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DETERMINATION OF RADIOGENIC HEAT PRODUCTION USING GAMMA RAY SPECTROMETRY AROUND RAFIN REWA HOT SPRING, DAN-ALHAJI, LERE, KADUNA STATE, NIGERIA.

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Abstract

Detailed ground radiometric survey covering 400m x 400m of part of Lere sheet, Kaduna state, Nigeria was carried out using gamma ray spectrometry. The research was aimed at determining the radiogenic heat production around Rafin Rewa, Dan Alhaji the study area. The number of points used for the data collection were 400 on 20 profiles spaced 20m apart. A map of radioactive heat production was produced and anomalous areas were detected from the map. It was observed that high anomalies were recorded on the western part of the study area with longitude 8^0 30′ 54″N and latitude $10^0$25′34″E. The results of the study showed a range of radioactive heat production varying from 0.155μWm^{-3} to 154.54 μWm^{-3} with mean value of 31.993 μWm^{-3}.This is higher than the Global mean value of Radioactive Heat Production which is 2.8 μWm^{-3}. Comparing the radioactive heat production map with the contour map of individual radioelements maps and ternary image map, this study has shown that Uranium and Thorium are the major contributing elements to the radiogenic heat of the study area.

***Keywords*:** *Radiogenic, Geothermal, Uranium, Thorium, Ternary map, Contour.*

1. Introduction

Geophysical methods play a great role in the exploration of geothermal energy. Exploitation of geothermal resources for energy is a common practice in areas where geothermal gradients are high, such as tectonically active regions and in volcanic areas e.g., Iceland and Italy [1, 2]. As demand for sustainable energy increases, and the technology to harness it improves, geothermal resources in relatively quiet regions prove increasingly viable. Geophysical surveys are targeted at measuring the geophysical parameters of the geothermal systems either directly from the surface of the earth or from shallow depth. Recent works by[3] have shown great potential for geothermal heat flow in Rafin Rewa. Hence, this study was undertaken to gain insight into the distribution of radiogenic heat around the study area using radiometric method. The radiometric method used, involves measuring the concentration of radioactive elements: potassium (K^{40}), Uranium (U^{238}, U^{235}) and Thorium (Th^{232}), using Gamma- ray spectrometer. The radiometric method is widely used in Earth 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 [4].

1.1 Location of the Study Area

The study area is located around Rafin Rewa, Dan-alhaji, Lere local government, Kaduna State, Nigeria. It is approximately 3 hour, 57 minute drive via Zaria-Panbeguwa-Jos road to Lere to Dan-alhaji (125km) to exact study location (128km). It is flanked at the north by Rishiwa and Geshere Ring Complexes respectively. The study area lies between latitude 10^o25′00″N –

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10°25′44″N, and longitude 8°30′00″E - 8°30′59″E. The exact location of the hot spring manifestation is at 10°25′35.7″N and 8°30′47″E with an elevation of 729m. Fig. 1, below is the google earth map showing location of the study area.

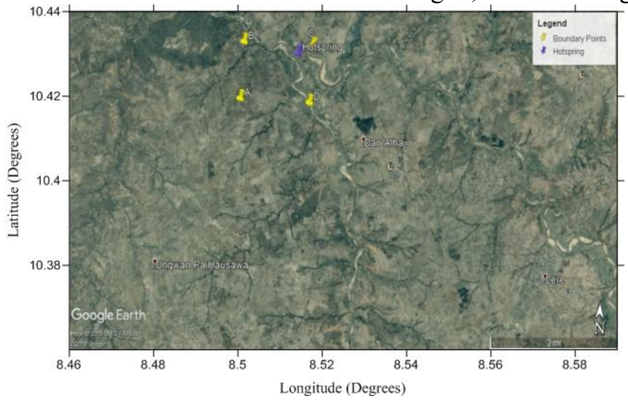

Figure 1. Google Earth Map of the Study Area.

1.2 Origin of Rafin Rewa Warm Spring

Rafin Rewa warm Spring is an ascending perennial spring that yields up to 0.1 l/s, flows from an unconfined aquifer, made up of saprolite, mostly gritty clays and clayey sands derived from the Weathering of migmatite on the Precambrian crystalline rocks of Northern Nigeria[3]. The water is fresh and alkaline, with a mineralization of 318 mg/l. The predominant cation is sodium, with 88.51 mg/l, while the predominant anion, bicarbonate is 207.0 mg/l. A gas with the smell of hydrogen sulphide bubbles and emanates from the spring as its water ascend to the surface. The water and gas are of endogenic origin, flowing from depth not less than 700 metres below ground level, thus making the spring the only known occurrence of juvenile water in Nigeria [3].

