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GEOCHEMICAL INVESTIGATION OF SOME ROCKS IN YELWA AREA OF MURI-LAU SUB-BASIN, NORTHERN BENUE TROUGH, NORTHEAST NIGERIA

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Abstract: ***Geological mapping of the Yelwa area revealed that the area is composed of sedimentary and volcanic rocks. The sedimentary rocks are categorized into Bima, Yolde and Dukul Formations whereas the volcanic rocks consist of basalt and phonolite. The limestone unit of the Dukul Formation host recrystallized calcite at six different locations. Geochemically the limestone is enriched in lime (CaO) 47.78 wt% with depletion in all other oxides such as silica (Si_2O) 8.02 wt%, alumina (Al_2O_3) 2.64, total iron (Fe_2O_3) 2.66 wt%, magnesia (MgO) 0.72 wt%, soda (Na_2O) and potash (K_2O) 0.26 wt%. The high lime (CaO) content coupled with low magnesia (MgO) content indicate that the rock is limestone with no dolostone and can be utilized for the production of Portland cement. The phonolites have average values of silica 58.65 wt%, alumina 19.91 wt%, total iron 3.36 wt%, soda 6.76 wt% and potash 5.46 wt% suggesting intermediate rock on account of silica saturation. The plots of major and trace elements strongly indicate that the rocks are phonolitic and have originated from a calc-alkaline magma. This study showed that the limestone from the Yelwa area of Muri-Lau sub-Basin in Northern Benue Trough can be used for the production of Portland cement.***

Keywords: Calcite, Limestone, Phonolite, Geochemical, Yelwa, Nigeria.

1. Introduction

The area of study is located between latitudes 9° 34'N to 9° 40'N and between longitudes 11° 06'E to 11° 12'E which forms part of the Federal survey of Nigeria sheet 173 SW Kaltungo. The area falls around Yelwa in Shongom Local Government Area of Gombe state. Geologically the study area conforms with the geology of the Muri-Lau sub-basin of the Northern Benue Trough (Fig. 1). The Benue Trough is a major NE-SW striking rift basin which extends for greater than 1000 Km, starting from the northern tip of the Niger Delta in the south to the southern tip of the Chad basin in the north. Its width ranges from 50-150 Km containing up to 6000 m of Cretaceous-Tertiary sediments dotted by volcanic plugs (Carter *et al*., 1963). It is geographically sub-divided into three major domains: Southern, Central and Northern (Nwajide, 2013). The Trough is believed to have formed from extensional process of Africa and South America which occurred during late Jurassic to early Cretaceous (Olade, 1975). Sinistral wrenching was believed to be the tectonic process responsible for the evolution of the Trough (Benkhelil, 1989).

The Northern Benue Trough is a Y shaped geological entity made up of three arms namely: the NE-SW striking Muri-Lau arm; the E-W striking Yola arm and the N-S striking Gongola arm (Dike, 2002; Shettima *et al*., 2018). In the Muri-Lau Arm, the Aptian-Albian Bima group, a continental formation represents the basal part of the sedimentary succession. It non-conformably overlies the Precambrian Basement Complex and consists largely of sandstones and clays series deposited in lacustrine-deltaic palaeoenvironmental setting. The Cenomanian Yolde Formation lies conformably on the Bima group and represents the beginning of marine incursion in the Muri-Lau sub-basin and consists of varieties of sandstones and shales. The marine formation comprises of Dukul, Jessu, Sekule, Numanha and Lamja were deposited during transgression-regression phase that affected the entire Benue Trough. The Lithology of all the marine sediments are characteristically similar consisting of sequences of shales, limetones, mudstones with few horizons of calcareous sandstones, siltstones and sandstones (Carter *et al*., 1963; Zaborski *et al*., 1997; Nwajide, 2013). This paper investigates the geochemical characteristics of limestone, calcite and phonolite in Yelwa area of the Muri-Lau arm of the Northern Benue Trough through major, trace and rare earth elements geochemistry.

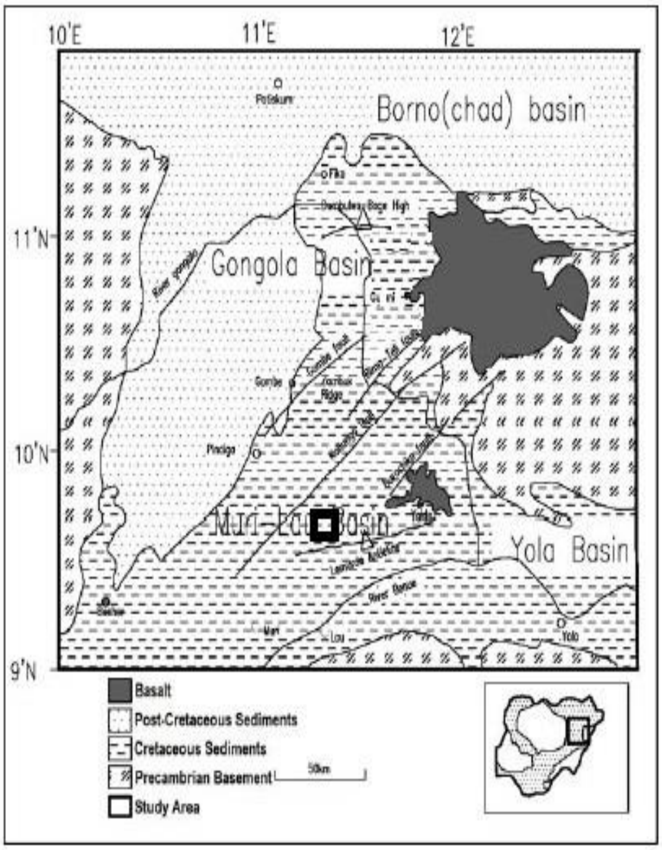

Figure 1: Geological map of the Northern Benue Trough showing the study area (Modified from Zaborski *et al*., 1997)

