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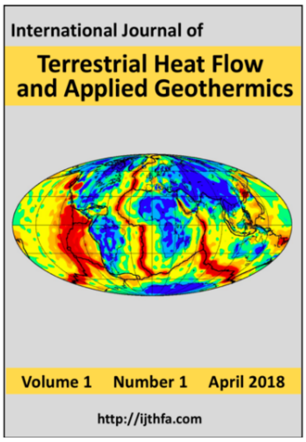

Heat flow in Rajasthan Craton, North–Western Indian Shield and its Implications

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Abstract

A synthesis and reinterpretation of surface heat flow values of the Rajasthan Craton(RC), north-western Indian Shield has been carried out. The results reveal that the q values are relatively high, varying from 52 to 96 mWm^{-2}. Appreciable variations in the magnitude of q are found between and within its geotectonic units, but with considerable overlap of values. Paleo–Meso Proterozoic Aravalli Super Group is generally associated with high q values, varying from 52 to 67 mWm^{-2}, with a mean value of 60 mWm^{-2}. Values of still higher order varying from 52 to 76 mWm^{-2} occur in North Delhi Fold Belt of Meso–Neo Proterozoic Delhi super Group, Tusham area, which is located towards north west corner of the Delhi Fold Belt in the Trans-Aravalli Province of RC, is characterized by a very high heat flow value. This is the highest of all heat flow values so far reported for the Proterozoic terrains of the Indian Shield, which is ascribed as due both to enhanced crustal radioactivity and renewed tectonic activity beneath its region. The heat flow values reported in areas of the Delhi Super Group and Aravalli Super Group are of short wavelength, naturally these are due to shallow sources. We infer that these are mostly due to varying degrees of concentration of heat producing elements in the upper crust. There are also no evidences of major tectono-thermal events after the Neo-Proterozoic times (~600Ma) in the study area. Hence, we conclude that observed variations in heat flow do not carry thermal transients of any recent tectonic activity.

1. Introduction

The Rajasthan Craton (RC) is one large segment of the Indian Shield. Its north-eastern sector remained mainly undisturbed after Precambrian era, while parts of its south-western sector underwent through various geotectonic and magmatic events. Surface heat flow values for two regions, in its North Delhi Fold belt of Meso-Neo Proterozoic Delhi Super Group, were reported by Gupta et al (1967) and Gupta and Rao (1970) Heat flow values, based on temperature measurements on ten bore holes of opportunity and thermal conductivity measurements on over one hundred core samples were summarized and presented at an annual convention, Gupta et al (1993). These values covered eight more locations of the Delhi and Aravalli Super Groups. Heat flow values for Trans-Aravalli region of RC has been reported by Sunder et al. (1990) and Roy and Rao (2000) reported heat flow data from four more locations of RC. The ensuing results are summarized, analyzed and discussed.

2. Methodology

Various rock formations from Recent to Archean are mainly exposed in the Rajasthan Craton which is located in the states of Rajasthan and north Gujarat of North-Western Indian Shield, spanning over an area of 80,000 square km. Its geological framework and tectonics have complex interrelations. Therefore, an attempt has been made to briefly outline their geothermal fields. The focus has been on the north-eastern sector, where most of the heat flow data is available. Subsequently, available heat flow values, for its fifteen locations, have been reevaluated. The data set considered include temperature logs for 22 bore holes and results of thermal conductivity measurements of various local rock formations.

3. Geological setting

The Rajasthan Craton occupies the north western part of the Indian Shield. It is one of its large crustal blocks with distinct geological characteristics (Figure 1). Pioneering work to elucidate its geology and tectonics has been done by various workers, notably Heron (1917; 1953), Gupta (1934), Gupta et al (1977), Sinha Roy (1984), Sinha Roy and Gupta (1995), Roy (1988), Roy and Jakhar (2002) and many other workers of Geological Survey of India. It has been divided into three provinces. These are: 1) the Archaean – Paleo Proterozoic Banded Gneissic Complex (BGC), also known as the Pre-

Aravalli Province. 2) The Proterozoic Aravalli – Delhi Province and 3) the Trans-Aravalli Province.

The Banded Gneissic Complex (BGC) varying in age from about 3300 to 2500 Ma (Gopalan et al., 1979) is made up of a heterogeneous assembly of Pre-Aravalli meta- sediments, migmatites, granites, metabasic rocks, which are intruded by a number of granitic plutons, ranging in age from Achaean to middle Proterozoic, Roy and Jakhar (2002).

