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Dear Editorial Manager,

I am enclosing herewith a manuscript entitled "*Geochemical and mineralogical study of the Cretaceous Sediments in Keri-Keri, Fika, Gongila, and Bima sandstone formation Bornu Basin, North-Eastern Nigeria*" for publication in the editorial manager for possible evaluation.

This work reflects research on deciphering possible mineralization in the Chad (Bornu) Basin to its role in mineral exploration and exploitation. My research corroborates previous studies indicating that the Kanadi-well has some economic mineral deposits such as; Barite, albite feldspars, and kaolinitic that could be exploited.

I believe this submission will be useful to your readers, as it addresses some critical methodologies for discovering economic minerals. The research stands to benefit students researching Earth Science Studies.

I believe this submission will be useful to your readers, as it addresses some critical methodologies for discovering the depositional environment of the study area. This manuscript has been submitted to sedimentary geology journal. The current version is a preprint which has not yet been peer reviewed. Subsequent versions of this manuscript may have slightly different content. If accepted, the final version of this manuscript will be available via the 'Peer-reviewed Publication DOI' link on the right hand side of this webpage"

GEOCHEMICAL AND MINERALOGICAL STUDY OF THE CRETACEOUS SEDIMENTS IN KERI KERI, FIKA, GONGILA, AND BIMA SANDSTONE FORMATION BORNU BASIN, NORTH-EASTERN NIGERIA

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Abstract

The mineralogical and geochemical composition of Cretaceous and Tertiary sediments of the Bornu Basin, northeastern Nigeria penetrated by Kanadi Wells, have been studied towards deducing aspects of their derivation and deposition. The sediments comprising the Bima Sandstone Formation, sandy-shale Gongila Formation, and, clayey and shaley Fika Formation are mainly composed of quartz (35-58%) and kaolinitic clay (0-50%) with the quartz sympathetically decreasing up the succession. The basal Bima Sandstone Formation is notably arkosic with 25% albite feldspars. A significant abundance (15-25%) of barite also characterized the sandy units of the Bima and Fika Formations. The SiO_2/Al_2O_3 ratios of 5 to 6 underline the general sandy nature of the sediments while the calcareous nature of Bima and Gongila Formation has reflected in their higher $(NaO+K_2O)/(MgO+CaO)$ ratios of 1 to 2. In addition, the occurrence of significant 2-3% SO_3 constituents showed the important occurrences of barite in the Bima, Gongila, and lower parts of, Fika Formations. The sediments are mostly shallow water deposition in tropical-like paleoenvironment(s).

Keywords: Geochemistry, Mineralogy, Kanadi-Well, Bornu Basin

1. Introduction

The Nigeria sector of the Chad Basin, known locally as the Bornu Basin, is one of Nigeria's inland basins occupying the northeastern part of the country. It represents about one-tenth of the total area extent of the Chad Basin, which is a region of large structural depression common to five countries, namely, Cameroon, Central African Republic, Niger Chad, and Nigeria. The Bornu Basin falls between latitudes 11°N and 14°N and longitudes 9°E and 14°E, covering Bornu State and parts of Yobe and Jigawa States of Nigeria. The Chad Basin belongs to the African Phanerozoic sedimentary basins whose origin is related to the dynamic process of plate divergence. It is an intracratonic inland basin covering a total area of about 2,335,000 km^2 with Niger and Chad Republics sharing more than half of the basin. The basin belongs to a series of Cretaceous and later rift basins in Central and West Africa whose origin is related to the opening of the South Atlantic (Obaje *et al.,* 2004). In Nigeria, other inland basins of the same series include the Anambra Basin, the Benue Trough, the Mid-Niger (or Bida) Basin, and the Sokoto Basin. The Nigeria sector of the Chad Basin, known locally as the Bornu Basin represents about one-tenth of the whole basin. It constitutes the southern sector of the Chad Basin. The aim is to investigate the mineralogical and petrological composition of the sediment penetrated by the Kanadi well in the Chad (Bornu) Basin in Northern Nigeria.

1.1 Geology and Location of the Study Area

The Chad Basin Nigeria (Fig. 1) constitutes only 6.5% of the entire basin (Oteze & Fayose, 1988) and covers about 152,000km^2 of territory in Bornu, Bauchi, Plateau, and Kano states (Obaje *et al.,* 1999). The Bornu Basin falls between latitudes 11^0N and 14^0N and longitudes 9^0E and 14^0E

with the altitude ranging from 300m within the lake to about 240km. The studied Kanadi well is in the southeast of Maiduguri in Kanadi near Gajigana. The stratigraphic record reveals remarkably detailed pictures of ancient settings where sediments have accumulated. The constituents and depositional setting of a basin are a direct effect of the origin and the stratigraphic setting of that basin (Obaje, 1999). The geochemical and mineralogical play a key role in determining the source of the sediment, the oxide can also be used to delineate the lithological differences, and the element can suggest prevailing conditions during deposition. The rate of weathering and paleo-redox condition also plays an important role because they suggest the kind of condition in which the sediment was deposited.

