Geology

SEDIMENTOLOGICAL CHARACTERISTICS AND ASPECTS OF HYDROCARBON POTENTIAL OF KINASAR-1 WELL SEDIMENTS, BORNU BASIN, NORTHEASTERN NIGERIA

M. E. NTON*
W. P. AROWOSEGBE

ABSTRACT

Subsurface samples from Kinasar-1 well, in the Bornu basin, northeastern Nigeria, were studied to deduce the lithofacies distribution, provenance, palaeodepositional environment and paleotectonic conditions of the basin . In addition, the hydrocarbon potential of the associated shales has been highlighted. The lithological sequence comprised a basal unit of over 1300m coarse grained sandstone of the Bima Formation, overlain by 1200m shaly unit with a sandy base, belonging to the Gongila Formation. This is successively overlain by thick carbonaceous Fika Shale, and capped by over 700m of sandstone with claystone intercalations which constitute the Chad Formation. Altogether, 29 representative samples, made up of 15 shale, 12 sandstone and 2 claystone from the well were sampled for this study.

The sandstones are angular to subrounded, coarse grained, poorly sorted, mostly coarsely skewed and platykurtic to lepturkurtic. Cross plots of textural parameters indicate that they are river sands and fluvial. Petrographic studies identify the sandstones as subarkose, with quartz mainly of monocrystalline with subordinate polycrystalline varieties. Heavy minerals comprised zircon, tourmaline, rutile, staurolite, and garnet from both the Chad and Bima Formations with average ZTR indices of 78.9 and 81% respectively. Clay mineral composition shows the predominance of kaolinte (av. 85.68%) with quartz constituting 15.32% of detrital fraction. This may be attributable to weathering of feldspar -rich rocks under humid conditions from the adjoining basement rocks of northern Nigeria.

Rock – eval studies revealed that the total organic carbon (TOC) ranges from 1.02 to 2.31wt% which indicate adequate organic matter for both the Fika Shale (1.19 to 2.31wt %) and the shaly facies of the Gongila Formation (1.02 to 1.41wt %). Generally, the Hydrocarbon Index (HI) and Genetic Potential (GP) are low, with average values of 50mgHc/gTOC and $0.82kg^{-1}t^{-1}$ respectively, thus indicating low hydrocarbon potential. Tmax values range from 360°C to 472°C and the calculated vitrinite reflectance varies from 0.58% to 1.23% which connote thermally immature to marginally mature sediments. Cross plots of HI versus TOC and Tmax versus HI imply that majority of the sediments are types III and IV kerogen which are terrestrial precursor and gas proned.

It can be deduced that the subarkosic sandstones are products of continental block provenace, derived probably from the Zambuk ridge and/or the north central basement complex of Nigeria and deposited in a fluvial environment. The immature to slightly mature shales are terrestrial precursors having potential to generate gas at appropriate maturation.

KEY WORDS: Provenance, Petroleum Potential, Bornu Basin

* Dept of Geology, University of Ibadan, Ibadan
Email: ntonme@yahoo.com
Phone contact:+2348023417013;+2348072544692

INTRODUCTION

The Chad Basin is the largest intracratonic basin in Africa and its Nigeria sector, locally called the Bornu Basin, represents about one tenth of the total area of the basin (Obaje, 2009). The Chad Basin belongs to a series of Cretaceous and later rift basins in Central and West Africa, whose origin is related to the opening of the South Atlantic (Obaje et al., 2004). Oil was discovered in the neighbouring Chad Republic sector from Kanem-1 well, located about 128km from the Nigerian boarder (Idowu, 1992) as well as oil and gas shows, encountered in Cretaceous sequences in the eastern Niger graben, which is structurally contiguous to the Benue, Chad, Sudan and Libyan rift complexes (Zanguina et al., 1998).

As early as 1980's, the Nigerian National Petroleum Corporation (NNPC) has shot several kilometres of seismic lines and also drilled many wildcat wells for the exploration of hydrocarbon in the Bornu basin. Nigeria's current proven national petroleum reserves asset, put at 32 billion bbl of oil and about 170 trillion standard ft of gas (Nexant, 2003) is derived solely from the Niger Delta. The present study aims at deducing the palaeodepositional environment, provenance, tectonic setting as well as the hydrocarbon potential of the basin. Such information would be useful to researchers and explorationists.

LOCATION OF STUDY AREA AND STRATIGRAPHY

The studied well is located at latitude 12°18'N and longitude 13°7'13"E and lie within the Bornu Basin (Fig. 1). The stratigraphy of the Bornu basin is discussed below;

Bima Sandstone

This is the oldest sedimentary unit in the Bornu Basin and overlies unconformably the Precambrian Basement Complex. It is made up of over 1000m of continental, poorly sorted, medium to coarse grained, sparsely fossiliferous, thick to massive bedded and feldspathic sandstone (Barber, 1965). According to Obaje (2009) the sandstones are coarser towards the base and comprised intercalations of greyish shale and sandstones which constitutes the upper part of the regionally known continental interclaire. The sandstones were derived from granitic basement terrain in response to uplift and weathering (Odusina et al., 1983). More over, Carter et al, (1963) and Odusina et al., (1983) reported that the Bima Sandstone is wholly continental in the northern part of the basin, while in the south, marine shales occur in its lower part, which constitute probably the pre –Bima beds of Avbovbo et al (1986). The formation is diachronous and probably of Albian-Turonian age (Obaje, 2009).

Gongila Formation

The Gongila Formation overlies the Bima Sandstone. The formation is made up of an alternating sequence of sandstone and shale with limestone beds. It marks the beginning of the first marine transgression into the basin. Carter et al., (1963), divided the formation into two members; a lower marine limestone- shale member, about 3m thick, lying on the Bima sandstones, and an upper sandstone –shaly member, consisting of white, creamy or purple sandstones, mudstones, shale and limestone interbeds . The formation is dated lower Turonian.

Fika Shale

The Gongila Formation is overlain by over 530m of marine shales, belonging to the Fika Formation. The shale is bluish – black, fossiliferous, occasionally gypsiferous, with thin limestone intercalations. As reported by Moumouni (2008), the Fika Shale and the overlying Gongila Formation, constitute the potential petroleum source rocks in the Bornu Basin. The Fika Shale ranges from Turonian – Maastrichtian in age.

Gombe Sandstone

The Gombe Sandstone overlies the Fika Shale in the Bornu Basin. It is composed mainly of sandstone, siltstone, shale, claystone, thin coal beds, lenticular oolitic to non-oolitic ironstones which are partly fossiliferous (Obaje, 2009). The formation is dated Maastrichtian and associated with estuarine/deltaic environment.

Kerri-Kerri Formation

The Kerri-Kerri Formation overlies the Gombe Sandstone in the Bornu Basin. The formation consists of intercalation of sandstones, massive gritty clays with colours varying from reddish brown, pink, yellow, purple to grey (Obaje, 2009). It is iron-rich and capped by vesicular and oolitic ironstones in some places. Texturally and lithologically, the formation resembles the Bima Sandstone, though the later is more feldspathic and consists of coarse grained sandstone. According to Chaanda et al., (2007), the Kerri-Kerri Formation wasdeposited in the southwestern portion of the basin and does not extend eastwards. The formation has been dated Palaeocene based on palynomorphs.

Chad Formation

The Chad Formation is the youngest and the uppermost Pliocene-Pleistocene sequence in the Bornu Basin and it overlies the Kerri-Kerri Formation. It consist of fluviatile and lacustrine thick bodies of claystones, separating three major

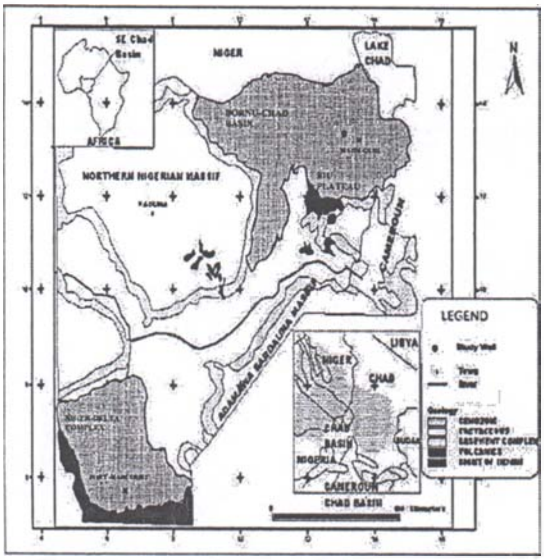

FIGURE 1. Geological Map of Nigeria showing the location of Bornu Basin position and of the study well; Map of part of Africa inset

sand bodies with lenses of diatomite,up to a few meters thick (Wright, 1985). Feldspathic sandstone dominate the base, which is overlain by gravels and a thick stratum of greenish-grey clay with a high proportion of fine grained sandstone, probably wind blown . The maximum thickness of the formation is over 800 meters near Maiduguri. Towards the end of the Tertiary, widespread volcanic activity occurred in the uplifted, southern and central areas. Such intrusions have NE-SW trend, and are located on the southern edge of the Chad Basin and the eastern edge of the Gongola arm. These magmatic bodies have been identified on seismic lines and often appear on the surface (Odusina et al., 1983).
The lithostratigraphic successions observed in the studied well is shown in Fig. 2

MATERIALS AND METHODS OF STUDY

Subsurface samples from Kinasar-1 well, within the Borno basin were obtained from the Nigerian Geological Survey Agency (NGSA), Kaduna, Nigeria. The Kinasar-1 well ranges from 60-4660m (Fig. 2). The well was logged and altogether, 29 ditch cutting samples, made up of fifteen (15) shale, twelve (12) sandstone and two (2) claystone were selected for a battery of analyses.

