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Pattern of Radiogenic Heat Production in Rock Samples of Southwestern Nigeria

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Abstract

Survey for radiometric minerals has become important over the last few decades because of the demand for alternative to present common source of energy. Radiometric survey is one of the geophysical techniques in use in exploration for geothermal energy, which is generated mainly from the decay of long-lived radioactive isotopes. The main objective of this study is to obtain the pattern of contribution of the elements to the radiogenic heat production (RHP) in the Southwestern Nigeria. Fresh rock samples were collected from six states in Southwestern Nigeria and the concentration of ^{48}K, ^{238}U and ^{232}Th from the samples were determined in the laboratory through spectrometry of emitted gamma rays, using a cylindrical NaI(Tl) detector. The results show that the contribution and rate of heat production of ^{40}K, ^{238}U and ^{232}Th in the samples vary significantly with geological locations, with ^{40}K as the major element which predominates in heat production, while ^{238}U and ^{232}Th are trace elements. The

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radiogenic heat production elements (RHPE) contribution shows that Ekiti, Ondo and Osun have the same pattern of radiogenic heat production contribution of the elements to the radiogenic heat production (RHP) in the Southwestern Nigeria. Fresh rock samples were collected from six states in Southwestern Nigeria and the concentration of ^{48}K, ^{238}U and ^{232}Th from the samples were determined in the laboratory through spectrometry of emitted gamma rays, using a cylindrical NaI(Tl) detector. The results show that the contribution and rate of heat production of ^{40}K, ^{238}U and ^{232}Th in the samples vary significantly with geological locations, with ^{40}K as the major element which predominates in heat production, while ^{238}U and ^{232}Th are trace elements. The radiogenic heat production elements (RHPE) contribution shows that Ekiti, Ondo and Osun have the same pattern of radiogenic heat production.

Keywords: Radiogenic heat, radionuclide, gamma-ray spectrometer, photopeaks, geothermal energy

1 Introduction

Geothermal energy is created by the heat of the earth. It generates reliable heat and emits almost no greenhouse gases. Geothermal energy is a reliable source of power that can reduce the need for imported fuels for power generation. It is also renewable because it is based on practically limitless resource. In addition, geothermal energy has significant environmental advantages because geothermal emissions contain no chemical pollutants or waste, they consist mostly of water, which is re- injected underground.

The Earth's internal heat derives from several sources but there are two main sources. One of the sources is the cooling of the Earth since its early history, when internal temperature was much higher than they are now. The other source is the heat produced by the decay of long- lived radioactive isotopes. This is the main source of the Earth's internal heat, which in turn, powers all geodynamic processes (Philip, 2005). The Earth is constantly losing heat from its interior, which is many times larger than the energy lost by other means, such as the changes in Earth's rotation and energy released in geothermal flux at a rate of about 4.4 x 10^3 W, which is equivalent to 1.4 x 10^{21} Jyr^{-1}.

Geophysical methods play a key role in geothermal exploration. The geophysical surveys are directed at obtaining indirectly from shallow depth and physical parameters of the geothermal systems. The various geothermal techniques in use in exploration for geothermal energy include subsurface (Shallow) temperature measurement (Lachenbrunch and Sass, 1997; Kintzinger, 1956; Lee, 1997; LesSchach and Lewis, 1993; Ranmingwong et al, 2000); Geochemical thermometric methods (Bandwell and MacDonald, 1965; Anderson and Johnson, 2000; Pertamina, 1997; Tripp and Ros, 1997); Magnetolluric methods (Johnson et al, 1992; Ushijima et al, 2000); Gravity method (Johnson, 1995; Sumintadireje et al, 2000) Aeromagnetic surveys (Reynold et al, 1990; Salem et al, 1999, 2000); Sesmic Method (Keller, 1981; Rajver et al, 1996) and Radioactive Method (Pasquale et al, 1997; Louden and Mareschal, 1996). Each of these methods has its own advantages and disadvantages. Some lack the maturity under difficult conditions which others become less useful for deep exploration because of lack of sensitivity. Considering the limitations of the various methods, it is probably necessary to use an integrated geophysical approach employing a wide variety of techniques.

Surveying for radiometric minerals has become important over the last few decades because of the demand for nuclear fuels (Keller, 1981; Ehinola et al., 2005). Radiometric surveying is employed in the search for deposits necessary for this application (Kintzinger, 1956; Philip, 2001). Radiometric surveys are of use in geological mapping as different rock types can be recognized from their distinctive radioactive signature.

The widespread occurrence of geothermal manifestations in Nigeria is significant because the wide applicability and relative area of exploitation of geothermal energy is of vital importance to an industrializing nation like Nigeria (Babalola, 1984). There are two known geothermal resource areas in Nigeria: the Ikogosi Warm Springs of Ondo State and the Wikki Warm Springs of Bauchi State. A combination of measurement and analyzing radionuclides contributions to geothermal heat production would help in the accurate evaluation of suspect geothermal resource areas for future detailed investigations and possible exploitation.