2. Materials and Methods

A total of nine (9) samples were selected for major, trace and rare earth element analysis using packages developed by ACMELABS, Vancouver, Canada. Samples analyzed include limestone, calcite and phonolite. The samples were subjected to total whole rock analysis employing the inductively couple plasma mass spectrometry (ICP/MS). The ICP/MS analysis, samples were broken to smaller fragments and packaged in a prescription nylon weighing 70 g – 80 g and sent for analysis. Each of the samples were crushed and then pulverized to atleast 85% passing through the 200 mesh size. Five grams (5g) each of the pulverized samples was fused with lithium metaborate/tetraborate which was rapidly digested in a weak nitric acid solution. The resultant solutions were used for the total whole rock analysis using the ICP/MS method.

3. Result and Discussion

The study area as shown in Fig.2 comprises of lithologic units such as Bima Sandstone, Yolde Formation, Dukul Formation, Basalt and Phonolite. Detail description of these rocks is given in Kamale and El-Nafaty (2019) and only description of the geochemically analyzed rocks is summarized here.

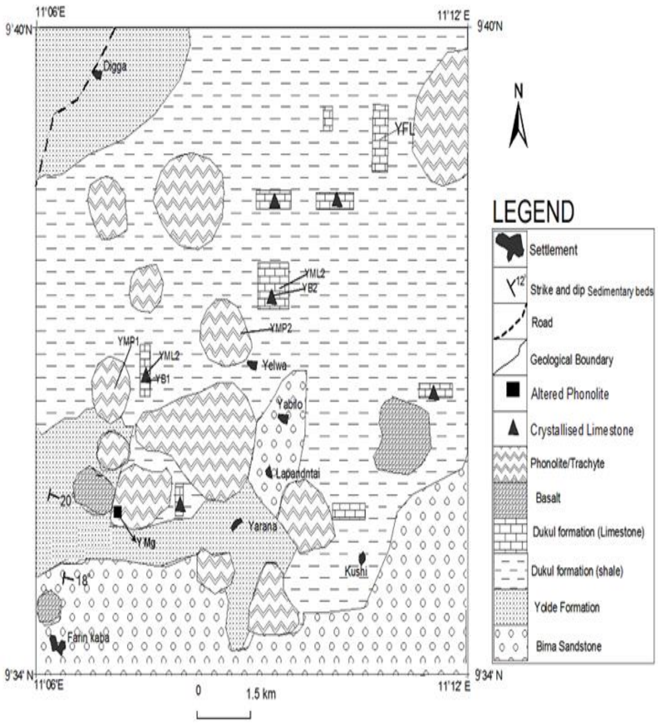

Figure 2: Geological map of Yelwa area

3.1 Limestone and Calcite from Dukul Formation

The limestone is made up of scattered loose slabs and blocks of varying dimensions in different locations within the shale. The limestone in some places forms continuous and extensive belts of more than 0.5km long, comprising of crystalline and fossiliferous varieties. Based on field observation the limestone is divided into three distinctive types: the crystalline varieties which are gray and brownish in colour and mostly occur in a belt that runs approximately in N-S direction for about 500m, the fossiliferous varieties that contains ammonites and bivalves, and a mixed variety that consists of large and small slabs and blocks of both crystalline and fossilliferous type similar to those reported by Coulon et al. (1996). In addition, recrystallized calcite portions which in most places appear plastered on the crystalline and fossiliferous limestone were encountered in six locations. Nwajide (2013) observed bands of re-crystallized calcite within shale and such clear calcite fringing limestone beds in Sekule and Lamja Formations. The calcite was believed to have been formed by heat of lava which melted the calcite in the limestone and carried it in solution. The calcite were later recrystallized and deposited on the limestone and rarely in small openings forming veinlets of recrystallized calcite this observation is similarly made by ealier workers in the Sekuliye Formation such as Carter *et al.* (1963); Nwajide (2013). The calcite is white in colour, massive and brittle material that is coated on top of the limestone (Plate 1), but some places it occur in form of veins of minor dimensions not exceeding 1m in length and 3.8cm in width, this occurrence is rare. It has hardness of 3-4 on Moh's scale with white streak and perfect cleavage in two directions and non-metallic lustre. The specific gravity ranges from 2.163 g/cm^3 to 3.810 g/cm^3. In all the areas no observable alteration zone was noticed.

Plate 1: Recrystallized Calcite, Limestone and Shale of Dukul Formation (N9^{o}36.694' and 11^{o}07.859')

3.2 Phonolites

The Phonolites are scattered in many locations of the Cretaceous sediments of the Yelwa area (Fig. 2). A total of 13 phonolitic plugs were mapped. The phonolites occur as outliers surrounded by older rocks including Bima, Yolde and Dukul Formations. The phonolites formed steep sided plugs (Plate 2) and hills, some of which exhibit columnar jointings which is very long and thin but poorly developed. Phonolite is generally gray in colour, dense, texturally it ranges from fine, through medium and porphyritic type in which feldspathoid phenocrysts in a groundmass of aegirine, nepheline and augite were observed in sample S55 (9^o 37.488'N; 11^o 08.106'E). Najime (2014) reported the occurrences of basalts, phonolites and trachyte in the Gboko area of the Middle Benue Trough having similar characteristics to the Yelwa phonolites.

Plate 2: Typical Plug of Phonolite (N9^{o}37.375' and E11^{o}09.132')

3.3 Geochemistry

The major, trace and rare earth element abundances of limestone and phonolite and their averages are presented in Tables 1 and 2.

