RESEARCH

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DISCOVERY

Geology and Petrography of the Rocks around Yelwa Area, North-eastern Nigeria

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Geological mapping of Yelwa area revealed that the area consists of Cretaceous sedimentary and Palaeogene volcanic rocks. The sedimentary rocks are represented by Bima, Yolde and Dukul Formations of the Yola sub-basin of the Upper Benue Trough. The volcanic rocks are Basalt, Phonolite and Trachyte which occur in form of outliers surrounded by older sediments. Crystalline calcite occurs within the limestone unit of the Dukul Formation in six different locations. Petrographic study indicates that, the Bima Sandstone consists essentially of quartz, orthoclase, microcline and biotite with minor iron oxides. The Yolde Sandstone consists largely of quartz, orthoclase, plagioclase and biotite with accessory iron oxide and zircon. Limestone of Dukul Formation is composed majorly of calcite and dolomite while microcline and quartz occur as minor minerals. Basalt is mainly composed of olivine, augite, plagioclase laths, and iron oxide. Olivine occurs mainly in form of phenocrysts and is irregularly fractured with inclusions of minor iron oxide in some crystals. Phonolite and trachyte largely consists of sanidine, plagioclase, aegirine and nepheline with accessory opaque ores. Sanidine show simple twinning conforming with Carlsbad law. Both sanidine and aegirine along with some plagioclase occur as phenocrysts which are aligned in a particular direction suggesting transportation of the crystals by flowing lava before solidification.

INTRODUCTION

The study area lie within Yelwa part of Shongom Local Government Area of Gombe state which constitute a portion of the Federal Survey of Nigeria sheet 173 SW Kaltungo conforming with parts of the geology of the Yola arm of the Upper Benue Trough (Fig. 1). The Benue Trough is a major geological feature in Nigeria, it is an elongated, intracontinental sedimentary basin with approximate length of 1000 Km which extends from the Niger Delta to as far as Chad Basin. The Basin originates in early Cretaceous and it is divided into three main structural units: the Upper, Middle and Lower Benue Trough. The origin of the trough has been debated extensively. King (1950) suggested that the Benue Trough originated as a result of a rift depression related to tensional stress which accompanied the separation of African plate from the South American plate. Burke and Dewey (1973) considered the Benue Trough to be an arm of a RRR forming at triple junction system about 120-130 Ma which was initiated by upwelling mantle convection currents, magmatism or hotspots in the region of the present day Niger-Delta (Cyril Chibueze Okpoli and Victor Ekere 2017; Paulinus N Nnabo and Jimoh Ajadi, 2017). According to Olade (1975) the Benue arm did not develop beyond the aulacogen stage. The other two arms showed active seafloor spreading to form the South Atlantic Ocean and Gulf of Guinea. The Benue Trough was compared to a similar structure at Afar (Burke et al., 1971). Evidence supporting this view was that new oceanic crust was generated beneath Abakaliki trough while below the Niger-Delta alternating negative and positive magnetic anomalies parallel to the Benue Trough trend were suggested. Grant (1971) proposed a Rift-Rift-Fault (RRF) type of model where transform faults have a prominent role along the margin of the Gulf of Guinea.

In the 1980s, models proposed for evolution of Benue Trough were based more on field geology and structural analysis than plate tectonic considerations (Benkhelil, 1982, Allix, 1983). In these models, sinistral wrenching was the dominant process responsible for the formation of the Benue Trough. Benkhelil (1989) concluded that the African plate did not behave as rigid block. There were intracontinental discontinuities inherited from Pan African structures which were reactivated before and during the break-up of Africa and South American plates during Mesozoic with intervals along the discontinuities. The evolution of Benue Trough was marked by tectonic activity characterized by various stages of stress, during the formation of Aptian-Albian sub-basins to compressional during the closure of the trough. The early stages of the basin development were marked by magmatic activities, especially along the Abakaliki trough (Benkhelil, 1987).

The Cretaceous sediments in the Benue Trough were variously deformed by two major tectonic phases which were responsible for the folding and fracturing of the sediments. The first tectonic event occurred during Santonian while the second occurred at the end of Cretaceous. The major deformational structures are the Abakaliki anticlinorium and Afikpo syncline in the Lower Benue Trough; the Giza anticline and Obi syncline in the Middle Benue Trough and Lamurde anticline and Dadiya syncline in the Upper Benue Trough (Nwajide, 2013).

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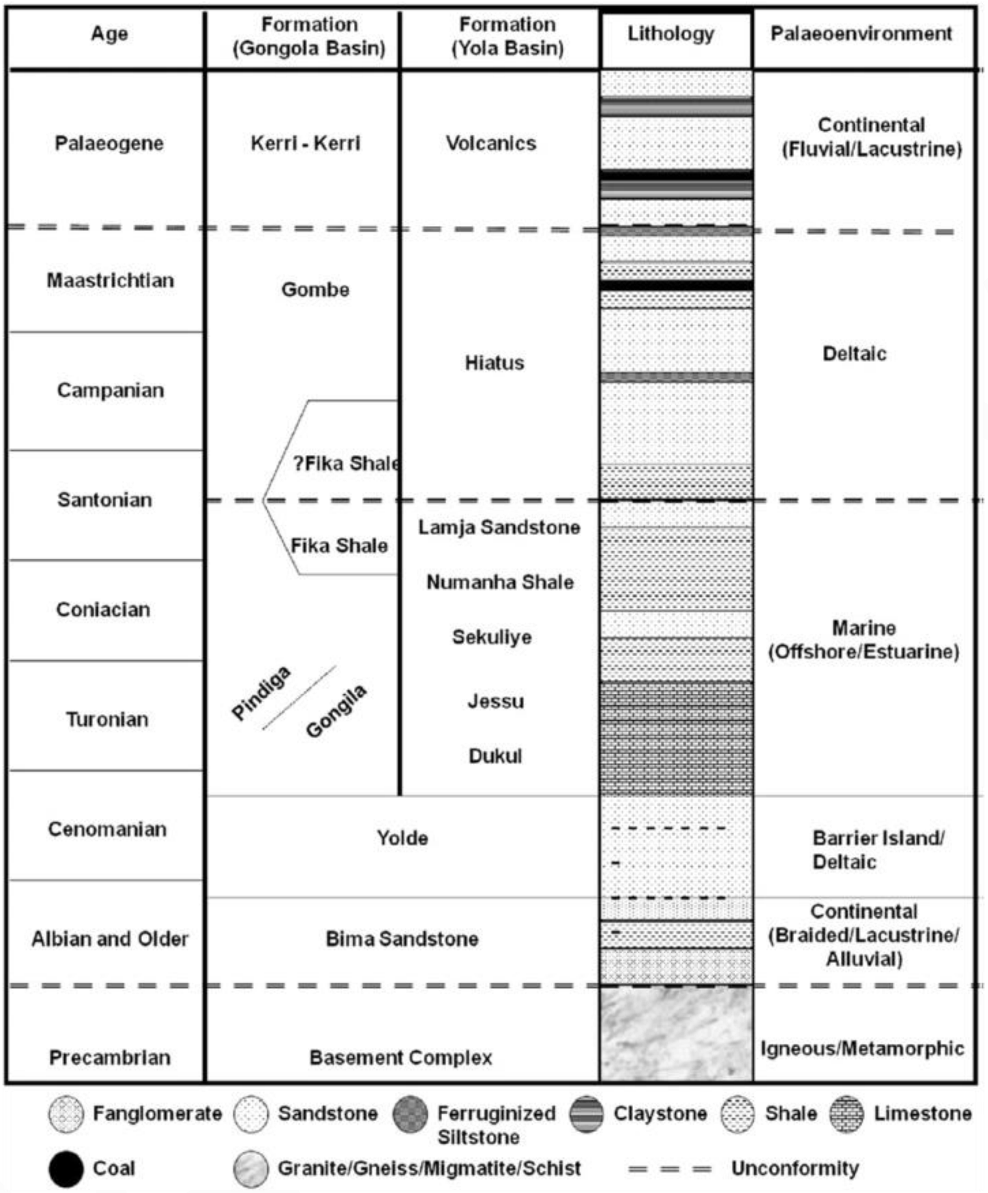
Table 1 The stratigraphy of the Upper Benue Trough (After Nwojiji et al., 2013)



Regional Geological Setting

Sedimentation in the Upper Benue Trough of Nigeria began during Aptian-Albian times and continued throughout Cretaceous period depositing pile of sedimentary rocks in succession of varying lithologies and environments of deposition that range from continental through marine to estuarine/deltaic. The Upper Benue Basin is subdivided into Gongola and Yola arms, where the Gongola arm is believed to be separated from Chad basin by an anticlinal feature termed the Dumbulwa-Bage High (Zaborski *et al*., 1997). Dike (2002) asserts that the Upper Benue Trough is made up of three arms: The E-W trending Yola arm, The N-S trending Gongola arm and NE-SW trending Muri-Lau basin. The stratigraphy of the Upper Benue Trough is presented in Table 1 while the summarized description of the sediments is given thereafter from oldest to youngest.

