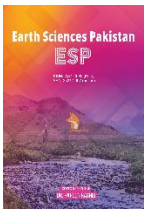
ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-2893 (Print)
ISSN: 2521-2907 (Online)
CODEN: ESPADC

Earth Sciences Pakistan (ESP)

DOI: http://doi.org/10.26480/esp.01.2024.75.83



RESEARCH ARTICLE

SEDIMENTOLOGICAL ANALYSIS OF VOLTA BASIN ROCKS IN THE BUILSA SOUTH DISTRICT (UPPER EAST) AND MAMPRUGU-MOAGDURI DISTRICT (NORTH EAST) RESPECTIVELY IN GHANA

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ARTICLE DETAILS

Article History:

Received 23 September 2024
Revised 18 October 2024
Accepted 01 November 2024
Available online 15 November 2024

ABSTRACT

Geological field mapping was conducted in the Builsa South District in the Upper-East Region (Field Sheet 1002D1), and the Mamprugu-Moagduri District in the North-East Region of Ghana (Field Sheet 1002D3). Rock samples were taken from the field for geochemical and petrographic studies to investigate the mineralogical composition, texture and microstructures in the rocks. The Kwahu/Bombouaka Group is the oldest sequence, unconformably overlying the Birimian basement complex rocks. This Group is also unconformably overlain by the sediments forming the Oti Group. The Yabraso sandstone Formation was the only member of the Kwahu/Bombouaka Group just as the Bimbila Formation was the only constituent of the Oti Group. Eight sedimentary facies were identified based on their lithological characteristics in the outcrops. Three (F1, F2 and F3) of the sedimentary facies belong to the Yabraso Formation whilst five (F4, F5, F6, F7, F8) of them belong to the Bimbila Formation. The Yabraso sandstone Formation generally has a finning-up sequence and is classified as quartz arenites with a few samples plotting as sub-arkose based on Folk (1974) classification system. The Bimbila Formation is stratigraphically divided into four units from oldest to youngest; Bimbila limestones, weakly micaceous siltstones and mudstones, Bimbila sandstones and Bimbila silexites.

KEYWORDS

Sediments, Volta Basin, Formation, Oti Group, Kwahu-Bombouaka Group

1. INTRODUCTION

In the 1960s, the Soviet Geological Survey Team (SGST) drilled boreholes in the Volta Basin, reaching depths of 17–764 meters (Lucas et al., 1980). Samples from the Nasia borehole which comprises the Yendi Formation, Prang Formation and Nasia Formation also known as Bimbila Formation by a group researchers indicated substantial amounts of sticky black oily bitumen in the Oti Group sandstones, shales, and siltstones (Kalsbeek, 2008; Carney *et al.*, 2010)). This discovery has led to numerous studies looking into the economic potential of the Volta Basin sediments. A major roadblock to the studies has been the scarcity of detailed stratigraphic data and the correlation of sedimentary successions in different parts of the basin. That is, stratigraphical correlations are often difficult due to limited detailed sedimentological studies of the various rock sequences in the defined stratigraphic units.

According to a study, the proposed lithostratigraphic subdivisions for the Volta Basin's northern and western boundaries do not apply to the basin's southern margin (Couëffé et al., 2011). The difficulty in precisely establishing geological units based on changes in sediment facies and biofacies, hampered the constraining of one formation from the other. As a result, earlier researchers in the Volta Basin proposed varied depositional environments for the sediments in the basin. A group researcher proposed near-shore or shoreface depositional environment for the Voltaian sediments based on deltaic and fluvial characteristics observed in the Kwahu/Bombouaka Group (Carney et al., 2010). However, Abu is of the view that the Kwahu/Bombouaka Group sediments were deposited in an epicontinental environment considering the rock types and their sequencing (shales, mudstones and siltstones) as well as the sedimentary structures (ripple marks and flute casts) in these rocks (Abu, 2018). Some researchers proposed fluviatile and floodplain depositional environment for the Voltaian sediments (Ayite et al., 2008).

A group researchers concluded that, the Kodjari Formation in the Oti Group represent a transition sediments from shallow marine to marine foreland depositional environments (Carney et al., 2010). The various depositional environments proposed by the previous workers are broadly summarized under Continental, Transitional, Marine, Evaporite and Glacial deposition environments. There is therefore the need to either confirm or refute the depositional environments proposed for the study area. Thus, this research work in the Builsa South and Mamprugu-Maogduri Districts in the Upper East and North East Regions respectively is to highlight the possible depositional environment (s) of the Voltaian sediments, based on new evidence from field mapping exercise of outcropping carbonate and sedimentary rocks.

Sedimentary basins have been investigated for their economic prospects using various methods such as remote sensing techniques, geophysical methods and systematic geological mapping. Among these methods, systematic geological mapping is commonly preferred for the investigation of a local or small area since it provides more detailed information (Miall, 1990). It is also used as ground truthing method to validate the findings from remote sensing and geophysical methods (Navarrete and Soria., 2016; Stow et al., 2020). Systematic geological mapping can be used to investigate sedimentological changes as well as characteristics of sediment including grain size, sorting, colour, fabric, sedimentary structures and fossil evidence in rocks of sedimentary basins (Ogbe and Osokpor., 2021).

Quick Response Code	Access this article online	
	Website: www.earthsciencespakistan.com	DOI: 10.26480/esp.01.2024.75.83

Cite the Article: Emmanuel Owusu-Budu, Matthew Coffie Wilson, Chiri Godfrey Amedjoe, Emmanuel Mensah (2024). Sedimentological Analysis of Volta Basin Rocks in The Builsa South District (Upper East) and Mamprugu-Moagduri District (North East) Respectively in Ghana. *Earth Sciences Pakistan, 8(1): 7***5-83.**

In this paper, we present the results of a detailed study conducted in the Builsa South and Mamprugu-Moagduri Districts of the Volta Basin. Systematic geological field mapping coupled with Petrographic and Geochemical studies were used to identify sedimentary structures and investigate micro textures and deformation as they occur in rocks. The results of these studies (changes in sediment facies and biofacies) were used for classifying the Voltaian rocks.

1.1 Location and Geological Setting

1.1.1 Location

The study area is located in the Builsa South District and the Mamprugu-Moagduri District in the Upper East and North East Regions of Ghana respectively as shown in (Figure). The area where the study was carried out comprises, Field Sheet 1002D1 which lies between Longi-tudes 1º 15' W and 1º 30' West and latitudes 10º 15' North and 10º 30' North of the Builsa South District and portion of Field Sheet 1002D3 which lies between Longitudes 1º 15' W and 1º 30' West 30 and latitudes 10º 00' North and 10º 15' North of the Mamprugu-Moagduri District (Nyarko, 2014a; 2014b). Wiase, Nandem and Gbedemblisi are some communities which can be located in Builsa South District with Fumbisi being the capital town, whereas Yezesi, Yezebisi, Mugu, Nangruma and Kubore are some communities which can be located in Mamprugu-Moagduri District with Yagaba as the capital town.

1.1.2 Geological Setting

The Builsa South and Mamprugu-Moagduri Districts generally consists of Birimian rocks and the Voltaian rocks. The Birimian rocks forms the base of the Voltaian rocks and are made up of metavolcanic rocks which occupy the orogenic belts and metasedimentary rocks which fills the basin (Anani et al., 2019). Birimian rocks encountered were mainly Basin type granitoids, Belt-type granitoids, metasediments and volcaniclastic rocks. Two unconformity bounded sequences make up the Voltaian rocks in the study area.

