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GEOCHEMICAL, PROVENANCE TECTONIC SETTING, SOURCE- AREA WEATHERING AND MATURITY STATUS OF TAR SANDS FROM ODE AYE AREA OF ONDO STATE, SOUTHWESTERN, NIGERIA.

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ABSTRACT *The geochemistry of the major oxides, provenance and tectonic setting as well as the maturity status of the Ode Aye bitumen-impregnated sand (tar sand) are presented in this study. Silica oxide (SiO_2) is dominant and ranges between 66.36 and 94.29 wt %. In a descending order, $Al_2O_3 > Fe_2O_3 > TiO_2$ .Their association suggests a relationship with clay minerals. The results of the calculations of log (SiO_2/Al_2O_3) < 1.5 and log ((Fe_2O_3+MgO)/(K_2O+Na_2O)) > 0 support the classification conditions of the sediments as lithic arenites. Sediments plotted in the passive continental margin as well as granite gneiss provenance field collaborating with continental sands (lithic arenites) that are of ferromagnesian potassic type. Granite and gneisses provenance probably provided the source sediments that were deposited in the passive margin that created favourable conditions for accumulation and maturation of organic matter in the studied area. The sediments however are immature and they tend towards chemical maturity due to their formation under semi humid and humid conditions.*

KEYWORDS: Lithic arenite, Ferromagnesian potassic, Passive margin, Immature sediments.

INTRODUCTION

The experience of tar sand and bitumen in Ode -Aye area of Ondo State has created different kinds of environmental fears of degradation on their land, crops, water, and their general health welfare. Ode Aye is a community that depends on their soil, water and their farm produce for their existence. The tar sand in this community exists in several farm lands including the palm tree plantations one of which is the present study area.

Tar sands (bituminous sand) were discovered in Nigeria in the beginning of the 20th century around 1900 (Akinmosin, Osinowo and Oladunjoye, 2009).Tar sands have similar composition as the light crude. Adegoke (2000) compared the Nigerian tar sands with the large deposits in Alberta Canada and Trinidad. Tar sands generally are believed to have formed from biodegradation and water-washing of light crude due to lack of cap rock. The Nigerian Tar sands are believed to have formed in a similar process. Tar sands are impregnated sands that yield mixtures of liquid hydrocarbons, which require further processing other than mechanical blending before becoming finished petroleum products.

Ode Aye area lies between latitudes 6° 34'N and 6° 64'N and longitudes 4° 54'E and 4° 74'E of the tropical rainforest belt of Nigeria. Vast deposit of bitumen is located in one of the palm tree plantations of Ode Aye area and this flows during the hot weather and hardens when the temperature cools down. Figure 1 shows the congealed (thickened) bitumen in one of the locations in the palm plantation. Ode-Aye is underlain by the sediment of Imo shale of South East, lateral equivalent of which is the Ewekoro and Akinbo formations of South west Nigeria (Fig 2). Ewekoro formation directly overlies the Abeokuta group (Ise, Afowo and Araromi formations) as observed from the section at Ewekoro and Sagamu quarries as well as the cored sections at Ibeshe (Omatsola and Adegoke (1981), and Agagu (1985).The Ewekoro is made up of greyish white and occasionally greenish limestone which is sandy toward the base and having a thickness that varies between 15-30m. This formation is dated to be Paleocene in age. Ise formation is the oldest formation in Abeokuta group and it uncomformably overlaps the Precambrian basement complex. Afowo formation indicates the commencement of deposition in a transitional environment after the entire basal and continental Ise formation. The sediments are composed of interbedded sands, shales and clays, which range from medium to fine grains in size (Omatsola and Adegoke; 1981 and Agagu; 1985) and this has been found to be bituminous in both surface and subsurface sections. The age is Maestrichian Araromi formation represents the youngest unit of the Abeokuta group. The formation is composed of shales, fine-grained sand, thin interbeds of limestone, clay and lignite bands (Omatsola and Adegoke; 1981; Agagu; 1985).

Figure 1. Congealed bitumen rich soil

LITERATURE/THEORETICAL UNDERPINNING

Sandstones are made up of detrital grains that form the framework of sediments, quartz being the most common mineral and the most stable. The abundance of quartz depends on its availability (source area geology), mechanical and chemical stability as well as its resistance to weathering and alteration. Rock fragments in sandstones usually give specific information on the provenance of a deposit once they can be tied to a particular source geological formation. The composition of sandstones according to Roser and Korsch, (1986, 1988), Huntsman-Mapilaa et al, 2005 has been used as sensitive indicator for provenance studies and weathering conditions at the source of sediments. The major assumption proposed for sandstone provenance studies is that each tectonic setting is made up of its own rock type, (Dickson and Suezek, 1979; Dickson, 1985). Bhatia (1983), Taylor and Mclennan, (1985) and Bakkiaraj, et al. (2010) suggested also that the geochemical composition of sediments is an important tool in the study of provenance. Since Ode Aye community is a non-pristine area with weathering, heavy metals occurrence, anthropogenic, natural processes and presence of bitumen; there is the necessity to study the provenance, tectonic setting, maturity status as well as the source-area weathering.

