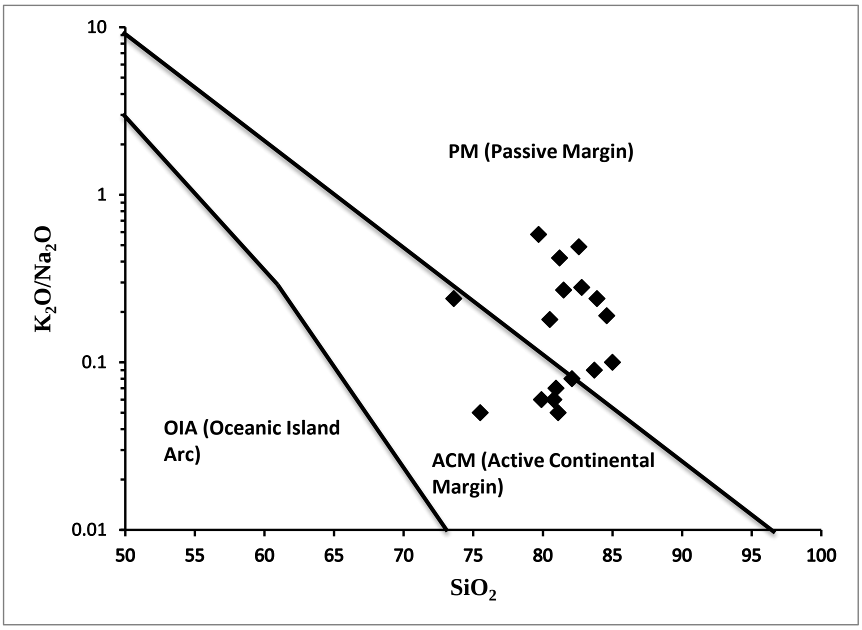

Figure 8. Tectonic discrimination plot for the Coastal Plain sediments, after [7].

Figures 9, 10 and 11 are also tectonic discrimination diagrams of the Coastal Plain sediments. Figure 12 also confirms that the Coastal Plain sediments are continental sands.

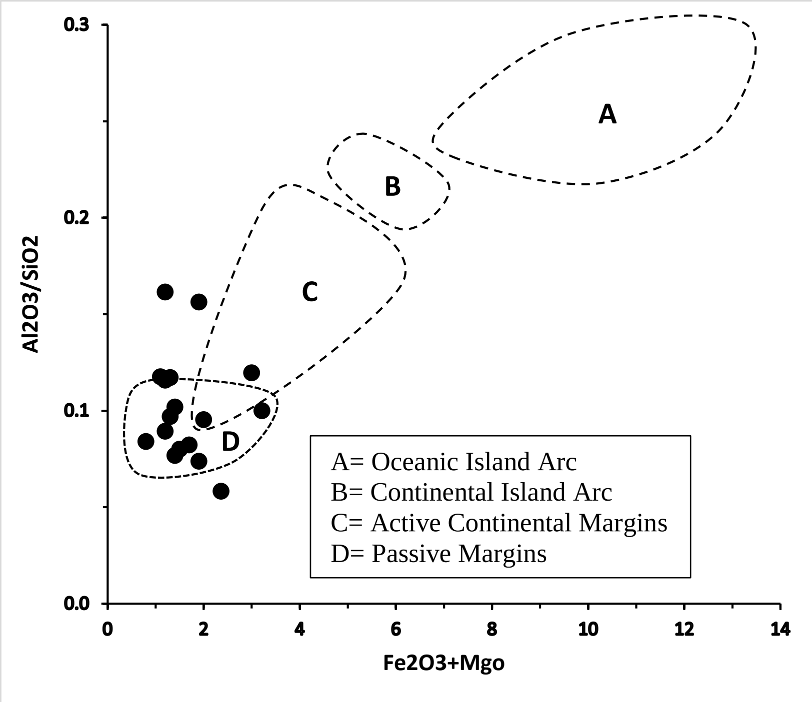

Figure 9. Tectonic setting discrimination Plot of Al_2O_3/SiO_2 versus Fe_2O_3 + MgO of the Coastal Plain sediments. Dashed lines denote the major fields representing various tectonic settings, after [14].