Bima Formation

The Aptian-Albian Bima sandstone, a continental formation represents the basal part of the sedimentary succession within the Upper Benue Trough, which rest directly and unconformably on the Precambrian crystalline Basement Rocks and consists of three siliclastic members: the lower Bima (B1), middle Bima (B2), and upper Bima (B3) (Carter *et al*., 1963; Guiraud, 1990)). The Formation generally consists of massively bedded, sparsely fossiliferous, poorly sorted, medium-coarse grained arenaceous feldspathic sandstone. The formation is mainly composed of sandstones, although the occurrence of shale intercalations have been reported (Carter *et al*., 1963, Avbovbo *et al*., 1986). The lithology is diverse indicating accumulation under widely varying conditions, including fluviatile, deltaic and lacustrine depositional environments (Carter *et al*., 1963; Allix, 1983; Guiraud, 1990).

Yolde Formation

The transitional Yolde Formation marked the Cenomanian deposition in the Upper Benue Trough (Allix, 1983). This Formation represents the beginning of marine incursion into the Upper Benue Trough. The Formation lies conformably on the Bima sandstone and is characterized by alternating sandstones, shales and dark grey mudstone which

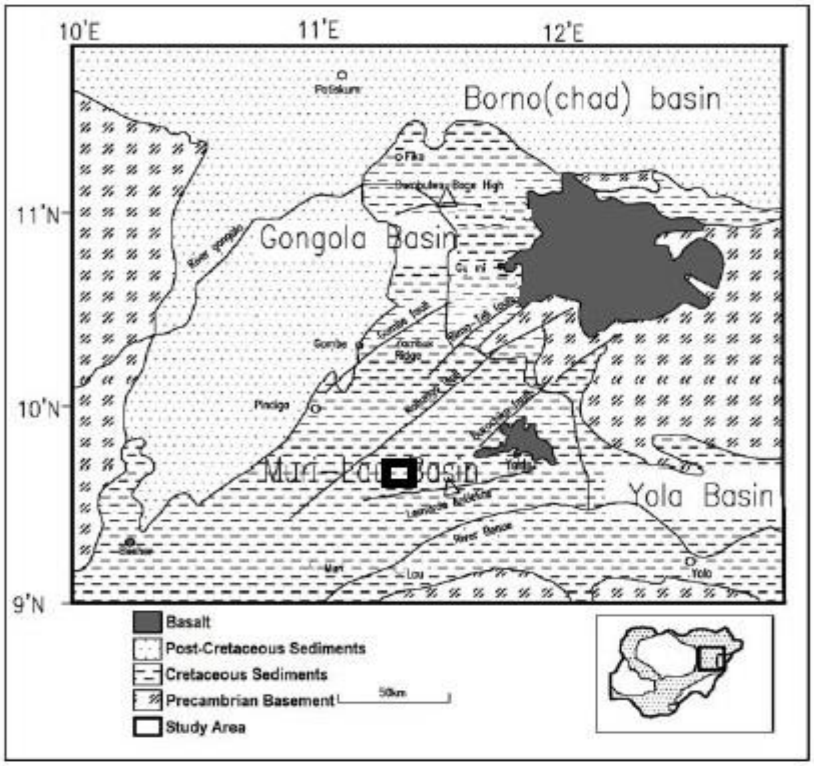


Figure 1 Geological map of the Upper Benue Trough showing the study area (Modified from Zaborski *et al*., 1997)

frequently displays dessication cracks. The sandstones are variable, usually coarse-grained and cross bedded, but sometimes regularly bedded with argillaceous intercalations (Carter *et al*., 1963).

Marine Formations

The late Cenomanian to early Turonian was a period of major transgression throughout the Benue Trough that culminated into possible link between waters of Gulf of Guinea to the south and Tethys sea to the north (Zaborski, 2003). The transgression marked the deposition of marine formations in the entire Benue Trough. This same transgression resulted in the deposition of Dukul, Jessu and Sekuliye Formations and the Numanha shales in the Yola arm of the Upper Benue Trough.

Dukul Formation

The Dukul Formation represents the basal part of the full marine sequences in the Yola Arm of the Upper Benue Trough. It conformably overlies the Yolde Formation and characterized by interbedding of shale and limestones that are variously fossiliferous and nonfossiliferous, marlstone and mudstone (Carter et al., 1963; Mamman, 1998; Nwajide, 2013). The shale in most places weather to form “cotton soil” a black clayey soil with high plasticity. The limestone occurs as shelly and nonshelly varieties forming scattered boulders and debris in the field. It consists of bioclastic packstone, algal laminate and mudstone (Nwajide, 2013).

Jessu Formation

The Jessu Formation was deposited during the mid-Turonian regressive phase of the Cenomanian-Turonian transgression-regression episode which affected the whole of Benue Trough. It comprises of an alternating succession of shale, mudstone, siltstone and flaggy sandstone (Carter et al., 1963; Allix. 1983; Nwajide, 2013). Allix (1983) suggest that the formation was deposited in shallow muddy shelf occasionally subject to open marine conditions.

Sekuliye Formation

The Coniacian Sekuliye Formation overlies the Jessu formation and is restricted to the Yola arm of the Upper Benue Trough. The formation is composed of greenish gray shales that are occasionally gypsiferous and thin bands of fossiliferous and nonfossiliferous limestone (Carter et al., 1963; Allix, 1983). Bands of recrystallized calcite occur within the shale, and such clear calcite is also found fringing the limestone beds (Nwajide, 2013).

Numanha Formation

The Campanian Numanha Formation shows successions consisting of blue-black, gypsiferous shales interbedded with greenish-grey mudstone, rare calcareous sandstone and oyster-bearing limestone. The shales are frequently intercalated by greenish or brownish laminated siltstone (Carter et al., 1963; Mamman, 1998). Thin carbonaceous horizons are associated with the shales (Nwajide, 2013). Allix (1983) regarded the Numanha shales to have been deposited in shallow marine environments ranging from delta to lagoonal paleoenvironmental settings.

Lamja Formation

The Maastritchian Lamja Formation rest on the Numanha Shales conformably and occur as small isolated exposures along eastern and southern margins of the Longuda plateau (Carter et al., 1963). Its lithology comprises of grey to black shales, siltstone, fine-grained sandtone, low rank coal and bioclastic oyster rich limestone (Allix, 1983). The siltstone is occasionally carbonaceous.