1.3 Geological Setting of the Study Area

The area is located at the fringes of the Jos Plateau, to the SW (fig. 2), the centre of the Nigerian Orogenic Younger Granite province of Jurassic age, and directly east of the nearby Rishiwa ringcomplex. The area is well drained by a good network of rivers most of which take their source from the nearby ring complexes of the Jos plateau (Fig. 2). The Geology is composed of migmatite gneiss (fig. 3) as the oldest rocks, Pan African granites and bauchites [3]. The bauchite is an unusual rock of acid to intermediate composition, containing, in addition to fayalite, extremely iron rich pyroxenes (ferrohedenbergite and orthoferrosilite) [5]. The topography of the area is more or less flat laying with the migmatites occurring as low lying exposures, while the granitic rocks stands out conspicuously thereby dotting the landscape.

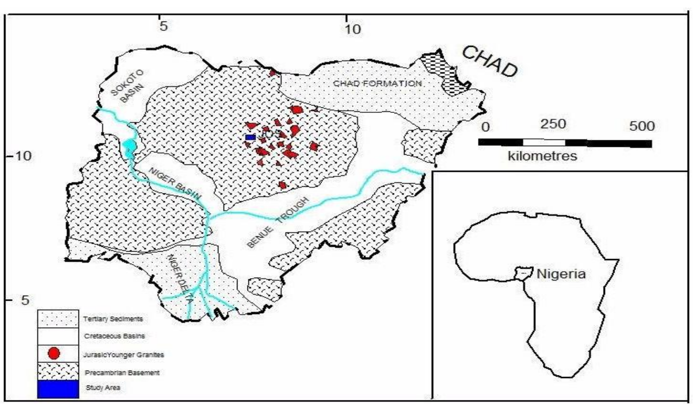

Figure 2. Geological Map of Nigeria Showing the Study Area [3].

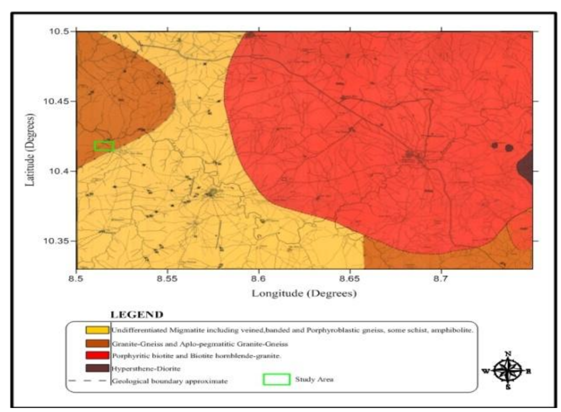

Figure 3. Simplified Map of Lere's Bedrock Geology Showing the Approximate Location of the Study Area adopted from NGSA [9].

2. Materials and Method

Digital Integral Spectral Analyser (DISA 300) gamma ray spectrometer, Geographical Positioning System (GPS), Measuring Tape (100m) Long, Hammer and Pegs were used for the survey.

The procedure for taking readings involved placing the spectrometer at each point and taking readings in the three channels. The instrument recorded activities in counts per second. It took an average of 5 minutes to take readings at one point. A Global Positioning System (GPS) was used to measure the latitude and longitude coordinates at each Station. The measurements were taken in orderly direction by N-S direction and an area was gridded 400 m by 400 mfor effective coverage of the survey site, at spacing intervals of 20 m between stations.Radiometric method was used by applying Gamma ray spectrometry in order to detect/ measure gamma ray emitted from radiogenic isotopes of Uranium, Thorium and Potassium from the survey site. Gamma-ray spectrometry allows determination of concentrations of selected radioelements from which the heat being produced from radioactive decay can be calculated.

Before taking the reading in the study area, background counts were measured at zero gamma ray emission site (in a large pool of water close to the survey area) since radiation over water is assumed to be background. In this research the background counts obtained for Potassium K_b is 13cps, UraniumU_b is 11.7cps and for ThoriumTh_b is 3.7cps. These were deducted from the individual windows count for the three radioactive isotopes of Uranium, Thorium and Potassium at each of the measurement site as it was guided by the instrument manufacturer.