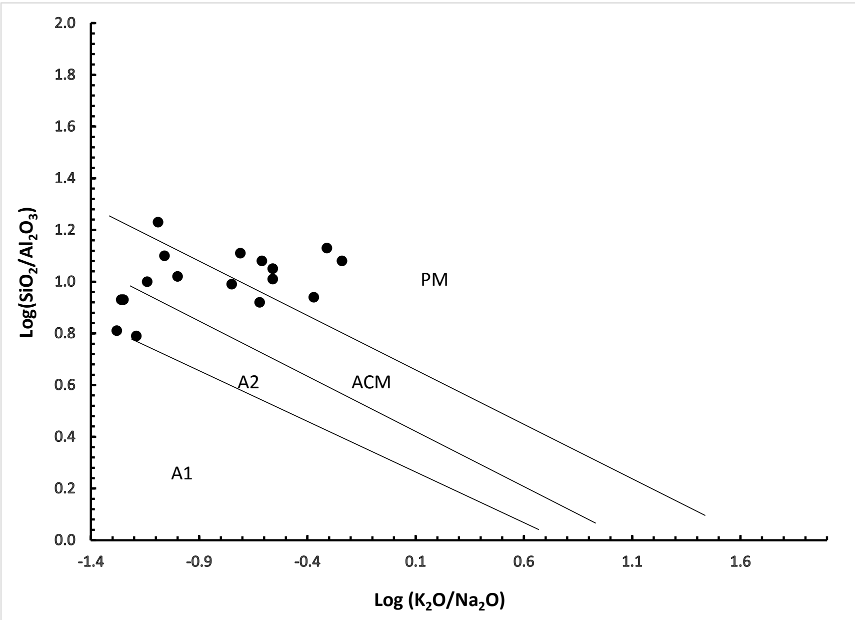

Figure 10. K_2O/Na_2O versus SiO_2/Al_2O_3 ratio – ratio diagram of the Coastal Plain sediments suggesting A2, PM and ACM tectonic setting, after [46]. A1= arc setting and andesitic detritus; A2= evolved arc setting, felsic pluton detritus ACM= Active Continental Margin; PM= Passive Margin.

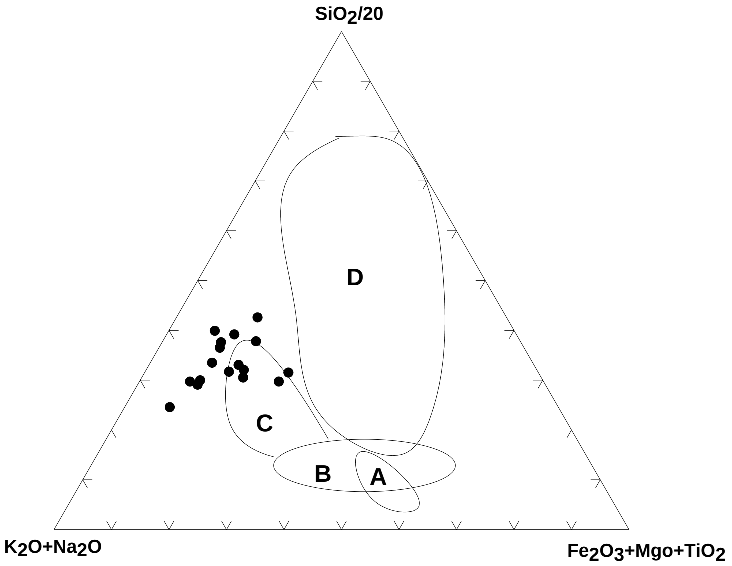

Figure 11. Plot of the major element composition of the Coastal Plain sediments on the tectonic setting discrimination diagram of [47]. A: Oceanic island Arc, B: continental island Arc, C: active continental margin, D: passive margin.

