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Pattern of Geochemical and Sedimentological Variability of the Albian to Cenomanian Upper Bima Sandstone, Benue Trough, Nigeria: Implications on Tectonic provenance and Source Area Weathering

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Abstract

This study presents the pattern of geochemical and sedimentological variability of the Albian to Cenomanian Upper Bima sandstone in Upper Benue Trough, NE Nigeria. The intent is to apply sedimentological investigations and major element concentrations of the upper Bima sediments (fine grained sandstones) in order to reveal source area weathering, provenance and tectonic setting of inferred source areas. The investigation approach involved field studies and collection of samples from different outcrop locations, followed by laboratory studies involving grain-size analysis (GSA) and major elements analyses using the Atomic Absorption Spectroscopy (AAS) method. Field studies show that the sandstones are indurated with evidence of soft-sediment deformation and range in color from white in fresh sample to reddish brown on weathering. In addition, the sandstone units are cross-bedded and show graded bedding exemplified by fining upward sequence. Textural examination indicates that the sandstones range from fine to medium to coarse grained, with graphic mean grain size of 0.16 to 2.21 mm. Standard deviation (sorting) ranges from 0.98 to 1.77Ø and implies moderately sorted to poorly sorted sediments. Inferred from the textural indices, the depositional environmental discrimination of the Bima Sandstone revealed a fluvial/river system-dominated sedimentary process. In addition, major elemental oxides show SiO_2 content greater than 75% for the Upper Bima Sandstone samples with depletion of mobile oxides such as Na_2O, CaO and K_2O through weathering and other sedimentary processes. On the basis of the major elements, the sandstones are classified as sublitharenite, and arkose types. Provenance and tectonic setting discrimination using geochemical data revealed typical felsic igneous-dominated cratonic environment while ternary plots (e.g. $SiO_2/20$ - K2O+Na_2O - TiO_2+Fe_2O_3+MgO) reflect passive continental margin setting for the Bima Sandstone. Tectonic setting discrimination diagrams based on major elements suggest a granitic provenance in a passive continental margin. Consequently, the source area is constrained to the Precambrian basement rock units of Adamawa areas to the north and southern parts of the Yola Basin. The Chemical Index of Alteration (CIA, average 79.63) reflects intense degree of chemical weathering in a tropical wet climate, and an A-CN-K plot suggests an upper continental crust provenance dominated by felsic to intermediate igneous rocks (tonalite, granodiorite and granite) of average granitic composition.

Keywords: provenance, tectonic setting, sandstone, geochemistry, Upper Bima Sandstone, Benue Trough

1. Introduction

Geochemical and sedimentological studies of sedimentary rocks can reveal the nature of source regions, the tectonic setting of sedimentary basins, and palaeoclimate conditions (Dickinson and Suczek, 1979; Valloni and Mezzardi, 1984; Bhatia and Crook, 1986; McLennan *et al.*, 1993; Armstrong-Altrin *et al.*, 2004). Although some geochemical ratios can be altered during weathering (through oxidation) (Taylor and McLennan, 1985) and/or diagenesis (Nesbitt and Young, 1989; Milodowski and Zalasiewicz, 1991), as long as the bulk composition of a rock is not totally altered, geochemical analysis is still an invaluable tool in the study of sandstones (McLennan *et al.*, 1993). Major element discrimination diagrams (e.g., Bhatia, 1983) have been used to discriminate the tectonic settings of sedimentary basins and this approach has been reported in various publications (e.g., Kroonenberg, 1994; Zimmermann and Bahlburg, 2003; Armstrong-Altrin *et al.*, 2004); although, caution is required in their indiscriminate use (Armstrong-Altrin and Verma, 2005). The most important clues for the tectonic setting of the basin comes from the relative depletion of oxides like CaO and Na_2O (the most mobile elements) and enrichment of SiO_2 and TiO_2 (the most immobile elements), among others. These oxides are assumed to show enrichment or depletion in quartz, K-feldspar, micas, and plagioclase. The ratio of the most immobile elements to the most mobile ones increases toward passive margins due to the relative tectonic stability (Bhatia 1983; Kroonenberg 1994; Roser and Korsch 1986; Zimmermann and Bahlburg, 2003; Armstrong-Altrin *et al.*, 2004) and hence prolonged weathering. This can be recorded in sediments as palaeo-climate index (Nesbitt and Young, 1982; Harnois, 1988; Chittleborough, 1991) and high degree of sediment recycling.

The Cretaceous to Tertiary Upper Benue Trough has been well studied (Cater *et al.,* 1963; Cratchley and Jones, 1965; Benkhelil, 1989; Braide, 1992a, b, c; Guiraud, 1990; Akande *et al.,* 1998; Ojo and Akande, 2001; Samaila *et al.,* 2008). While most of the publications aforementioned focused on regional geologic studies, only a few discussed upper Bima sandstone (Braide, 1992a and c; Etobro and Ejeh, 2007; Samaila *et al.,* 2008) and non on tectonic provenance and source area weathering based on major element geochemistry and sedimentology have been reported. In this study, we present geochemical data from the area close to *Girei*, around *Wuro Dole* and environs obtained from field geological mapping and analysis of surface sandstone exposures. These data were used for reconstructing the parent rock assemblages of these sandstones, their tectonic provenance, source area weathering and the physiographic conditions under which these sediments deposited.

2. General Geology of the Benue Trough

The Benue Trough is a NE-SW trending sedimentary basin, which extended from the Niger Delta to the Chad Basin, consisting of about 5000m of Cretaceous sediments (Fig.1). The Benue Trough is divided into Lower, Middle and Upper sections. The Upper Benue Trough bifurcates into a Gongola branch, striking N-S into Lake Chad, and an E-W Yola branch trending towards Yola and into Cameroon, along River Benue (Samaila *et al.,* 2008). A detailed description of its tectonic setting, sedimentary and tectonic phases are given by Benkhelil, (1989). Carter *et al.,* (1963) gave a vivid account of its geology. The Benue Trough is flanked on either side by crystalline rocks of the Nigerian Basement Complex composed of mainly of Precambrian to Early Paleozoic granites and gneisses (Cratchley and Jones, 1965; Offodile, 1976; Petters, 1982; Petters and Ekweozor, 1982) (Fig.1). The origin and tectonic evolution of the Upper Benue Trough has been reported by workers such as Benkhelil, (1989); Guiraud, (1990) and Braide, (1992a and b); stating that this part of the basin is structurally more complex than the middle and lower parts of the Benue Trough. Multiphase extension initiated during the Lower Cretaceous in relation to the opening of the south Atlantic made the Benue Trough to be a part of passive continental margin.

The Bima Sandstone, an entirely continental formation throughout the Upper Part of the Benue Trough, is the basal part of sedimentary succession (Samaila *et al.,* 2008). The sandstones, interpreted to be of alluvial fan to braided river origin (Benkhelil, 1989; Guiraud, 1990) lies unconformably on the Precambrian Basement Complex rocks (Fig. 2). A change from periods of tectonic activity to stable conditions was reflected from an upward textural and compositional maturation of grain size (Guiraud, 1993). The Bima Sandstone was subdivided into Lower, Middle and Upper Bima by Carter *et al.,* (1963). Guiraud, (1990) gave the lithostratigraphic terms,B_1, B_2 and B_3 to informally denote the major units of sediments formed in direct relationship with tectonic events that took place during Early Cretaceous times (Fig. 2). The lower Bima, B_1 is the oldest, coarse grained and the thickest sedimentary unit in the Upper Benue Trough. The middle Bima, B_2 is gravelly and also comprised of coarse grained sandstone separated at its base by a regional unconformity from the lower Bima B_1. The youngest unit, the Upper Bima (B_3), consists of cross-bedded sandy deposits and showed evidence of pre-consolidation or soft-sediment deformation (Samaila *et al.,* 2006).