The Nigeria sector of Chad (Bornu) Basin, which represents one-tenth of the total area extent of Chad Basin, is believed to be genetically linked with the Benue Trough, thus representing the northern border of a NE-SW trending aulacogen basin (Olaide, 1975) (Fig. 1). The Chad Basin is genetically and physically related to the fault and rift systems termed the West and Central African Rift Systems (WCARS), whose origin is generally attributed to the Cretaceous breakup of the Gondwanaland and the opening of the South Atlantic Ocean and Indian Ocean (Fairhead, 1986). The Benue-Chad axial Trough is believed to be the third and failed arm of the triple arm junction rift system that succeed in the opening of the South Atlantic during the early Cretaceous and the subsequent separation of the African and South American continents (Arbovbo *et al.,* 1986; Genik, 1992). A model of the tectonic setting of the Chad Basin, in general, was presented by (Genik, 1992).

1.2 Stratigraphic Setting

Sedimentation in the Bornu Basin began in the Albian with the deposition of a continental, sparsely fossiliferous medium to the coarse-grained feldspathic sandstone known as the Bima Sandstone (Mclennean, 1993). This formation rests directly on the Precambrian Basement Complex and it is composed mainly of sandstone and some shale intercalations (Carter *et al.,* 1963; Avbovbo *et al.,* 1986) (Fig. 2). The Bima Sandstone is conformably overlain by the Gongila Formation, which is composed of calcareous shale and sandstones, deposited in a shallow marine environment (Carter *et al.,* 1963) (Fig. 2). The deposition of this formation marks the beginning of marine transgression into the Bornu Basin (Carter *et al.,* 1963). The marine transgression which started in the Cenomanian reached its peak in the Turonian during which the bluish-black, ammonite-rich open marine Fika Shale was deposited, and this deposition continued into the Santonian (Carter *et al.,* 1963). Gombe Sandstone which contains intercalation of siltstone, shale, ironstone, and sandstone was deposited in the Maastrichtian and it unconformably overlies the Fika Shale. The Paleocene Kerri-Kerri Formation unconformably overlies the Gombe Sandstone and it represents the only record of Tertiary sedimentation in the Chad Basin (Adegoke *et al.,* 1978; Dike, 1993). In the Pleistocene and presumably during the Pliocene, the continental deposit of the Chad Formation was laid down on top of the Kerri-Kerri Formation (Carter *et al.,* 1963). Toward the end of the Tertiary and until recent times, widespread volcanic activities occurred in the South and Central part of the

Basin(Burke,1976).

2. Materials and Methods

Major and trace element analyses were carried out for clay samples using Inductively Couple Plasma- Optical Emission Spectrometry (ICP-OES) and X-Ray Fluorescence (XRF). With the ICP-OES (Optimal 2000DV), the elements analyzed were K, Al, Ca Mg, Fe, Mn, Ti, and P. The samples were at first ashed and 0.2 g of them were digested using concentrated Nitric acid (HNO3) and concentrated Hydrochloric acid (HCL). The samples were then introduced into the ICP-OES as a liquid medium and nebulized as an aerosol. The aerosol is dissolved, vaporized, and atomized, then excited and ionized to obtain characteristic atomic radiation from where the elements and their concentration were recorded.

In the XRF analysis, SiO_2 and Al_2O_3 were determined. Five grams (5g) of the pulverized samples were introduced into the X-Ray chamber of the minimal (Pan Analytical) XRF machine. The machine was calibrated and run having the results presented in the “result window” of the attached computer in weight percentage oxide (wt% oxide). The loss on ignition (LOI) was determined using a Carbolite furnace. One gram (1g) of the sieved samples of clay were transferred to crucibles and placed into a furnace that was set to 10000C for about one and a half hours. The samples were left in the furnace to cool, after which they were reweighed to determine the LOI.

3. Results and Discussion

3.1 Lithostratigraphy

The studied Kanadi-1 well which is southeast of Maiduguri in Kanadi near Gajigana contains marine and continental sediments comprising the Bima Sandstone Gongila Formation, Fika Shale Keri Keri, and Chad Formation (Table 1). The Keri Keri Formation has a restricted occurrence in the western part of the basin based on this study, hypo lecto and neo stratotypes (stratigraphic unit) are proposed for the Gongila Formation, Fika Shale, and the Chad Formation respectively (Fig. 3).

3.2 Mineralogy

The X-ray diffraction analysis carried out on the sediments sample of Keri-Keri, Fika, Gongila, and Bima formation from Kanadi-1 well, Bornu Basin shows the presence of Kaolinite as a clay mineral. The non-clay minerals in these samples include quartz, albite, barite, magnetite, zircon, and anatase (Fig. 4a-f).

The mineralogy generally indicated that Quartz has the least occurrence at KD 2 with values of 30 wt% and a maximum of 50 wt% at KD 12 and an average of 44 wt% for the study locality (Table 2). The minimum value of kaolinite was recorded in KD8 at 25 wt % and a maximum of 50 wt% at KD 2 with an overall average of 27.5 wt %. Other mineral occurrences were Anatase is absent in all samples except 8.00wt% in KD8, and Zircon is absent in all samples except 5.00wt% in KD4. Barite occurs ranging from 15.00 wt% at KD 6 to 25.00 wt% at KD 12 (Table 2, Fig. 5). Albite is absent in all samples except at KD10 where it occurs at a high value (25 wt%). The

sediments comprising the Bima Sandstone Formation, sandy-shale Gongila Formation, and, clayey and shaley Fika Formation are mainly composed of quartz (35-58%) and kaolinitic clay (050%) with the quartz sympathetically decreasing up the succession (Condie *et al.,* 1992). A significant abundance (15-25%) of barite also characterized the sandy units of the Bima and Fika Formations.

