

**GEOHERMAL RESERVOIR AT TATAPANI GEOHERMAL FIELD,
 SURGUJA DISTRICT, MADHYA PRADESH, INDIA,**

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ABSTRACT

The Tatapani Geothermal field, located on the Son-Narmada mega lineament is one of the most intense geothermal manifestation, with hot spring temperature of 98°C. in Central India. 21 Exploratory and thermal gradient boreholes followed by 5 production wells for proposed 300 KWe binary cycle power plant, have revealed specific reservoir parameters of shallow geothermal reservoir of 110°C in upper 350 m of geothermal system and their possible continuation to deeper reservoir of anticipated temperature of 160 ± 10°C.

Testing of five production wells done by Oil and Natural Gas Corporation concurrently with drilling at different depths and also on completion of drilling, have established feeder zones of thermal water at depth of 175-200 m, 280-300 m, maximum temperature of 112.5°C and bottom hole pressure of 42 kg/cm². Further interpretation of temperature and pressure profiles, injection test, well head discharges and chemical analysis data has revealed thermal characteristics of individual production wells and overall configuration of thermal production zones with their permeability, temperature, and discharge characteristics in the shallow thermal reservoir area. Well testing data and interpretation of reservoir parameters therefrom, for upper 350 m part of geothermal system and possible model of deeper geothermal reservoir at Tatapani have been presented in the paper.

Key words - Tatapani Geothermal convective reservoir, India

1. INTRODUCTION

The Tatapani geothermal field, situated in the Son-Narmada river basin in Central India, forms one of the most important geothermal manifestations, in Son-Narmada-Tapti mega lineament zone (Fig.1).

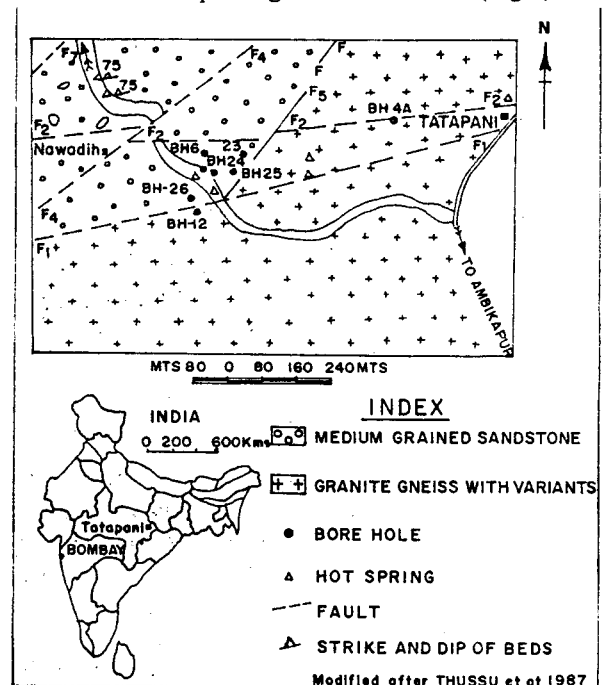


FIG. 1- MAP OF TATAPANI GEOHERMAL FIELD, INDIA

The geothermal manifestations at Tatapani are in the form of hot springs showing temperature of 50° to 98°c at surface over a marshy ground cover. (Geothermal Atlas 1991). Intense anomaly is observed over an area of 0.1 sq.km. (Ravi Shankar, 1987).

Geological Survey of India, carried out the investigation at Tatapani, comprising reconnaissance and semi-detailed survey including exploratory drilling of 26 boreholes, establishing upflow zone and zone with anomalous thermal gradient, over an area of 0.1 sq.km. Total 5 borewells GW/Tat/6 and 23 to 26, were completed as production wells producing + 1800 lpm of thermal water. Synthesis of sub-surface data for deducing reservoir configuration is presented here.