The Yolde Formation (Cenomanian to Turonian) rests on the Bima sandstone and it's succeeded by the marine Turonian to Campanian Pindiga and Gongila Formations in the Gongola sub-basin and its lateral equivalents, the Dukul, Jessu and Numanha Formations in the Yola sub-basin. The successions are overlain by the Campanian to Maastrichtian Gombe sandstone in the Gongola sub-basin and Lamja sandstone (lateral equivalents) in the Yola sub-basin (Carter *et al*., 1963). The Tertiary Kerri-Kerri Formation capped the succession west of Gombe in the Gongola sub-basin.

This work focuses attention on the Yola arm of the Benue Trough which is believed to have been formed from fault tectonics (Braide, 1990a). The study area lies within the region bounded by latitudes 9°17'45" to 9°23'00"N and longitudes 12° 35' 30" to 12° 41'00"E (Fig.3).

3. Methods

A geological field survey of the study area involved collection of 30 representative samples from different locations within the exposed areas of the Upper Bima Sandstone in the Upper Benue Trough as shown in figure 3. This is in addition to the logging of the lithostratigraphic profiles of the exposure at the different sampling locations.

Sequel to the field mapping exercise, the first phase of the laboratory studies involved granulometric or grain size analysis (GSA) conducted at the sedimentological laboratory of the Department of Geology, Delta State University, Abraka, Nigeria. The second phase involved major elements geochemical analysis which was carried out at the Central Laboratory of the Obafemi Awolowo University, Ile-Ife, Nigeria.

For the GSA, fifteen samples were selected, sun-dried and disaggregated. The samples were later weighed and sieved for particular size distribution following standard laboratory procedures using an automated Ro-tap shaker machine. From the GSA results, statistical parameters (Table 1) were obtained from plotted cumulative frequency curves. These statistical parameters include: graphic mean, standard deviation (sorting), graphic skewness, and graphic kurtosis; determined based on the concept of Folk and Ward (1957) and Folk (1974).

Chemical analyses (major elements) of twelve selected samples (fine sandstones were selected because they are likely to provide better geochemical results than the coarser grained rocks) were performed by Atomic Absorption Spectrophotometer (AAS) technique. Data evaluations of the geochemical information obtained in this study include estimations of elemental ratios and cross plots (for the assessment of compositional characteristics), evaluations of weathering indices (for the assessment of source area weathering conditions), ternary and discriminant plots (for assessment of provenance and tectonic setting). For example, in order to use major elements for provenance interpretations the discrimination diagram of Kroonenberg (1994), which used $SiO_2/20$- K_20+Na_2O - $TiO_2+Fe_2O_3t+MgO$ contents as variables was employed.

4. Results and Interpretations

4.1 Granulometric and Textural Studies

Results of the estimated textural and statistical indices are presented in Table 1. As stated in table 1, the Bima sandstone falls mainly within the medium to coarse sand range. This is indicated by the graphic mean of 0.16 to 1.9 phi; with the exception of the samples WD4 and WD51, having graphic mean of 2.21 and 2.0 phi respectively which implied fine sand. The inclusive graphic standard deviation (sorting) ranges from 0.98 to 1.77 phi suggesting a wider range poorly sorted to moderately well sorted sand. Inclusive graphic skewness ranges from -0.16 to 0.58 (average 0.07) implying nearly symmetrical to strongly fine skewed arrangement while graphic kurtosis ranged from 0.60 to 3.40phi (average 1.61) and suggest very platykurtic through extremely leptokurtic.

4.2 Major Element Distributions

The results of the major elements for the Bima sandstone samples are presented in Table 2, alongside with the weathering indices. The results were compared to average sandstone worldwide (Pettijohn, 1963; Potter, 1978, Osae *et al.,* 2006) and sandstone from other parts of Nigeria (Tijani *et al.,* 2010). As indicated in Table 2, the analyzed samples are dominated by silica with 74.18 to 78.20 wt. % $SiO_{2,}$ while Al_2O_3 and Fe_2O_3 ranged from 12.70 to 17.49 wt. % and 3.61 to 5.53 wt. % respectively. K_2O and Na_2O ranged 2.11 to 2.89 wt. % and 0.90 to 1.50 wt. % respectively. Other major oxides (TiO_2, MnO, MgO, CaO and P_2O_5 are either equal to one or generally below 1.0 wt. %. However, the samples, though with similar chemical trends exhibit elevated concentrations of Al_2O_3 (12.70 to 17.49 wt. %) and Fe_2O_3 (3.61 to 5.53 wt. %), which are clear indications of weathering processes. This is clearly supported by the low SiO_2/Al_2O_3 ratio of 4.24 to 6.6 (Table 3). A logarithm plot of ratios (SiO_2/Al_2O_3) against (Na_2O/K_2O) revealed that the Bima Sandstone samples are litharenite with a few arkose according to the diagram of Pettijohn *et al.,* (1972) (Fig. 4). These lithic-arenite and arkose were deposited under a continental fluvial environment as deduced from GSA plots (Fig. 5).

5. Discussion and Inferences

5.1 Texture statistical parameters and Depositional Environment

The statistical parameters from textural studies of clastic sedimentary rocks are useful tools in sedimentology for revealing the transportation history, sedimentary processes as well as the characteristics of the depositional environments (Folk and Ward, 1957; Folk, 1974; Friedman, 1967; 1969; Olugbemiro and Nwajide, 1997). For this study, plots of simple skewness against standard deviation (sorting) (Fig. 5A), as well as that of mean grain size against standard deviation (Fig. 5B) clearly shown that the Bima sandstone samples are of river sand and of fluvial origin, based on the concept of Friedman (1969) and Folk (1974) respectively.

5.2 Geochemistry and Tectonic Provenance

The major element geochemistry of the Bima Sandstone samples (Table 2) is discussed in terms of ternary plot and discrimination diagram to characterize the tectonic setting as proposed by Bhatia (1983) and Kroonenberg (1994). The ternary plot comprised of ($SiO_2/20$) – (K_2O+Na_2O) – ($TiO_2+Fe_2O_3$ + MgO) according to Kroonenberg (1994) (Fig.6). In this diagram (Fig.6), the majority of the Upper Bima Sandstone samples plot on field D with a few tending toward field C, active continental margin. The field D is equivalent to a passive continental margin tectonic setting (Bathia, 1983). However, the few Bima Sandstone samples tending towards field C are as a result of slight secondary K_2O + Na_2O enrichment probably related to diagenesis from an active margin input, probably the Cameroon volcanic line.

5.3 Geochemistry, Source Area Weathering and Climate Indices

Weathering of rocks results in depletion of alkalis and alkaline earth elements and preferential enrichment of Al_2O_3 (Cingolani *et al.*, 2003). Therefore, weathering effects can be evaluated in terms of the molecular percentage of the oxide components, using the formulae of chemical index of weathering (CIW = $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O] \times 100$; Harnois, 1988) and chemical index of alteration (CIA) = $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O] \times 100)$; (Nesbitt and Young, 1982). CaO* represents Ca in silicate minerals only (excluding calcite, dolomite, and apatite, Fedo *et al.,*1995) which are incidentally not present in the fluvio-continental Bima sandstone and also indicated by the very low content of CaO (0.05- 1.10 wt.%; Table 2). The CIW of Harnois (1988) is similar to the CIA with the exception of K_2O that is excluded from the equation. The CIA and CIW are often interpreted using similar approach, such that values of about 50 are for fresh or unweathered upper crust materials and about 100 for highly weathered residual soils with complete removal of alkali and alkaline earth elements (McLennam *et al.,* 1983; McLennam, 1993; Mongelli *et al.,* 1996). CIA values between 50 and 60 indicate a low degree of chemical weathering, between 60 and 80 moderate chemical weathering, and values greater than 80 indicating extreme chemical weathering (Fedo *et al.,* 1995). The CIA is also a very useful tool for providing a semi-quantitative assessment of palaeoclimate in the source area because a large amount of aluminous clay minerals generally forms by intense chemical weathering under tropical conditions and gives CIA values of 80 -100 (Tang *et al.,*2012). In contrast, under glacial environments where abrasion is dominant over chemical weathering, common CIA values range from 50 to 70 (Nesbitt and Young, 1982).

