

Determination of some physical parameters of Olumo rock, Abeokuta Ogun-State, Nigeria

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Abstract: The physical parameters of Olumo rocks namely, radiogenic heat, age of the rock, density and average absorbed dose rate were determined. The radioactive concentrations were also determined using gamma-ray spectrometry. The three natural radionuclides examined in the rock samples were namely ^{40}K , ^{238}U and ^{232}Th . The average radioactive concentration in each of the radionuclides were 961.49 BqKg^{-1} , 9.57 BqKg^{-1} and 112.38 BqKg^{-1} respectively. The average absorbed dose rate was $0.059 \pm 0.0043 \mu\text{Gh}^{-1}$ similar to the world's average absorbed dose rate of $0.059 \pm 0.012 \mu\text{Gh}^{-1}$ as recommended for normal environment by UNSCEAR. The highest radiogenic heat was found in ^{40}K with 93.37% of the total. Furthermore, the approximate age of Olumo rock, as per the activity concentration, was found to be 4.94×10^9 years. The average density was found to be $0,729 \text{ kgm}^{-3}$.

Keywords: Olumo rock age, radioactivity, radionuclides, ^{40}K , ^{238}U and ^{232}Th .

Introduction

Terrestrial radiation exposure originates from the primordial radionuclides, whose half-lives are comparable to the age of the earth, and the secondary radionuclides produced by their radioactive decay. The naturally occurring radionuclides include mainly ^{40}K , and the three radioactive decay chains originating with ^{238}U , ^{232}Th , and ^{235}U . These radionuclides are ubiquitously present in low concentrations in soil and water as a result of weathering and erosion of rock. The isotopic abundance of ^{40}K in natural potassium is only about 0.012%, but because potassium is widespread and is taken into the body as an essential element, it contributes on average about one-tenth of the internal dose from natural radiation (UNSCEAR, 1993). Another major exposure pathway to natural radiation results from the decay of ^{226}Ra in the ^{238}U series. This decay results in the formation of gaseous ^{222}Rn , which can enter the atmosphere through emanation from soil and building materials. The principal sources of internal exposure, and a major component of total background radiation exposure, are the rapidly decaying radionuclides formed as a result of successive decays of ^{222}Rn . Exposure occurs when these radionuclides, namely ^{218}Po , ^{214}Pb , ^{214}Bi , and ^{214}Po , are inhaled and retained in the lungs.

Additional but minor contributions to exposure come from the remaining non-series primordial radionuclides, primarily ^{87}Rb (NCRP, 1987), and cosmogenic radionuclides produced in the atmosphere by the interaction of cosmic rays with atmospheric argon, oxygen, and nitrogen. Cosmogenic radionuclides reach the earth through atmospheric mixing, precipitation scavenging, and gravitational settling; exposures result

primarily from ingestion and are relatively constant throughout the world.

Radioactive elements found in rock and soil from the earth makes their way into our bodies through the water we drink, food we eat, air we breathe which contains them. These naturally occurring radioisotopes such as carbon-14, potassium-40, Thorium-232, Uranium-238, Polonium-218, and Tritium (Hydrogen-3) expose us to radiation from within our bodies. The largest contributor to our daily exposure of radiation is the natural radioactivity and the major form of natural radiation is Radon gas. Radon-222 is a naturally occurring decay product of Uranium - 238 which is commonly found in rocks and soils.

Radon-222 is a gas which is odourless, colourless, tasteless, and chemically non-reactive. As it escapes from rocks and soils of which it is trapped, it enters the water we drink and air we breathe.

The distribution of uranium in the earth crust varies from place to place, so does the prevalence of radon gas. In areas where a surface rock contains a high concentration of uranium, radon gas could enter home through a crack in the foundation.

Motivation

The motivation for the studies came primarily from two sources, historical and scientific curiosity. Historical in the sense that Olumo rock is respected as the Egyptian respects Nile, hence the need to state briefly the historical perspectives.