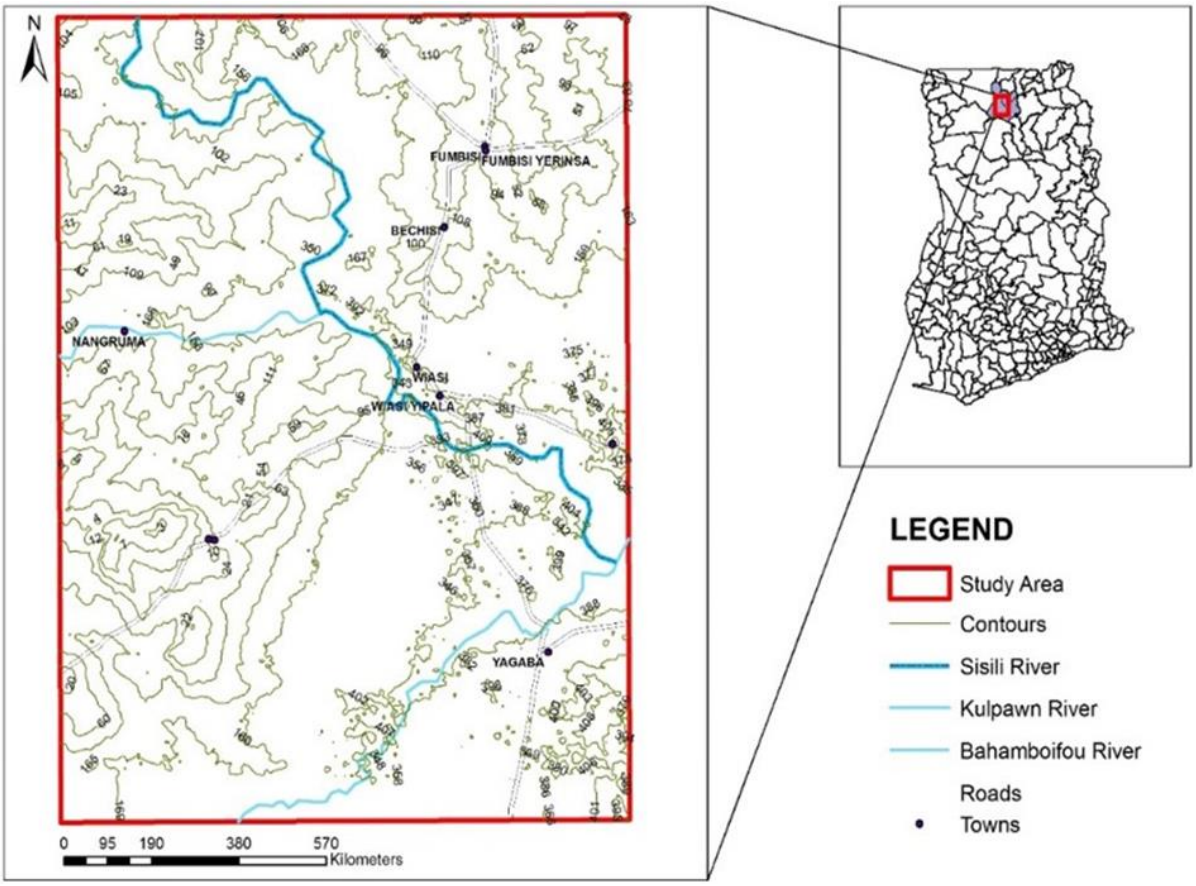

Figure 1: Map of Builsa South and Mamprugu-Moagduri Districts

The Kwahu/Bombouaka Group is the oldest sequence, unconformably overlying the Birimian basement complex rocks. This Group is also unconformably overlain by the sediments forming the Oti Group. Under the Kwahu/Bombouaka Group, the Yabraso Formation was the only member observed in the study area. They are commonly quartzose, medium grained, brownish in colour, flaggy and cross bedded. The rocks were observed at locations such as Yezebisi, Yezesi, Tumvum and along Yezesi-Nangruma bush path. At Tumvum, the Yabraso sandstones observed had slump structures in addition to the general features observed in the Yabraso sandstones. The attitudes of the beds are generally 053º/90ºNE, 057º / 082ºSE, 112º/45ºSW and 055º/77ºSE.

Under the Oti Group, the Bimbila Formation was the only member of the Oti Group observed. This Formation is stratigraphically divided into four units from the oldest to the youngest as Bimbila Limestones, Weakly micaceous Siltstones and Mudstones, Bimbila Sandstones and Silexites. The limestones were mostly creamy in colour, fine-grained and reacted with dilute HCL to produce effervescence. Two main types of limestones were observed during the geological mapping at the study area. These are the Clastic limestones and the Homogeneous limestones. The Clastic limestones mostly had quartz veins or quartz inclusions within the limestones. At certain parts of Yezesi, the clastic limestones appear elongated with multiple cracks and had microfolds. The homogeneous limestones are usually characterized by ill-defined ripple marks, varve structures, cavities and laminations. At Mugu, the limestones occurred as two distinct types with one package showing laminations with greyish green colour and the other package exhibiting a turtle-back feature with mud cracks and cream in colour. The general attitudes of the limestone outcrops are are 200º / 13º NW 354º / 10º NE, 278º and 274º. The weakly micaceous Siltstones and Mudstones which are greenish in colour, have very low amount of mica grains and contains a lot of quartz grains were encountered at Yezesi near the Kulpawn river.

Greenish Mudstones which are quartzose, weakly micaceous and were mostly altered were also observed together with the Bimbila Siltstones at Yezesi, Yagaba and Kubore. The rocks have a general strike of 085º. The Bimbila Sandstones occur in pockets and were mostly medium-grained and greyish green in colour. Bimbila Sandstones with dark grey colour was observed about 3.5 km from Yezebisi towards Yezesi. At Yezesi, the Bimbila sandstones were found to be occuring intermittently with the Bimbila limestones. The rocks had tafony / honeycomb structures which suggests the outcrops had partially been weathered especially in stream channels and close to streams. Moving from locations with Yabraso sandstone outcrops at Yezebisi to areas with Bimbila limestone outcrops at Yezesi, the only rock type observed were the dark grey Bimbila sandstones. Therefore, the Bimbila Sandstones could possibly be in contact with the Yabraso sandstones at Yezebisi and the Bimbila limestones at Yezesi. The Silexites are fine-grained, have high silica

content and occurs in diverse colours such as pink, brown and dark brown at Yezesi. The silexites were folded, fractured and had low angle dips. Also, the outcrops had alternations of thinly (about1cm) bedded siltstones and thickly (about 13cm) bedded silexites. The thin beds were argillaceous and more fractured than the thick beds. The silexites have a general strike of 085º, 090º and are folded in the Yezesi locality.