For this study, the calculated CIA and CIW values (Table 2) ranged 75.24 to 83.33 and 85.31 to 93.53 respectively. The calculated CIA values of the studied samples (75.24 to 83.33; average 79.63; Table 2 and Fig.7) indicated that the source area may have been subjected to a moderate to extreme degree of chemical weathering under tropical conditions with relatively abundant rainfall.

Molar proportions of Al_2O_3 (A), CaO^*+Na_2O (CN) and K_2O in the Albian to Cenomanian Upper Bima sandstone samples are plotted in A-CN-K compositional space (Fig.7) after Nesbitt and Young (1984, 1989) to estimate trends of chemical weathering and source rock compositions. Weathering trends might be predicted to be parallel to the A-CN join during the initial stages because Na and Ca are removed by chemical weathering of plagioclase feldspars as shown by solid arrow in Figure 7. As weathering continues, K-feldspars should also have been weathered releasing K and shifting the residual composition towards the Al_2O_3 apex. Also, the actual trend of the Upper Bima sandstone samples (dotted line) is sub-parallel to the A-CN join towards the compositions of Al_2O_3, almost similar to the predicted weathering trend (solid arrow). This slight divergent trend was possibly caused by potassium metasomatism (Fedo *et al.*, 1996, 1997) or K_2O enrichment during the sedimentary process. An additional advantage of the A-CN-K ternary plot is that it enables estimation of source rock compositions by backward projection (see solid arrow in Figure 7) of the samples to a point on the feldspar line (Pl-Ks). The intersection point provides an approximate ratio of plagioclase to K-feldspar in the source rock. Figure7 shows that the weathering trend suggests a range of tonalitic to granodioritic to granitic provenances. These may be related to the Precambrian Basement complex of Nigeria flanking the SE and NW part of the study area. It can be deduced from these lines of evidence that the Upper Bima Sandstone evolved from the weathering of the Basement Complex rocks. This consists of sediments derived from the Basement Complex rocks before and during Albian times in response to uplift and weathering.

6. Conclusions

Sedimentological statistical data revealed that the Bima Sandstone range from fine to coarse grained and deposited under a fluvial environment or a river system. The tectonic provenance of the Upper Bima sandstones of Upper Benue Trough in northeastern Nigeria has been assessed using major element geochemical studies. Geochemical characteristics suggest that these sediments are litharenitic and arkosic sandstones. Chemical Index of Alteration (CIA) values indicate that the source area underwent moderate to intense chemical weathering in a tropical climate, and an A-CN-K ternary diagram suggests a tonalitic to granodiorite to granitic source compositions. Major element compositions suggest two possible tectonic settings: a dominant passive continental tending towards a lesser active continental margin. If this is correct, the Albian to Cenomanian sediments of the Upper Bima were probably deposited in a passive basin situated close to an active continental margin (the Cameroon volcanic line). Using published data and geochemical data from this study, it can be concluded that the Nigerian Basement Complex rocks located in the northern and southern parts of the study area are most likely to have supplied source materials to the Yola Basin prior to and during the Albian to time as result of uplift and weathering.

References

Akande, S.O.; Ojo,O.J.; Erdtmann, B.D. and Hetenyi, M.,1998. Palaeoenvironment, Source rock potential and Thermal Maturity of the Upper Benue Rift Basins, Nigeria: Implications for hydrocarbon exploration. *Organic Geochemistry* **29** 531-542.

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

Armstrong-Altrin, J.S., Lee, Y.I., Verma, S.P. and Ramasamy, S., 2004. Geochemistry of sandstones from the Upper Miocene Kudankulam Formation, southern India: implication for provenance, weathering and tectonic setting. *Journal of Sedimentary Research*, **74**(2), 285–297.

Asiedu, D.K., Suzui, S., Shibata, T., 2000. Provenance of sandstones from the Lower Cretaceous Sasayama Group, inner zone of southwest Japan. *Sedimentary Geology*, **131**, 9–24.

Basu, A., 1985. Reading Provenance from Detrital Quartz, In: Zuffa, G.G. (ed.), Provenance of Arenites: Dordrecht, NATO ASI Series, C148, D. Reidel Publishing Company, 231-247.

Basu, A., 2003. A perspective on quantitative provenance analysis, In: Valloni, R., Basu, A. (eds.), Quantitative Provenance Studies in Italy. *Memorie Descrittive Della Carta Geologica dell'Italia,* **61**, 11–22.

Basu, A., Young, S., Suttner, L., James, W., and Mack, G.H., 1975. Re-evaluation of the use of undulatory extinction and crystallinity in detrital quartz for provenance interpretation. *Journal of Sedimentary Petrology*, **45**, 873–882.

Benkhelil, J. 1989. The origin and evolution of the Cretaceous Benue Trough, Nigeria. *Journal of African Earth Sciences*, **8**, 251-282.

Bhatia, M.R., 1983. Plate tectonics and geochemical composition of sandstones. *Journal of Geology*, **91**, 611–627.

Bhatia, M.R. and Crook, K.A.W., 1986, Trace element characteristics of greywackes and tectonic setting discrimination of sedimentary basins. *Contributions to Mineralogy and Petrology*, **92**, 181–193.

Braide, S.P., 1992a. Tectonic origin of preconsolidation deformation in the Bima Sandstone, Yola Arm, Benue Trough. *Nigerian Association of Petroleum Explorationists Bulletin* **7** (1) 39-45.

Braide, S. P. 1992b. Studies on the Sedimentation and Tectonics of the Yola arm of the Benue Trough: Facies Architecture and their Tectonic significance. *Journal of Mining and Geology*, **28**, (1) 23 – 31.

Braide, S. P. 1992c. Morphology and Depositional history of An Aptian–Albian Crevasse splay in the Bima Sandstone, Yola arm Benue Basin. *Nigerian Association of Petroleum Explorationists Bulletin,* **7**, (1) 46-50.

Carter, J.D., Barber, W., Tait, E.A. and Jones, J.P. 1963. The Geology of parts of Adamawa, Bauchi and Bornu Provinces in North-eastern Nigeria. *Geological Survey of Nigeria Bulletin* **30**, 1-109.

Chittleborough, D.J., 1991, Indices of weathering for soils and palaeosols formed on silicate rocks. *Australian Journal of Earth Sciences*, **38**, 115–120.

Cingolani, C.A., Manassero, M., Abre, P., 2003, 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,* **16**(1), 91-106

Cratchley, C.R. and Jones, G.P., 1965.An Interpretation of the Geology and Gravity Anomalies of the Benue Trough Valley, Nigeria. *Overseas Geological Survey, Geophysical paper* **1,** 1-26.

Crook, K.A.W., 1974. Lithogenesis and geotectonics: the significance of compositional variations in flysch arenites (greywackes), In: Dott, R.H., Shaver, R.H. (eds.), Modern and Ancient Geosynclinal Sedimentation: *Society for Sedimentary Geology Special Publication,* **19**, 304–310.

Cullers, R.L., 2000. The geochemistry of shales, siltstones and sandstones of Pennsylvanian–Permian age, Colorado, USA: implications for provenance and metamorphic studies: *Lithos*, **51**, 181–203.

Dickinson, W.R. and Suczek, C.A., 1979, Plate tectonics and sandstone compositions: *American Association of Petroleum Geologist Bulletin*, **63**, 2164–2182.

Etobro, A.A.I. and Ejeh, O.I., 2007. Maturity and Provenance of the Albian Bima Sandstone in Wuro-Dole and Environs, Yola Arm, Nigeria. *Continental Journal of Earth Sciences*, **2**, 14-24.

Fedo, C.M., Eriksson, K.A. and Krogstad, E.J., 1996. Geochemistry of shales from the Archean (≈3.0Ga) Buhwa

Greenstone Belt, Zimbabwe: implications of provenance and source-area weathering. *Geochimica et Cosmochimica Acta,* **60**, 1751-1763.