The counts obtained from gamma spectrometric measurements had to be converted to element concentrations to be meaningful. The procedure for estimating concentration of the three radioelements K, U and Th depends on the type of spectrometer used. For a threshold spectrometer such as the one used in this work, relationship between the count rates and the element concentration in parts per million (ppm) is directly proportional to the background corrected and stripped count rate (Ahmed, 1994). The background corrected count rates were converted to relative surface element concentrations using the following conversion equations given by the instrument manufacturers (Exploranium).

$$eTh\ (ppm) = K1\ (Thc - Thb) \quad (1)$$

$$eU\ (ppm) = K2[(Uc - Ub) - S1(Thc - Thb)] \quad (2)$$

$$\text{And } K\ (\%) = K3[(Kc - Kb) - S2(Uc - Ub) - S3(Thc - Thb)] \quad (3)$$

Where Thb = Average background reading in the Thorium channel

Ub = Average background reading in the Uranium channel

Kb = Average background reading in the Potassium channel

K1, K2, K3 and S1, S2, S3 are the sensitivity constants and stripping ratios for the spectrometer channels respectively. Using the constants supplied by the manufacturer, equation (1), (2), and(3) becomes,

$$eTh\ (ppm) = 13.3*(Thc - Thb) \quad (4)$$

$$eU\ (ppm) = \frac{200*[(Uc - Ub) - 0.62\ (Thc - Thb)]}{41} \quad (5)$$

$$\text{And } K\ (\%) = \frac{[(Kc - Kb) - 0.68\ (Uc - Ub) - 0.83\ (Thc - Thb)]}{154} \quad (6)$$

Equation (4), (5), and (6) were used to estimate equivalent surface concentration eTh, eU, and K% respectively.

The data were inserted in Excel sheet together with the coordinates of each data point and then data sheet was used in surfer program software and Geosoft Oasis montaj for gridding and plotting the contour maps.

The value of K (%), U (ppm) and Th (ppm) can be used to calculate the heat that is being produced by the radioactive decay in the rock (i.e., the radiogenicheat production). Radioactive Heat production (RHP) was calculated using Equation (7) which was developed for calculating the energy released during gamma decay of the radioelements.

According to [6, 7] Radioactive Heat Production (RHP) from ground gamma ray spectrometry data is given by the expression:

$$RHP\ (\mu Wm^{-3}) = \rho\ (0.0952C_u + 0.0256C_{Th} + 0.0348C_k) \text{ - - - - - - - - - - - - - - } (7)[6, 7].$$

Where: RHP=radiogenic heat production, ρ= density of rock adapted from [11], C_U, C_{Th}, C_K are the concentration of Uranium, Thorium and Potassium respectively.

4. Results and Discussion

The Uranium, Thorium and Potassium concentrations maps and radioactive heat map presents the colours, contours within the study area.

The Radiogenic Heat Production (RHP) Map shows the distribution of the heat around the research area detected on the ground surface and its intensity is presented in micro Watts per cubic metre unit (μWm^{-3}). Therefore the contours and colours shows the value range of radiogenic heat flowing from the underground or shallow depth to the surface.

TABLE 1: SHOWING RADIOACTIVE HEAT PRODUCED AT EACH STATION BY RADIOACTIVE ELEMENTS POTASSIUM, URANIUM AND THORIUM.

STATION NUMBERS	LONGITUDE (DEGREES)	LATITUDE (DEGREES)	POTASSIUM (K %)	URANIUM (U ppm)	THORIUM (Th ppm)	HEAT PRODUCTION HP(A)μMw/3
1	10.427667	8.514472	1.167772727	79.49253659	17.29	22.54266553
2	10.427611	8.514306	0.169590909	99.00473171	17.29	27.64657342
3	10.4275	8.514139	0.147318182	74.59936585	30.59	22.09225285
4	10.427417	8.514028	0.048551948	98.8837561	123.69	35.22928413
5	10.427306	8.513861	0.211798701	50.07302439	150.29	24.14089025
6	10.427167	8.513722	0.10011039	118.4261951	97.09	38.53685253
7	10.427056	8.513583	0.175175325	152.6330244	43.89	43.84896327
8	10.426944	8.513472	0.018331169	79.46229268	43.89	24.32929013
9	10.426806	8.513306	0.074850649	20.81985366	136.99	15.37647684
10	10.426722	8.513167	0.013850649	11.1544878	57.19	7.074069077

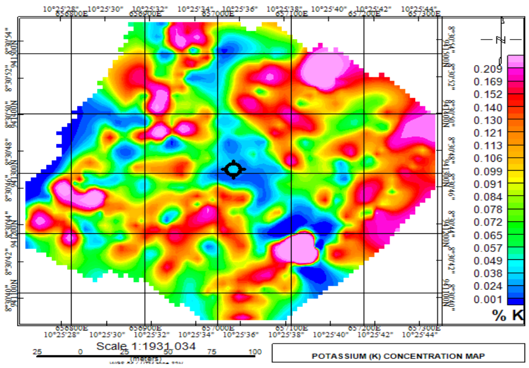

Fig 4: Map Showing the Concentration of Potassium (K) within the Study Area.