3.3 Geochemistry

The geochemistry of Sandstone of the (Keri-Keri, Fika, Gongila, and Bima) formation indicated a SiO_2 range of 60.20 wt % - 77.60 wt% with an average of 68.90 wt % (Table 3, Fig. 6). Al_2O_3 varies from 12.00 wt% - 18.24 wt% and averaged 15.12 wt %. Cao ranged between 0.76 wt % and 2.60 wt % with an average value of 1.68 wt %, whereas Na_2O occurs between 0.001 wt% and 1.60 wt%, with an average of 0.80 wt%. K_2O values range from 0.001 wt % to 1.32 wt % with an average of 0.66 wt %. F_2O_3 varies from 2.03 wt % to 12.20 wt % with an average of 7.10 wt %. MgO and MnO occur in subordinate concentrations with the MgO varying from 0.045 wt% to 1.00 wt% averaging 0.52 wt %, while MnO ranged from 0.001 to 0.25 wt% with an average of 0.13 wt % (Condie *et al.,* 1992; Kampunzu, 2005). TiO_2 occurs in traces and ranges between 1.38 wt% to 2.18 wt% averaging 1.78 wt%. The Loss on Ignition (LOI) ranges from 1.01 wt% to 5.10 wt% with an average of 3.1wt%. The basal Bima Sandstone Formation is notably arkosic with 25% albite feldspars. The SiO_2/Al_2O_3 ratios of 5 to 6 underline the general sandy nature of the sediments while the calcareous nature of Bima and Gongila Formation has reflected in their higher $(NaO+K_2O)/(MgO+CaO)$ ratios of 1 to 2 (Table 3). In addition, the occurrence of significant

2-3% SO_3 constituents showed the important occurrences of barite in the Bima, Gongila, and lower parts of, Fika Formations.

4. Conclusion

The relative concentration of the major oxide groups such as silica and alumina alkali oxides, iron oxide and magnesia has been used to classify the deposit. The cretaceous sediments are enriched in an authigenic mineral (Albite) which could mean that they originated either by the alteration of volcanic ash or by the temperature weathering of basic rocks. Albite occurs in Fika and Gongila formations.

The X-ray diffraction study used in the evaluation of the mineralogy of the Kanadi-1 well cretaceous sediments paved the way to the following conclusion: Sediment from Kanadi-1 well is quartz, followed by Kaolinite. Quartz and Kaolinite occur in all the formations. Barite and Albite abundance in the sediments shows a high terrigenous influence and delineated nearsource**.**

Declarations

Author contribution statement

Mafimisebi O. Peter Contributed materials, analysis tools, or data; Wrote the paper and Lateef Ogedengbe Lateef Contributed materials, analysis tools, or data.

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Competing interest statement

The authors declare no conflict of interest

Additional information

No additional information is available for this paper.

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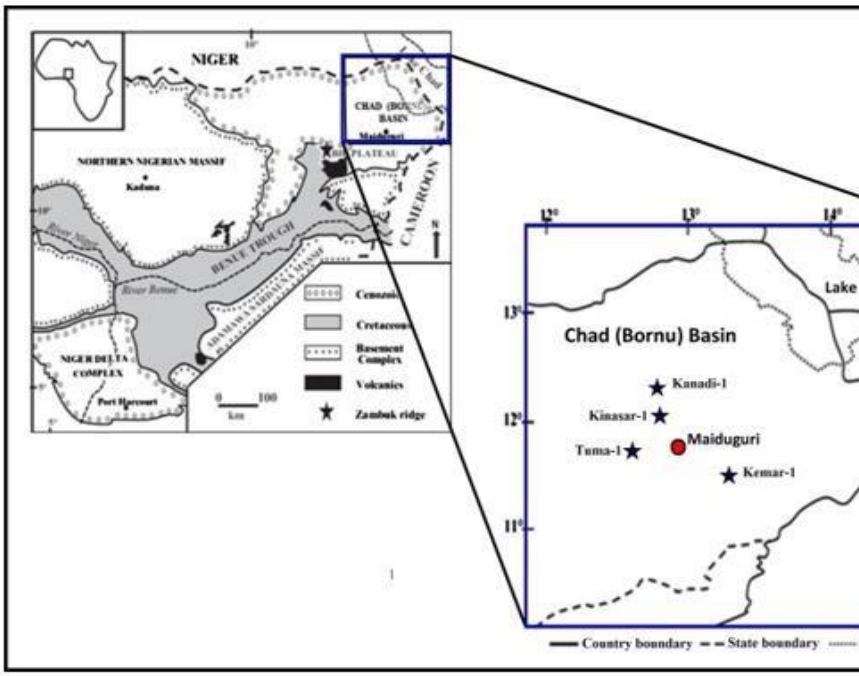

