ZIBELINE INTERNATIONAL
PUBLISHING

ISSN: 2521-2893 (Print)

ISSN: 2521-2907 (Online)

CODEN: ESPADC

Earth Sciences Pakistan (ESP)

DOI: <http://doi.org/10.26480/esp.02.2020.53.59>

CrossMark

RESEARCH ARTICLE

THE LITHOSTRATIGRAPHY OF THE NEAR-SURFACE IN PART OF SEDIMENTARY KOLMANI FIELD IN NORTHERN BENUE TROUGH, NIGERIA, USING SOIL CORE AND SEISMIC REFRACTION DATA

Glory G. Akpan^a, Etim D. Uko^{b*}, Owajiokiche D. Ngerebara^a^aDepartment of Geology, Rivers State University, PMB 5080, Port Harcourt, Nigeria.^bDepartment of Physics, Rivers State University, PMB 5080, Port Harcourt, Nigeria.*Corresponding Author Email: e_uco@yahoo.com

This is an open access article distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

ARTICLE DETAILS

Article History:

Received 02 May 2020

Accepted 04 June 2020

Available online 14 July 2020

ABSTRACT

Soil samples from 31 shallow boreholes were acquired at depths 0m, 1m, 2m, 3m, 4m, 5m, 7m, 10m, 15m, 20m, 25m, 30m, 35m, 40m, 45m, 50m, 55m, and 60m in Pingida (Kolmani Field) in Ako LGA, Gombe State, Nigeria. Using the same boreholes, seismic refraction data was also acquired. The aim of the survey was to delineate the near-surface lithology and velocity layering. The boreholes were drilled using rotary drilling rig and the core samples acquired and described using Wentworth Scale. Seismic refraction data acquired using a single trace Stratavisor NZXP portable digital recorder. The recording spread consisted of a single SM4-10Hz geophone positioned at depths where the soil samples were taken. A hammer was used as the energy source and placed 3m away from the hole to obtain the first breaks. The refraction data was interpreted using UDISIS Version 1.0.0.0 software. The soil layers in the Kolmani Field have three distinct layers specified as follows, namely, top weathered and sub-consolidated layers made up of intercalation of sandstone, gravel ash clay and muddy coal shale. The lithologic strata do not correlate throughout the field resulting from the highly variable elevation which ranged from 317m and 524m with average of 389.16m. The top weathered layer of laterite intercalated with cobbles with compressional wave velocity ranging from 342 ms⁻¹ to 517 ms⁻¹ with an average of 405.03 ms⁻¹. Beneath the weathered layer is the sub-consolidated Clay layer intercalated with silt and laterite of compressional wave velocity ranging from 440 ms⁻¹ to 1854 ms⁻¹ of average of 826 ms⁻¹. The underlying consolidated layer is the shale and coal layer having compressional wave velocity ranging from 1518 ms⁻¹ to 4201 ms⁻¹ with an average of 2162.65 ms⁻¹. The dominant lithologic sequences encountered are laterite, clay, silt, sand, gravel, coal and shale. The results of this work can be used for static corrections in seismic reflection processing, planning and assessing risk for engineering structures, and for groundwater exploration. The laterite, clay, silt, sand, gravel, coal and shale can be utilized in agriculture, construction, process industries, and environmental remediation.

KEYWORDS

lithology, stratigraphy, near-surface, seismic refraction, core, relief, geology, Northern Benue Trough, Nigeria.

1. INTRODUCTION

The lithology of a rock unit is its physical characteristics seen and described in terms of colour, texture, grain size, and composition (US Geological Survey, 2010; Bates and Jackson, 1984; Allaby and Allaby, 1999; American Heritage Dictionary, 2005). Lithology is the basis of subdividing rock sequences into individual lithostratigraphic units for the purposes of mapping and correlation between areas. In clastic sedimentary rocks, grain size is the diameter of the grains and/or clasts which are used to determine which rock naming system to use. In this system, sandstones and conglomerates, a word describing the grain size range is added to the rock name. Examples are "pebble conglomerate" and "fine quartz arenite". In rocks in which mineral grains are large enough to be identified using a hand lens, the visible mineralogy is included as part of the description.

In the case of sequences possibly including carbonates, calcite-cemented rocks or those with possible calcite veins, it is normal to test for the presence of calcite (or other forms of calcium carbonate) using dilute hydrochloric acid and looking for effervescence (Geology.com, 2016). The colour of a rock or its component parts is a distinctive characteristic of some rocks and is always recorded based on the Munsell colour system (US Bureau of Reclamation, 1998). Stratigraphy is concerned with the rock layers (strata) and layering (stratification). It is primarily used in the study of sedimentary and layered volcanic rocks. Though stratigraphy has two related subfields: lithostratigraphy (lithologic stratigraphy) and biostratigraphy (biologic stratigraphy). Most of the studies that have been carried out on the Northern Benue Trough focused on the stratigraphy, sedimentology, palaeoenvironmental interpretation, palaeontological and structural studies (Dike, 1993; Adegoke et al., 1986; Carter et al., 1963; Adegoke et al., 1978). However, studies focusing on seismic velocity

Quick Response Code

Access this article online

Website:

www.earthsciencespakistan.com

DOI:

[10.26480/esp.02.2020.53.59](https://doi.org/10.26480/esp.02.2020.53.59)

layering are very limited. In this regard, this paper integrates geological lithostratigraphy with seismic stratigraphy of the Northern Benue Trough. Near-surface refers to the uppermost tens of meters beneath Earth's surface.

