

Full Length Research Paper

Petrographic analysis of the Bima sandstone in the Upper Benue Trough, N. E. Nigeria

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Petrographic analysis of Bima sandstone of the Upper Benue Trough was attempted using field observations and representative samples from two widely separated areas. Petrographic and textural analysis of sandstone in both areas shows that the sandstone contains about 90% quartz and only about 5% orthoclase with iron oxide, silica and clay matrix as cementing materials. The grains of framework detritus range in size from coarse- to fine-grained and mostly sub-rounded and moderately sorted with no angular fragments. Interpretation of the results revealed that the sandstone is mostly quartz-arenites and arkose of mostly plutonic and metamorphic origins sourced from the crystalline basement of Adamawa, Cameroon, Mandara and Hawal Massifs, which border the trough as the source areas. Bima sandstone was formed during tectonic quiescence and in a humid tropical climate in the Mid-Cretaceous times. The deposition of the Bima sandstone was construed to have marine shoaling influence in a fluvio-deltaic environment.

Keywords: Bima sandstone, paleocurrent, Upper Benue Trough, petrography.

INTRODUCTION

Bima sandstone is the name given to the continental intercalaire in the Chad Basin and Upper Benue Trough of Nigeria (Falconer 1911). It is the oldest sedimentary deposit in these regions. The composition of Bima sandstone, mainly arkose to quartz arenite has generated wide speculations as to the source and environment of deposition (Falconer, 1911; Jones 1959; (Carter et al 1963; Murat, 1972; Braide 1990).

The detrital component of any sediment is a pointer to the source of the sediment (Ingersoll and Suozek 1979, Young 1976, Jones 1972), the paleoclimatic setting of the provenance (Suttner *et al.* 1981, James *et al* 1981), and the sedimentary processes that conveyed and dispersed these grains within the depositional basin (Breyer and Bart 1978, Klein 1977, Dovies and Ethridge 1975. Swett et al. 1971). The character and amount of interstitial cement and matrix are largely a function of diagenesis.

The Bima sandstone has good exposures in the Upper

Benue Trough. The study area (Fig. 1) comprises of Guyuk and Yola areas of the Upper Benue Trough. The Guyuk area represents the Gongola arm while Yola area represents the Yola arm of the Upper Benue Trough. These two areas are widely separated and have good exposures of the Bima sandstone. The choice of the two areas (Yola and Guyuk), was informed by excellent exposures of Bima sandstone in these areas and the zeal to provide a regional outlook for the study.

Geological Background

The origin and evolution of the Benue Trough have been variously described by many workers including King, (1950); Lees, (1952); Farrington, (1952); Cratchly and Jones, (1965); Wright, (1968, 1981); Olade, (1975); Burke, et al, (1972); Grant (1971); Freeth, (1978); Ofoegnbu, (1984); Nwajide, (1990) among others.

The depositional history of the area of study is marked by the deposition of Bima sandstone on the Precambrian Basement during the Aptian/Albian (Allix and Popoff, 1983; Popoff 1984). The Bima sandstone has been