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

Fedo, C.M., Young, G.M., Nesbitt, H.W. and Hanchar, J.M., 1997. Potassic and sodic metasomatism in the Southern Province of the Canadian Shield: evidence from the Paleoproterozoic Serpent Formation, Huronian Supergroup, Canada. *Precambrian Research,* **84**, 17-36.

Folk, R.L., 1974.Petrology of Sedimentary Rocks, Austin, TX, Hemphill Press, second edition, 182.

Folk, R.L., 1980. Petrology of Sedimentary Rocks: Austin, Texas, Hemphill, 159.

Folk, R.L., Ward, W.C., 1957. Brazo river bar: A study of the significance of grain size parameters. *Journal of Sedimentary Geology* **27**, 3–26.

Friedman, G.M., 1967. Dynamic process and statistical parameters compared for size frequency distribution of beach and river sands. *Journal of Sedimentary Petrology* **37**, 327–354.

Friedman, G.M., 1969. Differences in size distribution of populations of particles among sands of various origins. *Sedimentology* **26**, 3–32.

Guiraud, M.,1990. Tectono-sedimentary framework of the Early Cretaceous Continental Bima Formation (Upper Benue Trough, NE, Nigeria). *Journal of African Earth Sciences (special publication),* **10**, 341-353.

Guiraud, M., 19993. Late Jurassic Rifting- Early Cretaceous rifting and Late Cretaceous transpressional inversion in the Upper Benue Basin (N.E. Nigeria). *Bulletin des Centres de Recherches Exploration-Production Elf Aquitaine* **17**, 371-383.

Harnois, L., 1988, The CIW index: A new chemical index of weathering. *Sedimentary Geology*, **55**, 319–322.

Hayashi, K., Fujisawa, H., Holland, H.D. and Ohmoto, H., 1997. Geochemistry of ≈1.9 Ga sedimentary rocks from northeastern Labrador, Canada. *Geochimica et Cosmochimica Acta,* **61**, 4115-4137.

Herron, M.M., 1988. Geochemical classification of terrigenous sands and shales from core or log data. *Journal of Sedimentary Petrology*, **58**, 820–829.

Kroonenberg, S.B., 1994. 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, 69-81.

McLennan, S.M., 1993. Weathering and global denudation. *The Journal of Geology*, **101**, 295–303.

McLennan, S.M., Hemming, S., McDaniel, D.K. and Hanson, G.N., 1993. Geochemical approaches to sedimentation, provenance and tectonics, In: Johnsson, M.J., Basu, A. (eds.): *Geological Society of America, Special Papers,* **285**, 21–40.

Milodowski A.E. and Zalasiewicz J.A, 1991. Redistribution of rare earth elements during diagenesis of turbidite/hemipelagic mudrock sequences of Llandovery age from central Wales, In: Morton, A.C., Todd, S.P. and Haughton, P.D.W. (eds.), Developments in Sedimentary Provenance Studies. *Geological Society of London, Special Publication*, **57**, 101–124.

Mongelli, G., Cullers, R.L. and Muelheisen, S., 1996. Geochemistry of Late Cretaceous-Oligocene shales from the Varicolori Formation, southern Apennines, Italy: implications for mineralogical, grain-size control and provenance. *European* Journal *of Mineralogy*, **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*, **299**, 715–717.

Nesbitt, H.W. and Young, G.M., 1984. Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamic and kinetic considerations. *Geochimica et Cosmochimica Acta,* **48**, 1523-1534.

Nesbitt, H.W. and Young, G.M., 1989. Formation and diagenesis of weathering profiles. *The Journal* of *Geology* **97**, 129-147.

Offodile, M.E., 1976. The geology of the Middle Benue, Nigeria. *Cretaceous Research,* **1**, 101-124.

Olugbemiro, R.O., Nwajide, C.S., 1997. Grain-size distribution and particle morphogenesis as signatures of depositional environments of Cretaceous (non-ferruginous) facies in the Bida Basin, Nigeria. *Journal of Mining and Geology*. **33** (2), 89–101.

Ojo, O.J. and Akande, S.O., 2001. Palaeoenvironmental and Palaeoclimatic characteristics of the Cenomanian to Coniacian Sediments of the Upper Benue Trough, Nigeria. *Journal of Mining and Geology,* **37** (2) 143-152.

Osae, S., Asiedu, D.K., Banoeng-Yakubo, B., Koeberl, C. and Dampare, S.B., 2006. Provenance and tectonic setting of Late Proterozoic Buem sandstones of southeastern Ghana: Evidence from geochemistry and detrital modes: *Journal of Asian Earth Sciences*, **44**, 85-96.

Petters, S.W., 1982. Central West African Cretaceous Tertiary benthic foraminifera and stratigraphy, palaeontographical. *Abteilung* A**179**, 1-104.

Petters, S.W. and Ekweozor, C.M., 1982. Petroleum geology of the Benue Trough and south-eastern Chad Basin, Nigeria. *American Association of Petroleum Geologists Bulletin,* **65,** 1141-1149.

Pettijohn, F.J., 1963. Chemical composition of sandstones excluding carbonate and volcanic sands. In: Data of geochemistry, 6th Ed; *US Geological Survey Professional Paper*, 44a-S, 1-19.

Pettijohn, F.J., Potter, P.E. and Siever, R., 1972. Sand and Sandstones: New York, Springer-Verlag 618P.

Potter, P.E., 1978. Petrology and chemistry of modern Big River sands. *Journal of Geology*, **86**, 423–449.

Roser, B.P. and Korsch, R.J., 1985. Plate tectonics and geochemical composition of sandstones: a discussion. *The Journal of Geology*, **93**, 81-84.

Roser, B.P., and Korsch, R.J., 1986. Determination of tectonic setting of sandstone-mudstone suites using SiO_2 content and K_2O/Na_2O ratio. *The Journal of Geology* **94**, 635-650.

Roser, B.P., and Korsch, R.J., 1988. Provenance signature of sandstone-mudstone suites determined using discriminant function analysis of major element data. *Chemical Geology* **67**, 119-139.

Samaila, N.K.; Dike, E.F.C. and Obaje, N.G.2008. Microstructures in the Cretaceous Bima Sandstone, Upper Benue Trough, N.E. Nigeria: Implication for hydrocarbon migration. *Journal of African Earth Sciences,* **50**, 6-15.

Samaila, N.K., Abubakar, M.B., Dike, E.F.C. and Obaje, N.G., 2006. Description of soft-sediment deformation structures in the Cretaceous Bima Sandstone from the Yola Arm, Upper Benue Trough, Northeastern Nigeria. *Journal of African Earth Sciences,* **44**, 66-74.

Tang Y., San L., Yuang Y., Zhang Y. and Yang Y.; 2012.Geochemistry of Late Triassic pelitic rocks in the NE part of Songpan-Ganzi Basin, western China: Implications for source weathering, provenance and tectonic setting. *Geoscience Frontiers,* **3** (5) 647-660.

Taylor, S.R. and McLennan, S.M., 1985. The continental crust: its composition and evolution, Oxford, Blackwell, 312.

Tijani, M.N., Nton, M.E. and Kitagawa, R., 2010. Textural and geochemical characteristic of the Ajali Sandstone, Anambra Basin, SE Nigeria: Implications for its provenance. *Comptes Rendus Geoscience,***342**, 136-150.

Valloni, R. and Mezzardi, G., 1984. Compositional suites of terrigenous deepsea sands of the present continental margins. *Sedimentology*, **31**, 353–364.

Von Eynatten, H., 2003. Petrography and chemistry of sandstones from the Swiss Molasse Basin: an archive of the Oligocene to Miocene evolution of the Central Alps: *Sedimentology*, **50**, 703-724.

Zimmermann, U. and Bahlburg, H., 2003, Provenance analysis and tectonic setting of the Ordovician clastic deposits in the southern Puna Basin, NW Argentina. *Sedimentology*, **50**, 1079–1104.

Table 1: Result of the Statistical Parameters obtained from the Grain Size Analysis of some selected Sandstones of the Upper Bima.

