Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

ASSESSMENT OF TATAPANI GEOTHERMAL FIELD, INDIA, BASED ON HYDROTHERMAL MINERAL ASSEMBLAGES

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Key words: Hydrothermal minerals, epidote, stilbite, smectite, illite, Tatapani, India.

ABSTRACT

Tatapani is the most promising geothermal field located on Son-Narmada lineament in Central India. Two types of lithounits comprising Proterozoic basement rocks viz. granite gneiss, biotite gneiss, phyllite, and Lower Gondwana group consisting of sandstone , shale are exposed in this area. The contact between Proterozoic and Gondwana rocks is marked by Tatapani fault trending ENE-WSW. Hydrothermal alteration in form of silica sinter is observed in this area. Fractures in Proterozoic rocks control the permeability of the reservoir.

Five production wells have been drilled at Tatapani Geothermal Field, for establishing a binary cycle pilot power plant. The core samples recovered from these bore holes have revealed a variety of hydrothermal alteration minerals in veins and cavities. The prominent hydrothermal minerals observed are stilbite, quartz, laumontite, smectite, albite, with subordinate illite, and calcite. The assemblage stilbite - smectite suggests alkaline conditions and temperature range of 120 -150°C. Illite - smectite association is reported around 200m depth, indicating that the temperatures around 180°C prevailed in this zone. Platy calcite observed in the boreholes suggests presence of zone of loss of CO_2 and boiling. The possibility of two phase conditions prevailing in the reservoir is supported by the occurrence of platy calcite in the bore hole cores.

The temperatures suggested by hydrothermal mineral assemblages are comparable with the reservoir temperatures suggested by the aqueous geothermometers while the maximum temperature recorded in the borewells is 112.5°C. The difference between temperature indicated by hydrothermal alteration and temperatures recorded in the borewells may be attributed to the dilution or the heat loss by conduction, without attaining corresponding equilibrium in the chemical composition.

1. INTRODUCTION

Preliminary survey of the geothermal resources in India indicated presence of nearly 340 hot springs, most of which are intermediate to low temperature prospects (GSI 1991). These geothermal resources are usually located along a fault zone or lineament. The lineaments act as a conduit for upflow of the thermal water. The hot water circulation through the fractures in the reservoir rocks induce chemical action with the host rock resulting into the formation of the hydrothermal minerals which are mostly at equilibrium with the prevailing temperature conditions. Mineralogical observations and theoretical calculations are powerful tools by which history of the change in fluid chemistry and temperature within geothermal system may be characterized (Rochelle et al 1989).

Thus, the hydrothermal minerals preserve the record of palaeogeothermal conditions which prevailed in the reservoir. The correlation of the reservoir conditions indicated by the hydrothermal minerals to that suggested by the geochemical indicators or well testing data, is an important tool in deciphering the geothermal trends. An attempt has been made in this article to assess the reservoir conditions based on the hydrothermal mineral assemblages.

1. 1 Background Information

Thermal manifestations in Tatapani consist of hot springs (50-90°C) in marshy ground and hydrothermally altered clay zones, covering an area of about 0.1 sq.km (Ravishanker 1987). The detailed investigations by GSI included geological mapping, geophysical survey and drilling coupled with the chemical analysis of the thermal water. The sub surface geology of the area was reconstructed based on data from 26 bore holes drilled in this area (fig. 1). The earlier existing well GW/Tat/6 and four production wells GW/Tat/ 23 to 26, drilled during 1989-94, produce 1800 lpm hot water of 100°C (Pitale et al 1995), for a proposed binary cycle power plant (fig.2).

The reservoir temperature indicated by aqueous geothermometers varies widely, viz. silica from 127 to 157 °C, Na/K from 178 to 232°C, and K/Mg from 66 to 97°C (Sarolkar & Mukhopadhyay 1998). The variation in the temperatures of Na/K and K/Mg thermometers indicate the extent of mineral rock interaction during the upflow of hot water which may be reflected in the hydrothermal mineral assemblages.

