

Exploration Strategy for Hot Springs Associated with Gondwana Coalfields in India

P.B. Sarolkar

Geological Survey of India, Seminary Hills, Nagpur

psarolkar@yahoo.co.in

Keywords: Strategy, Gondwana Coalfield, Geothermal, Hotsprings

ABSTRACT

The Gondwana coalfields in India are a warehouse of fossil fuel energy sources. The coal bearing formations are deposited in deep subsiding basinal structures confined to half-grabens. The Talchir, Barakar, Barren Measures and Raniganj formations were deposited in this subsiding basin with basement rocks separated by faulted margins. The contact of Gondwana rocks with the basement is marked by faulted margins, while the downthrown side represents a basin of deposition where a huge pile of sediments were deposited. The cumulative thickness of the sedimentary pile in the basins varies from 1200 m to 3000 m, depending on the Gondwana formations deposited. Sedimentary rocks are mostly permeable, facilitating deep percolation and lateral movement of groundwater. The water percolating to deeper levels collects heat during the subsurface movement and follows the conduit provided by fault zones for upward movement toward the surface, giving rise to hot springs along Gondwana margins. The hot springs at Tatapani in the Surguja district (52°C –97°C), Anthoni Samoni in the Hoshangabad district (45°C –54°C), and Managuru (40°C–42°C) in the Khammam district are located along the fault controlled Gondwana margins. During drilling, hot water was encountered in the Mand –Raigarh coalfield in the Raigarh district and the Kothagudem coalfield in the Khammam district. These hot springs are of intermediate enthalpy and may be utilized for direct heat schemes, particularly during winter months. The need to explore the Gondwana coalfields for geothermal energy resources for site specific direct use and electricity generation is emphasized in this paper. The fault margins of the Gondwana basins form a suitable locus for exploration. Geophysical surveys associated with drilling along the intersecting lineaments are possible sites for geothermal exploration.

1. INTRODUCTION

Geothermal resources all over the world show affinity to structural features and tectonic blocks. Most geothermal fields are located along plate margins or fault zones. The Gondwana Coalfields are deposited in fault controlled subsiding basins or half-grabens. The huge amount of sedimentation in Gondwana basins makes a good storage area for groundwater due to good porosity and permeability.

Interbasinal faulting and formational contacts provide easy passage for the movement of subsurface water. Additionally, the inherent porosity and leaching cavities in sandstone provide sufficient porosity forming sandstones to store groundwater. The groundwater with deep circulation collects heat from the deeper part of reservoir, which forms hot springs if a suitable conduit to surface is available. Thus, the Gondwana basin is a suitable locale for formation of the hot springs.

2. GONDWANA BASINS IN INDIA

The Gondwana basins of Peninsular India are restricted to the eastern and central parts of country and are dispersed in linear belts along major river valleys, including the Damodar Koel, Son-Mahanadi, Narmada (Satpura area) and Pranhita-Godavari basins. The present day basins are likely to be the faulted and eroded remnants of past ones (Dy. Director General, 2007). The Gondwana Coalfields in India are scattered in the states of West Bengal, Jharkhand, Bihar, Chhattisgarh, Madhya Pradesh, Maharashtra and Andhra Pradesh. The important coal fields are shown in Figure 1.

All these coalfields have basements with faulted margins, along which Gondwana sedimentation took place. The Gondwana supergroup of formations hosts coal, coal bed methane, and number of hot springs. Some promising geothermal areas in Central India are associated with the Gondwana Formations. The important geothermal resources in India reported along the Gondwana margins are the Tatapani Geothermal field in the Surguja district, the Anthoni-Samoni hot springs in the Hoshangabad district, and the Salbardi hot springs in the Betul and Amaravati districts. U.L. Pitale et al. (1994) described the importance of Gondwana margins in the location of hot springs in Central India. In addition to the abovementioned hot spring areas, the Geological Survey of India has reported artesian flow of hot water from boreholes drilled in the Gadghora coal belt in the Raigarh, Chhattisgarh, and Birbhum districts of West Bengal. The properties of hot springs reported along Gondwana Coalfields are summarized in Table 1.