Historical background of Olumo rock

The ancient town of Abeokuta, which is about 100 kilometers from Lagos, stands at a height of about 91. 44 m above the sea level. It has a hot humid climate and average annual rainfall of 1.19m. With urban population of about a quarter of million, the town is set amidst a group of granite rock of primitive formation, the central one which is the famous Olumo rock. Abeokuta (meaning under the rock) derives its name from the Olumo rock. The rock is sacred in Abeokuta history as a place where the first settlers found refuge from their attackers (Ogunremi, 1981).

The first Egba to live in the cave under the rock gave it no name. Neither did the three brothers, Jibulu, Oso and Olunle who later joined him. They regarded Olumo as no more than 'Apata Nla' (a huge rock). It received the name Olufimo when the main part of Egba refugees came there. The name 'Olumo' derives from the rock begin naturally surrounded with caves which offers protection to Egbas in the days of inter-ethnic wars. Olumo means "the Lord puts an end to".

To the Egbas, Olumo rock stands not only as a monument of faith in unit but also a source of natural

strength and unflinching protection and substance from supreme being who led their ancestors through the perplexities of life safely to Abeokuta. For this refuge marked the end of their wanderings and struggles for existence. It marked the focal point of their "promise land" where they were free from incessant persecution and fears of annihilation.

Furthermore, there is a taboo that blood will gush out if any part of the rock is broken, all these led to the scientific curiosity.

In view of the historical background of the rock and the fact that the place is a tourist center, we decided to determine some physical properties of the rock namely, radioactivity concentration, radiogenic heat, age and density of the rock. Also the results obtained here may compliment the data base of some other studies in such as measurement of radioactivity of by-product of tin mining in Nigeria (Babalola, 1984, Sanni *et al.*, 1985, Oresgun & Babalola, 1990), distribution of gamma - emitting natural radionuclides in soils and water around nuclear research establishments, Ile - Ife, Nigeria (Olomo *et al.*, 1994), absorbed dose rates in air due to ^{40}K , ^{238}U and ^{232}Th in rock in south western Nigeria (Ajayi *et al.*, 1996), baseline studies of terrestrial outdoor gamma dose rate level in 18 major cities in Nigeria (Farai & Jibiri, 2000), activity concentration of top soil of IITA, Ibadan, Nigeria by gamma spectrometry (Okeyode & Farai 2007) etc.

Methodology

Sample Collection

The samples were collected from five different parts of Olumo rock located in Abeokuta, Ogun-State Nigeria. The rock is located off Alatis between Ikija and Kereku neighborhoods of about 110 kilometers from Lagos. The rock samples were obtained by hammering the rock to get coarse grained rocks. Care was taken to avoid contamination of samples.

Sample preparation

In order to determine the radioactivity concentration, the following steps were taken for the sample preparation: The coarse grained rock were disaggregated in a Meyer and Bouger jaw crusher and powdered in a Meyer and Bouger pulverizing machine. The prepared samples were placed in a plastic container of specific size, weighed, sealed and left for at least 28 days to attain secular radioactive equilibrium before gamma counting. For density determination, mass of the samples were measured by weighing balance and the volume of the samples were determined by Archimedes principle (Muncaster, 1985).

Sample counting

For the radioactive concentration, the detection assembly set up for this study consist of thallium activated sodium iodide detector NaI(Tl), the photo multiplier tube and multi channel analyzer (Camberra Series 10 plus MCA). The detector was enclosed in 100mm lead shield. The counting time of each sample was set to 25200 seconds (7 hours). Background count was measured for the same length of time. The net count was used for subsequent analyses. The detection efficiency was measured by counting a standard sample of known activity for the same length of time. The area under the peak is proportional to activity of the sample. The constant of

proportionality is measured of the efficiency of the detector for the radiation measurement.

