J. Ind. Geophys. Union (October 2014)
v.18, no.4, pp:469-471

Research Note

Applications of heat conduction equation based models in Indian geology

R N Singh
CSIR-National Geophysical Research Institute, Hyderabad 500 007
Corresponding Author: rnsingh@ngri.res.in

Heat transfer takes place within the lithosphere in the form of heat conduction. Thus heat conduction equation models have found extensive applications in constructing knowledge about thermal structure and evolution of continental lithosphere. This knowledge is vital for understanding the rheology and deformation of lithosphere. Organized work in this direction started in the country with establishment of the Theoretical Geophysics Division at NGRI Hyderabad in 1964. Such models are developed in confrontation with the data of heat flow, metamorphic pressure –temperature arrays of exposed rocks or xenoliths, composition of igneous bodies and thickness of the sedimentary basins within the continents or active and passive continental margins. Indian continental region is well endowed with these geological events, but all have not yet been confronted with the heat conduction equation models to build quantitative knowledge of thermal evolution of the Indian geological terrains. However, some significant problems have been addressed. These developments are:

- The present thermal regime of the lithosphere has been quantified using the available heat flow and heat generation data. Earlier studies found the Indian region to be hot with Moho temperatures exceeding 600^0C, whereas now with more observations and heat generation constraints, Indian region is found to be as cold as other shields (Rao et al, 1976; Singh, 1981; Singh and Negi 1982; Gupta et al 1991; Ramana et al 1999, 2003; Thigagrajan et al 2001; Manglik and Singh, 2002; Roy and Rao, 2000, 2003; Manglik 2006; Singh, 2007; Kumar et al 2007a,b). The results crucially depend on partitioning of the observed surface heat flow into the heat flow from the Moho and that due to crustal radioactivity. Earlier this partitioning was done using the linear surface heat flow - heat generation relationship. Now crustal structure revealed by geophysical methods and composition of exposed rocks are used to build radiogenic heat model of the crust.
- Pressure and temperature arrays from xenoliths of about 1Ga age from Dharwar craton and granulites and charnockites of southern India of about 3Ga age have been used to build models of thermal structure at these regions, which would be representative models of the paleogeotherms (Ganguly et al 1995, Roy and Mareschal, 2011; Singh and Ganguly, 2014). Metamorphic data have also been used to find the way the Indian cratonic region has cooled over the geological history (Singh, 1984).
- Models of thermal perturbations generating the charnockitic region in terms of advection of carbon dioxide fluxes and erosion of thrust sheet are developed (Ganguly et al 1995). The magnitude of flux and the thickness of thrust sheet are constrained so that the temperatures at depth increase to the level required for charnockitization. A combination of both processes is shown to be the cause of charnockitization in south India.
- Similarly thermal perturbation associated with Cuddapah basin is shown quantitatively to be due to the rise of melts from great depths to the base of the crust and resulting eclogitization led to subsidence for sedimentation to take place (Bhattacharya and Singh 1984). In an alternate model, Cuddapah basin, which is formed in the intracratonic set up over a long period of time, could be generated by subsidence of an extending lithosphere. The usual model of extension of lithosphere used to explain shorter duration basins and continental margins needs modifications. Extent of stretching required has been quantified from geochemical data of igneous bodies in Cuddapah basin (Anand et al 2003).

There are a large number of geological events and their signature products over the three billion years history of the Indian geological terrains. These can be better understood by confronting the heat conduction equation models with geological, geochemical and geophysical data of these events and products. Several of these events and products have been recently discussed and are listed in Table 1 (Meert et al 2010). Indian cratons, viz. Aravalli, Bastar, Bundelkhand, Dharwar, and Singhbhum, and surrounding mobile belts have several igneous, metamorphic and basin forming events. These episodes have occurred repeatedly during the last 3 billion years. Many of these problems can be posed as evolution of initial conditions or special type of boundary conditions, or changes in the thermal properties of the lithosphere. When sufficient observations are available, resort to inverse methodologies can also be adopted. Thermal models of each of these events can lead to an integrated picture of detailed thermal evolution of cratonic lithosphere. Table 1 also shows that all cratons stabilized by 2.5Ga age. Stabilization of cratons is generally explained in terms of isopicnicity hypothesis (Jordan,1975) wherein the density increase by heat loss is balanced by density decrease by loss of melt fractions from the cratonic keel. Dharwar craton also shows a keel structure (Srinagesh et al,1989) and more such studies are being conducted now. Recently a heat conduction model for the evolution of cratonic keel based on initial condition either by plume or subducted slabs has been developed (Eaton et al 2013). Such heat conduction models for the Indian cratons could

Table 1: Summary of the Precambrian History of India (Meert et al.,2010; copyright (2010) permission from Elsevier). All ages are in Ga.