2. GEOLOGICAL SETTING

Rocks of Archaean complex comprising coarse grey granitic gneiss, fractured chlorite schist and bands of calc-granulite and pyroxene granulite and Gondwana super-group comprising Talchir and Barkar Formations are exposed near Tatapani. A coarse grained felspathic biotite bearing porphyritic pink granite is ubiquitous around Tatapani. The Gondwana sediments are exposed over a wide area, northeast of Tatapani. Thin bands of conglomerate comprising pebbles of biotite gneiss, chlorite schist, sandstone and quartz veins are also observed within this area. Gondwanas in the area have general strike on N80°W-S80°E with dips of upto 15° towards north. They are gently folded into westerly plunging synform (Thussu et al 1987).

2.1 Structure

Tatapani fault (F1) is observed south of village Tatapani as a shear zone trending ENE-WSW with steep dip towards north (Fig.1). The fault is marked by a thick shear zone exposing brecciated granite gneiss which forms contact between the Gondwana and the Proterozoic rocks. Fault (F2) sub-parallel to Tatapani fault is exposed to the north of Tatapani fault. Cross-faults F4 and F5 trending NNE-SSW with steep dips towards NW show silicified indurated blocks of coarse sandstone and granite gneiss, along the fault plane, cutting across the Tatapani fault. These faults delimit the surface manifestations and high heat flow zone at the Tatapani geothermal field.

2.2 Sub-surface geology

Geological studies around Tatapani thermal springs reveal that the area east of Tatapani drains towards east while the area west of Tatapani drains towards northwest. The ground water in Gondwana rocks occurs in confined condition and wells in the Proterozoic rocks tap water under water table conditions (Thussu et al 1987). The water in Proterozoic rocks is restricted to fracture zone and cavities due to leaching.

The study of borehole cores has revealed that medium to coarse grained sandstone/siltstone, sheared and fractured at depth, is encountered upto the depth of 120 m, approximately. Hard, compact, sheared, fractured, coarse pink felspathic granite is encountered below Gondwana sediments. The contact between granite and sandstone is sheared in nature. The borehole cores show effects of intense fracturing, shearing, leaching, and brecciation including caught up patches of sandstone and gneissic rocks. Drilling data indicate presence of highly fractured zone and cavity due to leaching, from the depth of 233 to 237 m in the borehole GW/Tat/25 and 216 m to 239 m, in the borehole GW/Tat/26.

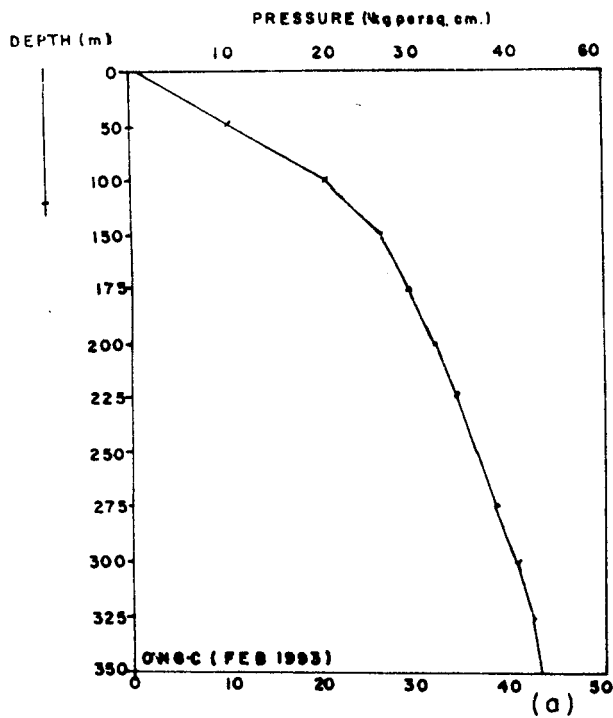
3. WELL TESTING

Downhole well testing was undertaken in association with the ONGC Ltd. to determine the temperature and pressure profiles of the production wells. Following parameters were recorded during the well testing. (Table-I).