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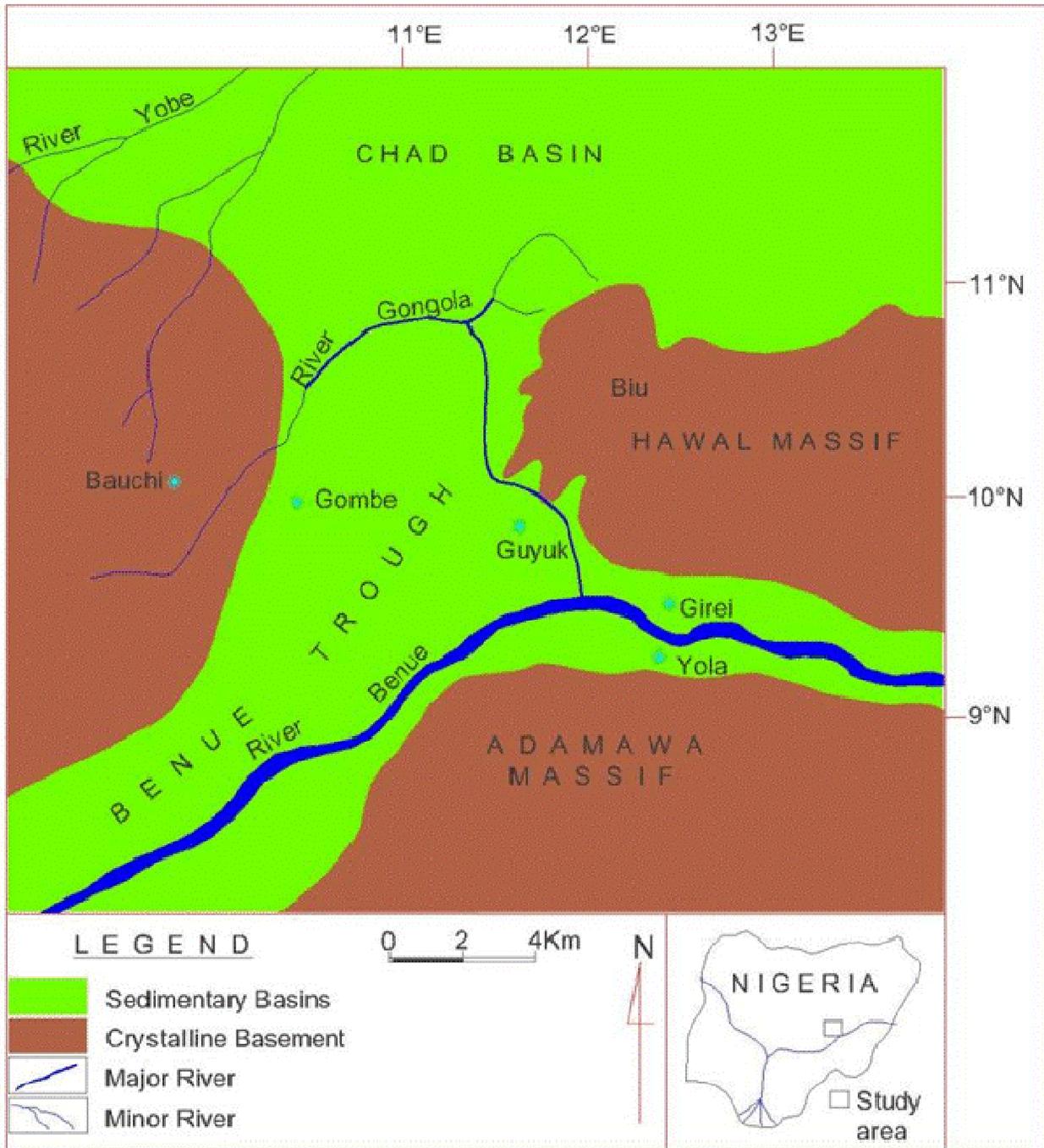


Figure 1. The Benue Trough and the bordering crystalline basement during the Cretaceous (modified after Maluski et al., 1995).

Differentiated into three units: Bima₁ (B₁), Bima₂ (B₂), and Bima₃ (B₃) from the oldest to the youngest respectively (Carter, et al. 1963; Guiraud (1991). The B₁, which falls outside the study area, is alluvial fan deposits and fan deltaic deposits. It is exposed in Burashika area and in Lamurde Anticline. The B₂, which is fluvatile, is exposed in the centre of Bagale Hills in the Yola area, Tula area of

the Gongola arm, and in the Lamurde Anticline of Lau Basin. It also occurs in Gwamba anticline, and Gagare anticline of Yola Arm. The B₃ is more widely exposed in all areas of the Upper Benue Trough than B₁ and B₂ (Benkheilil, 1983, 1986; Mourine et al, 1985).

The deposition of Bima sandstone was followed by the transitional Yolde Formation which inturn was succeeded

