An Investigation Of The Physical And Mineralogical Characteristics Of The Quaternary Formation Of The Chad Basin, Nigeria

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Abstract: The objective of this paper is to investigate the physical and mineralogical characteristics of the Quaternary formation of the Chad basin. This has been achieved by systematic collection of sediment samples at the depth of 5 and 10 metres respectively in two different locations (sites 1 and 2) in ascertaining the grain size distribution, mineral composition and grain morphology between January and March 2013. Granulometric analyses result showed that particle size distribution ranged from 2 mm to 6 µm across the area suggesting heterogeneous distribution of sandstone and siltstone units. Also, grain morphology results for site1 showed that very angular grains are dominant in both sandstone and siltstone units, while well rounded grains are totally absent. In site 2, sub-rounded grains are dominant in both sandstone and siltstone units. Mineral content analyses result showed that plagioclase and orthoclase feldspars are the most dominant minerals in sites 1 and 2; with about 38.7% and 36% total composition respectively, while zircon is having the least proportion (2.5%) in site 1 and iron oxide with 6% in site 2.

Index Terms: Chad Basin, Granulometric analysis, Mineral content, Nigeria, Sand stone, Sediments, Quaternary formation.

1 Introduction

The Chad Basin is an extensive structural depression in Central part of West Africa; it is the largest intracratonic basin in Africa [1], and the third largest endorheic basin in the world covering an area of about 902,000 sq mi or 2,335,000 km^2 [2, 3]. It is bounded in the east and north by Central Sudan and partly in Niger Republic, respectively. Its western border is marked by the River Niger and River Chad drainage systems and the southern part bordered by the Chad and Benue river systems. Approximately about one-tenth of the surface area of the Chad Basin is referred to as the South-western or the Nigerian arm of the Chad basin (Borno sub-basin) which covers areas of North-eastern Nigeria, bounded to the west by the Northern Nigerian Massif, and in the south by the Benue Trough and the Biu Plateau. The depositional history of the Chad basin show that the Bima sandstone is the oldest formation of the cretaceous sediments, the transitional Gongila formation lies conformably on top of the Bima formation; this is followed by the Fika shales which consist of gypsiferous materials. The Gombe sandstone overlies the Fika shale, the Kerri-Kerri formation rests conformably on the Gombe sandstone. The Chad formation lies on the Kerri-Kerri formation.

A pioneer investigation carried out by [4] revealed that the Chad formation reaches a thickness of at least 548 m at Maiduguri; in the central part of the basin the thickness may reach 600 to 700 m [5]. The Chad Formation and the Quaternary sediments are the main sources of groundwater supply in the Maiduguri area. The chad formation is composed of fluviatile and lacustrine clay separating the three major sand bodies, with lenses of diatomite up to a few meters thick [6, 1]. The sand in this series is uncemmented; the clay is massive and gritty in texture locally. Both the sand and clay range in colour from brown, yellow, and white to grey. The three sand bodies within the Quaternary formation correspond to the upper, middle, and lower aquifers as defined by [4]. The lower aquifer is typically composed of sands and clays while the middle and the upper are made of sandy clays, with diatomite and clays and sands, respectively. This study attempts to investigate the physical and mineralogical characteristics of the Chad formation exposed at Maiduguri in order to ascertain their physical and chemical compositions and provenance ; hence, the results of the findings can be viewed as a preliminary appraisal of the natural condition of the aquifer material in North-eastern Nigeria.

1.1 Description of the study area

Maiduguri is the capital of Borno state located in north-eastern Nigeria (Figure 1). It lies on a vast sedimentary basin attaining an average elevation of 300 m above sea level. The climate is semi-arid with three distinct seasons: a long hot dry season from April to May. Day time temperatures are in the range of 36 to 40°C and night time temperatures fall to 11 to 18°C. This is followed by a short rainy season from May to September with a daily minimum temperature of 24°C and a maximum of 34°C with relative humidity of 40 to n65% and annual rainfall from 560 to 600 mm. Finally, the cold (harmattan) season runs from October to March when temperatures fall to about 20°C and a dry dusty wind blows from the Sahara desert [5, 7].The vegetation of the study area is Savannah woodland which is divided into two zones: Sudan Savannah to the south and Sahel Savannah to the north.