2. METHODOLOGY

A systematic geological field mapping was conducted at the study area. During this exercise, traverses were conducted along excavated sites, rivers and streams, bush paths and road cuts in search of outcrops. The lithological association(s) were noted and textures of the rocks were classified in the field with the aid of hand lens and Wentworth scale. Sedimentary structures and attitudes of rocks as well as thickness of bedding at each outcrop location were measured with the aid of geological compass, tape measure and meter rule. Dilute hydrochloric acid was used to check the presence of carbonates. In areas of scarce outcrops, the colour of the soil and colour of the ant hills were closely examined to aid the identification of the prevalent lithologies. Pits were also dug in such areas to reveal the lithostratigraphy of the rocks in the study area.

A total of 51 samples from the Birimian supergroup, the Kwahu/Bombouaka Group and the Oti Group were collected during the geological field mapping exercise and was followed up by laboratory investigations. Twenty-three samples were picked for petrographic study at the Geological Engineering laboratory of KNUST, Kumasi. Thin sections with vertical and horizontal sections not exceeding 46 mm by 27 mm and a thickness of 30 microns were prepared from each rock sample. The rock minerals, grain size, sorting, grain fabric, parking of grains, grain percentage and matrix proportion were analysed by comparing them with visual percentage classification chart after (look for these papers and check to find the percentage charts) (Wentworth, 1992; Compton, 1962). The samples were studied using LEICA DM 750P and LEICA DM4 P optical microscopes. Eleven samples consisting of One Volcaniclastic and one granitoid for the Birimian supergroup, three limestones, one sandstone, one siltstone and one silexite of the Bimbila Formation and three sandstones of the Yabraso Formation were chosen for XRD investigation at the Laboratory of Regional Water and Environmental Sanitation Centre at KNUST- Kumasi (RWESCK).

3. RESULTS AND DISCUSSION

3.1 Sedimentary Facies of Yabraso Formation

The Yabraso sandstone is made up of three units from oldest to youngest as;

3.1.1 Facies 1 (F1) Basal Yabraso Sandstone First Unit - Oldest

The Basal Yabraso Sandstone is dark brown in colour, quartzose, coarse to medium grained, flaggy and cross bedded with pebble-sized and rounded quartz grainsIt was encountered on a hill at the western portion of Yezebisi. The beds are nearly horizontal with a general strike of 023º. This is the first unit-oldest layer (stratum) of the Yabraso Sandstone commented on above.

3.1.2 Facies 2 (F2) Yabraso Sandstone Second – Younger unit

Yabraso sandstone which is lithostratigraphically younger than the Basal Yabraso Sandstone has a finning-up sequence and comprises two units; lower (second) and upper (third) units as noted above. The lower (second) unit is brownish in colour, medium-grained, quartzose, flaggy, cross-bedded, well sorted when observed with the hand lens and had intercalation of thick (centimetric) and thin (millimetric) layers. These were observed in an excavated site about 1.5 kilometers eastward from the hill where the basal sandstones were encountered. Slump structures were observed in this Yabraso sandstone unit at Tumvum. The existence of slump structures in the Yabraso sandstones at Tumvum indicates that the sediments may have been deposited along a gently sloping, ramp-like system, causing local deformation of the strata (Tsoar et al., 1996). The attitudes of the beds are generally 233º/90ºNE and 112º/45ºSW.

3.1.3 Facies 3 (F3) Yabraso Sandstone Third – Youngest Unit

The upper (third) unit of the Yabraso sandstone is characterized by brownish to dark grey colour, quartzose, planar cross-bedding, fine to medium grains and closely packed sediment that are well sorted when observed with the hand lens. This unit was observed along the Nangruma-Yezesi bush path at the south western portion of Yezebisi. The attitudes of the beds are generally 057º/082º SE and 055º/77ºSE.

3.2 Petrographic analysis of Yabraso Formation

The Basal Yabraso Sandstones are characterised by coarse to medium-grained materials, predominantly quartz with orthoclase feldspar, plagioclase feldspar, biotite and muscovite occurring in trace amount. The grains are poorly sorted and are mostly sub angular to sub-rounded in shape. Ferruginous cement forms the binding agent of most of the samples. The muscovite grains are stretched and fractured signifying deformation of the grains. The second and third units are fine to medium-grained, well packed and clast supported. The dominant minerals are quartz with trace amounts of feldspars, opaque minerals and lithic fragments. They are classified as quartz arenites with a few samples plotting as sub arkose due to the presence of the feldspars based on Folk (1974) classification system.

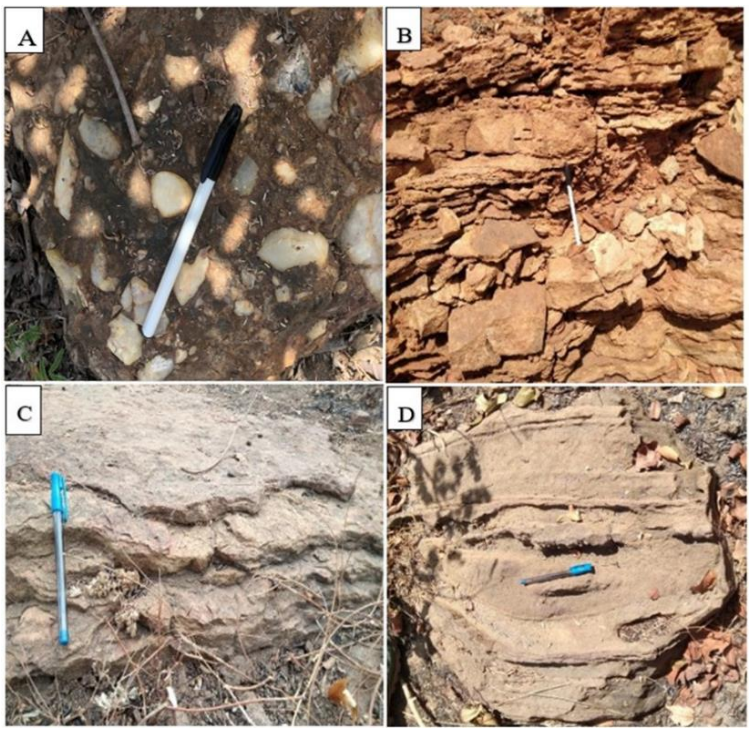

Figure 1: Photographs showing (A) Yabraso basal sandstone at Yezebisi (B) Yabraso sandstone with thick and thin beds at Yezebisi (C) Low angle cross bedding of Yabraso sandstone on Yezesi-Nangruma path (D) Slump structures in Yabraso sandstones at Tumvum

Table 1: Table showing the modal analysis of Younger Unit of Yabraso sandstone based on Compton (1962) classification

Sample ID	VG007/1 (Yabraso Sandstone)
MINERAL	**MODAL %**
Quartz	**86**
Feldspars	**4**
Mica	**2**
Iron Oxide	**1**
Rock Fragments	**2**