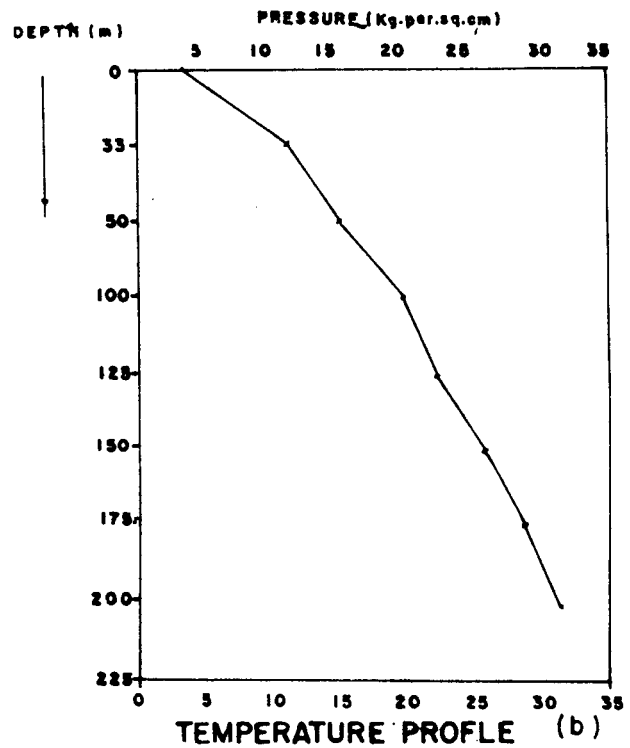
3.1 Temperature profile

Shut in temperature in the borehole rises from 98°c at the depth of 50 m to 112°c at the depth of 175 m - 200 m, (temperature gradient of .088 - .111°c/m. Maximum borehole temperature recorded is 112.5°c. There exists a zone of convective heat transfer making the temperature constant over the region between 175-225 m in the borewell Tat/6 and 160-255 m in the borewell Tat/23, below which the temperature drop shows existence of colder zones (Table-II). The temperature profile of GW/Tat/25 is a straight line with temperature drop taking place beyond 200 m. The temperature gradient is relatively sharp at shallow depths in the borewells Tat/23 and 25, as compared to the borewell Tat/6 (fig 2, abc).

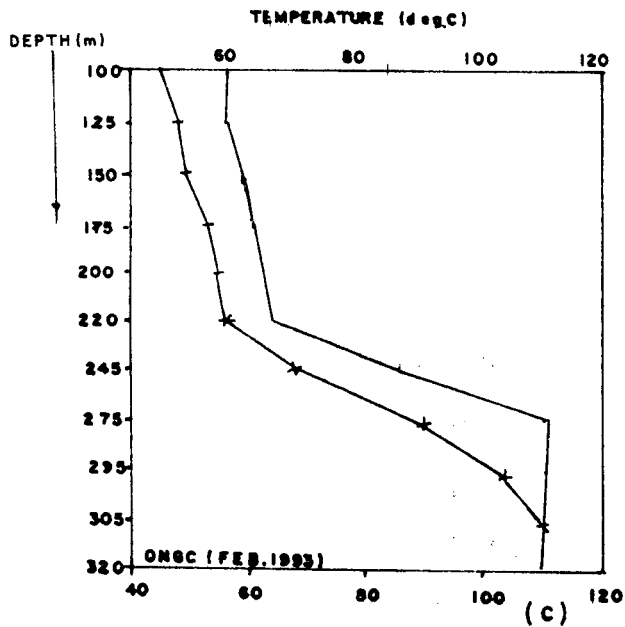
**SHUT IN PRESSURE PROFILE
WELL No. TAT/23**