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1.2 Geology and stratigraphy of the area

The origin of the Chad Basin is related with the separation of the African and the South American continents in the Early Cretaceous [8, 9, 10, and 11].According to [12] and [1] the Chad Basin was a tectonic cross point between a NE to SW trending "Tibesti-Cameroon Trough" and the NW to SE trending "Air-Chad Trough" in which over 3600 m of sediments have been deposited. The crystalline basement complex outcrops in the eastern, south-eastern, south-western and the northern rims of the basin; its configuration beneath the sediments near the lake has the semblance of a horst and graben zone [2]. The stratigraphy of the Chad Basin (Bornu sub-basin) shows a depositional sequence from top to bottom (Figure 2) which includes the younger Quaternary sediments, Plio-pleistocene Chad Formation, Turonian-Maastrichtian Fika shale, the late Cretaceous Gongila formation and the Albian Bima Formation [13]. The Bima sand stone forms the deeper part of the aquifer series and rests unconformably on the basement complex rocks. Its thickness ranges from 300 to 2000 m and the depth between 2700 and 4600 m [1].

2 MATERIALS AND METHODS

2.1 Sediment sample collection

Representative sediment samples (sandstone and siltstone units) that constitute bulk of the Quaternary Chad formation were systematically collected at two varying depths of 5 and 10 metres in two different locations (sites 1 and 2) respectively. Simple hand held auger and sampling tools such as shovel, digger, plastic bucket, polyethylene bags, and measuring tape were used. Hand augering was carried out at systematic depths of 5 and 10 m respectively, at each depth about 1kg of the sediment sample was collected, the sample is then divided into 2 portions (for granulometric and mineral content analyses) and poured into a properly labelled plastic bucket in each case. This procedure is repeated at the depth of 10 metres and in site 2. All the samples were transported to the sedimentary petrology laboratory at the Geology department, University of Maiduguri for analyses.

2.2 Sieve analysis

The portion of sediment sample retained on the No. 10 sieve is tested for grain size distribution by passing the sample through a number of sieves of different size openings as outlined by ASTMD (2000). The sieves are stacked in order, with the sieve with 2mm aperture size at the top. The sieves are agitated by mechanical means for about 10 minutes. When this mechanical process is completed, the weight of the particles retained in each sieve is determined using the Ohaus (Model T31P) digital balance, from which the individual and cumulative percentage weights were computed.

2.3 Mineral content analysis

The required amount of sediment sample with constant size was separated in the plastic bag, debris and organic matters were removed. Then, the samples were spread out carefully on a picking tray in such a way that particles do not overlap with one another. A magnifying microscope (Model WestburySP40) was used to observe, identify and count the various minerals in the sample based on their physical properties. Four specimen slides were prepared for each sample and the percentages of each mineral was calculated separately. Also, average percentage of each mineral was calculated from the aforesaid calculations.