Table 1: Major, Trace and Rare Earth Elements Composition of Limestone and Phonolite.

	Limestones					Phonolites			
Oxide (%)	YFL	YML1	YML2	YB1 (Calcite)	YB2 (Calcite)	YFP	YMP1	YMP2	YMg
SiO_2	7.23	9.57	7.25	5.38	2.34	57.63	55.62	55.72	65.64
Al_2O_3	2.16	3.32	2.10	1.86	0.55	18.27	20.35	20.40	20.61
Fe_2O_3	2.40	3.14	2.44	1.43	1.58	5.23	3.90	3.88	0.43
MgO	0.97	0.48	0.72	0.28	0.52	0.18	0.29	0.28	0.12
CaO	47.13	44.21	46.92	48.83	51.81	1.83	1.66	1.69	0.14
Na_2O	0.10	0.08	0.07	0.04	0.01	7.26	9.01	9.45	1.33
K_2O	0.29	0.19	0.30	0.10	0.02	5.51	5.45	5.45	5.43
TiO_2	0.11	0.19	0.11	0.09	0.03	0.28	0.42	0.43	0.04
P_2O_5	0.25	0.16	0.32	0.07	0.18	0.09	0.09	0.10	0.06
MnO	0.50	0.46	0.37	1.25	0.53	0.24	0.15	0.15	0.02
Cr_2O_3	n.d	0.003	n.d	n.d	n.d	n.d	n.d	n.d	n.d
LOI	38.7	37.7	39.3	39.7	42.3	3.2	2.8	2.2	5.9
SUM	99.91	99.90	99.93	99.91	99.93	99.79	99.77	99.79	99.74
Trace Elements (ppm)									
Ba	497	3261	513	7729	385	509	389	406	328
Sr	329	432.2	351.7	569.1	342.9	127.6	232.7	222.7	55.2
Rb	13.9	8.2	11.1	4.4	1.1	165.1	184.6	188.7	191.1
Sc	2	4	2	2	n.d	n.d	n.d	n.d	n.d
Be	n.d	n.d	1	n.d	n.d	5	7	5	5
V	12	24	11	9	13	8	8	9	8
Y	9.6	28.3	11.2	15.8	2.1	30.2	21.2	21.0	60.1
Zr	41.4	35.7	47.1	31.8	7.4	808.5	876.7	840.2	1171
Co	3.6	6.4	4.4	2.7	1.8	1.3	2.4	2.6	1.1
Ni	20	20	20	20	20	20	20	20	20
Cu	3.4	7.3	5.4	7.1	5.5	6.3	5.7	4.8	3.1
Zn	10	23	7	9	6	116	88	91	6
Ga	2.8	4	2.7	2.1	0.7	25.1	30	29.7	35.4
As	1	n.d	1.4	0.6	n.d	7.7	3.4	4	n.d
Se	1	0.7	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Nb	2.6	3.2	1.8	2.6	0.4	180.2	165.3	163.3	175.1
Mo	0.5	0.5	1.3	0.3	2.1	19.7	14.5	14.3	0.2
Ag	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Cd	n.d	n.d	n.d	n.d	n.d	0.2	0.2	0.1	0.1
Sn	10	n.d	n.d	n.d	n.d	3	3	3	7
Sb	n.d	n.d	n.d	n.d	n.d	0.2	n.d	n.d	n.d
Cs	0.4	0.4	0.3	0.1	n.d	3.1	2.3	2.2	0.2
Hf	1.1	1.0	1.1	0.8	0.2	15.9	14.9	15.1	24.2
Ta	0.2	0.3	0.2	0.4	n.d	11.9	9.9	10.3	19.9
W	n.d	n.d	n.d	n.d	n.d	3.0	3.8	4.7	2.7
Au	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Hg	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	0.03
Tl	n.d	n.d	n.d	n.d	n.d	0.2	0.2	0.1	n.d
Pb	4.8	6.5	4.3	8.2	2.4	11.1	13.4	12.7	8.1

Bi	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Th	2.8	3.2	2.2	1.9	0.5	21.1	27.7	25.9	38.3
U	1.1	0.8	0.9	0.4	0.6	5.9	8.5	7.6	4.3
Rare Earth Elements (ppm)									
La	16.1	29.5	14.1	13.6	3.9	118.7	100.2	97.9	180.7
Ce	27.3	54	26.6	25.3	5.7	202	146.1	137.7	288.4
Pr	3.12	7.24	2.94	3.31	0.56	19.57	12.60	11.51	26.56
Nd	12.4	32.5	11.9	14.6	2.4	60	36.4	33.3	81.6
Sm	2.23	6.44	2.07	2.64	0.40	8.21	4.75	4.67	12.15
Eu	0.47	1.60	0.46	0.71	0.10	1.71	1.09	1.14	1.15
Gd	2.06	6.14	2.12	2.97	0.38	7.02	4.20	4.02	10.04
Tb	0.29	0.88	0.29	0.39	0.05	0.99	0.59	0.60	1.74
Dy	1.59	4.36	1.67	2.12	0.26	5.60	3.69	3.35	9.75
Ho	0.32	0.77	0.33	0.39	0.06	1.05	0.71	0.67	1.95
Er	0.95	2.06	0.93	1.03	0.17	3.03	2.18	2.11	5.96
Tm	0.13	0.25	0.13	0.13	0.02	0.46	0.35	0.34	0.87
Yb	0.79	1.42	0.81	0.71	0.16	3.16	2.47	2.44	5.40
Lu	0.11	0.21	0.12	0.11	0.02	0.47	0.35	0.36	0.80
ΣREE	67.86	147.37	64.47	70.98	14.18	431.97	315.68	300.11	627.07
ΣLREE	63.68	137.42	60.19	63.13	13.44	417.21	305.34	290.24	600.6
ΣHREE	4.18	9.95	4.28	7.85	0.74	14.76	10.34	9.87	26.46

Note: YFL= Limestone; YML1= Limestone; YML2= Limestone; YB1= Calcite; YB2= Calcite; YFP= Phonolite; YMP1= Phonolite; YMP2= Phonolite, YMg= Altered phonolite. n.d = not detected.