The Proterozoic Aravalli – Delhi province is generally known as Aravalli – Delhi Fold Belt (ADFB). It consists of the Proterozoic supracrustal rocks of two groups, viz., 1) the Aravalli Supra Group with ages of 2500 – 1900 Ma and the rocks of the Delhi Super Group, with ages of 1900 – 1450 Ma, Roy (1990).

The rocks of the Paleo-Meso Proterozoic Aravalli Super Group are strongly radiogenic. Strata bound lead-zinc deposits occur in its Zawar formations, which also have copper mineralization in its Pur-Banera and Rajpur-Dariba areas. The Meso-Neo Proterozoic Delhi Super Group is further subdivided into two segments, viz., the North Delhi Fold Belt (NDFB) and the South Delhi Fold Belt (SDFB). The sub-basins of Khetri-Alwar-Ajabgarh and Bayana are parts of NDFB. Sin-kinetic intrusions occur in it and are of ~ 1715 Ma in age. Strata bound copper sulphide deposits occur in its Khetri belt and pyrite-phyrhotite deposits in the Saladipur area of Alwar Belt. An isochrone age of 1480 Ma for granite which intrudes at Saladipura has been reported by Gopalan et al (1979). Much younger ages of 850 Ma for granitic intrusion in the Delhi synclinorium have been reported. According to Sinha Roy (1984), the SDFB developed in Ajmer Mt. Abu (north-western Gujarat) sector. Post-Delhi Erinpura granites have profusely intruded SDFB.

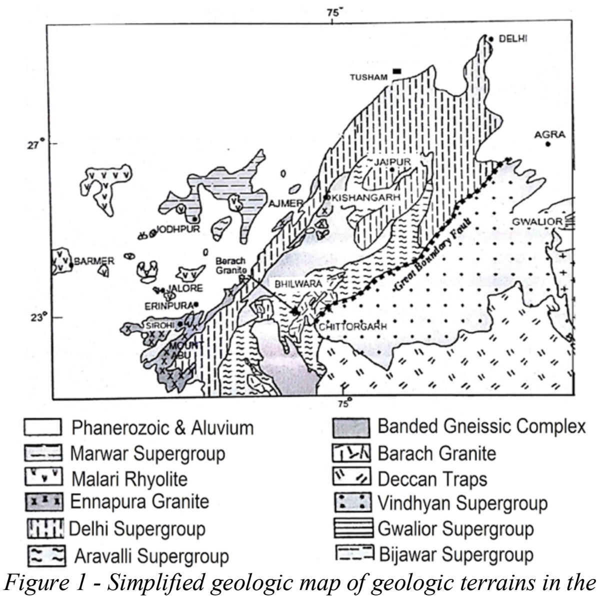

Figure 1 - Simplified geologic map of geologic terrains in the Rajasthan craton (Naqvi and Rogers, 1987).

The Trans-Aravalli Province is a vast region of Western Rajasthan and parts of its have experienced various phases of tectonic activity up to recent times. Malani Igneous Suite, which have been dated at 745 ± 10 Ma, cover an area of about 44,500 Km^2 of Western Rajasthan. Erinpura Granites have been considered to form its basement (Crawford and Compston, 1970). It extends up to Tasha, (located at 18^{0}53' N, 75^{0}55' E). Tusham granites have been dated (Pb-Sr method) at around 750 Ma (Kochhar et al., 1985). According to Srivastava (1988) acidic and basic magmatism in parts of Trans-Aravalli region may have continued up to the Paleocene.

The ADFB traverses the Rajasthan state of India in a NNE-SSW direction almost from end to end, extending over a distance of nearly 700 Km, continuing from Delhi on the NE to the plains of north Gujarat (Figure 1).

4. Results and Discussion

The available surface heat flow (q) data for the specific regions of Rajasthan Craton (RC) is summarized in tables 1 and 2. Table 1 provides a summary of surface heat flow in Rajasthan Craton. Here, NL is number of localities; NB number of boreholes. Additional information on geothermal gradients, thermal conductivity, heat Flow in these regions of Rajasthan Craton, are provided in tables (2a), (2b) and (2c) in the Appendix.

Table 1 - Summary of surface heat flow in Rajasthan Craton. NL - number of localities; NB – number of boreholes.