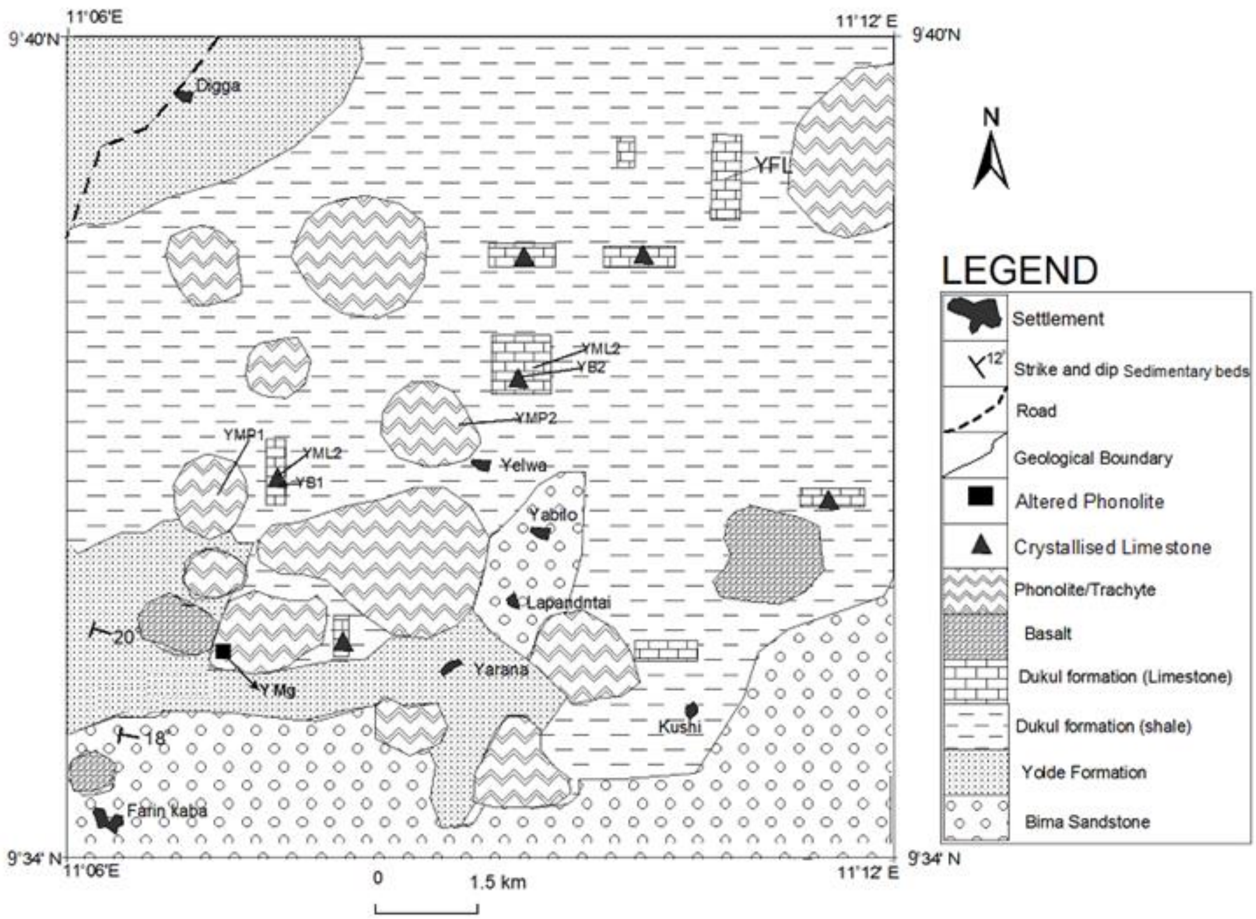


Figure 2 Geological map of Yelwa area

Volcanic rocks

Extrusive igneous activities took place during the Palaeogene in this part of the Upper Benue Trough producing numerous vent-forming features consisting of basalts, agglomerates, ash falls, lava, tuffs, phonolites, trachytes, tephrites, rhyolites and many types of pyroclastics (Carter *et al*., 1963; Turner, 1978; Islam, 1986; Wright, 1989; Obaje, 2009; Nwajide, 2013). The most voluminous outpouring of lavas occurred through sediments of the Benue Trough especially where basaltic Biu and Lunguda plateau dominate the topography.

The largest area of volcanic rocks in Nigeria is the Biu plateau covering an area of about 5,200 Km^2 with over 80 volcanoes occurring in form of tephra rings, cinder cones, and maars consisting of basaltic agglomerates, lavas, volcanic bombs, ashes and tuffs (Carter *et al*., 1963; Islam, 1986). The Lunguda plateau is the second largest covering an area of about 200 Km^2 overlying the Cretaceous deposits of the region, the volcanoes are formed as isolated conical hills of either basalts, trachytes, or phonolites, prominent among them are the isolated hills of columnar-joints basalts of Ngurore (Carter *et al*., 1963).

Over 300 volcanic plugs have been mapped within the Upper Benue Trough vast majority of which are olivine-basalts but phonolite and trachyte plugs dominate the rugged scenery notably between Filiya and Tangale peak (Carter *et al*., 1963).

METHODOLOGY

Geological Mapping

The Yelwa area was mapped on a scale of 1:50,000 using the topographic map sheet 173 SW Kaltungo as base map. A total area of about 144 Km^2 was covered using traverse compass mapping technique. Equipment used include compass-clinometer, geological hammer, Global Positioning System (GPS), digital camera, measuring tape, field note book, pen, pencil, indelible marker, masking tape, acid bottle, sample bags, and topographic maps among others. Representative rock samples where outcrops are exposed were chipped, described on the spot as hand specimen. Samples were then labelled, the locations noted and plotted on the base map with the aid of the GPS which gives exact coordinates of sample points in terms of latitudes and longitudes. The megascopic features and characteristic field relationships of the formations, structural elements as well as possible mode of occurrence of the various rocks and formations in the areas were measured, described and recorded in the field note book.

Petrography

A total of 104 rock and mineral samples were collected from the field, 38 were selected and taken to petrology and mineralogy laboratory of Geology department, University of Maiduguri and were thin sectioned. The thin section preparation procedure followed was that of Kerr (1977) which involves cutting a thin slice from the rock samples using cutting machines. The slices were polished with abrasive powder until a required level of polishing is attained. The polished surfaces of the slices were then mounted on the glass slides using araldite. The glass slide with the mounts were placed on the hot plate and heated for 10 minutes. The samples were removed from the hot plate and allowed to cool. The slides were once more polished to standard thickness of 0.03mm using abrasive powder on glass laps. Canada balsam drops were smeared on the glass slides while on the hot plate and very thin glass covers were placed on the finished polished surfaces in which gentle pressure were applied to remove trapped air bubbles as well as excess Canada balsam. The slides were allowed to cool, hardened while the overflow of the balsam was washed off using organic solvent. The slides were then properly labelled and subjected to petrographic studies using petrological polarizing microscope.

RESULTS

The study area consists of two major groups of rocks that are typical of Upper Benue Trough; the Cretaceous sedimentary rocks and the Palaeogene volcanic rocks. About 75% of the total area is underlain by Cretaceous deposits which occupy all areas except where the volcanic rocks extruded and dotted parts of the Cretaceous sediments (Fig. 2). Formations encountered are Bima Sandstone, Yolde Formation and Dukul Formation.

Bima Sandstone

The Bima sandstone occurs around Farin-Kasa, Yabilo and Lapandintai in the southern part of the study area (Fig. 2). The Bima sandstone lies directly and nonconformably on the floor of the Basement being the oldest formation. It is whitish, pinkish and grayish coloured. The texture varies from Fine, medium to coarse grained. The rocks are massive and thickly bedded forming extensive hills that run for few meters to several kilometres in extent (Plate 1). Generally the rocks are poorly sorted and exhibit various structural features that include cross-bedding, joints and micro quartz veins which are rare. The sandstones are in some cases generally very hard and indurated which do not break easily when hammered. Compositionally they are made up of predominantly quartz and feldspar with few samples containing mica. Weathering activities have affected this rock and breaks them to numerous boulders which roll to occupy plain areas.

Microscopic study indicates that the Bima sandstone is composed of quartz, orthoclase, microcline, biotite and iron oxide. The quartz range from 30% to 40% in composition and is colourless with low relief and weak birefringence. It is sub-angular to sub-rounded in form. The large grains are fractured and undergo undulose extinction while the smaller grains are less fractured and show parallel extinction. The orthoclase is colourless with low relief and weak birefringence. The form is sub-angular to sub-rounded with some being tabular in outline (plate 2). The interference colour is grey to dark grey of first order. It ranges from 5% to 25% compositionally in the rock. Microcline is colourless with low relief and weak birefringence. The form is tabular and many are cracked, having perfect cleavages in two directions at right angle or near so, exhibiting poly-synthetic twinning. The composition varies from 7% to 35% by volume in the rock. Biotite is brown in colour with high relief and strong birefringence. It occur as sub-angular to sub-rounded in form and it is strongly pleochroic with brown to dark brown to yellowish second order interference colours. It's about 2% to 15%. The iron oxide occur as reddish brown to dark sub-angular to sub-rounded grains, few are well-round (plate 2) with composition of 1% to 7% in the rock.

Yolde Formation

The Yolde Formation covers the extreme North-western corner around Digga and south-western part encompassing Yarana (Fig. 2). The Formation is generally well exposed and forms steep sided to intermediate hills but poorly exposed in some places. The Formation consists of alternating sequence of sandstones, siltstones and mudstones some of which are capped with minor ironstone (Nnabo *et al*. 2018). The formation appears in varying colourations including light, pinkish, purplish, brownish and yellowish varieties. It occurs as thickly bedded sandstone around Digga and Yarana area while in other locations it occurs as low-lying hills. Texturally it is made-up of a medium to fine grained sandstones, consisting of mainly quartz, feldspars and traces of iron-oxides. Structurally it is laminated, cross-bedded, and also exhibits convulate beddings (Plate 3).

In thin section the sandstone of the Yolde Formation consist of quartz, orthoclase, plagioclase, biotite, iron oxide and zircon. The quartz is colourless, fine to medium grained. It is sub-rounded to rounded in form and constitute about 30% to 55% of the rock. Orthoclase is colourless, sub-angular to sub-rounded in form. It shows Carlsbad twinning and in composition it vary from 20% to 40% while plagioclase shows albite twinning. Plagioclase ranges from 5% to 7% by volume. The biotite is brown with high relief and strong birefringence having sub-angular to sub-rounded form. It is srongly pleochroic exhibiting parallel extinction and compositionally ranging from 3% to 6% in the rock. The iron oxide is reddish in colour, sub-angular/irregular in form. The zircon is pale pinkish with very high relief and very strong birefringence. It occurs as short prismatic in form and exhibits pale tints interference colour of the fourth order. It constitutes less than 1% by volume of the rock. The photomicrograph of Yolde Formation is given in plate 4.