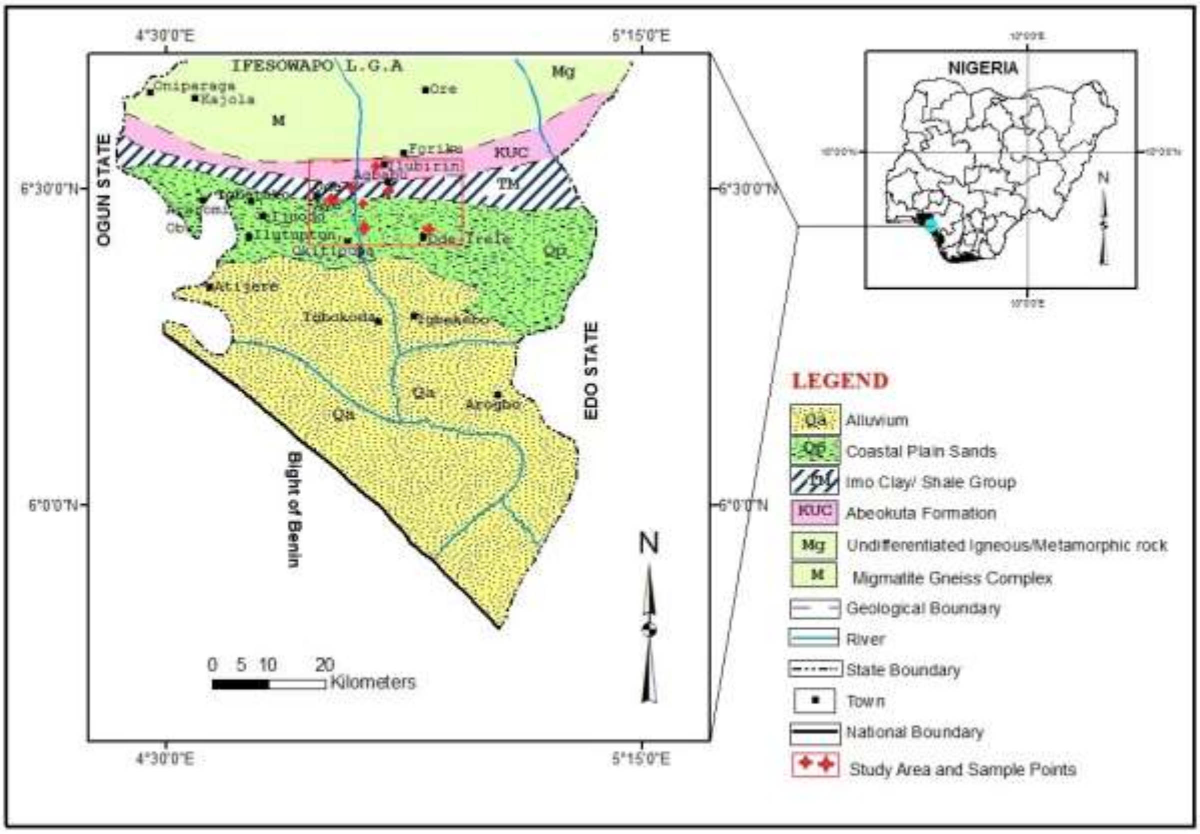


Figure 2. Geological map of Ode Aye area.

MATERIALS AND METHODS

Eight composite samples were obtained from Ode Aye bitumen-impregnated sand and they were subjected to chemical analysis in the Central Analytical Facilities, Stellenbosch University, South Africa. . Whole-rock major element compositions were determined by XRF spectrometry on a PANalytical Axios Wavelength Dispersive spectrometer following the proposal of Fairchild et al. (1999). The gas-flow proportional counter uses a 90% Argon-10% methane mixture of gas. Major elements were analyzed on a fused glass disk using a 2.4kW Rhodium tube. Matrix effects in the samples were corrected for by applying theoretical alpha factors and measured line overlap factors to the raw intensities measured with the SuperQ PANalytical software. The concentration of the control standards that were used in the calibration procedures for major element analyses fit the range of concentration of the samples. Amongst these standards were NIM-G (Granite from the Council for Mineral Technology, South Africa) and BE-N (Basalt from the International Working Group).

RESULTS /FINDINGS

Table 1 shows the result of major oxide composition of the Ode Aye bitumen impregnated tar sand. The results indicate that SiO_2 is dominant and varies from 66.36 to 94.29 wt % .Al2O3 content ranges between 3.02 and 10.96 wt %, Fe_2O_3 (0.68-2.49), and K_2O (0.07-0.46). Other oxides such as K_2O, Na_2O, MgO and CaO have low concentrations and each has less than unity (1). The low values of these oxides may be attributed to chemical destruction under oxidizing condition during weathering. The ratio of SiO2/Al2O3 ranges from 6.055 to 41.537 showing high silica to alumina content. K_2O/Al_2O_3 ratio is low (0.019-0.042) an indication of low K-bearing mineral contents in relation to alumina. K_2O/Na_2O ratio ranges between 0.0 and 11.50 supporting the low contents of K and Na bearing minerals. Al_2O_3/TiO_2 ratio varies from 4.28 to 9.37 showing a slightly high alumina relative to titanium oxide.

Table 1. Major oxides composition of the Ode Aye (Wt. %)

OXIDES	**SAMPLES NUMBER**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
SiO_2	81.40	86.70	82.99	89.01	91.86	66.36	94.29	85.90
Al_2O_3	6.79	5.48	7.31	5.23	3.02	10.96	2.27	4.43
K_2O	0.15	0.17	0.28	0.10	0.07	0.46	0.05	0.12
Na_2O	0.0	0.0	0.03	0.0	0.0	0.04	0.0	0.0
Fe_2O_3	1.10	1.98	2.49	2.11	0.68	1.29	0.71	1.42
MgO	0.11	0.15	0.16	0.15	0.07	0.17	0.09	0.09
CaO	0.03	0.03	0.06	0.03	0.03	0.07	0.03	0.05
TiO_2	0.94	1.28	1.30	1.22	0.50	1.17	0.51	0.62
MnO	0.01	0.03	0.03	0.04	0.00	0.01	0.01	0.00
SiO_2/Al_2O_3	11.988	15.82	11.35	17.02	30.42	6.06	41.54	19.40
K_2O/Al_2O_3	0.022	0.031	0.038	0.019	0.023	0.042	0.022	0.027
Al_2O_3/TiO_2	7.223	4.281	5.623	4.286	6.04	9.368	4.450	7.145
K_2O/Na_2O	0.0	0.0	9.333	0.0	0.0	11.50	0.0	0.0
CIA	97.5	96.5	95.18	97.6	96.79	95.05	96.59	96.30
CIW	99.6	99.45	98.78	99.42	99.02	99.00	98.69	98.88
MIA	95	93	90	95	93	90	93	92
PIA	99.6	99.4	98.7	99.4	98.9	98.9	98.7	98.9

DISCUSSIONS

Most of the oxides have been used to obtain cross plots. Figures 3 and 4 show some of the plots against SiO_2 and Al_2O_3 respectively. Major oxides, CaO, FeO, Fe_2O_3, MgO and TiO_2 correlate negatively with SiO_2 except Al_2O_3 which is positive and which trend upwards with R2=0,007 .The negatively correlated oxides have downward linear trend suggesting non association with SiO_2. Figure 3 indicates positive correlations between Fe_2O_3 and Al_2O_3 and between TiO_2 and Al_2O_3 implying their associations with clay. They trend upwards with (Fe_2O_3/Al_2O_3) R2=0.135 and (TiO_2/Al_2O_3) R2=0.481.