2. GEOLOGY

The Tatapani geothermal field is located at the southern margin of the Tatapani- Ramkola coal field at the contact with Proterozoic rocks. The Proterozoic rocks, represented by coarse pink granite gneiss, biotite gneiss, chlorite schist, in the order of decreasing abundance, are found in juxtaposition with Lower Gondwana sandstone separated by a ENE-WSW trending Tatapani fault. The Lower Gondwana sandstone is encountered in the boreholes down to a depth of 120m, below which granitic gneiss with pink porphyrytic feldspar is encountered. Thin zones of breccia up to 30 cm thickness are occasionally observed in the borehole cores. The fractures and the cavities formed due to leaching are filled in by hydrothermal alteration minerals: zeolites, pyrite, calcite and secondary silica. The silica sinter is observed near Newadih village. Quartz veins are observed in the fractured breccia of Tatapani fault.

3. HYDROTHERMAL ALTERATION MINERALS

Alteration within mineral veins has been sensitive to variations in fluid composition and temperature with time (Rochelle et al 1989). The factors controlling alteration in geothermal systems are temperature, permeability, rock type, fluid composition and duration of fluid rock interaction. Permeability plays a major role in determining which alteration minerals can be formed by controlling the amount of contact between circulating fluids and reservoir rocks (Cox and Browne 1998).

The hydrothermal minerals are observed in the fractures and cavities in the borehole cores. The fine fractures are filled by silica. Stilbite is commonly observed as cavity filling and so is laumontite. Platy calcite is reported along wider fractures.

The surface alteration comprises kaoline, silica sinter and deposition of calcium carbonate along few vents (Thussu et al 1987). The most common alteration minerals are quartz, stilbite, pyrite, calcite, montmorillonite with subordinate amount of illite and chlorite. The feldspar, microcline, muscovite may represent primary minerals from the host rock. Quartz is a major constituent in the surface deposit as well as in the borehole cores upto 300m. The veins are filled by cryptocrystalline silica and chalcedony.

3. 1 Borehole Tat/25

In the borehole Tat/25, the alteration minerals stilbite, quartz, albite, calcite, pyrite are observed at shallow level, < 100m depth. The assemblage stilbite, quartz, albite, calcite, pyrite, montmorillonite with minor illite and laumontite are reported at the depth >200m. Stilbite is reported at the depth of 100m and below, albite in the range of 100 to 240m. Calcite is reported at 2 levels, 60-100m, and 190-230m. Pyrite is reported as fine disseminations through out the borehole. Illite is reported between 160-220m depth. Laumontite is reported at the depth of 200m (Table 1).

3. 2 Borehole Tat/26

The hydrothermal alteration reported from the borehole GW/Tat/26, is stilbite, quartz, pyrite, albite, montmorilonite, calcite, with minor amount of illite and laumontite. Stilbite occurs at the depth below 100m, calcite at 60 and 160-190m, and pyrite below 60m. Shimmering white stilbite crystals are deposited in vugs and cavities. Albite is recorded below 170m depth. Montmorillonite and illite are observed below 180m depth and laumontite at the depth of 200m. Fine dissemination of pyrite are common in the rock (Table 2).

4. DISCUSSION

4. 1 Clay minerals

The appearance and disappearance of clay mineral assemblages occur at specific temperature (Harvey and Browne 1991). The transformation of smectite to illite with increasing temperature and depth of burial through a series of progressively more ordered illite -smectite interlayer structure was studied by Weaver (1956). In less permeable environment there is gradual transformation of smectite to illite with chlorite formed at temperature as low as 110°C as a by product (Harvey & Browne 1991). In rock types where conduit flow is dominant illite and chlorite form by direct precipitation from solution, whereas away from these conduits mixed layer illte-smectite clay structures may form as replacement of primary minerals in host rock. The primary alumino-silicate minerals such as feldspars, micas and ferrous minerals alter to clay minerals. The smectite occurrence at the depth of 170m indicates temperature around 120°C. The occurrence of illite + smectie shows temperature in the range of 130-180°C in conformity with the reservoir temperature of 160°C, indicated by silica geothermometer.