Dukul Formation

The Dukul Formation occupies much of the Northern as well as some areas of south central parts of the mapped area, including Yelwa and Kushi areas (Fig. 2). The formation is marked by general absence of highlands and characterized by featureless topography. Lithologically the area consist of sequence of extensive and widespread shale and few limestone bodies. The shales consist of dark coloured, fine grained, friable flat-lying outcrop that exhibit dessication cracks (Plate 5). The limestones are made up of scattered loose slabs and blocks of varying dimensions in different locations within the shales. The limestone in some places forms continuous and extensive belts of about 0.5 Km long which habors the crystalline and fossiliferous varieties. Based on field observation the limestone is divided into three distinctive types: the first is the crystalline variety which is gray and brownish in colour and mostly occur in a belt that runs approximately in N-S direction for about 500 M to 2 Km; the second is the fossiliferous variety that contains ammonites and bivalves, while the third group consists of large and small slabs and blocks of both crystalline and fossilliferous types. In addition recrystallized calcite portions which in most places appear plastered on the crystalline and fossiliferous limestone have been encountered in six locations. The limestone is grey, brown and dark in colour, fine grained in texture, massive and breaks into slabs with some containing fossil faunas (Plate 6).

In thin section the limestone is composed of calcite, dolomite, microcline, quartz and iron oxide. The calcite is cloudy and colourless, with high relief and strong birefringence. It is subhedral to euhedral in form, with perfect rhombohedral cleavage in two directions. It exhibits pearl grey higher order interference colour having a polysynthetic

Plate 1 Stretch of Bima Sandstone at Farin Kasa (N9º34.939' and E11º06.922')

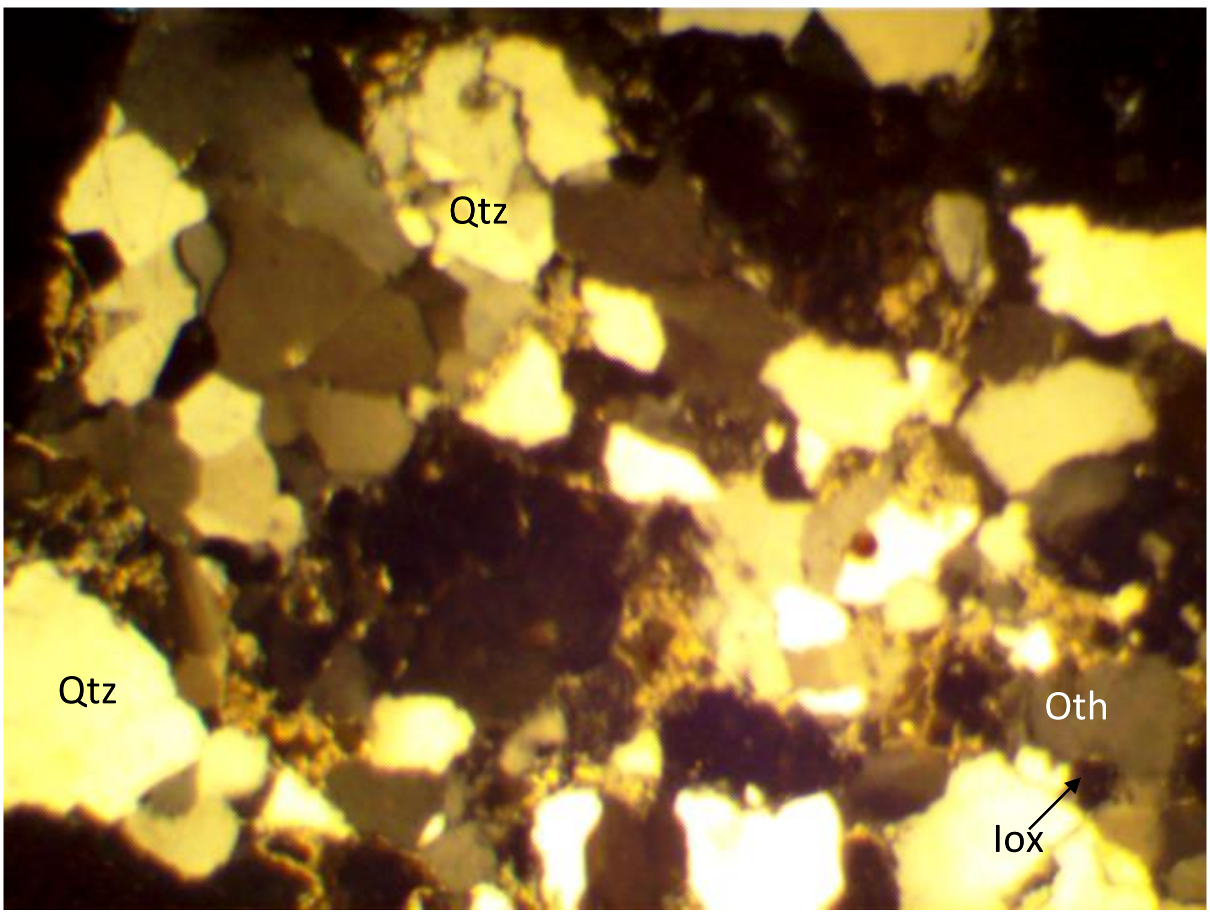


Plate 2 Photomicrograph of Bima Sandstone showing: Quartz-Qtz. Orthoclase-Oth. iron oxide-Iox. crossed polars. Length of photograph= 6.7mm

Plate 3 Convulate lamination and bedding in Yolde sandstone (N9º35.846' and E11º07.145')

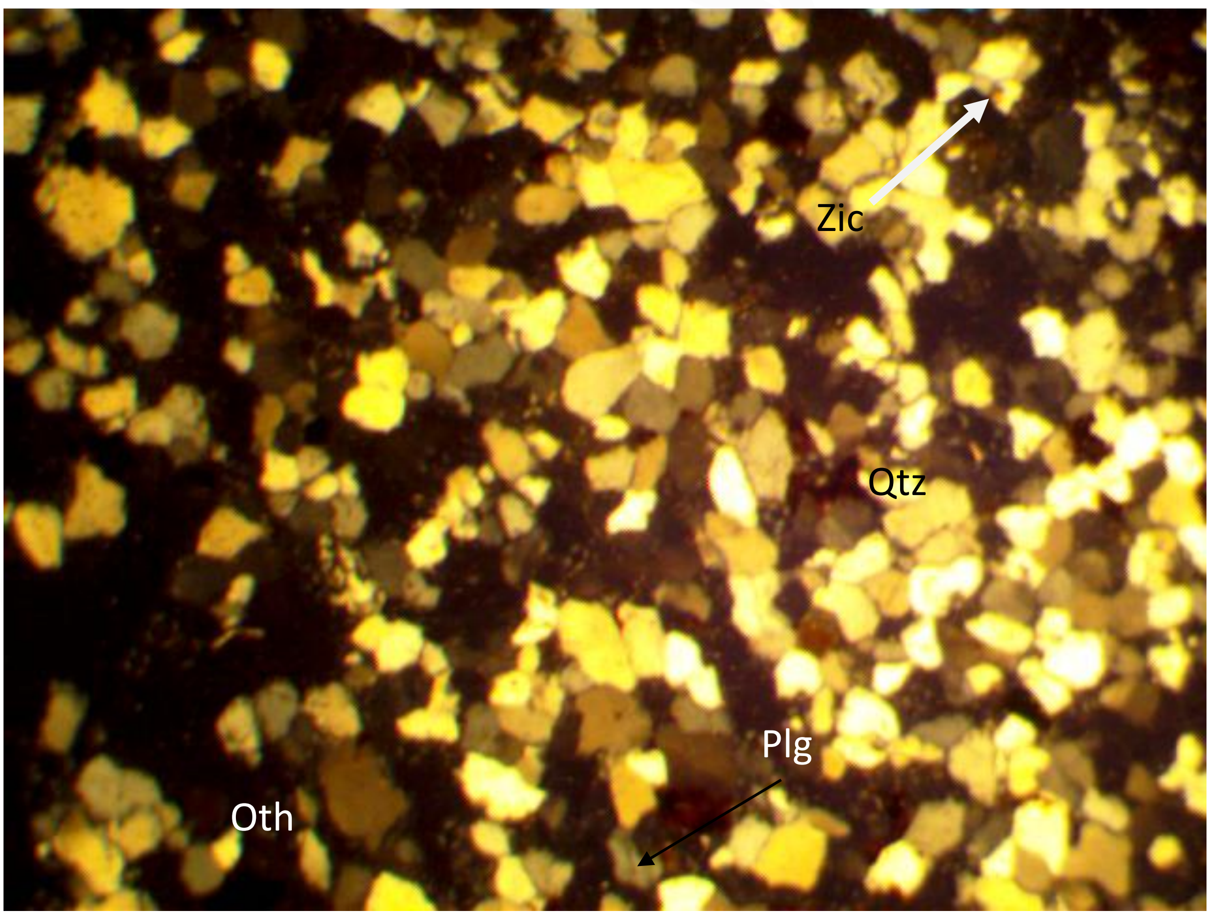


Plate 4 Photomicrograph of Yolde sandstone showing: Quartz-Qtz. Plagioclase-Plg. Orthoclase-Oth. Zircon-Zic. crossed polars. Length of photograph= 6.7mm

