PRESENT THERMAL STATUS OF INDIAN LITHOSPHERE

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1. ABSTRACT

The estimation of surface heat flow for Indian province is based on the temperature measured from the shallow borehole. Such estimation of surface heat flow is not very reliable for deep-seated structure. Numerous workers have given various empirical relations between surface heat flow, crustal and lithospheric thicknesses. These relations give more realistic information about the global thermal regimes. In the present paper, we discuss the lithospheric thickness obtained from the magnetotelluric studies for Indo-Gangetic and Peninsular regions with measured heat flow data in the region The lithospheric thickness and the heat flow of various parts of Indian regions has been compared with other regions of the world. The present study shows that the Indo-Gangetic basin has low heat flow values compared to the basins found in other parts of world The Peninsular regions of India show similar heat flow values as have been observed in other stable shield provinces.

2. INTRODUCTION

The Indian landmass is divided into three major tectonic regions: the Peninsular shield, the Indo-Gangetic plains and the Himalayan mountain system (Figure 1). Each of these regions has its own importance for detailed geological and geophysical investigations. Efforts have been made to deduce information about the crustal and lithospheric structure beneath the northern and central Indian Peninsular regions based on the gravity (Qureshy 1971), magnetic (Mishra 1984, Rajaram and Singh 1986), magnetometer array (Srivastava et al. 1984), MAGSAT (Agarwal et al. 1986, Singh and Rajaram 1990), heat flow study (Gupta and Rao 1970, Singh and Negi 1982, Gupta 1982, Gupta and Gaur 1984, Negi et al. 1987) and earthquake data (Bhattacharya 1981, 1991, Singh 1987, 1991). Various inferences about the thickness of the crust, lithosphere and their nature have been drawn which have not given a clear picture

Detailed deeper information about the crustal structure and the nature of the Indian lithosphere has been far from complete due to the non availability of seismic and magnetotelluric (MT) data. To get a clear understanding of the crustal and lithospheric structures, MT soundings at 29 locations covering part of Indo-Gangetic plains, northern and central parts of the Indian Peninsular regions were carried out during 1989 under a collaborative project with the University of Uppsala, Sweden and Indian Institute of Technology Kanpur, India. The MT results have given information about the subsurface resistivity structure beneath Indo-Gangetic plains and the Peninsular regions that have been discussed in detail by Singh et al. (1992, 1993, 1995). The lithospheric thickness and the resistivities are found to vary from place to place in the Indo-Gangetic plains and in the Peninsular regions. In this paper, we have made an effort to correlate the thermal status of Indian landmass with European landmass and correlate the thickness of the lithosphere obtained from MT studies with the heat flow information of other basins and shield regions of the world. The present study shows the thermal nature of Indian landmass.

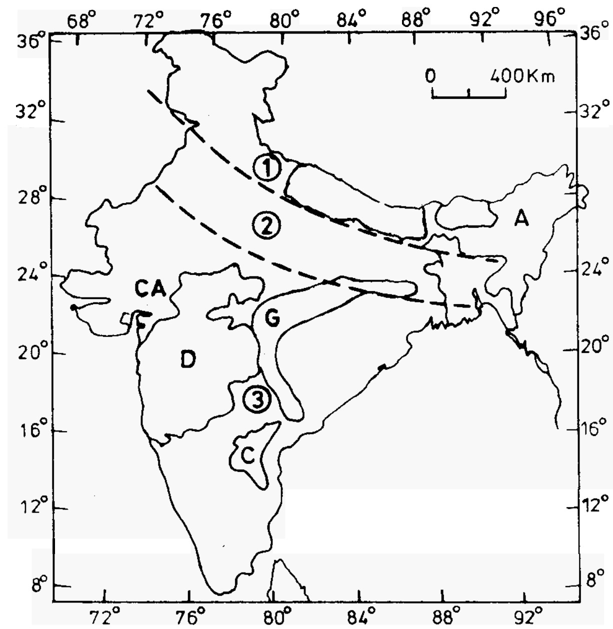

Figure 1 Geological division of Indian landmass and its various units: (1) Himalayan Orogenic belt, (2) Indo-Gangetic plain, (3) Indian Peninsular region, **A-** Assam basin, C- Cuddapah basin, **CA-** Cambay basin, D- Dharwar schist belt, G- Gondawana basin,