Geological Unit	NL	NB	q (mWm^{-2})	
			Range	Mean
1. Delhi Super Group North Delhi Fold Belt				
a) Khetri Copper Belt	4	8	72 – 76	74
b) Alwar Belt	4	5	52 – 62	55
2. Delhi Super Group South Delhi Fold Belt	1	1	62	62
3. Aravalli Super Group	4	5	55 – 67	62
4. Banded Gneissic Complex	1	1	56	56
5. Trans –Aravalli Province	1	2	93 – 100	96

The data shows:

i) A wide range of high Q values (51.5 to 99.7 mWm^{-2}) with small variations in its magnitude in its various geotectonic units, thereby implying that these are of short wave length. Naturally these variations are due to shallow sources. One factor for variations in the magnitude of surfaces heat flow is caused due to structural variations. High thermal conductivity of mineralized zones creates variations in subsurface temperatures and naturally of heat flow. Such situations are common in the areas of present study.

ii) That the areas underlain by the Proterozoic rocks of Alwar Belt, South Delhi Fold Belt and of Aravalli Super Group appear to be characterized with more or less similar high Q values (55-62mWm^{-2}). The high Q values in these segments of RC are: a) more or less of the same order as in the Bastor Craton Central India (Gupta et al., 1991) and Singhbhum in Central India (Verma et al., 1996), and b) are of higher magnitude than in the Archaean Dharwar Craton, South Indian Shield (Gupta, 1995). However such a heat flow characteristic of parts of RC and above mentioned Proterozoic parts of the Indian Shield is not anomalous, as Nyblade and Pollack (1993) and Gupta (1993) showed that the Proterozoic segments of the Precambrian Shields are generally associated with higher surface heat flow compared to the Archaean cratons.

In contrast with the observed normal heat flow pattern of the above-mentioned segments of the RC, its Proterozoic regions of Khetri Copper Belt and area of Tusham are characterized by relatively high heat flow values (Table 1). These have been attributed to high levels of radioactive heat production in these parts of the RC, by Sundar et al. (1990) and Gupta (1995). Tusham hill forms the northern most part of a late-Proterozoic igneous complex known as the Malani Complex, which consists of numerous high-level granites, which have high radioactive heat production, Kochhar (1989), Srivastava (1989). Presence and appreciable concentration of Uranium in various parts of present heat flow study has been reported by Atomic Minerals Division of India (AMD, 2013). However, a possibility of renewed tectonic activity beneath the Tusham region cannot be ruled out as it is located in the northwestern peripheral region of the northern part of the Indian Shield, which has experienced several earthquakes.

A compilation, including a synthesis and statistical analysis of geothermal data from terrains of Gondwana shields, was carried out by Gupta (1993). It was demonstrated that the observation of high heat flow in the Proterozoic sector of the Aravalli mountain belt cannot be considered anomalous. Its observed range is more or less of the same order as in other coeval Proterozoic regions of other Gondwana shields.

5. Conclusions

This study comprises a review and an analysis of the available surface heat flow data for fifteen locations of the RC. The results obtained reveal the following:

- High surface heat flow with wide variations in the magnitude and overlap of the values, and
- The high heat flow values are mainly consistent with high radioactive contributions from the subsurface upper crustal rocks of the related areas.

Further that the observation of high heat flow values, in the studied sectors of the RC, is not unique, as detailed analysis of heat flow data from Gondwana countries, Gupta (1993) and even global heat flow data (Mareschal and Jaupart(2005) show that the high heat flow and crustal heat production are characteristics of recycled Archaean crust. This inference holds good for the presently studied regions of RC.

6. Acknowledgments

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APPENDIX

Table 2a - Summary of geothermal gradient, thermal conductivity and heat flow data in Khetri and Alwar belts, Delhi Super Group, Rajasthan Craton, NW Indian Shield.