Laboratory Studies

Granulometric analysis

Twelve (12) representative sandstone samples were disaggregated and subjected to standard methods of grain size analysis using a set of sieves at 1/2 phi intervals (ASTM) on a Ro-tap sieve shaker for 15 minutes. Arising from the grain size distribution, cumulative curves were plotted from which statistical parameters were computed based on Folk and Ward (1957). Multivariate parameters were computed for the sandstones using the concept of Sahu (1964). Here; $Yu = 0.2852\ M_z - 8.7604\sigma_1^2 - 4.8932Ski + 0.0482K_G$. For Yu> - 7.419, it is interpreted as shallow marine deposits while values < - 7.419 is interpreted as fluvial deposits (Sahu, 1964). The grain size analysis was conducted at the Sedimentological Laboratory, Department of Geology, University of Ibadan, and Ibadan, Nigeria.

Thin section petrography

A total of eight (8) representative sandstone samples were selected for thin section petrography. Since all the samplesare loosely consolidated, they were all impregnated with resin before cutting. Each sample was mounted on a glass slide using Canada balsam and araldite and later examined under the flat stage of a petrological microscope model Brunnel. Point count method was used and based on this; individual percentages of the minerals were computed. Photomicrographs of features of interest were taken. Classification of the sandstones is based on Folk (1974).

Heavy Mineral Analysis

Heavy mineral analysis was carried out on twelve (12) representative sandstone samples. The bromoform (S. G. 2.85) extracts of the heavy minerals were rinsed with acetone, dried and mounted on slides using Canada balsam. Petrographic examination was conducted under a petrological microscope, model Brunnel. Photomicrographs of features of interests were taken and the sizes, shapes as well as the percentages of the non opaque minerals were estimated. Maturity index (ZTR) (Hubert, 1962) was estimated for each sample. Both the thin section petrography and heavy mineral examination were done in the Petrological Microscope Laboratory, Department of Geology, University of Ibadan.

X-Ray Diffraction

XRD analysis was carried out on two (2) claystone samples. The <2 micron clay fraction was ground in a mortar and distilled water added to it in a small glass beaker. It was stirred and allowed to settle for some hours. The clay particles were allowed to disperse and left to dry at room temperature and then stored in a desiccator. The dry mounts were loaded into a diffractometer model Philips pw, with Cu regulation and scanned from 2° to 30°. The diffractometer

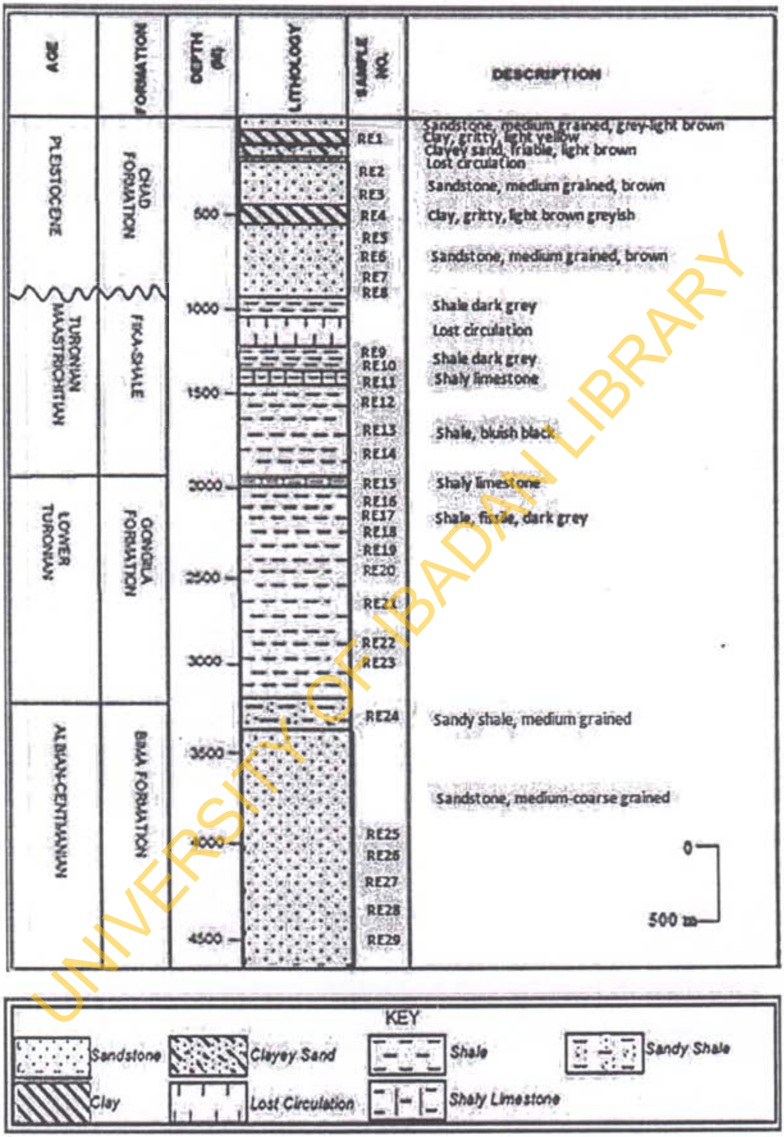

FIGURE 2. Lithostratigraphic succession and sampled points in Kinasar-1 well

TABLE 1: *Data of statistical parameters and qualitative description of the Sandstone samples*

Sample No	Grain size (Mean) (Mz)	Dispersion Sorting (σ_1)	Skewness (SK_1)	Kurtosis (K_G)
RE 2	-0.14(Very coarse Sand)	0.40 (Well sorted)	-0.64 (Strongly Coarse Skewed)	0.89 (Platykurtic)
RE2	-0.40 (Very coarse sand)	0.82 (Moderately well sorted)	0.05 (Near symmetrical)	1.46(Leptokurtic)
RE5	0.50 (Coarse sand)	1.36 (Poorly sorted)	0.18 (Fine skewed)	1.07 (Mesokurtic)
RE6	0.12 (Coarse sand)	1.13 (Poorly sorted)	0.12 (Fine skewed)	1.18 (Leptokurtic)
RE7	0.02 (Coarse sand)	1.29 (Poorly sorted)	-0.30 (Strongly Coarse Skewed)	1.46 (Leptokurtic)
RE8	-0.16 (Very coarse Sand)	0.65 (Moderately Well sorted)	-0.54 (Strongly Coarse skewed)	1.38 (Leptokurtic)
RE24	-0.10 (Very coarse Sand)	1.21 (Poorly sorted)	-0.35 (Strongly Coarse skewed)	1.18 (Leptokurtic)
RE25	-0.03 (Very coarse Sand)	1.14 (Poorly sorted)	-0.18(Coarse skewed)	1.22 (Leptokurtic)
RE26	-1.07 (Very coarse Sand)	1.77 (Poorly sorted)	-0.22 (Coarse skewed)	1.10 (Mesokurtic)
RE27	-0.12 (Very coarse Sand)	1.35 (Poorly sorted)	0.01 (Near symmetrical	1.22 (Leptokurtic)
RE28	-0.89 (Very coarse Sand)	1.30 (Poorly sorted)	-0.02 (Near symmetrical)	1.06 (Mesokurtic)
RE29	-0.43 (Very coarse Sand)	1.36 (Poorly sorted)	-0.01 (Near symmetrical)	1.13 (Leptokurtic)

operated under the following conditions; Copper K and radiated 40kv, Current: 100mÅ : X – Ray generator, 18kw: Target, 1.54056 Å (Cu), Range: 3-88 degree 2Θ, Step size: 0. 02° 2Θ, scanning speed: 1. 0000 deg/min, Divergence slit; angle 1 degree, Receiving slit: 1°, Scattering slit: 1°, Sample rotation: 1rev/sec. The diffractograms were compared with established standards and interpreted with reference to Brown (1972) and JCPDS (1974) tables of X-ray diffraction patterns. Quantitative estimation of the different minerals was carried out by computing their peak areas based on Gibbs (1967). The X-ray diffraction was carried at Acme Laboratory, Vancouver, Canada.

Rock Eval Pyrolysis

The process of Rock Eval Pyrolysis was described by Espitalie et al (1977) as a rapid method for the characterization of kerogen types and the determination of its maturity. Fifteen (15) representative shale samples were used for this analysis. About 80 – 100mg of each pulverized sample was heated initially at 300°C and followed by programmed pyrolysis at 25°C min to 550°C in an atmosphere of helium. The analysis was determined by Rock Eval II which has a Total Organic Carbon (TOC) module. These analyses were conducted at Weatherford Laboratory, Houston, Texas. U. S. A. Details of the instrumentation can be consulted in Arowosegbe, (2011).