3 RESULTS

Result of the granulometric analyses show the various distributions of the grain sizes which indicates that the sandstone units in both sites occurring at varying depth of 5 and 10 metres respectively exhibit similar physical characteristics. In site 1, the sandstone layer at 5 metres indicate that bulk of the layer was wholly composed of coarse sand (1mm) and medium sand (500µm) particles constituting about 24.4% and 17.9% of the total sediment sample percentage respectively. This layer is also characterised by fine gravel (2mm) with about 15.8 weight percentage. Other components of this sandstone layer occurring at 5 metres include fine sand (150 µm) and coarse silt (63 µm) representing about 5.62% and 4.4% of the total weight percentage respectively. Siltstone layer at the same site and depth show that it is mainly composed of fine sand (150 µm) and coarse silt (63 µm) particles totaling 28.2% and 26.68% of the total mass of the sample analysed respectively. Other constituents that made up this layer include coarse sand (1mm) 12.45%, fine silt (pan) 8.13% and medium sand (250 µm) representing 6.3% of the total sediment sample obtained. Grain size analysis of the sandstone unit occurring at 10 metres in site 1 shows that it is mainly composed of varying coarse sands; 1mm particles constituting 26.27%, 850 µm (6.77%), and 710 µm (9.19%) of the total weight percentage respectively. Medium sand (500 µm) and fine gravel (2mm) constitute about 18.7 and15.29% of the total weight percentage of the sediment sample individually. Also siltstone layer at the same site and depth shows that it is primarily made up of fine sand (150 µm) which comprises about 29.86% of the total weight percentage. Coarse silt at the same depth constitutes 25.4% of the total sediment sample and a coarse sand particle (1mm) encompasses about 11.35% of the siltstone sample. The remaining percentage was dominated by particles composed of medium sand in the range of 500 µm-250 µm. Similarly in site 2, at the depth of 5 metres, the sandstone sample obtained shows that it is principally composed of fine gravel (2mm) consisting about 13.63% of the total sample. Coarse sand with varying sizes that ranged between 1mm-500 µm contained greater portion of the sediment sample. Furthermore, siltstone unit at the same depth and site showed that it is dominated by fine sand and coarse silt each containing about 26.51 and 22.69% of the total siltstone sample respectively. This sediment sample is also dominated by coarse sand particles that ranged from 1mm-500 µm containing more than 30% of the siltstone sample. Other particles are medium sand containing about 9% and very fine silt particles (pan) containing about 7.11% of the total weight of the sample. Also, in site 2 and at the depth of 10 metres, sandstone units revealed that coarse sand with varying particle sizes (1mm-500 µm) dominates the sediment samples consisting of more than 60% of the sandstone sample, and fine gravel (2mm) constitute about 13.35% of the total sediment sample. Other materials include medium (250 µm) and fine sand (150 µm) each containing about 5.36 and 3.82% respectively. Furthermore, fine (63 µm) and very fine (pan) silt particles together constitute 4.62% of the total weight percentage of the sandstone sample. Consequently, the siltstone layer occurring at 10 metres at the same site is dominated by fine sand (150 µm) and coarse silt (63 µm) particles separately encompassing about 27.88 and 24.07% of the total weight percentage respectively. Also, coarse sand (1mm-300 µm) cumulatively constitutes about 22% of the total sediment sample. Lastly, very fine silt (pan) contains about 75% of the total siltstone sample. Results of the mineral content analysis show that the major mineralogical constituents of the sediments are; Quartz, orthoclase feldspar, Albite, microcline feldspar, zircon, iron oxide. Quartz and feldspar are the predominant minerals with quartz generally exceeding feldspar as Microcline feldspar and Albite also constitute moderate proportions in the samples analysed as shown in Tables 1 and 2.