Plate 5 Shale of the Dukul Formation exhibiting dessication cracks (N9º36.886' and E11º07.999')

Plate 6 Slabs, blocks and fragments of Limestone associated with shales of Dukul Formation (N9º36.818' and E11º09.461')

twinning. In composition it ranges from 52% to 75% by volume. Dolomite is grey with high relief and strong birefringence. It has rhombohedral cleavage perfect in two directions and subhedral to anhedral in form. The microcline is colourless with low relief and weak birefringence. It is tabular in form and exhibits cross hatched twinning. Compositionally it ranges from 12% to 20% by volume in the rock. Quartz is colourless, with low relief and weak birefringence. It is fine grained and show parallel extinction. It has composition varying from 3% to 5% by volume in the rock. The iron oxide is dark and irregular in form. It ranges compositionally from 1% to 5% by volume. The photomicrograph of limestone is given in plate 7.

Recrystallized Calcite

There are about six recrystallized calcite locations within the Dukul Formation all of which appears to have been similar in properties and are associated with crystalline and fossiliferous limestone forming stratiform and strata bound calcite occurences (Fig. 2). The areas of occurrence are of low-lying, gently undulating environment consisting of a sequence of shale and limestone. The calcite is white in colour, massive and brittle which is plastered on top of the limestone, however some occur in form of veins of minor dimensions not exceeding 1m in length and 2cm - 3.8cm in width (Plates 8 and 9). It has hardness of 3-4 on Moh's scale with white streak and perfect cleavage in two directions having non-metallic lustre. The specific gravity ranges from 2.163 g/cm^3 to 3.810 g/cm^3. In all the areas of calcite occurrence no observable alteration zone was seen. The volcanic plugs in the viscinity of calcite occurrences might have influence on the calcite recrystallization observed. The fluid from the plugs might be responsible for the recrystallization of calcite in the limestone.

Petrographic study of the recrystallized calcite indicates the presence of calcite and dolomite. The calcite has modal composition varying from 60% to 75% by volume in the rock. It is cloudy-white with high relief and perfect rhombohedral cleavage having tabular form. It undergoes symmetrical extinction showing pearl grey interference colours. It exhibits polysynthetic twinning. Dolomite is grey with high relief and perfect rhombohedral cleavage also having subhedral form. It exhibits pearl grey to white high order interference colours with extinction being symmetrical and exhibits polysynthetic twinning. Compositionally it ranges from 10% to 25% by volume. The photomicrograph of the recrystallized calcite is given in Plate 10.

THE VOLCANIC ROCKS

Volcanic rocks (mostly plugs) were encountered in which they occur almost all over the study area (Fig. 2). About 16 volcanic bodies were located during the course of the mapping exercise. Three are of basaltic origin all others were phonolite/trachyte plugs which are similar in appearance in hand specimen. The rocks occur in form of outliers surrounded by older Cretaceous rocks of the study area. Some of the volcanics might have direct relationship with calcite recrystallization in the study area.

Basalts

The Basalts occur in the area about 150m north of Farin-Kasa, and at Lodingor about 3Km NE of Kushi (Fig. 2). The basalts outcrops in the area in form of plugs and cones as well as numerous boulders and fragments scattered far away from the main bodies (Plates 11 and 12). The basalt was observed to extrude through the Bima and Yolde sandstones as well as Dukul Formation. The basalts are generally dark or black in colour, fine grained and densely massive, some contain isolated cavities and vesicles filled with secondary minerals (amygdales) tested to be calcite and rarely zeolite. In some locations, the basalts are massive devoid of vesicles and contain xenoliths of limestone. The limestone might have been engulfed by the flowing lava but could not be assimilated because of the rapid cooling of the lava and this resulted into formation of xenoliths of calcite. The heat generated by the cooling lava recrystallized the limestone into calcite. No area at which evidence of pyroclastic have been noticed.

In thin section the basalt was observed to consist of olivine, pyroxene, plagioclase and iron oxide. The olivine is colourless with fairly high relief and strong birefringence. The form is subhedral, anhedral and occurs mainly as phenocrysts. The large crystals are irregularly fractured with smaller ones being less fractured. It exhibit parallel extinction and twinning is absent. It ranges in composition from 25% to 35% in the rock. Pyroxene (augite) is colourless with high relief and strong birefringence. It occurs as short prismatic in form with cleavage in two directions. It show pale yellow first order interference colour and exhibit parallel extinction. It occurs mainly as groundmass with 10% to 27% compositional range. The plagioclase is colourless with low relief and weak birefringence. It is anhedral in form with lathlike habit of short dimension. It shows polysynthetic twinning. Compositionally it varies from 10% to 22% in the rock. Iron oxide appear dark in colour and occur as spots in the rock with composition in the rock ranging from 1% to 20%. The photomicrograph of basalt is given in Plates 13 and 14.

Phonolites/Trachytes

The Phonolites/Trachytes are scattered almost all over the Cretaceous sediments of the study area (Fig. 2). A total of about 13 phonolitic/trachytic plugs have been mapped. They occur as outliers surrounded by older formations of Bima, Yolde and Dukul Formations. The phonolite formed steep sided plugs and hills some of which exhibit columnar jointings which are very long and thin but poorly developed (Plate 15). Phonolite is generally gray in colour, dense, texturally it ranges from fine, through medium and porphyritic type in which sanidine phenocryst in a groundmass of aegirine, nepheline and augite have been observed in sample S55 (9° 37.488'N; 11° 08.106'E). In some locations the phonolitic and trachytic rocks formed moderate hills of small dimensions and were observed to be affected by chemical weathering exhibiting whitish colouration (Plate 16).

Microscopic investigation shows that the phonolite and trachyte consist of sanidine, plagioclase, aegirine, nepheline, and iron oxide. The sanidine constitutes about 10% to 25% in the rock and is clear white with low relief. It is euhedral to subhedral in form but some occur in form of lath-like habit and constitute part of phenocryst and groundmass that tends to be aligned in a define direction suggesting that crystals were transported by flowing magma before solidification. It has perfect cleavage in one direction. Birefringence is weak and has grey to white first order interference colour. It exhibits simple twinning conforming with Carlsbad law and undergo parallel extinction. Large crystal of sanidine enveloped by fine laths exhibiting trachytic texture was also observed. The Plagioclase is colourless with low relief and it occurs as prismatic crystals randomly arranged in fine grained groundmass. Birefringence is weak and it shows polysynthetic twinning. It undergoes symmetrical extinction. It has composition in the range of 17% to 23% in the rocks. Aegirine is greenish with high relief and long prismatic anhedral crystal form. It has less developed cleavage in two directions. It has strong birefringence and is strongly pleochroic. Aegirine show alteration from greenish to brownish colour. Nepheline is turbid white in