NIGER
NORTHERN NIGERIAN MASSIF
Kaduna
BENUE TROUGH
River Benue
NIGER DELTA COMPLEX
Port Harcourt
CAMEROON
Cenozoic
Cretaceous
Basement Complex
Volcanics
Zambuk ridge
0 100 km
12°
13°
14°
13°
12°
11°
Chad (Bornu) Basin
Lake
Kanadi-1
Kinasar-1
Tuma-1
Maiduguri
Kemar-1
Country boundary
State boundary

Figure 1

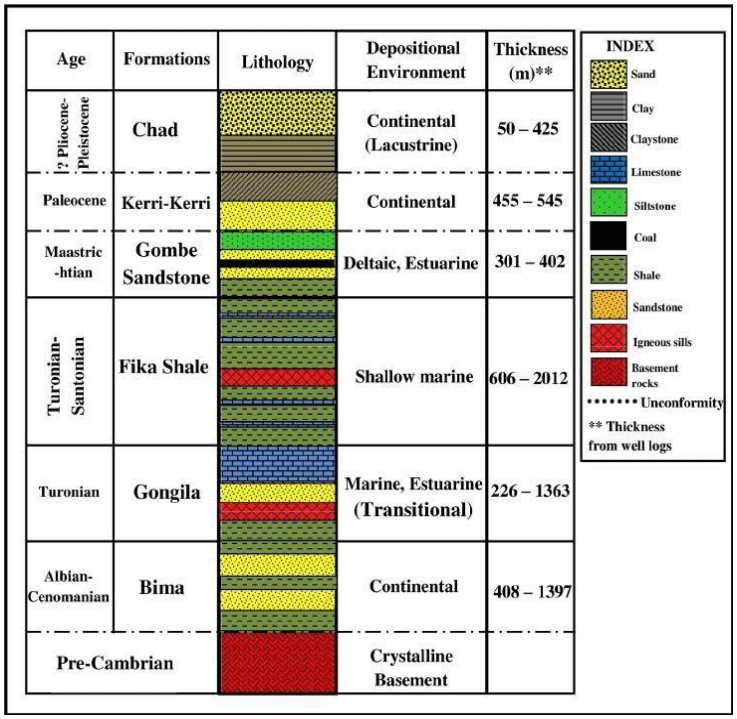
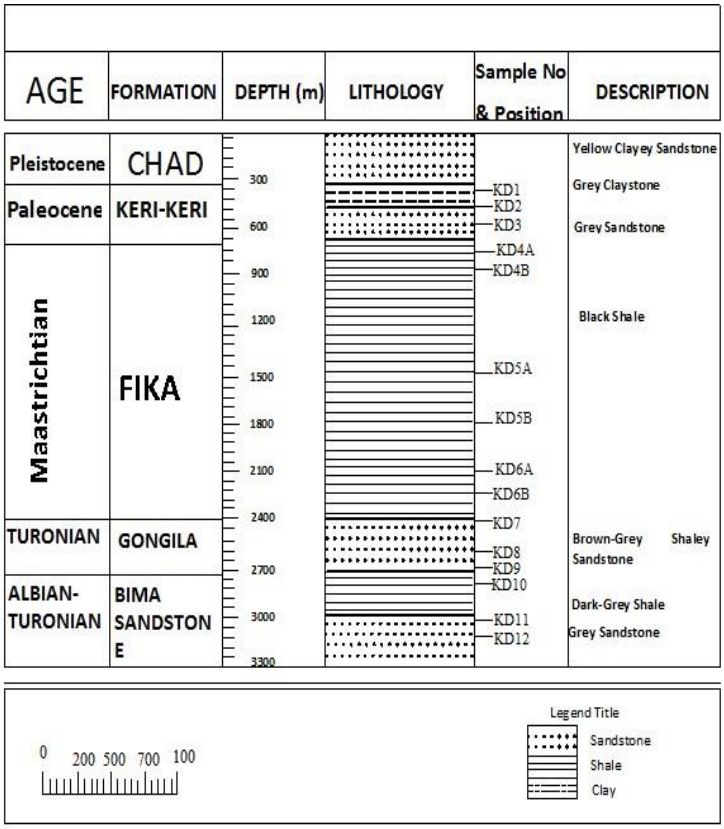
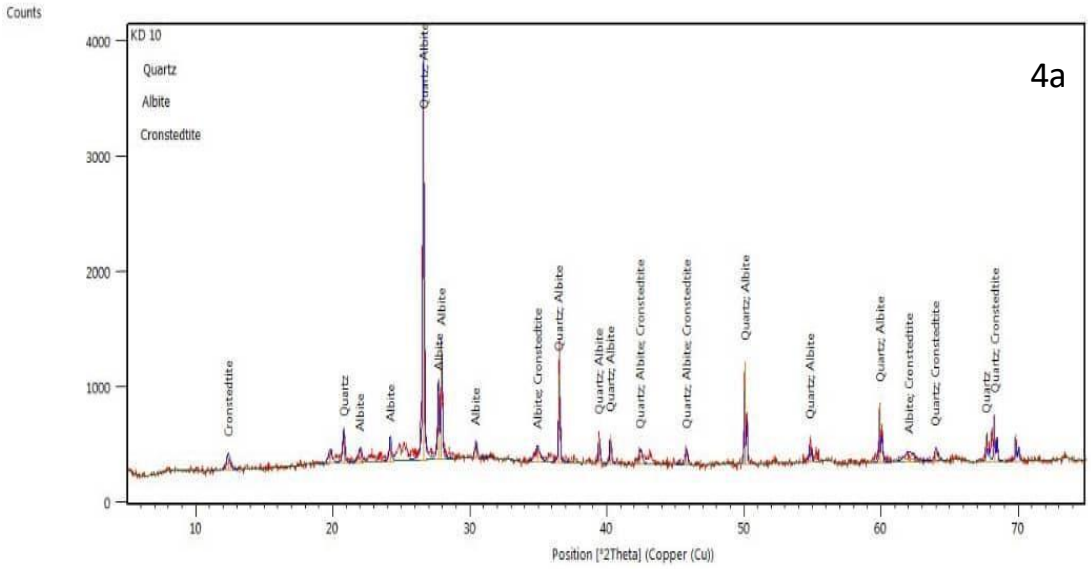