Sample Number	**Graphic Mean**	**Standard Deviation**	**Skewness**	**Kurtosis**	**Interpretation**
WD4	2.21	1.59	0.03	3.40	Fine grained, poorly-sorted nearly symmetrical, extremely Leptokurtic sandstone.
WD8	1.57	1.13	-0.10	1.94	Medium grained, poorly sorted, nearly symmetrical, very leptokurtic sandstone.
WD13a	0.61	1.45	0.44	1.83	Coarse grained, poorly sorted, strongly fine skewed, very leptokurtic sandstone.
WD18b	0.25	1.61	0.12	1.23	Coarse grained, poorly-sorted, near symmetrical, very Leptokurtic sandstone.
D24	1.94	1.68	0.32	1.75	Medium grained poorly-sorted, nearly symmetrical, very Leptokurtic sandstone.
D26	1.30	1.45	0.00	1.82	Medium grained poorly-sorted, nearly symmetrical, very Leptokurtic sandstone.
D28c	0.16	1.16	-0.05	1.41	Coarse grained, poorly sorted, fine skewed, very leptokurtic sandstone
D30	0.82	1.13	0.08	1.14	Coarse grained, poorly-sorted, nearly symmetrical, Leptokurtic sandstone.
D31	1.57	1.20	0.58	1.71	Medium grained, poorly sorted, strongly fine skewed, very leptokurtic sandstone.
WD35	1.52	1.25	-0.16	1.50	Medium grained, moderately sorted, coarse skewed, very leptokurtic sandstone.
WD44	1.08	0.98	-0.11	1.46	Medium grained, moderately sorted, coarse skewed, very leptokurtic sandstone.
WD46b	1.38	1.77	0.35	1.84	Medium grained, poorly sorted, strongly fine skewed, very leptokurtic sandstone.
WD47	0.79	1.50	0.38	1.42	Coarse grained, poorly sorted, strongly fine skewed, very leptokurtic sandstone.
WD50	1.34	1.27	-0.16	1.15	Medium grained, poorly sorted, coarse skewed, leptokurtic sandstone.
WD51	2.00	1.62	-0.16	0.60	Fine grained poorly-sorted, coarse skewed, very platykurtic sandstone.
Average	1.24	1.39	0.07	1.61	Medium grained poorly-sorted, nearly symmetrical, very Leptokurtic sandstone.

Table 2: Results of the Major Elements Analyses along side their Weathering Indices.

Sample No.	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	TiO_2 (%)	MnO (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O(%)	P_2O_5 (%)	Total	%CIA	%CIW
D3	75.71	16.94	3.61	0.07	0.05	0.16	0.07	1.23	2.13	0.02	99.99	83.16	92.87
D7	74.18	17.49	4.19	0.08	0.15	0.15	0.13	1.23	2.14	0.01	99.75	83.33	92.79
D8	75.52	16.10	5.00	0.06	0.05	0.12	0.05	1.13	2.13	0.01	100.2	82.95	93.17
D9	75.13	15.59	5.53	0.07	0.04	0.14	0.08	1.24	2.11	0.03	99.96	81.97	92.19
D10	75.41	15.85	5.05	0.07	0.05	0.11	0.08	1.22	2.13	0.02	99.99	82.21	92.42
D11	77.91	13.29	4.46	0.07	0.05	0.15	0.08	1.17	2.12	0.04	99.34	79.77	91.40
WD35	75.20	15.10	4.40	0.10	0.10	0.10	1.10	1.50	2.37	0.03	100.0	75.24	85.31
WD7	74.80	14.90	5.20	0.10	0.10	0.10	0.70	1.20	2.79	0.01	99.90	76.06	88.69
WD19	77.00	13.80	4.50	0.20	0.10	0.30	0.10	1.30	2.59	0.01	99.90	77.57	90.79
WD50	75.80	15.20	3.90	0.10	0.10	0.10	0.90	1.10	2.89	0.01	100.1	75.66	88.37
WD48	76.70	14.45	4.80	0.10	0.10	0.20	0.10	0.90	2.48	0.02	99.90	80.59	93.53
WD13	78.20	12.70	5.10	0.10	0.10	0.10	0.40	1.00	2.39	0.01	100.1	77.02	90.07
Modern Big Rivers (Potter,1978)	85.30	7.45	2.76	0.78	0.05	1.02	1.12	0.23	1.14	0.02			
Arkose (Pettijohn, 1963)	80.20	9.04	2.37	0.31	0.28	0.52	2.81	1.56	2.91	0.10			
Buem sandstone Ghana (Osae *et al.*,2006)	94.52	0.20	3.34	0.01	0.02	0.08	0.11	0.05	-	0.44			
Ajali sandstone (Tijani *et al.*,2010	78.8	10.5	3.25	1.03	0.01	0.04	0.01	0.01	0.03	0.06		99.5	99.8

%CIA: Chemical Index of Alteration has been calculated according to Nesbitt and Young (1982) = $Al_2O_3/(Al_2O_3+Na_2O+K_2O+CaO)$ X100

%CIW: Chemical Index of Weathering has been calculated according to Harnois (1988) = $Al_2O_3/(Al_2O_3+Na_2O+CaO^*)$ X100

Table 3: Profiles of Selected Elemental Ratios of the analyzed Bima Sandstone

Sample No.	**SiO_2/Al_2O_3**	**Na_2O/K_2O**	**Fe_2O_3/K_2O**	**K_2O/Al_2O_3**	**K_2O/Na_2O**
D3	4.47	0.58	1.69	0.13	1.73
D7	4.24	0.58	1.96	0.12	1.74
D8	4.69	0.53	2.35	0.13	1.89
D9	4.82	0.59	2.62	0.14	1.70
D10	4.76	0.57	2.37	0.13	1.75
D11	5.86	0.55	2.10	0.16	1.81
WD35	4.98	0.63	1.86	0.16	1.58
WD7	5.02	0.43	1.86	0.19	2.33
WD19	5.58	0.50	1.74	0.19	1.99
WD50	4.99	0.38	1.35	0.19	2.62
WD48	5.31	0.36	1.94	0.17	2.76
WD13	6.16	0.42	2.13	0.19	2.39