2.1 Tatapani Geothermal field, Surguja district

The Tatapani -Jhor geothermal field in the Surguja district is located in the Son valley along the margin of the Tatapani-Ramkola coalfield. The geological work carried out here has determined a sizeable geothermal anomaly. The geothermal anomaly is intense over an area of 0.5 km², with hot springs discharging water at up to 97°C (Ravishanker 1987). The hot springs at Tatapani are spread over an area of 0.05 km² along the Gondwana-Proterozoic contact. The hot springs discharge water at 52°C to 97°C. A total of 26 boreholes were drilled in this field, 5 of which produce hot water at >100°C on the surface. These 5 wells produced hot water with a cumulative discharge of 1200 lpm to 1800 lpm. The geological mapping of the area revealed a basement of Proterozoic rocks and pink felspathic, granite gneiss. These metamorphic rocks acted as a basement, over which the Gondwana sediments were deposited (Raja Rao 1983). A thick pile of Gondwana sediments was observed resting unconformably over the basement. Three sets of faults have been reported in these coalfields, and their interference has resulted in the development of a number of horst/graben structures (D.K. Das et al 2007). The southern boundary of the geothermal field is confined to the Tatapani fault trending ENE-WSW with dip of 78° toward the north (Thussu et al., 1987) and crosses faults trending NNE-SSW that demarcate the E-W extent of geothermal field.

Overlying Gondwana rocks with high porosity and permeability act a very good transmission zone for downward percolation of meteoric water (Pitale et al 1996). The downhole well testing of these production wells has indicated a maximum temperature of 112.5°C. The geothermal anomalous zone extends over an area of 1.26 km² for the isotherm of 100°C at a depth of 300 m. The heat flow values calculated from the borehole data are 241.4 mW/m², with a temperature gradient of 0.08° to 0.1°C/m (Ravi Shanker, 1987).

2.2 Anthoni- Samoni hot springs, Hoshangabad district

The Anthoni-Samoni Geothermal field is located in the foothills of Pachamarhi, in the southern part of the Narmada lineament zone, near the Gondwana contact with basic sill in Chhindwara district. The geothermal manifestations are in the form of isolated hot springs and clusters of hot springs with sporadic gaseous activity located along a nala. The temperatures of the hot springs range from 30°C to 43°C.

The Gondwana sediments comprise mostly the Talchir Formation of greenish grey splintery shale, fine grained sandstone, and rhythmite. This formation trends N60°W-S60°E to E-W with moderate dips toward the south. The Bagra Formation, comprising coarse conglomerate and silty brick red clay, is brought in juxtaposition with the Talchir Formation and Proterozoic rocks due to ENE-WSW trending faults and numerous sympathetic minor faults trending N50°W-S50°E which act as conduits for upflow of thermal water.

Free flow of thermal water was encountered in borehole ANH-1 at a depth of 585 m with well-head temperature of 50°C and in borehole ANH-2 at a wellhead temperature of 53°C and a flowrate of 130 lpm. The thermal gradient varies from 0.058°C/m to 0.109°C/m in this area.

