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RADIOGENIC HEAT PRODUCTION IN CRUSTAL ROCK SAMPLES FROM CROSS-RIVER STATE, NIGERIA

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ABSTRACT

Radiogenic heat production of some rock samples from Cross-River State, Nigeria, obtained from Laboratory analysis of Uranium, Thorium and Potassium using a gamma-ray spectrometer is reported in this paper. The samples are representative of the major rock types in the state. The contribution of each of the radioelements to total heat production in the region studied may be seen as 4.81%, 48.21%, and 46.98% by ^{40}K, ^{238}U and ^{232}Th respectively. The radiogenic heat production is found to depend on the rock type.

KEY WORDS: Radiogenic heat, Radionuclide, gamma-ray spectrometer, geothermal.

INTRODUCTION

Geophysical methods play a key role in geothermal exploration since many objectives of geothermal exploration can be achieved by these methods. The geophysical surveys are directed at obtaining indirectly, from the surface or from shallow depth, the physical parameters of the geothermal systems. In geothermal exploration an approach which is capable of providing a high level of confidence level that geothermal fluids will be recovered on drilling is sought rather than high level of resolution as in other geophysical exploration techniques like seismology and resistivity surveys.

The various geophysical techniques in use in exploration for geothermal energy include: subsurface (shallow) temperature measurements (Kintzinger, 1956, Lee, 1977,and LeSchack and Lewis, 1983); Geochemcial thermometric method (Sigvaldason, 1973, Rajver, 2000); Electrical methods (Banwell and MacDonald, 1965, Davenport et al., 2003, Tripp and Ros, 1997); Magnetotelluric method (Johnston et al, 1992, Ushijima et al, 2000); Gravity method (Sumintadireja et al, 2000) Aeromagnetic and Magnetic surveys (Reynolds et al, 1990, Salem et al., 1999, 2000); Seismic method (Keller, 1981, Rajver et al., 1996) and Radioactive method (Pasquale et al., 1997, Louden and MaresChal, 1996). Each of these methods has its advantages and disadvantages. Some lack the maturity under difficult conditions while 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.

In this study, the radioactive method is used in measuring the concentration of radioactive elements - Potassium (^{40}K), Uranium (^{238}U) and Thorium (^{232}Th) using Gamma-ray spectrometer. The results are aimed at understanding the rock types responsible for the heat in the Earth in the studied area.

The gamma-ray spectrometry method is widely used in Earth's sciences for the determination of naturally occurring radioactive materials (Chiozzi et al., 2000). Heat produced by radioactive decay in rocks is of fundamental importance in understanding the thermal history of the Earth and interpreting the continental heat flux data (Chiozzi et.al., 2000)

Cross River State is on of the South-South States of Nigeria and shares a common boundary with Akwa Ibom, Anambra, Benue, Ebonyi and Imo States. Her boundary is with Eastern is the Cameroon Republic.

The State is characterized by both basement complex (Crystalline rocks) and sedimentary formations (Oshin and Rahaman,1986; Akpanowo, 2003). The land surface is underlain by rocks of varying ages and composition, ranging from young quaternaries to ancient rocks laid down some one to five hundred million years ago.(Abasiattai, 1987). These are: Alluvium – a mixture of silt and sands, North of the alluvium extend a different rock type known as coastal plains sands which vary greatly in texture, three shale groups of varying composition outcrop immediately east and north-east of the Coastal Plains sands. The three groups outcrop in a rapid succession at Biakpan, Aningeje and Odukpani where they are intercepted with clays and limestone.

The rest of the state is covered by a complicated system of ancient rocks, known as basement complex. They extend for some 10,000km^2 conveying most of western Odukpani, northern Akamkpa, eastern Obubra and the Cross River Valley South of Ikom where they are locally masked by tertially materials only to reappear north of Ikom through the whole of Obudu Local Government Area. (Abasiattai, 1987).

DATA ACQUISITION

The process of data acquisition involves both fieldwork and laboratory measurements. 14 rock samples were collected from different locations in Cross River State. The samples were chiseled out from in-situ rocks and were identified at the Dept of Geology, University of Ibadan. The samples were then sealed and labelled in 1000ml Marinelli containers, dry-weighted and stored for three weeks before counting. This is to allow the reaching of secular equilibrium between the ^{226}Ra and ^{222}Ra and their products. The rock samples were collected from different locations scattered over the state to make them representative enough of the major rock types in the state.