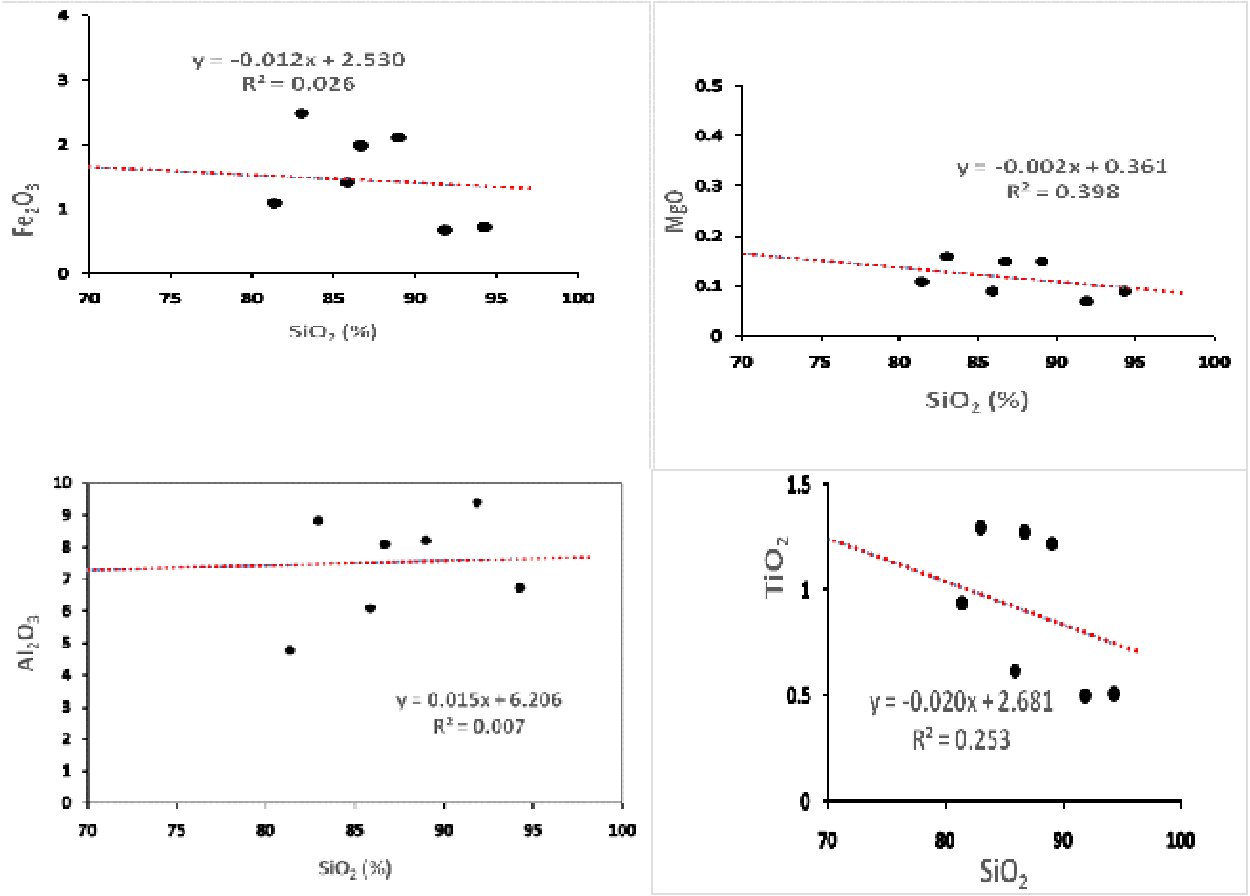
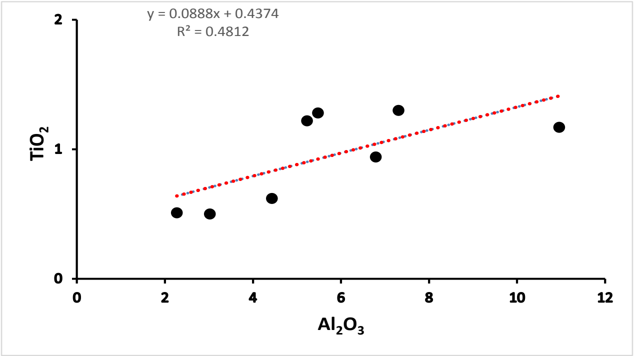


Figure 3. Cross plots of major oxides against SiO_2 showing correlation



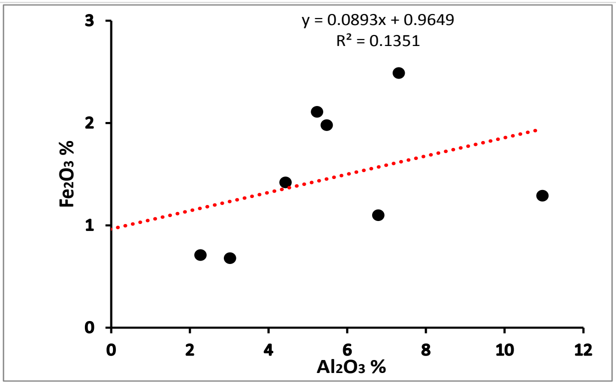


Figure 4. Cross plots of major oxides versus Al_2O_3 showing correlations.

Several geochemical classification schemes have been adopted by scholars such as Pettijohn et al, (1972), Blatt et al,(1972), Folk, (1974), Heron, (1988) and Lindsey, (1999). The plot of log ratios of Fe_2O_3/K_2O against SiO_2/Al_2O_3 shows that the Ode Aye tar sand sediments fall within the iron sand (Fe-sand) field (Fig 5).

