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Earth Science

HEAT-FLOW AND THERMAL STRUCTURE OF THE SINGHBHUM CRATON, EASTERN INDIA.

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ABSTRACT Heat-flow or flux (HF) heat-production (HP) and thermal gradient (TG) were measured over the Singhbhum cratonic area using laboratory QL-10 divider-bar thermal conductivity meter, low counting level gamma ray spectrometer (GRS) and borehole temperature logging field instrument thermistor probe. Radiogenic heat production element(HPE) of the crustal rocks are important key parameter to construct lithospheric thermal structure. Radioelemental studies are extensively conducted in various provinces of Indian shield as a part of heat flow study except in the Singhbhum Craton(SC) which is located around 21°00′00″N′ to 23°15′00″N latitudes and 85°00′00″E to 86°45′00″E longitudes in the Eastern India (Pal, S.K. et al,2006). Determination of HF by systematic measurement of TG in deep boreholes and TC of the rocks pertaining those boreholes of the major rock formations and to estimate thermal structure of the Singhbhum craton. For this measurements granites and gneisses rock samples are collected in the different parts of the SC for radio elemental and HF measurements in laboratory by GRS and TC (thermal conductivity) meter instrument, from different places of East &West-Singhbhum districts of Jharkhand and Mayurbhanj and Keonjhar Districts of Orissa state belongs to SC. Granite is a felsic intrusive plutonic igneous rock composed of Quartz, Plagioclase and K-feldspar as major mineral. Accessory minerals are Biotite, Hornblend, Titanite, Apatite and Zircon along with OPAC minerals (Magnetite, Haematite). Gneiss is a high grade metamorphic rock, it is formed by the metamorphosis of granite rock. Gneiss is a felsic rock containing Orthoclase, Plagioclase Feldspar and Quartz forms the light colour bands and Biotite, Pyroxene, Amphibole is mafic mineral forms the dark colour bands core of the SC. These granites and gneisses are rich in radio elements (Th, U and K) and produces a high heat production value compare to other rock types.

KEYWORDS : Singhbhum craton, gamma-ray spectrometer, thermal conductivity, temperature gradient, heat-flow, heat-production.

Introduction

There are four cratons in the Indian shield. These are Dharwar, Bastar, Bundelkhand and Singhbhum craton. The SC is also called Singhbhum-Orissa craton in eastern India.It is made of Archaean rocks that are exposed in an area of ~ 40,000 Km² (Saha and Sarkar,1977) in Singhbhum and surrounding districts of Jharkhand and northern part of the State of Orissa. Major rocks of the SC are Singhbhum granites complexes (SBG-I, SBG-II, SBG-III), Older Metamorphic Tonalite-gneiss(OMTG) and Kolhan Group (Saha and Sarkar,1994), SBG-II is younger one. Singhbhum-Orissa craton is geologically complex and mineralogically rich area in Indian subcontinent. Geochronologic age of the sialic crust of the SC ~3700 Ma or older (Ghosh et al.1996; Mishra et al. 1999). The carbonization of the Singhbhum Archaean craton is at around 3100 Ma. HF, HP and thermal structure of all cratons has accomplished till now except Singhbhum craton. Main objectives of this paper to determine HF value of the SC for measuring the HP of major rock formations of the SC to find out the crustal HP model and to build up of the thermal structure of the SC. Mean radiogenic HP for the granites ranges between 0.9 and 1.5 $\mu W\ m^{-3}$ whereas for gneisses it is 1.1 $\mu W\ m^{-3}$. The average heat flux or Heat Flow(HF) of this craton ≥54 mWm^{-2}

Geological background of the Singhbhum craton

Indian shield is generally a large area of exposed Precambrian crystalline igneous and high grade metamorphic rocks that form tectonically stable areas. A shield is that part of the continental crust in which Precambrian basement rocks in the age range of 3.6-2.6Ga crop out extensively at the surface, consist vast areas of granitic or granodioritic gneisses, usually tonalitic composition. These terrains, constituting the continental crust, attained tectonic stability for prolonged period (since Precambrian time) and are designated cratons. The Singhbhum craton is bordered by Chhotanagpur Gneissic Complex(CGC) to the north, Eastern Ghats mobile belt to the southeast, Bastar craton to the southwest, and alluvium to the east.