This portion of Earth both affects and is impacted by human activities such as building, excavating, tunnelling, and storing or accidentally releasing hazardous materials. Many of the planet's mineral and groundwater resources are located in the uppermost subsurface layers. The techniques of near-surface geophysics are being increasingly used to benefit society in activities such as nuclear-waste storage, carbon sequestration, precision agriculture, archaeology, crime-scene investigations, and cultural-resources management. Near-surface geophysicists conduct a huge range of scientific and engineering investigations in service of society (Doll et al., 2012; Everett, 2013). Moreover, near-surface geophysicists address basic scientific questions relevant to a spectrum of natural processes that include biogeochemistry, coastal processes, climate change, ecology, hydrology, tectonics, volcanology, and glaciology (Slater et al., 2006).

Near-surface geophysical data are now routinely used, for example, in basic geoscience investigations such as environmental remediation, natural-hazards risk assessment, water resource management, gas hydrates and permafrost studies, glacier and ice-sheet mass transport, watershed-scale and coastal hydrology, fault-zone characterization, and the reconstruction of Earth's tectonic, volcanic, and extra-terrestrial impact history. The aim of the paper is to delineate the near-surface lithology and velocity layering using core and seismic refraction data acquired in Kolmani Field in the Northern Benue Trough during reflection seismic survey.

2. THEORETICAL BACKGROUND

2.1 Uphole Seismic Refraction Method

In Uphole seismic method (Figure 1), a deep hole is drilled, and an uphole tool, a detector cable is placed in the hole. An energy source (hammer) placed on earth surface at an offset of 3m away from the well. A seismograph on the surface measures the arrival times, T , of the generated sound energy to the detector down the hole. These arrival times are corrected for the slant travel and source paths are then plotted against the detector depths, X . The velocities of the layers are computed automatically from the reciprocals of the slopes of the straight-line segments. The generalized depth equations of the subsurface layers are:

Figure 1: Schematic Diagram for Uphole (UPH) Data Acquisition.

$$Z_i = \frac{t_i V_i V_{i+1}}{2(V_{i+1}^2 - V_i^2)^{\frac{1}{2}}} \quad (1)$$

The thicknesses, for a three-layer case are:

$$Z_1 = \frac{t_1 V_1 V_2}{2(V_2^2 - V_1^2)^{\frac{1}{2}}} \quad (2)$$

$$Z_2 = \frac{t_2 V_2 V_3}{2(V_3^2 - V_2^2)^{\frac{1}{2}}} \quad (3)$$

The time intercepts t_1 and t_2 are read from the plot and their values used to determine the thickness of the subsurface layers.

2.2 Geologic Lithostratigraphic Descriptions

The nature and structure of a given soil depends on weathering, decomposition, erosion processes (US Bureau of Reclamation, 1998). Soils possess a number of physical characteristics which can be used as aids to size identification in the field. A handful of soil rubbed through the fingers can yield sand (and coarser) particles which are visible to the naked eye. Silt particles become dusty when dry and are easily brushed off hands and boots. Clay particles are greasy and sticky when wet and hard when dry, and have to be scraped or washed off hands and boots. Clays include silty clays and clay-silt. Clay grains are usually the product of chemical weathering of rocks and soils. Clay minerals are produced mainly from the chemical weathering and decomposition of feldspars, such as orthoclase and plagioclase, and some micas. They are small in size and very flaky in shape. The key to some of the properties of clay soils, e.g. plasticity, compressibility, swelling/shrinkage potential, lies in the structure of clay minerals. The range of particle sizes encountered in soil is very large: from boulders with a controlling dimension of over 200mm down to clay particles less than 0.002mm (2mm) (Figure 2). Some clays contain particles less than 1 mm in size which behave as colloids.

Figure 2: Size scale for soils identification [Wikipedia, 2020]

3. LOCATION, GEOLOGY, SOIL, CLIMATE AND GEOMORPHOLOGY OF STUDY AREA

3.1 The Benue Trough

The Benue Trough (Figure 3) is regarded as rift basin in central West Africa that extends NNE-SSW for over 1000km in length and 150km in width. The Benue Trough is bounded to the North and South by Chad and Niger Delta basins, respectively (Nwajide, 2013; Matheis, 1976; Abubakar, 2014; Abubakar et al., 2019). Cretaceous sediments with some Tertiary sediments filled in the Benue Trough (Figure 3) and attained a total thickness of about 6000 m (Carter et al., 1963; Abubakar, 2014; Abubakar et al., 2019; Zaborski et al., 1997). The sediments were associated with some Tertiary volcanism (Zaborski et al., 1997). The Benue Trough was formed during the breakup of Gondwanaland in the early Cretaceous that led to the separation of Africa and South American plate (Matheis, 1976). King and Stoneley proposed a rift system model associated with tensional movement and host and graben model, respectively, for the evolution of the Benue Trough (King, 1950; Stoneley, 1966). Grant proposed a Rift Rift Failed (RRF) triple junction model that led to plate dilation and the opening of the Gulf of Guinea (Grant, 1971).