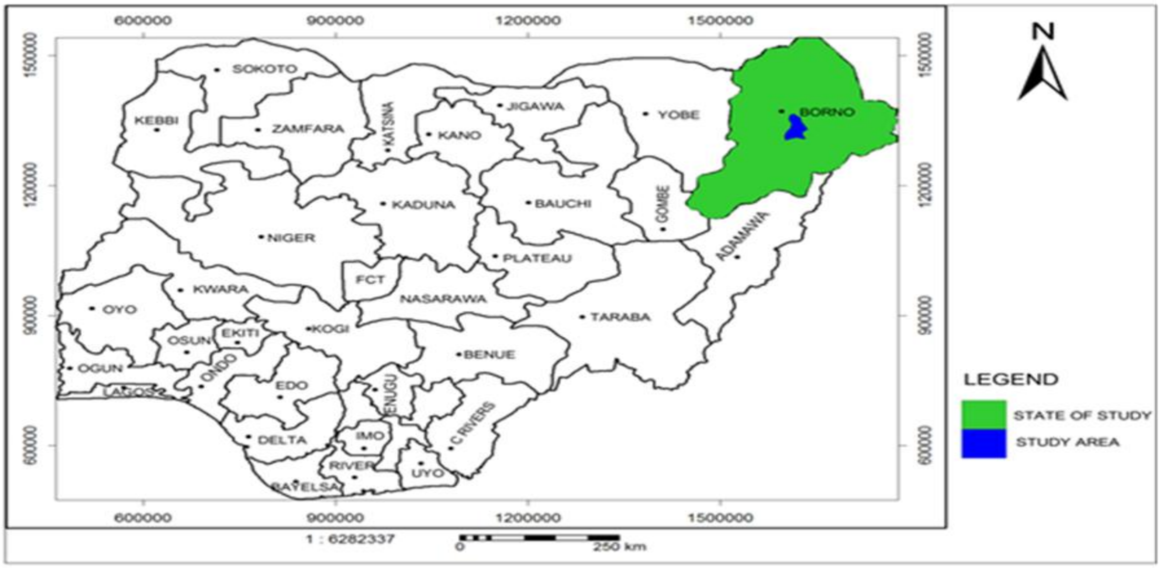

Figure 1 Map of Nigeria insert Borno state showing the study area

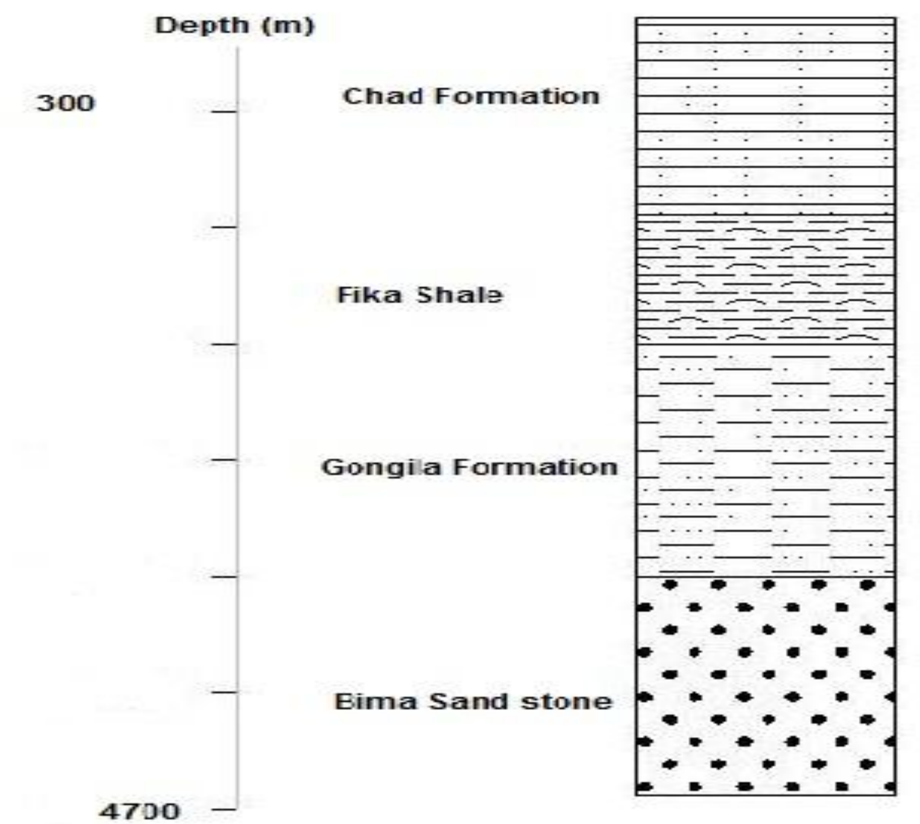

Figure 2 Cross section showing the stratigraphy of the Chad Basin

Table 1 Modal Composition results for site 1(Percentage Composition)