**SHUT IN PRESSURE PROFILE
WELL No TAT/25**

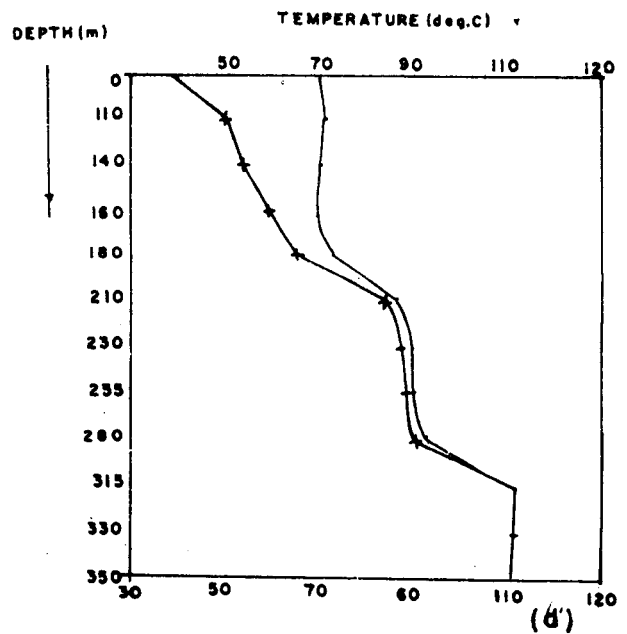


**TEMPERATURE PROFILE
WELL No. TAT/6**



158 lpm — Series 1 — Series 2. 252 lpm

INJECTING COLD WATER AT THE RATE OF
158 lpm & 252 lpm.



252 lpm — Series 1 — Series 2 500 lpm

INJECTING COLD WATER AT THE RATE OF
252 lpm : 500 lpm.

