Radiogenic heat production in pebble from rocks in Ekiti State, Nigeria

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A simple model is proposed for obtaining radiogenic heat production in crystal rocks in Ekiti State, Nigeria. The model is based on measurement of radionuclides such as Potassium, Uranium and Thorium Concentrations in the rock samples using NaI (TI) detector. To assess the validity of the results obtained from the model, the results are compared with the data of other researchers. The total value of heat produced range from 1.60 to 4.97 $pWkg^{-1}$, with a mean value of 2.73 $pWkg^{-1}$. Heat flow in the rock samples oscillates between 12.53 and 38.46 mWm^{-2} with a mean value of 21.37 mWm^{-2}. These values lie within the upper bounds of heat flow data around the world.

I. INTRODUCTION

Many analyses have been made of the Potassium, Uranium and Thorium in the rocks forming the continental and oceanic crusts, and in samples of the earth's mantle exposed as uplifted slices in mountain belts or as xenoliths in basalts, massif peridotites, kimberlites, eclogites, pyroxenites and megacrystalline assemblages [1-3].

Radioactive decay gives off heat. The role of radiogenic decay in generating high-temperature thermal regimes in near-normal-thickness crust has been largely ignored [4]. This oversight reflects a perception that radiogenic – heat-production concentrations are generally too low to generate significantly elevated conductive thermal regime especially, in Ekiti state southwestern Nigeria [5]

Heat flowing from the surface of the earth can be divided into three components, viz: heat from radiogenic decay of heat producing elements HPE (potassium, uranium and thorium) in lithosphere, heat conducted through the lithosphere from the underline convective mantle and orogenic heat convectively transported from magmas and fluids that enter the lithosphere from below during orogenic events [6]

Since is it well known that every rock contains natural radionuclides such as Potassium, Thorium and Uranium, the radioactivity levels depend strongly on the type of rock? The amount of heat generated is proportional to the rate of decay and the amount of radioactive material present at the time. This includes the fact that surface heat flow correlates positively with heat production in particular heat flow provinces [7-11].

The present study is undertaken to measure heat produced in pebble of rocks of Ekiti State South Western Nigeria. This is due to the fact that soil is produced from rocks by action of wind, frost, glacier, temperature, gravity through the action of chemical weathering. It is imperative to know the heat produced from these rocks that formed soil as they are being used for building and construction purposes. The study area lies on longitude 7º 37' east of Greenwich meridian and latitude 5º 13' north of the equator. The area has a general elevation of 300-700 metres above sea level. Local peaks rise to 1000 m at Efon-Alaye. Other hill-like structures, which are less prominent, rise only a few hundred metres above the general elevation at Ikere, Emure, Ado and Aramoko to mention but few within Ekiti. The area is well drained. Among the several short coastal rivers draining the region are river Oshun, river Owena, river Elemi and river Ogbese. The rocks are of the basement complex types and though covered by some sedimentary and igneous deposits [12]. The rocks sequence in the area are pegmatite's and aplites, granitic, charnokitic rocks, the quartzite series [13,14].

II. MATERIALS AND METHOD

The coarse-grained rock samples were disaggregated in Meyer and Burger jaw crusher and powdered in a Meyer and Burger pulverizing machine at the department of Geology, University of Ibadan Nigeria. Two hundred gram (200 gm) of each rock samples were then placed in plastic containers of specific size sealed and left for 3 weeks to attain secular radioactive equilibrium before gamma counting.

The detection assembly set up for this study consists of the thallium-activated sodium-iodide detector NAI(TI), the photo multiplier tube and the multichannel analyzer (Canberra serried 10 plus MCA). The detector has a resolution of about 8% of 0.662 MeV of Cs-137, which is capable of distinguishing the gamma ray energy, considered during the measurement. The counting time of each sample was set for 10 hours (36000 secs) in order to produce a sufficient number of counts. The concentrations part per million (ppm) by weight of potassium (K), thorium (Th) and uranium (U) are shown in Table I.

TABLE I. K, U and Th concentrations.

No of samples and location		Concentration parts per million by weight		
		K	U	Th
1	Itako Emure	0.6921	0.0131	0.0211
2	Okuta Elemure	0.3718	0.0154	0.0087
3	Oke-Aremo	0.6397	0.0100	0.0252
4	Ose Emure	0.3383	0.0226	0.0173
5	Oke Ilisa Omuo	0.3569	0.02340	0.0157
6	Ori-Utagba Ikole	0.3679	0.0236	0.0239
7	Ori-Utala Ikole	0.4389	0.0225	0.0110
8	Oke-Efo Ire	1.0302	0.0223	0.0300
9	Agbayan Ikere	1.3225	0.0169	0.0104
10	Ugele Ikere	1.2175	0.0247	0.0785
11	Oke Igbara Ilawe	0.4135	0.0211	0.0028
12	Eyinrin Ilawe	0.9184	0.0211	0.0172
13	Aponkojuya Ilawe	0.3341	0.0264	0.0258
14	Uta-Olo Ilawe	1.1730	0.333	0.0702
15	Eyinrin Igede	0.4389	0.0225	0.0110
16	Olota Ado	1.0302	0.0223	0.0300
17	Esiku Ilupeju	0.9376	0.0093	0.0400
18	Umojo Ilupeju	1.1265	0.0146	0.0170
19	Aorogun Osi	0.5901	0.0141	0.0139
20	Ewekerewe Osi	1.0599	0.0343	0.0217
21	Alele Aramoko	0.6086	0.0199	0.0062
22	Ijuku Aramoko	0.7651	0.0303	0.0255
23	Eyo Ijero	0.2215	0.2004	0.0210
24	Igemo Ijero	0.8655	0.0435	0.0092