Mineral composition	Site 1 sandstone (5m)	Site 1 sandstone (10m)	Site 1siltstone (5m)	Site 1 siltstone (10m)
Quartz (SiO_2)	35%	40%	44%	36%
Orthoclase feldspar ($KAlSi_3O_8$)	29%	20%	19%	24%
Microcline feldspar ($KAlSi_3O_8$)	20%	19%	14%	18%
Albite ($NaAlSi_3O_8$)	10%	16%	14%	13%
Zircon ($ZrSiO_4$)	-	-	2%	3%
Iron Oxide (Fe_2O_3)	6%	5%	7%	6%

Table 2 Modal Composition results for site 2 (Percentage Composition)

Mineral composition	Site 1 sandstone (5m)	Site 1 sandstone (10m)	Site 1siltstone (5m)	Site 1 siltstone (10m)
Quartz (SiO_2)	40%	35%	39%	30%
Orthoclase feldspar ($KAlSi_3O_8$)	29%	21%	22%	30%
Microcline feldspar ($KAlSi_3O_8$)	16%	20%	20%	19%
Albite ($NaAlSi_3O_8$)	11%	13%	17%	14%
Zircon ($ZrSiO_4$)	4%	2%	2%	3%
Iron Oxide (Fe_2O_3)	-	9%	-	3%

4 DISCUSSION

The detailed information obtained from the grain size analyses result as highlighted above suggests that the provenance or source of the materials is within a proximal distance. The provenance source can be linked to the North-eastern basement complex or the Manadara Mountains which is located about 135 kilometres east of the study area. The Mandara Mountains are composed of migmatite-gneisses outcrops and they are principally dominated by older granites chiefly made up by feldspars, mica, quartz etc. Thus, in this regard, the sediments of the study area can be strongly correlated to the aforesaid source. During the formation of clastic rocks, materials passes through several evolutionary phases including but not limited to; pedogenesis, erosion, transportation, deposition, and burial. [14 and 15] argue that sand composition can successfully be correlated with specific adjacent geological environments. They further stressed that in some cases spatial changes could be related to derivation from other sources. Also, Particle size analysis of sediment can provide important clues to the nature and provenance of materials [16]. Also, grain size analysis is an essential tool for classifying sedimentary environments [17]. The mineralogical composition of the sediments implies limited chemical decomposition and disintegration from their provenance. This further suggests that the parent rock may be located in an area where mechanical disintegration predominates chemical decay and little time was allowed during their transportation, hence there is little abrasion and decomposition of the minerals. Also, according to Bowen's Reaction Series, quartz is the last mineral to crystallize at lower temperature. Furthermore, Quartz is the most abundant and durable mineral in all siliciclastic sediments representing almost all common parent rocks [18, 19]. In multicycle sediments some quartz may survive from several generations away and represent some remote parent rocks. Therefore, quartz has the greatest potential of all detrital minerals for reading provenance of arenites [20]. Due to these reasons it is universally believed that quartz is the most common and resistant mineral on the earth surface [21, 22].

5 CONCLUSION

The study revealed that the Quaternary formation materials are deposited by fluvial process, the gravely nature of the lower unit suggest sedimentation under high energy environment with the upper silt and clay units deposited later as the energy of the transporting medium subsided. Quartz, orthoclase feldspar, Albite, microcline feldspar, zircon, and iron oxide are the minerals that form bulk of this geological environment in the order of their dominance. This implies limited chemical decomposition and disintegration from their provenance. The physical and mineralogical characteristics of the sediments presented in this study could be utilised in determining the attenuation capacities of the sediments and correlating the amount of dissolve constituents (cations) in the groundwater to the mineral contents respectively.

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