RESULTS AND DISCUSSIONS

Textural Characteristics

The result of grain size analysis is shown in Table 1. The Kinasar-1 sandstones range from coarse sand to very coarse sand with range between -1. 07mm to 0. 50mm. The standard deviation reflects poorly sorted to well sorted sediments with ranges between 0. 40 to 1. 77 and majority

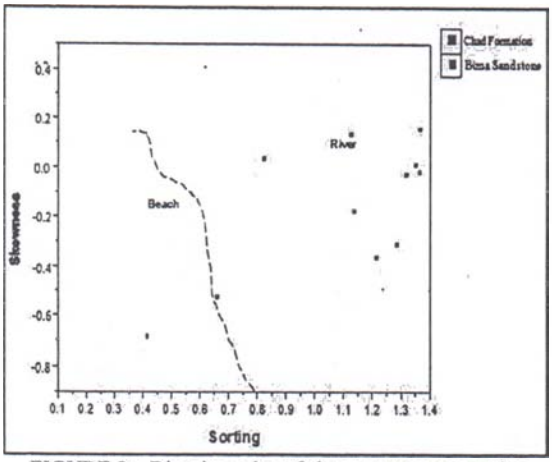

FIGURE 3a. Bivariant plot of skewness versus sorting (After Friedman, 1961)

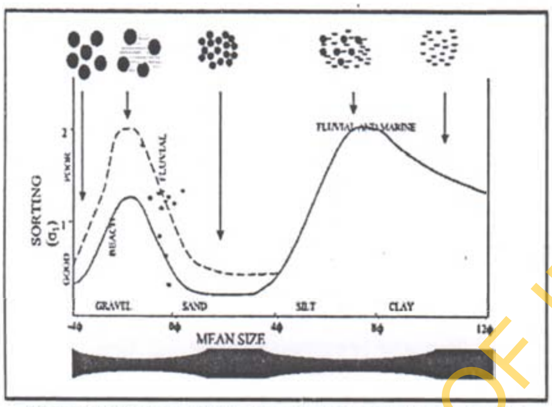

FIGURE 3b: Bivariant plot of sorting versus mean size (After Friedman, 1961).

in the poorly sorted class. Skewness values are between -0. 64 to 0.18 while values of kurtosis range between 0.89 and 1.46 with leptokurtic type dominating and few mesokurtic populations. Bivariate plots of skewness versus sorting (Fig 3a) and sorting versus mean size (Fig. 3b) based on Friedman (1961) show that the sandstones are within river sands and fluvial setting respectively. Multivariate analysis based on the concept of Sahu (1964) shows that the majority of the sediments are fluvial (Table 2).

. The probability curves for Kinasar-1 sandstones are mainly of the upper two segmented populations of the three segmented patterns of Visher (1967).

Petrography

The result of the thin section petrography is shown in Table 3. It can be seen that quartz is the dominant detrital mineral; varying from medium to coarse grained and constituting an average of 90%. The quartz grains arepoorly sorted and range from angular to subangular (Figs. 4a and 4b). Most quartz grains are monocrystalline with mild undulatory extinction while some are polycrystalline varieties, especially the larger grains. Some quartz grains are partly sutured and few are straight. The feldspars range from 4 to 10% and dominated by potasic type. Rock fragments are very few (1 to 5%) and are represented mainly by granite or chert fragments. The rarity of lithic fragments implies either that the source rocks were severely weathered or that the grains were recycled. This corroborates the findings of Akarish and El-Gohary (2008). The matrix and/or cement are composed mainly of clays (kaolinite). Most of the matrix fill the pore spaces and reduce the porosity. The sandstones aresubarkose based on Quartz, Feldspar + Rock fragment ratio (Folk, 1974, Fig. 5) and higher proportion of the chemically stable and physically resistant mineral (quartz).

Limited ranges of heavy minerals were observed in thin section, with the opague minerals constuiting a greater proportion (Fig. 6). The non opaque heavy minerals are mainly zircon, rutile, tourmaline, staurolite and garnet. The ZTR index ranges from 71%-91% (Table 4) and indicates that the sediments are mineralogically mature. Hoque and Ezepue (1977) observed that sandstones attain higher mineralogical than textural maturity due to intense weathering both at the source and during transport.

Clay Mineralogy

A typical diffractogram of the claystone of Kinasar-1 well isshown on Fig 7. It can be deduced that the clay mineralogy is mainly made up of kaolinite (85.68%) while quartz (15.32%) is the non clay mineral. The kaolinite peaks are shown at 2Θ values of 20.1°, 34.6°and 39.8° while the intensities are reflected by quartz at 2Θ values of 27.0°and 42.2°. The presence of kaolinite has been associated with the development of sufficient porosity or permeability to allow for the migration of interstitial water within the provided growth space, weathering of available feldspar under humid condition and availability of sufficient organic matter to maintain low pH during decomposition (Burke and Mankins 1971). Kaolinite is also known to be associated with continental and near shore sands (Visher, 1969). It can therefore be deduced that the presence of kaolinite could be attributable to weathering of feldspar –rich rocks under low pH conditions and associated with fluviatile environment. .

Tectonic Setting

Dickinson, (1985) has observed thatin sandstone provenance studies, different tectonic settings contain characteristic rock types which when eroded, produce sandstones with specific compositional ranges. The petrographic studies revealed that the sediments of Kinasar-1 are characterized by higher proportion of quartz, predominance of monocrystalline variety, more potash feldspar than plagioclase type, a paucity of rock fragments and a low P/F (plagioclase/ total feldspar) ratio. These properties are consistent with those sediments deposited in passive continental margin environment (Crook, 1974; Taylor and Mclennan, 1985; Potter, 1986). Crook (1974) proposed the use of quartz content to infer tectonic setting, and linked quartz-rich (>65 % quartz) sandstones to passive (Atlantic-type) continental margins; intermediate quartz (15-65% quartz) sandstones to active (Andean-type) continental margins, and quartz poor (< 15% quartz) sandstones to magmatic island arcs. The quartz-rich (averaging 90% quartz) sandstones revealed from this study, thus correspond to the atlantic-type sandstone of Crook (1974). According to Roser and Korsch (1986), passive margin sediments are largely quartz-rich sediments derived from plate interiors or stable continental are and deposited in intra-cratonic basins or on passive continental margins.

Many workers (e. g Crook, 1974; Dickinson and Suszek, 1979; Dickinson et al., 1983; Cavazza and Ingersoll, 2005; Greene et al., 2005; Akarich et al., 2008) have used the detrital framework composition of sandstones to establish tectonic setting and provenance types. In the Qt-F-L plot (Fig. 8) of Dickinson and Suszek, (1979), the sandstone in this study falls mainly on the continental block provenace field, indicating a rifted and uplifted continental basement setting for the Bornu Basin sandstones. In such a setting, the sands shed from fault-bounded uplifts of the basement and accumulate in the trough. According to Dickinson et al., (1983), sandstones plotting in this field are mature sandstones derived from relatively low-lying granitoid and gneissic sources, supplemented by recycled sands from associated platform or passive marging basins. Also, sandstone that falls within the continental block provenance are mainly derived from exposed shield areas and platforms or from uplifted (basement) areas and are deposited in stable sites (Bhatia, 1983; Taylor and Mclennan, 1985; Potter, 1986). As reported by Olade (1978),theNigerian basement was doomed and rifted in the pre-Early Cretaceous times to form the Benue-Chad aulacogen. However, by Turonian time, the basement complex was lowered prior to erosion and consequent deposition of sediments. The rugged topography and the distance of transportation would have given rise to typically quartzo-feldsparthic sandstones of classic subarkosic character.

FIGURES 4a & b: Photomicrograph of sandstone samples RE8 and RE3, respectively (in cross nicols) showing monocrystalline and polycrystalline quartz. Qm=Monocrystalline quartz, Qp=Polycrytalline, F=Feldspar

Paleoclimatic setting

Suttner et al., (1981) utilised quartz, feldspar and rock fragments (QFR) ternary plot to discriminate climatically induced compositional differences in Holocene sands. Using a similar approach (Fig. 9), it can be seen that the Kinasar-1 sedimentsfall within the plutonic humid climatic setting. Indications are that the basement rocks ofthe northern massif and Adamawa highlands of Nigeria, which are the possible source areas, were situated in a humid climatic setting.

Provenance

The mineralogical composition and textural attributes of sandstones reflect the source rock composition, climatic and tectonic settings (Suttner et al., 1981, Dickinson and Suczek, *TABLE.2: Multivariate results of sandstone of the Study area (Based on Sahu, 1964)*

Sample	Results	Interpretation
RE2	**-1.7323**	**Shallow marine**
RE3	**-5.8905**	**Shallow marine**
RE5	**-16.8898**	**Fluvial**
RE6	**-11.6820**	**Fluvial**
RE7	**-13.0325**	**Fluvial**
RE8	**-6.3434**	**Shallow marine**
RE24	**-11.0850**	**Fluvial**
RE25	**-10.4538**	**Fluvial**
RE26	**-26.6209**	**Fluvial**
RE27	**-15.9902**	**Fluvial**
RE28	**-14.6821**	**Fluvial**
RE29	**-16.2224**	**Fluvial**

1979). The sandstones are poorly sorted and texturally immature(Table 1). Such sediments according to Amaral and Pryor (1977) are deposited under variable current velocities. Folk (1974) has reported that these kind of sediments are usually deposited near to the source. Most of the sandstones are leptokurtic and unimodal in distribution. The high proportion of quartz (> 90%), as well as the presence of K-feldspar in the sandstone suggests that the source was exposed to prolonged weathering and/or recycling. This mineralogy is consistent with their derivation from granitic or acidic high- grade metamorphic rocks. All the studied samples contain both strained and unstrained quartz grains. Although the strained quartz could in part be due to the post depositional effect of folding and metamorphism, the occurrence of both strained and unstrained quartz suggest that some of them could be inherited from the source area and therefore, suggest a metamorphic and/ or plutonic source for the quartz grains (Young, 1979).

The presence of feldspar minerals and the preponderance of these over lithic fragments (Table 3) is suggestive of primary rather than reworked source rock (Pettijohn et al., 1973). The presence of polycrystalline quartz that are of nearly equant grains with sutured intercrystalline boundaries (Figs. 4a and b) and presence of feldspar favours a plutonic igneous granitoid source as the dominant source rock (Pettijohn et al., 1973, Blatt etal., 1972).