Results

Determination of radionuclide concentration in the samples

Using the mathematical relationship that the concentration C is proportional to the area A under the photo peak. We have:

C proportional to A; $C=kA$

Table 1. Gross area count under photo peak for Olumo rock samples (G_{AC})

Sample	^{40}K	^{238}U	^{232}Th
Rock A	15605±2.07	335±44.61	5834±3.64
Rock B	13095±2.34	305±34.24	5584±3.87
Rock C	14234±2.92	329±28.95	5672±3.35
Rock D	13425±2.98	348±35.21	5425±3.67
Rock E	16208±2.32	289±56.24	5826±5.09

Table 2. Area under the photo peak due to the background count (B_C)

Radionuclides	Background counts
^{40}K	1918±7.43
^{238}U	179±61.75
^{232}Th	1194±8.21

Table 3. Net area count under photo peak for Olumo rock samples (N_{AC})

Sample	^{40}K	^{238}U	^{232}Th
A	13687±5.36	156±17.14	4640±4.59
B	11177±5.09	126±27.60	4393±4.34
C	12316±4.51	169±26.54	4478±4.86
D	115071±4.45	168±26.54	4231±4.54
E	14290±5.11	110±5.51	4632±3.12

Table 4. Conversion constants $K(\text{BqKg}^{-1}/\text{cps})$ and gamma ray lines for each of the radionuclide

Radionuclides	Constant K ($\text{BqKg}^{-1}/\text{cps}$)	Gamma-ray lines
Potassium - 40	1923.7	1460
Uranium - 239	1695.5	1765
Thorium- 232	632.8	2615

Table 5. Radioactivity concentration of Olumo rock samples

Sample	^{40}K (BqKg^{-1})	^{238}U (BqKg^{-1})	^{232}Th (BqKg^{-1})
A	1044.829±21.73	10.496±58.55	116.516±20.73
B	853.222±17.74	8.478±0.05	110.313±19.63
C	940.17±19.56	10.092±0.06	112.448±20.01
D	878.413±18.27	11.371±0.06	106.32±18.92
E	1090.86±22.69	7.401±41.28	116.314±20.70
Average	961.49±19.99	9.67±0.05	112.38±19.99

K, the proportionality constant is a multiplicative factor which is constant for each radionuclide at constant geometry. It is determined by the detector efficiency of the assembly. Tables 1 & 3 give the sample gross area count and their net area count respectively. Table 2 provides data on area under the photo peak due to the background count (B_C).

- $N_{AC} = G_{AC} - B_C$
- N_{AC} = Net Area Count
- C_T = Counting Time
- K = Conversion factor
- B_C = Background count
- G_{AC} = Gross area count

$$C = \frac{N_{AC}}{C_T} x K$$

- C = Concentration of radio nuclides
- N_{AC} = Net Area Count
- C_T = Counting time (25,200 seconds)
- K = Constant of proportionality (Conversion factor) shown in Table 4.

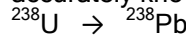
rock site was calculated.

Radioactive dating

Approximate age of Olumo rock

The discovery of radioactivity by Henri Becquerel in 1896 ultimately had profound implication for the evolution of the earth. By that time sedimentary layering outcrops was somewhat understood, at least to the point where it was known that observed sedimentary strata must have taken hundredths of millions of years to accumulate. The energy associated with gravitational collapse, allowed a maximum age of 25Ma. For about 3 decades geologists debated whether to accept this age. The argument became moot due to the discovery of radioactivity. From the point of view of the evolution of the earth, the discovery of radioactivity provided a means of determining absolute date for rocks. From the equation $A(t) = A_0 e^{-\lambda t}$

Note: ^{238}U is chosen from the 3 radionuclides because the decays of nuclear for the ^{238}U decay constant are very accurately known.



$$\lambda_{238} = 1.55 \times 10^{-10} \text{ yr}^{-1}$$

(Essential on Geophysical Research, 2005)