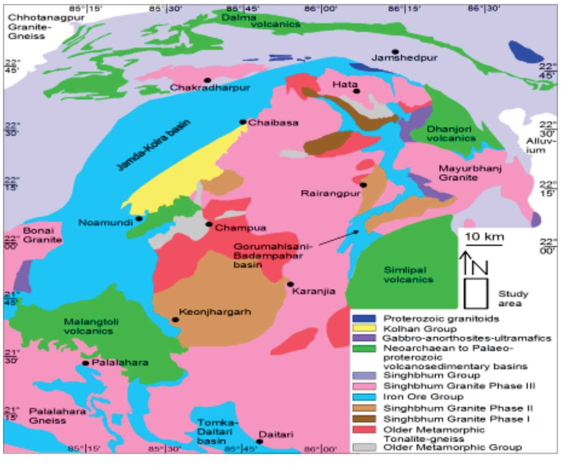

Fig.1: Geological map of the Singhbhum craton (modified after Saha, 1994) showing three phases of granites (SBG-I, II, III), Older Metamorphic Tonalite Gneiss (OMTG) and Older Metamorphic Group (OMG).

Table1: Geological succession of the Precambrian rocks of SC and surrounding areas (after Sarkar et al.,1969):

South of cupper belt thrust zone in Singhbhum	North of cupper belt thrust zone in Singhbhum
End of Singhbhum Orogenic Cycle (c.850 m.y.)	
Biotite granite-gneiss of SE Singhbhum Soda granite, granophyre Newer-Dolerites Granophyres (East of Gorumahisani) ? Chakradharpur granite gneiss Gabro-anorthosite (1470 m.y.) ? Kuilapal granite gneiss Ultramafic intrusions (within and outside of Singhbhum granite) Kolhan group (c.1500-1600 m.y.) Jagannathpur lavas (1600-1700 m.y.) Dhanjori Dhanjori Lavas Formation Quartzite Conglomerate ……Dalma lavas overlap… Dhalbhum Singhbhum Formation Group ? (2000-1700 m.y.)	

Unconfirmity	
End of Iron Ore Orogenic Cycle (c.2700 m.y.)	
Singhbhum granite Epidiorites (intrusives)	
Iron ore Group	Upper shales with sandstones and volcanics Banded hematite jasper Lower shales Basic lavas Sandstone and Conglomerate
Unconformity	
End of Older Metamorphic orogenic cycle (c.3200 m.y.) Granitic activity Basic intrusives Older metamorphic group: calc-gneisses, Calc-schist, hornblende schist, quartzite and quartz schist	

Gravity data in Singhbhum craton

Table 2: Stratigraphic column for Singhbhum and surrounding areas with measured densities of major rock units (after Verma et al.,1978) over SC:

Group and Formation	Rock Type	Mean density (g/cm^3)
Gabbro/dolerite	Metagabro/ Metadolerite	3.05
Singhbhum Group (i) Chaibasa Formation (ii) Dhalbhum Formation	mica schists, orthoquartzites with orthmetamorphic basic schists, sericite, phyllites, Carbon. phyllites and chlorites tremolite schist	2.78
Jagannathpur lavas/ Dhanjori lavas/ Dalma lavas	metabasic/ metavolcanic/ lava flows	3.05
Magmatic members of Singhbhum granite	granite, diorite, granodiorite	
i) Saraikela granite	granite, granodiorite and hornblende granodiorite	2.70
ii) Haludpukur granite	hornblende granodiorite,	2.68
iii) Tiring granite	augen gneisses, biotite granite	2.69
iv) Dalima granite	granodiorite granite, biotite	2.69
v) Jorapokhar granite	granite and granodiorite	2.63
vi) Hatgamaria granite	granite and granodiorite	2.59
vii) Rairangapur granite	granite and granodiorite	2.66
viii) Basoi granite	granite and granodiorite	2.63
ix) Romapahari-Bangriposi granite	granite, granodiorite and granophyres	2.67
Iron Ore Group	shales and phyllites/basal sandstone with conglomerate	2.73
Basement granite-gneisses	pink granite, coarse-grained granite with abundances of quartz and biotite, and gneisses	2.67/2.69

Thermal conductivity(K)

TC (symbolically K in W/mK) is the first key parameter for estimating the HF study. Small and thick disc shaped sample core with comparable thicknesses is prepared accordingly high temperature and low-temperature TC instruments. Generally, divided-bar apparatus is used for the TC measurement in laboratory. This is the direct measurable laboratory instrument. The K values over SC of granites and gneisses rock varies in the wide ranges. Measurable of K is 2.68W/mK to 3.07W/mK in granites and in gneisses it varies 2.41W/mK to 3.1W/mK.