Fig.-2

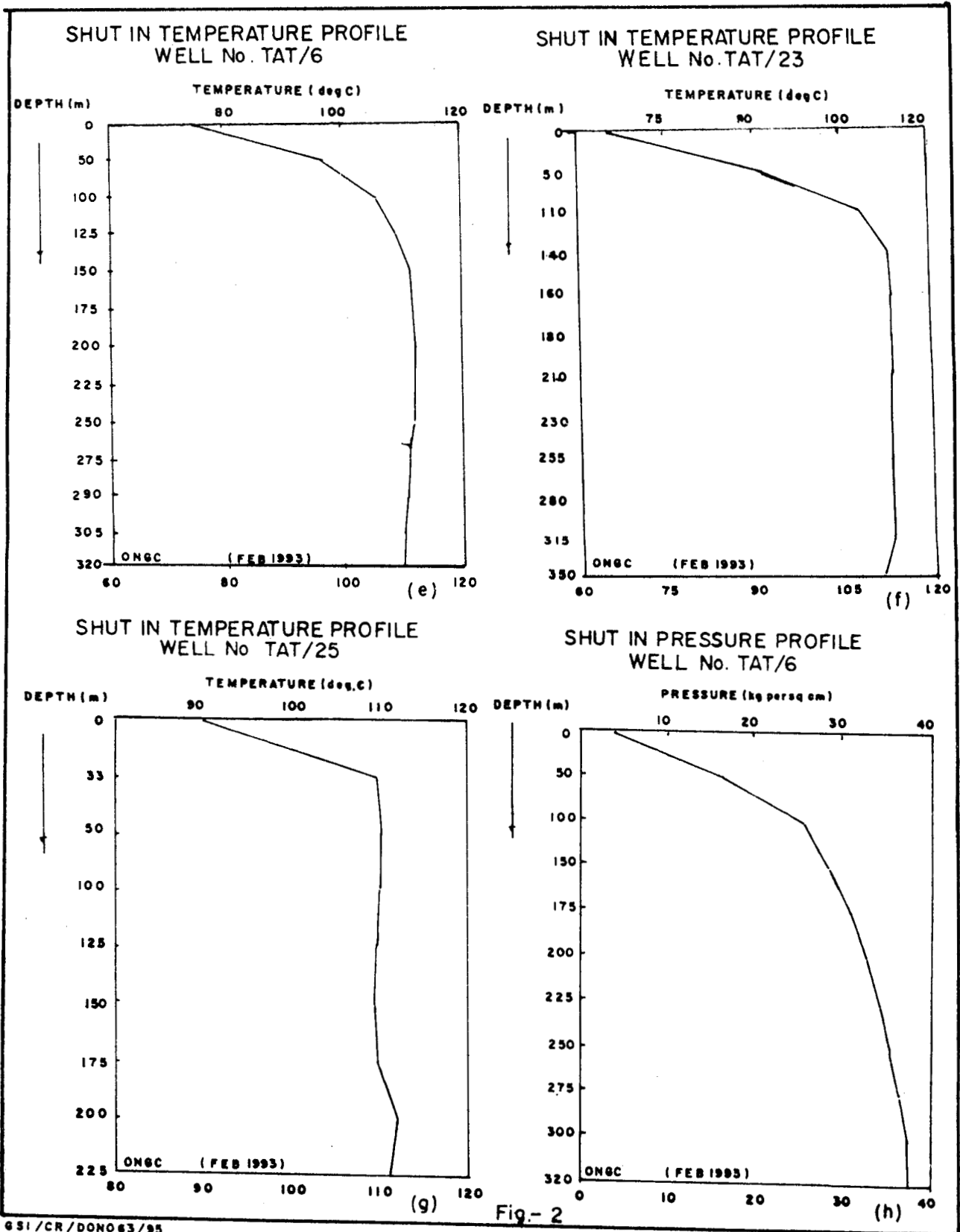


TABLE - I

Production well parameters

Borehole No.	Depth in m.	R1 (m)	Temperature at surface °c	Discharge lpm	Ener-gy potential KW
Tat/6	320		99-99.5	289-293	510.2
Tat/23	353.15	451.110	99-100	269-303	501.4
Tat/24	244.60	451.000	99.5-100	431-451	773.2
Tat/25	350.70	450.810	+100	255-269	459.4
Tat/26	239	451.090	99-100	498-508	881.9

TABLE - II

Thermal Characters of shallow reservoir

Borehole No.	Depth in m.	Depth of blow out zone	Thermal gradient above out zone	Depth at which Maximum temperature is recorded	Hot water feeder zones in m.	Mixing zones in m.
Tat/6	320	100-110m	0.63°c/m	225 m	125-150m 220-275m major	305-320m
Tat/23	353.15	100-120m	0.58°c/m	240m	110-140m 180-210m 280-315m	330-350m
Tat/24	244.60	100-110m	0.63°c/m	-	-- Data awaited	--
Tat/25	350.70	35-55m	1.27°c/m	200 m	33-55 m 175-200m	Below 200m
Tat/26	239	70-80m	0.87°c/m	-	--Data awaited	--

The occurrence of fracture zones, from 233 m to 245 m and around 300 m in borewell Tat/25 and increase in discharge from borehole during drilling through this depth range, suggests presence of two major thermal feed zones in this depth range. In well Tat/26, thermal water feed zones are indicated beyond depth of 209 m.

Maximum flowing well temperature at well head is recorded to be 110°c in the borewell Tat/6.

During the well head discharge, fluid from the colder zones gets heated up in convective zone to the maximum borehole temperature. The heat loss due to the conduction to the adjacent cooler zones causes drop in fluid temperature by 1-2°c, on reaching well head/surface. The fluid temperature drops down to 100°c because of flashing, when exposed to the atmosphere (GSI-ONGC 1993). The cold water injection temperature profile of borehole Tat/6, indicates influx of hot fluids from deeper zones also.

Deep Schlumberger soundings in the area have already indicated low resistivity zones at the depths of about 300m to 600m (Joga Rao et al 1987).

3.2 Pressure profile

Pressure profile indicates that the pressure in borewells is higher than hydrostatic pressure at respective depths. Pressure profile of Tat/6, indicates high permeability below 140 m depth. The formation is less permeable below the depth of 250 m than in the 140 m - 250 m depth zone. In the borehole Tat/23, the permeability zone ranges from depth of 100 - 150 m, 275 - 300 m while in Tat/25, it is recorded at 33 - 55 m, 100 -125 m, and 175 - 200 m depth range. The pressure profile shows a sharp increase in pressure at Depth range of 100 - 150 m in all the borewells (Fig 2. def). The low pressure above this depth gives rise to flashing, thereby reducing the fluid temperature to 100°C at well head. Circulation of cold water in the borewells Tat/25 and 26, during drilling operation, resulted in increase in pressure in all the wells. This suggests that all the borewells are tapping the same reservoir and the fracture pattern is interconnected. The pressure profile indicates steady increase in pressure with depth suggesting thereby the continued influx of hot brine from the feeder zones.