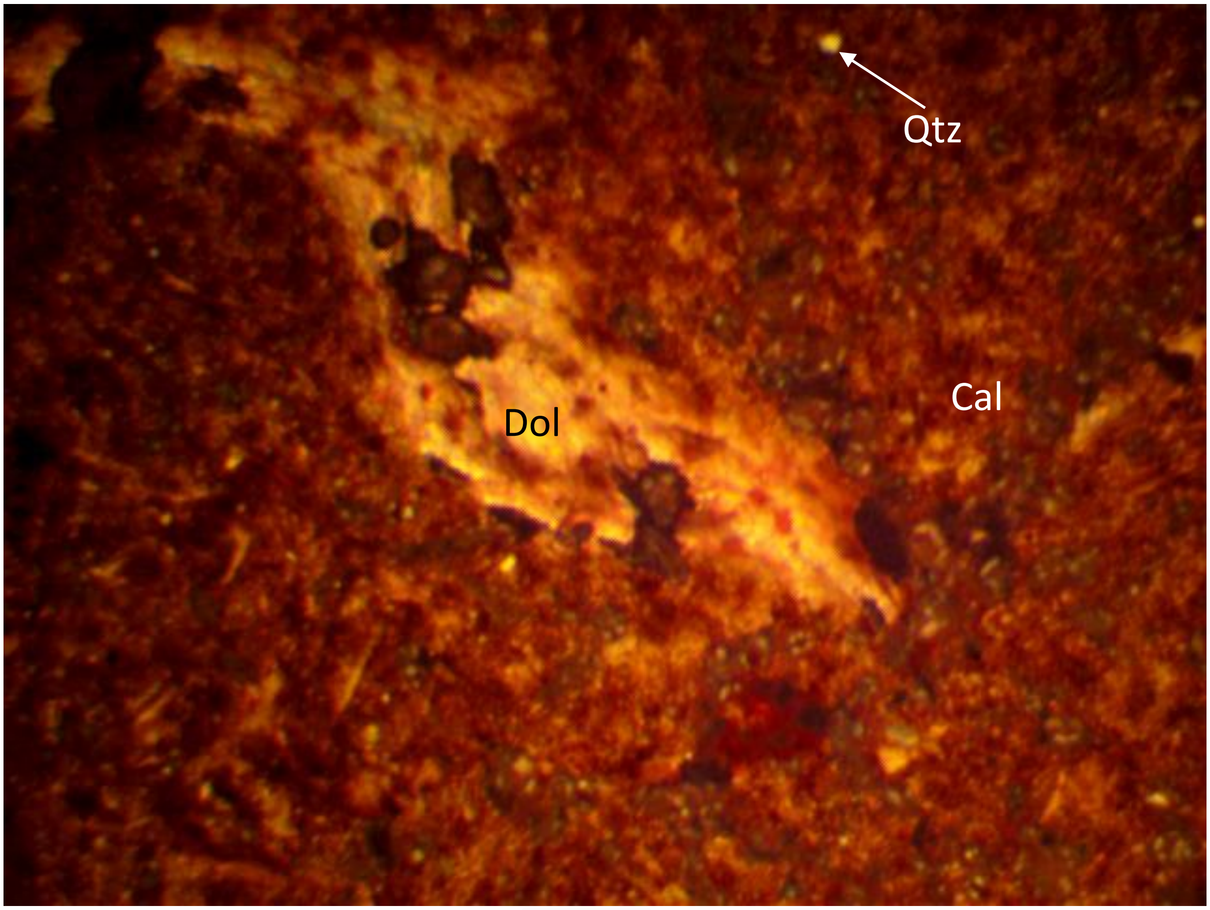


Plate 7 Photomicrograph of Dukul Formation limestone showing: Calcite-Cal. Dolomite-Dol. Quartz-Qtz. Crossed polars. Length of photograph = 6.7mm

Plate 8 Recrystalized calcite on limestone of Dukul Formation (N9°36.449' and E11°07.878')

Plate 9 Recrystallized calcite restricted to Limestone unit of Dukul Formation (N9°36.694' and 11°07.859')

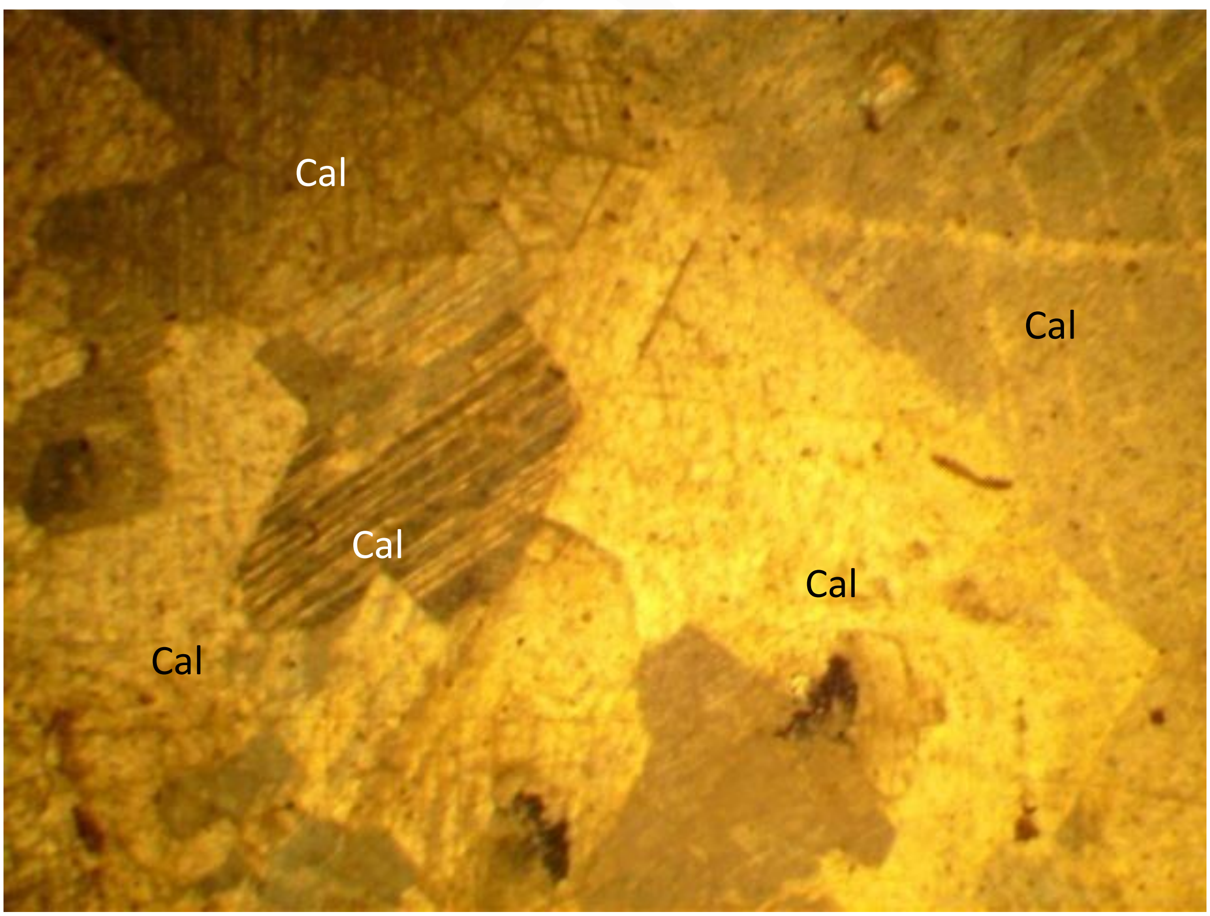


Plate 10 Photomicrograph of recrystallized calcite of Dukul Formation showing: Calcite-Cal. crossed polars. Length of photograph= 6.7mm

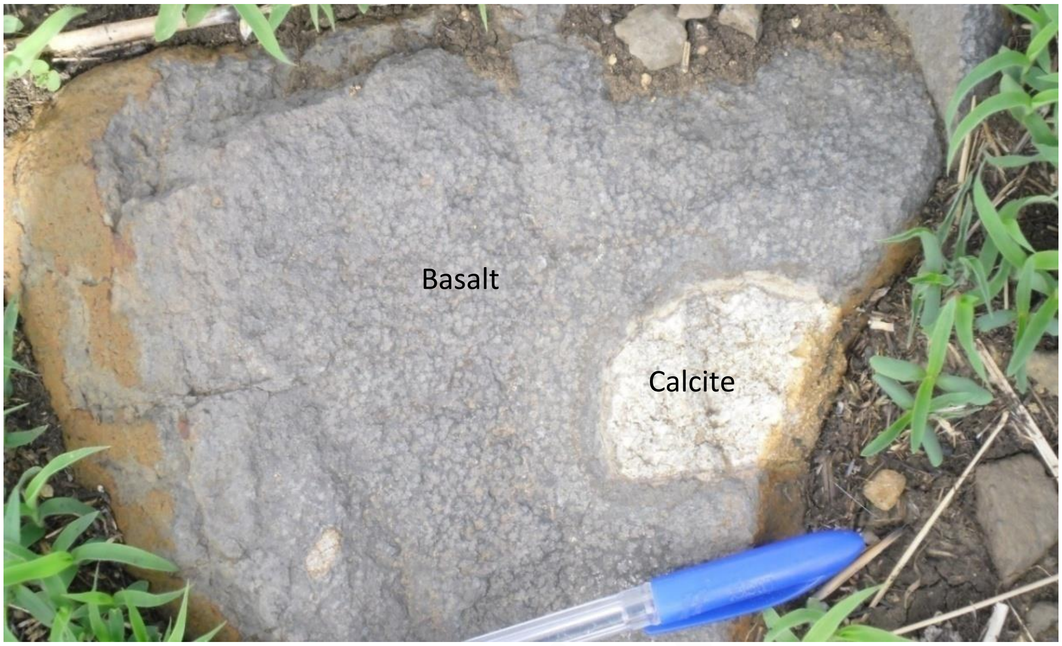


Plate 11 Basalt exhibiting Xenoliths of calcite (N9°36.505' and E11°11.869')

