An integrated geophysical appraisal of Tarabalo hot spring region, Odisha: preliminary findings

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Keywords

Hot Springs, Resistivity, VLF, Magnetic, Fractured zone, High grade metamorphosed rocks.

Summary

Geophysical investigations were carried out using Resistivity, VLF and Magnetic methods to delineate the subsurface structure around the hot springs of Tarabalo in central Odisha. The present investigation aimed to delineate the shallow subsurface configuration of the study area to understand the probable fracture network and weak zones feeding the cluster of hot springs spread over the area. The study deciphers highly fractured three layered subsurface configurations with depth ranges of 1-50 m, 50-70 m and beyond 70 m consisting of different composition and physical properties. Resistivity study reveals a conducting channel continuing beyond 70 m depth which is also in accordance with the VLF results. The magnetic highs in the region surrounding the hot spring may be due to the high iron content of Khondalite and Charnockite group of rocks which are overlaid by thick quaternary sediments. Thus, it can be inferred from this preliminary geophysical investigation that the hot springs in the study area are feeded by the heat source at a depth greater than ~70 m through some conducting channels and fracture network. A high resolution Gravity, magnetic and deep resistivity study is indispensable for a detailed understanding of the subsurface geothermal system.

Introduction

With the rise of energy consumption and adverse environmental impact of the non-renewable energy resources, the demand for various renewable resources like geothermal energy has been substantially increased. In general, the heat source is a shallow magmatic body arises may be due to mantle plum activity or active tectonics or presence of radiogenic sources (Mishra and Kumar, 2014; Baranwal and Sharma, 2006). Furthermore, geothermal provinces generally associate with high temperature gradient from that of the surrounding and must contain great volume of fluid at high temperatures in shallow depths ~3-4 km (avg.) for economic recoverable energy (Gupta and Roy, 2007). Geothermal exploration also helps to decipher the tectonic history of the region. A geothermal system causes in-homogeneities in the physical properties of the subsurface, which may be observed as anomalies measurable from the surface. Thus, it is apparent that physical characterization and mapping of geothermal reservoirs and their environments can be well established by an integrated geophysical study. In geothermal provinces at a certain depth the country rock become conductive due to thermal excitation, the fluid flow through the fractures also accounts for the conductivity of the region. Such conducting regions can also be identified by Very Low Frequency (VLF) electromagnetic as well as resistivity method. Due to hydrothermal alteration in the region various ultra basic rocks can be identified and in such cases Magnetic Method can be effective for delineation of anomalous zones (Telford et al., 1976; Mariita, 2007). The major and representative Geothermal potential provinces in India spreads over 300 anomalous regions among which 7 major geothermal provinces are identified by Geological Survey of India. The geological and structural criteria for occurrences of prospective Geothermal Provinces in an area can be summarized as follows (Razdan et al., 2008):

- Existence of Cenozoic folding and upliftment in an orogenic belt.
- Occurrence of structural depressions/grabens, associated with late Tertiary and Quaternary upliftment in non-orogenic belts.
- Related to deep fault zones associated with recent seismicity.
- Occurrences of Tertiary or Quaternary volcanic activity.

Further according to physical properties, like temperature gradient, type of sources, and product of geothermal system, they can be broadly classified into following categories (Gupta and Roy, 2007):

(1) vapor-dominated,
(2) hot water,
(3) geopressured,

(4) hot dry rock (HDR),
(5) magma.

The hot springs of Tarabalo area (20°15'4.68"N, 85°19'15.57"E) in Nayagarh district of Odisha lies in the Mahanadi basin. The occurrence of these hot springs may be associated with tertiary or quaternary upliftment in non-orogenic belt. A cluster of hot springs is spread over an area of about 8 acres in the Tarabalo region with a temperature ranging around 40°C-65°C (Baranwal and Sharma, 2006).