Table 2: Average of major oxide composition of Yelwa, Ashaka and Gboko rocks

	This Study (Average)			This study	Gboko Phonolite (Najime, 2014)
Oxide (%)	Limestone (n= 3)	Calcite (n= 2	Ashaka Limestone (n=11) (AQL, 2017)	Phonolite (n=4)	Average (n= 3)
SiO_2	8.02	3.86	18.09	58.65	51.88
Al_2O_3	2.64	1.20	5.33	19.91	21.15
Fe_2O_3	2.66	1.51	1.99	3.36	4.63
MgO	0.72	0.40	0.55	0.22	1.06
CaO	46.09	50.32	38.99	1.33	2.74
Na_2O	0.083	0.03	0.25	6.76	9.29
K_2O	0.26	0.06	0.89	5.46	4.20
TiO_2	0.14	0.06	0.34	0.29	1.02
P_2O_5	0.24	0.13	0.30	0.09	0.21
MnO	0.44	0.89	0.32	0.14	0.15

3.3.1 Major Elements Composition of Yelwa Limestone

Lime contents in the Yelwa limestone ranges from 44.21 wt% to 51.81 wt% with an average of 46.09 wt%, which is much higher than the 38.99 wt% average for the Ashaka limestone. This shows that the Yelwa limestones are qualitative and can be used for the production of cement.

The silica contents of the limestones (n=5) of Yelwa area range from 2.34 wt% to 9.51 wt% and have average of 8.02 wt% while the Ashaka limestone (which is being quarried for the production of cement) has silica averaging 18.09 wt%. This indicates that the silica content in Yelwa limestone is less than that of Ashaka limestone.

Alumina contents in the Yelwa limestones vary from 0.55 wt% to 3.32 wt% with an average of 2.64 wt% whereas the Ashaka limestone has 5.33 wt% average indicating a lower alumina content of the Yelwa limestones.

The Yelwa limestones have Fe_2O_3 contents varying from 1.43 wt% to 3.14 wt% with 2.66 wt% average while the Ashaka limestone averages 1.99 wt%, suggesting that Yelwa limestone has higher iron content than the Ashaka limestone.

The alkalis (Na_2O and K_2O) in the Yelwa limestones have values ranging from 0.01 wt% to 0.10 wt% with an average of 0.08 wt% and 0.02 wt% to 0.30 wt% with average of 0.26 wt% respectively. Relative to the Ashaka limestone with 0.55 wt% and 0.78 wt% averages respectively, alkalis of the Yelwa samples are lower.

3.3.2 Trace Elements Geochemistry of Yelwa Limestone

The most important trace elements in the limestone are the Ba, Rb and Sr.

The Ba contents in the limestone (n=5) (Table 3) vary from 385 ppm to 7,729 ppm, averaging 2,477 ppm, the Garudamangalam limestone in India have Ba content of 2,516 ppm (Babu *et al.*, 2014) while the crustal average of Ba (Taylor, 1964) is 456ppm, indicating that the Yelwa limestone is enriched in Ba content compared to crustal average and is slightly lower than the Garudamangalam Limestone.

The Sr contents of the limestone of Yelwa study area range from 329.0 ppm to 569.1 ppm with an average of 404.98 ppm, while the Garudamangalam limestone has Sr value of 608 ppm (Babu et al., 2014) and the crustal average value of Sr is 320 ppm (Taylor, 1964). This suggests that the Yelwa Limestone is enriched in Sr compared to the crustal average and is lower than the Garudamangalam limestone.

Rb contents in the limestone of Yelwa vary from 1.1 ppm to 13.9 ppm with an average of 7.74 ppm, whereas the

Garudamangalam limestone show Rb value of 25 ppm. Reference to the 49ppm average crustal value of Taylor (1964), Rb content is grossly low in Yelwa limestone.

3.3.3 REE Pattern of Yelwa Limestone

The REE pattern in limestones (Fig. 3) are marked by moderate to high enrichment in the LREE with weakly negative europium anomaly and lower values of HREE having parallel and flattened trends. Chemical sediment such as limestones is most likely to reflect the composition of the sea water from which they were precipitated (Rollinson, 1993). The inverse of this is seen in limestones of Yelwa area which show enrichment in LREE relative to HREE with no Ce anomaly, indicating that redox-level of the surface of ocean water did not allow for oxidation of Ce due to fluctuations. This corresponds with the view of Elderfield and Greaves (1981).

Figure 3: Chondrite-normalized REE pattern of limestone of Yelwa study area. [Normalizing values were those of Taylor and Mclennan, (1985)].

YFL – Limestone

YML1 – Crystalline limestone YB1 – Recrystallized calcite

YB2 – Recrystallized calcite YML2 – Crystalline limestone

3.3.4 Major Elements Composition of Yelwa Phonolites

The phonolites of Yelwa area (n=4) have silica contents ranging from 55.62 wt% to 65.64 wt% with an average of 58.65 wt% while that of Gboko area have an average silica content (n=3) of 51.88 wt% (Najime, 2014). This indicates a slightly higher silica enrichments in the Yelwa phonolites.