More monocrystalline quartz grains, poorly sorted, angular to sub-angular grain suggesting a plutonic origin rather than from basic rocks (Potter, 1978, Roser et al., 1996). This is also supported by the presence of kaolinite which is a product of weathering horizons and soils developed on granitic rocks (Akarish and El-gohary, 2008). Zircon has been described as the most ubiquitous, non-opaque minerals in silica-rich rocks (Blatt et al.,1980) and the abundant presence of zircon, tourmaline and hornblende favours plutonic igneous (granitiods) origin as the dominant source. Rutile is unstable in low grade metamorphic rocks (Force, 1970). Tourmaline is associated with low grade metamorphic and acid igneous rocks. The presence of staurolite and garnet and also indicate some contribution from metamorphic rocks. Garnet is found in pegmatites as well as in high grade metamorphic rocks (Folk, 1974). The possible source areas include the central Nigeria basement complex and Zambuk ridge which are known for these types of rocks. This proposition is supportedby the presence of more k-feldspar than plagioclase (Hindrix, 2000; Osae et al., 2006).

Depositional Environment

The sandstones are coarse to very coarse grain, poorly sorted (Table 1) and suggests fluctuation in energy of deposition. They are platykurtic to leptokurtic and indicate derivation from more than one source and corroborates the findings of Shettima et al., (2001). The bivariate plots of skewness versus sorting and sorting versus meansize (Figs. 3a and 3b) plus multivariate analysis based on the concept of Sahu, 1964 (Table 3) indicatethat the sandstones are mainly of fluvial environment.

Visher (1965) has described kaolinte as a clay mineral type more abundant in fluvial sands. In addition,the presence of carbonaceous fissile shale within the Fika and Gongila Formations as observed from the ditch cuttings suggests that, it was deposited in shelf to shoreface environment (Akande and Mucke 1993, Obi, 2000).

HYDROCARBON PROSPECT

Organic Matter Quantity

It is known that adequate amount of organic matter, measured as percentage total organic carbon (TOC) is a necessary pre-requisite for sediments to generate oil or gas (Cornford, 1986). The TOC values range from 1.02 – 2.31wt%, with an average of 1.70wt% (Table 5). This implies that sediments of the Kinasar-1 well, are above the threshold limit of 0.5wt% TOC, reported for the generation of organic matter from clastic sediments (Tissot and Welte, 1984).

S1 values range from 0. 06 – 0. 24 mgHc/gTOC rock (Table

TABLE 3: Detrital grain modes and their derived QFL indices

Sample No	Qm	Qp	F	L	M	Qt(%)	F(%)	L(%)	M.I
RE2	88	6	5	1	0	94	5	1	0.96
RE3	93	2	4	1	0	95	4	1	0.95
RE5	84	5	8	2	1	89	8	2	0.89
RE8	80	5	10	4	1	85	10	4	0.85
RE24	78	7	10	4	1	86	10	4	0.86
RE25	76	10	9	5	0	86	9	5	0.86
RE27	85	5	6	4	0	90	6	4	0.87
RE28	85	9	5	1	0	94	5	1	0.94
Range	80-93	2-10	4-10	1-5	0-1	85-95	4-10	1-5	0.85-0.95
Average	87	6	7	3	1	90	7	3	0.90

Qt =Qm +Qp,
Qm =monocrystalline quartz,
Qp = polycrystalline quartz,
F = total feldspar,
L = unstable lithic fragment,
M = mica
M.I = maturity index

5) thus indicating low level of thermal maturity (Chaanda et al., 2007). The source rock potential is indicative of the quantity of hydrocarbons that the rock has the potential of producing should burial and maturation continue (Akande et al., 2005; Klemne and Ulmishek, 1991). According to Petters and Cassa, (1994), S2 value of 2.5mgHc/g TOC, represents the minimum value a source rock must contain to be a fair source rock. The source rock potential (S2) values range from 0.27 – 1.15mgHc/g TOC (Table 5). Arising from the values obtained from this study, the values of S2 are less than the recommended limit of 2.5mgHc/g rock and suggest that thesamples have poor hydrocarbon potential. Petroleum generic potential (GP) range from 0.33 – 1.90kgHc/g rock which is generally lower than 2kgHc/g rock expected for good source rock (Dymann et al., 1996). This suggests low hydrocarbon potential, thus corroborating the findings of Olugbemiro, (1997) and Obaje et al., (2004).

Organic Matter Type

Organic matter in a sedimentary rock, among other conditions influences to a large extent the quality of hydrocarbon generated due to different organic matter convertibility (Tissot and Welte, 1984) . It is obvious that the generation of oil and gas is related to the rank, quality and type of organic matter or macerals (Murchison, 1987).

Cross plots of HI versus OI (Fig. 10) show that the majority of the samples plot within type IV kerogen. According to Petters and Moldown, (1993), such kerogen type can be associated with reworked and oxidized sediment. Very few samples (RE3 and RE6) plot within type III kerogen which is attributable to terrestrial organic matter. This corroborates the findings of Nton et al., (2009) in the eastern Dahomey basin.

Cross plot of source richness (HI) versus TOC (Fig. 11) indicate that the majority of the sediments plot within gas source rock. In addition, plot of HI against Tmax (Fig. 12) shows that the sediments are mainly type IV, inert and reworked organic matter. It can be implied that the sediments are terrestrial and mainly reworked, immature organic matter, with prospect to generate gas rather than oil at appropriate maturity.

Organic matter maturity

Thermal maturity describes the extent of heat-driven

TABLE 4: Relative abundance (%) and ZTR index of the heavy mineral from Kinasar-1 well

Sample Code	Opaque	Zircon (%)	Tourmaline (%)	Rutile (%)	Hornblende (%)	Garnet (%)	Staurolite (%)	Kyanite (%)	ZTR Index (%)
RE2	561	42	26.8	14.6	1.2	-	15.2	-	83.4
RE3	410	46	24	8.6	-	0.8	20.6	-	78.6
RE5	306	40	22.5	11.3	-	5	20	1.2	73.8
RE6	367	45.8	25.9	13.5	-	-	14.8	-	85.2
RE7	459	51	21	12	0.7	0.7	14.6	-	84
RE8	652	42	19.2	22.8	-	0.6	15.4	-	84
RE24	362	34.6	19.2	27	-	-	19.2	-	80.8
RE25	425	34.7	27.9	18	-	-	19.4	-	80.6
RE26	329	38.6	21	15.8	-	-	24.6	-	75.4
RE27	538	37.4	26.2	18.7	-	0.9	16.8	-	82.3
RE28	261	46	14.3	10.7	-	9	20	-	71
RE29	526	55.2	21.7	14.1	-	-	7.9	1.1	91

Z = Zircon, St = Staurolite, G = Garnet, T = Tourmaline, R = Rutile, H =Hornblend Ky =Kyanite

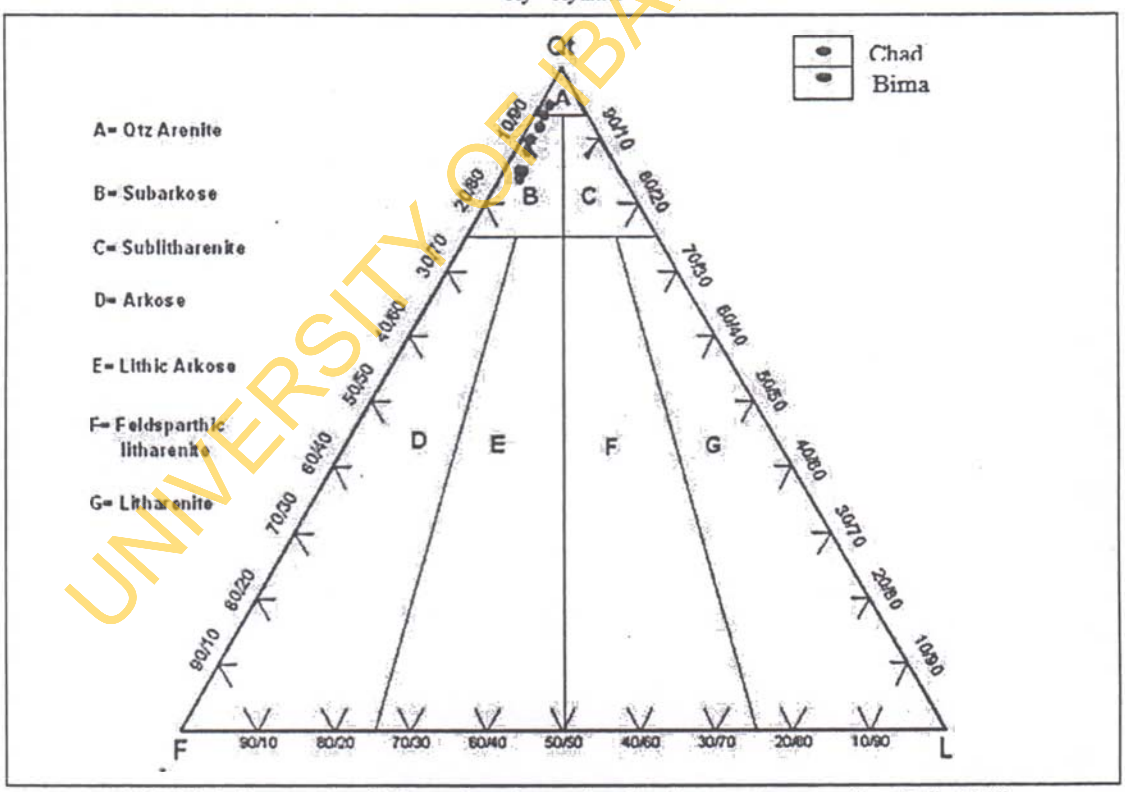

FIGURE 5 : Ternary plot of Kinasar-1 sandstones based on framework composition (Folk, 1974)