3. RELATION OF CRUST AND LITHOSPHERIC THICKNESS WITH HEAT FLOW

The terrestrial heat flow, which is the outflow of heat from the Earth's interior, is considerably affected by deep-seated tectonic processes. Knowledge of the surface heat flow pattern on the continental scale thus provides an important tool for studying the lithospheric structure and helps us to understand the nature of its long-term evolution.

The surface heat flow data from different geological regions in India have been recorded and discussed by various Indian workers (Verma and Narain 1968, Gupta and Rao 1970, Verma and Gupta 1975, Rao et al. 1979 and Gupta 1981). It is evident from these data that the surface heat flow decreases as the age of Precambrian orogeny increases. which is also found by Polyak and Smirnov (1968).

The crustal radioactivity generates a substantial part of the terrestrial heat flow; the thick crust corresponds to the regions of high surface heat flow, while low heat flow corresponds to thinner crust. However an opposite tendency, i.e., low heat flow at thicker crust is observed over Ukrainian shield (Kutas 1979), Baltic shield (Swanberg 1974). most parts of East European platform, (Figure 2) and Cambay region in India (Gupta 1982).

An inverse relation between the heat flow and the crustal thickness is found on the basis of detailed regional studies in various parts of the Europe (Figure 2). Figure 2 shows a large variability in heat flow data If we ignore the heat flow data of Alpine belt and Black sea, a fairly strong negative correlation is found. Such negative relation gives a higher heat flow in thinner crust and low heat flow in thicker crust (Cermak 1982). Ryback et al. (1977) has found higher surface heat flow (≥65 mW/m^2) over Alpine crust, whereas Chapman et al. (1979) found heat flow greater than 78 mW/m^2. Further, Ryback et al. (1977) estimated heat flow value ≈25 mW/m^2 at moho depth (50-55 km) in the central part of Alpine belt.

These thermal parameters indicate that a substantial part of heat energy is supplied by the crust of Alpine region. Cermak (1982) inferred that crustal thickening in the younger mountains, such as the Alps caused by inter-thrusting in orogens and the increased heat flow may thus be a transient phenomenon. The heat flow data in Alps region (rectangular dashed-box), as shown in Figure 2, decreases significantly with the crustal thickness. A small decrease in heat flow value with increase of crustal thickness indicates that the heat flow in the region is likely due to dominant source of heat flow lies within the crust itself Ryback et al. (1977) ruled out the possibility of molten material of granitic composition because the material can not be partially molten at this temperature. Ryback et al. (1977) finally concluded that intermediate chemical composition formation (Greenschist facies) is the most probable cause. Such formation also shows low seismic velocity that is characteristic of the radioactive formation.

