TAPOBAN HOT WATER SYSTEM, NW HIMALAYA, INDIA - A UNIQUE EXAMPLE OF HEATING UNDER NORMAL GRADIENT CONDITIONS

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SUMMARY - Tapoban is one of the 112 hot spring localities of Northwest Himalaya, known for its copious borehole discharges. Thermal waters, though having temperatures of 80" to 90°C, have characteristically very low TDS content of < 500 mg kg^{-1}. This is because fluids have mainly interacted with quartzite. Stable isotope data provide unequivocal evidence that recharge zones of thermal discharges are located at altitudes of > 3000 m. A simple model of normal gradient heating offers the most plausible explanation for the thermal anomaly of the area.

1. INTRODUCTION

Tapoban, in Chamoli district of Uttar Pradesh, is one of the important hot spring localities of Northwest Himalaya, where thermal manifestations in the form of hot springs, with discharge temperatures of 38" to 65°C, occur over a spread of more than a km along the left bank of river Dhauliganga. Cumulative discharge of over a dozen hot springs, clustered around four locations, is about 15 l s^{-1}.

The rocks exposed in the area around Tapoban mainly consist of gneiss, schist and quartzite belonging to the Central Crystallines of Proterozoic age. These rocks are intruded by a basic sill. Prominent NE-SW trending fracture zones, traversing the area, apparently provide structural control for the emergence of thermal manifestation. Hot spring zones are confined to major shear zones within quartzite.

Geophysical surveys were not particularly successful in the area. Topographic constraints greatly restricted the distance between the electrodes, resulting in shallow penetrations only. Moreover, as thermal fluids are very dilute (Table-1) and probably confined to isolated channels, geophysical signatures of thermal anomaly are not distinct. The lowest resistivity values of 100 ohm-m to depth of 165 m were, therefore, taken as possible indication of geothermal anomaly. Resistivity increases, rather abruptly, at deeper levels to values as high as 5500 ohms-m (Ravi Shanker, 1991).

During the first stage of exploration, five 50 m holes were drilled at Tapoban. Two of these holes recorded high downhole temperatures, approaching 60°C. Consequently, deeper drilling was taken up in the area. Four drillholes, with depths of 291 to 728 m, have been drilled in the area, three of which have a cumulative discharge of about 40 l s^{-1} (144 tons hr^{-1}) of 66 to 91°C (average enthalpy 330 Jg^{-1}) fluid.

2. GEOCHEMISTRY

Chemistry of thermal discharges is given in Table-1. For comparison, composition of a cold spring is also given. Thermal discharges are significantly enriched only in HCO_3 and SiO_2, and to some extent, in Mg. Although hot springs and cold spring have identical Ca content of about 45 mg l^{-1}, discharges from boreholes have nearly twice of that. Borehole discharges are supersaturated with respect to calcite, which, consequently, gets deposited on the surface. A 6 m high mound of deposits, mainly carbonates, has developed around borehole AGW-3.

Silica concentration provides the only reliable clue to possible reservoir temperatures. A temperature of 115°C is indicated assuming that neither any silica has precipitated during the ascent of the fluid nor the fluid has been diluted. Interestingly, the gaseous composition of thermal discharges (CO_2 = 78.6 mole %, N_2 = 18.8 mole %, O_2 = 2.3 mole %, other gases in traces) gives 120°C as the temperature of latest equilibrium of gases (Srivastava *et al.*, 1996).

3. STABLE ISOTOPES

A characteristic feature of Northwest Himalayan hot spring areas is that thermal discharges are more depleted in their $\delta^{18}O$ and δD values compared to those recorded in the local meteoric water, represented by cold springs adjacent to thermal manifestations (Giggenbach *et al.*, 1983, Absar *et al.*, 1996). Tapoban hot water system probably offers the best example of these apparent negative δD and $\delta^{18}O$ shifts (Table-2). Thermal discharges fall under two groups. First group

Table 1 : Chemistry of Thermal and Non-thermal Discharges at Tapoban, NW Himalaya, India

Sample	Temp. (°C)	Chemical Constituents (mg l^{-1})							
		HCO_3	Cl	SO_4	Ca	Mg	Na	K	SiO_2
Cold Spring	14	127	10	30	46	7	5	7	6
Hot Spring	59	278	12	27	42	26	15	8	69
Hot Spring	39	214	11	20	48	11	5	2	33
Borehole AGW-2	81	366	14	26	82	20	8	3	66
Borehole AGW-3	91	363	15	27	90	26	12	6	91
Borehole AGW-6	66	380	15	30	95	25	15	9	84