	Oldest age	Stabilization age	Metamorphic events	Igneous events	Sedimentary basins
Aravalli	~3.5	~2.5	~2.0 (t) 1.7-1.6 (t) 0.95-0.94 (s) 0.99-0.836 (t)	1.711-1.66 (g) 0.82-0.75(g, d)	Marwar (<0.635)
Bundelkhand	~3.3	~2.5	3.3 (t) 2.7 (t) 2.5 (t)	2.15 (d) 2.00 (d) 1.1 (k)	Vindhyan (1.8-1.0)
Singhbhum	~3.5-3.8	~2.5		3.3 (g) 3.1 (g) 3.5 (v) 2.1 (d) 1.5 (d) 1.1 (d) 0.9 (v)	Dhanjori (~2.5) Kolhan (~1.1)
Bastar	~3.5	~2.5	2.5 (t) 2.3 (t) 1.1 (t)	2.5 (v) 1.9 (d)	Chhattisgarh (~1.1) Indravati (1.1 ?)
E. Dharwar	~2.7	~2.5	2.7-2.5 (t)	2.5 (g) 2.4 (d) 2.2 (d) 1.9 (d) 1.2 (d) 1.1 (k,l) 1.0 (d)	Cuddapah (~1.8-1.0) Kurnool (< 0.6 ?) Pranhita–Godavari (1.1) Bhima (1.1-0.6 ?)
W. Dharwar	~3.6	~2.5	3.3 (t) 3.1 (t)	3.35 (v) 2.6 (g) 2.5 (g) ? (d)	Kaladgi (1.1-0.6 ?)
S. Granulite	~3.5	~2.5	~2.5 (t) 0.8-0.9 (t,s) 0.5-0.6 (t,s)	0.5 (g)	None

Abbreviations: (t) = tectonothermal; (s) shear; (d) dyke intrusion; (k) kimberlite/lamproite intrusion; (g) granitic and/or mafic intrusions; (v) volcanism answer questions about their stability. Thus there is great need to develop heat conduction equation models of these events and processes, as listed in Table 1, to arrive at quantitative understanding of the Indian geology.

ACKNOWLEDGEMENTS

Author is grateful to INSA for award of a senior scientist scheme. He is also thankful to Ajay Manglik for going through the manuscript and for suggestions.

REFERENCES

Anand, M., Gibson, S. A., Subbarao, K. V., Kelley, S. P. and Dickin, A. P., 2003. Early Proterozoic melt generation processes beneath the intra-cratonic Cuddapah Basin, Southern India. Journal of Petrology, v.44, pp: 2139–2171.

Bhattacharya, S and Singh, R N., 1984. Thermo-mechanical structure of the southern part of the Indian Shield and its relevance to Precambrian basin evolution, Tectonophysics, v.105, pp:103-120.

Eaton, David W. and HK Claire Perry., 2013. Ephemeral isopycnicity of cratonic mantle keels, Nature Geoscience, v.6.11, pp:967-970.

Ganguly, J, Singh, R N and Ramana D V., 1995. Thermal perturbation during charnockitization and granulite facies metamorphism in southern India. Journal of Metamorphic Geology, v.13, pp: 419–430. doi: 10.1111/j.1525-1314.1995.tb00229.x

Gupta, M. L., Sunder, A. and Sharma, S. R., 1991. Heat flow and heat generation in the Archean Dhanvar cratons and implications for the Southern Indian Shield geotherm and lithosphere thickness. Tectonophysics, v.l94, pp:107-122.

Jordan, T. H., 1975. The continental tectosphere, Rev. Geophys., v. 13, no.3, pp: 1–12, doi:10.1029/RG013i003p00001.

