

Existence of a giant geothermal heat source in the Central India indicating feasibility to develop large geothermal energy plants: A Review

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Abstract

The estimated potential of geothermal energy in India is 10 GW but no commercial geothermal energy plant exists till now. Geothermal research is limited to discrete geological, geophysical, geochemical and heat flow studies over about 300 hot springs since last three decades. Present study integrates that isolated information from the published literature to identify and evaluate the potential of geothermal energy projects in central India.

Present study revealed an east-west trending deep sheeted giant conductive zone associated with eastern part of Son-Narmada-Tapti (SONATA) lineament based on several published Magnetotelluric (MT) and other studies in central India. The high conductive zone is approximately 500-kilometer-long which extends from Tatapani to Bakreswar geothermal provinces. The resistivity of the zone is less than 100 ohm-m, and its depth ranges from 3 to 5 kilometers below the surface. The deep conductor is connected with multiple shallower conductive pockets within the depth less than 1 km near the hot springs. Such shallower features are potential geothermal reservoirs. The temperature of the geothermal reservoir estimated by several researchers in these geothermal provinces ranges between 205°C to 220°C. Thus, the geothermal systems in the eastern part of SONATA have multiple intermediate to high enthalpy reservoirs and have good potential of electricity generation from geothermal energy.

The authors hence suggest detailed 2D/3D MT and audio magnetotelluric (AMT) surveys along with gravity and magnetic are highly recommended over the entire area to established the continuity of the deeper conductor and locating near-surface potential reservoirs in the region.

1. Introduction

Geothermal energy is perceived as one of the most promising renewable energies across the globe. Shankar et al. (1991) estimated India's geothermal energy potential at 10 GW. Since the last three decades, numerous organizations and individuals have conducted geological, geochemical, heat flow and geophysical investigations on approximately 300 hot springs. However, in India there is currently no commercial geothermal power production facility as geothermal research is limited to isolated studies. There is lack of integrated approach to establish a geothermal power project. There is an urgent need to incorporate all relevant studies in order to identify geothermal provinces with the potential for commercially exploitable geothermal energy.

Present study aims to integrate relevant information from several published works of central India to identify a potential geothermal zone along Son-Narmada-Tapti (SONATA) lineament (Figure 1) which may be useful for future develop of geothermal energy in India.

Review of Published Works

SONATA is the primary focus of geological, geophysical, geothermal, and geochemical research in central India. Tatapani, Surajkund, and Bakreswar are the three most significant geothermal provinces along SONATA for geothermal energy development. Numerous works are published with extensive detail on SONATA and these three areas. The subsurface details of geothermal systems associated with SONATA can be revealed by integrating the pertinent published works.

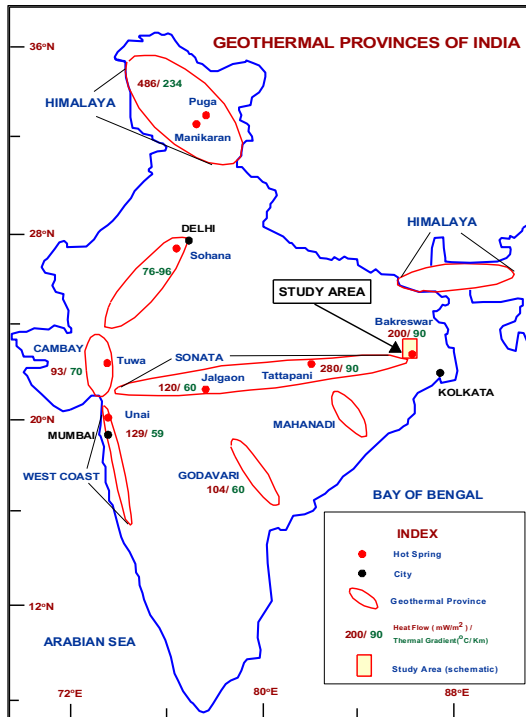


Figure 1: Geothermal provinces of India (after PhD thesis of Sinharay, R. K. (2004)).