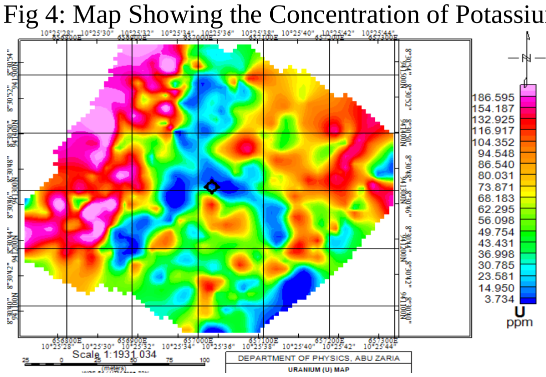

Fig. 5. Uranium Concentration Map of the Study area.

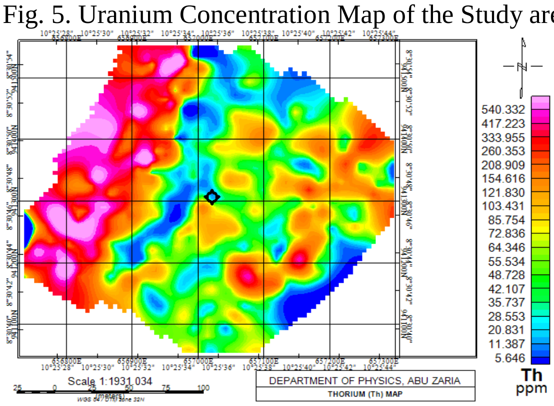

Fig.6. Thorium Concentration Map of the Study area.

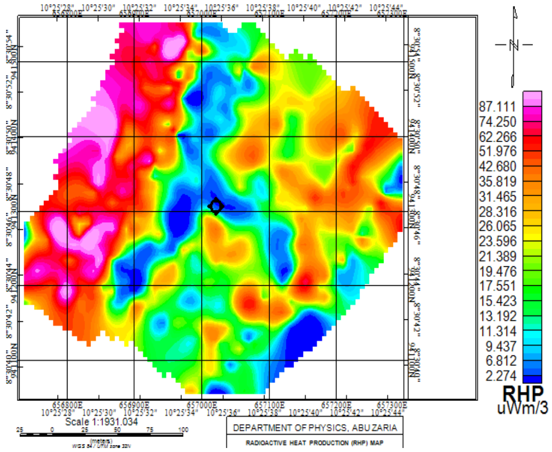

Fig 7. Radioactive Heat Production Map in the Study Area.

TERNARY IMAGE OF THE ANALYSED DATA.

The table 4.1 illustrates how the various colors that appear in a ternary image can be interpreted. Red areas are high in Potassium, green areas are high in Thorium and blue areas high in Uranium. Cyan areas are high in Thorium and Uranium; magenta areas are high in Potassium and Uranium and yellow areas are high in Potassium and Thorium. White areas have high levels of all three radio-elements and black areas have low levels of all the three radio-elements of interest (U, Th and K).

Table 2. Preparation and Interpretation of Ternary Images of Spectrometry data [8]

Radioelement	Potassium	Thorium	Uranium
Red	High	Low	Low
Green	Low	High	Low
Blue	Low	Low	High
Cyan	Low	High	High
Magenta	High	Low	High
Yellow	High	High	Low
Black	Low	Low	Low

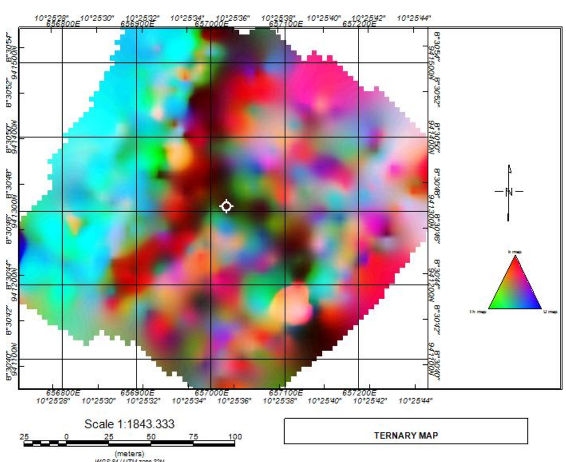

Fig 8. Ternary Map of the Study Area.