Aulacogen model was proposed whereas a wrench faulting was considered the prevailing tectonic process during the evolution of the Benue Trough (Olade, 1975; Benkheilil, 1982; Matheis, 1976). The Benue Trough is subdivided into Northern, Central and Southern portions (Nwajide, 2013). The study area is situated in the Northern Benue Trough. The Northern Benue Trough is the North-eastern end of the Benue Trough and it is divided into the N-S trending Gongola Sub-Basin and the E-W trending Yola Sub-Basin (Nwajide, 2013; Zaborski, 1988). In the Gongola Sub-basin, the oldest lithostratigraphic unit (Figure 4) is the Aptian-Albian thick continental Bima Sandstone that unconformably overlies the Precambrian crystalline basement rocks. Kolmani is in the Benue Trough of Nigeria within which the study area is located is the most important of all the Cretaceous sedimentary basins of Nigeria. It is an elongated rift approximately 1000km long and 50- 150km wide trending NE-SW and

overlying the pre-Cambrian shield of the West African Mobile Belt (Benkhelil, 1989; Guiraud, 1990; Sidi et al., 2015).

Figure 3: Map of Nigeria showing the Study Area

The Benue Trough is an elongated partly fault-bounded depression occupied by up to 6,000m of marine and fluvio-deltaic sediments that have been compressively folded into a non-orogenic shield environment (Carter et al., 1963; Wright, 1985). The northern limit of the trough is the southern boundary of the Chad Basin, which is in turn separated from the trough by an anticlinal feature called while the southern limit of the trough is the northern boundary of the Niger-Delta (Zaborski et al., 1997). Marine and fluvio-deltaic sediments infill the entire Benue Trough ranging from Late Aptian to Paleocene in age (Adegoke et al., 1986; Allix, 1983). The Benue Trough runs through the NE-SW central parts of Nigeria from the Niger Delta in the SW right up to the Bornu Basin in the NE of Nigeria. It is subdivided arbitrarily into lower, middle and upper portions.

The Northern Benue Trough comprises of the area extending from the Bashar-Mutum Biyu line as far north as the 'Dumbulwa-Bage High' which separates it from the Borno Basin (Zaborski, 1998). It includes an E-W trending Yola Arm and an N-S trending Gongola Arm which are separated by an area structurally dominated by four major NE-SW trending sinistral strike-slip faults, the Gombe fault, Bima-Teli fault, Kaltungo fault and Burashika fault. A group researchers referred to the median zone as Zambuk Ridge (Carter et al., 1963). The Cretaceous succession in the Upper Benue Trough comprises of early Cretaceous continental clastics, the Bima Group, Yolde Formation, Pindiga Formation and lateral equivalents in the Yola Arm which are the Dukul Formation, Jessu Formation, Sekule Formation, Numanha Shale and Lamja sandstone, sandy members of the middle part of the Pindiga Formation in the Gongola Basin, Gombe Sandstone, Kerri-Kerri Formation and Neogene to Quaternary Basalts (Zaborski et al., 1997).

Age	Gongola Arm	Yola Arm	Paleoenvironment
Tertiary	Kerri - Kerri Formation		Continental (Fluvial / Lacustrine)
Maastrichtian			
Companian	Gombe Sandstone	Erosion?	Continental (Lacustrine / Deltaic)
Santonian			
Coniacian	Fika Shale Deban Fulani Gulani	Lamja Numanha Sekuliye	Marine (Offshore / Estuarine)
Turonian	Pindiga Formation Dumbulwa Kanawa	Jessu Dukkul	
Cenomanian			
	Yolde Formation		Transitional
Albian and older	Upper Bima Sandstone Member	Braided	Continental
	Lower Bima Sandstone Member	Alluvial/Braided Lacustrine	
Precambrian	Basement Complex	Igneous/Metamorphic	

Figure 4: Stratigraphic successions of Upper Benue Trough (Tukur et al., 2015)

3.1.1 The Bima Formation

The continental Bima Group comprises the oldest sediments in the Northern Benue Trough which directly and unconformably overlie the crystalline Basement rocks. Several workers described the Bima Group;

however, provided the most detailed account and described its three parts as (Guiraud, 1990):

Lower Bima Sandstone (B1) is a highly variable unit with an overall thickness of 0-1500m. Individual lithofacies distribution was controlled by synsedimentary tectonic activity which created a number of sub-basins with associated volcanism. Lithofacies association within a sub-basin consist of conglomeratic alluvial fan or debris flow deposits, adjacent to active basin-forming faults, grading laterally into fining-upward fluvial sequences into lacustrine deposits with interbedded clays, fine-grained sandstones and calcareous sandstones. In the sector of the Gombe Inlier, the Bima Group is greatly attenuated. It is represented by pebble conglomerates and poorly sorted arkosic sandstone similar to the lower Bima Formation elsewhere. Radiometric ages from intercalated lavas suggest an age from Albian to close to Jurassic- Cretaceous boundary (Guiraud, 1990).