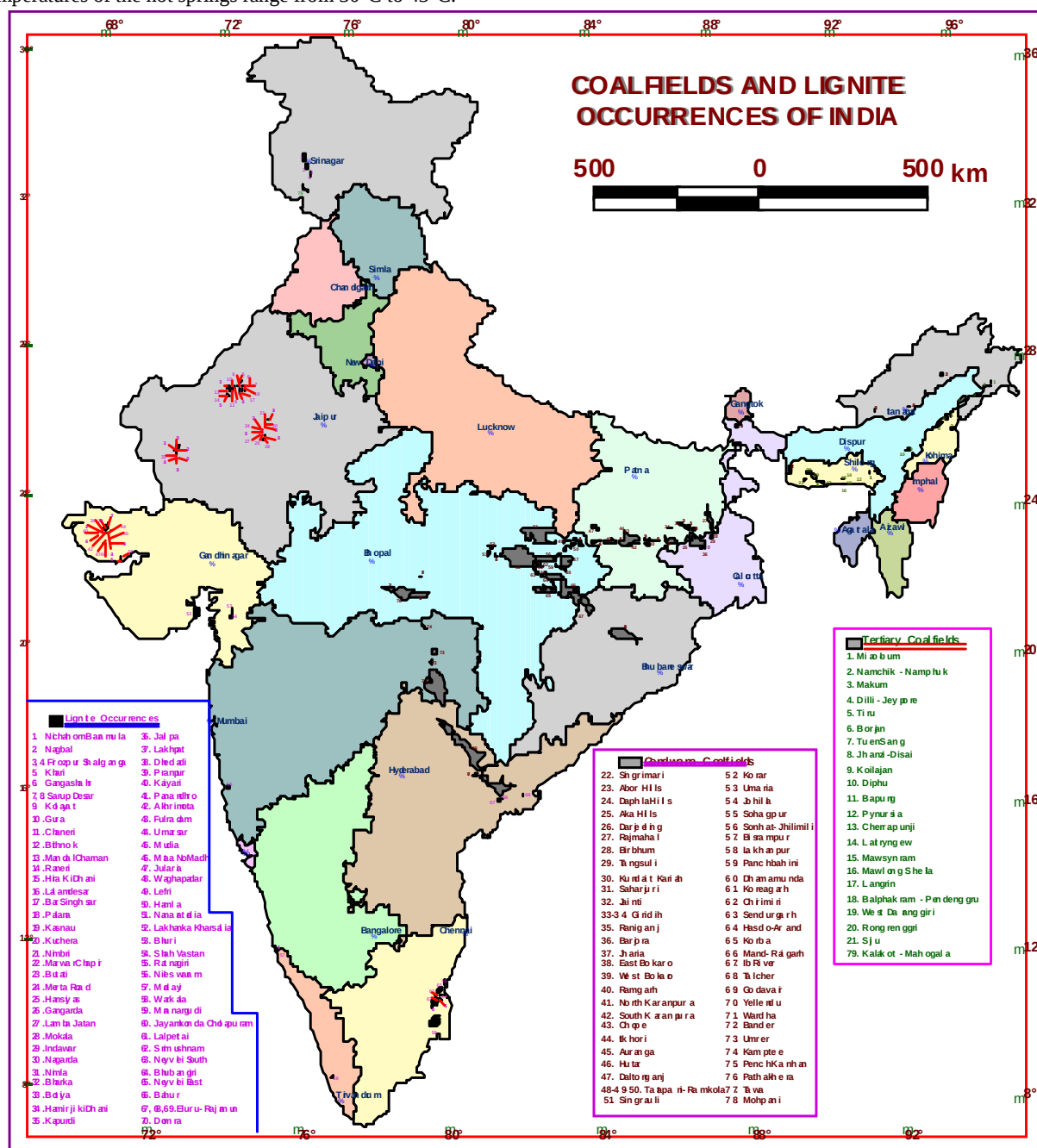


Figure 1: Gondwana Coalfields in India

Table 1: Summary of hot springs along the Gondwana Margins

Area	Temperature Hot springs	Temperature Bore wells	Base Temperature	Water discharge	Remarks.
1. Tatapani District Surguja	52°C to 97°C	110- 112.5	160±10°C	1200 to 1800 lpm	Artesian flow in 5 borewells of <350 m depth
2. Anthoni- Samoni	30°C to 43°C	52°C to 56°C	≈100°C	Spring-50-60 lpm Borewell- 130 lpm	3 boreholes. One borehole gives burning methane gas. Water of 54°C
3. Salbardi	38°C to 42°C	65.1°C	100-110°C	NA	Hot springs along river bank. Drilled 2 boreholes upto 623m depth.
4. Godavari Valley	40°C to 62°C	40- to 50 °C	100-150°C	Variable upto 900 lpm	Hot water discharge from borewells and mine inclines
5, Tata –Joram, Palamau district	50°C to 65°C	NA	123°C to 150°C	100-126 lpm	Gondwana and
6. Gadghora, Raigarh district*	NA	52°C	NA	NA	Borehole in Gondwana produces hot water
7. Birbhum district*	NA	50°C to 58°C	NA	50 to 110 lpm	Artesian flow in 2 borewells 300 to 500 m depth

(1 to 5 After GSI 1991 and Pande O.P. 1996, * GSI exploration data)

2.3 Salbardi hot spring, Betul district

Hot water springs with temperatures ranging from 38°C to 42°C emerge from the banks of the Maru river in the Salbardi area of the Amaravati district. Salbardi hot springs are located along the Maru River at the border of Amravati and Betul districts (Figure 2B). The hot springs are restricted to the contact of granitic gneiss, dolerite dykes, and Gondwana sandstones along the Maru River. The Gondwana rocks contain a 200 m thick layer of medium to coarse grained, friable sandstone trending ENE-WSW with dips of 12° -17° toward the north (Saxena R. K, 1987). Two boreholes, SAL-1 and SAL-2, were drilled to depths of 642.30 m and 495 m, respectively.