Alumina contents in the Yelwa phonolite is in the range of 18.27 wt% to 20.61 wt% with an average of 19.91 wt% while that of Gboko area has average alumina content of 21.15 wt%.

The Phonolites of Yelwa have Fe_2O_3 contents that range from 0.43 wt% to 5.23 wt% with an average of 3.36 wt% while the Gboko phonolite has average Fe_2O_3 content of 4.63 wt% (Najime, 2014). The values show that the Yelwa phonolites are lower in alumina and Fe_2O_3 compared to the Gboko phonolites.

The lime content of the Yelwa phonolite vary from 0.14 wt % to 1.83 wt % with an average of 1.58 wt% while those of Gboko have an average lime value of 2.74 wt% (Najime, 2014). This means that the Yelwa phonolites have lower lime contents compared to the Gboko phonolites.

In the Yelwa area the phonolites have alkalis contents from 1.33 wt% to 9.45 wt% with an average of 6.76 wt% and 5.43 wt% to 5.51 wt% averaging 5.46 wt% for potash and soda respectively. However, the phonolites of Gboko area have average values of of 4.20 wt % and 9.29 wt% for potash and soda respectively. This shows that the potash content in Yelwa phonolites is higher compared to the Gboko phonolites while the soda contents are much lower than that of Gboko phonolites.

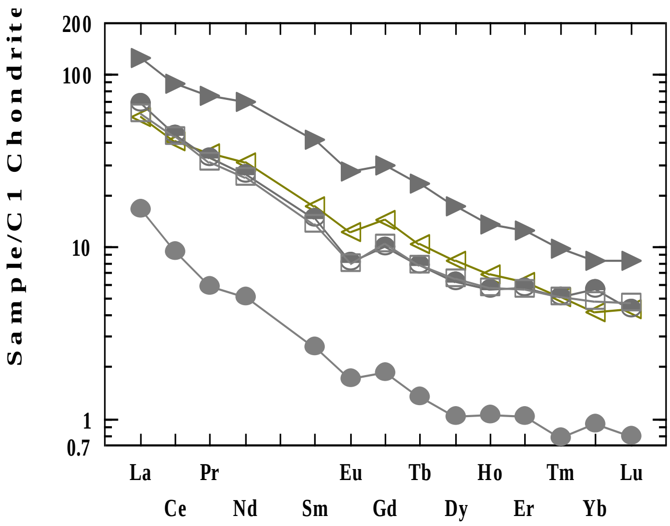

Figure 3: Chondrite-normalized REE pattern of limestone of Yelwa study area. [Normalizing values were those of Taylor and Mclennan, (1985)].

On the plot of AFM ternary diagram (Fig. 4) all the phonolitic rocks plot within the calc-alkaline field. It has been observed however, that one sample plot near the A-apex (total alkalis) end, thus proving that these rocks are strongly alkaline in nature. All the samples plot very close to the A-F side indicating their high alkalinity, significant feldspar affinity and low mafics.

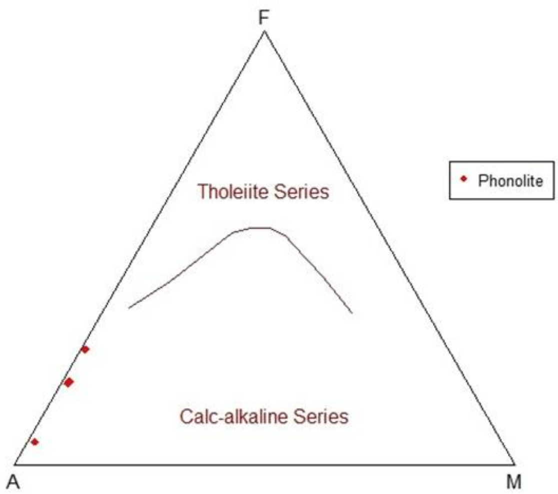

Figure 4: AFM ternary diagram for Yelwa phonolites (After Irvin and Baragar, 1971).

On the TAS volcanic diagram (Cox *et al*., 1979) it is observed that three samples plot within the phonolite field which are intermediate in silica composition and alkaline in nature (Fig. 5). However, one sample plot in dacite field which is acidic in silica composition and sub-alkaline in nature. This sample was observed to be an altered phonolite in hand specimen, indicating that some alkaline elements were removed during alteration, which resulted in enrichment of silica.

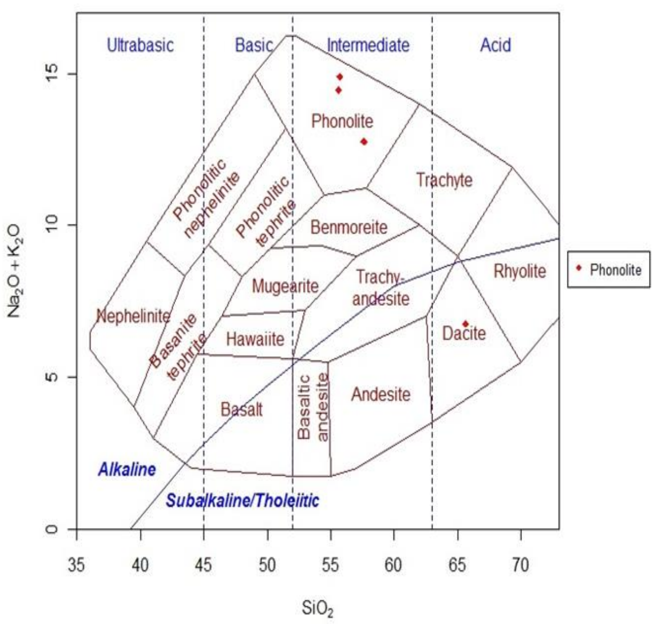

Figure 5: TAS diagram for Yelwa phonolites (After Cox et al., 1979)

On the TAS (volcanic) bivariate discrimination diagram of Le Bas *et al*. (1986) (Fig.6), it is observed that three of the four sample plotted in the phonolite field which are intermediate in silica composition and alkaline in nature. The remaining samples plot on the boundary between dacite and rhyolite. Field observation indicated that this (fourth) sample has witnessed some degree of degradation by alteration, suggesting that the rock might have been phonolitic but due to some remobilization of elements during alteration its chemistry changed to that of dacite/rhyolite composition.