Table 2 : δD & $\delta^{18}O$ Composition of Thermal and Non-thermal Discharges at Tapoban, NW Himalaya, India

Sample	δD‰ SMOW	$\delta^{18}O$‰ SMOW
Borehole AGW-2	- 10.9	- 71.3
Borehole AGW-3	- 12.4	- 76.5
Borehole AGW-6	- 12.8	- 80.0
Hot Spring - 1	- 11.2	- 74.0
Hot Spring - 2	- 12.8	- 80.0
Cold Spring - 1	- 9.5	- 64.0
Cold Spring - 2	- 10.0	- 64.0
Cold Spring - 3	- 8.6	- 56.0

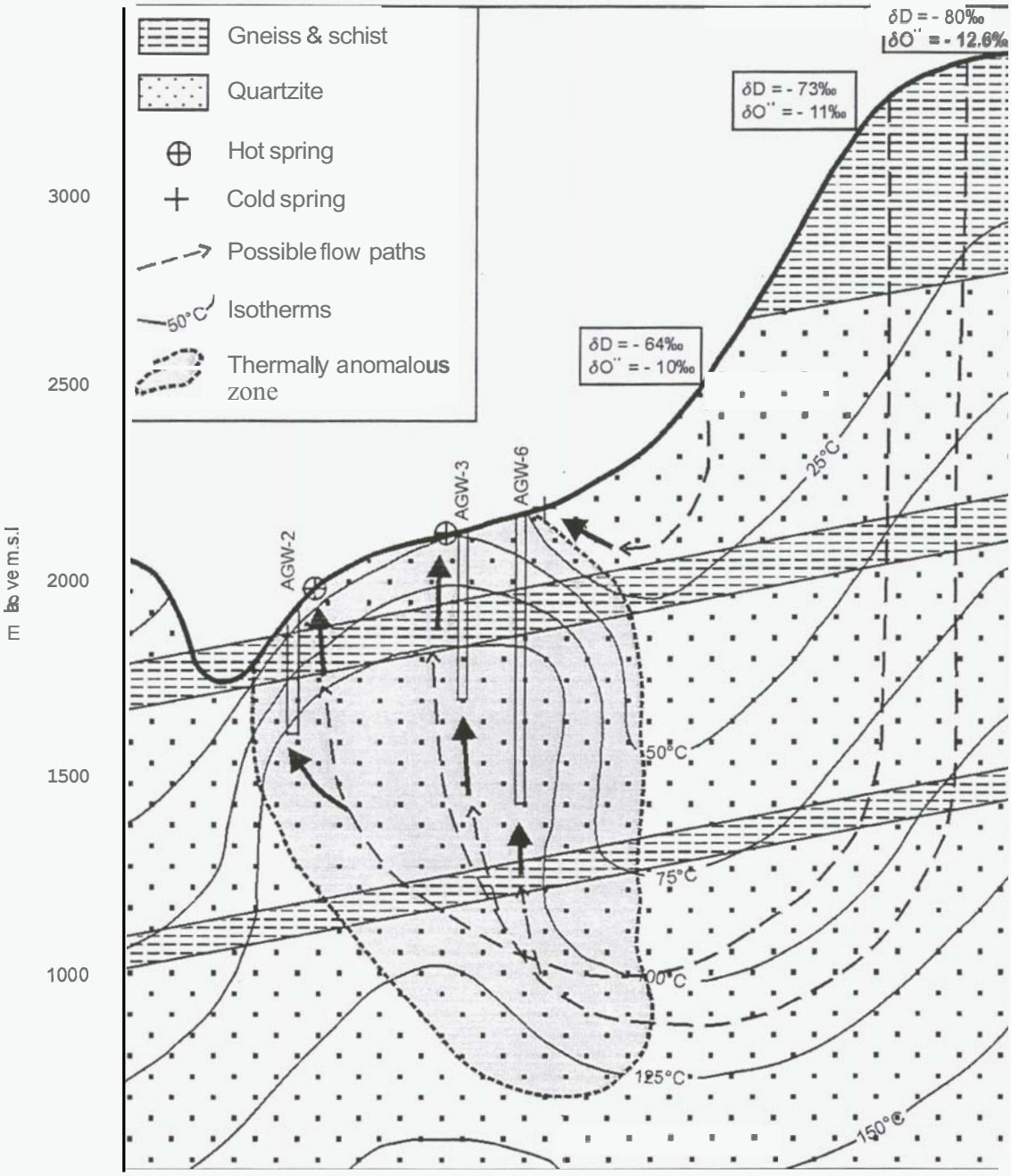
(AGW-3, AGW-6 and Hot Spring-2) has 6D = -80.0 to -76.5‰ and $\delta^{18}O$ = -12.8 to -12.4‰ and the second group (AGW-2 and Hot Spring-]) has δD = -74.0 to -71.3‰ and $\delta^{18}O$ = -11.2 to -10.9‰. Compared to these values, those of cold springs, particularly Cold Spring-3, are appreciably enriched. As stable isotopes of geothermal fluid can not get depleted by any of the processes related to the genetic and thermodynamic conditions prevailing in the hydrothermal systems, the only logical explanation is that thermal waters, instead of getting recharged from cold water bodies located in the vicinity, have their recharge zones at much higher altitudes. Using straight-line equations similar to those of Giggenbach *et al.,* (1983), recharge zones for Tapoban thermal fluids are inferred to lie at altitudes of 3000 m above m.s.l. or even more. As shown in Figure-1, there is a distinct possibility that the cumulative recharge to the system may be from more than one levels. Stable isotope composition of the two groups of thermal discharges at Tapoban, for example, is best explained assuming recharge from two levels, more isotopically – depleted discharges having been derived from higher altitude. Further, stable isotope data indicate that flow paths for the two groups of thermal discharges are probably not in hydrological continuity as they retain their isotope signatures. In case the two flow paths would have merged, stirring-up of fluids might have given rise to thermal discharges of more homogeneous isotopic composition.