Thermal gradient(dt/dz)

TG (symbolically dt/dz in °C/Km or mK/m) is the second parameter for the estimation of HF value. The rate of change of temperature with respect to increasing depth in borehole is termed as temperature gradient or geothermal gradient. Borehole resistance (ohm) is measured by thermistor (borehole resistance sensor) probe with the depth interval of 3m by Fluke digital borehole temperature sensor instrument, which resistance is converted to temperature(°C) in laboratory using standard formula: $T=[A/(B+LogR)]-C-273$, where A, B, C are constant values depending on Fluke temperature instrument and T is the converted temperature (in °C). TG or dt/dz of any temperature vs. depth curve is calculated in the linear segments of the curve, after drawing triangle and applying tangent rule TG values are calculated in graph paper. Figures 2,3,4 and 5 in following is the depth versus temperature plots of different parts of the SC areas. Figure 2 is upto 400m depth and initial temperature starts in 30.2°C, after 55m depth the value is disturbed upto 62m.

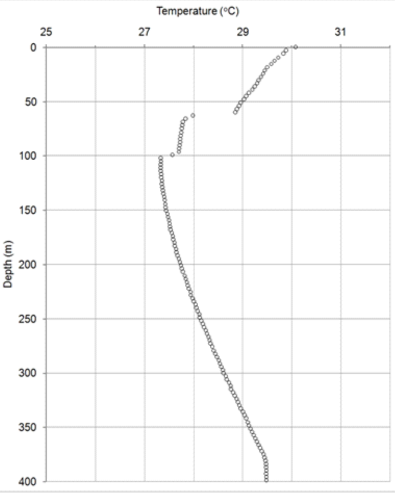

Fig.2: Temperature vs. depth profile over Singhbhum craton in borehole-1.

In figure 3, starting temperature is 29.7°C and discontinuity of curve started ~80m to 90m, total depth of the borehole-2 is around 320m.

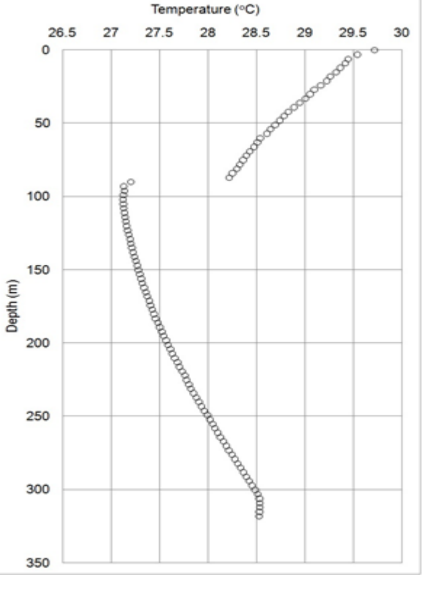

Fig.3: Temperature-depth profile in borehole-2.

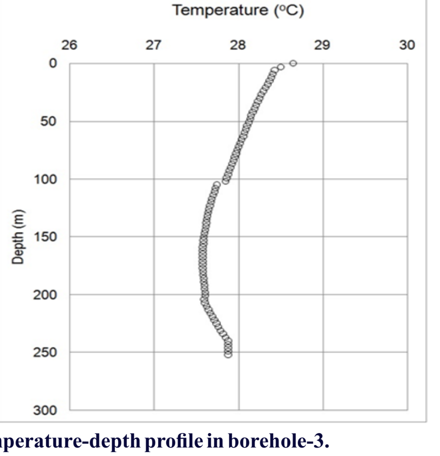

Fig.4: Temperature-depth profile in borehole-3.

Figure 4 is the borehole-4 temp vs. depth curve and the total depth of the BH-3 is 255m-260m.

Figure 5 is the plotted data of BH-4 of total depth around 200m, initial temperature is 28.1 °C and there are two small discontinuities there upto 25m depth.

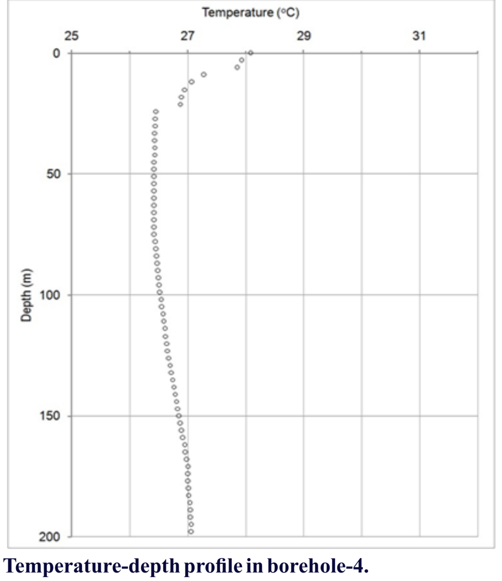

Fig.5: Temperature-depth profile in borehole-4.

Above data (BH1-4) shows that temperature gradient varies in the range of 16mK/m to 21mK/m whereas mean gradient is 18.5mK/m.

Heat-flow(q_z): Heat flow or flux (W/m^2 or mw/m^2) is the heat radiated or emitted per unit surface of the area and calculated by the following formula: q_z=-K*dt/dz.Calculated HF varies widely in the SC and the average value of HF is ≥54mW/m^2 at the borehole location places.