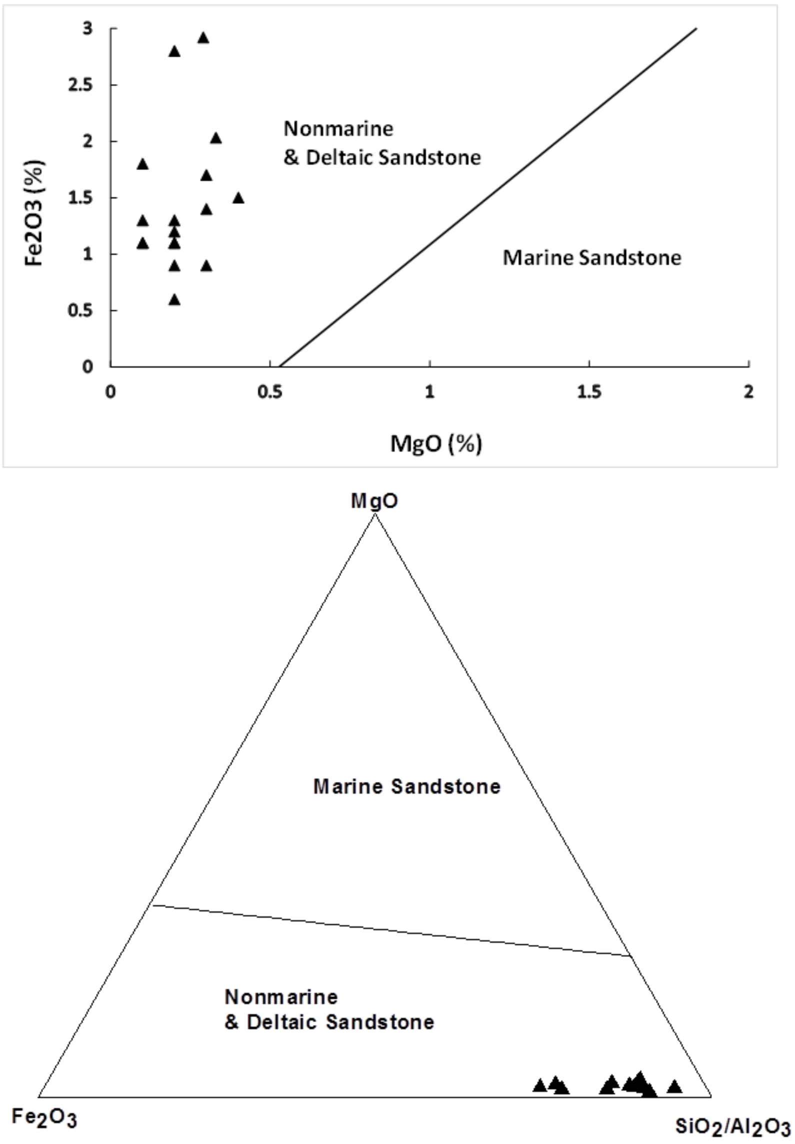

Figure 12. Binary and ternary diagrams showing characterization and differentiation of marine from nonmarine sandstones. The Coastal Plain sediments plotted in the non-marine and deltaic field, after [48].

V. CONCLUSIONS

The Coastal Plain sediments are of continental origin. The weathering indices indicates a very low degree of weathering of the source materials, suggestive of materials from reworked clastic sediments. However, MIA values for the samples indicates no weathering of the source material, which is not in agreement with the CIA, CIW PIA. The immobile Fe and Ti and the less mobile Mg elements were depleted, this suggest that they may be from a common source with more felsic minerals and dearth of ferromagnesian minerals. The high Al_2O_3/TiO_2 ratio also suggests felsic source rock. The tectonic setting is the active continental Margin and the passive continental margin, which suggests sediments from multiple sources of igneous and gneissic origin plus reworked older sediments.