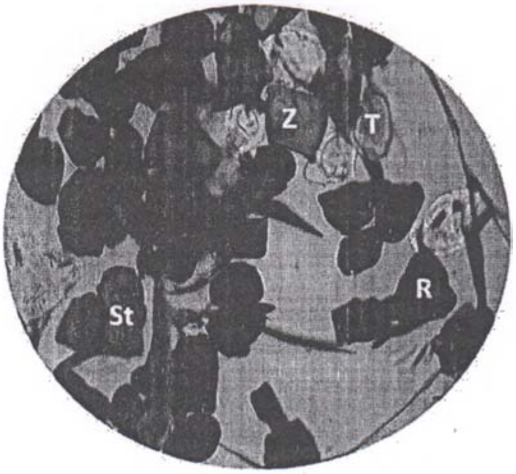

FIGURE 6: Photomicrograph of Heavy Minerals in samples RE25, showing zircon tourmaline and rutile (Cross polar) Magnification x2 0.

reactions, which converts sedimentary organic matter into petroleum (Peters and Moldowan, 1993). The T_{max} values range from 360° - 472°C (Table5) and portray immature to peak mature condition. Highest value of 472°C for sample RE9 may not really connote maturity more so with lesser S2 and TOC values (Table 5). As reported by Obaje et al., (2004), T_{max} increases with depth, except where faults, unconformities and contamination (migrated oil and bitumen) cause variation which may also be derived from drilling mud. In this study, such variations may be due to contamination.

The production index (PI) is a parameter that assesses the generation status of source rocks. Hunt (1979) suggested that PI values from 0.008 to 0.4, are characteristic of source rock in the oil window after which gas is the main hydrocarbon phase produced. In this study, the Production Index ranges from 0.05 to 0.38 (av. 0.22) (Table 5) and portray ummature to early immature status of organic matter. The plot of HI versus Tmax (Fig. 12) shows that most of the samples, especially the Fika Shale, cluster around 435°C, which is early, while those from the Gongila Formation are within the condensate-wet gas zone. The calculated vitrinite reflectance ranges from 0.58% to 1.23% (Table 5) and portray thermally immature to marginally mature sediments.

The hydrogen index (HI) is used to characterize the kerogen type and the maturation level in conjunction with oxygen (OI). The hydrogen index (HI) values range from 24 - 76mgHc/g TOC. Petters (1986), suggested that at thermal

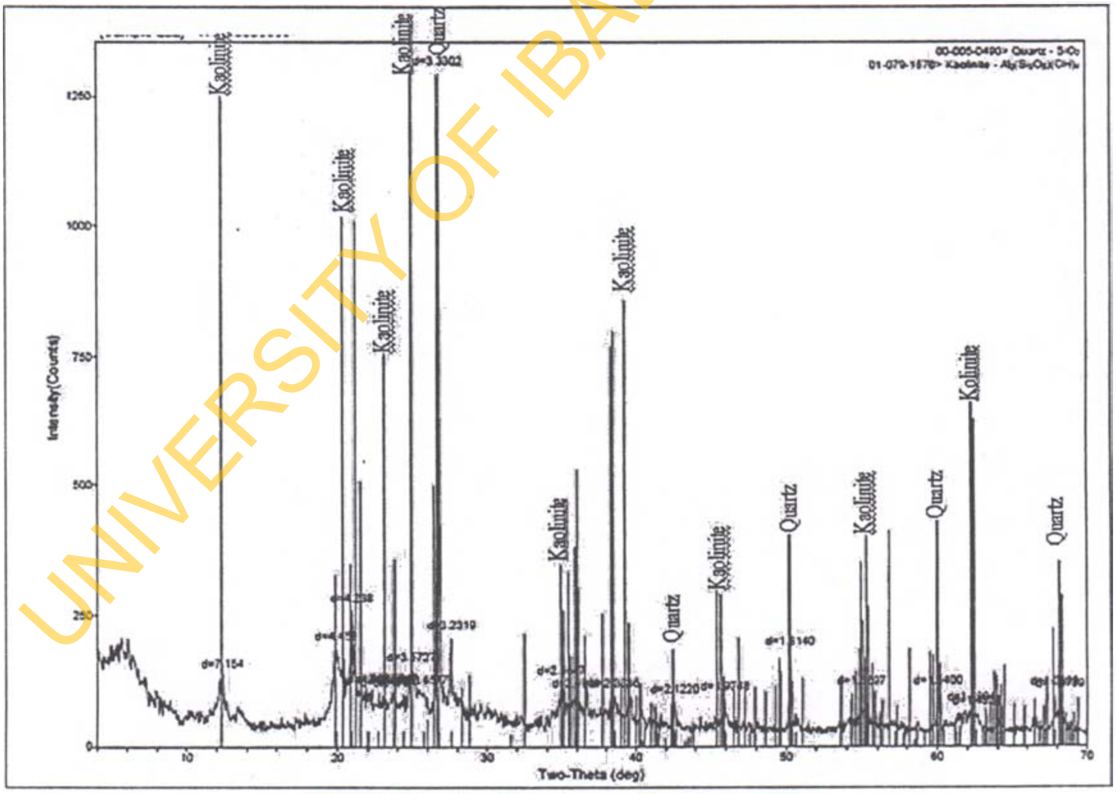

FIGURE 7: X –Ray Diffractogram for sample RE4

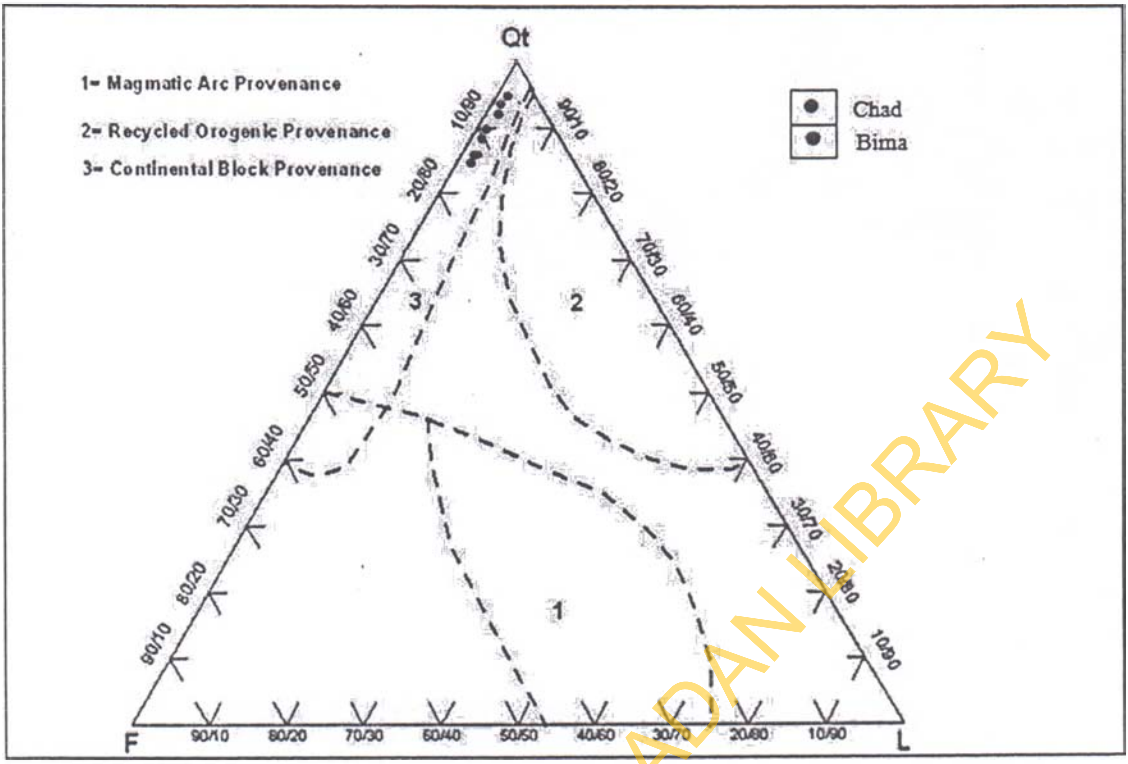

FIGURE 8: Ternary plot of Qt-F-L for Kinasar-1 well sandstone for Paleo-tectonic setting (After Dickinson and Suszek, 1979).