The Middle Bima Sandstone (B2) which is widely distributed, fairly uniform unit consisting of fining upward cycles each 5-10m thick. It has trough and tabular cross bedding and clays and palaeosols may occur at the top of individual cycles. Overall thickness ranges from 100-500m. In a study they reported fossil wood, silicified *Metadopocarpoxylon libanoticum* (Edwards) to which a Late Aptian age was assigned (Guiraud, 1990). The Upper Bima Sandstone (B3); a fairly homogeneous, relatively mature, fine to coarse grained sandstone characterized by tabular crossbedding with sets of a few tens of centimeters to a few meters thick. Convolute bedding and overturned cross bedding are common. Its thickness ranges from 500-1500m.

3.1.2 The Yolde Formation

The name Yolde Formation was proposed for the transition beds recognized earlier between the Bima Group and the Pindiga Formation (Carter et al., 1963; Falconer, 1911). A type section was designated in the Yolde stream in the western part of the Yola Arm. The Yolde Formation gives rise to a subdued topography often with sparse vegetation cover and is poorly exposed in most part of the Gongola basin. The Yolde Formation is indeed a transitional sequence between the continental Bima Group and the marine deposits of the lower part of the Pindiga Formation. The lower sandstone-mudstone portion of the Yolde Formation is interpreted to be of fluvial origin, the upper portion with more thinly and regularly bedded bioturbated sandstones and low diversity bivalve faunas at the top is of shallow marine origin. Adegoke suggested a Late Albian to Late Cenomanian age for the Yolde Formation on the basis of its palynofossils (Adegoke et al., 1986; Adegoke et al., 1978).

3.1.3 The Pindiga Formation

The name Pindiga Formation was proposed for the calcareous beds and clay shales previously described (Carter et al., 1963; Suleiman et al., 2015). The Pindiga Formation developed in the Gongola Basin is equivalent to Dukul Formation, Jessu Formation, Sekkuliye Formation, Numanha Shale and Lamja Sandstone of the Yola Basin. In the Gongola-Gombe sub basin, the Gongola Formation and Fika Shale are the lateral equivalents of the Pindiga Formation. Lithologically, the Pindiga Formation is made up of dark/black carbonaceous shales and limestones intercalated with pale coloured limestone, shale and minor sandstone. Earlier, regarded the Pindiga Formation as consisting of five members, from bottom to top, the members are the Kanawa member, Dumbulwa member, Deba-Fulani member, Gulani member and lastly the Fika member (Zaborski et al., 1999).

3.1.4 The Gombe Sandstone

Overlies the Pindiga Formation and represents the youngest Cretaceous sediments in the Gongola arm of the Upper Benue Trough, The Gombe Sandstone is a sequence of estuarine and deltaic sandstones, shales, siltstones and ironstones which overlie the Pindiga, Gongola and Fika shale Formations in the Gongola arm of the Upper Benue Trough. Falconer named Gombe Sandstone near Gombe town as Gombe grits and clays and assigned an Eocene age to it (Falconer, 1911). Ahmed described the

Gombe Sandstone at Kware stream as consisting of well bedded fine to medium grained sandstone, sandy and silty micaceous shale and occasional mudstones (Ahmed, 2007). Akande described the Gombe as consisting of three (3) major lithofacies; lower bed characterised by mudstones and ironstones, middle bed composed of well bedded sandstones and siltstones, while the upper bed is composed of cross-bedded sandstones and siltstones (Akande et al., 1998).

The Maastrichtian Gombe Sandstone is lithologically similar to the Bima sandstone, attesting to the reestablishment of the Albian palaeoenvironmental conditions (Obaje and Abaa, 1996). Gombe State consists of fourteen (14) geological units: (i) Alluvium (ii) Basalt (iii) Coarse Porphyritic Homblende Granite (iv) Undifferentiated Granite, Migmatite & Granite Gneis (v) Migmatite and Granite Gneis (vi) Porphyritic Granite (vii) Coarse Porphyritic Biotite (viii) Shale and Minor Sandstone (ix) Older Basalt (x) Shale Sandstone and Limestone (xi) Sandstone, Siltstone and Shale (xii) Shale, Limestone and Sandstone (xiii) Shale and Mudstone (xiv) Sandstone, Siltstone, Shale, Coal and Ironstone.

3.1.5 The Kerri-Kerri Formation

represents the record of Early Tertiary sedimentation in North-eastern Nigeria and overlies the Cretaceous Gombe Sandstone unconformably in the Gongola Basin of the Upper Benue Trough. The Formation is essentially flat laying to gentle dipping of about 5° (Carter et al., 1963). The Kerri-Kerri Formation consist predominantly of grits and ferruginous sandstones, siltstones and claystones often kaolinite with well-developed crossbedding. The maximum thickness of the Kerri-Kerri Formation is about 300m, although it varies from 300m to over 320m (Dike, 1993). This sequence is deposited in a wide range of environments inducing fluvial, deltaic and marginal lacustrine (Dike, 1993). The type section of this Formation is exposed at Kadi about 100km north of Koforoti. The Formation is considered to be Palaeocene in age.