REFERENCES

List and number all bibliographical references in 9-point Times, single-spaced, at the end of your paper. When referenced in the text, enclose the citation number in square brackets, for example: [1]. Where appropriate, include the name(s) of editors of referenced books. The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in "[3]"—do not use "Ref. [3]" or "reference [3]". Do not use reference citations as nouns of a sentence (e.g., not: "as the writer explains in [1]").

Unless there are six authors or more give all authors' names and do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished" [4]. Papers that have been accepted for publication should be cited as "in press" [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

[1] S. R. Taylor, and S. M. McLennan, The Continental Crust: its Composition and Evolution: An Examination of the Geological Record Preserved in Sedimentary Rocks: Oxford, U.K., Blackwell, 1985.

[2] D.J, Wronkiewicz, and K.C. Condie, Geochemistry of Archean shales from the Witwatersrand Supergroup, South Africa: source-area weathering and provenance. Geochim. Cosmochim. Acta, 1987, 51: pp. 2401–2416.

[3] D.J, Wronkiewicz, and K.C. Condie, Geochemistry and provenance of sediments from the Pongola Supergroup, South Africa: Evidence for a 3.0-Ga-old continental Craton: Geochimica et Cosmochimica Acta, 1989, 53: pp. 1537–1549.

[4] M. R. Bhatia, and K. W. Crook, Trace element characteristics of greywackes and tectonic setting discrimination of sedimentary basins. Contributions to Mineralogy and Petrology, 1986, 92: pp.181-193.

[5] B.K., Das and B. Haake, 2003. Geochemistry of Rewalsar Lake sediments, Lesser Himalaya, India: Implications for source-area weathering, provenance and tectonic setting. J. Geosci., 7: pp.299–312.

[6] Z. Jin, F. Li, J. Cao, S. Wang, J. Yu, Geochemistry of Daihai Lake sediments, Inner Mongolia, north China: Implications for provenance, sedimentary sorting and catchment weathering. Geomorphology, 80, 2006. pp. 147–163.

[7] B. P. Roser and R. J. Korsch, Determination of tectonic setting of sandstone-mudstone suites using SiO_2 content and K_2O/Na_2O ratio. J. Geol., 1986, 94: pp.635-650.

[8] B. P. Roser and R. J. Korsch, Provenance signature of sandstone-mudstone suite determined using discriminant function analysis of major element data. Chem. Geol., 1988, 67: pp.119-139.

[9] P. Huntsman-Mapilaa, A.B. Kampunzuc, B. Vinkc, S. Ringrosea, Cryptic indicators of provenance from the geochemistry of the Okavango Delta sediments, Botswana. Sedim. Geol., 2005, 174: pp.123–148.

[10] W.R. Dickinson and C.A. Suczek, Plate tectonics and sandstone compositions: American Association of petroleum Geologist, 1979, 63: pp.2164 – 2182.

[11] W.R. Dickinson, Interpreting provenance relation from detrital modes of sandstones, *in* Zuffa, G.G. (ed.), Provenance of Arenites: NATO ASI Series, C 148, D. Reidel Publishing Company, Dordrecht, 1985, pp.333–363.

[12] H.W. Nesbitt and G.M. Young, Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. Nature, 1982, pp.299: 715–717.

[13] A.E. Milodowski, and J.A. Zalasiewiez, Redistribution of rare-earth elements during diagenesis of turbidite / hemipelagite, mudrock sequences of Landovery age from central Wales. Geological Society of London, special Publications, 57, 101-124. Mining Geol., 1991, 154 (1): pp.65-68.

[14] M. R. Bhatia, Plate tectonics and geochemical composition of sandstone. J. Geol., 1983, 91: pp.611-627.