The present study infers highly fractured three layered subsurface configurations from resistivity data where as high magnetic anomalous zone is seen towards the north of the study region while magnetic lows were identified in the hot spring areas which inferred fractured terrain which feeds the hot spring. The study also indicates the existence of conducting channel that feeds the hot springs from deeper sources magmatic in nature.

Geological settings

The area lies in the central region of the Eastern Ghats Mobile Belt and is comprised of high grade metamorphic gneisses, i.e., khondalites (garnet – sillimanite gneisses), charnockites (hypersthene bearing granites) and porphyritic gneisses. In some regions megacrystic gneisses and quartzo-feldspathic gneisses are found in association with metasedimentary rocks (Chetty, 2014). Literature suggest that the high grade gneisses are formed due to partial melting of the metasedimentary rocks as marked by the parallel alignment of the metasedimentary rocks with the foliation of host gneisses. The formation of megacrystic gneisses and quartzo-feldspathic gneisses due to intrusion of melts during the hydrothermal phase followed by magmatization of metasedimentary rocks also suggest plum activities in the past. In some regions like that of Rengali isolated Dykes are seen which suggests a major tectonothermal event around 0.8Ga. (Chetty, 2010). Structural Hills, Denudational Hills, Residual Hills, Lateritic uplands and Alluvial plains can be identified in and around the Tarabalo region. Granite Gneiss, Khondalite, Charnockite (Precambrian) & Alluvium (Quaternary) are the major geological formations in the region. The hot springs are spread over an area of 8 acres which is surrounded by marshy land.

Geophysical Investigations

In the present study, resistivity, VLF and magnetic surveys were carried out for characterization and mapping of the region (Figure 1).

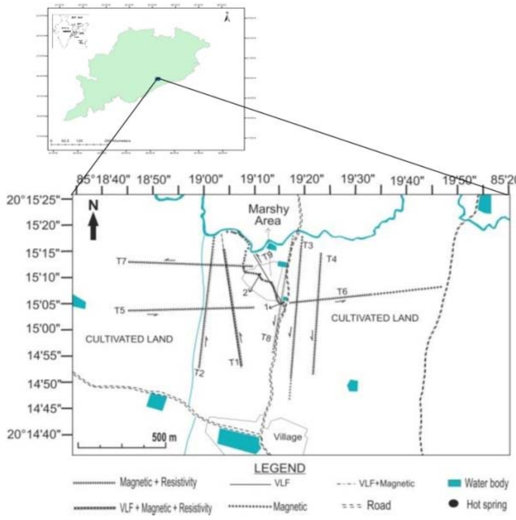

Figure 1: Map showing the geophysical survey profiles in Tarabalo Hot Spring Area

A. Resistivity studies:

Resistivity method has a strong response to physical properties parameters like salinity, temperature, alteration and porosity (permeability) that vary in geothermal province. Electrical resistivity methods are among the most widely used geophysical tool to delineate geothermal regions. It also provides data for shallow structural interpretations which may be a helpful to map the channel network in geothermal province.

The resistivity study was performed with an automated multi-electrode switching system (IRIS syscal R1 plus). Due to space constraints 8 profiles with lengths of 480 m or 720m were deployed at different places near to the hot springs area with 10m electrode spacing (Figure 1). The observed data of the Wenner-Schlumberger array were inverted and interpreted using the rapid two-dimensional (2D) resistivity inversion least squares method of Res2DINV software which was originally developed by Loke (1998). The apparent vertical resistivity profiles resulted after inversion display layer of different resistivity (from top to bottom). The different resistivity layer may be categorized into 3 different zones or sub surface layering (Figure 2) as follows:

1. Shallow conductive layer (5-60 Ohm.m, depth <50 m): This zone may be composed of Alluvium, clay, loose sand and water.
2. Moderate Resistive Layer (60-250 Ohm.m, depth 50-70 m): This zone may be comprised of sand and coarse grained sediments of the Quaternary deposits.
3. High Resistant Layer (250-700 Ohm.m, depth >70 m): This layer may be comprised of Precambrian rock types like (Khodalites and Charnokites).