3.2 Climate, Geomorphology and Soil of Study Area

According to a study, Gombe State which is popularly referred to as the 'Jewel in the Savannah' was carved out from the former Bauchi State by the Federal Military Government of Nigeria on 1st October, 1996 (Ikusemoran et al., 2016). The State shares boundaries with Yobe State to the north, Adamawa and Taraba States to the south, Borno State to the east, and Bauchi State to the west. In Gombe State Official Website, the topography of Gombe State is made up of mainly mountainous, undulating and hilly to the south-east and flat opens plains in the western part of the State (Gombe State Tourism Board, 2014). Gombe State Tourism Board also described the hills of Gombe State as having beautiful dome shaped rock formations with fascinating scenery which are ideal for climbing and camping (Gombe State Official Website, 2015). The Famous Tangale dome shaped rock/hill formation, Tula Hills, the Bima hills as well as Filiya-Dadiya hills and the Ndinijam Kargo Hill are some of the hills in these mountainous regions.

Most parts of the State are located within the valley of River Gongola and on some highlands and mountain ranges. The river basin is a generally lowland area with altitudes ranging from 184 to 351m heights above sea level. They concluded that more than 33% of the land of Gombe State lies within the Gongola valley. This River Gongola valley formed an east-west narrow land area in Dukku and Nafada LGA at the extreme northern part of the State, and except the intrusion of Kulani-Degri-Likkar hills in the southern part of the state, the entire western border of the state comprised the river basin. The highest peak of the highlands in Gombe State is Kilang hill in Shangom LGA with altitude of 1158m above the sea level. Only 5.8% of the land areas of Gombe State are of highlands, with Kaltungo, Balanga and Shangom LGAs having more than 10% of their land area as highlands (Ikusemoran et al., 2016).

River Gongola is the largest and the most important river in the State. The River enters the State in the north-west through Bauchi State and flows eastward through Dukku, and Nafada LGAs. At Nafada, the Gongola bends in a loop southward forming natural boundary between the state and

Borno and Adamawa states in the eastern parts before it joins River Benue at Numan, outside the state (Ikusemoran et al., 2016). According to Abubakar, Gombe state has two distinct climates, the dry season (November-March) and the rainy season (April-October) with an average rainfall of 850mm (Abubakar, 2013). The mean annual temperature is about 32°C, while the vegetation of the state is that of savanna woodland comprising scattered shrubs and trees.

4. MATERIALS AND METHODS

3.1 Determination of Orthometric Heights

The data for this work was acquired in the course of acquiring 3D seismic reflection data. Field equipment used for the study include a map of the study area, sampling bags, Global Position System (GPS), Camera, measuring tape, masking tape, marker pens, field notebook, pen, pencil, shovels, and drilling rig.

4.2 Up-Hole Drilling, Sample Collection and Description

The ellipsoid heights of the selected Uphole points were determined using Leica Viva GS10 GPS. The mud rotary method was used to drill the boreholes. After drilling the required depth, the drill stem was pulled. The *sample-catching* tool was lowered with a depth-measurement string to bring soil/rock sample to the surface. The samples were placed in containers and labelled (Figure 4), and analysed. The general description included colour, grain size, texture and mineral assemblage (Wentworth, 1922).

Figure 4: Examples of Rock/Soil Samples

4.3 Up-Hole Seismic Data Acquisition and Processing

Before starting data acquisition operations, the cables, geophone, energy source, and the NZXP Seismograph were tested for efficiency and proper timing. The refraction recording spread consisted of a single SM4, 10Hz geophone positioned as shown in Figure 1. Each hole was drilled to a depth 65 meters in each case, out of which 60 meters was the maximum depth of recording in most cases. The receiver depths were: 0m, 1m, 2m, 3m, 4m, 5m, 7m, 10m, 15m, 20m, 25m, 30m, 35m, 40m, 45m, 50m, 55m, and 60m. A hammer was used as the energy source and placed 3m away from the hole to obtain the first breaks (Figure 1). The recording parameters are in Table 1. NZXP Strata Visor Refraction Seismograph equipment was used to record the arriving energy from hammer source. The processing of the data was carried out using UDISYS Version 1.0.0.0 processing software. For each shot a single-trace record was produced (Figure 5). The first breaks pick were digitized and interpreted using UDISYS Version 1.0.0.0 software, and produce T-X graphs (Figure 6) from which velocities and depths were computed.

Table 1: Uphole Acquisition Parameters

Specific Parameter	Specification
Recording System	Stratavisor NZXP
Source	Iron base plate and Hammer (18pounds)
Detector Model	SM4, 10Hz hydrophone
Record Length	512ms
Sample Rate	0.125ms
Offset	3m away from hole

Figure 5: Typical Seismic Monitor Record from the Survey with a single geophone.

Figure 6: Example of Travel -Time (T) versus Offset (X) Crossplot

5. RESULTS AND DISCUSSION

Results are presented in Tables 3 and 4 and Figures 7 – 13.

3.1 Lithostratigraphy

The Lithology has dominantly Laterite, Clay, and Coal with intercalations of cobblestones, shale, sandstone, and silt (Table 3). The lithologies of the wells could not be correlated due to the highly variable elevation and the intensive intercalations of the soils and rocks as shown in Figure 7.

