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Assessment of Radiogenic Heat Production in Soil Samples around Ife Steel Rolling Mill Site in Southwestern Nigeria

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ABSTRACT: In this study, the analysis of soil samples was carried out to determine the concentrations, distribution and the pattern of Radiogenic Heat Production of some heavy elements in soil samples inside a steel rolling mill in Ile-Ife, Osun State, Nigeria within latitudes 6033'N and 6046'N; and longitudes 4044'E and 4054'E. The distribution of K, U, and Th was particularly investigated in this site. Soil samples were collected from thirty (30) points along three traverses at a space interval of 20cm covering a survey area of 80cm by 60cm within the Rolling mill. The analysis of the soil samples using a cylindrical NaI(Tl) detector reveals that the contents of the radioactive elements in the soil fall below the WHO's critical values of contaminated soil. Field observations and soil properties show that the soils were derived from weathering of pre-existing sedimentary bedrocks which constitute the geology of the area. 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, with ^{40}K as the major element which predominates in heat production for the Upper profile of the study area, while ^{238}U and ^{232}Th are 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, radionuclide, geothermal energy.

1 INTRODUCTION

Geothermal energy is a reliable source of power that can reduce the need for imported fuels for power generation. It is renewable because it is based on practically limitless resource and has significant 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 main source of the Earth's internal heat, which in turn, powers all geodynamic processes [21].

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 [13], [12], [14], [15], [23]; Geochemical thermometric methods [3], [1], [20], [30]; Magnetolluric methods [9], [31]; Gravity method [29]; Aeromagnetic surveys [24], [27]; Sesmic Method [11], [22] and Radioactive Method [19], [16]. These various techniques have 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 for accuracy.

Surveying for radiometric minerals has become important over the last few decades because of the demand for nuclear fuels [11], [6]. Radiometric surveying is employed in the search for deposits necessary for this application [12], [21].

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 [2]. There are three known geothermal resource areas in Nigeria: the Ikogosi Warm Springs of Ekiti State, the Wikki Warm Springs of Bauchi State and the Rafin Rewa Warm Springs of Jos in Plateau 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 work, the radioactive method was applied to measure the concentration of radioactive elements such as Potassium (40K), Uranium (238U) and Thorium (232Th), using 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 Geological setting

The Most of Southwestern part of Nigeria belongs to the schist belt. To be specified, Osun (which is the parent case study) and Oyo belong to crystalline basement region, Ogun State belongs to basement complex (undifferentiated) region. The major rocks in the southwestern Nigeria are igneous, sedimentary and metamorphic. The igneous rocks include the older granite, pegmatite, rhyolite and dolerite while the sedimentary rocks include the Shale, Coal measures, and Coastal plains and Alluvium. The metamorphic rocks include the undifferentiated basement complex.

1.2 Radiogenic elements and heat production

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 238U, 235U, 232Th and 40K. The isotope 235U has a shorter half- life than 238U 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:

$$Q= 0.\ 00348C_k+95.2C_u+ 25.6C_{th} \quad [28] \qquad (1)$$

However, conduction is the most significant process of heat transport in solid materials. 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 [21].

Consequently, convection is also the most important form of heat transport in the fluid core.

2 Materials and Method of Measurement

The process of data acquisition involves both fieldwork and Laboratory measurements. The study area was divided into Upper, Middle and Lower profiles. The Upper profile consists of points 1-10, the Middle profile consists of points 11-20 while the Lower profile is from point 21-30. Soil samples were taken from thirty (30) points on all the profiles. The soil samples were collected from different lithologies and geological settings characterizing the areas around the site. The Fig. 1 is the cross section map showing the areas from which the soil samples were collected (the exact location is represented by each sample code) and the area where samples were collected from the steel rolling dump site. The summary of the soil types, sample location and code are presented in Table 1. The Surrounding sites are coded as follows: Upper profile (UP), Middle Profile (MP) and Lower Profile (LP) the code UP1 stands for the soil samples collected from a point in the upper profile.