The temperature of springs ranges from 38°-42°C. Thermal gradients calculated based on thermal-logging of boreholes SAL-1 to SAL-5 range from 0.056 to 0.092°C/m. The maximum temperature was recorded in borehole SAL-1 at 65.1°C. The anomalous thermal gradient may be due to the proximity to megalineament, having thermally anomalous nature at deeper levels (GSI 1991). The hot water emerges to the surface via conduits provided by fractured rocks along fault planes. The thermal water is mostly of the bicarbonate sodium type. Thermal gradients in all three fields range from 0.054°C/m- 0.11°C/m, which is two to three times the normal value (Ravi Shanker, 1987).

2.4 Godavari valley hot springs, Khammam district

Godavari valley, trending NW-SE, is an active graben in which thick piles of coal bearing Gondwana sediments were deposited over Proterozoic basement. Hot water springs in Manuguru (36°C to 38°C), Bugga (41°C to 44°C), Agnigundala (62°C), and the Kothagudem coalfield in the Khammam district have been reported in this area. Hot water at 40°C was encountered in an incline developed for coal mining at Manuguru. Besides this, some boreholes discharge hot water at 41°C to 46.5°C (GSI 1991). The majority of the hot springs are of the Na-Ca-HCO₃-Cl type. The Agnigundam hot spring indicates a base temperature of >100°C. Anomalous thermal gradients and borehole temperatures have been recorded in boreholes drilled in Godavari valley for oil exploration. Base temperatures of 150°C at Agnigundam and around 100°C at Bugga and Manuguru have been estimated (Saxena V.K. 2007).

2.5 Tatta Thermal Spring, Palamau district, Bihar

Talta and Jarom hot springs in the Palamau district of Bihar are located in the vicinity of faulted contact between Proterozoic rock and Gondwana sediments. These hot springs are located on the eastward continuity of the Son-Narmada lineament and are exposed on the surface at the Tatapani Geothermal prospect in the Surguja district. Temperatures of 50°C and a discharge of 108 lpm have been recorded at Jarom, while temperatures at Tatta varies

from 61°C to 65.5°C with a discharge of 126 lpm. Base temperatures of 150°C at Jarom hot springs and 123°C at Tatta hot springs have been estimated. The heat flow in this area is estimated to be 122 mW/m² (GSI 1991). Tatta-Jarom, located in the Palamau district are in the vicinity of a major fault/shear zone which separates the Proterozoic basement from the Gondwana basin (J.M. Prasad 1996).

2.6 Other coal bearing areas-

During exploration for coal deposits around Ghargoda in the Mand-Raigarh coalfield in the Raigarh district of the Chhattisgarh state, a borehole drilled near the village of Tilaipali discharged free flowing hot water at 52°C.

2.7 Hot water in Mahallah Coal block, Birbhum district

The Geological Survey of India has discovered a new potential geothermal block in the Gondwana Coalfields in the Birbhum district. Under the guidance of Director Gautam Mukhopadhyay, geologists Basudeb Data, Saugata Datta, and Pradip Kumar Datta encountered free flowing hot water at 50°C with a discharge of 50 lpm and 58°C with discharge of 110 lpm in two boreholes during an investigation for coal in the east extension of the Birbhum coalfield in the Mahallah block of the Birbhum district (Figure 3). The hot water is clear, odorless, and has no turbidity, but shows bubbles of gas emission. The chemical composition of hot water from these boreholes is presented in Table 2.