Table 3: Core Samples descriptions from well-bore cuttings

Depth (m)	Sample Description
0-10	95% Laterite; 05% Cobblestone.
10-20	70% Laterite; 20% Cobblestone; 10% Pepple.
20-30	90% Clay; 10% Silt; 05% Laterite.
30-40	70% Clay; 10% Silt; 05% Laterite; 10% Coarse Sandstone; 05% Gravel.
40-50	90% Clay; 10% Sandstone.
50-60	90% Black Coal; 10% Shale.
60-65	90% Shale; 10% Coal.

Table 4: Uphole Parameters

S/N	Weathered Layer Thickness, [Z ₁] (m)	Sub-Consolidated Layer Thickness, Z ₂ (m)	Weathered Layer Velocity, V ₁ (ms ⁻¹)	Sub-Consolidated Layer Velocity, V ₂ (ms ⁻¹)	Consolidated Layer Velocity, V ₃ (ms ⁻¹)	Elevation (m)	Easting	Northing
1	9.7	26.4	414	794	2214	373	725842.7	1097616
2	13.2	26.4	414	770	2077	367	721903.5	1098309.9
3	9	31.9	414	626	1944	421	717976.5	1099005
4	20.9	11.6	354	1070	1717	433	714036.7	1099700.3
5	27.6	0	372	1854	3714	420	710098.1	1100393.8
6	7.7	39.3	387	804	1727	460	709405	1096455.7
7	26.3	33.7	342	1229	4201	414	713344	1095760.6
8	10.4	22.3	406	669	2327	371	717283.2	1095066.6
9	14.1	11.5	467	928	1934	354	721221.4	1094372.3
10	9.2	0	353	1970	2246	375	725160.6	1093680.2
11	8.4	35.3	338	440	2139	348	724467	1089738.6
12	5.2	0	353	471	1807	352	720525.8	1090432.8
13	9.5	26.2	517	628	2115	362	716587.1	1091126.8
14	6.3	25.4	470	835	1812	388	712646.6	1094372.3
15	7.3	32.9	481	712	2061	430	708708.8	1092516.6
16	7	31.3	414	732	2674	524	704770.4	1093210.5
17	13.9	32.4	406	662	2575	482	700830.3	1093904.1
18	7.2	19.4	423	759	2115	407	700136.2	1089966.5
19	6.9	9.4	423	649	1788	407	704074.5	1089270.1
20	8	15.9	423	739	1687	406	708013.1	1088576.5
21	12.2	22.1	344	666	1712	357	711955.4	1087883
22	17.3	31.4	414	867	1811	372	715893.7	1087183.2
23	6.9	35.7	517	810	2683	342	719831.8	1086493.7
24	8.5	41.3	398	800	2250	336	723770.4	1085796.2
25	7.2	36.8	357	753	2045	326	723077.5	1081861.2
26	8.1	31.1	335	702	1978	332	719138	1082552.9
27	4.5	17.6	485	664	1518	317	715196.7	1083247.7
28	6.4	17.9	352	613	1549	336	711259.9	1083942
29	18	10	345	762	2062	392	707320.8	1084638
30	8.7	44.2	414	981	3229	443	703381.7	1085331.8
31	10.2	26.3	424	647	1331	417	699444.4	1085634.2
Average	10.83	26.63	405.03	826	2162.65	389.16		

5.2 Velocity Layering

The near-surface soil in the area of study has 3 distinct layers specified as follows: (a) Top weathered layer of laterite intercalated with cobblestones with compressional wave velocity ranging from 342 ms⁻¹ to 517 ms⁻¹ with an average of 405.03 ms⁻¹ (Figure 8); (b) sub-consolidated Clay intercalated with silt and laterite of compressional wave velocity ranging from 440 to 1854 ms⁻¹ of average of 826 ms⁻¹ (Figure 9); (c) underlying consolidated layer is the consolidated clay intercalated with shale and coal layer having compressional wave velocity ranging from 1518 to 4201 with an average of 2162.65 ms⁻¹ (Figure 10). Velocity was observed to generally increase with depth, from surface to the refractors and into the consolidated layer continuum, at each location.

Weathered thickness varies substantially in the area of study, ranges between 4.5m and 27.60m with an average of 10.83m (Figure 11). This indicates the necessity to correct for this layer when conducting reflection seismic survey in the area. Sub-consolidated thickness varies between 9.4m and 44.2m with an average of 26.63m (Figure 12). The weathered and sub-consolidated thicknesses (Figures. 8 and 9) do not show any trending with elevation (Figure 10). The elevation is fairly uniform varies between 326m and 524m, averaging 389.16m (Figure 13). The interpreted data showed a substantial variation of the weathered layer thickness. This highly variable thickness indicates the necessity of correcting for this layer during seismic reflection exploration.