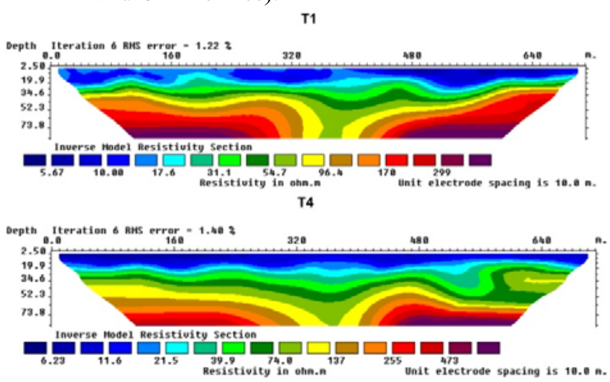

Figure 2: Apparent resistivity cross-section along profiles T1 and T4 in Tarabalo region.

Beside these, it was observed that a low resistive (40-70 Ohm.m) channel interrupts the high resistive layer (>250 Ohm.m) at a depth around 50-70m and continuing beyond 70 m around the central part of the profiles laid near to the hot springs (Figure 2). This may be inferred as main fractures which feed the hot springs in the region.

B. VLF studies:

VLF electromagnetic survey was performed along two N-S profiles with 10 m station interval using IRIS TVLF instrument is used for VLF measurements (Figure 1). Measurements were performed at 17100 Hz Frequency corresponding to the transmitting radio station at Mumbai. The Real and imaginary anomaly percentage were computed from the measured tilt angle (θ) and ellipticity (e) using the formula $tan\theta \times 100$ and $e \times 100$, respectively (Ogilvy and Lee, 1991). The apparent current density was computed from the real anomaly values using linear digital filtering approach (Karous and Hjelt, 1983). High current density indicates conducting zones.

Current density cross section of VLF profile carried at Tarabolo along T1 shows a conductive feature at a lateral distance of 600m and beyond. Profile T9 also reveals the presence of conducting zones at ~75m, ~175-225m, and ~300 m along the profile. Profile T9 passes through the marshy area and between the hot springs 1 and 2 (Figure 1 & 3). The high conductive zones can be inferred as fracture zone extending beyond 60 m which feeds the hot springs. This is also in agreement with the findings of Baranwal and Sharma (2006) over this area.

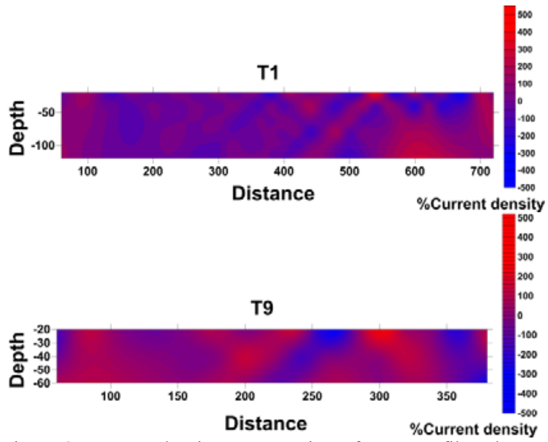

Figure 3: Current density cross-section of VLF profiles along T1 and T9 in Tarabalo region.

C. Magnetic studies:

Geological studies of the area suggest the lithological unit comprised of fractured Precambrian rocks overlaid by thick quaternary sediments. Those fractures may act as a good feed to the hot springs as well as the ground water (Kundu et al., 2002) and these fractures may be inferred from magnetic anomaly with magnetic lows (Henkel and Guzman, 1977)

In the present study, GSM 19T Proton Magnetometer was used to collect total magnetic field data from 537 observation locations along 8 profiles with 10 m station interval around the Tarabalo hot spring region (Figure 1). Data is gridded with minimum curvature gridding technique and after IGRF correction the anomaly map is prepared for the region (Figure 4).