4. 2 Calcite

The single phase geothermal fluid separated into two phase fluid at some stage causing deposition of calcite. Calcite reported at two levels, 60 m and >120m depth, indicates that the boiling zone shifted upwards with time. The dilution of hot water by meteoric water might have caused cooling of the fluid and upward shifting of the boiling zone. The calcite is a major mineral at the depth of 200-250m, associated with small amount of silica. Calcite seems to have deposited by loss of gas phase (CO_2) from liquid phase in Tatapani hot water system. The resultant decrease in gas pressure caused boiling at lower temperature at that depth (Thussu et al 1987).

4. 3 Silica Sinter

At Copahue (Argentina), in the area called Cop2, is a fossil geothermal manifestation, which is showing characteristics of neutral to alkaline alteration represented mainly by the siliceous sinter superimposed over the acid alteration. (Graciela Mas et al 1996). The alteration adjacent to Cop2 well presents minerals such as montmorillonite and siliceous sinter related with neutral to alkaline fluids. The acidity of alteration fluids decreases gradually from the alunite zone through the kaoline zone to montmorillonite zone.

Similarly, the siliceous sinter near Newadih village suggests that the geothermal fluid was neutral chloride water. The palaeogeothermal manifestations had a wider extent as observed from the silica sinter deposit near Newadih and east of the Tatapani fault.

4. 4 Chlorite and Laumontite

Occurrence of chlorite in geothermal areas generally indicates temperature exceeding 200°C (Henley & Ellis 1983). However, presence of laumontite suggests a maximum of about 240-250°C (Liou 1971). Steiner (1968) recorded chlorite at Wairakei at temperature as low as 110°C to at least 270°C. The wide difference in the temperature is attributed to the two different conditions of formation (Yau et al 1988).

Laumontite reported at the depth of 200m suggests temperatures >200°C,as suggested also by the Na/K thermometer .

4.5 Pyrite

The occurrence of pyrite is rather unusual which points to reducing conditions with low pH, mostly caused by the absorption of H_2S released in boiling by the steam heated water. Pyrite occurs all along the well in the borehole cores and does not show any oxidation.

Pockets of sulphur associated with the advanced argillitic alteration and kaolinite rich alteration zones imply generation of low (at most 4) pH fluid due to condensation of steam and absorption of gases in near surface ground water immediately after the depressurization of the system (Absar et al 1996).

4.6 Microscopic Study

The thin section study of core samples revealed that the rock comprises minerals formed in two phases. Quartz, porphyrytic feldspar, microcline and biotite are primary minerals while medium to fine grained quartz, smectite, illite, chlorite and epidote occupying vugs and cavities, represent secondary minerals. Feldspar show alteration to clayey minerals along cleavages and fractures. Epidote is reported as an alteration product of feldspar (fig.3). Thus, albite, quartz, montmorillonite, illite, chlorite, and epidote are common hydrothermal minerals in Tatapani. The formation of epidote at the expense of feldspar (fig.4) suggests profuse water rock interaction at the temperature of ≈ 250°C. The formation of illite smectite may be attributed to cooling of the reservoir to 160-180°C, in a later stage. The association of calcite with the epidote (fig.5) suggests a zone of boiling at the present depth of 200m and temperature of 250°C.

Teklemariam et al (1996) reported overprinting of argillitic alteration over propylitic alteration in Langano field of Ethiopia. Similarly, in the Tatapani field, propylitic alteration is associated with the argillitic alteration which suggests change in geothermal regime within a short time period. The geothermal water was near neutral chloride water as inferred from the hydrothermal minerals.

4.7 Thermal logging

The thermal logging of the borehole Tat/25, (fig.6) indicates temperature of 104°C at the depth of 50m, 106°C at 100 m and the maximum temperature of 112°C at the depth of 200m. The thermal profile of Tat/23 shows slight reversal of temperature below the depth of 275 m due to cold water incursion. The assemblages stilbite -quartz, suggest similar temperature range while montmorillonite-illite and laumontite indicate temperature higher than that recorded in the thermal logging. This confirms the view that the geothermal regime at shallow level has cooled down considerably due to dilution and conduction.