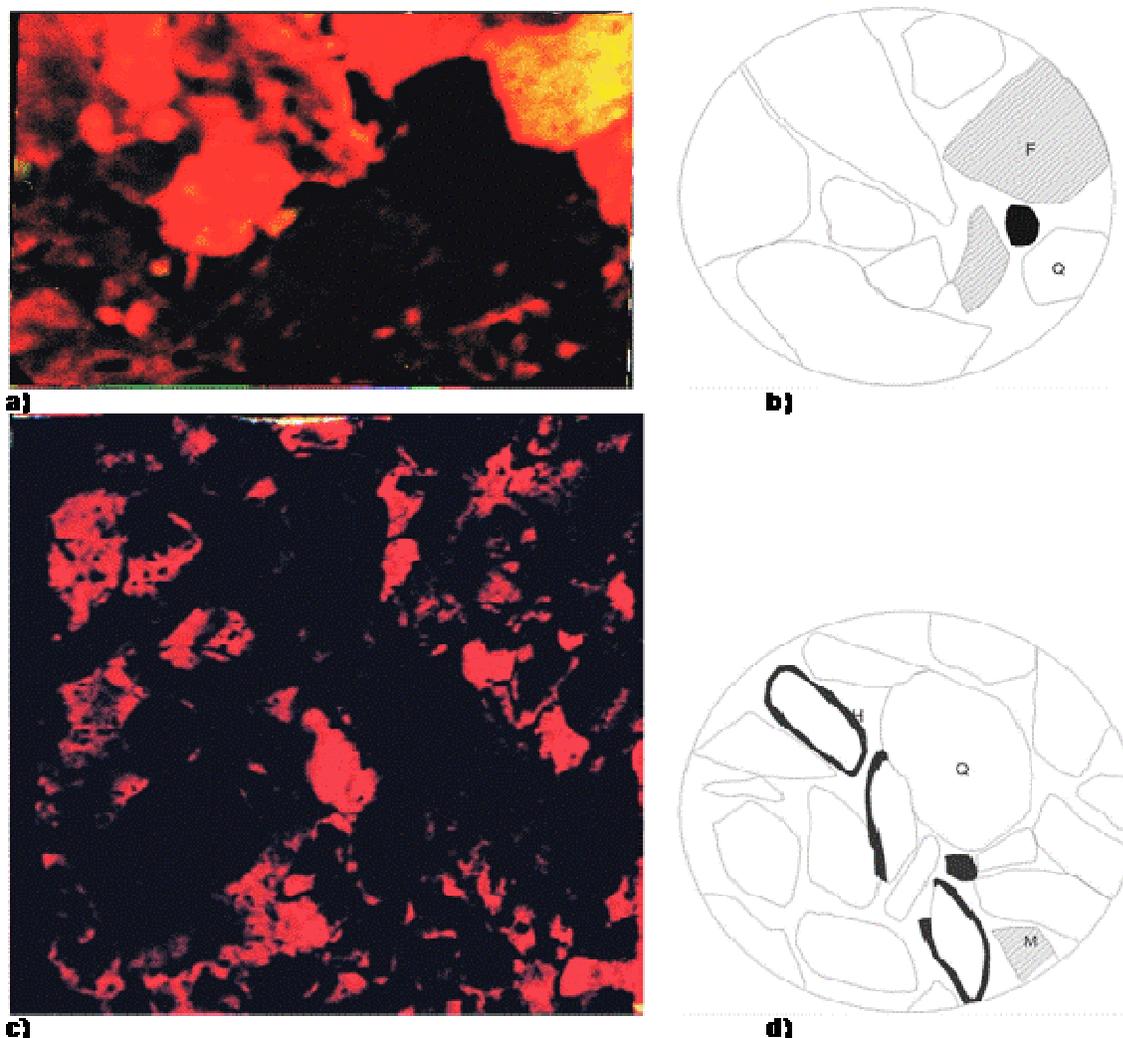


Figure 2. Photomicrographs and sketches of samples 1 as seen under the microscope. Magnification x40. b) Sketch of a) (sample 1) showing quartz feldspar, mica and possibly zircon. d) Sketch of c) (sample 2) showing quartz overgrowths and haematite coatings around quartz grains.

by marine sequences of Dukul, Jessu, Sukuliye, Numanha and Lamja Formations, with the Lunguda Basalt capping the sequence in the area. The Yolde to Lamja Formations were together regarded as marine sequences in this study. This study was carried out on the Bima₃ (B₃). Therefore, any mention of Bima sandstone in this paper hitherto, refers to the Bima₃ Formation only.

METHOD OF STUDY

Two areas (Yola and Guyuk) were selected for this study due to better exposure of the Bima sandstone. Each area was subdivided into a number of localities in which detail field observations and samples collection were made. In the northern part of the study area

four representative rock samples (sample 1, 2, 3 and 4) were selected, prepared into slides and petrographically studied under a petrographic microscope equipped with a camera. Because of poor photographic quality, each sample slide was also sketched, as appear under the microscope. The samples (Sample 16, 17 and 23) collected in the southern part of the study area were subjected to compositional and textural analyses.

RESULTS

Results of the field observations and sample analyses from the northern part of the study area shows that sample 1 (Fig. 2a) appears to be sub-arkosic containing about 75% quartz with about 25% orthoclase.