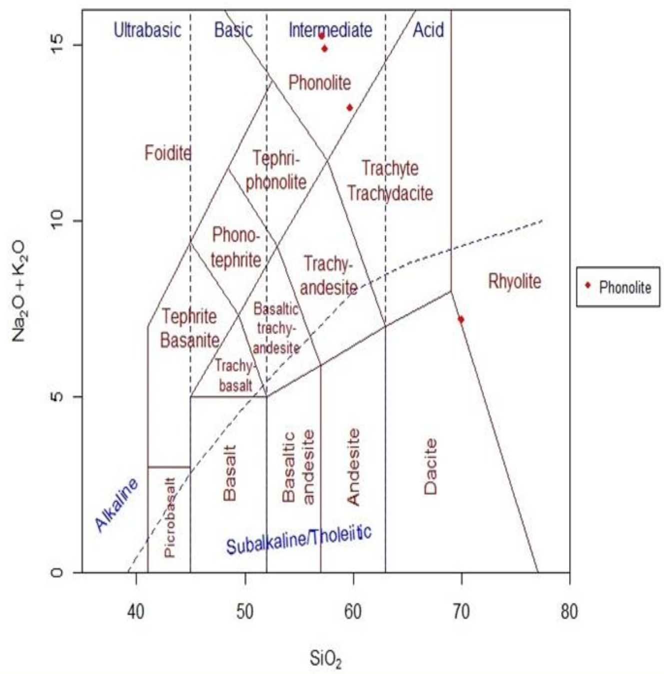

Figure 6: TAS diagram for Yelwa phonolites (After Le Bas *et al*., 1986)

The Winchester and Floyd (1977) Zr/TiO_2-SiO_2 bivariate diagram (Fig. 7) showed that three samples plotted in the phonolite field, and the fourth one that was earlier observed to be altered one plotted in the field of trachyte.

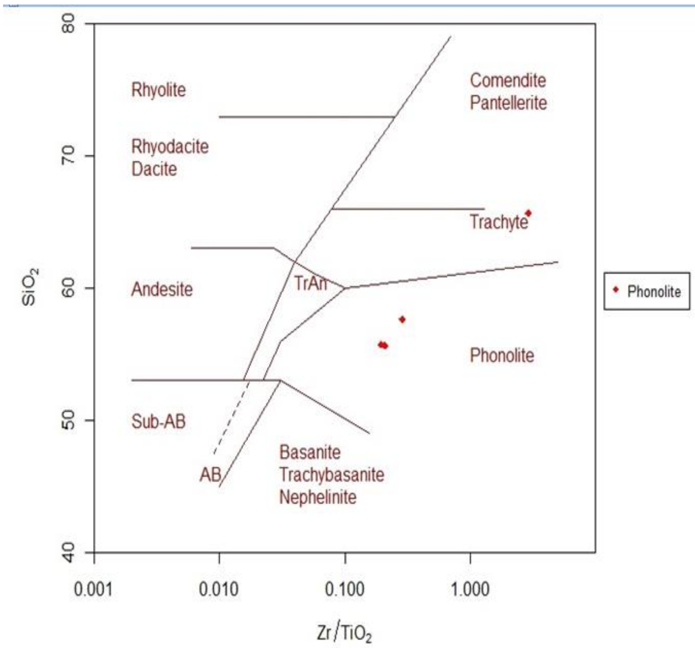

Figure 7: Zr/TiO_2 – SiO_2 diagram for Yelwa phonolites (After Winchester and Floyd, 1977).

3.3.5 Some trace elements and large ion lithophile element (LILE) of Yelwa phonolites

The average values of LILE elements (Ba, K, Rb and Sr) and their ratios along with other trace elements considered important due to their abundances in the phonolite such as Zr, Zn, Nb, Ta and Th as well as average crustal values are shown in Table 3.

Table 3: Comparative average values of some trace elements

Sample Element	Yelwa Phonolites	Gboko Phonolite	Crustal Average
Ba	400.5	506.67	425
K	45312.54	34,855.8	25,000
Rb	182.38	93.97	90
Sr	159.55	403.27	375
Zr	924.1	-	193
Zn	75.25	-	67
Nb	170.98	-	27
Ta	13.00	-	2
Th	28.25	-	10.5
K/Rb	248.45	370.92	285
K/Ba	113.14	68.79	36
Ba/Rb	2.196	5.42	7.8
Rb/Sr	1.143	0.23	0.12

and large ion lithophile (LILE) ratios of Yelwa phonolites (ppm)

Crustal average for elements (After Mason, 1966)
Crustal average values of elemental ratios (After Holland, -1978; Taylor and Mclennan, 1985).

Gboko Phonolite (After Najime, 2014)

- Not determined.

The average value of Ba in Yelwa phonolites (n=4) is 400.5 ppm and that of Gboko area (n=3) is 506.67 ppm, while the average crustal value for Ba is 425 ppm (Mason, 1966). This indicates that the Yelwa phonolite has lower Ba content compared to the phonolite of Gboko area and is depleted in Ba with reference to the crustal average value.