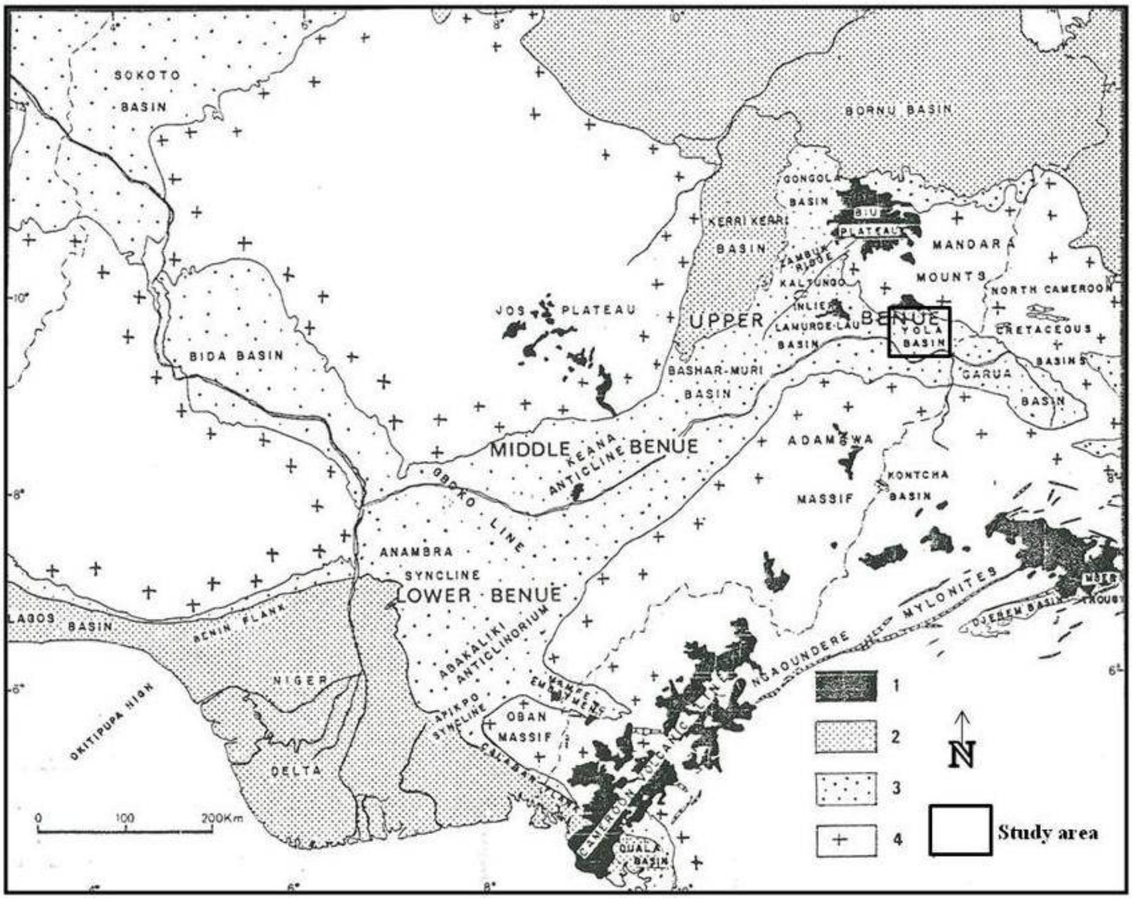

Figure 1: Map of Nigeria showing the study area, main geographical and stratigraphic units of the Benue Trough and its surroundings: (1) Tertiary volcanic; (2) Quaternary and Tertiary sediments; (3) Cretaceous sediments; (4) Basement complex (After Benkhelil, 1989).

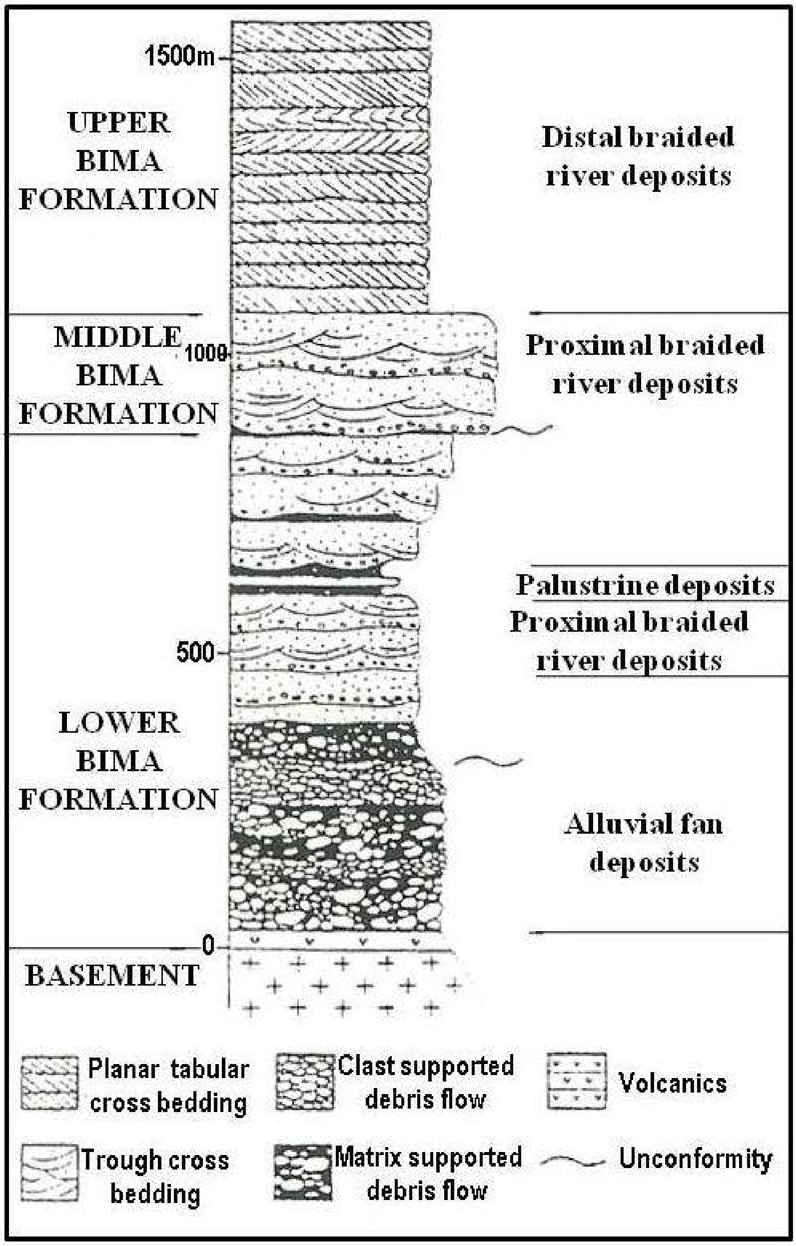

Figure 2: Bima Group generalized lithostratigraphical profile (Modified after Guiraud, 1990).

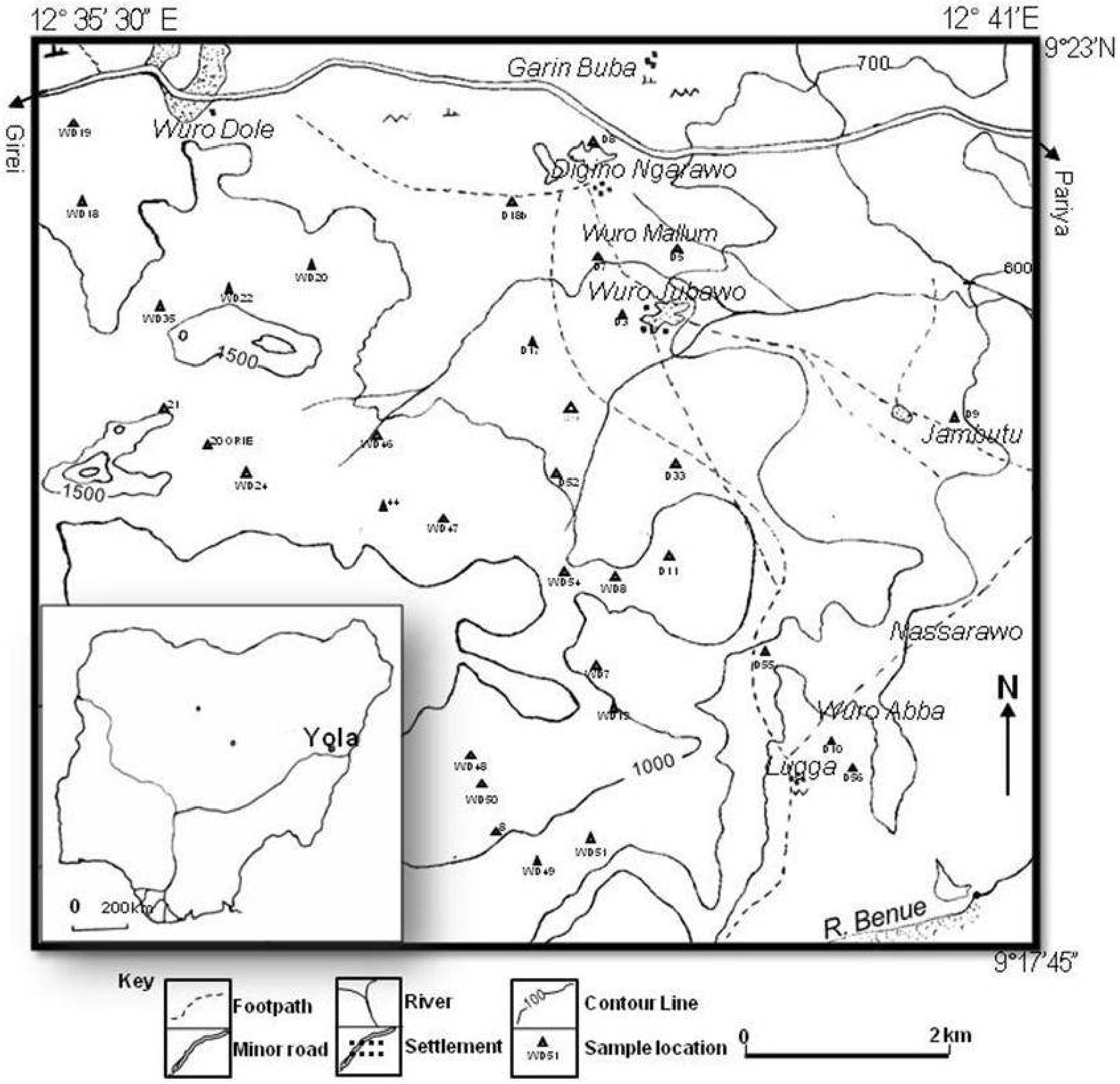

Figure 3: Location Map of Study Area.