In this study, we use the radioactive method, which involves measuring the concentration of radioactive elements: potassium (^{40}K), Uranium (^{238}U) and Thorium (^{232}Th), using Gamma- ray spectrometer. The gamma-ray method is widely use in Earth's Sciences for the determination of naturally occurring radioactive materials. Heat produced by radioactive decay in rocks is of the fundamental importance in understanding the thermal history of the Earth and interpreting the continental heat flux data (Chiozzi et al, 2000, 2007).

2 Geological setting

Major part of Southwestern part of Nigeria belongs to the schist belt. To be specified, Lagos State belongs to geological area of post-cretaceous, Osun and Oyo belong to crystalline basement region, Ogun State belongs to basement complex (undifferentiated) region. While Ondo and Ekiti belong to post-cretaceous region, which comprises of shale and sandstone.

3 Radiogenic elements and heat production

Energy released by short- lived radioactive isotopes may have contributed to the initial heating, but the short- lived isotopes would be consumed quite early. The heat generated by long- lived isotopes has been an important heat source during most of Earth's history. In order to be a significant source of heat radioactive isotopes must have a half- life comparable to the age of the Earth, the energy of its decay must be fully converted to heat and isotopes must be sufficiently abundant. The main isotopes that fulfill these conditions are ^{238}U, ^{235}U, ^{232}Th and ^{40}K. The isotope ^{235}U has a shorter half- life than ^{238}U and release more energy in its decay. The heat Q produced by radioactivity in a rock that has concentrations C_u , C_{th} and C_k respectively, of these elements is

$$Q= 0.\ 00348C_k+95.2C_u+ 25.6C_{th} \text{ (Rybach et al, 1988)} \qquad (1)$$

Heat can be transported by three processes: conduction, convection and radiation, conduction and convection require the presence of a material; radiation can pass through space or a vacuum. Conduction is the most significant process of heat transport in solid materials. However, it is an inefficient form of heat transport and when the molecules are free to move, as in fluid or gas, the process of convection becomes more important. Although the mantle is solid from the standpoint of the rapid passage of seismic waves, the temperature is high enough for mantle to act as a viscous fluid over long time intervals (Philip, 2005). Consequently, convection is also the most important form of heat transport in the fluid core.

4 Materials and Method of Measurement

Sixty fresh rock samples of different lithologies were collected from different location of Osun- Osogbo River in Osun State, Nigeria. The rock samples were crushed to fine grains to minimize self-absorption and to have geometry and matrix. Each sample was carefully packed in a 39.1g plastic container, sealed and weighed. They were then left for thirty days in order for gaseous members of Uranium and Thorium series reach secular equilibrium before counting.

Natural radionuclide of relevance for the radiogenic heat production are mainly ^{40}K and gamma- ray emitting nuclei in decay series of ^{238}U and ^{232}Th Gamma radiation analysis allows various gamma emitter to be distinguished and the quantitative content of Potassium, Uranium and Thorium to be calculated.

Concentration of ^{48}K, ^{238}U and ^{232}Th are determined in the laboratory through spectrometry of emitted gamma rays using a cylindrical NaI(Tl) detector (model No 802 series) by Canberra Inc. The gamma rays, which interact with the scintillator, are converted into pulses with height proportional to the energy of the gamma rays.

These pulses are amplified and fed to a multichannel analyzer (Canberra series 10 multichannel analyzer). All the samples were counted for 18000 sec, as this was considered adequate for measurement of the low activity of the samples. The efficiency and quantitative calibration of the apparatus was determined using a standard material prepared from Rocketdyne laboratories, Califonia, USA.

5 Analyses

The photopeak area values were converted into concentration in $Bqkg^{-1}$ and then later to part per million (ppm). These concentrations in ppm were later used for determination of the radiogenic heat production using Rybach equation (Eq. 1) where C_u , C_{th} and C_k are concentrations in ppm of Uranium, Thorium and Potassium, respectively. Multiplying the radiogenic heat production values by the rock density gives the radiogenic heat generated in cubic meter of the rock (Wm^{-3}) The area under photopeak represents the counts due to each radioactive nucleus and was computed from the memory of the Multichannel Analyzer (M.C.A.). These are presented in table 1. The area under the photopeak is a measure of the activity of the radionuclide producing the photopeak. The photopeak counts obtained for each rock sample after subtracting the background value was converted to concentration by using standard conversion factor *K*. Thereafter, the concentration of the radionuclide were converted from $Bqkg^{-1}$ to ppm (part per million).

The amount of heat generated per second by natural Uranium, Thorium and Potassium were obtained by using Rybach's equation, and then the total radiogenic heat production for each sample was obtained by summation of the three isotopes heat production.