Where $A(t)$ is the original radioactive concentration of ^{238}U

A_0 is the initial radioactive concentration or ^{238}U

t is the time (age of the rock)

$$\frac{A(t)}{A_0} = \frac{1}{2}, \quad \frac{9.57}{A_0} = \frac{1}{2}$$

$$A_0 = 19.14 \text{ BqKg}^{-1}$$

$$\ln A(t) = -\lambda t \ln A_0$$

$$\ln 9.57 = -\lambda_{238} t \ln 19.14$$

$$2.26 = -1.55 \times 10^{-10} \times -2.95 t$$

$$t = \frac{2.26}{4.5725 \times 10^{-10}}$$

$$t = 4.94 \times 10^9 \text{ years.}$$

Radiogenic heat

The knowledge of abundant distribution of natural radioactivity in rock is used to evaluate the heat generated in rocks. The heat flow does not only come from the original heat in the rock but is also due to the radioactivity in the rock. The evidence that evaluations of distribution of isotopes are responsible for the rock radioactivity: ^{40}K , ^{238}U and ^{232}Th are of fundamental importance in establishing the radiogenic basis for rock heat.

To convert the concentration in Bq/Kg to heat, requires some factors given by Birch (1954):
 1ppm U = 0.73 $\mu\text{Cal/gyr}$, 1ppm Th = 0.20 $\mu\text{Cal/gyr}$,
 1% K = 0.7 $\mu\text{Cal/gyr}$.

The conversion factors from Becquerel to ppm is shown in Table 7. Table 8 reveals the radioactive concentration of Olumo rock samples in ppm using the factors in Table 7.

Table 6. The absorbed dose rate for each rock sample

Sample	^{40}K (nGy/hr)	^{238}U (nGy/hr)	^{232}Th (nGy/hr)	Total D(nGy/hr)
Rock A	43.8± 0.22	4.5 ± 0.26	77.6 ± 0.26	125.98
Rock B	35.85±0.18	3.64 ± 0.21	73.47 ± 0.25	112.95
Rock C	39.49±0.20	4.31± 0.25	74.89 ± 0.25	118.69
Rock D	36.89± 0.18	4.8 ± 0.28	70.81 ± 0.24	112.58
Rock E	45.82± 0.23	3.18 ± 0.18	77.47 ± 0.26	126.47
TOTAL				119.33±8.67

Absorbed dose rate determination

The absorbed dose rate D (nGy^{-1}) due to activity concentration (BqKg^{-1}) of ^{40}K , ^{238}U and ^{232}Th was calculated using the equation below (Beck *et al.*, 1972):