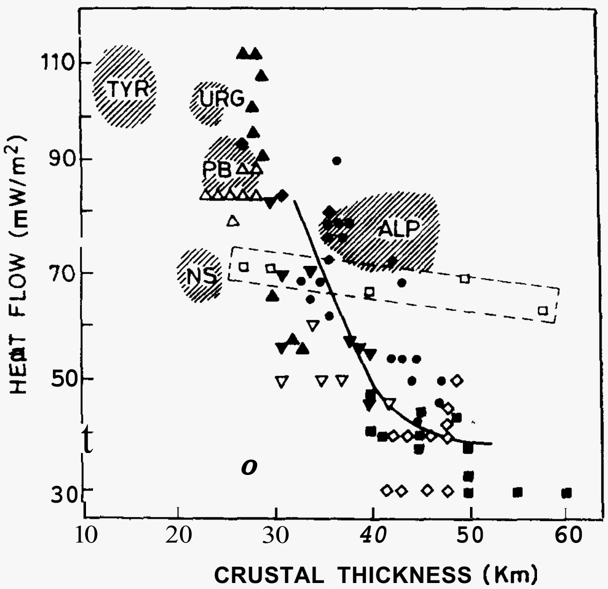

Figure 2 Heat flow versus crustal thickness in Europe (modified after Cermak, (1982). ALP Alps, NS North Sea, PB Pannonian Basin, TYR Tyrrhenian Sea, URG Upper Rhinegraben. ■ Ukrainian Shield, ▼ Bohemian massif, • Poland, ▲ Neogene basin (Czechoslavokia), ∆ Pannonian basin (Romania), ▽ Transsylvanian basin (Romania), 0 Carpathian foredeep (Romania), ◇ Black Sea, □ Alps, ♦ Spain.

In Black sea region, a low surface heat flow (28-40 mW/m^2) is observed at its abnormally thin crust (22-35 km) (Morelli et al. 1967). whereas a reasonable amount of heat (20-30 mW/m^2) out flows by upper mantle. Pollack and Chapman (1977) have empirically shown that almost 60% of the average heat flow of any region attributed from the upper mantle and 40% fiom the crust. This indicates that the crustal rocks have very poor heat generating, thermal conducting constituents as well as have no recent tectonic activity that could add to the surface heat flow values.

4. INDO-GANGETIC BASIN, PENINSULAR BASIN, PENINSULAR REGIONS AND HEAT FLOW

Numerous efforts have been made to estimate the crustal thickness in various parts of Indian landmass based on gravity and earthquake data Narain (1973) summarized the studies of numerous workers and estimated the average crustal thickness of the Indian Peninsula to be 35- 40 km. But the inherent error in estimating crustal thickness over Indian landmass by gravity data is obvious due to large influence of Indian Ocean Gravity Low (IOGL), particularly in the southern Peninsula and coastal region. Later on, the deep seismic sounding (DSS) studies (NGRI 1979, Kaila et al. 1979, 1981) have given accurate picture of the crustal structure in several parts of Indian landmass

A positive correlation between heat flow and crustal thickness, contrary to the European regions (Cermak 1982), has been obtained by Gupta (1982) for different basins of Indian Peninsular region except Cambay basin. The negative correlation shown in the Cambay basin (northern part) has been ascribed to transient thermal perturbations fiom a cooling magmatic body (Verma et al. 1968, Gupta et al. 1970, Gupta 1981). If contribution from the magmatic body is subtracted the heat flow data will show similar values (Gupta 1982). whereas the heat flow values of different basins (Table 1), show that heat flow of the Cambay basin is found similar to other basin of the World. Attempts were also made to interpret the observed relation between crustal thickness and surface heat flow for Indian landmass since no simple relation appears to exist (Chapman et al. 1979).

Table 1 : Heat Flow values of different sedimentary basin of the India and the Europe.

BASINS	HEATFLOW VALUES (mW/m^2)	REFERENCES
INDIA		
Assam	60.5	
Cambay	83.0	Gupta (1982)
Cuddapah	75.0	
Gondawana	75.0	
Carpathian	75.0	Kutas (1979)
Createaceous (Bohemian massif)	72.0	Cermak (1976)
Pannonian	82.0	Stegena et al. (1975)

The crustal radioactivity generally contributes a major component of the surface heat flow in shield areas. If the crustal thickness is considered to be large due to a thicker top radioactive layer or middle layer containing granitic formation, it will tend to raise the surface heat flow value. The difference in the average thickness of granitic layer. of the order of a few kilometers along DSS profiles, has been shown in the southern Indian shield (Kaila et al. 1979, 1981, NGRI 1979). However, DSS results suggest two moho boundaries (Vyskocil 1972, Kaila et al. 1979), indicating an additional material of low radioactive from below.