6 Results and Discussion

The photopeak counts obtained for each rock sample was converted to concentration in Bqkg-1 by using standard conversion factor. Thereafter, the concentration of the radionuclides were converted from Bqkg-1 to ppm (part per million) as presented in table 1. Radiogenic heat production was computed from the U, Th, K concentration using the formula (1) proposed by Rybach et al (1988), and presented in table 2.

Considering the distribution of the radiogenic heat production elements (RHPE) contribution, it shows that Ekiti, Ondo and Osun have the same pattern. This can be seen from the pattern of distribution shown in the table 3, where K is the major element which predominates in heat production while U and Th are trace elements.

The main objective of this study is to obtain the pattern of contribution of the elements to the radiogenic heat production in the Southwestern Nigeria. To determine this, the data obtained was transformed to relative importance index (RII) for each element to determine the rank of the elements. The relative index was evaluated using the following expression

$$RII = \frac{\Sigma w}{A \times N} : (O \leq index \leq 1) \qquad \text{(Ojo, 2007)}$$

Where

w = weighting given to each factor by the respondents, and ranges from 3 to 1.

A = highest weight (i.e. 3 in this case) and

N = total number of respondents.

The result of this analysis is shown in the table 4. Considering the range of RII (0.888-0.555), it shows that all the elements have contributed to radiogenic heat production (RHP). However, K-40 (RII = 0.888) is the major element with the highest contribution in the Southwestern Nigeria, while U-238 and Th-232 contribute equally and moderately. Early work on crustal rock samples of Southeastern Nigeria shows that Th-232 is the highest contributor to the radiogenic heat production in that region (Joshua et al., 2008). This is contrary to the present result. This might be as a result of difference in geological setting of these regions. In addition, convectional geochemistry considers K as a major element (those which predominate in any rock analysis) and U and Th as trace elements (Rudnick et al., Mchennan, 2001; Jaupart and Marechal, 2003) which is corroborated with the present result.

Table 1: Concentration of K, U and Th in ppm

		Concentration of Radionuclide in ppm		
S/N	LOCATION CODE	^{40}K	^{238}U	^{232}Th
1	EK1	26496.69	0.43	0.49
2	EK2	28778.73	0.34	1.26
3	EK3	129052.8	1.97	3.83
4	EK4	54573.99	1.49	0.31
5	LA1	81577.14	0.85	0.96
6	LA2	34370.56	0.85	0.24
7	LA3	38953.16	0.30	0.04
8	OG1	941.99	0.10	0.12
9	OG2	926.57	0.06	0.71
10	OG3	3428.72	0.02	0.73
11	OG4	2473.29	0.06	0.88
12	OG5	3100.91	0.19	0.82
13	OG6	2983.80	0.09	1.13
14	OG7	2007.75	0.05	0.77
15	OG8	1563.86	0.10	0.63
16	OG9	462.07	0.17	0.30
17	OG10	1921.32	0.12	1.03
18	ON1	1803.66	0.34	0.27
19	ON2	1127.82	0.32	0.39
20	ON3	5405.29	0.45	0.07
21	OS1	719.09	0.13	0.06
22	OS2	611.55	0.06	0.01
23	OS3	8504.87	0.81	0.24
24	OS4	2015.04	0.16	0.82
25	OS5	37964.35	0.36	0.06
26	OS6	24764.86	0.50	0.15
27	OS7	16973.65	0.04	0.52
28	OS8	31529.8	0.22	010
29	OS9	60154.42	0.15	0.50
30	OS10	18485.37	0.08	0.59
31	OS11	35102.65	0.30	0.05
32	OS12	1208.74	0.20	0.05
33	OY1	728.18	0.38	3.24
34	OY2	27333.93	0.28	1.00
35	OY3	2553.13	0.09	0.89
36	OY4	26701.82	0.47	0.54
37	OY5	22553.25	0.40	0.40
38	OY6	1091.49	0.25	0.29
39	OY7	568.58	0.00	0.63
40	OY8	674.55	0.14	0.32
41	OY9	11762.27	0.31	0.58
42	OY10	12167.31	0.13	0.54
43	OY11	2546.97	0.46	0.34
44	OY12	536.69	1.00	0.10

45	OY13	12672.48	0.12	0.08
46	OY14	12101.1	0.12	0.43
47	OY15	14857.78	0.01	0.48
48	OY16	38827.46	0.44	0.50
49	OY17	35695.95	0.37	0.48
50	OY18	27879.58	0.16	0.57
51	OY19	28165.95	0.18	0.95
52	OY20	20548.07	0.27	0.46
53	OY21	32106.7	0.42	0.68
54	OY22	42847.65	0.41	0.80
55	OY23	28837.61	0.64	0.27
56	OY24	1582.56	0.54	0.30
57	OY25	20386.51	0.45	0.15
58	OY26	24558.18	0.66	0.21
59	OY27	15752.81	0.33	0.31
60	OY28	36369.26	0.25	0.14