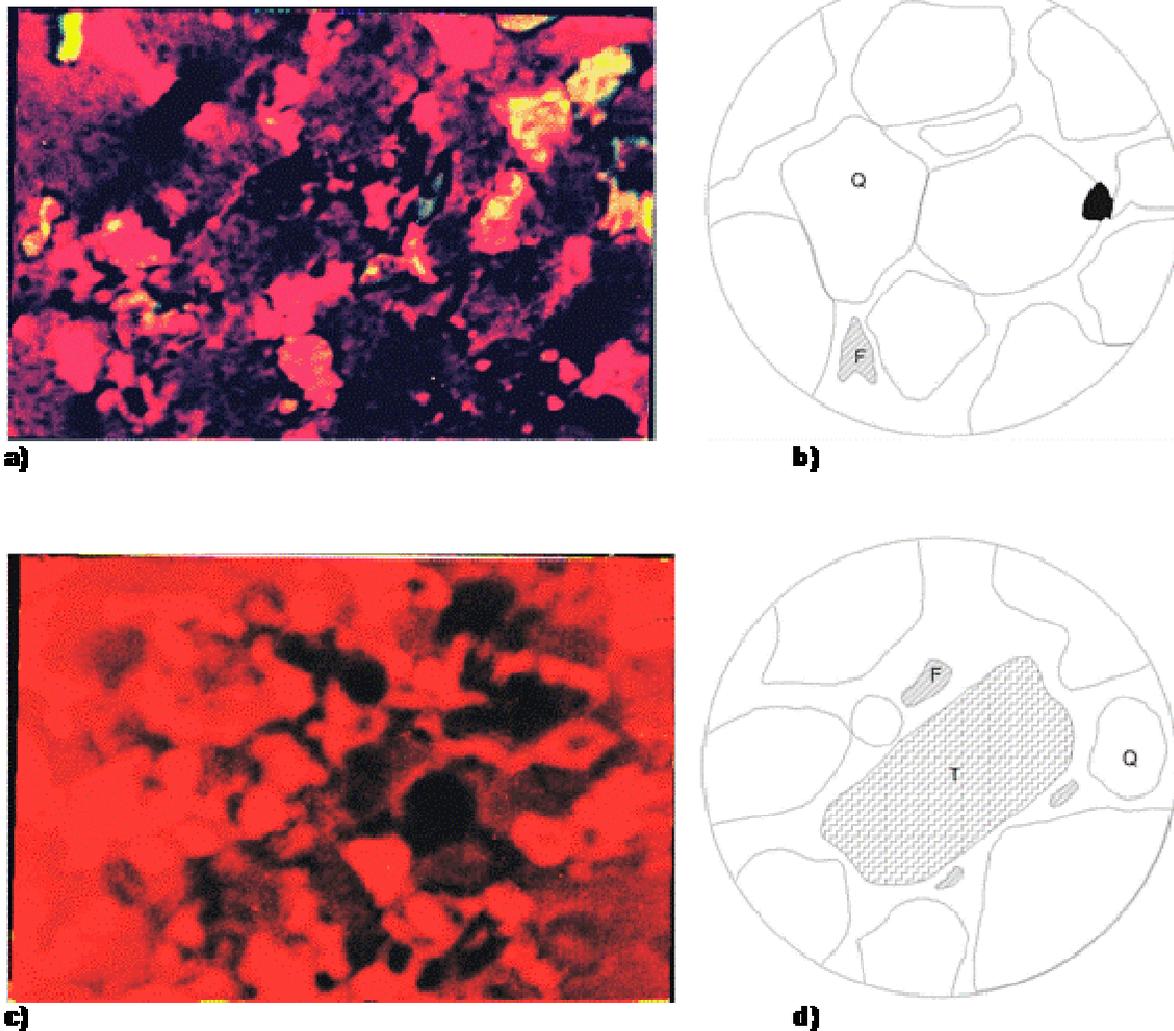


Figure 3. Photomicrographs and sketches of samples 3 and 4 as seen under the microscope. Magnification x40. b) sketch of a) (sample 3) showing fairly rounded quartz grains with tangential, line and point grain contacts. d) sketch of c) (sample 4) showing Tourmaline with poor cleavage partings surrounded by detrital quartz and feldspar grains.

It also contains iron oxide whose reddish colour is suggestive of haematite. The boundaries between the grains are characterised mostly by tangential contacts with few sutured contacts. The grains are poorly sorted.