Table 2: Chemical composition of bore well water

Radicals	Bakreshwar BKR-1	Boreholes BMH-2	Boreholes BMH-1
pH	9.1	8.5	8.7
Condu at 25°C	580	1355	1368
CO ₃	37	26	53
HCO ₃	53	249	241
Cl	100	250	280
SO ₄	25	6	5
Ca	4	8	8
Mg	2	5	5
Total hardness as CaCO ₃	20	40	40
Na	124	264	266
K	3	6	5
TDS	354	799	785
SiO ₂	78	39	23
B	0.5	0.5	0.5
F	12	9	10
As ppb	10	30	10

The boreholes drilled here encountered the nearly 270 m thick Barakar formation, but in borehole BMH-3, the Barakar formation is omitted due to a fault trending NW-SE, as can be seen in Figure 3. Here, 240 m thick Rajmahal formation and 100 m thick Tertiary sediments are reported to occur. Borehole BMH-3 discharged hot water of 56°C to 58°C. Balaram Das and Sanjay K. Biswas carried out geophysical logging of these boreholes under the guidance of Director U.K. Biswas by deploying a Robertson-micrologger –II unit. Borehole BMH-1 was reported to have Trap- barakar contact at a 388 m depth. Thermal logging was used to measure temperatures of 60°C near the surface and 70°C at a depth of 78 m, indicating a temperature gradient of 0.125°C/m. The results of this thermal logging are shown in Figure 4. A reversal in temperature to 62°C is observed until a depth of 240 m.

The borehole BMH-3 was reported to have temperatures of 40°C at a depth of 80 m, 20°C at a 225 m depth, after which it remains constant. Thermal logging of both boreholes has indicated heavy cold water influx in the boreholes, as suggested by the temperature reversal. The reservoir temperature indicated by geothermometers varies from 74°C -93°C using silica and 127°C to 137°C using the Na/K method. The preliminary investigation suggests that the area has a good potential for geothermal energy of intermediate enthalpy.

Thus, in addition to coal deposits, the Gondwana basins host geothermal energy of low to intermediate enthalpy.

3. DISCUSSION

The alternate shale-sandstone sequence in Gondwana sediments gives rise to confined instances of groundwater occurrence. The fractured Proterozoic rocks provide easy access to meteoric water for deep circulation in the reservoir. Overlying Gondwana rocks with high porosity and permeability, act as a very good transmission zone for the downward percolation of meteoric water (Pitale et al 1996). The meteoric water, which percolates to deeper levels, collects heat from the hot rock. The hot brine then begins to rise toward the surface due to buoyancy and passage provided by shear zone. A conduit for the upflow of thermal water is provided by intersections of fractures and faults, as illustrated in Figure 2.

The Tatapani- Ramkola Coalfield is marked by the boundary faults against the Surguja crystalline complex toward the north, east and south and is concealed under the younger Panchet formation in the west. Boundary faults along N-E & S peripheries brought the Barakar, Barren Measures, and Raniganj formations in juxtaposition with the Surguja crystalline complex (Das et al 2007). The total thickness of these sediments may vary from 2000 m to 3000 m, depending on the sequence of formation developed in particular depositional basin. The deep sedimentary basin provides passage for the deep circulation of surface water to collect heat from the sub-surface. This water is discharged on the surface through conduits provided by the boundary faults. During drilling, this hot water exhibited artesian flow due to buoyancy and hydrostatic pressure at the depth.

3.1 Strategy for exploration

An exploration strategy is a long term approach toward exploration in a sedimentary basin (S.K. Roy 2007). There are several stages of exploration:

Surface mapping and geochemical survey of hot water bodies.

Sub-surface studies – Geophysical Survey, mostly resistivity profile grid pattern survey and MT survey for reservoir demarcation.

Exploration by drilling deep boreholes > 1000 m.

Synthesis and interpretation of data.