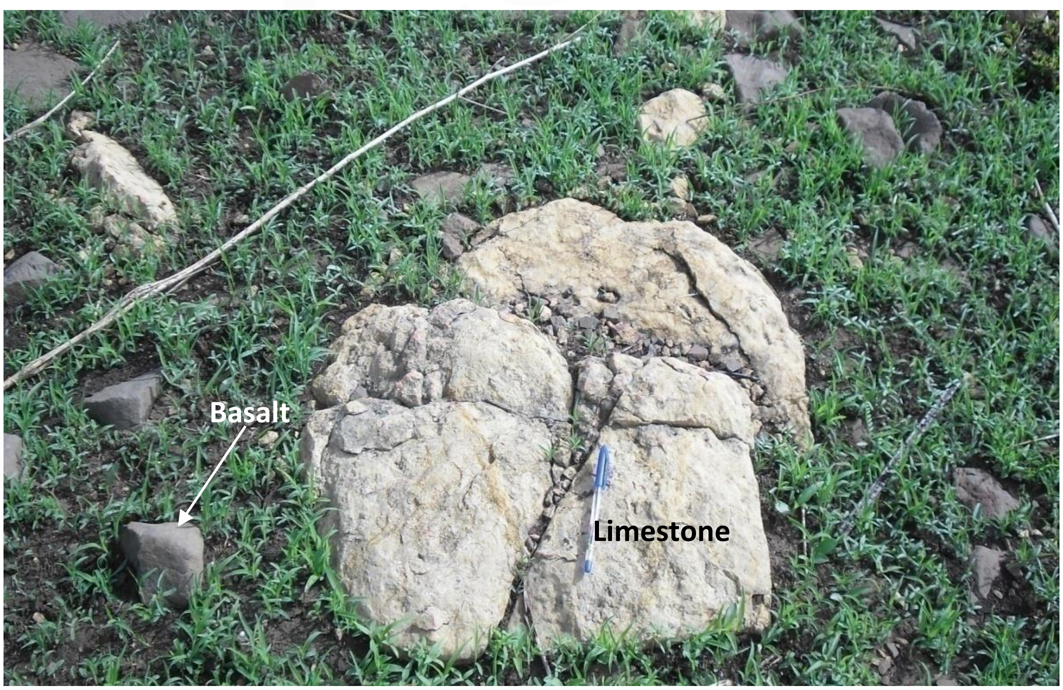


Plate 12 Blocks of Basalt and limestone (N9°36.126' and E11°11.324')

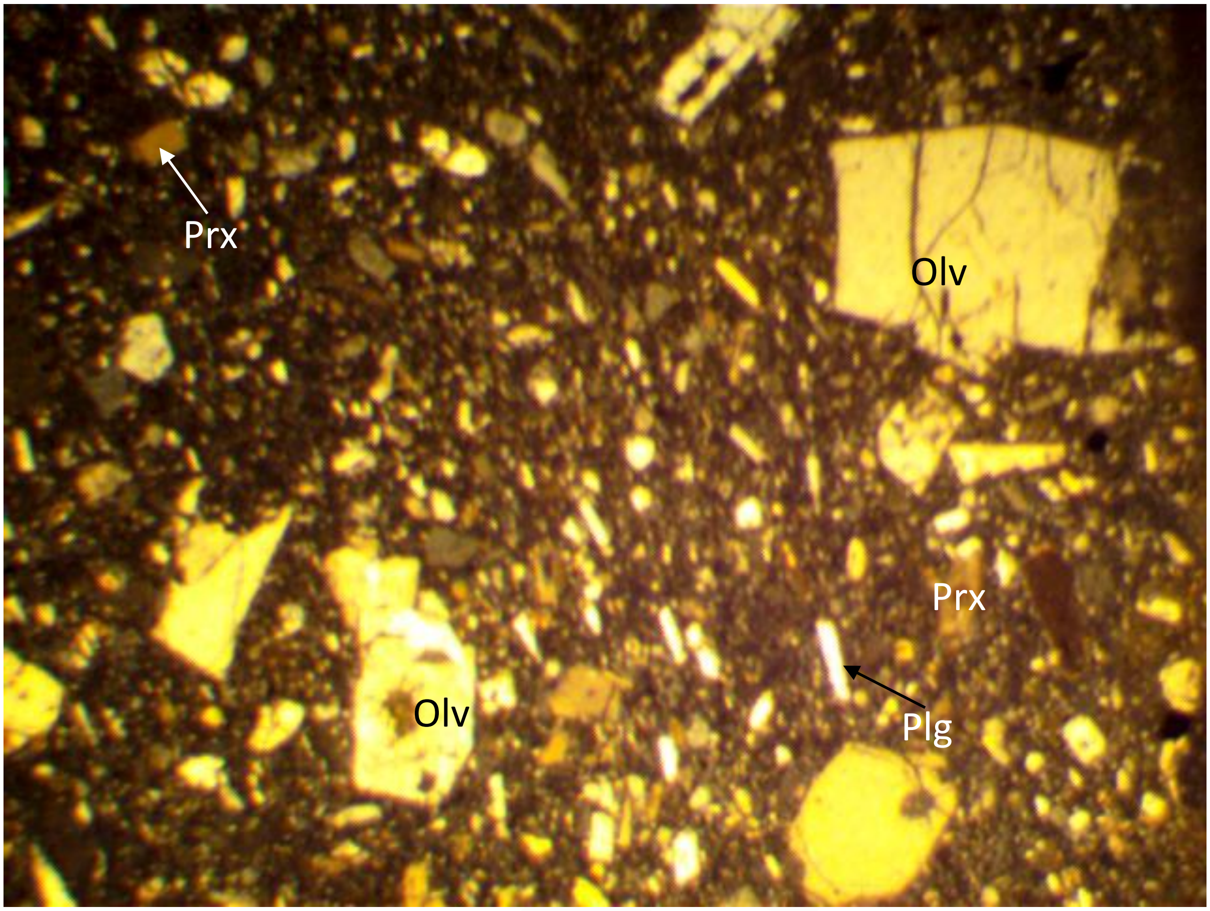


Plate 13 Photomicrograph of basalt showing: Olivine-Olv. Pyroxene-Prx. Plagioclase-Plg. Crossed polar. Length of photograph= 6.7mm

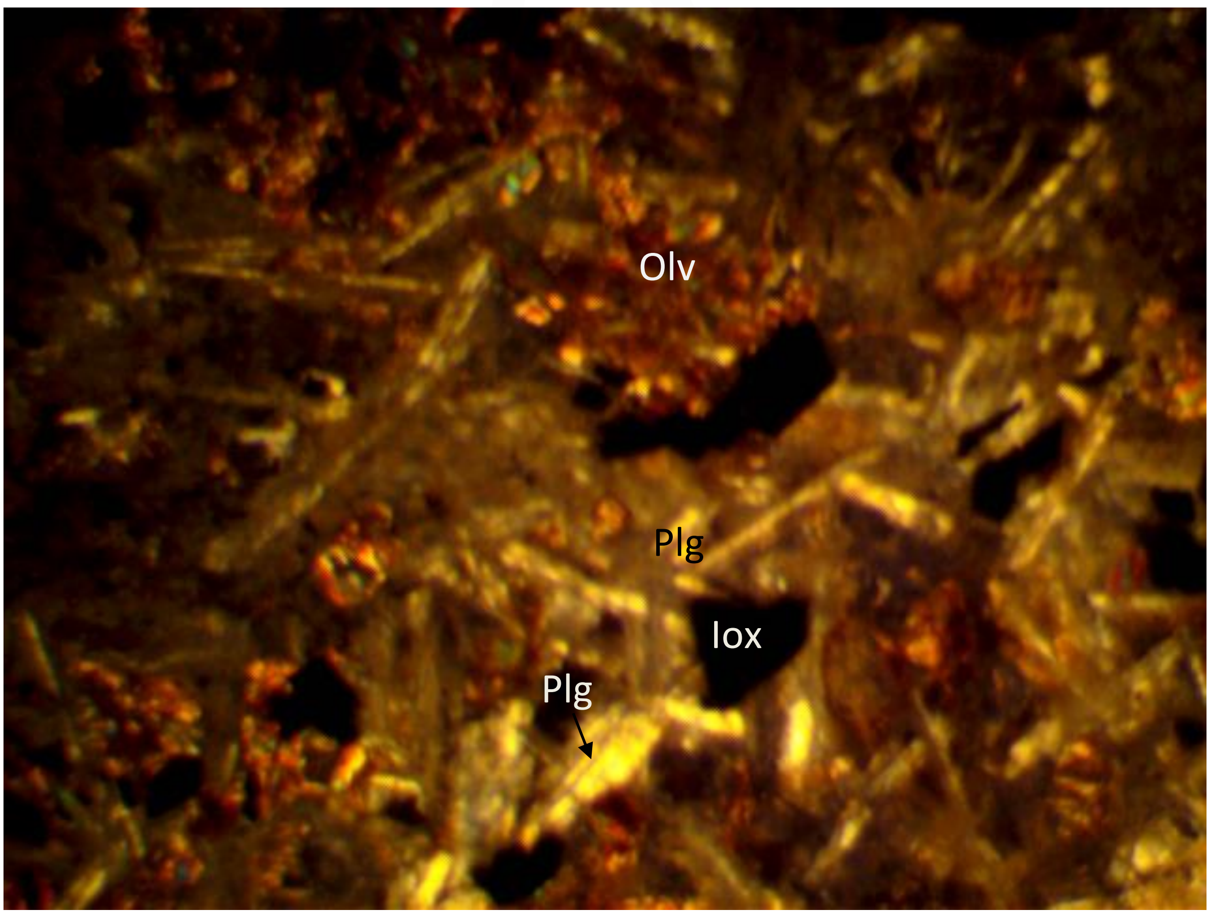


Plate 14 Photomicrograph of Basalt showing: Plagioclase-Plg. Olivine-Olv. Iron oxide-Iox. Crossed polars. Length of photograph= 6.7mm