Sample 2 (Fig. 2c) contains about 98% quartz with orthoclase constituting only about 2% of the detrital fraction. The quartz is characterised by the presence of anhedral crystals with parallel extinction while the orthoclase mineral grains have subhedral crystal forms. The boundaries between the grains are characterised by interpenetrate contact which gave indication of diagenetic process that took place after deposition. The grains were moderately sorted and well rounded. Sample 3 (Fig. 3a) contains about 95% quartz with only about 5% orthoclase. It also contains iron oxide and appreciable matrix with kalsinite as the only recognisable matrix

mineral. The inter-grain boundaries are characterised mostly by floating contacts with few concavo-convex contacts. The grains are sub-rounded to round.

In sample 4 (Fig. 3c), quartz (about 98%) dominate orthoclase (about 2%). Though both quartz and orthoclase have low relief, the quartz is anhedral in form while orthoclase is subhedral. Inter-grain boundaries are characterised by sutured contacts. The grains are rounded to well rounded.

In summary, the sandstone contains variable proportions of quartz, orthoclase, iron oxide, clay matrix minerals and no angular or rock fragments. The quartz (over 95%) predominate over all other minerals in the sandstone. The inter-grain boundaries are characterised wholly by interpenetrate contacts and the grains are well rounded.

Table 7. Summarised compositional and textural data of Bima Sandstone south of study area (Albert, 1992).

Sample No.	Framework composition (%)		Texture (average)			Average cement composition (%)		
	Quartz	Feldspar	Mono/poly quartz grains	Concavo-convex and sutured grain contact (%)	Tangential grain contact (%)	Point grain contact (%)	Line grain contact (%)	(silica, clay, iron oxide)
16	99	1	2/5	31	8	24	37	11
17	100	-	7/1	27	-	12	61	4
23	91	9	6/7	20	11	27	44	16
Average	97	3	1.2	26	6	21	47	10

The compositional and textural data of the Bima sandstone in the southern part of the study area is summarised in Table 1 above.

All the samples, particularly sample 23, show good compositional and textural features. Sample 23 is sub-arkosic, containing about 91% quartz and 9% feldspars. But on the average, the percentage of quartz with respect to feldspar content is 97%. There are little or no rock fragments. For the quartz, the monocrystalline and polycrystalline grains have straight to strongly undulose extinction. However, the later have curved concavo-convex to sutured intra-grain boundaries. The polycrystalline grains contain 2 to 5 crystals. They are morphologically elongated or flattened and do not generally show parallel crystallographic orientation. Feldspars constitute 9% of the detrital fractions in samples 23 and 1% in sample 16. On the average, the feldspar content is 3%. Microcline appears more common, but plagioclase and orthoclase grains are present and are extensively altered. Mica, as muscovite is present in minor amounts. The observed non-opaque heavy minerals include zircon, rutile, garnet and tourmaline. ilmenite seem to be present but in negligible amounts. There is very little matrix in all the samples. In sample 23 however, the matrix is more prominent than in the other samples. Recognised matrix minerals include quartz, feldspar and clay minerals. According to Pettijohn's (1973) classification, the Bima sandstones in the study area are, on the average, quartz arenites.

Texture

Results of textural analysis in both the northern and southern part of the study area shows that the grains of framework detritus range in size from coarse to fine sand sizes on the average. The grains are mostly subrounded and moderately sorted. The study reveals that line, tangential, concavo-convex and sutured grain contacts are common. On the average however, the line (long) contacts (47%) predominate followed by concavo-convex and sutured grain contacts (26%). Based on the above results, the Bima sandstone in the study area are

texturally and mineralogically mature (Folk, 1968; Friedman, 1967).

Cement materials constitute a significant proportion in some of the samples, ranging from 4% in sample 17 to 16% in sample 23, with an average of 10% on the total samples studied. At least 3 different types of cement were recognised and these include, in order of abundance, iron oxide, silica and clay minerals. The iron oxides (haematite/limonite) occur mostly as clots between grains and as evading around sand grains where grains are not in contact, indicating a diagenetic origin. Textural relations suggest that it either formed before silica or was contemporaneous with it. Silica cement is present especially in sample 17 in the form of microcrystalline to crystalline aggregates in pores and as syn-axial overgrowth on silica grains. The quartz overgrowths are more common in sample 17 and appear as the first authigenic precipitate. The clay minerals occur in some samples as unoriented microcrystalline aggregates. They appear to succeed silica precipitation in paragenetic sequence. However, some of the clay occurs at contacts indicating detrital origin. They must have been deposited along with other framework aggregates. The dominant clay is kalsinite.