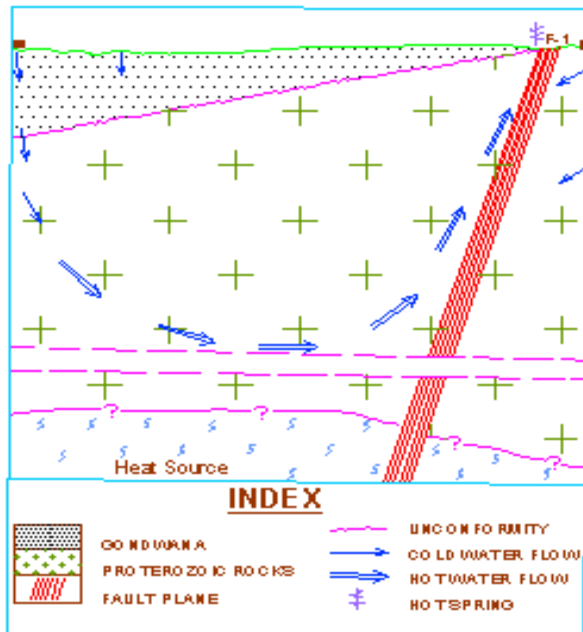


Figure 2: Schematic model of Tatapani geothermal reservoir

The exploration for geothermal resources in Gondwana is a rather tricky situation. As the Gondwana sediments are affected by intrabasinal faults, the ideal situation for development of geothermal resource is disrupted. The various stages of exploration are as follows.

- Geological Mapping-** Geological mapping involves a preparation of detailed geological maps representing all the lithological units exposed on the surface, with structural elements recorded. The lithological contacts, strike and dip of formations, unconformity, and fault trend and nature are essential data in this map. After preparing the detailed map, surface geothermal manifestations may be delineated and such areas may be selected for detailed survey.
- The areas with surface/sub-surface geothermal manifestations may be delineated for further survey. The geochemical analysis of hot and cold springs and borewell water in the area may be carried out to ascertain the hot water extent in the surface area.
- Geophysical survey** in the form of resistivity surveys may be carried out to ascertain the zones of low resistivity in the basin. A geophysical survey profile showing the extent of low resistivity areas may be prepared. Advanced methods like MT surveys, which can have deeper penetration, may be preferred if the extent of geothermal manifestation is larger. The indication of large aquifer zones with proper depth data is useful for planning exploration programs. A 3-D structural model of the depositional basin, including the disposition of faults, is helpful in designing a borehole plan.
- The average thermal gradients in Gondwana Sediments are almost normal geothermal gradients.

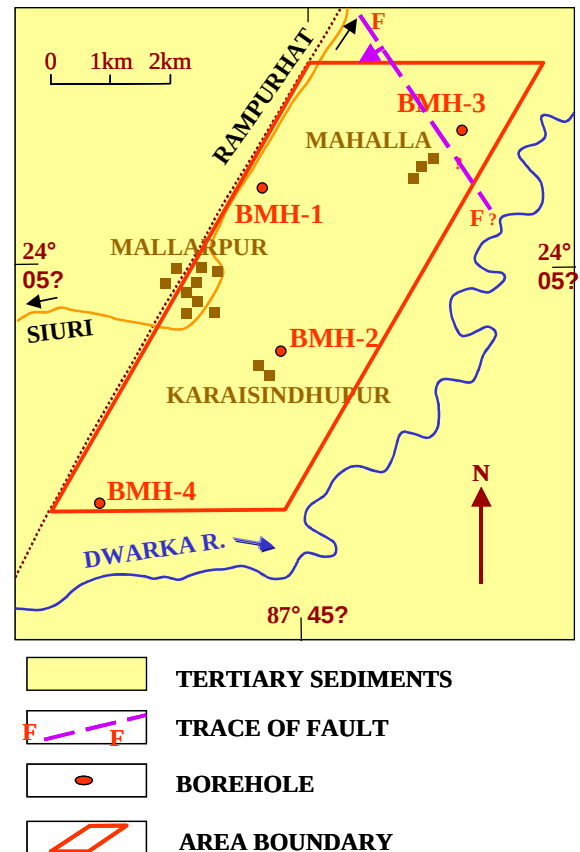


Figure 3: Geological map of Mahallah block, Birbhum district

Thus, hot water resources may be available at a depth of >1000 m, where the deep circulation of groundwater is feasible. Pitale et al. (1996) postulated a 2-D model for the geothermal system in the Tatapani geothermal area of the Surguja district (Figure 2), suggesting that the deep circulated water in conduits provided by marginal fault may cause the ascension of hot water to the surface. This model may be extended to all hot springs in the Gondwana basins, with local modifications.