$$D (\text{nGy}^{-1}) = 0.042C_k + 0.0429C_u + 0.666C_{Th} \dots\dots\dots(1)$$

C_k = the radioactivity concentration of ^{40}K

C_u = the radioactivity concentration of ^{238}U

C_{Th} = the radioactivity concentration of ^{232}Th

Using equation (1), the absorbed dose rates in air at the

Fig.1 Radioactivity concentrations of the radionuclides in the rock

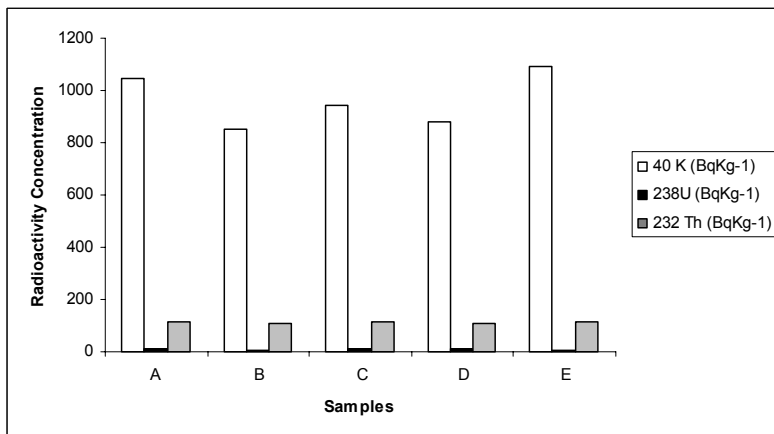
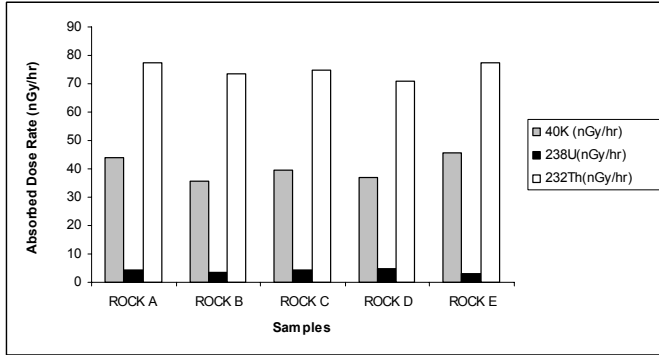


Fig.2. The absorbed dose rate of each rock sample



Determination of density of Olumo rock

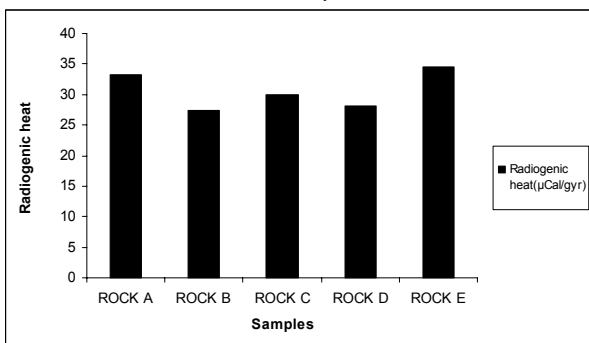
The mass of each rock sample was measured by Weighing Balance and volume was determined by the volume of water displaced in a beaker (using Archimedes principle).

Mass of Rock A = 0.2Kg ----- Volume of Rock A= 0.30m³
 Mass of Rock B = 0.199Kg -----Volume of Rock B=0.25m³
 Mass of Rock C = 0.2Kg ----- Volume of Rock C=0.29m³
 Mass of Rock D=0.198Kg-----Volume of Rock D=0.24m³
 Mass of Rock E=0.20Kg-----Volume of Rock E=0.20m³

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Density of Rock A = 0.667Kg/m³
 Density of Rock B = 0.796Kg/m³
 Density of Rock C = 0.689Kg/m³
 Density of Rock D = 0.825Kg/m³
 Density of Rock E = 0.667Kg/m³
 Average density of the rock samples = 0.729Kg/m³

Fig.3. Radiogenic heat at Olumo rock against each sample



Results and discussion

The highest radioactive concentration of ⁴⁰K was found in rock sample E with 1090.860BqKg⁻¹. This high value could be due to presence of abundant radioactive minerals such as Smectite, kaolinite, feldspars and so on in the sample. The radioactive concentration order was followed by rock sample A with 1044.829Bqkg⁻¹. Samples C and D also had their radioactive concentrations of ⁴⁰K as 940.170Bq/Kg and 878.413Bq/Kg respectively. The

smallest radioactive concentration of ⁴⁰K was found in rock sample B with 853.22Bq/Kg (Table 5, Fig. 1).