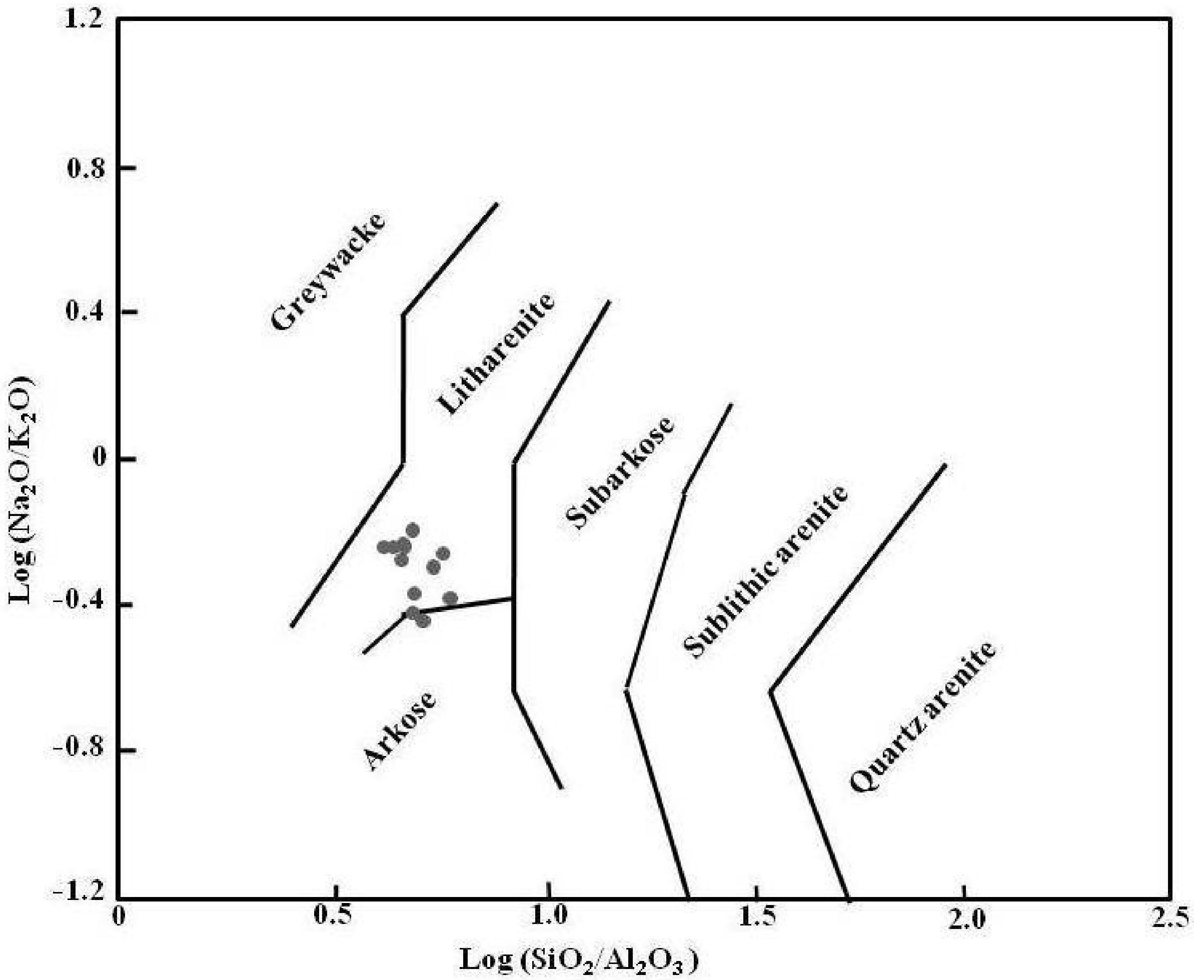

Figure 4: Chemical classification of samples from the Bima sandstone on log(SiO2/Al_2O_3 *versus* log(Na_2O/K_2O) diagram of Pettijohn *et al.* (1972).

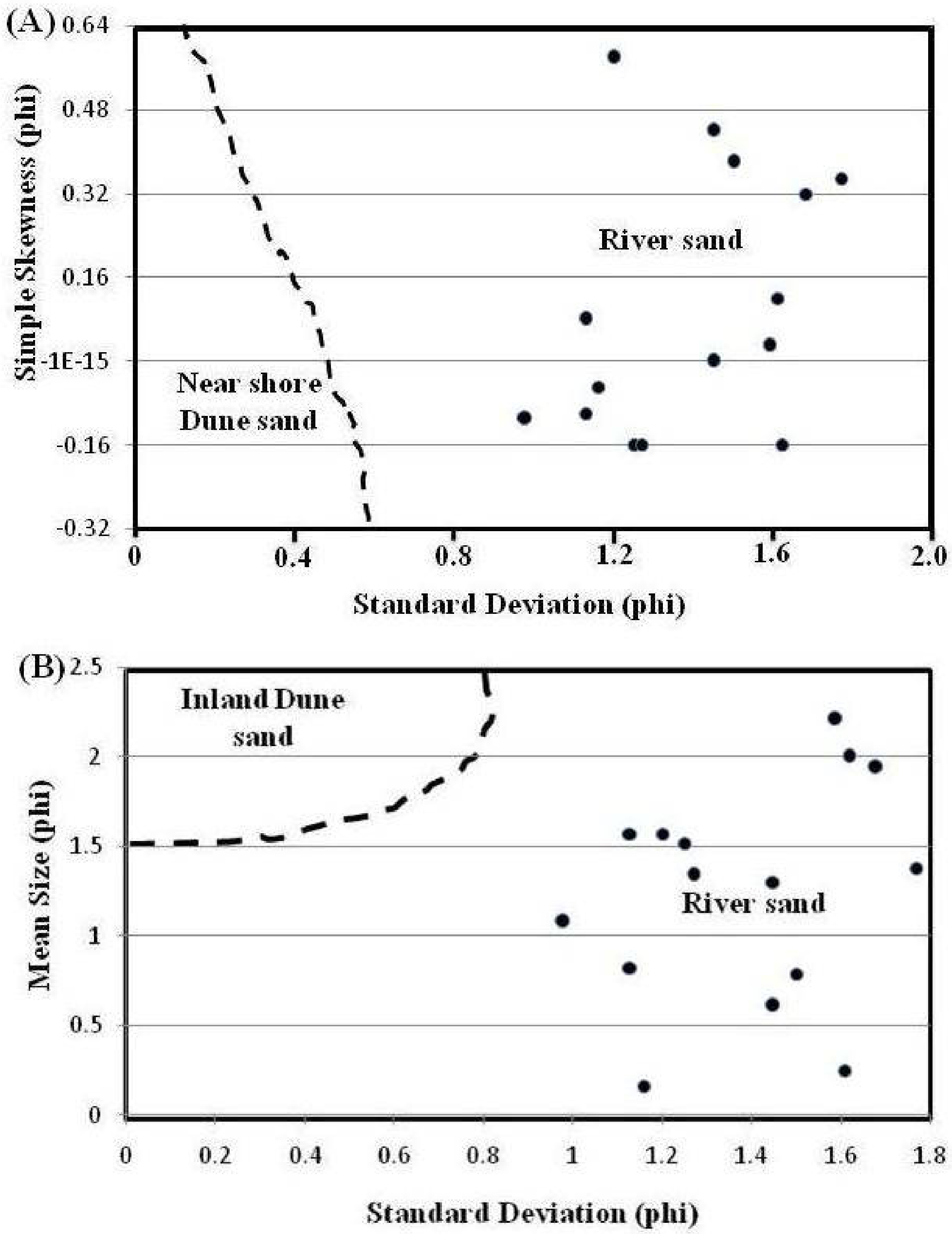

Figure 5: Depositional environmental discrimination of the Bima sandstone: A- Simple Skewness against Standard Deviation. B- Mean Grain Size against Standard Deviation.