Thus, the occurrence of minerals indicating different temperature and pH conditions in the hydrothermal alteration indicates that the geothermal regime has changed with time. The hydrothermal alteration minerals suggest temperature higher than that measured in the borehole at 200m. The difference between indicated and measured thermal profile may be due to cooling down of the reservoir with time and dilution effect from the ground water in the overlying porous Gondwana rocks. The reversal of thermal profile in the borehole Tat/23, below the depth of 250m supports the above observation.

4.7 Permeability

The presence of albite at the depth of 160-200m indicates low permeability, emphasizing the fact that the permeability is controlled by fractures. The hydrothermal alteration minerals might have sealed the fractures reducing the permeability of reservoir rocks. The hydrothermal alteration has sealed thin fractures adversely affecting the porosity of the rock (Thussu et al 1987).

5. CONCLUSION

The hydrothermal alteration mineralogy is an useful tool to assess the changes in the geothermal regime over the time. The assemblages stilbite, quartz, albite, calcite, illite montmorillonite, laumontite, chlorite and pyrite assist in assessing the temperature and permeability of the geothermal field.

- The association of low and medium temperature hydrothermal assemblages at 200m depth suggests that the geothermal field underwent two different temperature regimes, the earlier around 230°C as indicated by the presence of laumontite and chlorite, which subsequently cooled to a geothermal regime of 160 to 180°C as indicated by the illite-montmorillonite assemblage. Chlorite is reported to be formed in the temperature range 110- 270°C hence it is not a reliable indicator of the palaeogeothermal conditions. Thus, the alteration mineralogy supports the view that the reservoir temperature at deeper level may be in the range of 160-180°C, in conformity with the temperature indicated by aqueous geothermometers.
- The intensity of alteration is maximum at the Tatapani fault zone. Widespread silica sinter observed along the fractures suggest that the geothermal fluids were alkaline chloride type.
- The surface manifestations decreased over the period as the fractures were sealed by the hydrothermal mineral deposition and subsequent reduction in the permeability. The decrease in permeability caused decrease in water to rock ratio of the reservoir and resulted into boiling of fluid at depth. Steam heated water was formed near the surface as an effect of boiling. The zone of boiling shifted upwards with time.
- Hydrothermal alteration indicates 2 stages in geothermal regime, >200-230°C, and 160-180°C, the later in conformity with the aqueous geothermometers. Thus, the present temperature profile may have been developed due to dilution and loss of heat by conduction. The correlation of Na/K geothermometer and hydrothermal alteration assemblages suggests temperature of 160-180°C for the reservoir.

The above observations indicate that Tatapani is an active geothermal system and encouraging results may be expected from exploration to deeper levels.

Acknowledgements

The author is grateful to Dr.S.K. Acharyya, Director General, Geological Survey of India, for granting permission to publish the paper. Sincere thanks are expressed to Dr.S.S. Kanwar, Dy.Director General and Mr. V.V.Mulay, Director, for providing facilities to write the paper and to Dr.Pitale, for guidance during the work. The help extended by the officers of GSI during the work is gratefully acknowledged. The author is grateful to Dr. P. R. L. Browne, and Dr. C.C. Harvey, Geothermal Institute, Auckland, for the motivation in the study of alteration minerals.