Considering the 2-D model and the trend and dip of the marginal fault, it is suggested that the exploration for geothermal sources in Gondwana basin may be initiated on a down dip of the marginal fault to penetrate the sedimentary sequence (800-1000 m) unaffected by structural disturbances. The formation of a geothermal reservoir depends on the porosity and permeability of the lithological units, the recharge area, the scope of lateral movement of subsurface water, and easy access to the deep groundwater through marginal faults acting as vents for upward movement of deep circulated water. Thus, systematic geological studies aided by geophysical surveys (including the resistivity method) may be useful in delineating the area for detailed geothermal resource exploration in the Gondwana basins.

Lineaments provide an easy locale for hot spring manifestations. Maps of chloride rich zones of geochemical anomaly superimposed on those of low resistivity areas indicate the subsurface distribution of hot water sources. MT surveys may suggest additional information about the depths and areas of water bearing zones. Considering these data, the trend of hot water bodies may be deciphered in relation to the lineaments. A drilling plan to tap the hot water zone at a depth of >600 m and parallel to the trend of

the lineament may prove to be successful. The boreholes drilled on the downthrown side of the fault zone would be good production wells.

4. CONCLUSION

The Gondwana basins in India host geothermal resources of low to intermediate enthalpy. The hot water is aligned along the lineaments is mostly confined to the dip side of marginal faults. The hot water is formed due to the deep circulation of meteoric water in Gondwana sediments. Exploration programs in low resistivity anomaly zones in the dip side of the fault zone may lead to the discovery of high quality hot water aquifers.

ACKNOWLEDGEMENTS

The author expresses gratitude to Mr. R. K. Vishnoi, Dy. Director General, GSI, Central Region and Mr. K.K. K. Nair, Dy. Director General, GSI Op Maharashtra for granting permission to publish this paper. The author is thankful to the officers and staff of GSI, Operation Maharashtra for extending support in the preparation of this paper.

REFERENCES

Das D.K., Bhattacharyya S, Gangopadhyay B (2007): High resolution analysis of fault system and its implication

on tectono -sedimentary history of Tatapani- Ramkola coalfield, Surguja district, Chhattisgarh, Sp pub no. 9, Gondwana Geological Magazine, pp-99-106.

GSI (1991): Geothermal Atlas of India, Sp Pub no.19, pp-60-108

Pande O.P. (1996): Global geothermal energy utilization and its relevance to India, in Geothermal in India, GSI Sp pub 45, pp-11-20

Dy. Director General (2007): Resource Scenario of solid fossil fuel of India and its future perspective, energy scenario in 2020, Sp pub no. 9, Gondwana Geological Magazine, 71-80.

Ghosh P.K. (1954): Hot springs of India, GSI records volume 80.

Pitale U.L, Karve A.E, Sarolkar P.B. (1994): Geothermal potential along Gondwana margins in Central India, 9th International Gondwana Symposium, pp-1279-1287

Pitale U.L., P. B. Sarolkar, H. S. Rawat, S.N. Shukla (1996): Geothermal reservoir at Tatapani Geothermal field, Surguja district, Madhya Pradesh, India; Proc Stanford Geothermal workshop, pp-565-572