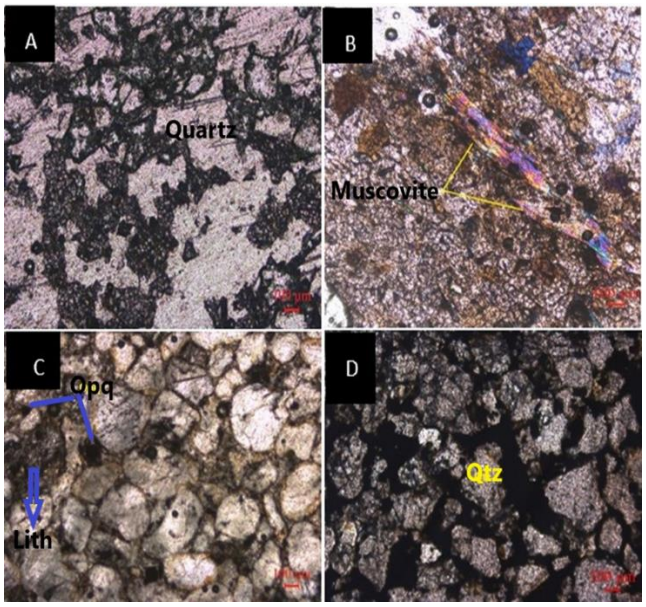

Figure 2: (A) Poorly sorted grains of Basal Yabraso Sandstone (PPL 5x) (B) Deformed muscovite grains of Basal Yabraso Sandstone (XPL 5x) (C) Well sorted and rounded grains of Younger Yabraso Sandstones (PPL 5x) (D) Sub angular and highly fractured grains of Younger Yabraso Sandstones (PPL 5x)

3.3 Sedimentary Facies of Bimbila Formation

3.3.1 Facies 4 (F4)

In the Yezesi and Yezebisi area, the limestones encountered were mostly creamy in colour, fine-grained and reacted with dilute HCL to produce effervescence. The homogeneous limestones usually had varve structures, laminations and cavities ill-defined ripple marks. The recognition of varve structures in the limestone samples narrows the possible environments of deposition to lacustrine (lake) or marine environments. The presence of ill-defined ripple marks on the limestones at Yezesi is an indication of a bottom water current - a feature common to marine environments (Schimmelmann et al., 2016). The Yezesi and Yezebisi limestones have general attitudes of 200º / 13º NW, 354º / 010 NE, 278º and 274º. At Mugu, the limestones were mainly cream in colour and had concretion with mud cracks. This unit spreads over a large area. A limestone package with laminations and greyish green colour occurred at a little portion of this area. The outcrops are homogeneous and occur as pockets in some areas whereas in other areas, they have a general attitude of 042º/16º/SE.

3.3.2 Facies 5 (F5)

Limestones mostly with quartz veins or quartz inclusions encountered in the study area were referred to as clastic limestones. At certain portions of Yezesi, the clastic limestones appear elongated. Some outcrops also had multiple cracks and microfolds. The clastic limestones occur intermittently with the homogeneous limestones at certain areas such as Yezebisi and Yezesi (Figure 3). The intermittent occurrence of the clastic limestones with the homogeneous limestones suggests a transgressive-regressive system of the environment of deposition (marine environment) (Kejonen et al., 2004). The clastic limestones were deposited during the transgressive period of deposition and is characterized by the presence of quartz grains whereas the homogeneous limestones were deposited during the regressive period. The presence of outcrops with microfolds, cracks and elongations suggest that the rocks at Yezesi have undergone deformation. The attitude of the Yezesi and Yezebisi clastic limestones are 225º and 40º respectively.

3.3.3 Facies 6 (F6)

Thinly bedded Bimbila Siltstones and mudstones which are fine-grained, greenish in colour, weakly micaceous and contains a lot of quartz grains were encountered at Yezesi near the Kulpawn river, Yagaba and Kubore. The mudstones are mostly altered. The rocks have a general strike of 085º.

3.3.4 Facies 7 (F7)

Medium-grained Bimbila sandstones which are dark grey in colour and often occurred in pockets were observed in the study area. They were encountered about 3.5 km from Yezebisi towards Yezesi. This package of Bimbila sandstone had no sedimentary structures. At Yezesi and Yezebisi, medium-grained Bimbila sandstones which are greyish green in colour were found to be occuring intermittently with the Bimbila limestones. The rocks had tafony / honeycomb structures suggesting weathering in the outcrops especially along dried stream channels. Honeycomb weathering in the Bimbila sandstone is interpreted as a structure developed in a coastal environment (nearshore marine environment). Honeycomb weathering commonly occurs as a result of deposition of sediments within a transgressive-regressive system (wetting / drying cycle) of the marine environment (Kejonen et al., 2009).

3.3.5 Facies 8 (F8)

Fine-grained siliceous Silexites of different colours such as pink, brown and dark brown were observed at Yezesi and Fumbisi. At Yezesi, the silexites had folds, fractures and were gently dipping. Also, the outcrops had intercalations of thinly (millimetric) bedded siltstones and thickly (centimetric) bedded silexites. The thin beds were argillaceous and more fractured than the thick beds. The thick beds were silt-enriched as compared to the thin beds which were argillaceous. The alternation of the thick and thin beds suggests a transgressive and regressive mode of the depositional media during different seasons of deposition according to (Simons et al., 1961). The thick layers characterized by coarse sediments were dumped by a depositional medium of high-current velocity whereas the thin layers were deposited by low-current velocity of the transporting medium. The rocks have a general strike of 085º, 090º and are folded in the Yezesi locality.