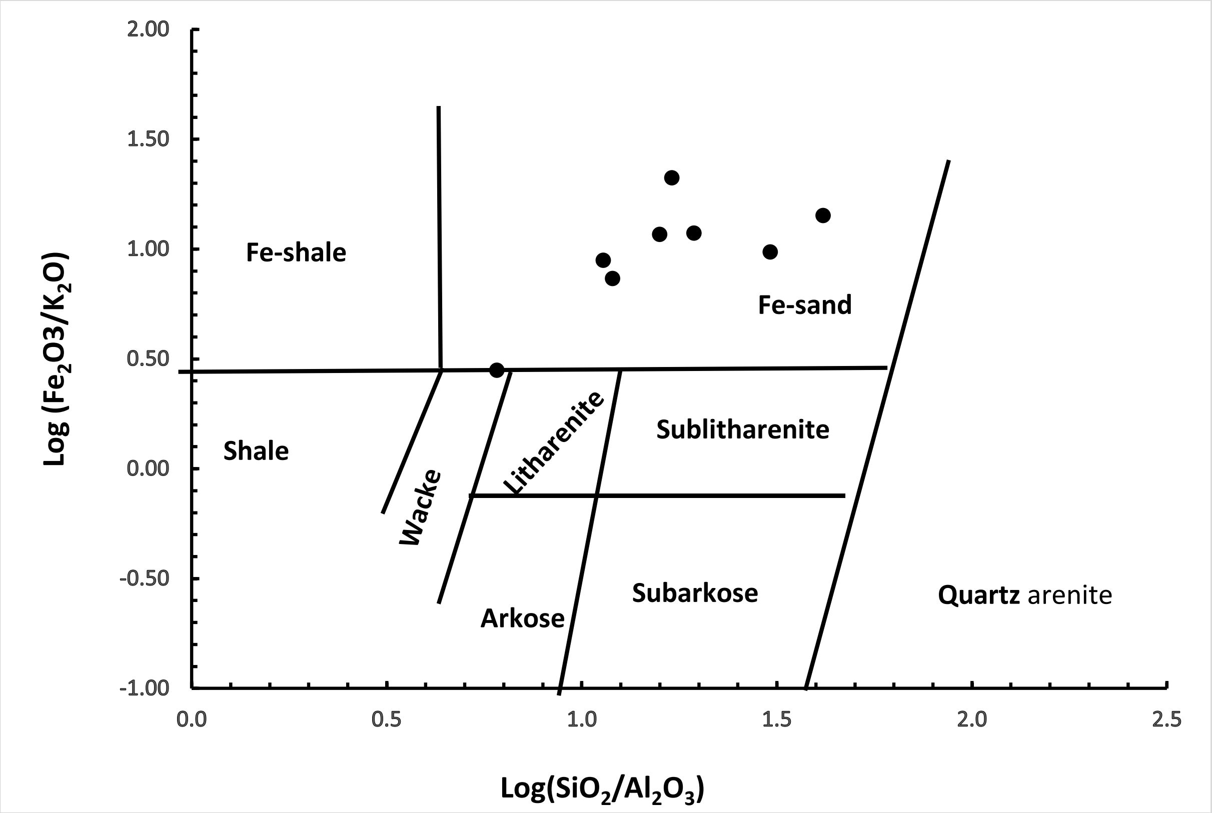


Figure 5. Chemical classification of the Ode Aye sediments based on log (SiO_2/Al_2O_3) *vs.* log (Fe_2O_3/K_2O) diagram of Herron (1988).

Using the guidelines as proposed by Lindsey, (1999) for chemical classification of sandstone, four reference sets are as shown below ;

1) Quartz arenite: log (SiO2/Al_2O_3) ≥ 1.5

2) Graywacke: log (SiO_2/Al_2O_3) < 1 and log (K_2O/Na_2O) < 0

3) Arkose (includes subarkose): log (SiO2/Al2O3)<1.5 and log(K2O/Na_2O≥ 0 and log ((Fe2O3+MgO)/(K2O+Na2O)) < 0

4) Lithic arenite (subgraywacke, includes protoquartzite): log (SiO2/Al2O3) < 1.5 and either log (K2O/Na20) < 0 or log ((Fe2O3+MgO)/(K2O+Na2O)) > 0.

Based on these sets, the value of log (SiO2/Al2O3) ≥ 1.5 for the Ode Aye sediment is 1.34 and therefore falls short of quartz arenite. The average value of log (K2O/Na2O) < 0 for the sampled area is 0.25, therefore condition 2 does not hold since it is higher than zero. In condition 3 the values obtained for log (SiO2/Al2O3) < 1.5 and log (K2O/Na2O) ≥ 0 are 1.34 and 0.25 respectively while the average log ((Fe2O3+MgO)/(K2O+Na2O)) < 0 value is 1.25 . Going by this the sediments cannot be classified as arkose. The values obtained match log (SiO2/Al2O3) < 1.5 and log ((Fe2O3+MgO)/(K2O+Na2O)) >0 of condition 4 thus supporting the chemical classification of the sediments as lithic arenites. The calculation for log Fe2O3+MgO)/(K2O+Na2O) > 0 shows also that the value 1.13 is greater than zero and therefore supports the lithic arenite conditions . Lithic arenites usually contain 30-80% quartz and 5-50% lithic fragments. The compositional maturity can vary broadly depending on the nature of the lithic fragments while the textures commonly range from sub -mature to mature. These statements can be collaborated from the immature nature of the sediments as obtained from the proposals of Michael, et al. (1998).

Using the ternary diagram proposed by Blatt et al., (1972), the Ode Aye tar sands plotted mainly in ferromagnesian potassic sandstones field. (Fig 6).The ternary diagram by Blatt et al., (1972) omitted sandstones with less than 5% Al2O3, consequently, quartz arenites is missing. Based on the work by Lindsey (1999) using data from Pettijohn (1963; 1975), average lithic arenites plotted in the ferromagnesian Potassic sandstones field, whereas average greywacke would plot in the sodic sandstone field while average arkose would appear in the potassic sandstones field. Figure 7 indicates that the sediments fall on litharenite field and in the boundary of quartz arenite and sublitharenite.

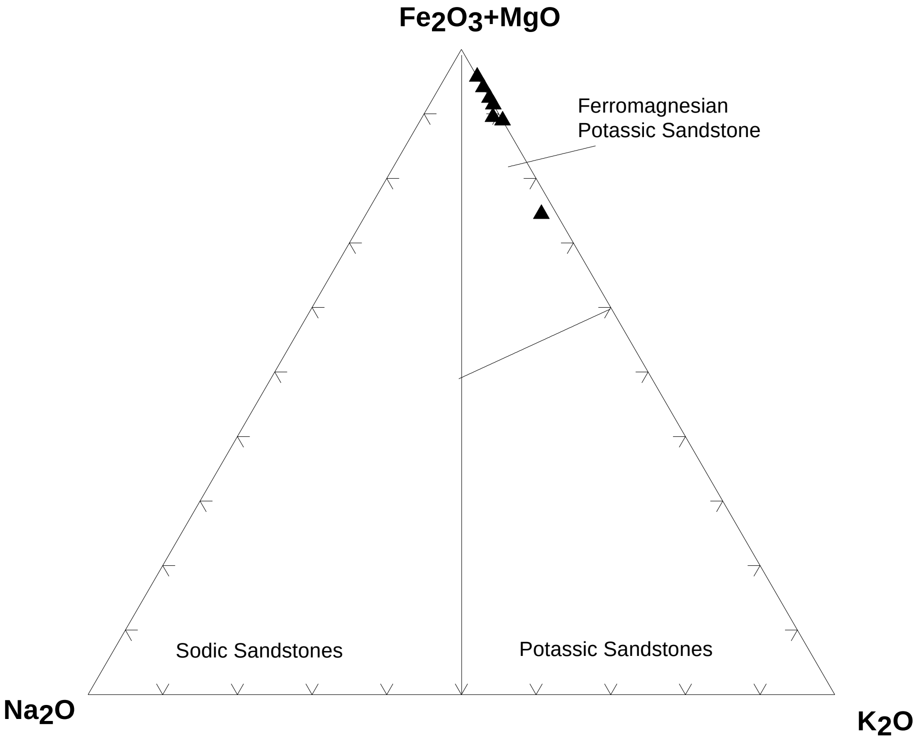


Figure 6. Ternary diagram of Fe2O3+MgO-Na2O-K2O of Ode Aye tar sand from Blatt et al. (1972).