Borehole No. BMH-2, Mahallah area, Birbhum coalfield, West Bengal

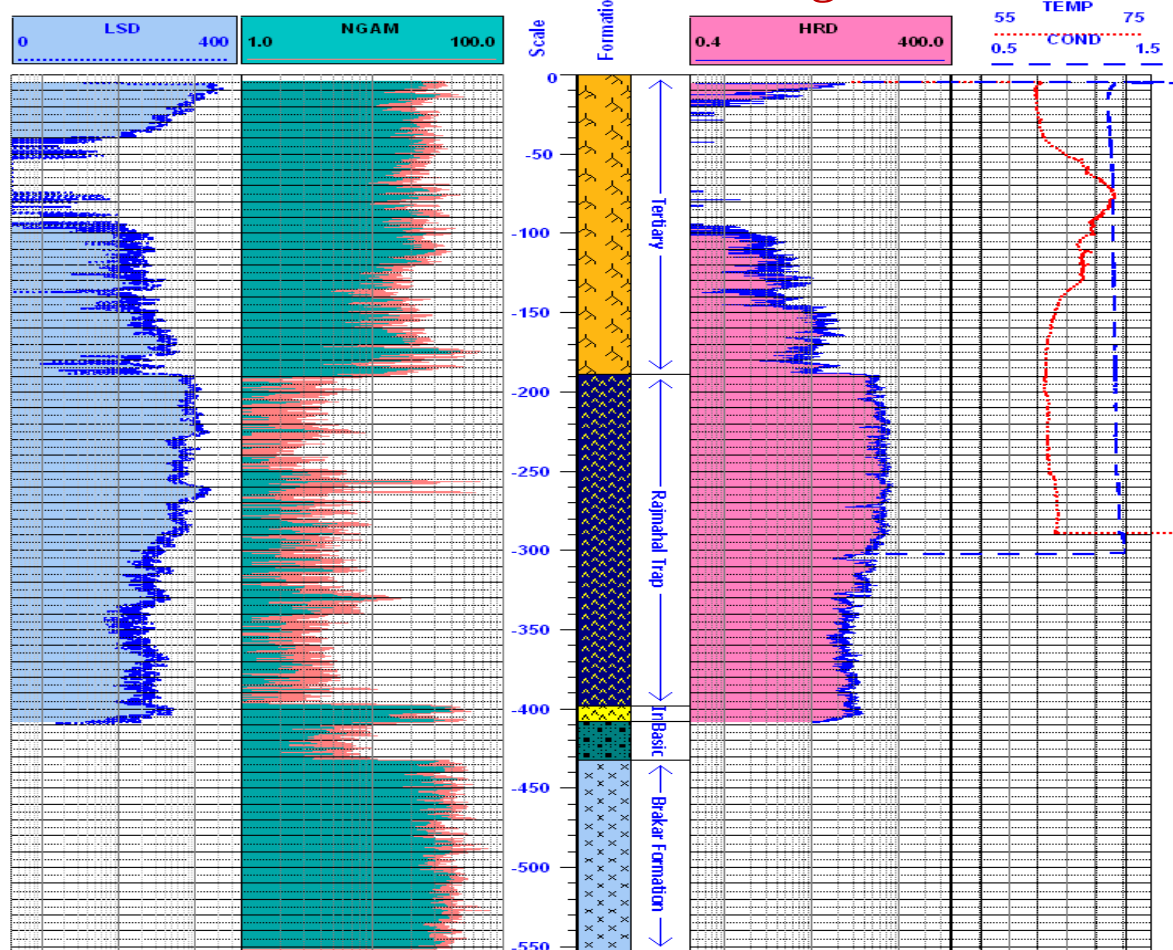


Figure 4: Thermal log of borehole BMH-2

- Prasad J.M. (1996). Geothermal energy resources of Bihar, in geothermal energy in India, GSI Sp Pub .45, pp-99-118
- Raja Rao (1983): Coal fields of India, Maharashtra and Madhya Pradesh states, GSI memoirs 45, pp-1-25.
- Ravishanker (1987): Status of geothermal exploration in Maharashtra and Madhya Pradesh, GSI records vol.115 pt 6, pp-6-29.
- Roy S.K. 2007: Exploration strategy for hydrocarbon search in present scenario in India, Sp pub no. 9, Gondwana Geological Magazine, pp-55-58.
- Saxena R.K. (1987): Geothermal potential of Salbardi warm springs district Betul Madhya Pradesh and district Amaravati, Maharashtra; Geo, Surv. Ind, rec. Vol. 115, pt 6, pp 175-183.
- Saxena R.K. (1987): Geothermal potential of Salbardi warm springs, districts Betul, Madhya Pradesh and Amaravati Maharashtra, Geo, Surv. Ind, rec. vol.115, pt 6, pp 175-180.
- Saxena V.K. (2007): rock water interaction and chemical equilibrium in hydrothermal system, Godavari valley, A.P., India, Sp pub no. 9, Gondwana Geological Magazine, pp-211-214.
- Thussu J.L, Prasad J.M., Saxena R.K., Gyan Prakash, Muthuraman K. (1987): Geothermal energy resources potential of Tatapani hot spring belt, district Surguja, M.P., Geo, Surv. Ind, rec. Vol.115, pt 6, pp 29-55.