High magnetic anomalies are observed surrounding the hot springs of the study area. An elongated high magnetic anomaly zone (NW-E trending) is also observed around the hot springs of the study area. Some localized magnetic lows can be identified near the fissure zones. This may be caused by the hot water of the springs. The adjacent magnetic highs may be inferred as high grade metamorphic and crystalline rocks which are overlaid by thick quaternary sediments as evident from the geological set up of the region (Chetty, 2014).

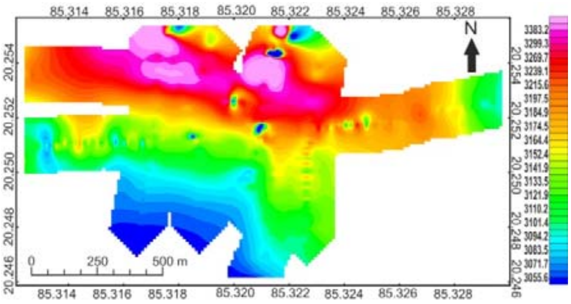

Figure 4: Magnetic anomaly map of the Tarabalo Hot spring region.

Discussion and Conclusions

The Tarabalo hot springs along with other hots springs complex in Odisha lies on the Mahanadi Shear Zone (MSZ) (Figure 5) (Pradhan and Jena, 2016). Mishra and Kumar (2014) has indicated the possibilities of plum / sub-plum activities in the MSZ during Meso-Neoproterozoic period. This indirectly suggest a deeper heat source for the study area. This fact was also discussed by Pradhan and Jena (2016). According to them, these dipper sources may account for the heat sources to warm the water which comes to the surface through some deep fracture network. Again, the possibilities of exothermic reaction and disintegration of radioactive minerals as heat sources cannot be ruled out (Baranwal and Sharma, 2006; Pradhan and Jena, 2016). The main goal of the integrated geophysical study is to critically examine these facts and provide a reliable solution by delineating the detailed subsurface configuration of the region. Accordingly, a preliminary integrated geophysical investigation has been carried out in the study area to understand the near surface configuration.

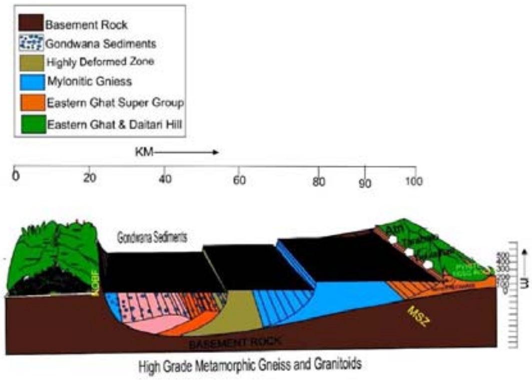

Figure 5: Model of Mahanadi Graben with Faults and Hot Springs. (Pradhan and Jena, 2016)

The present geophysical investigations revealed the existence of fractured formation. Resistivity survey in the region suggest a 3 layered structure with shallow conductive layer (≤50 m depth), a moderate resistive layer (between 50-70m depth), and high resistive layer (≥70 m depth). The resistivity profiles near to hot spring (within 5-50m distance from Hot Springs) shows a low resistivity channel intersecting through the moderate as well as high resistive layers and extending beyond 70 m depth. Such depth extent of conducting channel is also observed in the VLF current density section along the profile T9 (Figure 3, between 175-225 m location). The observed high magnetic anomalies can be attributed as the presence of high grade metamorphosed and crystalline rocks comprising of magnetic minerals (e.g., Khondalite and Charnockite). Thus, the present study indicates the existence of fractures that are feeding the hot springs from deeper sources magmatic in nature. However, the exact nature and depth of the heat source in the study area is not well understood yet. This can be accomplished by high resolution Gravity, magnetic as well as deep resistivity studies and rigorous modeling of the subsurface.

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