3.3 Injection tests

The temperature profile during the cold water injection into the wells indicate that the borewell GW/tat/6 has one major permeability zone from 220 - 300 m. and the other from 150 - 175 m, thus categorising this well as deeper permeable zone well. The cold water injection profile of Tat/23 indicates permeable zones from 110 - 140 m, 180 -210 m and 280 - 315 m, and thus the well can be classed as multiple zone low permeability well (Table-II).

Detailed configuration of hot water body as arrived from testing of production wells in the regional context of the geothermal reservoir at Tatapani is given in Fig.3.

4. GEOTHERMAL RESERVOIR

Ground water in upper porous and permeable sedimentary sequence of Gondwana supergroup percolates downwards through deep faults and fracture zones in Tatapani geothermal field, to the deeper

thermal reservoir in the proterozoic rocks.

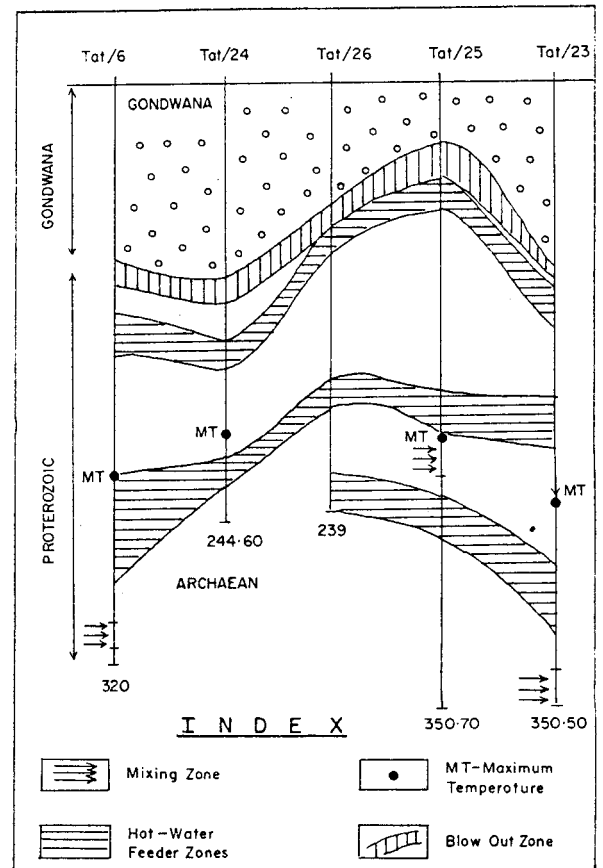
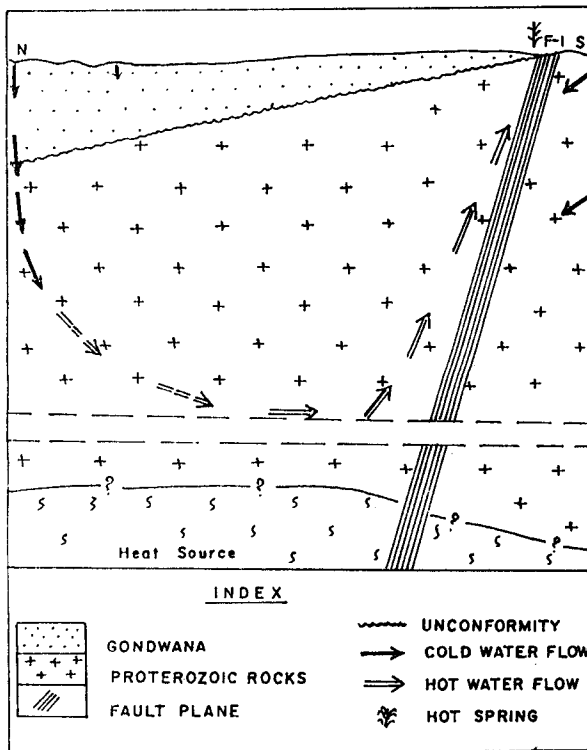