Geological studies

The major geological feature relevant to geothermal energy in central India is east-west trending Son-Narmada-Tapti (SONATA) lineament as it is associated with number of host springs (Figure 1). The SONATA lineament zone is exposed in the state of Maharashtra and Madhya Pradesh extending between latitude 20°N to 25°N and longitude 73°E to 84°E with age of rocks varying from Archean to recent time (Jain et al. 1995(a)). The lineament is defined by north and south bounding faults. The Son-Narmada South Fault (SNSF) is occasionally exposed as a fault or ductile shear with intrusive granites though mostly covered by Gondwana sediments (Chattopadhyay et al., 2019).

Shanker, 1995 has given a very detailed account of the association of SONATA with the hot springs. In his study he has recorded 53 hot springs and wells along the entire stretch of the lineament. The work includes the geothermal springs for entire length of SONATA with the westernmost hot spring is Unai in Gujrat (20O51/N, 73O24/E), and the easternmost is Bakreswar in Nepal (23O52/N, 87O25/E). This is a significant work (Shanker, 1998) which discusses

geothermal activity of entire SONATA and not limited within the exposed western section of the lineament. The author suggested the presence of plutonic bodies over the area emplaced at variable depths and working as extensive and active heat source.

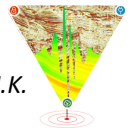
Geophysical studies

Jain et al., 1995(b) have carried out gravity survey over and mapped Bouguer gravity anomaly over the entire length of SONATA spreading from longitude 71°E to 88°E. The work shows complex density distribution with close associations of high and low Bouguer anomalies. Such distribution indicates the presence of subsurface 3D bodies over the area which supports the postulate of Shankar, 1995.

Patro and Sharma, 2016 carried out 3D magnetotelluric (MT) survey by acquiring 153 MT stations in the western part of the SONATA. The 3D inversion results revealed number of highly conductive bodies (< 10 Ohm-m) of various size and shapes at different depths (Figure 2A). The authors inferred that such bodies are mafic-ultramafic intrusive rocks by intense crust-mantle interactions. Malleswari et al., 2019 also carried out 3M survey over the geothermal region of Tattapani which is located in the eastern part of SONATA shows similar high conductive zones at depth (> 4 km) which is moving upward in several location very close to surface (about a km). These zones of high conductivity are potential sources of heat for the geothermal system.

Magnetotelluric studies have also been carried out over two important hot springs Suraj Kund and Bakreswar hot springs located at eastern part of SONATA by Shalivahan et al., 2004, Sinharay et al., 2004, Tripathi et al, 2019 and Rao et al., 2014. The 2D inversion results shows a 10 km thick highly conductive zones (<10 ohm-m) at a depth of 5 km at Surajkund (Figure 3A) ranging up to the depth of 15 km. The authors concluded that this highly conductive zone is magmatic intrusive which is supplying heat to the geothermal system.

A similar conductive zone with resistivity less than 100 Ohm-m is observed in 2D inversion result (Figure 3B) of Bakreswar geothermal province (Shalivahan et al., 2002) at similar depth of Tattapani (4-5 km). The authors suggested that the highly conductive zone may be a source or part of a source or a geothermal reservoir connected to the source. A shallow highly conductive zone is also found at a depth of about 1 km



in the given 2D section (Figure 3B) which may be a geothermal reservoir getting connected to hot spring. Thus, subsurface conductivity structure of Bakreswar and Tatapani geothermal province have a lot of similarity indicating presence of similar geothermal system in both the area.