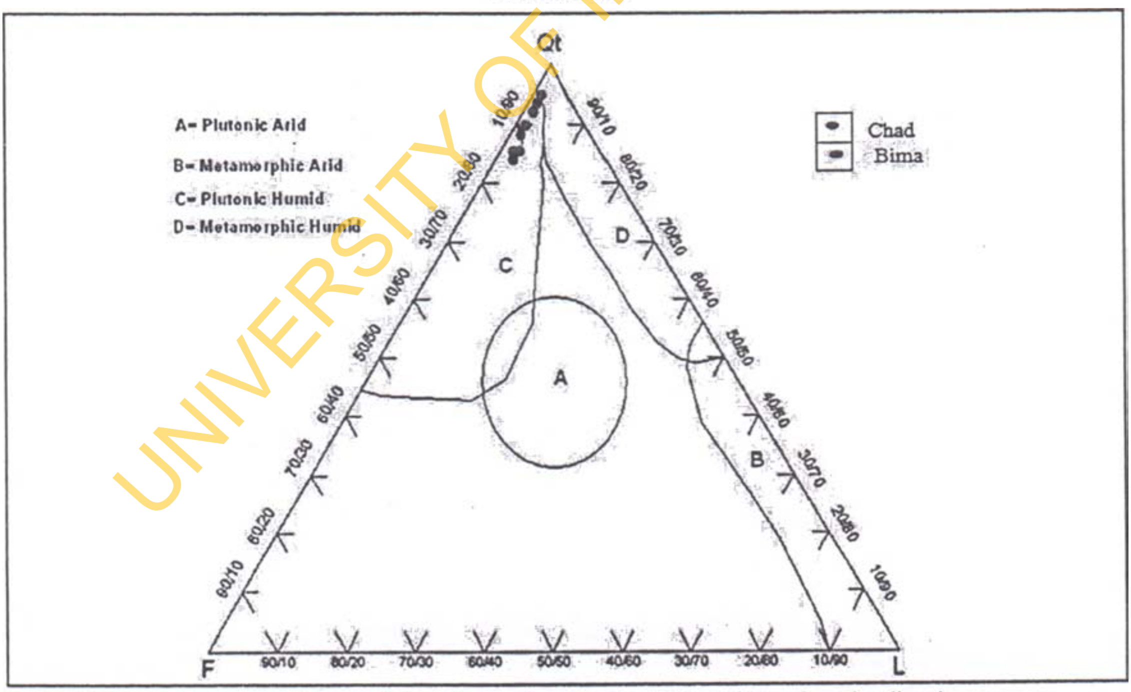

FIGURE 9: Ternary Plot of Qt-F-L for Kinasar-1 well sandstone for paleoclimatic deduction (After Suttner et al., 1981).

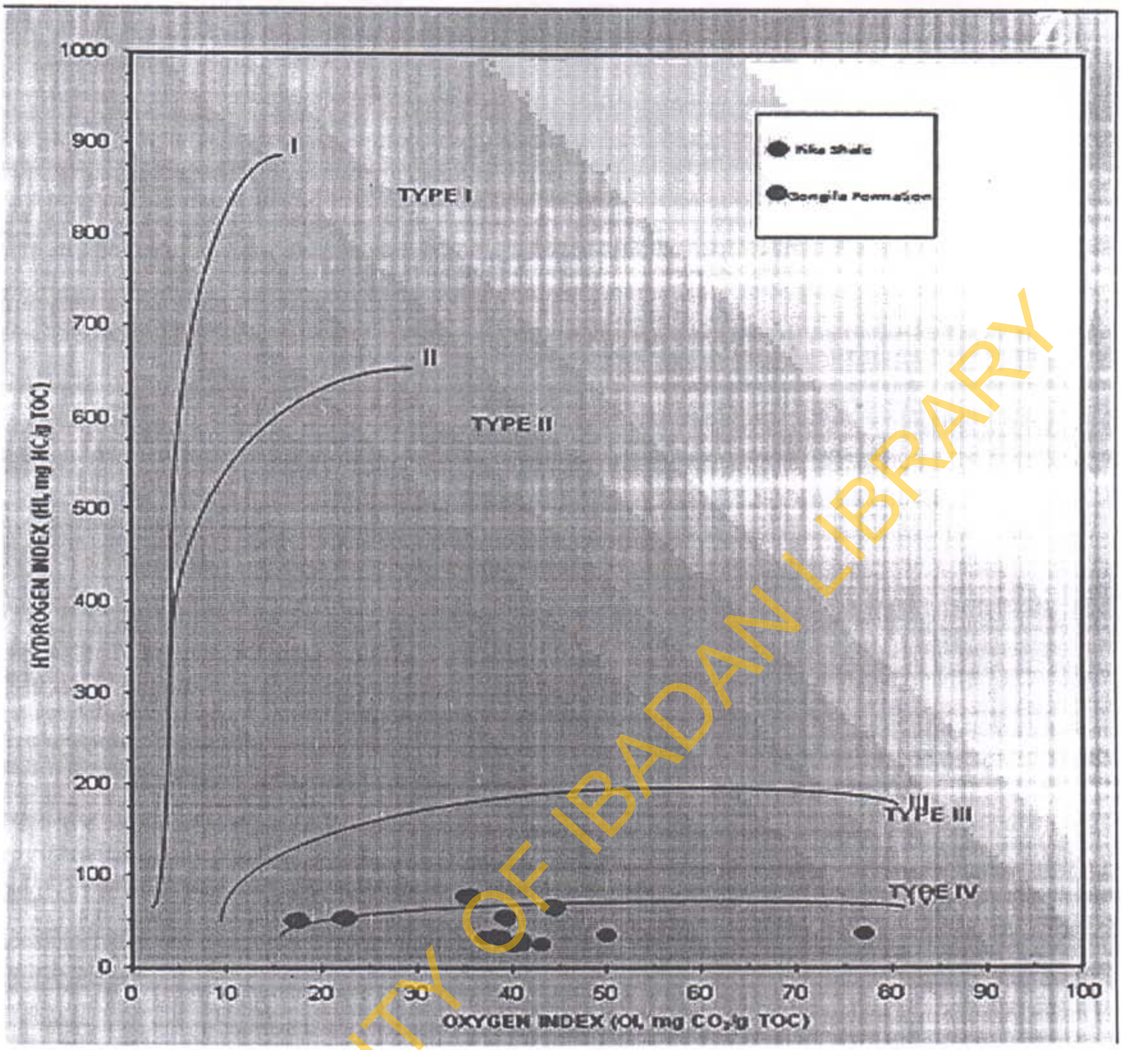

FIGURE 10: A plot of Hydrogen index against Oxygen index for the studied Well (After Van Krevelen, 1961)

maturity equivalent to vitrinite reflectance of 0.6% (Tmax 435°C), rocks with HI above 300mgHc/g TOC produce oil; those with HI between 150 – 300mgHc/g TOC produce oil and gas; those with HI between 50 – 150mgHc/g TOC produce gas while those with less than 50mgHc/g TOC are inert. Arising from this,over 70% of the samples have HI< 50mgHc/g TOC,thus indicating type IV kerogen. This points mainly to inert and reworked organic matter. Higher values of HI (30%; between 50-150 mg Hc/g TOC) fall within type III kerogen thus indicating contributions from terrestrial plants, hence gas prone (Obaje, 2004). From these parameters, it can be deduced that the sediments are mainly types 111 and IV organic matter which portray gas prone and inert, having immature to slightly mature status.

SUMMARY AND CONCLUSIONS

Sedimentological and Rock eval Pyrolysis studies of subsurface samples from Kinasar-1 borehole within the Bornu Basin, northeastern Nigeria show that the sediments are made up of sandstones, claystones and shales. The sandstones are subarkose, poorly sorted, texturallyimmature and sourced from both igneous and metamorphic terrains. It can be referred that the sandstones were deposited on a passive margin that received large amount of submature to mature sediments from the hinterland areas. The sandstones are product of continental block of plutonic origin deposited in fluvial environment. The associated clay mineral is kaolinite and indicates weathering of feldspar-rich rocks from the adjoining basement rocks. The non opaque

TABLE 5: Result of TOC and Rock Eval Pyrolysis

Sample code	Formation	TOC (wt%)	S1 (mg/g)	S2 (mg/g)	Cal %R_o	GP (S1+S2)	Tmax (°C)	HI(mgHc /gTOC)	OI(mgCo$_2$ /gTOC)	S2/S3	S1/TOC*100	PI (S1/ S1+S2)
RE9	Fika	1.58	0.10	0.86	0.78	0.96	442	54	39	1.39	6	0.10
RE10	Fika	1.19	0.12	0.77	0.76	0.89	440	65	44	1.46	10	0.13
RE11	Fika	1.47	0.16	1.12	0.58	1.90	435	76	35	2.15	4	0.05
RE12	Fika	1.51	0.07	0.50	0.66	0.57	438	33	38	0.88	5	0.12
RE13	Fika	2.31	0.15	1.15	0.82	1.30	445	50	17	2.88	7	0.12
RE14	Fika	2.04	0.11	1.09	0.83	1.08	445	53	22	2.42	5	0.09
RE15	Gongila	1.18	0.17	0.38	0.76	0.55	442	32	37	0.86	14	0.31
RE16	Gongila	1.03	0.08	0.31	0.82	0.39	445	30	41	0.74	8	0.21
RE17	Gongila	1.16	0.07	0.29	1.23	0.36	472	25	41	0.60	6	0.19
RE18	Gongila	1.12	0.06	0.27	1.22	0.33	464	24	40	0.71	5	0.18
RE19	Gongila	1.30	0.17	0.32	0.87	0.49	449	25	43	0.57	13	0.35
RE20	Gongila	1.20	0.08	0.30	0.86	0.38	441	25	43	0.59	7	0.21
RE21	Gongila	1.02	0.14	0.37	1.00	0.51	457	36	77	0.47	14	0.27
RE22	Gongila	1.41	0.21	0.35	-1	0.56	386	25	43	0.58	15	0.38
RE23	Gongila	1.10	0.24	0.39	-1	0.63	360	35	50	0.71	22	0.38

TOC= Wt % organic matter
S1,S2= mg Hydrocarbons per gm of rock
S3=mg carbon dioxide per gram of rock
S1/TOC= normalized oil content –S1 x100/TOC
GP=Petroleum genetic potential-S1+S2
HI =Hydrogen index-S2x100/TOC
OI =Oxygen Index-S3x100/TOC
Tmax= oC
PI=Production index-S1/(S1+S2)

heavy mineral assemblages are mainly zircon, rutile, tourmaline, staurolite and garnet with ZTR index ranging from 71%-91% which indicate that the sediments are mineralogical mature and strongly amplify a source from nearby basement rocks. The associated shales have adequate source rockpotential, especially within the Fika Formation. They are mainly Types III and IV kerogen and of thermally immature to marginally mature status. It can then be deduced that the sandstones are products of continental block provenance and were deposited by river processes while the shales are reworked sediments from terrestrial organic matter with prospect for gas generation at maturity.