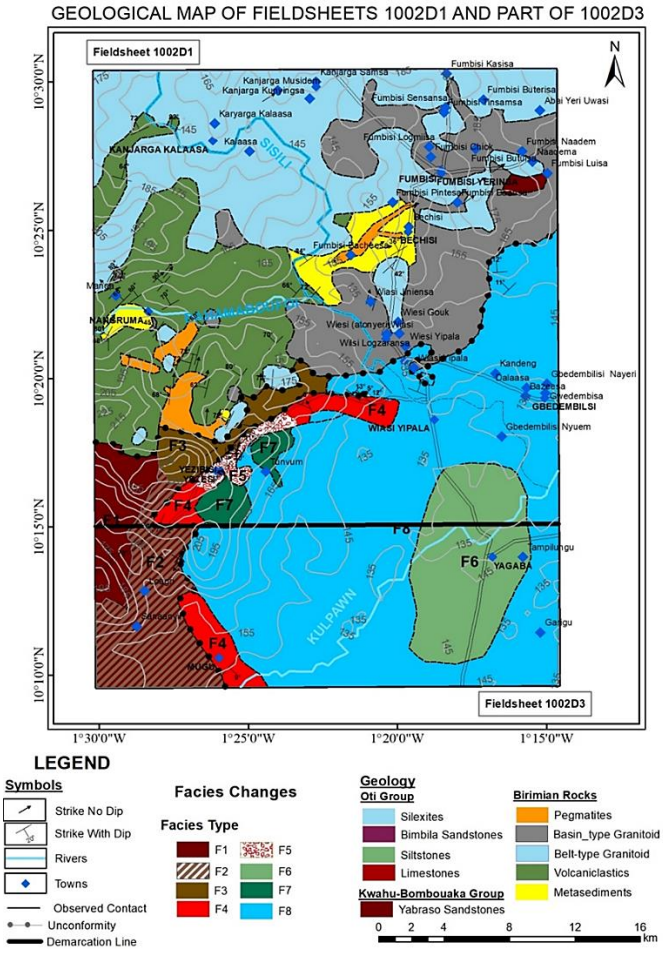

Figure 3: Geologic Map of Fieldsheets 1002D1 and Part of 1002D3

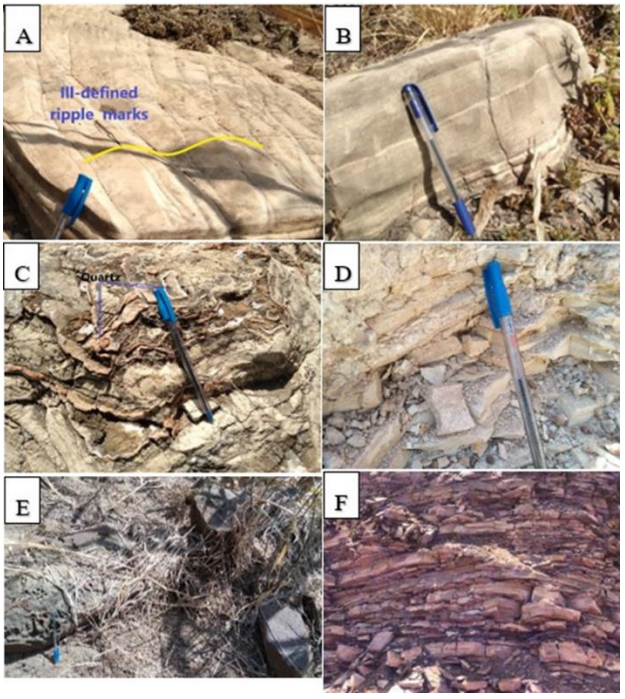

Figure 4: Photographs showing limestones with; (A) limestones with ill-defined ripples at Yezesi (B) Varve structures on limestones (C) Microfolds and quartz veins in limestones (D) Siltstones and mudstones at Yezesi (E) Greyish green Bimbila sandstones with honey-comb structures (F) Alternation of thick and thin beds of silexites and siltstones respectively.

3.4 Petrographic analysis of Bimbila Formation

3.4.1 Limestones

The limestones encountered in the field are characterized by fine grained size matrix, quartz grains, dolomite grains and iron oxides. The Yezesi limestones are composed of calcites and dolomites with trace amounts of quartz and opaque minerals.

The quartz grains are sub-rounded and monocrystalline in nature. The Mugu limestones are composed of dolomite, calcite, biotite and iron oxide. The dolomite grains occur as subhedral to anhedral rhombs which are coarse grained, cloudy, brown, and display undulatory extinction. The clay minerals are very fine grained, mainly sheetlike, laminated at certain portions and with a general cross laminated structure. The quartz and opaque minerals are clouded with clay minerals and iron oxide cement giving the rock a yellowish-brown look. The quartz grains are silt sized and are mainly angular with a few being rounded and elongated. The opaque minerals are fine-grained and rounded. They also exhibit framboidal features and hence suspected to be framboidal pyrite. The fossils observed in the Bimbila Siltstones could not be precisely identified.

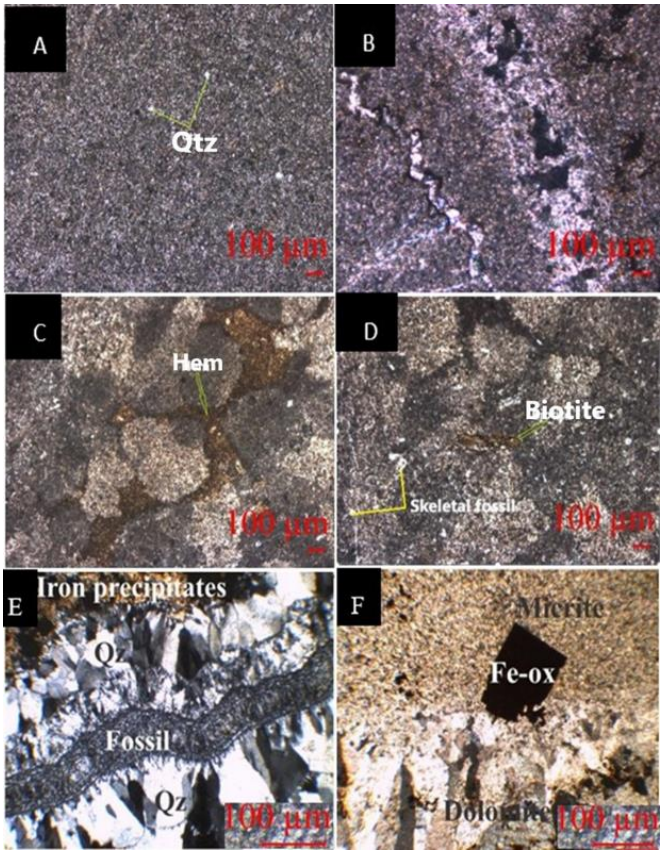

Figure 5: Photomicrograph showing Bimbila limestones with (A) Silt-sized quartz grains (PPL 5x) (B) Calcite veins (XPL 5x) (C) Hematite filling pores between dolomite grains (PPL 5x) (D) Stretched biotite and skeletal fossil (PPL 5x) (E) Quartz grains and a fossil with iron precipitates defining its boundary (XPL 5X) (F) Dolomite-micrite boundary, with euhedral iron oxide/sulphide suspected to be pyrite (XPL 5X)

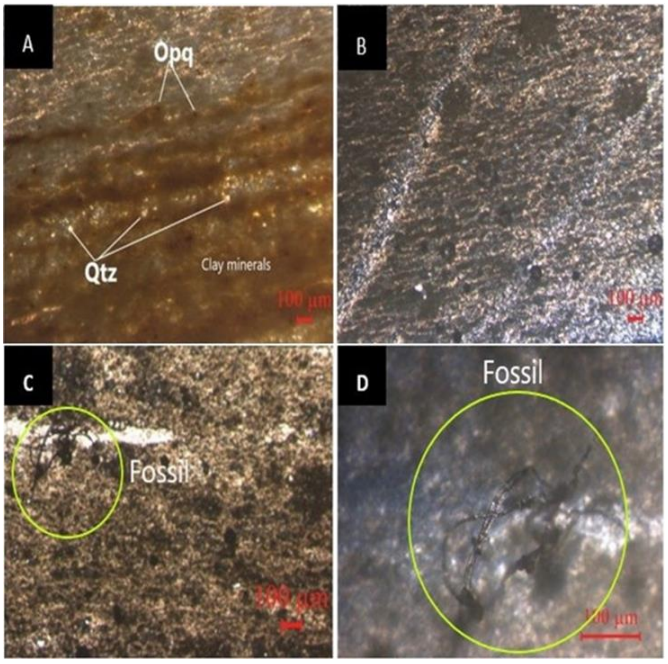

Figure 6: Photomicrographs showing Bimbila siltstones with (A) Fine-grained minerals (XPL 5x) (B) General cross lamination (XPL 5x) (C)

3.4.2 Bimbila sandstones

The rock is composed mainly of medium grained sediment with quartz, plagioclase feldspar and orthoclase feldspar making up the framework grains of the Bimbila sandstones. There are little to zero matrix content, with siliceous, dolomitic and ferruginous cement as the cementing materials of the framework grains. The quartz grains are coarse to medium grained, subrounded to rounded, display a general undulatory extinction and are mostly conchoidally fractured. The quartz grains occur as both monocrystalline and polycrystalline types with the polycrystalline type revealing the deformation of the sandstone sample. The rock may be considered texturally mature due to the presence of little or no matrix, dominance of rounded grains which are well sorted. The Bimbila Sandstones are classified as quartz arenites with a few samples plotting as sub arkose based on Folk classification system as shown in (Folk, 1974).