DISCUSSION

Provenance

The relationship between the major detrital constituents of sandstone (quartz feldspar and rock fragments) not only measures compositional maturity, but also reflects provenance of material and even distinguishes between deep-seated and supracrustal provenance (Pettijohn, 1975). Other indicators of provenance include some features of quartz grains such as the crystallinity (whether polycrystalline or monocrystalline) and extinction properties under cross polars (Tucker, 1981).

The predomination of quartz over orthoclase (feldspar) and the absence of lithic fragments in the sandstone in the northern part of the study area (Fig. 4) indicate supermaturity (Pettijohn, 1975). Supermature

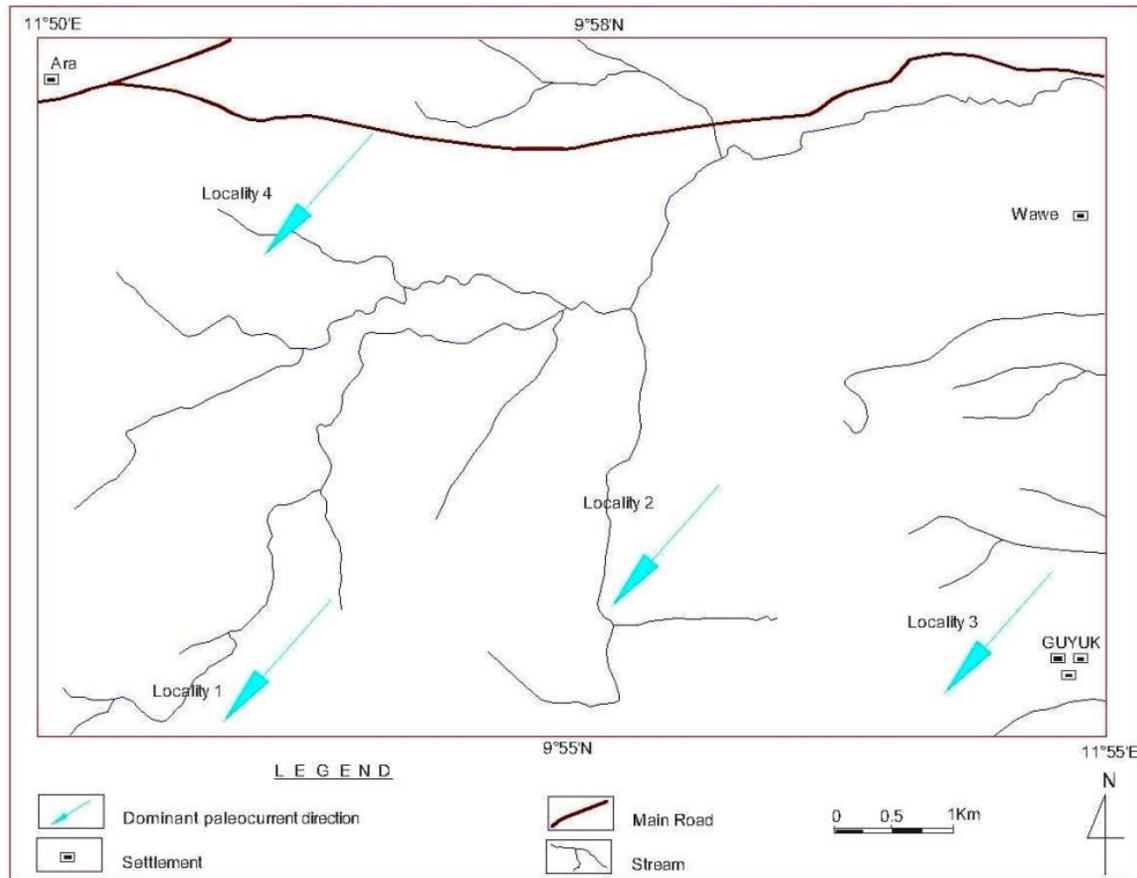


Figure 4. Dominant paleocurrent direction in the northern part of the study area (Haruna, 1997).

sandstone arises from long distance transport and much reworking and therefore provides less evidence of the provenance of sandstone (Tucker, 1981). However, the presence of anhedral and subhedral crystal forms with parallel extinction is indicative of a granitic source (Folk 1968). The formation of haematite requires an oxidizing condition (Tucker, 1993). The presence of iron oxides (haematite in sample 1 and 3) is therefore suggestive of deposition in continental environment or post depositional alterations.