LABORATORY MEASUREMENT

A gamma-ray scintillation spectrometry system was used for the measurement of the natural radionuclide concentration in the different rock samples collected for this study. The spectrometer is a Canberra 7.6cm X 7.6cm

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NaI(T1) (Model No. 802-series detector. The resolution of the detector is about 8% at ^{662}KeV of ^{137}Cs, which conforms to the rule (Farai and Sanni, 1992, Jibiri, et al, 1999).

The ability of the NaI(T1) gamma ray spectrometer to differentiate between radiation energies and sources in the environment is the basis of its application in this work.

ANALYSIS

The procedures proposed by Chiozzi et al., 2000; Tzortzis et al., 2003 and EG and ORTEC, 1999 are used to obtain the concentration in BqKg^{-1}. Conversion to ppm (parts per million) was achieved using the conversion factors 0.0302,12.2222, and 4.0740 of BqKg^{-1} to 1ppm for ^{40}K, ^{238}U, and ^{232}Th respectively.

To calculate the radiogenic heat production we use the well-known equation by Rybach:

$$Q = 95.2C_U + 25.6C_{Th} + 0.00348C_k \qquad (1)$$

where

Q is the radiogenic heat rate per kilogram.

C_U, C_{Th}, and C_K are concentrations (in ppm) of Uranium, Thorium and Potassium respectively.

Finally multiplying the heat generated by the density of each rock sample we obtained rate of heat production per meter cube. This gives the measure of heat flow in the area.

RESULTS AND DISCUSSIONS

The concentration of each radionuclide (in ppm) is shown in table 1, with the uncertainties. The heat produced per unit volume is recorded in table 2. The heat produced per unit volume of the rock sample is plotted in figure 1.

It was observed that despite the lower concentration of ^{238}U in all the rock samples compared with either ^{40}K or ^{232}Th. The heat produced by Uranium is highest in six of the rock samples. This shows that heat production is not necessary a function of the concentration of the nuclides in a given rock sample but more of the type of radionuclide involved. Uranium being more massive produces more heat per decay than the other two: Potassium and Thorium.

The rock samples classified into three groups: Igneous rocks (code no CR1 - CR8); Sedimentary rocks (Code No. CR9 and CR12) and Metamorphic (code numbers CR13 – CR14). It was also observed that the heat production in igneous rocks (3.68□Wm^{-3} - 6.81□Wm^{-3}) is much higher than those of the other two types. Also among the igneous intrusions pegmatite have higher heat production than Dolerite. Heat production rate in pegmatite is comparable to those of the older granites. Thus we cannot see any noticeable influence of the age of the rock samnles on the heat production.

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

				CONCENTRATION IN PPM		
S/N	Location Code	Rock Type	Mass/Kg	K - 40	U - 238	Th - 232
1	CR1	Granite	0.1505	30237.56±1363	14.48±0.48	33.75±1.81
2	CR2	Pegmatite	0.156	29190.23±1316	11.64±0.42	39.25±2.01
3	CR3	Pegmatite	0.1128	34220.99±1597	9.70±0.48	41.03±2.25
4	CR4	Pegmatite	0.1565	14363.52±772	6.97±0.35	30.58±1.66
5	CR5	Granite	0.1355	34573.19±1550	11.12±0.45	45.87±2.34
6	CR6	Granite gneiss	0.2985	36806.81±1449	9.26±0.27	20.65±1.06
7	CR7	Granite	0.0935	14979.11±951	7.46±0.50	28.14±1.82
8	CR8	Dolerite	0.1725	10380.26±601	5.00±0.29	23.05±1.32
9	CR9	Limstone	0.18	13203.02±697	6.67±0.31	26.59±1.45
10	CR10	Limstone	0.2565	13489.82±645	4.05±0.21	13.18±0.79
11	CR11	Limstone	0.33	9857.96±478	4.61±0.19	16.92±0.88
12	CR12	Shale	0.143	28723.71±1322	5.74±0.34	18.08±1.18
13	CR13	Quartz (Muscorite)	0.1495	11136.16±662	4.13±0.30	22.68±1.36
14	CR14	Quartzite	0.165	8488.16±539	3.57±0.27	18.38±1.14