The soil samples were compressed to fine grains to minimize self-absorption and to have geometry and matrix. Each sample was carefully packed in 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 40K and gamma- ray emitting nuclei in decay series of 238U and 232Th Gamma radiation analysis allows various gamma emitter to be distinguished and the quantitative content of Potassium, Uranium and Thorium to be calculated.

Concentration of 40K, 238U and 232Th 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 36000 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.

3 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.

4 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 [25], and presented in table 2.

Considering the distribution of the radiogenic heat production elements (RHPE) contribution, it can be seen from the pattern of distribution shown in the table 3, that 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 a steel rolling mill in Ile-Ife, Osun State, 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 [18]:

$$RII = \frac{\sum w}{AxN} \qquad (0 \leq index \leq 1)$$

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 works on crustal rock samples of

Southeastern Nigeria shows that Th-232 is the highest contributor to the radiogenic heat production in that region [10] while K-40 is the highest for Southwestern Nigeria. The later corresponds to the present result. This might be as a result of differences and similarities in the 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 [7] which is corroborated with the present result.

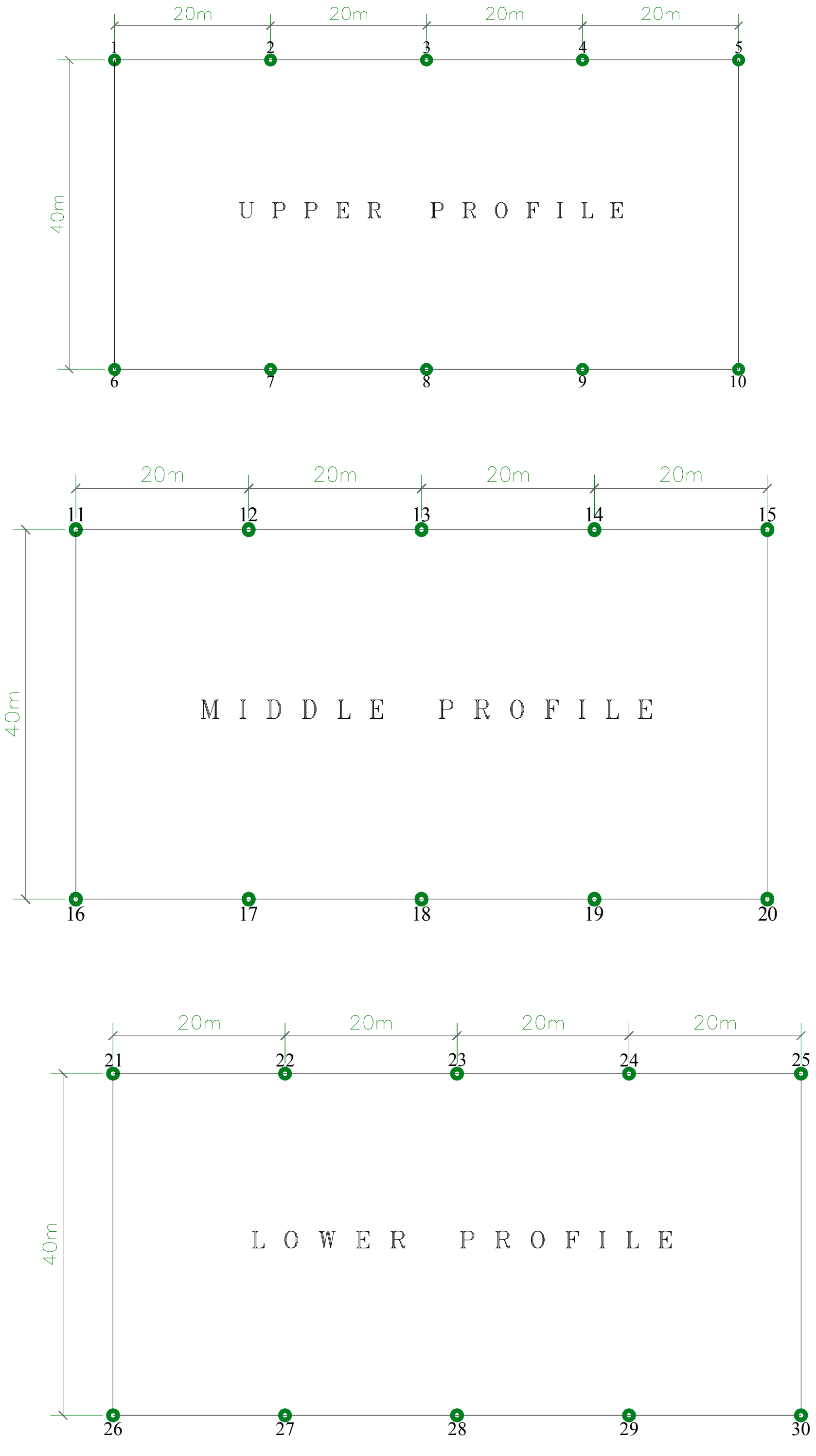

Figure 1: Survey area of Rolling Mill

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

		Concentration of Radionuclide in Ppm		
S/N	Profile Code	^{40}K	^{238}U	^{232}Th