The highest radioactive concentration of ²³⁸U was found in Sample D with 11.371Bq/Kg (Table 7). High value of ²³⁸U concentration could be due to high presence of Uranium minerals such as Uraninite, Zircon, Sphene, Monazite and so on, it could also be due to high presence of sand fraction in the soil sample (Sand fraction contain Zircon) with moderate silt-sized fractions which increase surface areas of soil and enhance release and availability of Uranium. The radioactive concentration order of ²³⁸U was followed by rock sample A with 10.496Bq/Kg. Samples C and B also had their radioactive concentration of ²³⁸U as 10.092Bq/Kg and 8.478Bq/Kg respectively. Rock sample E which is the richest in ⁴⁰K had the lowest radioactive concentration in ²³⁸U of 7.401Bq/Kg. Also, Table 5 showed the highest radioactive concentration of ²³²Th found in the rock sample A with 116.516Bq/Kg the highest value of thorium concentration could be due to presence of abundant radioactive thorium minerals such as monazite, Zircon and Thorianite followed by rock sample E 116.314Bq/Kg. Rock samples C and D also have the radioactive concentration of 112.448 Bq/Kg and 106.320 Bq/Kg. The smallest radioactive concentration of ²³²Th was also found in rock sample B which also had the lowest Concentration of ⁴⁰K. Using Table 6, (Fig. 2) it was shown that the average absorbed dose rate of Olumo rock samples collected is 0.0596± 0.00434µGyh⁻¹. From the coefficient of equation (1), the contribution of each radionuclide to the total dose level does not directly reflect on the concentration of the sample .

Thorium (²³²Th) had the highest value of the absorbed dose among the three radio nuclides detected in the rock samples collected, thus ²³²Th had the highest dose level at Olumo rock. The approximate age of Olumo rock had been found to be about 4.94X10⁹ yrs and the age is nearly comparable to the age of the earth. For the radiogenic heat, It was apparent that the heat produced by ⁴⁰K was highest while ²³⁸U produced the least heat, (Table 9, Fig. 3).

Conclusion

The method of gamma spectrometry (Adams & Dams 1975) had been used to measure the radioactivity concentration of five Samples collected from Olumo rock in Abeokuta, ogun state. Nigeria. The result shows that the concentration of ⁴⁰K is much higher than that of ²³⁸U while ²³²Th leads the table of radioactive concentration. The activity concentration was then used to determine the gamma absorbed dose rate level in air due to the three primordial radionuclides in the samples. The average absorbed dose rate in air at Olumo rock is 0.059±0.0043µGyh⁻¹ which is nearly equal to that of the world average absorbed dosed rate of 0.059±0.012 µGy h⁻¹ (UNSCEAR, 2000).

Table 7. Conversion factors from Becquerel to part- per million

Radionuclides	K-40	U-238	Th- 232
Bq/Kg	0.0302259	12.22222	4.074074
ppm	1	1	1

Table 8. Radioactive concentration of Olumo rock samples (ppm) using the factors in Table 7

Sample	⁴⁰ K (ppm)	²³⁸ U (ppm)	²³² Th (ppm)
Rock A	34529.53	0.8586	28.5994
Rock B	28197.29	0.6937	27.076
Rock C	31070.76	0.8257	27.6009
Rock D	29029.81	0.9304	26.0967
Rock E	36058.76	0.6055	28.5498

Table 9. Radiogenic heat at Olumo rock site using the conversion factors

Sample	K (%)	²³⁸ U (ppm)	²³² Th (ppm)	Total heat ($\mu\text{Cal.g}^{-1}\text{yr}^{-1}$)
Rock A	93.22	0.63	5.72	33.19
Rock B	76.13	0.51	5.42	27.35
Rock C	83.89	0.60	5.52	30.00
Rock D	78.38	0.68	5.23	28.10
Rock E	97.34	0.44	5.71	34.49
Average	85.79	0.57	5.52	30.63

Considering the contribution of ⁴⁰K, ²³⁸U and ²³²Th. ⁴⁰K is identified as the highest contributor to the radiogenic heat production in the rock studied, ⁴⁰K contributes an average of 93.37% to the total heat production, ²³⁸U contributes 0.62% while ²³²Th contributes 6.00%. Generally the implication of high radiogenic heat production invariably has high geothermal prospects while areas of low radiogenic heat production also shows low geothermal prospects (Nubi, 2006). The average density for the five Olumo rock samples collected was found to be 0.729Kg/m³.

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