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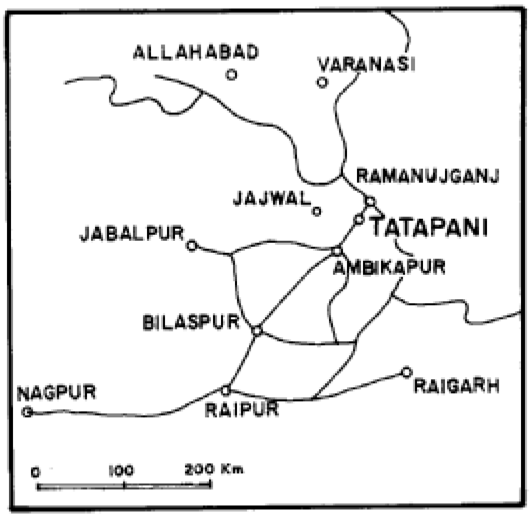

Fig. 1 LOCATION MAP OF TATAPANI

Table1: Hydrothermal alteration minerals in borehole GW\Tat\25

Depth	S	L	Q	A	Ch	Ca	M	Mi	Il	Py	Mu
0											
20											
30											
40											
50											
60			+			+		+		+	
70											
80											
90											+
100	+		+							+	+
110	+		+	+							
120						+					
130											
140	+			+							
150											
160											
170	+		+	+				+	+	+	
180				+							
190	+		+	+		+	+	+			
200	+	+	+								
210	+			+							
220			+	+	+			+	+		+
230	+		+	+	+	+	+	+	+		
240	+		+								
250	+		+				+				
260	+		+					+			
270											
280											
290											
300											
310	+		+								
320											
330											
340											
350											

S- Stilbite, L- Laumontite, Q- Quartz, Ca- Calcite, Ch- Chlorite, M- Montmorillonite, Il – Illite, A – Albite, Py-Pyrite, Mi- Microcline, Mu- Muscovite.

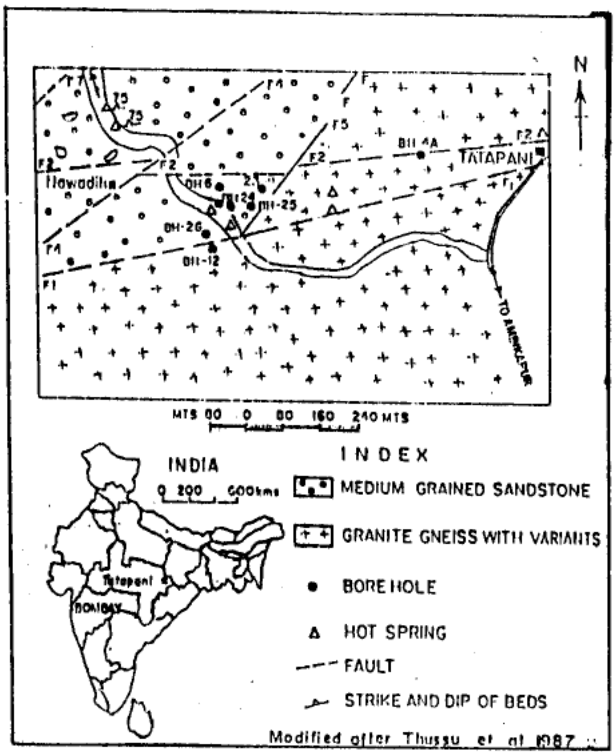

Fig.2, Geological map of Tatapani area.

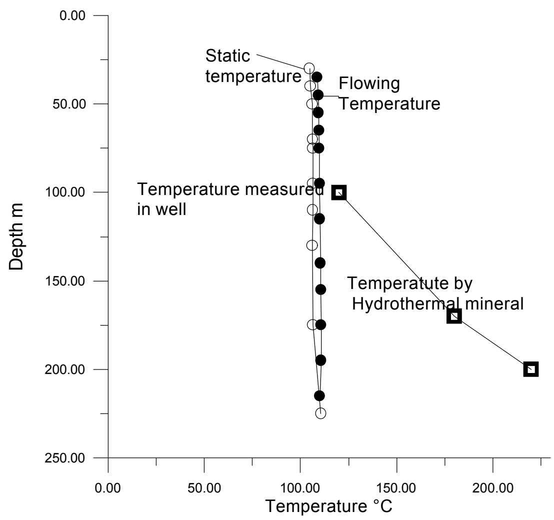

Fig6, Comparison of temperature indiacated by hydrothermal minerals and measured in the well.