Figure 7: Example of Subsurface Lithologic Correlation

Figure 8: Weathered Layer Velocity (V_1)

Figure 9: Sub-Consolidated Layer Velocity (V_2)

Figure 10: Consolidated Layer Velocity (V_3)

Figure 11: Weathered Layer Thickness (Z_1)

Figure 12: Sub-Consolidated Layer Thickness (Z_2)

Figure 13: Elevation

6. CONCLUSION

The rock layers in the Kolmani Field have three distinct layers specified as follows, namely, top weathered and sub-weathered layers made up of intercalation of laterite cobble, pebble, clay, and silts. The consolidated layer is made up of intercalation of sandstone, gravel ash clay and muddy coal shale. The wells' lithologic strata are not correlatable, and the elevation is highly variable which ranged from 317m and 524m with average of 389.16m. Top weathered layer of laterite intercalated with cobblestones with compressional wave velocity ranging from 342 ms^{-1} to 517 ms^{-1} with an average of 405.03 ms^{-1} (b) sub-consolidated Clay intercalated with silt and laterite of compressional wave velocity ranging from 440 ms^{-1} to 1854 ms^{-1} of average of 826 ms^{-1} (c) underlying consolidated layer is the consolidated clay intercalated with shale and coal layer having compressional wave velocity ranging from 1518 ms^{-1} to 4201 ms^{-1} with an average of 2162.65 ms^{-1} . The dominant lithologic sequences encountered are laterite, clay, silt, sand, gravel, coal and shale. The results of this work can be used in seismic processing, planning and assessing risk for engineering structures, and for groundwater exploration. The laterite, clay, silt, sand, gravel, coal and shale components can be utilized in agriculture, construction, process industries, and environmental remediation.

ACKNOWLEDGEMENT

The authors are grateful to Frontier Exploration Services (FES) a subsidiary of Nigeria National Petroleum Corporation (NNPC) for provision of data.

REFERENCES

- Abubakar, B.Y., 2013. North-east economic summit: Up-scaling agricultural-business in the north-east through innovative value and agricultural clusters. A paper presented by the executive secretary, agricultural research council of Nigeria at a workshop organized by the agricultural research council of Nigeria at Mabushi Abuja between 3rd and 4th.
- Abubakar, M.B., 2014. Petroleum potentials of the Nigerian Benue Trough and Anambra Basin: a regional synthesis. *Nat Resour*, 5, Pp. 25-58.
- Abubakar, U., Usman, M.B., Bello, A.M., Garba, T.A., Hassan, S., 2019. Geochemical and palaeo current analysis of the Tertiary Kerri-Kerri Formation in the Gongola Sub-Basin of the Northern Benue Trough