III. RESULTS AND DISCUSSION

Table I gives the various radioisotopes detected and measured with their concentrations part per million by weight in the rock samples. From this we observed that with the exception of the ^{40}K, all the other radionuclides detected and measured came from the ^{238}U and ^{232}Th decay series such as ^{214}Bi and ^{208}TI respectively. The calculated heat productions per sec in (pWkg^{-1}) are given in Table II. These were estimated using the Ryback [15] relationship, which is given as;

$$H_R = 95.2C_{(U)} + 25.6C_{(Th)} + 0.000348C_{(K)}$$

where H_R is the quantity of heat produced due to the specific activity concentrations part per million (ppm) by weight $C_{(U)}$, $C_{(Th)}$ and $C_{(K)}$ of Uranium, Thorium and Potassium in KBqkg^{-1} respectively. The total value of heat produced H_{RT} ranges from 1.5973 to 4.9677 pWkg$^{-1.}$ The mean value was calculated to be 2.73 pWkg^{-1} in the area

Heat flows out of the sample from various locations within the state were calculated using Turcotte and Schubert relationship [16] given as:

$$H_F = H_{RT}(Mm + Cr)/S$$

where H_F is the heat flow in (mWm^{-2}), H_{RT} is the total heat production from radioactive decay in the rock; $Mm + Cr$ is the mass of mantle plus crust given as 4×10^{24} kg and S is the total surface are of the earth given as 5.1×10^{14} m^2 [16]. Heat flow is also presented in Table II. It oscillates between 12.5278 and 38.9624 mWm^{-2} with a mean value of 21.3748 mWm^{-2} corresponds to Archean crust estimates [17,18]. The results in the Table II show that heat flow at Ose Emure (20 mWm^{-2}), Ori-Utala Ikole (19 mWm^{-2}), Eyinrin Ilawe (19 mWm^{-2}), Eyinrin Igede (19 mWm^{-2}) and Eyo Ijero (19 mWm^{-2}) correspond to Archean crust estimates [17,18]; while those of Oke-Ilesha Omuo (29 mWm^{-2}), Ewekerewe Osi (30 mWm^{-2}) and Ijuku Aramoko (28 mWm^{-2}), Oke–Efo Ire (23 mWm^{-2}), Aponkojuya Ilawe (25 mWm^{-2}) and Olota Ado (23 mWm^{-2}) went with Bulk crust estimates [19].

TABLE II. Heat production and heat flow.

No of samples and location		Heat production per sec 10^{-12}Wkg^{-1}				Heat flow
		K	U	Th	Total	(mW/m^2)
1	Itako Emure	0.0002	1.2470	0.5400	1.7872	14.0173
2	Okuta Elemure	0.0001	1.4661	0.2227	1.6889	13.2463
3	Oke-Aremo	0.0002	0.9520	0.6451	1.5973	12.5278
4	Ose Emure	0.0001	2.1515	0.4429	2.5945	20.3490
5	Oke Ilisa Omuo	0.0001	3.2368	0.4019	3.6388	28.5390
6	Ori-Utagba Ikole	0.0001	2.2467	0.6118	2.8586	22.4204
7	Ori-Utala Ikole	0.0002	2.1420	0.2816	2.4238	19.0102
8	Oke-Efo Ire	0.0004	2.1230	0.7680	2.8914	22.6776
9	Agbayan Ikere	0.0005	1.6089	0.2662	1.8756	14.7106
10	Ugele Ikere	0.0004	2.3514	0.0096	4.3614	34.2071
11	Oke Igbara Ilawe	0.0001	2.0087	0.0717	2.0805	16.3176
12	Eyinrin Ilawe	0.0003	2.0087	0.4403	2.4493	19.2102
13	Aponkojuya Ilawe	0.0001	2.5133	0.6605	3.1739	24.8933
14	Uta-Olo Ilawe	0.0004	3.1702	1.7971	4.9677	38.9624
15	Eyinrin Igede	0.0002	2.1420	0.2816	2.4238	19.0102
16	Olota Ado	0.0004	2.1230	0.7680	2.8914	22.6776
17	Esiku Ilupeju	0.0003	0.8854	1.0240	1.9097	14.9780
18	Umojo Ilupeju	0.0004	1.3900	0.4352	1.8256	14.3184
19	Aorogun Osi	0.0002	1.3423	0.3558	1.6983	13.3200
20	Ewekerewe Osi	0.0004	3.2654	0.555	3.8213	29.9710
21	Alele Aramoko	0.0002	1.8945	0.1587	2.0534	16.1051
22	Ijuku Aramoko	0.0003	2.8846	0.6528	3.5377	27.7467
23	Eyo Ijero	0.0001	1.9421	0.5376	2.4798	19.4494
24	Igemo Ijero	0.0003	4.1412	0.2355	4.3770	34.3294

IV. CONCLUSION

The crustal values of potassium, uranium and thorium adopted constitute 50-80% of both Archean crust estimates and Bulk crust estimates [20]. The heat flow in the samples may be the result of intrinsically heat production in the crust or from refraction of heat flow from Archean cratons due to the presence of thick mantle roots. These values lie well within the upper bounds of the heat flow data. The existence of these anomalous heat- production concentrations in the rocks in Ekiti state has important implications for generating high geothermal gradient regimes without searching for external heat source.

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