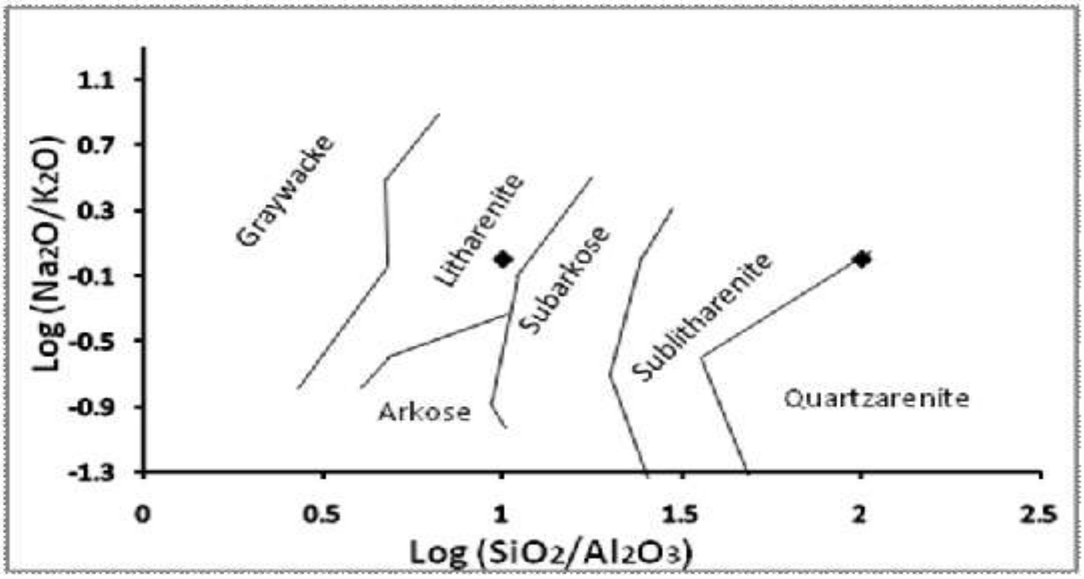


Figure 7. The plot of log Na2O/ K_2O versus log (SiO_2/Al_2O_3).

Maturity of sediments describes the composition and texture of grains in clastic rocks especially sandstones. Texture is a reflection of the grain sizes, how sorted the sample is while composition reflects how much the composition of rock fragments, clay contents and other are. A mature sediment is more uniform in appearance and exhibits little compositional variation while an immature sediment contains/ more angular grains, diverse grain sizes, and is compositionally diverse (Boggs, 2006). Maturity is reflected best in quartz, rock fragments, feldspars and grain size.

The values of the log (K2O/Na2O) ratio shows a range of between 0.97 and 1.06 with a mean value of 0.25. This indicates that the tar sands are immature. It implies also that potassium is absent in the sediments. Figure 8 shows that majority of the sands tend towards increasing chemical maturity because they formed under Semi- humid/humid conditions.

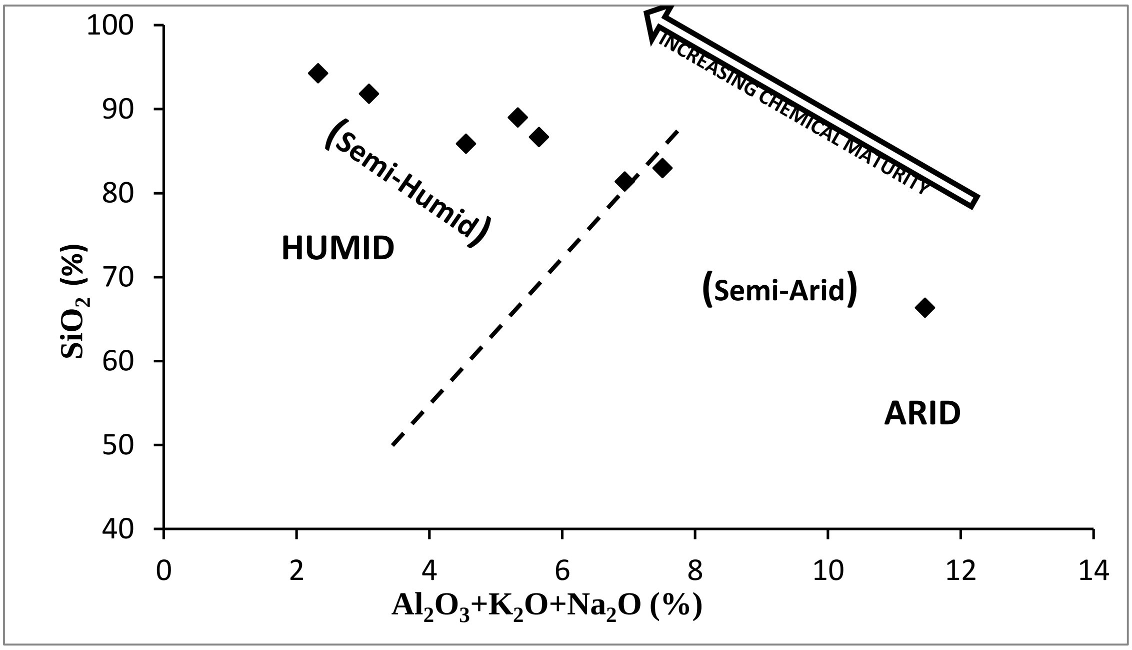


Figure 8. Chemical maturity of the Ode Aye tar sand components expressed by bivariate plot of SiO2 Vs Al2O3 +K2O+Na2O (After Suttner and Dutta, 1986)

The chemical composition of any rock be it sedimentary depends majorly on the composition and weathering conditions of the source rock areas, (Nesbitt and Young (1989) and Nesbitt et al .1996). Nesbitt and Young (1982) evaluated the degree of chemical weathering/alteration by using the chemical index of alteration (CIA), where CIA = molar (Al2O3/[Al2O3+CaO+Na2O+K2O]). This index expresses well when Ca, Na, and K are decreasing while the intensity of weathering is increasing (Duzgoren-Aydin et al. 2002). Another index is the Chemical index of weathering (CIW) proposed by Harnois, (1988). CIA and CIW have similar formular except that K2O is not in the equation for CIW. CIW = molar (Al2O3/(Al2O3+ CaO + Na2O). Their interpretations are equally similar with values of 50 for unweathered upper continental crust and roughly 100 for highly weathered materials with complete removal of alkali and alkaline-earth (McLennan et al. 1983; McLennan, 1993;

Mongelli et al. 1996). This implies that when CIA has Low values as much as 50% or less, it reflects cool and / or arid conditions (Fedo et al. 1995), and when the value is more than 50 it grades from moderate to high degree of weathering of the source rock areas. The CIA ranges between 95 and 97% (Av.96 %), while CIW ranges from 98.8 to 99.6 % with an average of 99. % an indication of a very high degree of weathering of the source materials. The plagioclase Index of Alteration (PIA) can be used to measure the intensity of the chemical weathering using the molecular proportion: PIA= [(Al2O3-K2O)/(Al2O3 +CaO -Na2O)] x100 where CaO* is the CaO residing only in the silicate fraction.(Fedo et al.1995). Unweathered plagioclase has the PIA value of 50 while phanerozoic shales have PIA value of 79. The PIA values in the tar sands range between 98.7% and 99.6% suggesting a high degree of weathering. The Mineralogical Index of Alteration (MIA) has also been used as a parameter to indicate the extent of weathering in a rock (Voicu et al.1997). The MIA is calculated as MIA= (MIA-50) x2. When the values of MIA lie between 0 and 20%, it is designated as incipient meaning just started; between 20 and 40% it means weak weathering ; 40-60% (moderate) and between 60 and 100% extreme degree of weathering. Extreme value of 100% indicates complete weathering of the primary rock material into its equivalent weathered product (Voicu and Bardoux, 2002). MIA values for the Ode Aye tar sands range from 90 to 95% an expression of the very high intensity of the weathering in agreement with the CIA, CIW and PIA respectively. It should be noted that Na, K and Ca are highly mobile elements and their depletion in the rocks implies heavy leaching due to an enhanced chemical weathering. In the present study, the ranges of Na2O (00-0.04), K2O (0.07 -0.46) and CaO (0.03-0.07) exhibit impoverished contents, thus synchronizing with an increased chemical weathering as confirmed earlier by CIA,CIW,PIA and MIA respectively.