5. Discussion and Conclusion

Interpretation of potassium concentration distribution, Uranium concentration distribution, and Thorium concentration distribution; figures 4, 5 and 6 respectively, were done to determine areas of high concentrations of individual radioactive elements and radiogenic heat production map (Figure 7) to determine radiogenic heat around the study area. The estimated radioactive heat production values are governed by the amount of Uranium, Thorium, and Potassium measured from ground spectrometric survey and, therefore, they are surficial or apparent values. In general, the radioactive heat production varies greatly with rock type. Any rock in the study area that indicate highest amount of radiogenic heat production from these radioelements can be characterized by high heat flow.

6. Conclusion

The area possesses a range of radioactive heat production varying from 0.1552 μWm^{-3} to 154 μWm^{-3} with mean value of 31.993 μWm^{-3}. High heat-producing granites record HPR values well in excess of the global mean of 2.8 μWm^{-3}. The radioactive heat production in the study area may be from the existence of migmatite gneiss since gneiss had more of the radiation than many other rocks type and the geology of the study area is composed of migmatite gneiss as the oldest rocks, Pan African granites and bauchites.

Figure 7 above, the distribution of radioactive heat production which cover some parts of the study area and it is higher in the western part along northwest part of the map and some locations in the eastern part along northeast direction along longitude 8^0 30′ 40″ – 8^0 30′ 54″ and latitude 10^0 25′ 28″ – 10^0 25′ 34″. From the map of the individual radioactive elements (Potassium, Uranium and Thorium) concentration in North-Western part of the study area can be considered as area with highest gamma rays concentration, While the RHP map shows that North-Western part of the study area can be characterized as the area with high distribution of radiogenic heat production and can be concluded that Uranium and Thorium are the two major contributor to the radiogenic heat in the study area.

References

[1] Yerima Mohammed Kwaya, EwaKurowska, Abdullahi Suleiman Arabi, (2013). Geothermal Gradient and Heat Flow in the Nigeria Sector of the Chad Basin, Nigeria. Computational Water, Energy, and Environmental Engineering, 2016, 5, 70-78.http://www.scirp.org/journal/cweee http://dx.doi.org/ 10.4236/ cweee.2016.52007

[2] Pasquale P.V and Vedoya M. (2000). Ground Radiometric Survey of U, Th, and K on Lipori Island, Italy Journal of Applied Geophysics, 38,207-217.

[3] Garba M..L, E. Kurowska, K. Schoeneich, I. Abdullahi (2012). *Rafin Rewa Warm Spring, a new Geothermal Discovery.*American International Journal of Contemporary Research Vol. 2 No. 9; September 2012.

[4] Chiozzi, R. Pasguale, V.M. Verdoya, P. Cabella and D. Russo, (1997). *Thermo physical Properties of the LapariIavas (Southern Tyrrherian Sea)*. Annal Di. Genocidal, XL (6): 1493- 1503.

[5] Oyawoye, M.O., and Makanjuola, A.A.(1972): Bauchite: a fayalite-bearing quartz Monzonite. Proc. 24th LG.C.(Montreal), Sect. 2, 251-266.

[6] Rybach, L. (1988): Determination of Heat Production Rate. In: Hänel, R., et al. (eds.). Handbook of Terrestrial Heat-Flow Determination, Kluwer Academic Publishers, Dordrecht (1988), 125-142.

[7] Saleem, A. &Fairhead, D. (2011). Geothermal reconnaissance of Gebel Duwl area, Northern Red Sea, Egypt using airborne magnetic and spectral gamma ray data. Getech. Pp. 1-22.

[8] Preparation and Interpretation of Ternary Images of Spectrometry data-CRANK FIELD UNIVERSITY, UK.

[9] Nigerian Geological Survey Organization (NGSA), 2006, Mineral Resources Map of Nigeria, map scale 1:2,000,000.

[10] Ahmed, A.L. (1994). *Ground follow up surveys of some Radiometric Anomalies at Jingir, Plateau* State, using gamma ray spectrometry. Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria.