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The Model of Radiogenic Heat Production in the Federal Capital Territory (FCT), Abuja, Nigeria

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Abstract

Geothermal energy is created by the heat within the Earth. The analysis of granite rock samples was carried out to determine the concentrations in part per million (ppm) by gamma ray spectroscopy using a well calibrated NaI(Tl) detector system, distribution and the potential of Radiogenic Heat Production of some heavy elements in rock samples in Abuja, Federal Capital Territory, Nigeria within latitudes 8°25´N to 9°20´N and longitudes 6°45´E to 7°39´E were evaluated. The distribution of K, U, and Th was principally investigated in this study area where granite rock samples were collected from forty (40) locations in the area. The analysis of the granite rock samples using a well calibrated NaI(Tl) detector reveals the contents and the distribution of the radioactive elements. The results also 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 using a standard equation, with 238 U as the major element which predominates in heat production in the study area, with 232 Th also contributing significantly while 40K is a trace elements. The radiogenic heat production elements (RHPE) contribution shows that all the points on the sites have the same pattern of radiogenic heat production contribution of the elements to the radiogenic heat production (RHP).

Keywords

Radiogenic Heat, Radioactive, Elements, Geothermal Energy, Abuja

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1. Introduction

Geothermal energy is produced by the heat of the earth. It generates reliable heat and emits almost no greenhouse gases. Geothermal energy is a dependable 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 considerable environmental advantages because geothermal emissions contain no chemical pollutants or waste, they consist mostly of water, which is re-injected underground.

One of the sources of the Earth's internal heat is the heat produced by the decay of long-lived radioactive isotopes. This is the major source of the Earth's interior heat, which in turn, powers all geodynamic processes [Philip 2005].

During radioactive decay, mass is changed into energy. Except for the tiny amount associated with the antineutrino and neutrinos generated in β- and β+ decay or electron capture, respectively, all of the energy ends up as heat. During decay process of the radioactive nuclides in rocks, emission of α, β, γ particles change into radiogenic heat [9]. The amount of radiogenic heat per unit time (i.e. rate of radiogenic heat production) generated from rocks is independent of occurrence forms, temperature and pressure of the rocks, but determined only by the concentration of the radioactive nuclides in the rocks [11]. Certain peaks in the corresponding γ-spectra are characteristic for the different decay series while the continuous background spectrum is due to

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Compton-scattering and photoelectric absorption. The assessment of the amount of radioactive elements was the subject of several studies during the last few decades, due to its importance in modelling the thermal evaluation of the lithosphere. The radioactive isotopes 232 Th, 40K, and 238U contribute most of the terrestrial heat flow. If we want to understand the nature of the mantle, heat generating potential and the crust of the earth, then these elements are fundamental. The energy emitted by all of these decay processes, consisting of the kinetic energy of the emitted particles and the γ-radiation associated with the different decay processes, is absorbed in the rocks and finally transformed into heat. The study of the radiogenic heat production is important in shedding brightness on any anomalously high thermal regime in any of region.

In this work, the radioactive method was applied to measure the concentration of radioactive elements such as Potassium (40K), Uranium (238U) and Thorium (232Th), using well calibrated Gamma- ray spectrometer. The heat produced by radioactive decay in soils and rocks is of fundamental importance in understanding the thermal history of the Earth and interpreting the continental heat flux data.

1.1. Objective of This Study

The objectives of this work are to investigate the radiogenic heat production potential, the patterns of the heat production and the major contributor to the heat production of the study area.

1.2. Geological Setting

The Federal Capital Territory (FCT), Abuja, Nigeria lies within latitudes 8°25´N to 9°20´N and longitudes 6°45´E to 7°39´E.The geology of the Federal Capital Territory is generally the crystalline basement rocks. Older granite mainly porphyroblastic granite and migmatite, porphyritic granite, granite gneiss, biotite gneiss and pockets of medium-grained biotite and biotite hornblende granite constitute the dominants rocks in the area [2] [12]. The geological map of Abuja, which shows the various rock types underlying the area, is presented in figure 1.