1	UP1	24830.09	1.97	0.08
2	UP2	25506.19	1.49	0.43
3	UP3	14176.53	0.85	0.48
4	UP4	11042.8	0.85	0.50
5	UP5	54573.99	0.30	0.48
6	UP6	81577.14	0.10	0.57
7	UP7	35370.56	0.06	0.95
8	UP8	36993.16	0.02	0.46
9	UP9	941.99	0.06	0.68
10	UP10	926.57	0.19	0.80
11	MP11	3228.72	0.09	0.27
12	MP12	2373.29	0.05	0.30
13	MP13	3200.91	0.10	0.15
14	MP14	2883.80	0.17	0.21
15	MP15	2217.75	0.12	0.31
16	MP16	1663.86	0.34	0.14
17	MP17	562.07	0.32	0.08
18	MP18	1721.32	0.45	0.43
19	MP19	1803.66	0.13	0.48
20	MP20	1227.82	0.06	0.50
21	LP21	6405.29	0.81	0.48
22	LP22	919.09	0.16	0.57
23	LP23	811.55	0.36	0.95
24	LP24	8704.87	0.50	0.46
25	LP25	2235.04	0.04	0.68
26	LP26	38664.35	0.22	0.80
27	LP27	25674.86	0.15	0.27
28	LP28	17873.43	0.08	0.30
29	LP29	32629.7	0.38	0.10
30	LP30	60154.47	0.48	0.26

Table 2: Radiogenic Heat Production in pW/kg

		Heat Production in pW/kg			
S/N	Profile Code	^{40}K	^{238}U	^{232}Th	Total
1	UP1	3.29	80.90	6.23	90.42
2	UP2	3.22	28.93	1.09	33.24
3	UP3	11.93	9.76	3.16	24.85
4	UP4	8.61	5.74	18.10	32.45
5	UP5	10.79	74.81	22.29	107.89
6	UP6	121.38	6.09	22.47	38.94
7	UP7	6.99	18.45	20.93	46.37
8	UP8	5.44	8.15	28.85	42.44
9	UP9	1.61	4.71	19.82	26.14
10	UP10	6.69	9.66	16.19	32.54
11	MP11	6.28	15.96	7.71	29.95
12	MP12	3.93	11.82	26.23	41.98
13	MP13	18.11	32.57	6.92	227.6
14	MP14	2.50	30.22	9.88	42.6
15	MP15	2.13	42.51	1.73	46.37
16	MP16	28.60	12.16	1.51	42.27
17	MP17	6.01	5.87	0.21	12.09
18	MP18	22.12	77.03	6.02	205.17
19	MP19	87.12	15.42	21.09	123.63
20	MP20	79.07	33.91	1.62	114.6
21	LP21	111.72	47.85	3.80	171.37
22	LP22	90.34	4.10	13.30	236.74
23	LP23	68.33	21.30	2.65	92.28
24	LP24	100.16	13.83	12.65	152.64
25	LP25	6.21	7.85	14.98	29.04
26	LP26	4.53	28.4	1.30	34.23
27	LP27	85.12	19.31	1.21	105.64
28	LP28	88.85	35.99	82.84	207.68
29	LP29	96.92	26.24	25.65	148.81
30	LP30	76.49	8.40	22.87	107.76