Age
Formations
Lithology
Depositional Environment
Thickness (m)**
? Pliocene-Pleistocene
Chad
Continental (Lacustrine)
50 – 425
Paleocene
Kerri-Kerri
Continental
455 – 545
Maastric-htian
Gombe Sandstone
Deltaic, Estuarine
301 – 402
Turonian-Santonian
Fika Shale
Shallow marine
606 – 2012
Turonian
Gongila
Marine, Estuarine (Transitional)
226 – 1363
Albian-Cenomanian
Bima
Continental
408 – 1397
Pre-Cambrian
Crystalline Basement
INDEX
Sand
Clay
Claystone
Limestone
Siltstone
Coal
Shale
Sandstone
Igneous sills
Basement rocks
Unconformity
** Thickness from well logs

Figure 2

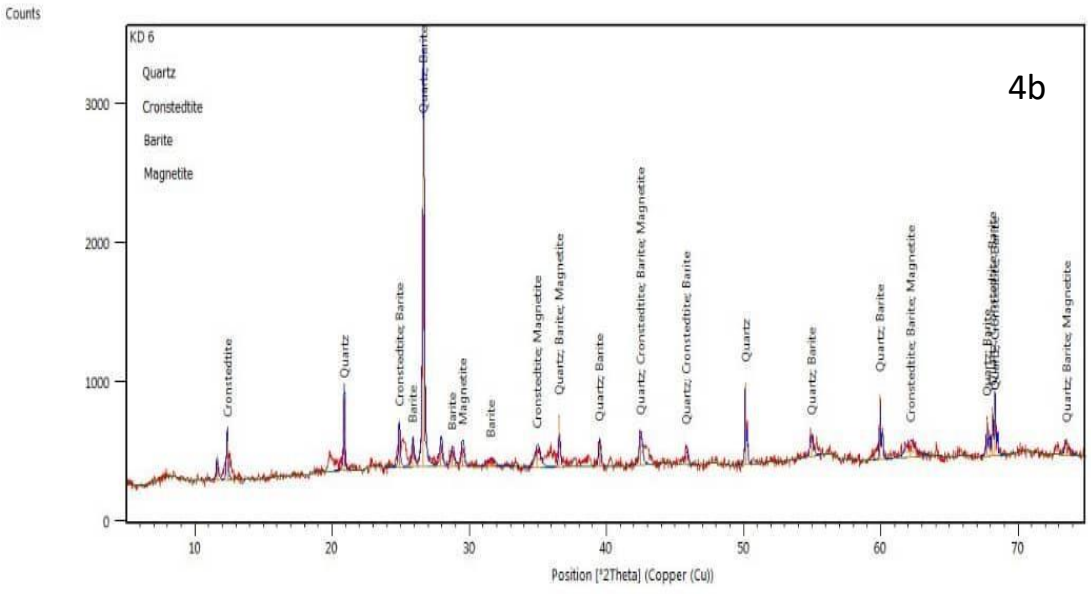


232 Figure 3

233



235 Figure 4a



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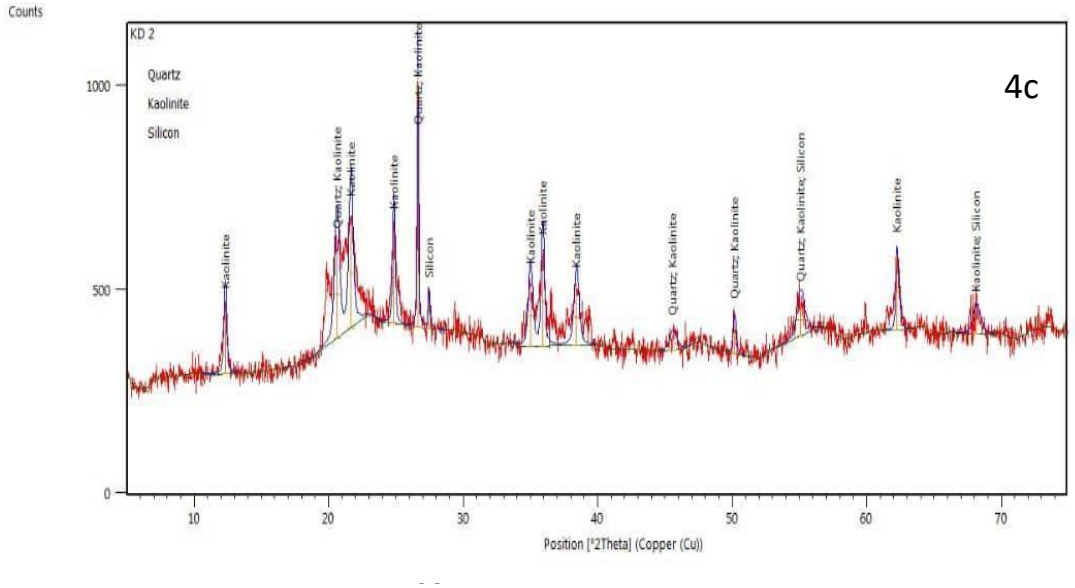

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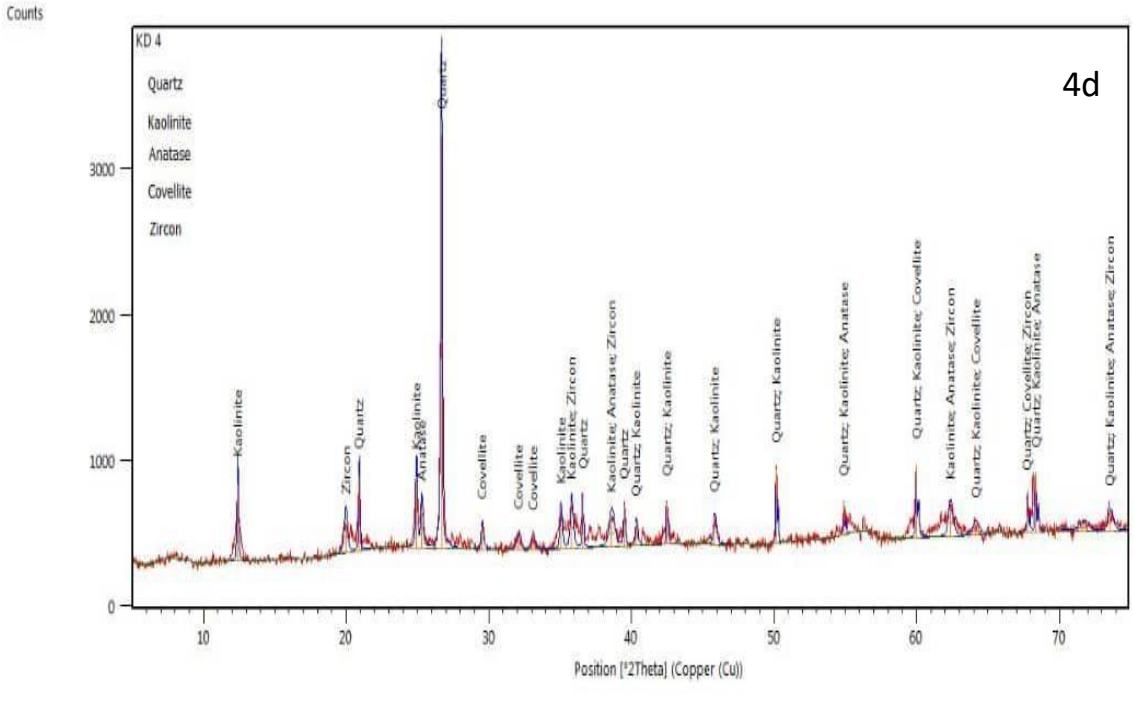

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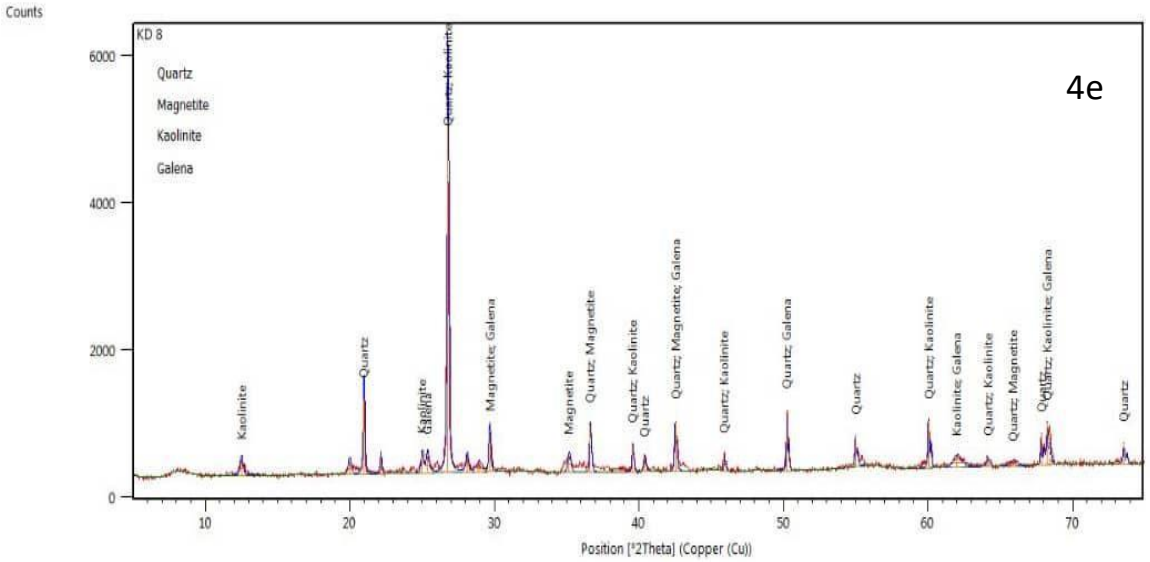