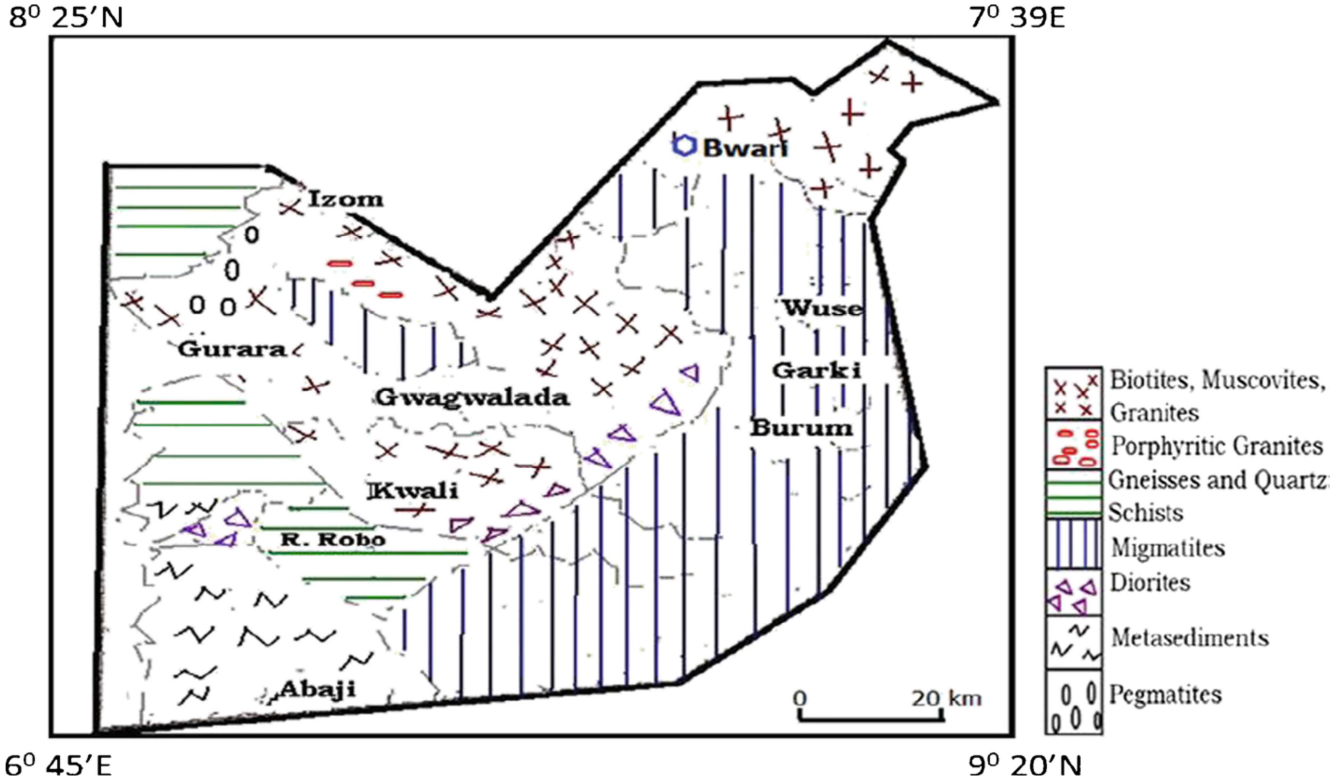

Figure 1. Geological map of Abuja [2].

1.3. Radiogenic Elements and Heat Production

The main isotopes that fulfil these situations are 238U, 235U, 232Th and 40K. The isotope 235U has a shorter half- life than 238U and release extra energy in its decay. The heat Q produced by radioactivity in a rock that has concentrations Cu, Cth and Ck respectively, of these elements is

$$Q = 0.00348C_k + 95.2C_u + 25.6C_{th} \quad [6] \quad (1)$$

used by [4][7]

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 important process of heat transport in solid materials. However, it is an inefficient type 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.

2. Materials and Method of Measurement

2.1. Sample Collection

A total of forty (40) granite rocks samples were collected from eight quarry sites spread across (AMAC, Bwari and Kuje) the Area Councils of Federal Capital Territory, FCT, Nigeria. Five samples were randomly collected from each quarry sites. The eight quarries selected are Arab Contractors of Nigeria (ACN), Dantata&Sawoe (D&S), Venus Mining (VQ), Dai JinJia (DJJ), Zeberced Quarry Nigeria (ZB), Titong Quarry (TG), Cappa Granite Company (CGC), and Perfect Stones Quarry (PS) and are situated at Mpape, Ushafa, Dutse-Alhaji, Durumi village, Kubwa, Pyankasa, Gosa and Kuje districts. The Area Councils (AC) that fall within the study area includes Abuja Municipal Area Council (AMAC), Bwari Area Council (Bwari) and Kuje Area Councils (Kuje). The collected samples were labeled at the point of collection and the coordinates recorded. The collected samples were put in the polythene bag and then transported to the laboratory for further processing. The selected quarry sites and their locations are listed in Table 1.

Table 1. Quarry Name and their coordinates.