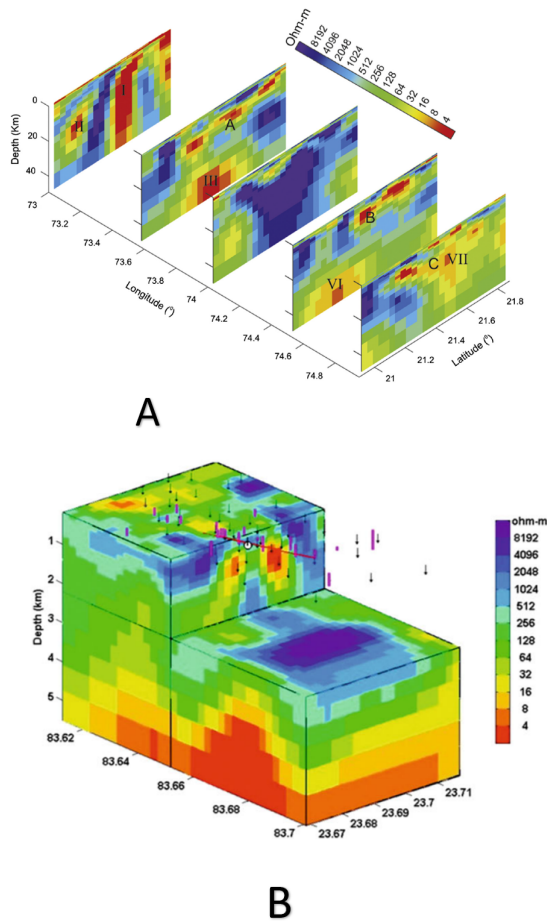


Figure 2: The 3D Magnetotelluric inversion results of A) western part of SONATA and B) over Tatapani geothermal province, associated with the eastern part of SONATA (after Patro and Sharma, 2016 and Malleswari et al., 2019).

Thus, the existing MT 2D and 3D results show the presence of highly conductive zones along the SONATA in different shape and size at the varying depth. The conductors are thicker below the hot springs and have moved up to a depth of 1 km or less below at the geothermal provinces. Hence, the highly conductive thick zones are possibly the highly heated rocks which are supplying heat to the geothermal systems. Veeraswamy and Harinarayan, 2005 has provided deeper 2D geoelectric section along Tatapani

which shows highly conductive zone below Tatapani hot spring (Figure 4) which is explained as a “trail and outburst of mantle plume”.

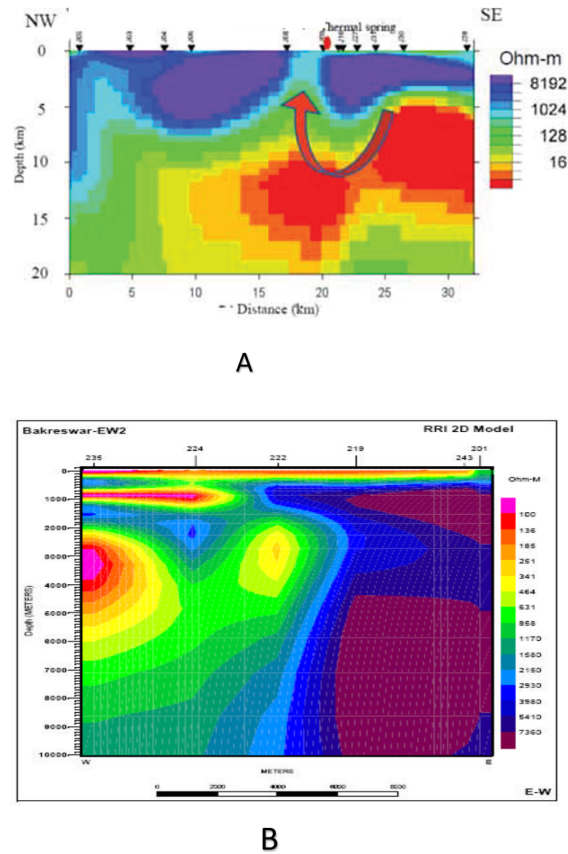


Figure 3: The 2D Magnetotelluric inversion results of two geothermal provinces located at the eastern part of SONATA, A) Surajkund (after Rao et al., 2015) and B) Bakreswar (after Shalivahan et al., 2004).