Roser and Korsch (1986) proposed a tectonic discrimination diagram using K2O/Na2O ratio versus SiO2 (Fig. 9) to determine the tectonic setting of clastic rocks. The cross plot is used to discriminate between sediments deposited in the Passive Continental Margin, Active Continental Margin and the Oceanic Island Arc. The studied samples plotted in the Passive Continental Margin (PM) tectonic settings.

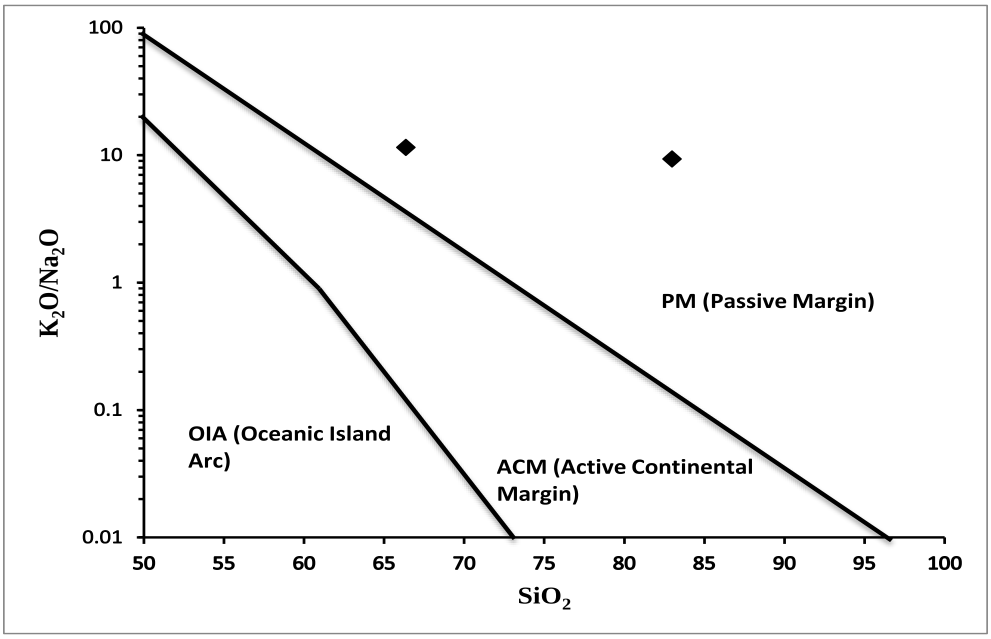


Figure 9. Tectonic discrimination plot for the tar sand (After Roser and Korsch, 1986).

The plot of log SiO_2/Al_2O_3 against log K_2O/ Na_2O in Fig 10 supports that the sediments in the studied area were deposited in the Passive deposited in the continental margin (PM). Passive margins are areas of economic importance as they form reservoirs of petroleum. Mann, et al. (2001) classified 592 giant oil fields into six basins and tectonic-setting categories, and noted that continental passive margins account for 31% of giant oil fields. Continental rifts which are likely to evolve into passive margins with time contain another 30% of the world's giant oil fields. Basins associated with collision zones and subduction zone are where most of the remaining giant oil fields are found. Passive margins are petroleum storehouses because these are associated with favourable conditions for accumulation and maturation of organic matter.

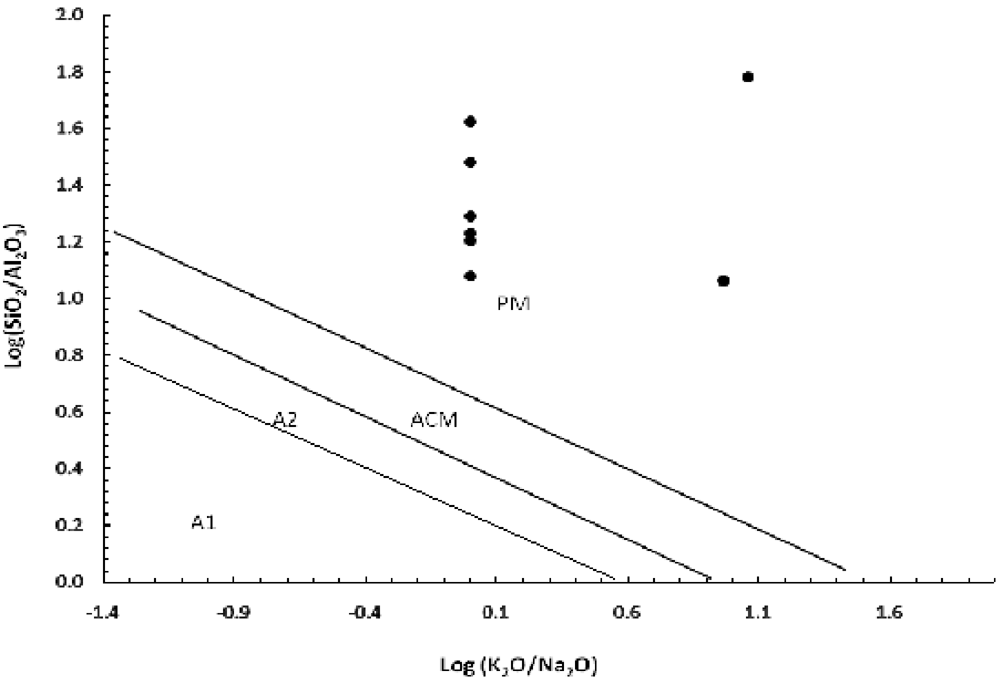


Figure 10. Plot of Log (SiO2/Al_2O_3 versus Log (K2O/Na_2O) (after Maynard et al.1982). Al=arc setting and andesitic detritus; A2= evolved arc setting; felsic pluton detritus; ACM= Active continental margin; Pm= Passive margin.