3.4.3 Silexite

The rock is composed of quartz, clay minerals, iron oxides and opaque crystals with the iron oxides serving as the cementing material of the framework grains. The quartz grains are silt sized and occur in thin size fractions. Some of the quartz grains are elongated and others are rounded. The opaque crystals are fine grained and rounded, with some platy and elongated types. Some portion of the rock shows framboidal opaque materials with veins suspected to be fossil evidence of plant rootlet. The clay minerals are mainly sheetlike and laminated. The quartz and opaque minerals are clouded with clay minerals, and iron oxide cement giving the rock a reddish-brown colour.

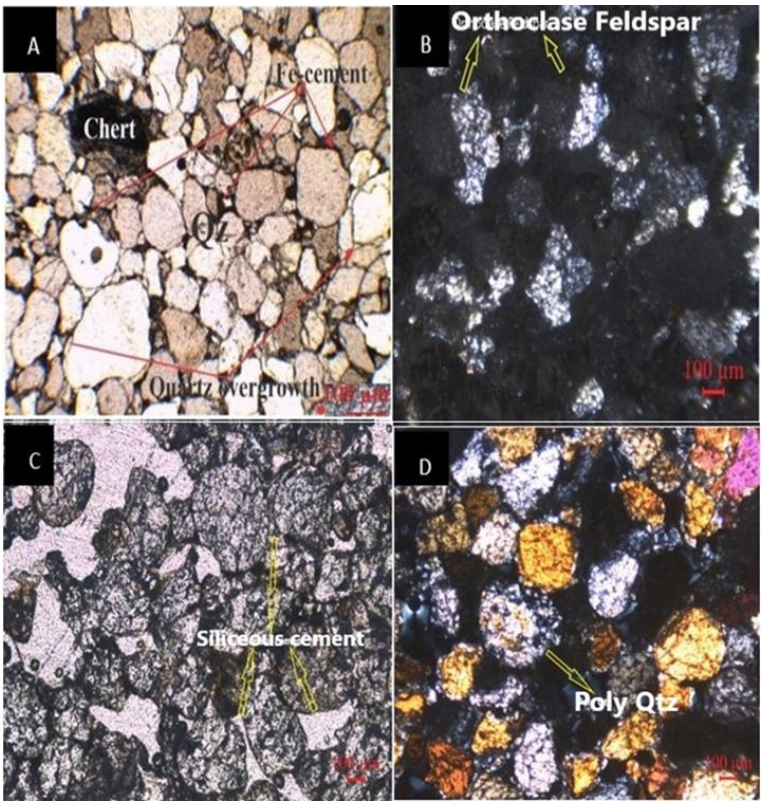

Figure 7: Photomicrograph of Bimbila sandstone showing (A) Bimbila sandstone with Medium-grained quartz which are sub-rounded to rounded, well sorted, clast supported with ferruginous cement (PPL 5x) (B) Carlsbad twinning of Orthoclase feldspars (XPL 5x) (C) Medium-grained quartz which are sub-rounded to rounded, well sorted, clast supported with siliceous cement (PPL 5x) (D) Polycrystalline quartz (XPL 5x)

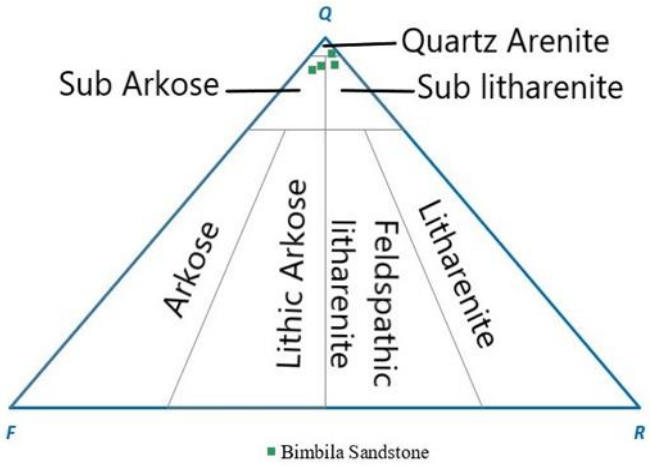

Figure 8: QFL plot showing the compositional classification of Bimbila sandstone (modified after Folk, 1974). Abreviation; Q – Quartz, F – Feldspar, R– Rock fragment

3.5 XRD analysis of Bimbila Formation

3.5.1 Limestone

The Bimbila Limestone has gypsum, a sulphate mineral occurring in it and the XRD analysis indicates to be 15. 1% the concentration level being major. This is an affirmation that the Bimbila limestone were deposited in an environment that is more marine in nature than lacustrine. Sulphates in the marine environment helps with the release of hydrogen sulphide through microbial sulphate reduction when dissolved oxygen and nitrate have been exhausted at the bottom and interstitial waters around organic debris (Marshall and Pirrie, 2013).

3.5.2 Weakly micaceous Siltstones and mudstones

The weakly micaceous Siltstones and Mudstones are composed of clay minerals, quartz, iron oxides and opaque crystals. The presence of fine-grained siliciclastic sediments such as quartz, mica and microcline are inferred as the dominant depositional sedimentary process (Holz et al., 2009). Due to the presence of pelitic sediments coupled with the presence of gypsum, a significant mineral in marine environments, the weakly micaceous Siltstone and mudstones are interpreted as having been generated partly in an offshore marine setting.

3.5.3 Facies sequence of the Builsa South and Mamprugu-Maogduri Districts

The facies sequence of the Builsa South and Mamprugu-Maogduri Districts of the Volta Basin is discussed based on the texture of the sediments, lithological association, fossil evidence and the observed sedimentary structures within the rocks in the study area. Two unconformity bounded sequences make up the Voltaian rocks in the study area. The Kwahu/Bombouaka Group is the oldest sequence, unconformably overlying the Birimian basement complex rocks. This Group is also unconformably overlain by the sediments forming the Oti Group. The Yabraso Formation composed of three units is the only member of the Kwahu/Bombouaka Group whereas the Bimbila Formation comprising of four units from oldest to youngest as; Bimbila limestones, weakly micaceous siltstones and mudstones, Bimbila sandstones and Bimbila silexites is the only member of the Oti Group. The Basal Yabraso Sandstone which is the oldest unit of the Yabraso Formation forms the base of the facies sequence of the Voltaian rocks in the study area.