Plate 15 Plug of Phonolite exhibiting columnar jointings (N9°37.375' and E11°09.132')

Plate 16 Whitish phonolite due to chemical weathering (N39°36.075' and E11°08.821')

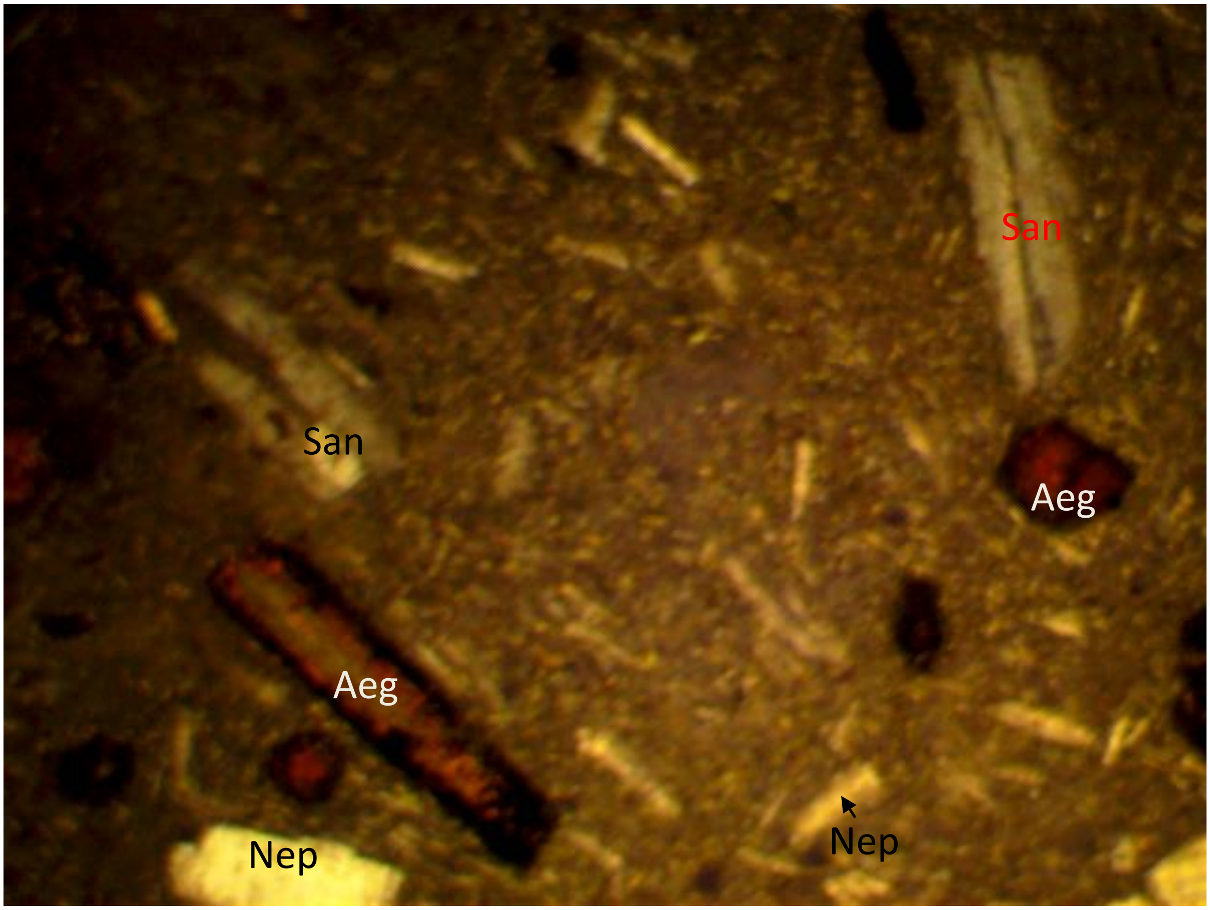


Plate 17 Photomicrograph of phonolite showing: Nepheline-Nep. Sanidine-San. Aegirine-Aeg. Crossed polars. Length of photograph= 6.7mm

colour having low relief and less apparent cleavage. It occurs in short prismatic and euhedral form within fine grained matrix. It shows light grey to dark grey first order interference colours and exhibits parallel extinction with weak birefringence. The iron oxides occur as anhedral to irregular form. The photomicrograph of the phonolite is given in Plate 17.

DISCUSSION & CONCLUSION

Geological mapping of Yelwa area was conducted and the geological map presented in Fig. 2. The area consists of Cretaceous sedimentary rocks and Palaeogene volcanic rocks. The sedimentary rocks are represented by Bima, Yolde and Dukul Formations while the volcanic consists of basalt and phonolite/trachytes. The Bima Sandstone occur in form of extensive hills that run for few metres to several kilometres consisting of thickly bedded, medium to coarse grained sandstones, hard, massive and sometimes indurated sandstones. Structurally, it exhibits cross bedding, bedding planes and joints with some samples near Farin Kasa containing rare veinlets of quartz suggesting that some quartz were partially melted and injected into the sandstone. In thin sections the Bima Sandstone consists of quartz, orthoclase, microcline, biotite and iron oxide. The Yolde Formation form steep sided hills of sandstones which are capped with ironstone occasionally. Lamination and convulate bedding are the main structural features of this rock which is believed to be due to disturbance during or after deposition, consolidation or burial which is in conformity with the view of Owen, (1996). Petrographic investigation revealed the presence of quartz, orthoclase, plagioclase, biotite, iron oxide and zircon. The Dukul Formation consists of a sequence of shale and limestone. The shale is dark, fine grained and friable flat-lying with dessication cracks, the cracks are wide about 1.5cm on the average. The limestone occurs as scattered loose slabs, blocks and fragments. A belt of limestone running N-S for 2 Km have been mapped and observed to have contained crystalline and fossiliferous varieties. It ranges from grey, brown to dark. In thin section the limestone contains calcite, dolomite, quartz, microcline and iron oxide.

Recrystallized calcite occurs in the limestone at six locations forming strata bound mineral occurence. The calcites were observed to have been formed by heat of lava which melts the calcite in limestone and carried it in solution. The calcite were later recrystallized and deposited on the limestone and rarely in small openings in the limestones forming veinlets of recrystallized calcite. Similar recrystallized calcite fringing limestone bodies was reported by Nwajide, (2013). In thin section the recrystallized calcite consists of calcite and dolomite.

A total of 16 volcanic bodies were located during the mapping exercise. Three are of basaltic origin and 13 are phonolites/trachyte. Basalts occur as outliers surrounded by older rocks forming plugs and hills as well as boulders and blocks that roll to distances. The basalt is dark, fine grained, dense and massive some are vessiculated and filled with amygdales of calcite, the non vesiculated varieties contain xenoliths of calcite. Microscopic investigation show that the basalt consists of olivine, pyroxene, plagioclase, augite and iron oxide. In some slides the olivine occurs as large phenocrysts with fractures and inclusions of pyroxene and iron oxide. The plagioclase occurs in lath-like habit, other samples contain anhedral nepheline crystals. Phonolite occurs as hills and steep sided plugs in the field. They are grey in colour, dense and range in texture from fine through medium to porphyritic. One plug was observed to exhibit poorly developed columnar jointing that are thin and long (Plate 15). Alteration was observed in one sample marked by whitish colour and high silica content (Plate 16) which indicate leaching of some elements. Petrographically it consists of sanidine, plagioclase, aegirine, nepheline and iron oxide. Sanidine and nepheline occur as phenocryst in most samples.

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