Quarry name	Coordinates
Arab Contractor of Nigeria (ACN)	9.1385N7.507E
Dantata & Sawoe (D&S)	8.9137N7.279E
Dai jin jia (DJJ)	8.9177N7.2885E
Cappa (CGC)	9.2245N7.4022E
Perfect Stones (PS)	9.166N7.501E
Titong (TG)	8.9868N7.394E
Venus Mining (VQ)	9.190N7.3777E
Zeberced(ZB)	9.1603N7.311E

2.2. Sample Preparation

The collected samples were air dried at room temperature in the laboratory. The rocklab ring mill at the Centre for Energy Research and Development (CERD) were used to crushed and pulverizes the samples after which all were sieved through 2mm mesh sizes. The samples were filled into Polyvinylchloride containers (PVC) which were then hermetically sealed with the aid of PVC tape to prevent the escape of airborne ^{222}Rn and ^{220}Rn from the samples.

All the samples were weighed and stored for at least 28 days prior to measurement in order to attain radioactive secular equilibrium between ^{226}Ra and ^{228}Ac and their short lived progeny. After the secular equilibrium was attained, the gamma spectrometry measurement of the samples were then carried out using a well calibrated NaI(Tl) at the CERD.

3. Analysis

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 *Cu, Cth* and *Ck* are concentrations in ppm of Uranium, Thorium and Potassium, respectively. 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 2. 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.

4. Result 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 2. 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 3. Considering the distribution of the radiogenic heat production elements (RHPE) contribution, it shows that Abuja has a potential. This can be seen from the pattern of distribution shown in the table 3, where U is the major element which predominates in heat production while Th also contribute significantly but K is trace elements.

Report has shown that crustal rock samples of Southeastern Nigeria have Th-232 has the highest contributor to the radiogenic heat production in that region (Joshua et al., 2008) and another contrary report suggested that its 40K with highest contributor to radiogenic heat production. This might be as a result of difference in geological setting of these regions. In this study, 238U contribute more than other radionuclides in radiogenic heat production pattern of the area.

Table 2. Radionuclide activity concentration of the granite rock samples from each quarry site.

Sample code	^{40}K (ppm)	^{238}U (ppm)	^{232}Th (ppm)
ACN 1	10.79	0.87	0.98
ACN 2	17.99	0.93	0.70
ACN 3	38.42	1.01	0.86
ACN 4	14.12	0.78	0.80
ACN 5	12.56	0.94	0.71
CGC 1	36.45	0.99	0.83
CGC 2	62.74	0.90	1.08
CGC 3	60.77	0.77	0.68
CGC 4	84.46	0.84	0.81
CGC 5	45.04	0.87	1.08
D/S 1	12.61	0.91	0.72
D/S 2	43.12	0.98	0.63
D/S 3	31.67	1.01	0.26
D/S 4	21.91	0.77	0.76
D/S 5	30.12	0.79	0.46
DJ 1	56.46	1.06	0.84
DJ 2	43.77	0.94	0.41
DJ 3	46.09	1.36	0.72
DJ 4	29.00	1.27	1.03
DJ 5	30.92	1.14	1.07
PS 1	29.95	0.91	0.99
PS 2	34.91	1.17	0.97
PS 3	29.19	0.92	0.75
PS 4	10.03	1.24	0.98
PS 5	17.14	1.17	1.23
TG 1	17.72	1.08	0.33
TG 2	17.09	0.96	0.83
TG 3	56.73	0.78	0.80
TG 4	28.85	0.87	0.96
TG 5	23.98	0.85	1.15
VQ 1	20.90	0.46	0.41
VQ 2	17.45	0.58	0.56
VQ 3	22.79	0.47	0.68
VQ 4	21.57	0.72	0.95
VQ 5	31.39	0.80	0.61
ZB 1	22.30	1.05	0.57
ZB 2	31.80	1.04	0.92
ZB 3	18.28	0.89	0.68
ZB 4	35.84	0.88	1.17
ZB 5	47.82	0.94	1.42

Table 3. Potential radiogenic heat productions in pw/kg.