- North-eastern Nigeria: implications for provenance, tectonic setting and palaeo weathering. *Springer Nature Applied Sciences*, 1, 1149.
- Adegoke, O.S., Agumanu, A.E., Benkheilil, M.J., Ajayi, P.O., 1986. New stratigraphic, sedimentologic and structural data on the Kerri-Kerri Formation, Bauchi and Borno States, Nigeria. *J. Afric Earth Sci.*, 5, Pp. 249-277.
- Adegoke, O.S., Jan Du Chene, R.E., Agumanu, A.E., Ajayi, P.O., 1978. Palaeontology and age of the Kerri-Kerri Formation, Nigeria. *Rev Espan Micropaleontol*, 2, Pp. 267-283.
- Ahmed, I.H., 2007. Geology and economic potential of barite mineralization on Gombe inlier, Gombe State, Nigeria. Retrieved from <http://www.grin.com/en/e-book/212495/geology-and-economic-potential-of-barite-mineralization-on-gombe-inlier>.
- Akande, S.O., Ojo, O.J., Erdtmann, B.D., Hetenyi, M., 1998. Paleo-environments, source rock potential and thermal maturity of the Upper Benue rift basins, Nigeria: Implications for hydrocarbon exploration. *Organic Geochemistry*, 29 (1-3-3 pt 1), Pp. 531-542.
- Allaby, A., Allaby, M., 1999. *Oxford Dictionary of Earth Sciences* (2nd ed.). Oxford University Press. ISBN 0-19-280079-5, Pp. 320.
- Allix, C., 1983. The Benue trough Structure and Evolution, Pp. 172-201.
- American Heritage Dictionary. 2005. The American heritage science dictionary. Houghton Mifflin Harcourt. ISBN 978-0-618-45504-1, Pp. 364.
- Bates, R.J., Jackson, J.A., 1984. *Dictionary of Geological Terms* (3rd ed.). American Geological Institute. ISBN 0-385-18101-9, Pp. 299.
- Benkheilil, J., 1982. Benue trough and Benue chain. *Geol. Mag.*, 119, Pp. 158-168.
- Benkheilil, J., 1989. Bornu, Benue Trough, the Niger Delta and its offshore, Tectono Sedimentary reconstruction during the Cretaceous and Tertiary from Geophysical data and Geology: in Kogbe, C.A. [Ed], *Geology of Nigeria*. (Abi print and pak Ltd, Ibadan, Pp. 309.
- Carter, J.D., Barber, W., Tait, E.A., Jones, G.B., 1963. The Geology of parts of Adamawa, Bauchi and Borno Provinces in Northeastern Nigeria. *Geological Survey of Nigeria Bulletin*, 30, Pp. 76.
- Dike, E.F.C., 1993. Stratigraphy and structure of the Kerri-Kerri Basin, north-eastern Nigeria. *J. Min Geol.*, 29, Pp. 77-93.
- Doll, W.E., Miller, R.D., Bradford, J., 2012. The emergence and future of near surface geophysics. *The Leading Edge*, 31, Pp. 684-691.
- Everett, M.E., 2013. *Near-Surface Applied Geophysics*. Cambridge University Press, UK, Pp. 1.
- Falconer, J.D., 1911. *The Geology and Geography of Northern Nigeria*. Macmillan Publishers, London.
- Geology.com. 2016. The Acid Test for Carbonate Minerals and Carbonate Rocks.
- Gombe State Official Website, 2015. Gombe State Physical Setting. Retrieved January 15, from <http://www.onlinenigeria.com/links/gombeadv.asp?blurb=262#ixzz2ndQmdOJS>,
- Gombe State Tourism Board, 2014. Gombe State Tourism. Retrieved May 17, from <http://www.goodlife.com.ng/gltourism.php?gltourism=read&id=75>, 2013.
- Grant, N.K., 1971. The South Atlantic Benue Trough and Gulf of Guinea Cretaceous Triple junction. *Geol Soc Am Bull.*, 82, Pp. 2259-2298.
- Guiraud, M., 1990. Tectono Sedimentary Framework of the Early Cretaceous continental Bima Formation. Upper Benue Trough, North-eastern Nigeria. *Journal of Africa Earth Sciences*, 111, Pp. 341-353.
- Ikusemoran, M., Wanah, B.B., Mbaya, L.A., 2016. Geospatial techniques for terrain analysis of Gombe State, Nigeria. *Journal of Geography, Environment and Earth Science International*, 6 (1), Pp. 1-20.
- King, L.C., 1950. Outline and distribution of Gondwanaland. *Geol Mag*, 87, Pp. 99-110.
- Matheis, S.G., 1976. Short Review of the Geology of the Chad Basin in Nigeria, Elizabeth Publication Company, Lagos, Nigeria.
- Nwajide, C.S., 2013. *Geology of Nigeria's sedimentary basins*. CSS Bookshops Ltd, Lagos.
- Obaje, N.G., Abaa, S.I., 1996. Potentials for Coal derived gaseous hydrocarbon in the Middle Benue Trough, Nigeria, *Journal of Petrol. Geol.*, 19, Pp. 74-89.
- Olade, M.A., 1975. Evolution of Nigeria's Benue Trough: a tectonic model. *Geol. Mag.*, 112, Pp. 575-583.
- Sidi, M.W., Thaffa, A.B., Garga, A.B., 2015. Geotechnical Investigation of Soil around Arawa-Kundulum Area of Gombe Town, North-Eastern Nigeria, Nigeria. *Journal of Applied Geology and Geophysics*, 3, Pp. 07-15.
- Slater, L., Knight, R., Singha, K., Binley, A., Atekwana, E., 2006a. Near-surface geophysics: a new focus group. *Eos*, 87, Pp. 249-250.
- Stoneley, R., 1966. The Niger delta region in the light of the theory of continental drift. *Geol Mag.*, 103, Pp. 385-397.
- Suleiman, U.A., Hamza, H., Zaborski, P.M., 2015. Middle cretaceous sequence stratigraphy at the Ashaka cement quarry in Gongola Basin of the Upper Benue trough, northeast Nigeria. *OSR Journal of applied geology and geophysics (IOSRJAGG)*, 3 (2), Pp. 59-67.
- Tukur, A., Samaila, N.K., Grimes, S.T., Kariya, I.I., Chaanda, M.S., 2015. Two-member subdivision of the Bima Sandstone, Upper Benue Trough, Nigeria: based on sedimentological data. *Journal of African Earth Sciences*, 104, Pp. 140-158.
- US Bureau of Reclamation, 1998. Technical Service Centre Engineering Geology Group. Classification of rocks and description of physical properties of rock. *Engineering Geology Field Manual (PDF)*, Pp. 57-90.
- US Geological Survey, 2010. *Lithology: Earthquake Glossary*.
- Wentworth, C.K., 1922. A scale of grade and class terms for clastic sediments. *The Journal of Geology*, 30 (5), Pp. 377-392.
- Wright, J.B., 1985. Origin of the Benue Trough. In *Geology of Nigeria*. C. A. Kogbe (Ed.) Elizabethan Pub. Co.
- Zaborski, P., Francis, U., Alexander, I., Paulinus, N., Kalu, I., 1999. Stratigraphy and Structure of the Cretaceous Gongola Basin, Northeast, Nigeria. *Bulletin Centre Res, Elf Explor. Prod.*, Pp. 169-171.
- Zaborski, P.M., 1998. A review of the Cretaceous system in Nigeria. *Africa Geoscience Review*, 5, Pp. 385-483.
- Zaborski, P.M., Ugodulunwa, F., Idornigie, A., Nnabo, P., Ibe, K., 1997. Stratigraphy and structure of the Cretaceous Gongola Basin, northeast Nigeria. *Bull Centres Rec Explor Prod Elf-Aquitaine*, 21, Pp. 153-186.