Table 3: Average Radiogenic Heat Production

Profile	40K	238U	232Th
UP1-10	6.90	24.72	15.91
MP11-20	52.59	27.75	8.29
LP21-30	89.17	21.33	18.13
Average	49.55	24.60	14.11

Table 4: General Analysis of Results

Radionuclide Element	RII	Rank
40K	0.888	1
238U	0.555	2
232Th	0.555	3

5 CONCLUSIONS

It was observed from the result that radioactive minerals are present in all the soil samples and the heat production pattern of the middle and lower profiles are the same. The upper profile had a high radiogenic heat production due to the heaps of waste metal scraps dumped at the site. There is irregular contribution of these radionuclides (U, Th, and K) to the radiogenic heat production in the soil as a result of their geological location.

Hence the model of radiogenic heat production of Osun state of Nigeria has K as the major element, which predominate in heat production while U and Th are trace elements.

REFERENCES

[1] D.L. Anderson and G.R. Johnson, Application of the Self Potential Method to Geothermal. Geophysics, 38 (6), (2000), 1190 -1192.

[2] O.O. Babalola, High-Potential Geothermal Energy Resource Areas of Nigeria and their Geological and Geophysical Assessment. American Association of Petroleum Geophysicists Bulletin, 68, (1984), 231-244

[3] C.J. Bandwell and W.J. MacDonald, Resistivity Survey in New Zealand thermal areas. Eight Commonwealth mining and metallurgical Congress, Australia and New Zealand, New Zealand Section, (1965), 1- 7.

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

[5] P.V. Pasquale and M. Vedoya, Radiometric Survey for Exploration of Hydrothermal Alteration in Volcanic Sites. Journal of Geophysics, 93,(2007), 13- 20.

[6] E.A. Ehinola, Radiogenic heat production in the cretaceous sediments of Yola arm of Nigeria Benue. Through: Implications for thermal history and hydrocarbon generation. J. Applied Sci., 5, (2005), 696-701.

[7] C. Jaupart and J.C. Mareschal, Heat flow and thermal structure of the lithosphere data. , (2007), 217-251. In: Crustal and lithosphere dynamics (Ed.

[9] J.M. Johnson, L. Pellirin and G.W. Hohmann, Evaluation of Electromagnetic Methods for Geothermal Reservoir Detection. Geothermal Resources Council Translation, 16, (1992), 241- 245.

[10] E.O. Joshua O.A. Ehinola, M.A. Akpanowo and O.A. Oyebanjo, Radiogenic heat production in crustal rock samples of Southeastern Nigeria. European Journal of Scientific Research, 23 (2), (2008), 305-316.

[11] G.V. Keller, Exploration for Geothermal Energy. In: Fitch, A.A. (Ed.). Developments in Geophysical Exploration. Method. Applied Science Publication, (1981), 107- 150.

[12] P.R. Kintizinger, Geothermal Survey of hot ground near Lordsburg. New Mexico Science. 124, (1956), 629- 630.

[13] A.H. Lachenbruch and J.H. Sass, Heat flow in the United States and thermal regime of the Crust, the earth's crust, its nature and physical properties. Heaecock, J.G. (Ed.). AGU Monograph, 20, (1977) 626- 675.