The interpretation of the orthoquartzitic Bima sandstone in the northern part of the study area shows a granitic provenance. This is supported by textural parameters, which indicate protracted weathering, transport from a granitic source and deposition under continental conditions.

In the southern part of the study area (Fig. 5) however, the abundance of quartz and the relative absence of labile minerals (feldspar) and lithic fragments in the sandstone is suggestive of reworked rather than primary source (Tucker, 1981). The only indication of primary source is in sample 23 collected near the bridge at Vinikilang, which contains about 9% feldspar and very little rock materials. The predominance of quartz over

feldspar might also be due to long period of transportation (Pettijohn, 1975). The absence of inclusion-free anhedral quartz grains and volcanic rock fragments in the samples indicate a non-volcanic source (Tucker, 1981).

The presence of numerous Polycrystalline quartz, common undulose quartz extinction and feldspar, though in small amount and zircon favours a plutonic granitoid source as the dominant source rock (Pettijohn, 1975). The heavy mineral assemblage (zircon, tourmaline and rutile) of these rocks in the samples support this contention. The presence of garnet, which is a metamorphic mineral, suggests contribution from metamorphic source. This is supported by the fact that the majority of the quartz grains in sample 17 are elongated or flattened rather than equant.

The composition of the Bima sandstone (quartz arenites) in this part of the study area is interpreted in this work to reflect provenance, relief, transport distance and possibly low rates of sedimentation rather than a reworked source. The characteristics of the sandstone (sub-rounded framework grains; more quartz than feldspar; predominance of microcline and presence of muscovite; more monocrystalline quartz grains; less or