The average K value of Yelwa phonolites is 45,312.54 ppm and that of Gboko area is 34,855.80 ppm. The crustal average value for K is 25,000 ppm. This indicates that the Yelwa phonolites have higher K content compared to phonolite of Gboko area and enrichment of K was observed with reference to crustal average.

Rb content in the phonolite of Yelwa area has an average value of 182.38 ppm while that of Gboko area has value of 93.97 ppm and the crustal average value for Rb is 90 ppm. This indicates that Rb is higher in Yelwa phonolite than that of Gboko, and is enriched in Yelwa phonolite compared to the crustal average.

In the Yelwa phonolites, an average Sr value is 159.55 ppm while in Gboko area the average value is 403.27 ppm. The average crustal value is 375 ppm (Mason, 1966). This shows decrease of Sr in Yelwa phonolite compared Gboko samples and depletion compared to crustal average.

In the Yelwa area the phonolites have an average K/Rb content of 248.45 ppm while the average K/Rb of the Gboko phonolite is 370.92 ppm and the average crustal value for K/Rb is given as 285 ppm (Holland, 1978; Taylor and Mclennan, 1985). This indicates that the Yelwa phonolite have lower K/Rb ratio compared to the phonolite of Gboko area as well as the crustal average.

The average K/Ba ratio in the Yelwa phonolites is 113.14 ppm while that of Gboko is 68.79 ppm and the crustal average value is 36 ppm. This indicates that the Yelwa area phonolite have higher K/Ba ratio compared to the phonolite of Gboko area and is enriched with reference to the crustal average.

The Yelwa phonolite gave an average Ba/Rb ratio of 2.196 ppm as compared to the Gboko phonolite which gave an average of 5.42 ppm while the average crustal value is 7.8 ppm. Indicating depletion of Ba/Rb in Yelwa phonolite compared to the Gboko phonolite as well as the crustal average.

Rb/Sr ratio averages 1.143 ppm in the phonolite of Yelwa area and 0.23 ppm in the phonolite of Gboko area. However, the average crustal value for Rb/Sr is 0.12 ppm, indicating slight enrichment of Rb/Sr in Yelwa phonolite compared to both Gkobo area phonolite and crustal average.

Other trace elements considered important due to their relative abundance in the Yelwa phonolites are Zr, Zn, Nb, Ta and Th.

The Zr in the Yelwa phonolites ranges between 808.5 ppm to 1171 ppm and averages 924.1 ppm while the average crustal value of Zr was given as 193 ppm (Mason, 1966) indicating that the Yelwa phonolite is higher in Zr content.

Zn in Yelwa phonolites have composition ranging from 6 ppm to 116 ppm and its average is 75.25 ppm whereas the crustal average value of Zn is 67 ppm (Mason, 1966). This indicate that the Yelwa phonolite is higher in Zn compared to the crustal average.

Nb contents in the Yelwa phonolites shows values that ranged from 163.3 ppm to 175.5 ppm with an average of 170.98 ppm. The average crustal value for Nb is 27 ppm indicating that the Yelwa phonolites are enriched in phonolite compared to the crustal average. The Ta has values ranging from 9.9 ppm to 19.9 ppm with an average of 13 ppm in the Yelwa phonolites. The crustal average value for Ta is 2 ppm (Mason, 1966) which indicates that the Yelwa phonolite has high Ta compared to the crustal average.

Th in the Yelwa phonolite have values that ranges from 21.1 ppm to 38.3 ppm and averages 28.25 ppm. The average crustal value of Th is 10.5 ppm, indicating that the Yelwa phonolite has high Th compared to crustal average.

On the Nb/Y Vs Zr/Ti bivariate diagram of Pearce (1996), all the four samples plotted in the middle of the phonolite field which indicate phonolitic origin for the samples (Fig.11).

The Co-Th bivariate diagram of Hastie et al. (2007) (Fig. 12) indicated that all the four samples of phonolite plotted in the region of high-K, calc-alkaline and shoshonite series. This is in conformity with the AFM plot (Fig. 4) where the samples plotted in calc-alkaline field, suggesting that the phonolite are of high K-calc alkaline series.

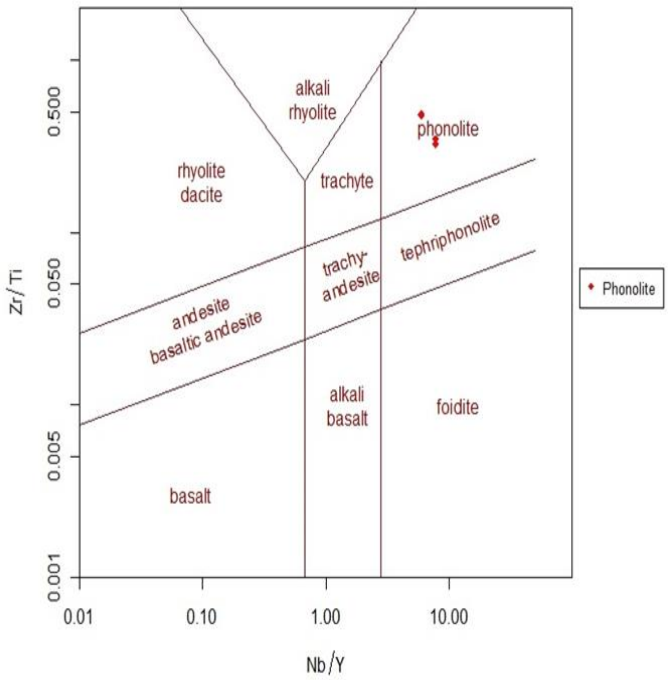

Figure 11: Nb/Y vs Zr/Tl bivariate diagram for Yelwa phonolites (After Pearce, 1996).