Fig.3. SCHEMATIC DIAGRAM OF SHALLOW THERMAL RESERVOIR, TATAPANI

The sub-surface data and thermal logs indicate that the blow out zone is mainly confined to the contact between the Gondwana and Proterozoic rocks, around the depth of 120 m, shallowing of blow out zone is observed around the borewell Tat/25. The geothermal reservoir is mainly restricted to the Proterozoic rocks, over which the Gondwana sediments rest unconformably acting as a cap rock, preventing loss of heat to the surface. The high fracture intensity due to faulting/tectonism and cavities due to leaching in Proterozoic rocks, provide enough permeability for easy flow of thermal water, in the reservoir. Overlying Gondwana rocks with high porosity and permeability act as very good transmission zone for downward percolation of meteoric water. The alternate shale-sandstone sequence in the Gondwana sediments, give rise to confined conditions of groundwater occurrence. The sheared nature of Proterozoic rocks provide an easy access to the meteoric water for deep circulation in

the reservoir.

At Tatapani geothermal field, the meteoric water which percolates to deeper level, collects heat from the hot rock. This hot brine is impounded at Tatapani fault (F1) which dips northerly. The hot brine starts moving up due to buoyancy and obstruction caused by the shear zone, resulting in hydrothermal pressure. Intersection of fractures saturated with upflowing thermal water, with main fault plane acts as conduit for upflow of thermal water. Where this is true depiction of the system, temperature and flow might be increased by drilling to intersect the fault at depth (Culver 1991). The thermal log of the boreholes drilled around the fault F2, show inversion of temperature near the bottom indicating influx of coldwater at deeper level along the fault plane. The thermal gradients also fall due to cold water mixing resulting into the deepening of blow out zone and 100°C isotherm. The borewells in the proximity of Tatapani fault (F1) show higher thermal water temperature at well head and shallowing of isotherms. Thus, the fault (F1) acts as conduit for upflow of the thermal water to the surface (Fig.4).



G.S.I.C.R.D.O.No.8/96
Fig-4 SCHEMATIC MODEL OF TATAPANI GEOTHERMAL RESERVOIR INDIA

The intersection zone of faults F4, F5 with the faults F1 and F2 which is marked by brecciation, acts as the channel for access of thermal fluid to the surface. The lack of thermal springs south of the Tatapani fault (F1) may be due to less fracture permeability in the granite gneiss terrain.

The sub-surface data indicates that the reservoir is conical in shape with apex exposed to surface in the form of geothermal manifestations. The base extends in all directions, widening the extent of reservoir at the depth. The estimated area of reservoir of 100°C temperature, at the depth of 1500 m, is computed to be 7.2 sq.km. Total energy potential of this computed reservoir, is estimated to be 18.35 MWe, and for the shallow proven part of upper 350m is of the order of 300 KWe of power generation by binary cycle (Pitale et al 1995). The configuration of upper 350 m part of the geothermal reservoir as revealed from well testing data (Fig 3) is summarised below.

- * Hot water body is confined to fractured Proterozoic rocks. Gondwana sediments act as cap rock.
- * Blow out zone is around 100 m depth, with shallowing upto 55 m, in well Tat/25.
- * There are three main feeder zones of thermal water.
- * Thermal water upflow is controlled by Tatapani fault and also intersection of the other parallel and cross faults.
- * Maximum temperature of 112.5°C is recorded around depth of 200 m.
- * Inflow of hot water in production wells is through the fault and fracture system intersected in the boreholes. The water mixing zones are prominent in the boreholes near the fault F2.
- * Cold water incursion in the thermal reservoir explored by drilling, is inferred below the depth of 300 m.

5. CONCLUSION

The geothermal reservoir at Tatapani is restricted to fractured Proterozoic rocks. The maximum temperature recorded in the borehole is 112.5°C while temperature recorded at well head is 110°C. The major fracture zones are restricted to the depth of 175 m to 250 m and around 300m. The hydrothermal convective system is suggested for Tatapani geothermal field. The hot water at Tatapani is normal meteoric water which percolates down through fractures to deeper parts of the reservoir and gets heated up, and upflowing as hot brine. The ENE-WSW trending faults (F2-F3) form a zone of influx of cold water. The Tatapani fault and its zone of intersection with NE-SW trending cross faults act as conduit for upflow of thermal water. The studies have revealed configuration of hot water body in upper 350 m part of geothermal system at Tatapani with shallowing of reservoir around borewell Tat/25. (Fig. 3).

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