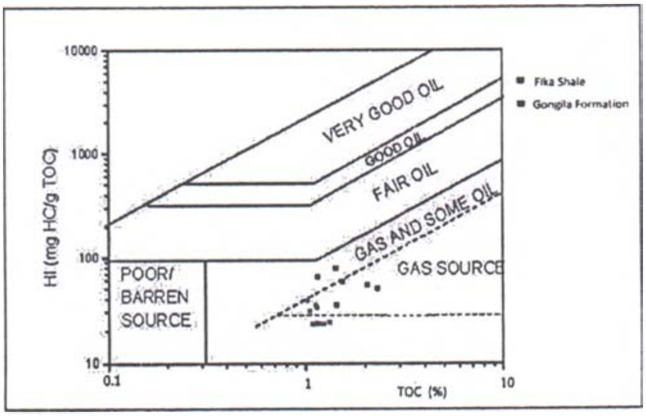

FIGURE 11: Cross plots of HI versus TOC (Adapted From Jackson et al., 1985)

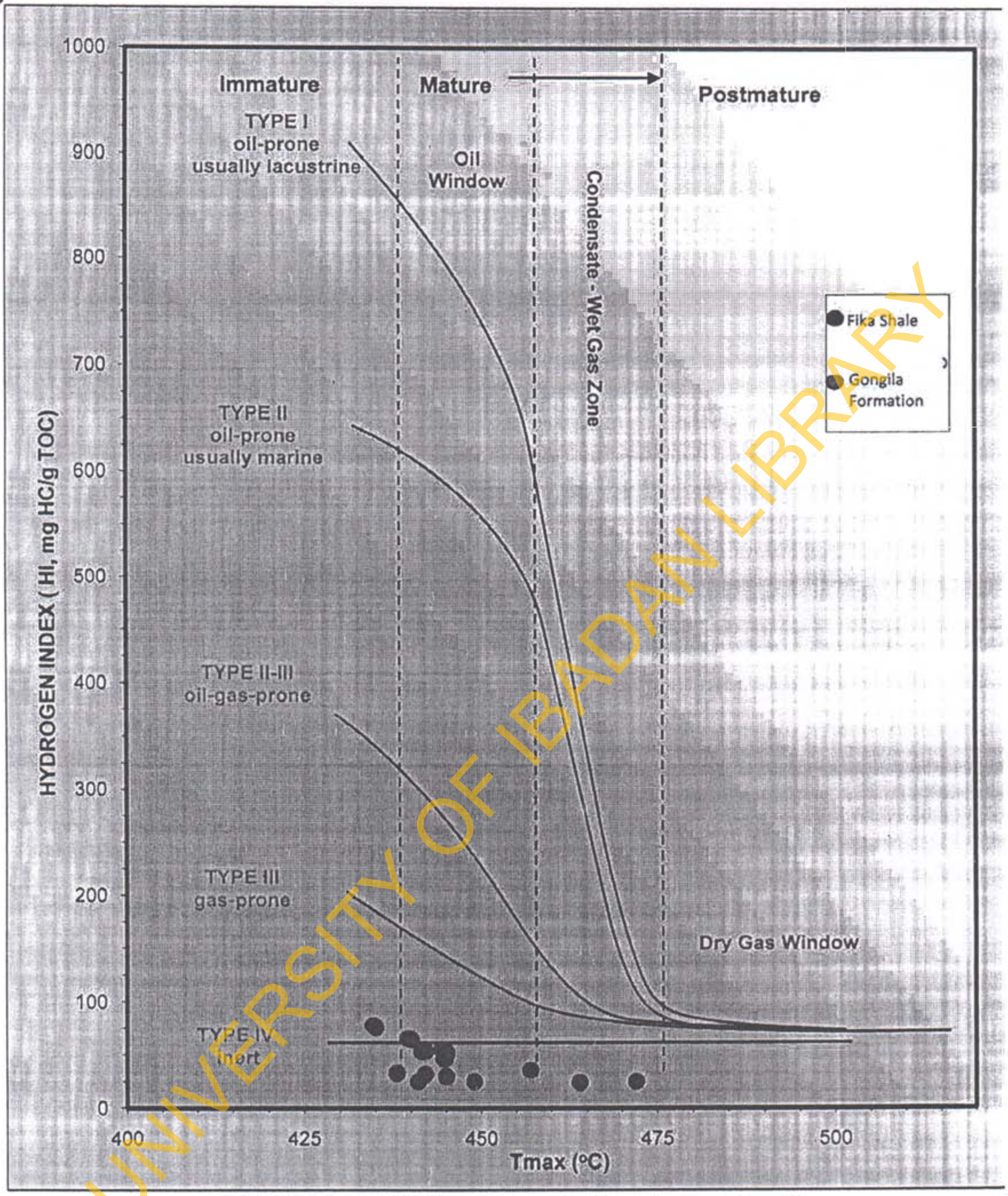

FIGURE 12:A plot of Hydrogen index against Tmax for the study well

ACKNOWLEDGEMENTS

The authors are grateful to the Nigerian Geological Survey Agency (NGSA), Kaduna for provision of well samples. The technical assistance of the Staff and Management of Acme Laboratory, Canada and Weatherford Laboratory, Texas, USA are invaluable. The corresponding author in particular expresses delight in the goodwill and encouragement enjoyed from his family, colleagues and students at the Department of Geology, University of Ibadan, Nigeria.

REFERENCES

AKARISH, I. M. AND EL-GOHARY, A. M. 2008. Petrography and geochemistry of lowerPaleozoic sandstones, East Sinai, Egypt: Implications for provenance and tectonic setting. Journal of Asian Earth Sciences. Vol. 52. pp. 43-54.

AMARAL, E. J. AND PRYOR, W. A., 1977. Depositional environment of St. Peter Sandstone deduced by textural analysis. Journal of Sedimentary Petrology. Vol. 47. pp. 32 – 52.

AROWOSEGBE, P. W., 2011. Sedimentological and Organic Geochemical Characterization of Kinasar-1 well sediments, Bornu Basin, Northeastern Nigeria. Unpublished M. Sc. Dissertation, Department of Geology, University of Ibadan, 122p.

AVBOVBO, A. A., 1980. Basement geology in the sedimentary basins of Nigeria. Geology vol. 8 pp 323-327.

BARBER, W., 1965. Pressurewater in the Chad Formation of Borno and Dikwa Emirates, Northeastern Nigeria. Geological Survey of Nigeria Bulletin, Vol. 35, 138p.

BHATIA, M. R. 1983. Plate tectonics and geochemical composition of sandstones. Journal of Sedimentary Petrology. Vol. 91, pp. 611–627.

BLATT, H. MIDDLETON, G. AND MURRAY, R. 1980. Origin of sedimentary rocks. Pretice Hall Incorporation. Englewood. 782 p.

BROWN, G. 1972. The X-ray identification and crystal structures. Mineralogical Society 544p.

BURKE, K. 1976: The Chad Basin: an active intra-continental basin. Tectonophysics, Vol. 36, pp. 197 - 206.

CARTER, J. D., BARBER, W. AND HONES, G. P. 1963: The geology of parts of Adamawa, Bauchi Bornu provinces in north-eastern Nigeria. Bulletin of Geological Survey. Nigeria, Vol. 30, pp. 109.

CAVAZZA, W. INGERSOLL, R. 2005. Detrital modes of the Ionian forearc basin fill (Oligocene- Quartenary) reflect the tectonic evolution of the Calabria- peloritani terrrane (southern Italy). Journal of Sedimentary Research. Vol. 75, pp. 268-279.

CHAANDA, M. S. OBAJE, N. G, LAR, U. A. AND MOUMOUNI, A. 2007. Petroleum Geochemistry of Kuchalli-1 in the Nigeria sector of the Chad Basin. Continental Journal of Earth Sciences. Vol. 1, pp. 18-24.

CROOK, K. . A. W. 1974. Lithostratigraty and geotectonic: The significance of composition variation in flysch arenites (graywakes). In: R. H. Dott, R. H. Shaver (Eds.), Modern and Ancient Geosynclinal Sedimentation. Society of Economic Paleontolology. Special Publication. Vol. 19, pp. 304–310.

DICKINSON, W. R, 1985. Interpreting provenance relations from detrital modes of Sandstones. In: Zuffa, G. (Ed.), Provenance of Arenites. Reidael, Dordrecht, pp. 333-361.

DICKINSON, W. R., SUCZEK, C. A. 1979. A plate tectonic and sandstone compositions. American Association of Petroleum Geologist Bulletin. Vol. 63, pp. 2164–2182.

DICKINSON, W. R., BEARD, L. S., BRAKENRIDGE, G. R., ERJAVEC, J. L., FERGUSON, R. C., INMAN, K. F., KNEPP, R. A., LINDBERG, F. A., RYBERG, P. T. 1983. Provenance of North American Phanerozoic sandstones in relation to tectonic setting. Bulletin of American Geological Society. Vol. 94, pp. 222–235.