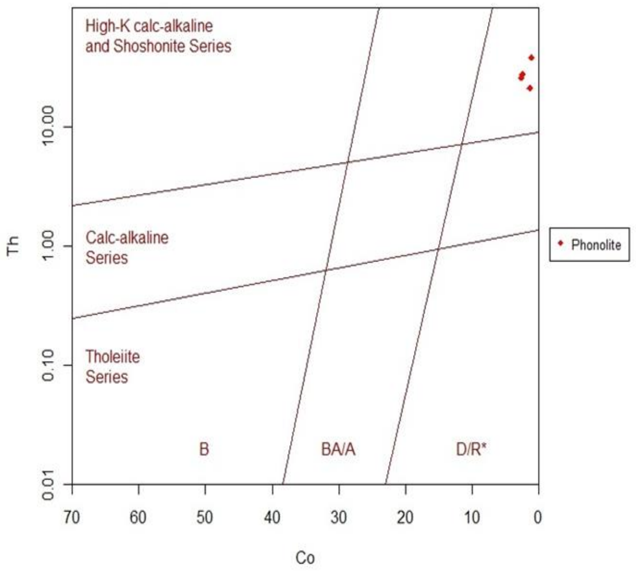

Figure 12: Co vs Th bivariate diagram for Yelwa phonolites (After Hastie et al., 2007).

The chondrite-normalized incompatible multi-element patterns for the phonolites of Yelwa (Fig. 13) show that there is enrichment in some trace elements such as Cs, Rb, Th, U, La, Nb, Ta, Ce, Nd, Zr and Dy as depicted by positive anomalies while negative anomalies indicate depletion in elements such as: Ba, K, Sr, Pr, P and Tl. Lack of negative anomalies in Nb and Ta in the spider diagram suggest crustal input (Coulon *et al*., 1996) indicating crustal parentage for the Yelwa phonolite lava.

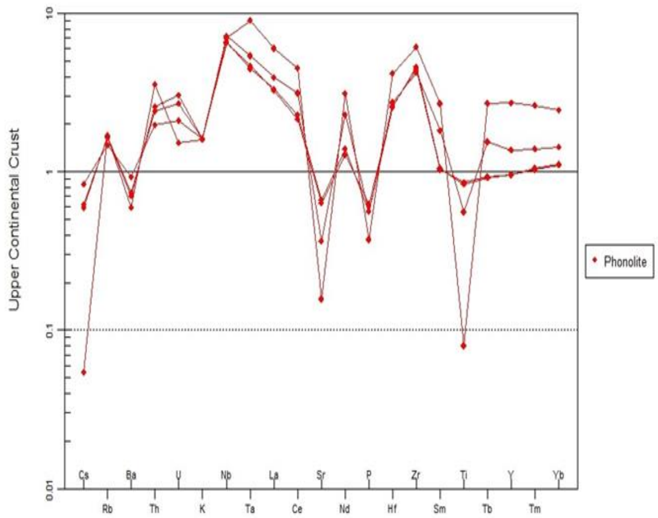

Figure 13: Incompatible element spider plot for Yelwa phonolites. [Normalizing values are those of Taylor and Mclennan (1995)].

3.3.6 REE Patterns in the Rocks of Yelwa Area

The phonolites (Fig. 14) are highly enriched in LREE with pronounced negative Eu anomally and are depleted in HREE, whose patterns are parallel and nearly flattened. The extreme depletion of HREE relative to LREE indicates the presence of garnet in the melt from which the phonolite crystallized (Rollinson, 1993).

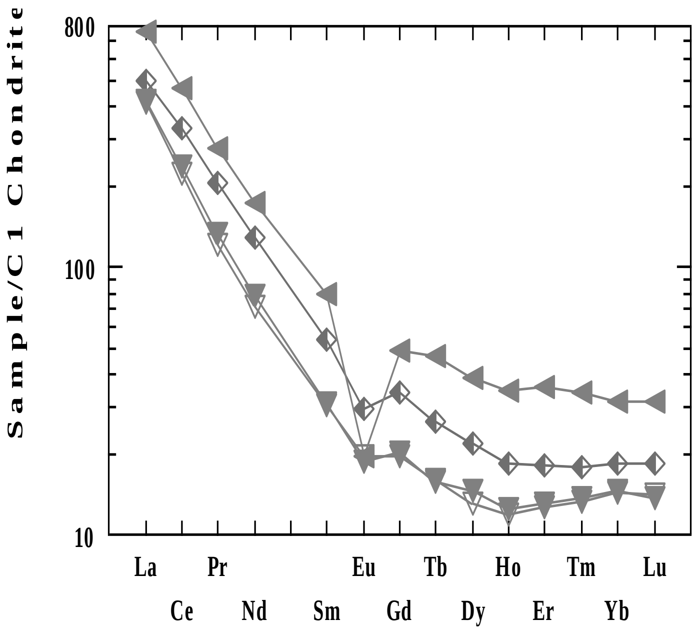

Figure 14: Chondrite-normalized REE pattern of Yelwa Phonolites. [Normalizing values were those of Taylor and Mclennan, (1985)].

YFP – Phonolite YMP2 - Phonolite
YMg – Altered Phonolite YMP1 – Phonolite

4. Conclusion

The limestone of the Yelwa area is enriched in lime content and depleted in oxides such as silica, alumina, total iron, magnesia, soda, potash and apatite. The limestone coupled with the recrystallized calcite having high lime content low impurities such as Mg, Pb, Zn, and S similar to the Ashaka limestone have met the requirement for utilization in Portland cement production. Geochemical parameters indicate that the phonolites are calc-alkaline that evolved from same parental magma.

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