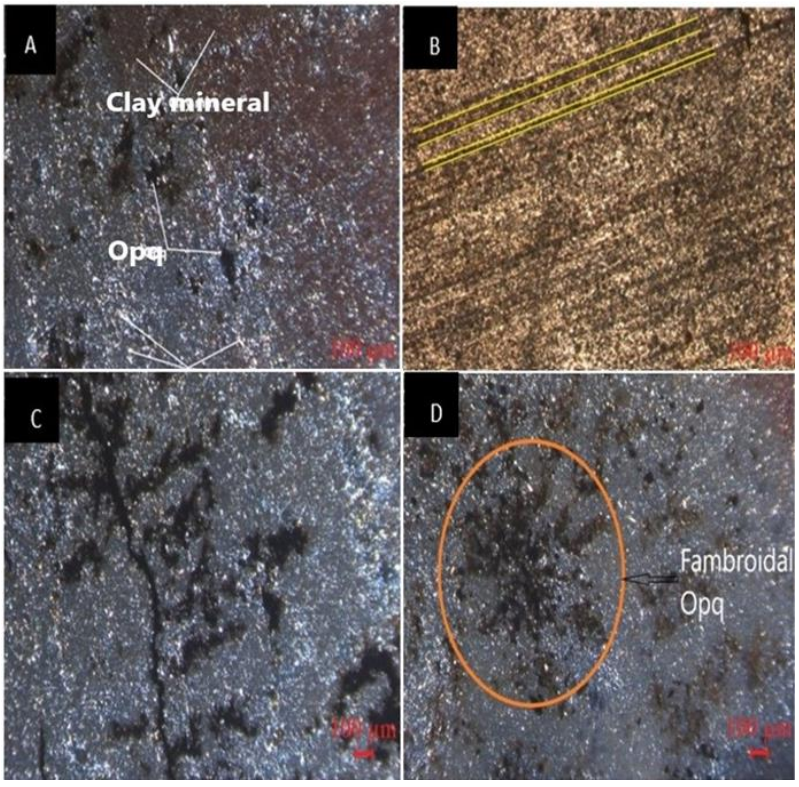

Figure 9: Photomicrographs of silexite showing (A) Nodular and elongated quartz grains and clay minerals (XPL 5x) (B) Laminations in rocks (PPL 5x) (C) Fossil evidence of plant rootlet (XPL 5x) (D) Fambroidal opaque minerals (XPL 5x)

Table 1: Table showing modal analysis of Bimbila siltstone based on Compton (1962) classification

Sample ID	**VG004/1 (Siltstone)**
MINERAL	**MODAL %**
Clay minerals (e.g chlorite)	**50**
Quartz	**30**
Iron Oxide	**15**
Opaque Minerals	**3**
Fossil	**2**

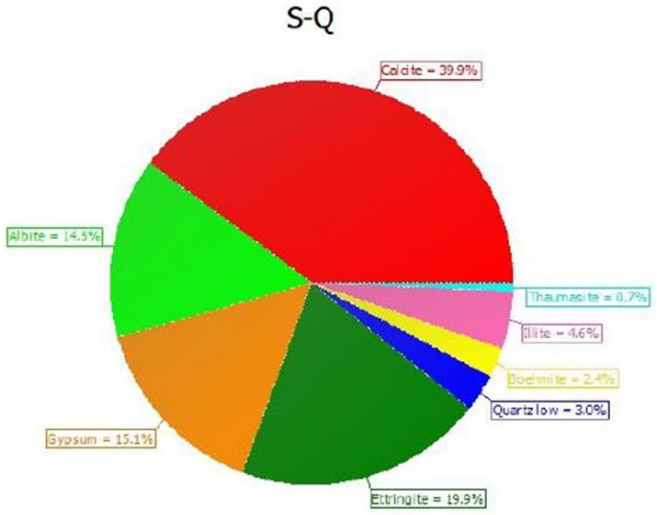

Figure 10: Pie chart illustrating the mineralogy of Bimbila Limestone

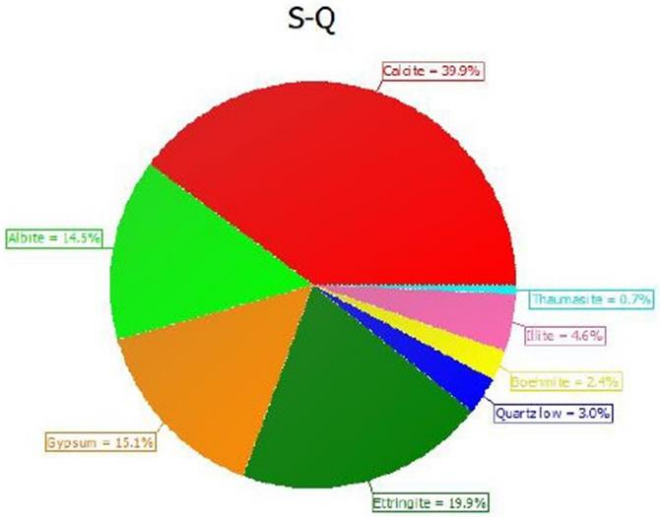

Figure 11: Pie chart illustrating the mineralogy of Weakly micaceous Bimbila siltstone

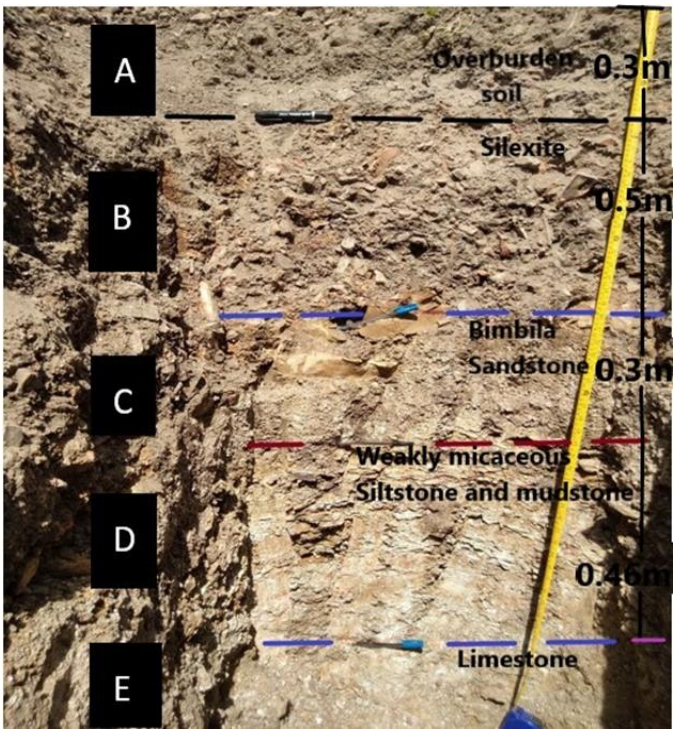

Figure 12: Photograph showing the lithostratigraphy of the Bimbila rocks in a dug pit at Yezesi

This unit is characterized by medium grained sediment with pebble-sized and rounded quartz pebbles in the field. The rocks are poorly sorted and were found to be unconformably overlying the metasediments at the Yezebisi hill. The Basal Yabraso Sandstone is overlain by the second-unit of the Yabraso sandstone. The second-unit of the Yabraso sandstone is brownish in colour, medium-grained, quartzose, flaggy, cross-bedded, has slump structures, is well sorted when observed with the hand lens and had intercalation of thick (centimetric) and thin (millimetric) layers. This unit is also overlain by the third unit of the Yabraso sandstone which is characterized by brownish to dark grey colour, quartzose, planar cross-bedding, fine to medium grains and closely packed sediment that are well sorted when observed with the hand lens. Moving from the Yabraso Sandstones upward, the first unit of the Bimbila Formation as observed from the dug pits is the Bimbila limestones.