Table 2: Radiogenic Heat Production in pW/kg

		Heat Production (pW/kg)			
S/N	Location Code	^{40}K	^{238}U	^{232}Th	Total
1	EK1	92.21	41.04	12.50	145.75
2	EK2	100.15	32.13	32.21	164.49
3	EK3	449.1	187.41	98.08	734.59
4	EK4	189.9	141.66	7.95	339.51
5	LA1	238.89	80.63	24.53	344.05
6	LA2	119.61	80.90	6.23	206.74
7	LA3	135.59	28.93	1.09	165.58
8	OG1	3.29	9.76	3.16	16.21
9	OG2	3.22	5.74	18.10	27.06
10	OG3	11.93	74.81	22.29	109.03
11	OG4	8.61	6.09	22.47	37.17
12	OG5	10.79	18.45	20.93	50.17
13	OG6	10.38	8.15	28.85	47.38
14	OG7	6.99	4.71	19.82	31.52
15	OG8	5.44	9.66	16.19	31.29
16	OG9	1.61	15.96	7.71	25.28
17	OG10	6.69	11.82	26.23	44.74
18	ON1	6.28	32.57	6.92	45.77
19	ON2	3.93	30.22	9.88	44.03
20	ON3	188.11	42.51	1.73	232.35
21	OS1	2.50	12.16	1.51	16.17
22	OS2	2.13	5.87	0.21	8.21
23	OS3	29.60	77.03	6.02	112.65
24	OS4	7.01	15.42	21.09	43.52
25	OS5	132.12	33.91	1.62	167.65
26	OS6	86.18	47.85	3.80	137.83
27	OS7	59.07	4.10	13.30	76.47
28	OS8	109.72	21.30	2.65	133.67
29	OS9	209.34	13.83	12.65	235.82
30	OS10	64.33	7.85	14.98	87.16
31	OS11	122.16	28.4	1.30	151.86
32	OS12	4.21	19.31	1.21	24.73
33	OY1	2.53	35.99	82.84	121.36
34	OY2	95.12	26.24	25.65	147.01
35	OY3	88.85	8.40	22.87	120.12
36	OY4	92.92	44.55	13.78	151.25
37	OY5	78.49	38.40	10.34	127.23
38	OY6	3.80	24.12	7.29	35.21
39	OY7	1.98	5.54	16.17	23.69
40	OY8	2.35	13.39	8.19	23.93
41	OY9	40.93	30.28	14.72	85.93
42	OY10	42.34	11.98	13.84	68.16
43	OY11	8.86	43.41	8.63	60.9

44	OY12	1.87	94.94	2.60	99.41
45	OY13	44.10	11.34	1.97	57.41
46	OY14	42.11	10.04	11.03	63.18
47	OY15	51.71	1.24	12.24	65.19
48	OY16	135.12	41.62	12.65	189.39
49	OY17	124.22	35.17	12.67	171.66
50	OY18	97.02	15.41	14.52	126.95
51	OY19	98.02	17.53	24.30	139.85
52	OY20	71.51	21.95	11.66	1O5.12
53	OY21	111.73	40.19	17.36	169.28
54	OY22	149.12	39.16	20.23	208.51
55	OY23	100.36	61.26	6.96	168.58
56	OY24	5.51	50.93	7.69	64.13
57	OY25	70.95	42.85	3.76	117.56
58	OY26	85.46	62.96	5.34	153.76
59	OY27	54.82	31.28	7.92	94.02
60	OY28	126.57	23.93	3.46	153.96

Table 3: Average Radiogenic Heat Production (RHP)

Location (state)	K-40	U-238	Th-232
Ekiti	207.8	100.56	37.69
Lagos	164.69	63.49	238.79
Ogun	6.90	16.52	2.93
Ondo	66.11	35.1	6.18
Osun	69.03	23.92	6.70
Oyo	62.30	31.58	21.26
Average	96.138	45.20	55.60

Table 4: The results of the analysis

Element (Radionuclide)	RII	Rank
K-40s	0.888	1
U-238	0.555	2
Th-232	0.555	3

7 Conclusions

The main conclusions that are derived from the present work can be summarized as follows:

(i) Radioactive minerals are present in all the rock samples collected.

(ii) There is uneven contribution of these radionuclides (U, Th, and K) to radiogenic heat production in rock as a result of their geological location.
(iii) The radiogenic heat production elements (RHPE) contribution shows that Ekiti, Ondo and Osun have the same pattern of radiogenic heat production.
(iv) The pattern of radiogenic heat production of Southwestern region of Nigeria has K as the major element, which predominate in heat production while U and Th are trace elements.

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