Table 2: Hydrothermal alteration minerals in borehole GW\Tat\26.

Depth m	S	Q	A	M	L	Ca	Py	Mu	Il	Mi
10	ö									
20										
30										
40										
50										
60		ö				ö	ö			ö
70										
80										
90										
100	ö	ö					ö	ö		
110										
120										
130										
140										
150										
160										
170	ö	ö	ö			ö	ö	ö		ö
180	ö	ö	ö	ö		ö			ö	
190	ö	ö	ö	ö		ö				ö
200	ö	ö	ö		ö					
210										
220										

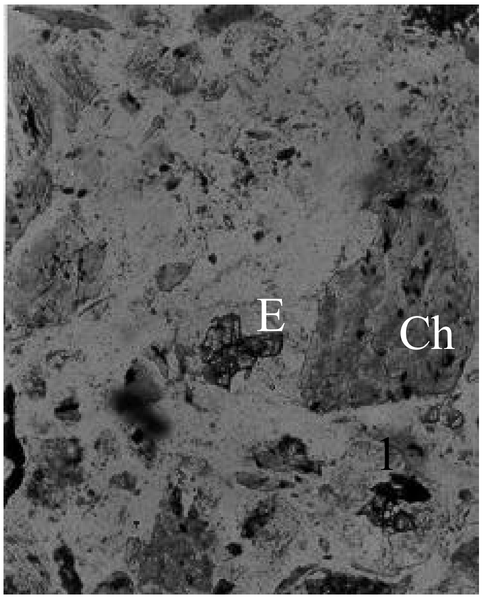

Fig.3, Microphotograph showing epidote, feldspar, chlorite, iron oxide in pink granite. Polarised light, X 16.

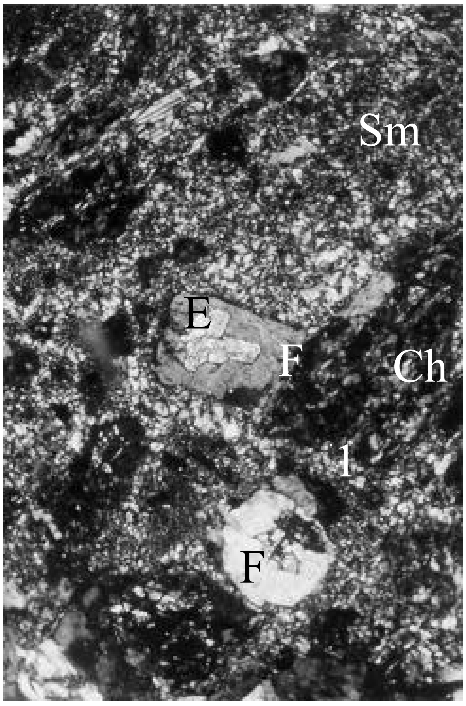

Fig.4, Epidote as alteration product of feldspar, with chlorite, within groundmass of feldspar. X nicols, X 16.

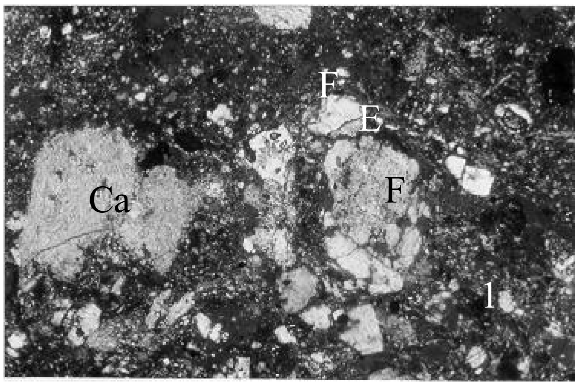

Fig.5, Tabular crystal of calcite in association with feldspar, chlorite, epidote and iron oxides, signifies zone of boiling. X nicols, X 16.

E= Epidote, CH= Chlorite, F= Feldspar,
Ca= Calcite, I= Iron oxide, Sm= Smectite.