DYMANN, T. S., PALACOS, J. G., TYSDAL, R. G., PERRY, W. J. AND PAWLEWIEZ, 1996. Source rock potential of Middle Cretaceous rocks in southwestern Montana: American Association of Petroleum Geologist Bulletin, Vol. 80, p p. 1177-1184.

ESPITALIE, J., MADEC, M., TISSOT, B. P., MENNING, J. J. AND LEPLAT., 1977. Source rock characterization method for exploration, Offshore Techn. Conf. Paper 2935, 11th Annual OTC, Houston

FOLK, R. L, 1951. Stages of textural maturity in sedimentary rocks. Journal of Sedimentary Petrology. Vol. 21, pp. 127 - 130.

FOLK, R. L., 1974. Petrology of Sedimentary Rocks. Hemphils, Austin, Texas, 182 p.

FOLK, R. L. AND WARD, W. C. 1957. Brazo river bar: a study of the significance of grain size parameters. Journal of Sedimentary petrology. Vol. 27, pp. 3-26.

FORCE, E. R. 1970. Metamorphic source of titanium placer deposits. A geochemical cycle. United State Geological Survey Professional paper. 959B, 16 p.

FRIEDMAN, G. M. 1961. Terminology of crystallization textures and fabric in sedimentary rocks. Journal of Sedimentary Petrology. Vol. 35, pp. 643-655.

GIBBS, R. J., 1967. Quantitative X-ray diffraction analysis using clay mineral standards extracted from the samples to be analyzed. Clay Minerals, Vol. 7, p. 79 – 90.

HOQUE, M. AND EZEPUE, M. C. 1977. Petrology and Palaeogeography of the Ajali Sandstones. Journal of Mining Geology. Vol. 14(1), pp19-22.

HUNT, J. M., 1979. Petroleum geochemistry and geology. Freeman publisher, San Francisco, 617pp

IDOWU, J. O. 1990: Some aspects of the Petroleum

Geochemistry of Upper Cretaceous Shale from the Upper Benue Trough and south-weastern Chad Basin Nigeria. Unpublished Ph. D thesis, University of Ibadan, Nigeria.

JACKSON, K. S., HAWKINS, P. J., and BENNET, A. J. R., 1985. Regional facies and geochemical evolution of southern Dension Trough, APEA Journal, Vol. 20, pp. 143-150.

JCPDS, 1974. Selected powder diffraction data for mineral. 1st Edition. In: L. G. Berry (ed.), Joint Committee on Powder Diffraction Standards, Philadelphia, 833p.

KLENME, H. D. AND ULMISHEK, G. H. 1991. Effective petroleum source rocks of the World: Stratigraphic distribution and controlling depositional factors. American Association of Petroleum Geologist. Bulletin Vol. 75, pp. 1809 – 1851.

KRUMBEIN, W. C. AND PETTIJOHN, F. J. 1932. Manual of sedimentary petrology Appleton Century Crotts Incorporation. New York. 549p.

MOUMOUNI, A., 2008. Organic geochemical, organic petrological and biostratigraphical evaluation of the hydrocarbon potential of the Nigerian sector of the Chad basin. Unpublished Ph. D. Thesis, Nasarawa State University, Keffi, Nigeria, 180p.

MURCHISON, D. G., 1987. Recent advances in organic petrology and organic geochemistry: an overview with some references to oil from coal. In : A. C. Scott (ed.) Coal and coal bearing strata. Geological Society Special Publication, Vol. 32, pp 257-302.

NEXANT, I., 2003. National Oil and Gas Policy: A Draft report Prepared for the Bureau of Public Enterprises (Nigeria) by Nexant Griffin House, First Floor South, 161Hammersmith Road, London.

NTON, M. E. 1998. Sedimentology and depositional environment of Awi Formation, Calabar Flank, Southeastern. Nigeria. Journal of Mining and Geology, Vol. 35, No 1, pp. 23-36.

NTON, M. E., IKHANE, P. R., AND TIJANI, M. N., 2009: Aspect of Rock Eval studies of the Maastrichtian – Eocene sediments from subsurface in the eastern Dahomey Basin Southwestern Nigeria. European Journal of Scientific Research, pp. 417 – 427.

OBAJE, N. G. , 2009: Geology and Mineral Resources of Nigeria. pp. 69 – 76.

OBAJE, N. G., WEHNER, H., SCEEDER, G., ABUBAKAR, M. B. AND JAURO, A., 2004. Hydrocarbon prospectivity of Nigeria's inland basins: From the viewpoint of organic geochemistry and organic petrology,American Association of Petroleum Geologist. Bulletin, Vol. 88 (3), pp 325 – 353.

ODUSINA, A. A., MUBARAK, S. O.,, BEKA, F. T. AND NWANGWU, U., 1983. Geology and Petroleum Potential of the Nigeria sector of the chad basin. Research Bulletin Vol 3, Exploration Research Section (R &D), Project No. ER/RD/43. NNPC, PH,Nigeria 47p

OKOSUN, E. A., 1995. Review of the Geology of Bornu Basin. Journal of Mining and Geology, Vol. 31, No. 2, pp. 113-122.

OLADE, M. A., 1975. Evolution of Nigeria's Benue Trough (aulacogen), a tectonic model. Journal of Mining Geology, Vol. 7, pp. 1-13.

OLUGBEMIRO, R. O. 1997: The Hydrocarbon potential, thermal maturity and Palaeoenvironments of the Cretaceous series in Bornu Basin, N. E. Nigeria. Ph. D Thesis, Institute and Musseum for Geologie and palentologie der Universitat Tubingen, Germany.

OSAE, S. ASIEDU, D. K, YAKUBU, 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 Africa Earth Science. Vol. 44, pp. 85-96.

PETERS, K. E., 1986. Guidelines for evaluation petroleum source rocks using programmed pyrolysis. AAPG Vol. 70, No. 3, pp. 318-329.

PETERS, K. E. AND CASSA, M. R., 1992. The Petroleum system from source to trap. In: L. B. Magoon and W. G. Dow (eds). Applied Source rock Geochemistry, AAPG Memoir.

PETERS, K. E., AND MOLDOWAN, J. M., 1993. The Biomarker Guide: Interpreting Molecular Fossils in Petroleum and Ancient Sediments. --New Jersey: Prentice-Hall.

PETTIJOHN, F. J., POTTER, P. E. AND SIEVER, R, 1973. Sand and Sandstones. Springer Verlag. Berlin 618p

POTTER, P. E. 1978. Petrology and chemistry of modern Big River sands. Journal of Geology, Vol. 86, pp. 423–449.

ROSER, B. P., COOPER, R. A., NATHAN, S. AND TULLOCH, A. J., 1996. Reconnaissance sandstone geochemistry, provenance, and tectonic setting of the lower Paleozoic terraines of the West Coast and Nelson, New Zealand. New Zealand. Journal of Geology. Geophysics. Vol. 39, pp. 1–16.

ROSER, B. P., KORSCH, R. J. 1986. Determination of tectonic setting of sandstone mudstone suites using SiO_2 content and K_2O/Na_2O ratio. A Discussion Journal of Geology. Vol. 94, pp. 635–650.

SAHU, R., 1964. Textual Parameters: An Evaluation of Flu-vial and Shallow Marine Deposits. Journal of Sedimentary Petrology. Vol. 34, pp. 513-520.

SUTTNER, L. J., BASU, A. AND MACH, G. H. 1981: Climate and origin of quartz Arenites. Journal of Sedimentary Petrology. Vol. 51, pp. 1235 – 1246.

TAYLOR, S. R. AND MCLENNAN, S. M. 1985. The continental crust: its composition and evolution. Blackwell Science Publisher, 312 p.

TISSOT, B. G., AND WELTE, D. H., 1984. Petroleum formation and occurrence: A new approach to oil and gas exploration. Berlin, Springer-Verlag, 699 p.

VISHER, G. S., 1965. Use of vertical profile in environmental reconstruction. Amer. Assoc. Petrol. Geol. Bull. 49: p 41 – 61.

VISHER, G. S., 1969. Grain size distribution and depositional processes. Journ. Sed. Petrol. Vol. 39: 1074 – 1106

VAN KREVELAN, D. W., 1961., Coal Typology, Chemistry, Physics and Constuition. Elservier, Amsterdam, 514pp.

WEAVER, C. E,, 1960. Possible uses of clay minerals in search for oil. American Association of Petroleum Geologist Bulletin. Vol. 44, pp. 1505 – 1518.

WRIGHT, J. B., HASTINGS, D. A., JONES, W. B. AND WILLIAMS, H. R. 1985: Geology and Mineral Resources of West Africa. George Allen and Unwiin, London. 171p.

YOUNG, F. G. 1979. The lowermost Paleozoic McNaughton Formation and equivalent Cariboo Group of eastern British Columbia: piedmont and tidal complex. Geological Survey of Canada, Bulletin 288, 60 p.

ZANGUINA, M.A, BRUNETON AND GONNARD, 1998. An introduction to the petroleum geology of Nigeria: Journal of Petroleum Geology. Vol. 21, No. 1, pp. 83 – 103.

Παραλαβή εργασίας:
- αρχική από τους συγγραφείς στις 24.01.2012
- τελική από την Κριτική Επιτροπή στις 25.02.2012

Manuscript received from:
- the authors on 24.01.2012
- the Review Committee on 25.02.2012