Authors such as Blatt et al., (1980); Bhatia, (1983); Bhatia and Crook (1986); Roser and Korsch, (1986, 1988), have related sandstone geochemistry to specific tectonic environment. Roser and Korsch (1988) used the discriminant function plot of (Fig. 11) to define four (4) main provenances: mafic igneous provenance; intermediate igneous provenance; felsic igneous provenance; and granite gneiss provenance. The Ode Aye tar sand sediments plot converged in the granite gneisses provenance field suggesting that the granite gneiss might have been the source area that provided the sediments that were deposited in the passive margin. Granite gneiss forms part of the basement complex in line with the rocks of the studied area.

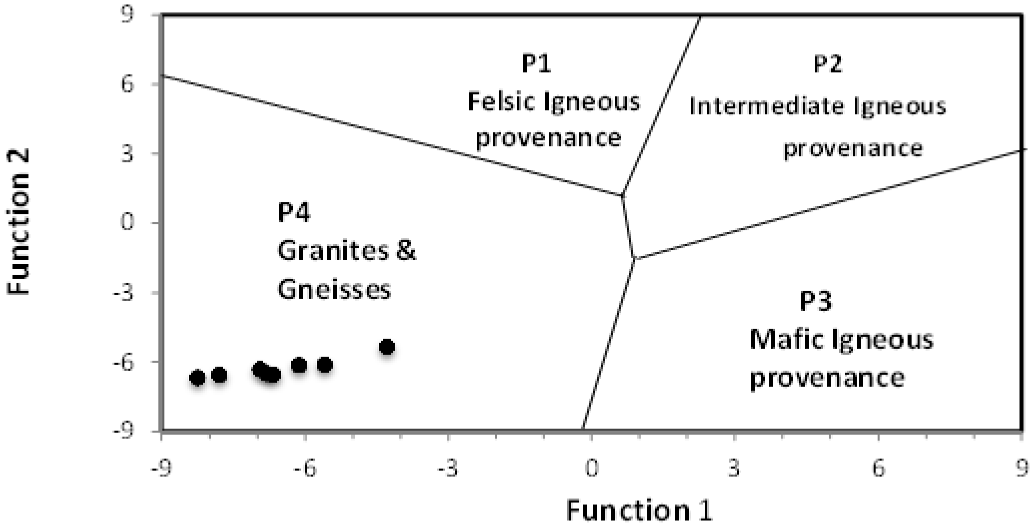


Figure 11. Discriminant function plot with major elements for provenance signatures. (After Roser and Korsch, 1988)

Figures 12 and 13 confirm that the tar sands of Ode Aye are continental sands since the sediments plotted in the non-marine & deltaic sandstone fields of the binary diagram of Ratcliffe et al. (2007).

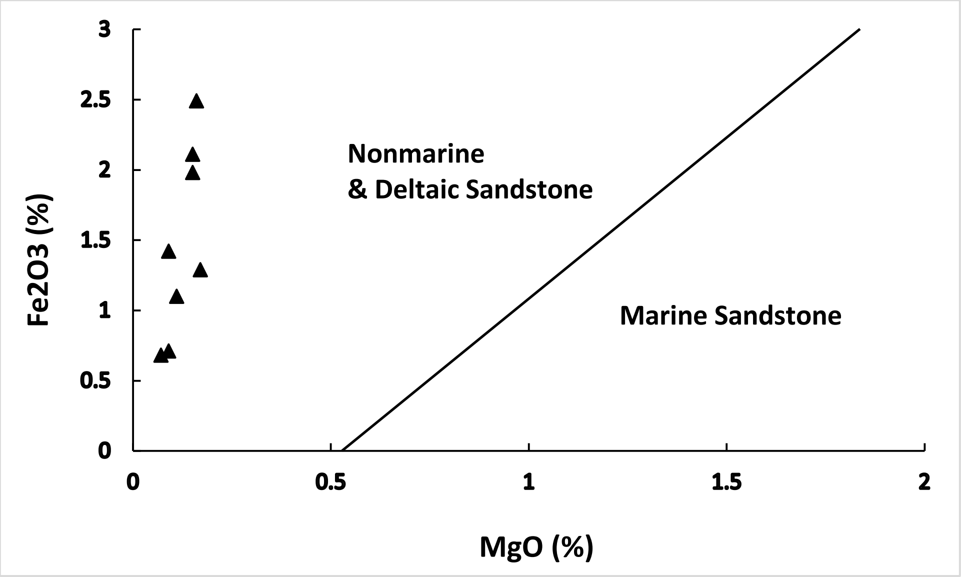


Figure 12. Binary diagrams showing characterization and differentiation of marine from non-marine tar sand (after Ratcliffe et al. 2007).

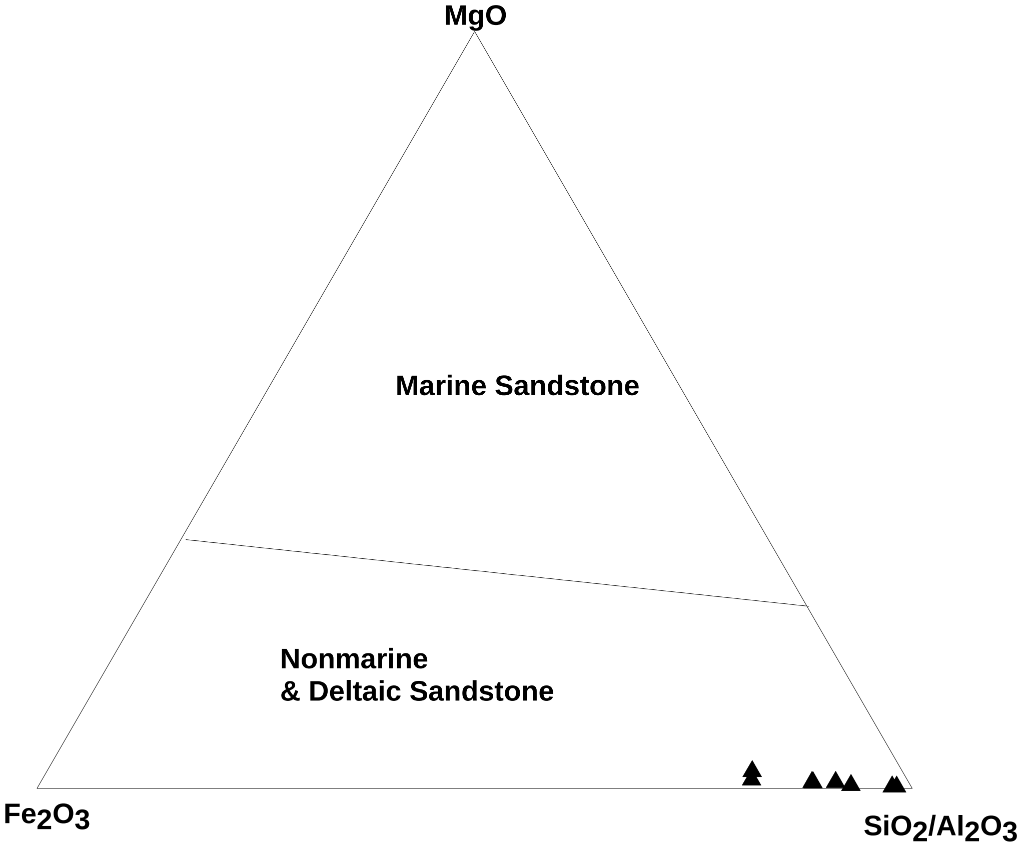


Figure 13. Ternary diagram showing characterization and differentiation of marine from non-marine tar sand (after Ratcliffe et al. 2007).