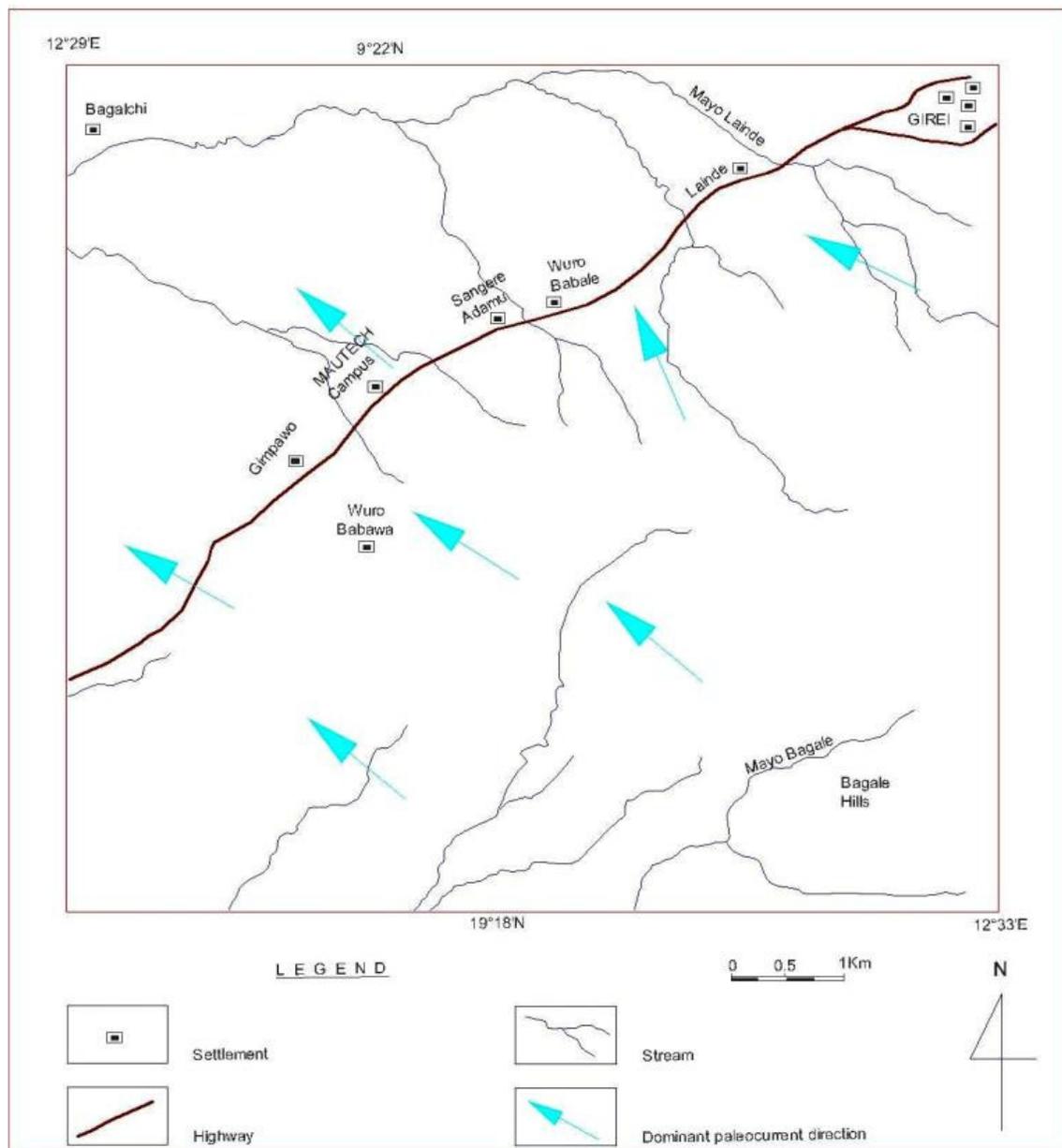


Figure 5. Dominant paleocurrent direction in the southern part of the study area. (Albert, 1992).

near absence of rock fragments) indicate longer distance transport and possible low rate of deposition.

Paleoclimatic Setting

The basis for the possible paleoclimatic interpretation of the source area is the detrital clay mineral composition (predominantly kalsinite) of the Bima sandstone. Clay minerals are formed by the alteration and replacement of other silicate minerals such as feldspars and micas, and direct precipitation (Tucker, 1981). The degree of leaching and the pH - eH of the soil water are the two

main factors controlling clay minerals formation, and stability and both factors are largely determined by climatic conditions. The presence of abundant kalsinite in the study area is typical of acid tropical areas where leaching or alteration is intensive. The paleoclimatic setting of the source area is the humid tropics, where weathering of feldspars is intense.

Paleotectonic Setting

During the evolution of the Benue Trough, thermotectonic doming and rifting associated with high heat flux resulted

in a bulge (high relief) of the marginal basement blocks to the trough (Ofoegbu et al, 1990; Ofoegbu and Unsaha, 1990). The uplifted marginal blocks must have been eroded and re-deposited in the rift valley. This period of uplifting was followed by a gradual subsidence of the blocks until equilibrium (low relief) was reached. Ofoegbu et al (1990) contended that this cycle was repeated several times.

The composition of the sandstone suggests a relatively low source relief and long distance (approximately 70-100km) of transport. This means therefore, that the sediments were shed from their source after the basement rocks had equilibrated and of relatively low relief.

The contention is supported by the early Cretaceous tectonics of the Benue Trough and its marginal basement rocks (Olade, 1978, Ofoegbu, et al; 1990; Nwajide, 1990).

CONCLUSION

Petrography of Bima sandstones from Yola and Guyuk areas of the Upper Benue Trough points to the crystalline borderlands of the Upper Benue Trough such as the Hawal, Mandara, Adamawa and Cameroon Massifs or their remote extensions as the most probable source of Bima sandstone. For the composition and texture of these crystalline borderlands were found to be concomitant with the ones discovered in this study. The Adamawa, Cameroon, Mandara and Hawal Massifs, like most Precambrian to lower Paleozoic Basement Complex rocks of Northern Nigeria, consist mostly of migmatite gneisses, metasedimentary and granitoid rocks (McCurry, 1976).

Bima sandstone was derived from the borderlands during period of tectonic quiescence, low relief and in a humid tropical climate that enhanced rapid weathering of the rocks. The weathered products were worked by minor streams and piled in alluvial plains and fans, which were further, reworked by meandering streams and intermittent shallow marine inundations at the central part of the trough. Hence the fluviodeltaic origin of Bima sandstone is hereby confirmed.

Other physical observations made in the field, show that the sediments were transported in an obliquely convergent manner from the marginal areas toward the center and southwestwards in the area of the trough. This observation is in line with that of Braide (1990), using facies architecture models of the Bima sandstone in the Yola arm.

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