Geology	Location	S. No	Coord. Lat^0: N Lon^0: E	BH.ID	Depths (m)	Γ ^{0}C Km^{-1}	γ W/m/^{0}C	Heat Flow (mW/m^2) site	Heat Flow (mW/m^2) Mean	Ref.
Delhi-Supper Group a) Khetri Copper Belt	Madan – kudan	1	28^{0}04’, 75^{0}48’	-	-	-	-	-	73	Gupta et al (1967)
		1.1		S-47	120-700	21.75	3.37	73		
		1.2		S-48	150-300	20.26	3.61	73		
				S-48	300-460	22.39	3.41	76		
		1.3		S-49	150-300	20.62	3.47	71.5		
	Kolihan	2	27^{0}59’, 75^{0}49’	-	-	-	-	-	74	Gupta et al (1993)
		2.1		KKBH-52	172-248	18.23	4.1	74.7		
		2.2		KKBH-69	107-255	18.0	4.1	74		
	Muradpur	3	28^{0}6.7’, 75^{0}53.1’	-	-	-	-	-	75	
		3.1		DHM-14	182-230	21.83	3.39	74		
		3.2		DHM-7	63-173	25.17	3.02	76		
	Kalapahar	4	28^{0}03’, 75^{0}45’	IVB-7	179-300	18.71	3.85	72	72	
Delhi-Super Group b) Alwar Belt	Saladipura	5	27^{0}39’, 75^{0}31’	SPBH-63A	91.5-180	19.97	2.6	52	52	Gupta et al (1993)
	Tejawala	6	27^{0}36.4’, 75^{0}15’	TSBH-2	120-148	15.6	3.3	51.5	51.5	
	Bhagoni	7	27^{0}17’, 76^{0}24’	-	-	-	-	-	61	Gupta and Rao (1970)
		7.1		DBBH-9	162-216	20.1	3.02	61		
					224-286	16.2	3.71	60		
		7.2		DBBH-18	74-192	21.2	2.95	62		
					192-279	16.6	3.72	62		
	Golbad-shapur	8	27^{0}16’, 76^{0}04’	GBH-1	70-191	17.4	3.2	55.7	56	Gupta et al (1993)

APPENDIX (continuation)

Table 2b. Summary of geothermal gradient, thermal conductivity and heat flow data in South Delhi Fold Belt and Aravalli Super Group, Rajasthan Craton NW Indian Shield.

Geology	Location	S.No	Coord. Lat^0: N Lon^0: E	BH Id.	Depths (m)	Γ ^{0}C Km^1	γ W/m/^{0}C	q (mW/m^2) Site	q (mW/m^2) Mean	Ref.
2. Delhi Super Group South Delhi Fold Belt	Jaswantgarth	9	24^{0}48'10", 73^{0}27'35"	-	105-150	15.8	3.95	62	62	Roy&Rao (2000)
3.Aravalli Super Group	Sideswar – kalan	10	25^{0}1.5', 74^{0}41'	BRU-21	117.4 - 255	15.5	3.55	55	5.5	Gupta et al (1993)
	Rajpur Dariba	11	25^{0}0030", 74^{0}09'30"	-	-	-	-		64	Roy& Rao (2000)
	(Sideswar Khurd)	11.1		KD-14	75-207	12.7	4.9	62		
					236-341	15.5	3.95	61		
		11.2		KD-6	56-175	12.7	5.16	65		
					175-203	17.5	3.95	69		
	Zawar (Mochia mine)	12	24^{0}21'50", 73^{0}42'37"	WMI/5 / 48	201-236	15.2	4.52	69	67	
					238-250	19.1	3.60	69		
					252-322	12.2	5.09	62		
					322-366	14.7	4.52	67		
	Zawar Baroi	13	24^{0}21, 73^{0}44'	BMU-4	72-293	14.5	4.2	61	61	Gupta et al (1993)

Table 2c. Summary of geothermal gradient, thermal conductivity and heat flow data in Banded Gneissic Complex and Trans-Aravalli Province, Rajasthan Carton, NW Indian Shield.

Geology	Location	S. No	Coord. Lat^0: N Lon^0: E	BH Id.	Depths (m)	Γ ^{0}C/Km	γ W/m/^{0}C	q (mW/m^2) Site	q (mW/m^2) Mean	Ref.
4.Banded Gneissic Complex	Merta	14	24^{0}38', 73^{0}51'	DABOK	81-153	14.1	3.95	56	56	R0y & Rao (2000)
5. Trans-Aravalli Province	Tusham	15	28^{0}53', 75^{0}55'	-	-	-	-	-	96	Sundar et al (1990)
		15.1		MT-35	130-230	26.09	3.55	92.6		
					290-310	25.51	3.69	94.1		
		15.2		MT—36	155-225	23.72	4.12	97.7		
					245-275	24.2	4.12	99.7		