CONCLUSION

The provenance, tectonic setting and maturity status of Ode Aye bitumen- rich sand were studied using the result of major oxides. The result indicates that the silica content ranges from 66.36 to 94.29 wt % showing its dominance.

Various plots of SiO_2 show negative correlation with Fe_2O_3, MgO and TiO_2 and positive correlation with Al_2O_3, an indication of its association and abundance with clay materials. The classification of Pettijohn et al. 1972, Blatt et al. 1975 and Heron, 1988 used for plotting show that the sediments plotted in the Fe- sand field.

However, the use of Lindsey, 1999 chemical classification guidelines classified the tar sand sediments as lithic arenites which in maturity rating is immature and tend towards increasing chemical maturity having formed under semi-humid and humid conditions. Sediments of the tar sand were deposited in the passive continental margin which are places known around the world as areas that house economic reservoirs of petroleum.

REFERENCES

Agagu 0.A., (1985): A geological guide to Bituminous sediments in Southwestern Nigeria. Unpublished Report, Department of Geology University of Ibadan.

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

Bhatia, M. R. (1983) Plate tectonics and geochemical composition of sandstone. J. Geol., 91, 611-627.

Bhatia, M. R. and Crook, K. W. (1986) Trace element characteristics of greywackes and tectonic setting discrimination of sedimentary basins. Contributions to Mineralogy and Petrology, 92, p.181-193.

Blatt H, Middleton G., and Murray R., (1972): Origin of sedimentary rocks; Eaglewood cliffs New Jersey Prentice-Hall. p 634.

Blatt, H., Middleton, G., and Murray, R. (1980). Origin of sedimentary rocks; Eaglewood cliffs Prentice-Hall, New Jersey, 634 p.

Dickson, W.R., Suczek, C.A. 1979. Plate tectonics and sandstone compositions: American Association of petroleum Geologist, 63: 2164 – 2182.

Dickson, W.R. (1985): Interpreting provenance relations from detrital modes of sandstones, in Zuffa G.G. (ed.), Provenance of Arenites. Dordrecht, D. Reidel Publishing Company, pp. 333-361.

Fairchild, I., Graham, H., Martin, Q.,and Maurice, T., (1999) : Chemical Analysis of Sedimentary Rocks in: Techniques in Sedimentology (ed. T. Maurice), p. 274-354.

Duzgorem-Aydin, N.S, Aydin, A and Malpas, J.(2002). Reassessment of chemical weathering indices; case study On pyroclastic rocks of Hong Kong. Engineering geology. Vol 63: 99-119.

Fedo, C.M, Nesbitt, H.W and Young, G.M.(1995).Unravelling the effects of potassium metasomatism in sedimentary Rocks and paleosols with implications for paleoweathering conditions and provenance. Geology. Vol23: (10). 921-925.

Folk R.L. (1974): Petrology of sedimentary rocks. Hemphills Austin Texas. 159pp.

Harnois, L.(1988). The C.I.W Index: a new chemical index of weathering. Sedimentary geology., Vol 55: 319-322.

Herron M.M., (1988): Geochemical classification of terrigenous sands and shales from core or log data. Journal of Sedimentary petrology. 58(5): p.820-829.

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

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

Lindsey, D.A. (1999): An Evaluation of Alternative Chemical Classifications of Sandstones. United State Geological Survey Open-File Report 99-346, 23pp.

Mann, P., Gahagan, L and Gordon, M.B (2001). Tectonic setting of the World's giant oil fields.Part 1. "A new classification scheme of the world's giant fields reveals the regional geology where explorationists may be most likely to find future giants"

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

Mclennan, S.M, Taylor, S.R, Eriksson, K.A. (1983). Geochemistry of archean shales from the Pilbara Supergroup, Western Australian. Geochim. Cosmochin. Acta, Vol. 47: 1211-1222.

Mclennan, S.M .(1993).Weathering and global denudation. Journal of geology, Vol. 101: 295-303.

Mongelli, G, Cullers, R.L and Muelheisen, S.(1996). Geochemistry of late Cretaceous-Oligocenic shales from Varicolori formation, Southern Apennines, Italy: implication formineralogical,grain-size control and provenance. European journal of mineral; Vol. 8: 733-754.

Nesbitt, H.W and Young, G.M .(1982). Early proterozoic climates and plate motions inferred from major element chemistry of lutites. Nature. Vol. 299: 715-717.

Nesbitt, H.W and Young, G.M .(1989). Formation and diagenesis of weathering profiles. Journal of geology, Vol. 97: 129-147.

Nesbitt, H.W, Young, G.M, Mclennan, S.M and Keays, R.R. (1996).Effects of chemical weathering and sorting on the petro genesis of siliclastic sediments with implications for provenance studies.. Journal of Geology, Vol. 104: 525-542.

Omatsola, M.E and Adegoke, O.S., 1980. 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 pp 268.

Omatsola, M.E and Adegoke O.S.,1981. Tectonic and cretaceous stratigraphy of the Dahomey basin. Jour. Of mining Geol.Vol. 154 (1): p.65-68..

Pettijohn, F.J., Potter P.E and Siever R., (1972): Sand and Sandstone. New York, Springer. 618pp.

Pettijohn, F. J., (1963): Chemical composition of sandstones—excluding carbonate and volcanic sands, *in* Fleischer, M., ed., Data of Geochemistry, sixth edition, U. S. Geological Survey Professional Paper 440-S, 21 pp.

Pettijohn, F. J., (1975): Sedimentary rocks, third edition: New York, Harper & Row, 628 pp.

Ratcliffe, K.T, Morton, A.C, Ritcey, D.H and Evenchick, C.A. (2007). Whole-rock geochemistry and heavy mineral Analysis as petroleum exploration tools in the Bowser and Sustut basin, British Columbia, Canada. Bulletin Of Canadian petroleum geology, Vol.55: 320-336.

Roser, B. P. and Korsch, R. J. (1986) Determination of tectonic setting of sandstone-mudstone suites using SiO2 content and K2O/Na2O ratio. J. Geol. Vol. 94: 635-650.

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

Suttner, L.J and Dutta, P.K.(1986). Alluvial sandstone composition and paleoclimate. L. Framework mineralogy. Journal of sedimentary petrology, Vol.56: 329-345.

Taylor, S. R., and McLennan, S. M. 1985. The Continental Crust: its Composition and Evolution: An Examination of the Geological Record Preserved in Sedimentary Rocks: Oxford, U.K., Blackwell, 328 pp.