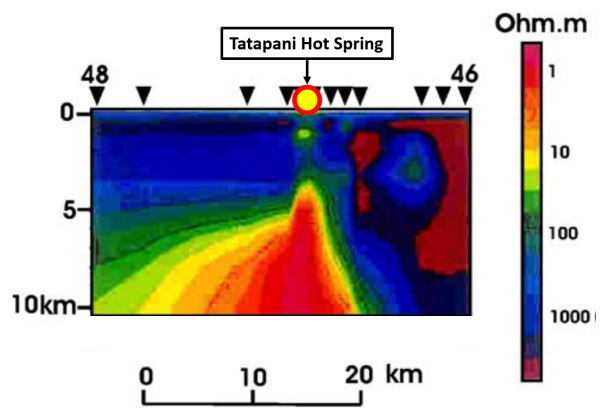
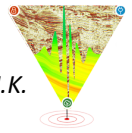


Figure 4: Deep conductivity structure of Tatapani geothermal province (after Veeraswamy and Harinarayan, 2005).



Geochemical studies

Chandrasekharam and Antu, 1995 carried out the geochemical studies over the area and estimated the geothermal reservoir temperature to be between 205 and 215 degrees Celsius. Singh et al., 2015 provided detailed chemical characteristics of the hydrothermal systems located in the eastern part of SONATA. The authors analyzed chemical and isotopic compositions of spring waters. They concluded that the temperature of the interacting rocks of Bakreswar geothermal system has temperature exceeds 220°C whereas temperature of geothermal reservoir at Surajkund is 190°C. They concluded that the heat source of Bakreswar geothermal system is both the intrusive granite and deep-seated fault system.

Discussions and Conclusions

Hydrothermal system has mainly four components, i.e., heat source, thermal fluid flow path, geothermal reservoirs and surface expressions in terms of hot springs, warm springs or geysers. All three major eastern geothermal provinces of SONATA show highly conductive deep structures that continue beneath the major hot springs at a depth of 4-5 km from the surface. The zone is approximately 10 km thick below Surajkund (Figure 3A) and similar thickness is expected below Tatapani (Figure 4). The thickness of the highly conductive zone in Bakreswar is limited to about 2 kilometers (Figure 3B), but the associated low-resistance zone extends to a depth of 10 kilometers with the potential for a deeper origin. Such high conductive zones are identified as volcanic intrusions, associated partial melting, mafic or ultramafic intrusive bodies etc. by most of the researchers. The length of the high conductive zones is approximately 500 km when interpolated between Tatapani to Bakreswar geothermal provinces. However, the entire zone should be covered by detailed MT survey to established the continuation and providing high resolution subsurface resistivity images.

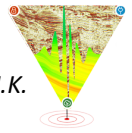
The host rocks in all the three geothermal provinces are very resistive (> 5000 Ohm-m) which is behaving like a cap, preventing the vertical flow of thermal fluid directly to the surface. Hot springs in these geothermal provinces are located close to the fault or fracture zones. Tatapani (Figure 2B) and Bakreswar areas show few near surface conductors (<1 km) which are possibly the geothermal reservoirs. The geothermal

reservoir temperature in all three geothermal systems is estimated between 205°C to 220°C by geochemical and isotopic analysis. These geothermal reservoirs, thus are intermediate (moderate to high enthalpy reservoirs (Williams et al., 2011) and have potential to generate electricity from geothermal energy. Hence, the eastern part of SONATA is very attractive area to establish geothermal energy production facility.

However, a detailed 2D and 3D MT and audio magnetotelluric (AMT) survey along with gravity and magnetic is strongly recommended over the entire area between Bakreswar and Tatapani in order to check the continuity of the deeper conductor and to locate near-surface reservoirs that are not just beneath the hot springs but may be sometime a few kilometers away.

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