Kumar, P. Senthil, Rajeev Menon, and G. K. Reddy., 2007a. The role of radiogenic heat production in the thermal evolution of a Proterozoic granulite-facies orogenic belt: Eastern Ghats, Indian Shield, Earth and Planetary Science Letters, v.254, pp: 39-54.

Kumar, P.S., Menon, R., and Reddy, G.K., 2007b. Crustal geotherm in southern Deccan basalt province, India: The Moho is as cold as adjoining cratons: *in* Foulger, G.R., and Jurdy, D.M., eds., Plates, plumes, and planetary processes: Boulder, Colorado, Geological Society of America Special Paper 430, doi: 10.1130/2007.2430(14).

Manglik, A., 2006. Mantle heat flow and thermal structure of the northern block of Southern Granulite Terrain, India. Journal of Geodynamics, v.41, pp: 510-519.

Manglik, A., and Singh, R. N., 2002. Thermomechanical structure of the central Indian shield: Constraints from deep crustal seismicity. Current science, v. 82, pp: 1151-1157.

Meert, Joseph G., Manoj K. Pandit, Vimal R. Pradhan, Jonathan Banks, Robert Sirianni, Misty Stroud, Brittany Newstead, and Jennifer Gifford., 2010. Precambrian crustal evolution of Peninsular India: a 3.0 billion year odyssey. Journal of Asian Earth Sciences, v.39, pp: 483–515

Ramana, D.V., Thiagarajan, S. and Rai, S.N., 2003. Crustal thermal structure of the Godavari graben and coastal basin, Current Science, v.84, no.8, pp: 1116-1122.

Ramana, D.V., Thiagarajan, S. and Singh, R.N., 1999. Thermal modeling along the Kavali-Udipi profile in Southern Indian shield, Acta Geophysical Polonica, v.47, no.4, pp: 423-433.

Rao, R. U. M., G. V. Rao, H. Narain., 1976. Radioactive heat generation and heat flow in the Indian shield, Earth Planet. Sci. Lett., v.30, pp:57–64.

Roy, S., and R. U. M. Rao., 2000. Heat flow in the Indian shield, J. Geophys. Res., v.105, no.B11, pp: 25587–25604, doi:10.1029/2000JB900257.

Roy, S. and Rao, R U M., 2003. Towards a crustal thermal model for the Archaean Dharwar craton, southern India, Physics and Chemistry of the Earth, Parts A/B/C, v. 28, no. 9-11, pp: 361-373

Roy S and Mareschal, J.-C., 2011. Constraints on the deep thermal structure of the Dharwar craton, India, from heat flow, shear wave velocities, and mantle xenoliths. Journal of Geophysical Research: Solid Earth (1978–2012), 116(B2), B02409, doi:10.1029/2010JB007796

Singh, R N and Negi, J G., 1982. High Moho temperature in the Indian shield, v.82, pp: 299–306.

Singh, R N., 1981. State of stress in the northern part of the Indian plate, In:Zagros, Hindu Kush, Himalaya: Geodynamic Evolution, H K Gupta and F M Delany (eds), Geodynamic Series, v. 3, pp: 307-312, American Geophysical Union, Washington

Singh, R N., 1984. Thermal evolution of the Indian shield and its subjacent mantle, Tectonophysics, v.105, pp:413-418.

Singh, R. N., 2007. Modeling Erosion Induced Subsurface Thermal Changes and Tectonic Consequences, J. Geological Soc. India, v. 70, pp: 489-498.

Singh, R.N. and Ganguly, J., 2014. Modelling Paleogeotherms in the Continental Lithosphere: A Brief Review and Applications to Problems in the Indian Subcontinent In: Modelling magmatic and allied processes, Eds: S Kumar and R N Singh, pp: 89-108 Springer.

Srinagesh, D., Rai, S. S., Ramesh, D. S., Gaur, V. K., and Rao, C. V. R., 1989. Geophysical Research Letters, v.16, pp: 1055-1058.

Thiagarajan, S., Ramana, and Rai, S.N., 2001. Seismically constrained two-dimensional crustal thermal structure of Cambay basin, J.Earth System Sci, v.110, pp:1-8.