[15] D. Bakkiaraj, R. Nagendra, R., Nagarajan, and J. S. Armstrong-Altrin, Geochemistry of sandstones from the Upper Cretaceous Sillakkudi Formation, Cauvery Basin, Southern India: Implication for provenance. Journal of the Geological Society of India, 2010, 76: pp.453-467.

[16] J.S. Armstrong-Altrin, Y.I. Lee, S.P. Verma, S. Ramasamy, Geochemistry of sandstones from the upper Miocene kudankulam Formation, southern India: Implication for provenance, weathering and tectonic setting. Journal of sedimentary Research, 2004, 74(2): pp.285 – 297.

[17] J.S. Armstrong-Altrin, S.P. Verma, Critical evaluation of six tectonic setting discrimination diagrams using geochemical data of Neogene sediments from known tectonic settings: Sedimentary Geology, 2005, 177(1-2): pp.115-129.

[18] H.D. Klemme, Geothermal gradient, heat flow and hydrocarbon recovery. In: A.G. Fisher and S. Judson (eds). Petroleum and global tectonics. Princeton University Press, 1975, pp. 251-304.

[19] D.R. Kingston, C.P. Dishroon, and P.A. Williams, Global basin classification system. American Association of Petroleum Geologists Bulletin, 1983, 67: pp.2175-2193.

[20] H.A. Jones and R.D. Hockey, The Geology of part of Southwestern Nigeria. Bull. Geol. Surv. Nig., 1964, 31: 101.

[21] M.E. Omatsola, and O.S. Adegoke, Tectonic Evolution of the Dahomey basin [West Africa] and its implication in the opening of the North and South Atlantic. Broc. 26th Int. Geol. Paris, 1980, pp.268.

[22] Omatsola, M.E and Adegoke O.S. 1981. Tectonic and Cretaceous stratigraphy of the Dahomey basin. Journal of Mining Geology, 154 (1): p.65-68.

[23] O.A. Agagu, A geological guide to Bituminous sediments in Southwestern Nigeria. Unpublished Report, Department of Geology University of Ibadan, 1985.

[24] A. Akinmosin, A.A. Odewande, and A.I. Akintola, Geochemical Composition and Textural Features of Some Carbonate Rocks in Parts of Southwestern Nigeria. Ife Journal of Science, 2005, 7, (1): pp.101-111.

[25] A. J. Whiteman, Nigeria: Its petroleum geology, resources and potential, graham and trotman, London, 1982, Vol 2.

[26] O.S. Adegoke, Stratigraphy and Paleontology of the Ewekoro Formation (Paleocene) of Southwestern. Nig. Bull. Am. Paleontol., 1977, 71(293): 375.

[27] F.G.A. Ogbe, Stratigraphy of Strata Exposed in Ewekoro Quarry, Southwestern Nigeria. In: African Geology, 1972, pp.305-322.

[28] C.A. Kogbe, Geology of Nigeria. Second revised edition Publ by Rockview Nig. Ltd, 1976.

[29] C.A. Cingolani, M. Manassero, P. Abre, Composition, provenance, and tectonic setting of Ordovician siliciclastic rocks in the San Rafael block: Southern extension of the Precordillera crustal fragment, Argentina: Journal of South American Earth Sciences, 2003, 16(1):pp. 91-106.

[30] N. S. Duzgoren-Aydin, A. Aydin, and J. Malpas, Reassessment of chemical weathering indices: case study on pyroclastic rocks of Hong Kong. *Engineering Geology,* 2002, 63: pp.99–119.

[31] L. Harnois, The C.I.W. index: a new chemical index of weathering. *Sedimentary Geology,* 1988, 55: pp.319–322.

[32] S.M. McLennan, S.R. Taylor, K.A. Eriksson, Geochemistry of Archeanshales from the Pilbara Supergroup, Western Australia. Geochim. Cosmochim. Acta,, 1983, 47: pp.1211–1222.