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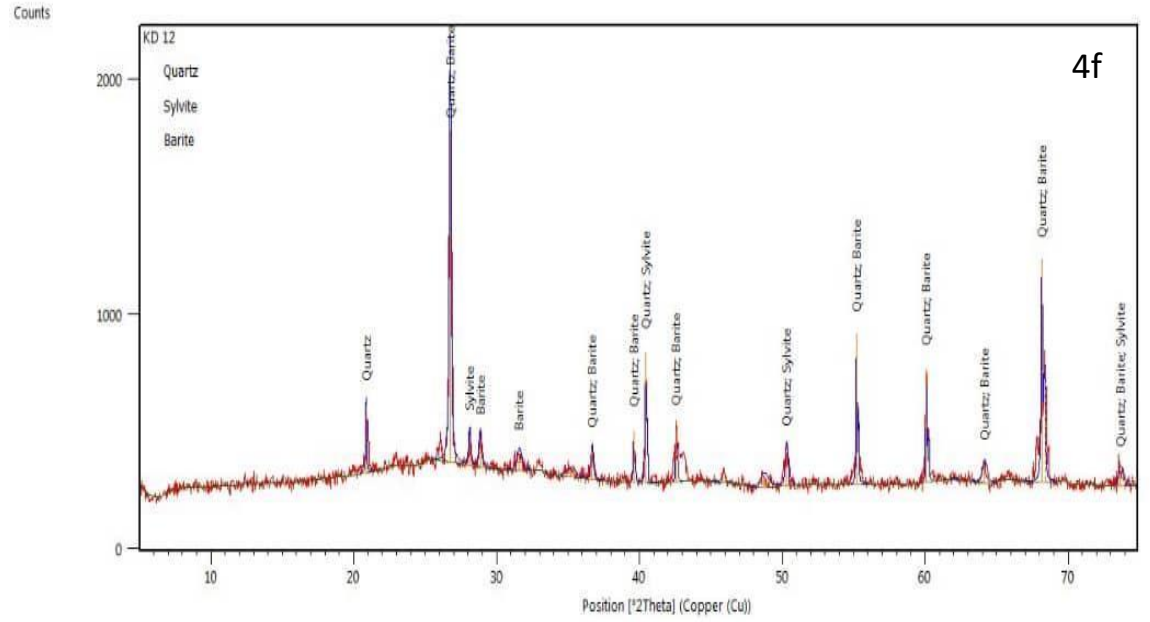