S/N	Locations code	^{40}K	^{238}U	^{323}Th	Total Heat
01	ACN 1	0.038	82.824	25.088	107.95
02	ACN 2	0.063	88.536	17.920	106.52
03	ACN 3	0.134	96.152	22.016	118.30
04	ACN 4	0.050	74.256	20.480	94.79
05	ACN 5	0.044	89.488	18.178	107.71
06	CGC 1	0.127	95.248	21.248	116.62
07	CGC 2	0.218	85.680	27.648	113.55
08	CGC 3	0.211	73.304	17.408	90.92
09	CGC 4	0.294	79.968	20.736	101.00
10	CGC 5	0.157	82.824	27.648	110.63
11	D/S 1	0.044	86.632	18.432	105.11
12	D/S 2	0.150	93.296	16.128	109.57
13	D/S 3	0.110	96.152	6.656	102.92
14	D/S 4	0.076	73.304	19.456	92.84
15	D/S 5	0.105	75.208	11.776	87.09
16	DJ 1	0.196	100.912	21.504	122.61
17	DJ 2	0.152	89.488	10.496	100.14
18	DJ 3	0.160	129.472	18.432	148.06
19	DJ 4	0.101	120.904	26.368	147.38
20	DJ 5	0.108	108.528	27.392	136.03
21	PS 1	0.104	86.632	25.344	112.08
22	PS 2	0.121	111.384	24.832	136.34
23	PS 3	0.102	87.584	19.200	106.89
24	PS 4	0.035	118.048	25.088	143.17
25	PS 5	0.060	111.384	31.488	142.93
26	TG 1	0.062	102.816	8.448	111.33
27	TG 2	0.060	91.392	21.248	112.70
28	TG 3	0.194	74.256	20.480	94.93
29	TG 4	0.100	82.824	24.576	107.50
30	TG 5	0.083	80.920	29.440	110.44
31	VQ 1	0.073	43.792	10.496	54.36
32	VQ 2	0.061	55.216	14.336	69.61
33	VQ 3	0.080	44.744	17.408	62.23
34	VQ 4	0.075	68.544	24.320	92.94
35	VQ 5	0.109	76.160	15.616	91.89
36	ZB 1	0.078	99.960	14.592	113.68
37	ZB 2	0.111	99.008	23.552	122.67
38	ZB 3	0.064	84.728	17.408	102.20
39	ZB 4	0.125	83.776	29.952	113.85
40	ZB 5	0.166	89.488	36.352	126.01

Table 4. Average heat value produced for each location with coordinate (pw/kg).

Sample code	^{40}K	^{238}U	^{323}Th	Total heat produced(Q)
ACN	0.066	86.25	20.736	107.05
CGC	0.201	83.405	22.938	106.54
DS	0.097	84.918	14.490	99.51
DJ	0.143	109.861	20.838	130.84
PS	0.084	103.006	25.190	128.28
TG	0.100	86.442	20.846	107.34
VQ	0.080	57.691	16.435	74.21
ZB	0.109	91.392	24.371	115.87

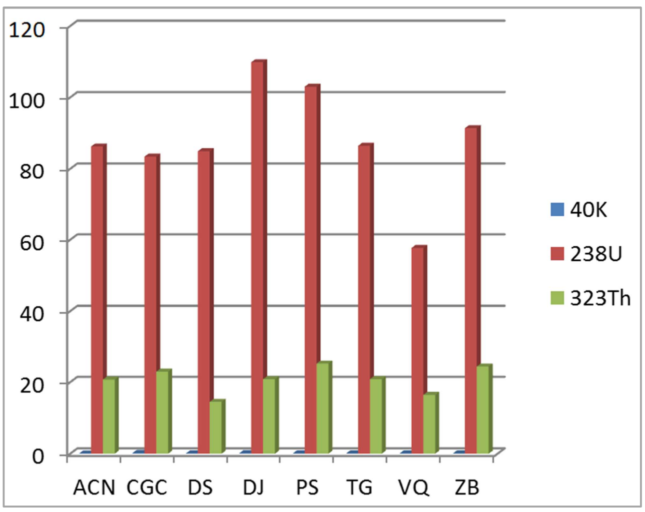

Figure 2. Trends of radiogenic heat production of the study area.

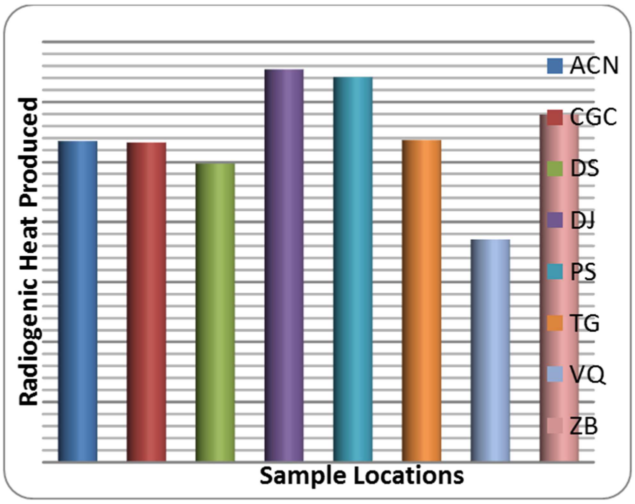

Figure 3. The total radiogenic heat produced per sample locations.

5. Conclusions

Granites typically have high concentrations of the unstable isotopes of uranium, thorium and potassium which decay and produce radiogenic heat [10]. The study has showed the presence of radionuclides in the granite rock sample collected with variation in their contribution to the radiogenic production because of the geology and it is seen from the study that 238U is the major contributor to the radiogenic heat production of the FCT, Abuja while 323 Th contribution is fair and 40K is a trace element (figure 2) and (table 4). DJ and PS have the highest heat produced while VQ has the lowest heat produced in the study area (figure 3) and (table 4).

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