[33] S.M. McLennan, Weathering and global denudation. J. Geol., 1993, 101: pp.295–303.

[34] G. Mongelli, R.L. Cullers, and S. Muelheisen, Geochemistry of Late Cretaceous-Oligocene shales from the Varicolori Formation, southern Apennines, Italy: implications for mineralogical, grain-size control and provenance. Eur. J. Mineral., 1996, 8: pp.733–754.

[35] C.M., Fedo, H.W. Nesbitt, and G.M. Young, Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosols, with implications for paleoweathering conditions and provenance. *Geology,* 1995, 23: 10, pp.921- 924.

[36] G. Voicu, M. Bardoux, L. Harnois, and R. Grepeau, Lithological and geochemical environment of igneous and sedimentary rocks at Omai gold mine, Guyana, South America. Exploration and Mining Geology, 1997, 6: pp.153-170.

[37] G. Voicu, M. Bardoux, Geochemical behaviour under tropical weathering of the Barama-Mazaruni greenstone belt at Omai gold mine, Guiana Shield. Applied Geochemistry, 2002, 17: pp.321-336.

[38] R.L. Rudnick, and S. Gao, The Composition of the Continental Crust. In *Treatise on Geochemistry*. Elsevier–Pergamon, Oxford–London, 2003, Vol. 3: pp. 1-64.

[39] H.W. Nesbitt, G. Mackovics, R.C. Price, Chemical processes affecting alkali sand alkaline Earth during continental weathering. Geochim. Cosmochim. Acta,, 1980, 44: pp.1659–1666.

[40] M. Singh, M. Sharma, H. L. Tobschall, Weathering of the Ganga alluvial plain,northern India: implications from fluvial geochemistry of the Gomati River.Appl. Geochem., 2005, 20: pp.1–21.

[41] H. Vital, K. Stattegger, Major and trace elements of stream sediments from the lowermost Amazon River. Chem. Geol., 2000, 168: pp.151–168.

[42] Z. Liu, C. Colin, W. Huang, K.P. Le, S. Tong, Z. Chen, A. Trentesaux, Climatic and tectonic controls on weathering in South China and the IndochinaPeninsula: clay mineralogical and geochemical investigations from the Pearl,Red, and Mekong drainage basins. Geochem. Geophys. Geosyst. 2007, 8: Q05005.doi:10.1029/2006GC001490.

[43] R.M. Garrels, and F. T. Mackenzie, *Evolution of Sedimentary Rocks.* Norton & Company, New York, 1971.

[44] W.R. Dickinson, L.S. Beard, G.R. Brakenridge, J.L. Erjavec, R.C. Ferguson, K.F. Inman, R.A. Knepp, F.A. Lindberg, and P.T. Ryberg, Provenance of North American Phanerozoic sandstones in relation to tectonic setting: Geological Society of America Bulletin, 1983, 94: pp.222-235.

[45] H. Blatt, G. Middleton, and R. Murray, Origin of sedimentary rocks; Eaglewood cliffs Prentice-Hall, New Jersey, 1980.

[46] J.B. Maynard, R, Valloni, and H.S. Yu, Composition of modern deep-sea sands from arc-related basins: in Leggett, J.K., eds., Trench forearc geology: sedimentation and tectonics on modern and ancient active plate margins. *Geol. Soc. Lond. Spec. Pub*., 1982, 10: pp.551–561.

[47] S.B. Kroonenberg, Effects of provenance, sorting and weathering on the geochemistry of fluvial sands from different tectonic and climatic environments: Proceedings of the 29th International Geological Congress, Part A, 1994, pp.69-81.

[48] K.T. Ratcliffe, A.C. Morton, D.H. Ritcey, and C.A. Evenchick, Whole-rock geochemistry and heavy mineral analysis as petroleum exploration tools inthe Bowser and Sustut basins, British Columbia, Canada. Bulletin of Canadian Petroleum Geology, 2007, Vol. 55: pp.320–336.