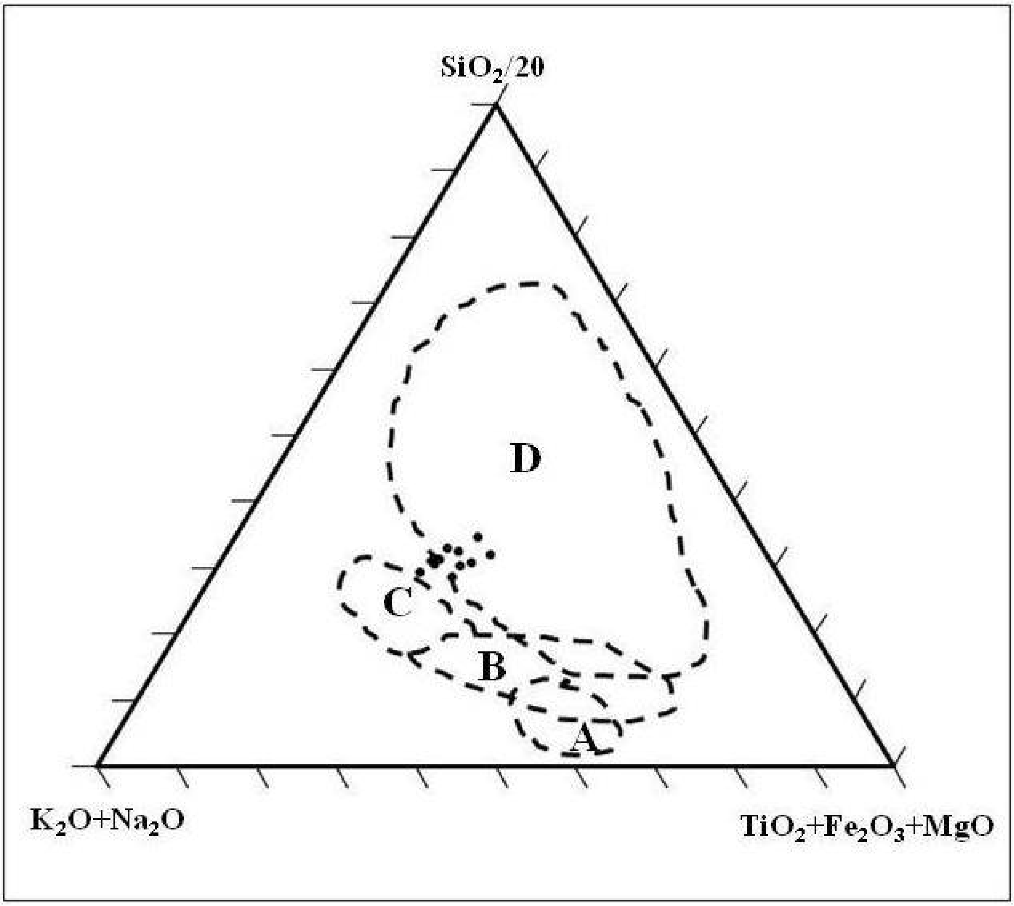

Figure 6: Plot of Major Element Composition of the Bima Sandstone on the tectonic setting discrimination diagram of Kroonenberg (1994). Field labels: A=Oceanic island Arc; B=Continental island Arc; C=Active continental margin; D= Passive margin.

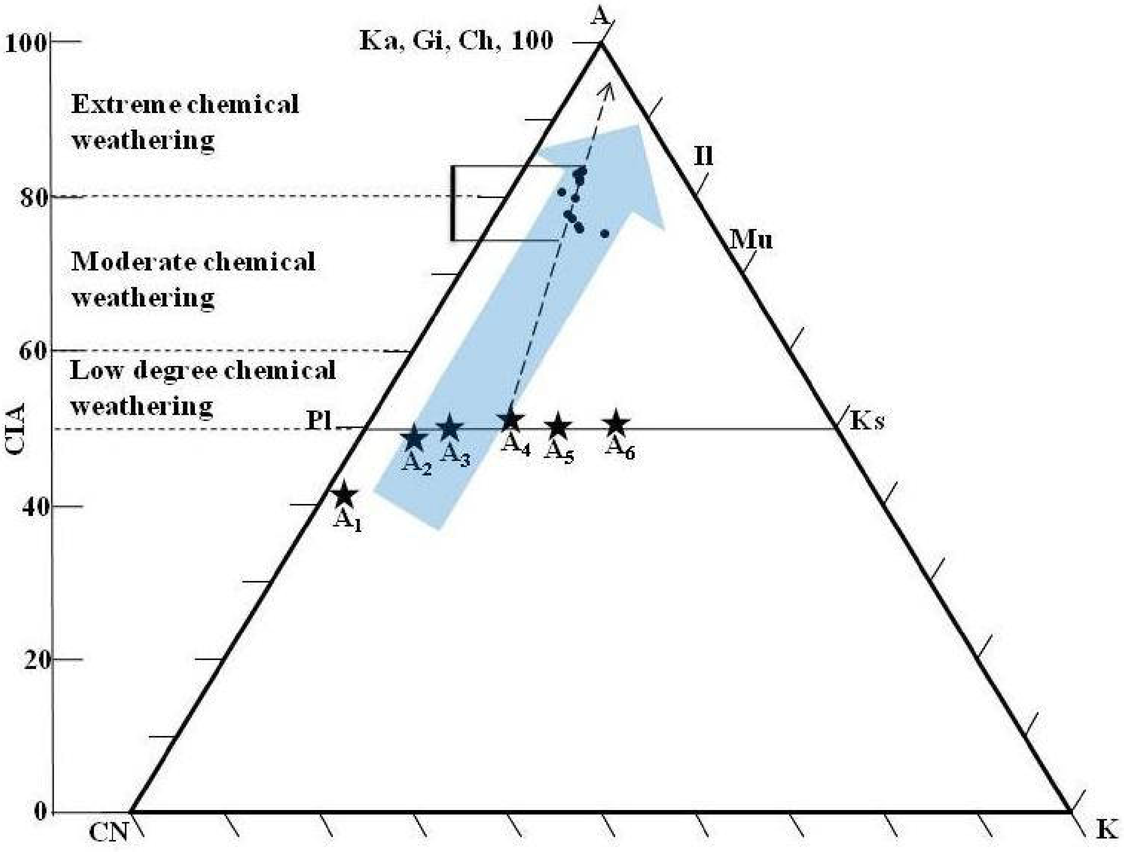

Figure 7: A-CN-K ternary diagram of molecular proportion of Al_2O_3- (CaO^*+Na_2O)-K_2O for Bima Sandstone (Nesbitt and Young, 1984). The CIA scale shown at the left side of the figure for comparison. Ideal compositions of minerals labeled: Pl, Plagioclase; Ks, K-feldspars; Il, illite; Mu, Muscovite; Sm, Smectite; Ka, Kaolinite; Gi, gibbsite; Ch, Chlorite. Solid arrow indicates the actual weathering trend for the samples. Stars: average compositions of gabbro (A1), tonalite (A2), granodiorite (A3), granite (A4), A-type granite (A5) and charnockite (A6) from Fedo *et al*. (1997). Solid arrow indicates the predicted weathering trend for tonalite; dotted arrow shows the actual weathering trend for the samples.