[14] T.C. Lee, On Shallow- hole temperature measurements. A test study in the Salton Sea Geothermal Field: Geophysics, 42, (1977), 572- 583.

[15] L.A. Leschack, and J.E. Lewis, Geothermal Prospects Surveys. Geophysics, 48 (7), (1983), 975- 996.

[16] K.M. Louden, and J.C. MaresChal, Measurements of radiogenic heat production on basement samples from sites 897 and 900. In: Whitmarsh, R.B, Sawyer, D.S., Klaus, A. and Masson, D. G. (Eds.). College Stattion, Tx (Ocean Drilling program). Proc. ODP, Sci. Results, 149, (1996), 675- 682

[17] S.M. McLennan, Relationship between the trace element composition of sedimentary rocks and upper continental crust. Geochemistry Geophysics Geosystems 2, (2001), (article 2000GC000109).
[18] G.K. Ojo, An assessment of factors influencing contract period of construction project in South Western Nigeria. International Conference Proceeding of Faculty of Environmental Design and Management, Obafemi Awolowo University, Ile-Ife, (2007), 119 – 125.
[19] Pasguale, V.M. Verdoya, P. Chiozzi, R. Cabella and D. Russo, 1997. Thermo physical properties of the Lapari Iavas (Southern Tyrrherian Sea). Annal Di. Genocidal, XL (6): 1493- 1503.
[20] Pertamania, Liporan Mingyuan Pemboran Sumur. Report for Geothermal Division, Jakarta, (1997), 1- 4.
[21] A.O. Philip, An Introduction to Geophysical Exploration Mc Graw-Hill, New York, 70, (2005), 63-89.
[22] D. Rajver, Geophysical exploration of the low enthalpy Krsko Geothermal Fields, Slovenian. Proceeding W.G.C., (2000), 1605- 1607.
[23] T. Ramingwong, S. Lertsrimongkol, P. Asnachinda and Preservdigai, Update on Thailand Geothermal Energy Research and Development. Proceeding W. G. C., 30 (2000), 29- 68.
[24] R.L. Reynolds, J.G. Rosenbaun, M.R. Hudson and N. S. Fishman, Rock Magnetism, the distribution of Magnetic Minerals in the Earth's Crust and Aeromagnetic anomalies In: Hanna, W.F. (Ed.). Geologic Applications of Modern Aeromagnetic Surveys: U.S. Geological. Survey Bulletin, 1924, (1990), 24- 45.
[25] K. Rybach, R. Hokrick and W. Eugester, Vertical Earth Heat Probe Measurements and Prospects in Switzerland. Communication and Proceedings. 1, (1988), 67- 372.
[26] A. Salem, A. Elsirafi and K. Ushihima, Design and Application of high resolution aeromagnetic survey over Gebel Duri area and its extension, Memories of the Graduate School of Engineering, Kyushu University, 59 (3), (1999), 201- 203.
[27] A. Salem, K. Ushijima, A. Elsirafi and I. Mizunaga, Spectral Analysis of Aeromagnetic Data for Geothermal Reconnaissance of Quesri Ara, Northem Red Sea. Egypt. Proceeding W.G.C.,(2000) 4: 873- 876.
[28] G.E. Sigvaldason, Geochemical method in geothermal exploration. UNESCO, (1973), 44- 49.
[29] P.S. Suminatadireja, H. Sudarman and K. Ushijima, Gravity Data Surveys at the Kamojang Geothermal Field. Proceedings. W. G. C., (2000), 1777- 1780.
[30] A.C. Tripp and H. P. Ross, SP modeling. U.S. Department of Energy and Geothermal Energy Technical Site, (1997), 234-239.
[31] K.K. Ushijima, and W.H. Relton, 2D Inversion of VES and MT data in Geothermal Area. Proceedings W.G.C., (2000), 1909-1914.