Table 2: Heat Production in Micro Watts Per Meter Cube

					HEAT PRODUCTION (microW/m^3)		
S/N	Location Code	Rock Type	Density (kg/m^3)	K - 40	U - 238	Th - 232	Total
1	CR1	Granite	2900	0.31	4.00	2.51	6.82
2	CR2	Pegmatite	2900	0.29	3.21	2.91	6.41
3	CR3	Pegmatite	3000	0.36	2.77	3.15	6.28
4	CR4	Pegmatite	2900	0.14	1.92	2.27	4.33
5	CR5	Granite	2800	0.34	2.96	3.29	6.59
6	CR6	Granite gneiss	3000	0.38	2.64	1.59	4.61
7	CR7	Granite	2800	0.15	1.99	2.02	4.16
8	CR8	Dolerite	2830	0.10	1.35	1.67	3.12
9	CR9	Limstone	2700	0.12	1.72	1.84	3.68
10	CR10	Limstone	2630	0.12	1.01	0.89	2.02
11	CR11	Limstone	2700	0.09	1.19	1.16	2.44
12	CR12	Shale	2000	0.20	1.09	0.93	2.22
13	CR13	Quartz (Muscorite)	2800	0.11	1.14	1.68	2.93
14	CR14	Quartzite	2830	0.08	0.95	1.32	2.35

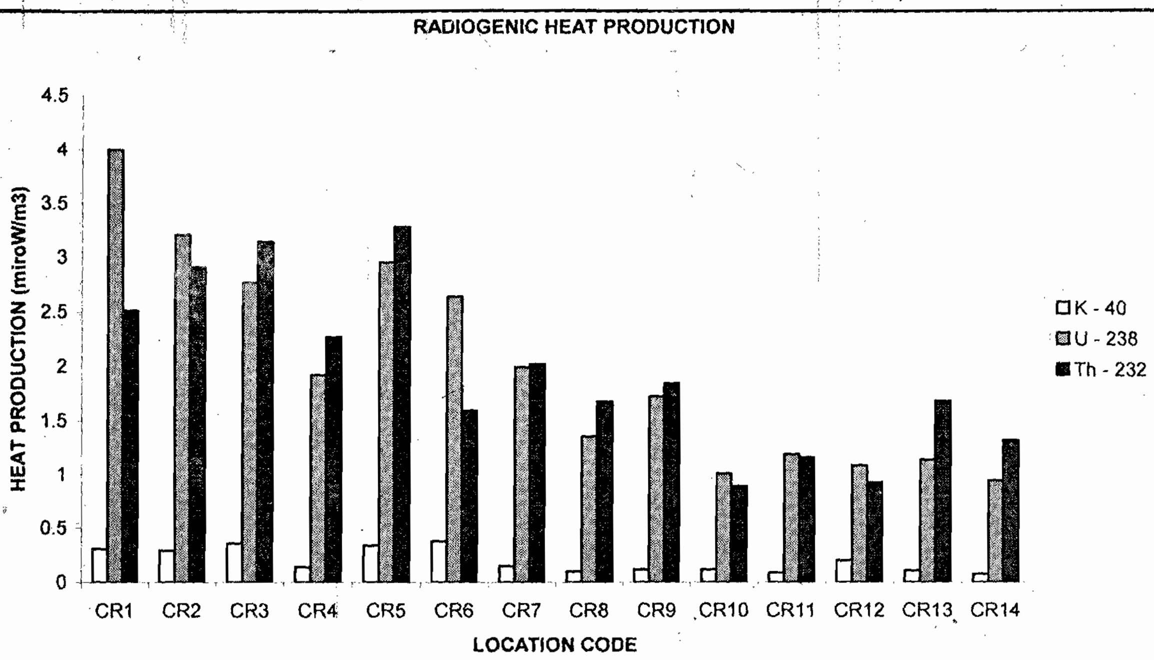

Fig. 1 Heat Produced per unit Volume of the rock sample

The calculated values of heat production in all the rock samples show weak correlation (0.35) with their densities.

Considering the heat production of each radioelement, Uranium contributes 48.21% to the total heat production. This is followed by Thorium (46.98%), while Potassium accounts for only 4.81%. This shows that Uranium and Thorium contribute the bulk of the total heat production.

CONCLUSION

In conclusion, it is observed that the heat production depends on the rock type. An integrated geophysical method is necessary to make conclusive statement about heat flow in the region under investigation. However, the general observation worldwide of higher heat production in igneous rock is obtained.

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