The crustal thickness of Archean segment of Indian region is not more than 40 km, while it is 50-55 km thick in Ukrainian shield (Sollogub et al. 1973). This suggests that the thickening ofthe crust and lithosphere of Indian Peninsula has not occurred because of the rapid northward movement of the Indian landmass after its detachment from Gondawanaland (Gupta 1982). The theoretical steady-state crustal temperatures for three craton, Dhanvar, Aravalli and Singhbhumi, calculated by Gupta (1982) are indicative of a stable continental crust for most parts of the Indian Peninsular region.

In order to determine the regional character of surface heat flow, one must take into account the heat flow from the upper mantle. The relationship between heat flow and lithospheric thickness has been studied earlier by Pollack and Chapman (1977) and Crough and Thompson (1976). Negi et al. (1987) have compiled the heat flow data with the lithospheric thickness from the sedimentary basins and the shield areas from the various parts of the world and optimized the results in context to Indian landmass as shown in Figure 3. The lithospheric thickness estimation based on Curie depth inferred from MAGSAT data (Mishra 1984, Aganval et al. 1986), agrees well with the lithospheric depth estimated by heat flow data except for the Dhanvar region (Negi et al. 1987).

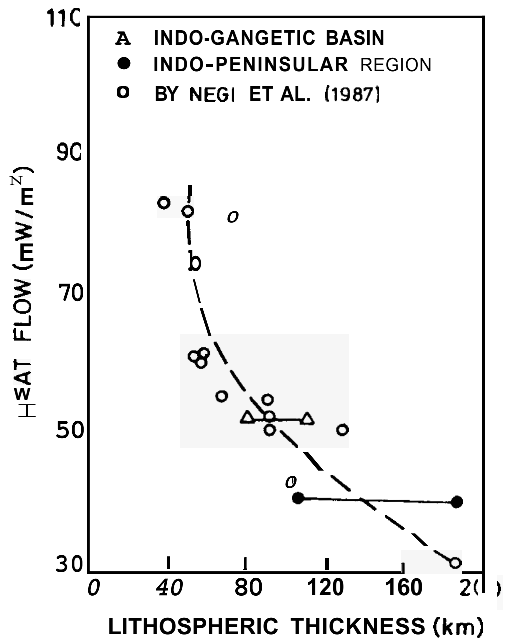

Figure 3 Relationship between heat flow and lithospheric thickness of Indian landmass. Open circles are data obtained fiom Curie depth.

Recently, the lithospheric thickness estimated by MT method by Singh et al. (1992, 1995) in Indo-Gaugetic basin and Singh et al. (1993) in Indian Peninsular region show the lithospheric thickness of the order of 90-110 km and 100-180 km, respectively. The heat flow values, obtained by projecting the range of lithospheric thickness over optimized curve in Figure 3, for Indo-Gaugetic basin lies between 46-55 mW/m^2 and for Indian Peninsular region between 33-48 mW/m^2. The heat flow value of Indo-Gangetic basin by Shanker (1988) lies between 31-41 mW/m^2 (Table 1). The heat flow value of this basin is very low in comparison to the heat flow values of basin provinces. The region has low heat flow inspite of major earthquakes, active neotectonism and upper Tertiary orogenesis. The possible reason of low heat flow may be due to presence of fluids in the lower crust of the Indo-Gangetic basin (Singh et al. 1992).

5. CONCLUSIONS

The present results show that the correlation between lithospheric thickness and measured heat flow data by Negi et al. (1987) over Indian landmass is valid for Indian Peninsular region, but not for the Indo-Gangetic basin. Though the heat flow measured data are very limited and not very reliable since it is only based on the temperature from shallow borehole. Due to this limitation, the present study is only limited to qualitative analysis of the lithospheric thickness and the heat flow data for Indian region. It is concluded that the measured heat flow data and the lithospheric thickness are well related to each other and both can play an important role in the interpi-etation of the MT results to deduce an appropriate resistivity model. It is also found that the lithospheric heat flow of the Indo-Gangetic basin is exceptionally lower compared to the basins found in other parts of the world fiom where the heat flow and lithospheric thickness data are available

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