The limestones observed are fine grained and creamy in colour. The limestones are overlain by weakly micaceous greenish siltstones and mudstones which are very fine grained and quartzose. Above the weakly micaceous siltstones and mudstones are the greyish green, quartzose, medium-grained Bimbila sandstones. Capping the sequence is the silexites which are represented by very fine-grained siliceous sediment. The dimensions of the pit were 2m by 1m and dug to a depth of 2m. Dark grey soil (overburden soil) was encountered at the top with thickness of 0.3m. The next layer comprises dark grey soil mixed with Silexites of 0.5m thick. 0.3m thick greenish sandstones were observed after the altered Silexites. A 0.46m thick weakly micaceous greyish green siltstones and mudstones forms the next layer after the greenish sandstones. The remaining layer below the weakly micaceous greyish green siltstones and mudstones comprises the Bimbila limestones.

4. Conclusions

Sedimentological analysis of the Volta Basin rocks in the Builsa south and Mamprugu-Moagduri districts have thoroughly been studied through systematic geological field mapping, petrographic analysis and X-ray diffraction method. Two unconformity bounded sequences constitute the Voltaian rocks in the study area. The Kwahu/Bombouaka Group is the oldest sequence, unconformably overlying the Birimian basement complex rocks. This Group is also unconformably overlain by the sediments forming the Oti Group. The Yabraso sandstone Formation was the only member of the Kwahu/Bombouaka Group just as the Bimbila Formation was the only constituent of the Oti Group observed in the study area.

Eight sedimentary facies were identified based on their lithological characteristics and prevalent sedimentary structures in the outcrops. Three (F1, F2 and F3) of the sedimentary facies belong to the Yabraso Formation whilst five (F4, F5, F6, F7, F8) of them belongs to the Bimbila Formation. The Yabraso Formation is stratigraphically divided into three units from oldest to youngest as; the Basal Yabraso Sandstone characterised by medium grained sediments with pebble-sized and rounded quartz pebbles, Yabraso Sandstone-younger unit which is medium to coarse-grained with intercalation of thick and thin beds, characterised by flaggy beds and has slump structures at Tunvum, Yabraso Sandstone-youngest unit which is fine to medium-grained, are closely packed and show low angle cross bedding.

The Yabraso Sandstone Formation generally has a finning-up sequence with the lower unit showing a textural and compositional immaturity evidenced by its matrix composition, dominance of subangular grains, poor sorting of grains and the presence of mica grains. The upper units are considered texturally and compositionally mature due to the presence of little or no matrix and the dominance of rounded quartz grains which are well sorted. The Yabraso sandstones are classified as quartz arenites with a few samples plotting as sub arkose based on Folk (1974) classification system. The Bimbila Formation is stratigraphically divided into four units from oldest to youngest as; Bimbila limestones, weakly micaceous siltstones and mudstones, Bimbila sandstones and Bimbila silexites.

Acknowledgement

The authors are very grateful to the Ghana National Petroleum Corporation (GNPC) for sponsoring the Project to identify and study the Volta Basin rocks at the Northern and Upper Regions of Ghana.

Declaration of Competing Interests

The authors have no competing interest to declare relevant to this article's content.

FUNDING

This work was funded by the Ghana National Petroleum Corporation (GNPC) Petroleum Engineering Chair under the auspices of the Department of Petroleum Engineering (KNUST), Kumasi, Ghana, with grant number PE-001-201,901-0102.

REFERENCES

Anani, C.Y., Bonsu, S., Kwayisi, D., and Asiedu, D.K., 2019. Geochemistry and provenance of Neoproterozoic metasedimentary rocks from the Togo structural unit, Southeastern Ghana. J. African Earth Sci. 153, Pp. 208–218. https://doi.org/10.1016/j.jafrearsci.2019.03.002

Carney, J.N., Jordan, C.J., Thomas, C.W., Condon, D.J., Kemp, S.J., Duodo, J.A., 2010. Lithostratigraphy, sedimentation and evolution of the Volta Basin in Ghana. Precambrian Res. 183, Pp. 701–724. https://doi.org/10.1016/j.precamres.2010.08.012

Couëffé, R., Vecoli, M., 2011. New sedimentological and biostratigraphic data in the Kwahu Group (Meso- to Neo-Proterozoic), southern margin of the Volta Basin, Ghana: Stratigraphic constraints and implications on regional lithostratigraphic correlations. Precambrian Res. 189, Pp. 155–175. https://doi.org/10.1016/j.precamres.2011.05.009

Holz, M., França, A.B., Simoes, M., Marques, J., 2009. A stratigraphic chart of the Late Carboniferous / Permian succession of the eastern border of the Paraná Basin, Br . Related papers. J. South Am. Earth Sci. https://doi.org/10.1016/j.jsames.2009.04.004

Kalsbeek, F., 2008. The Voltaian Basin, Ghana, Workshop and Excursion, March 10-17, 2008.

Kejonen, A., Kielosto, S., Lahti, S.I., 2004. Simulating the growth of tafoni. Earth Surf. Process. Landforms 29, Pp. 1225–1233. https://doi.org/10.1002/esp.1087

Kejonen, A., Kielosto, S., Lahti, S.I., 2009. The Volcano-Sedimentary Succession of the Archean Sodium Group, Ventersdorp Supergroup, South Africa: Volcanology, Facies and Geochemistry. Precambrian Res.

Lucas, J., Prevot, L., Trompette, R., 1980. Petrology, mineralogy and geochemistry of the late Precambrian phosphate deposits of Upper Volta (W. Africa). Journal, Geol. Soc. 137, Pp. 787–792. https://doi.org/10.1144/gsjgs.137.6.0787

Marshall, J.D., Pirrie, D., 2013. Carbonate concretions—explained. © Blackwell Publ. Ltd, Geol. Assoc. Geol. Soc. London, Geol. Today, 29 (2), Pp. 53–62.

Miall, A.D., 1990. Principles of sedimentary basin analysis. Springer Science & Business Media.

Navarrete, R., Soria, A.R., 2016. Sedimentary heterogeneity and petrophysical characterization of Barremian tsunami and barrier island / inlet deposits: The Aliaga outcrop as a reservoir analogue (Galve sub-basin , eastern Spain) 73, Pp. 188–211. https://doi.org/10.1016/j.marpetgeo.2016.02.032

Ogbe, O.B., Osokpor, J., 2021. Depositional facies, sequence stratigraphy and reservoir potential of the Eocene Nanka Formation of the Ameki Group in Agu-Awka and Umunya, southeast Nigeria. Heliyon 7, Pp. e05846. https://doi.org/10.1016/j.heliyon.2020.e05846

Schimmelmann, A., Lange, C.B., Schieber, J., Francus, P., Ojala, A.E.K., Zolitschka, B., 2016. Varves in marine sediments: A review. Earth-Science Rev., 159, Pp. 215–246. https://doi.org/10.1016/j.earscirev.2016.04.009

Simons, D.B., Richardson, E.V., ALB Ertson, L., 1961. Medium Sand Flume Studies Using. United States Gov. Pri ' ting Off. Washingt.

Stow, D., Nicholson, U., Kearsey, S., Tatum, D., Gardiner, A., Ghabra, A., Jaweesh, M., 2020. The Pliocene-Recent Euphrates river system: Sediment facies and architecture as an analogue for subsurface reservoirs. Energy Geosci., 1, Pp. 174–193. https://doi.org/10.1016/j.engeos.2020.07.005

Tsoar, H., White, B., Berman, E., 1996. The effect of slopes on sand transport - numerical modelling Haim Tsoar as. Landndscape und Urban Plan., 34 2046, Pp. 171–1881.