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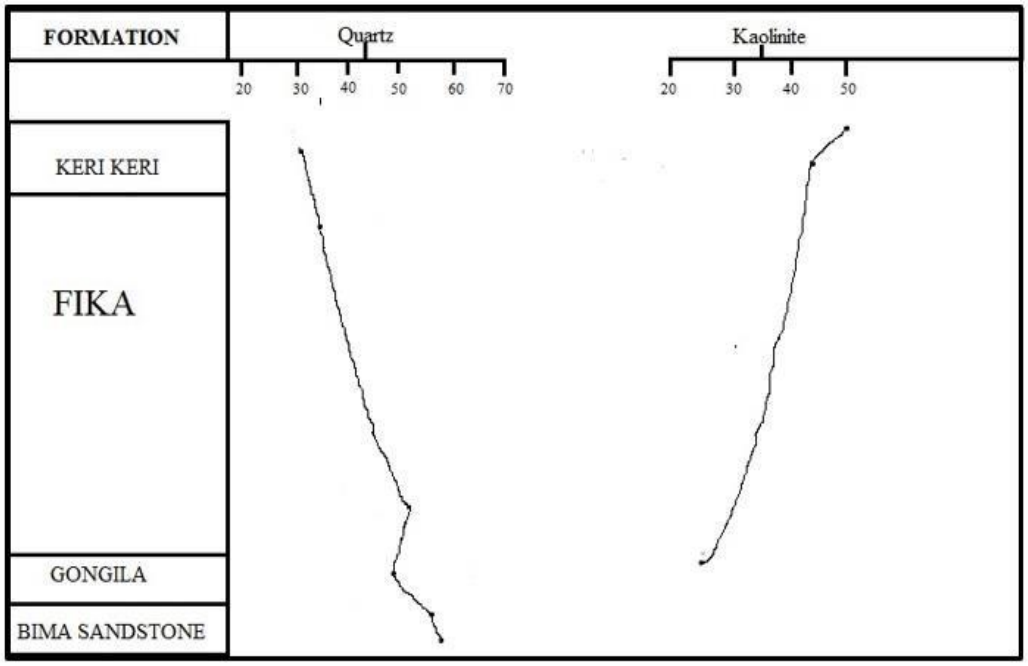
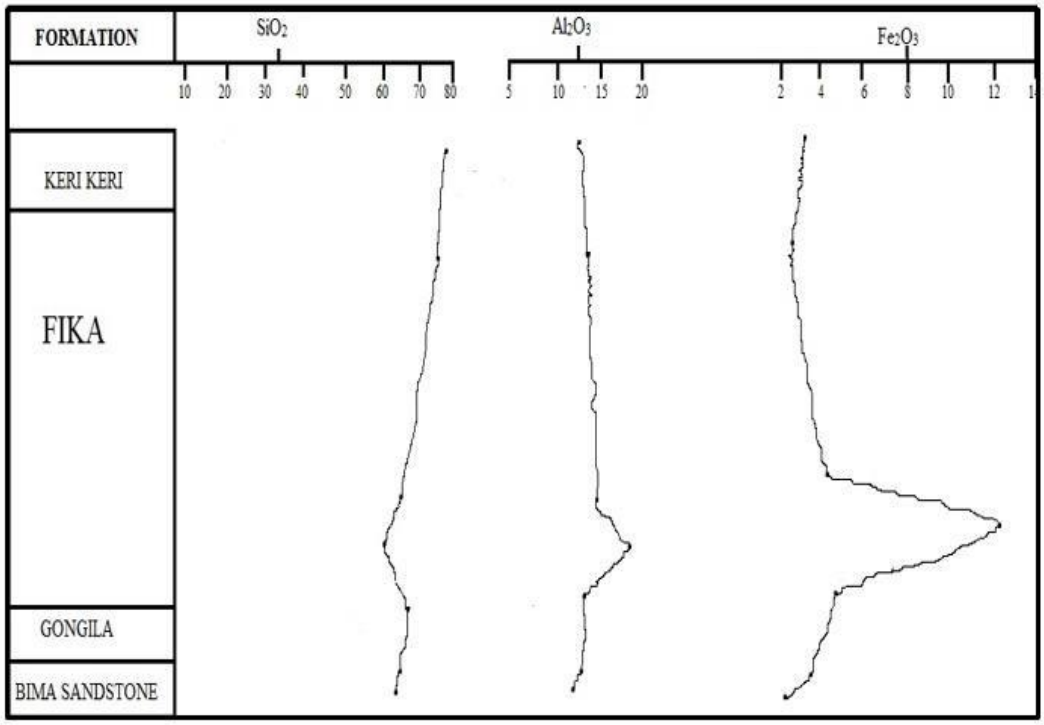


247 Figure 5



249 Figure 6

252

253 **Table 1**

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Sample	Depth(m)	Formation	Lithostratigraphic Description
KD 2	400-650	Keri Keri	Grey claystone
KD 4	700-1500	Fika	Black shale
KD 6	2000-2325	Fika	Black shale
KD 8	2625-2700	Gongila	Brown-greyshaley sandstone
KD 10	2775-3000	Bima Sandstone	Dark grey shale
KD 12	3150-3400	Bima Sandstone	Grey sandstone

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256

257 **Table 2**

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S/N	KD 2	KD 4	KD 6	KD 8	KD 10	KD 12
Quartz	30	35	52	50	56	58
Kaolinite	50	44	__	25	__	__
Anatase	__	8	__	__	__	__
Zircon	__	5	__	__	__	__
Barite	__	__	15	__	__	25
Magnetite	__	__	5	10	__	__
Albite	__	__	__	__	25	__

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Table 3

Sample No	KD 2	KD 4 A	KD 5	KD 6	KD 8	KD 10	KD11
Formation	Keri Keri	Fika	Fika	Fika	Gongila	Bima Sandstone	Bima Sandstone
SiO_2	77.60	76.10	67.40	60.20	67.70	67.20	67.30
TiO_2	2.18	1.80	1.87	2.07	1.53	1.72	1.38
Al_2O_3	13.00	13.64	14.30	18.24	13.30	13.02	12.00
Fe_2O_3	3.41	2.35	4.38	12.20	4.80	3.74	2.03
MgO	0.045	0.88	0.40	1.00	0.53	0.84	0.76
CaO	0.88	1.70	0.84	2.60	0.76	1.60	1.08
Na_2O	0.001	0.63	1.00	1.04	1.60	1.40	0.84
K_2O	0.001	0.50	1.60	1.06	1.00	1.32	0.76
MnO	0.001	0.12	0.001	0.075	0.25	0.13	0.11
SO_3	Nd	Nd	Nd	3.20	2.10	2.00	3.10
L.I.O	1.01	1.20	2.50	5.10	2.30	3.76	2.72
SiO_2/ Al_2O_3	5.97	5.58	4.71	3.30	5.09	5.16	5.61
$(Na_2O+K_2O)/(MgO+CaO)$	0.00	0.44	2.10	0.58	2.02	1.11	0.87

Nd: Not detected