Heat-production: HP (in µWm^{-3}) is heat generated or produced per unit volume of the surface area and is calculated from the abundances of Th (ppm), U (ppm), K (%) as follow (Birch, 1954):

HP = ρ* (0.026 * Th + 0.035 * K + 0.097 * U),

where ρ=density of the rock in g per cc.

Radioelemental (Th,U,K) concentration of Singhbhum granite and gneisses: (^{232}Th, ^{235}U and ^{40}K) abundances on 104 rock samples that consist of OMTG, SBG I, SBG II and SBG III from northern part of the SC using laboratory low-level counting GRS to characterize their radiogenic HP. Study shows that the Th, U and K vary in a narrow range for the granites and gneisses of the SC. This also brings out very striking result that the granites of the SC have very low Radioelemental abundances compared to the most of the granites in the different geological provinces of the Indian shield, such as the Aravalli province, the Dharwar craton, etc.

Histogram diagrams of the following curves showing Th, U, K abundances and heat HP of the major rock types from the northern part of Singhbhum craton:

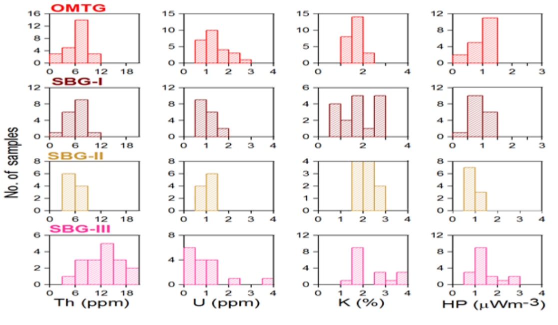

Fig.6: Concentrations of Th, U, K and heat production (HP) of the major rock types from the northern part of Singhbhum craton.

Table 3: Radioelemental concentrations and HP of the Singhbhum granite and gneiss:

Rock type	N	Th(ppm)	U(ppm)	K (%)	HP (µ W m^{-3})
OMTG	28	6.8(2.3)	1.4(0.5)	1.6(0.3)	1.1(0.3)
SBG-I	18	6.4(1.8)	1.1(0.4)	1.8(0.8)	0.9(0.2)
SBG-II	11	5.8(1.6)	1.0(0.2)	2.0(0.4)	0.9(0.1)
SBG-III	18	12.7(4.6)	1.2(1.2)	2.3(0.9)	1.5(0.6)

Thermal structure of the Singhbhum craton

Table 4: Summary of TG, TC, HF and HP data in Singhbhum craton for knowing thermal structure of SC:

Measured parameter	Mean value
TG	18.5 mK/m
HF	≥54 mW/m^2
HP of SBG-I	0.90(µ W m^{-3})
HP of SBG-II	0.9(µ W m^{-3})
HP of SBG-III	1.5(µ W m^{-3})
HP of OMTG	1.1(µ W m^{-3})

Results and discussions

(1) Mean concentration Th(ppm) is 6.8(2.3), U (ppm) is 1.4 (0.5) and K (%) is 1.6 (0.3) in OMTG(Th/U=4.85:1),when the number of measured samples N =28,where parenthesis values indicates the standard errors (2) Same concentrations in SBG-I(Th/U=5.81:1) is 6.4(ppm),1.1(ppm) and (1.8%).(3)Radioelemental abundances of SBG-II (Th/U=5.8:1) is 5.8(ppm),1.0(ppm) and 2.0(%) and (4) in SBG-III(Th/U=10.58:1) it is 12.7(ppm),1.2(ppm) and 2.3(%).(5)Th:U proportion is high in SBG-III and low in OMTG.(6) High HPE is in SBG-III and low in either SBG-I or SBG-II.(7) Average TG is 18.5 mK/m and mean HF is ≥ 54 mW/m^2 in SC.

Conclusions

In the granites, mean Th ranges between 5.8 and 12.7 ppm, mean U ranges between 1.0 and 1.2 ppm, mean K ranges between 1.8 and 2.3%.

In the gneisses, mean Th is 6.8 ppm, mean U is 1.4 ppm and mean K is 1.6%.

Mean radiogenic heat production for the granites ranges between 0.9 and 1.5 µW m^{-3} whereas for gneisses it is 1.1 µ W m^{-3}. The granitic/ gneissic rocks of the Singhbhum craton have comparatively low Radioelemental abundances than the other granites of the Indian shield such as the granites of the Bundelkhand craton, the Aravalli province, the Dharwar craton, etc.

The averages TG is 18.5 mK/m in SC, it is higher than Dharwar craton, Cuddapah Basin area (Roy and Rao.,2000).

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