4. DISCUSSION AND CONCLUSION

A conceptual model of Tapoban hot water system is attempted in Figure-1, which basically superimposes stable isotope data over a simplified geological base. Also drawn are isotherms assuming a slightly elevated normal geothermal gradient of 50°C km^{-1} as considered logical for Parbati valley geothermal area by Giggenbach *et al.* **(1983).** It needs to be mentioned here that Parbati valley, also in northwest Himalaya, is very similar to Tapoban system in many respects, such as, temperature and **reservoir lithology ,** and fluid composition.

Relative lack of chemical alteration of thermal discharges is readily explained taking into consideration the possibility that the fluid has mainly interacted with quartzite. Among the anions, Cl and ***SO,*** hardly show any variation in cold and hot springs. Bicarbonate, however, has been appreciably gained **by** thermal discharges during their deeper circulation through CO, – rich soil zone. Among the cations, K-Mg pair (Giggenbach ***et al.***, 1983) is clearly out of equilibrium as indicated by anomalously low reservoir temperatures, lower than even discharge temperatures, calculated using their relative concentrations. It appears that there has been a very late, near-surface addition of Mg to thermal waters during their rise through clay-rich zones.

Calcium content in borehole discharges is twice that in hot springs (which is similar to Ca-content in the cold spring). In the light of stable isotope evidence for hot springs and boreholes having been fed by the same fluid at deeper levels, it is difficult to envisage an additional source of Ca-supply to borehole discharges, particularly, when the bulk of water-rock interaction, evidently, occurs within quartzite. Differences in Ca-content of thermal discharges may probably be best understood in terms of variations in conditions



The fact that thermal discharges are considerably depleted in both δD and $\delta^{18}O$ compared to those in the local meteoric water gives unequivocal evidence in favour of their recharge zones being in higher altitudes (1000 to 1500 m above discharge sites). Fluids descending to levels of about 1000 m above m.s.l. (800 to 1000 m below discharge sites) may attain temperature in excess of 100°C through normal gradient heating. The upflow zone of these fluids defines the local thermal anomaly, which may be picked up by geophysical surveys. At Tapoban, as the descending solutions interact mainly with quartzite, their chemistry is not significantly affected except for the temperature-dependent addition of SiO_2 and an increase in HCO_3 due to dissolution of CO_2 in the soil zone.

governing the solubility of calcite and its precipitation.

Formation of carbonate mounds over borehole sites clearly indicates that borehole discharges, with composition nearest to that of the deep 115°C fluid, are supersaturated with respect to calcite. Relative lack of carbonate deposits around hot spring sites, on the other hand, is explained by taking in to account conductive cooling by about 50 to 60°C of originally calcite-supersaturated fluid during its rather circuitous ascent to surface. Decreasing temperatures would result in lowering the saturation index of calcite, thus precluding its precipitation. Calcium and HCO_3 values in hot springs may, therefore, be taken as nearest to

those expected in the reservoir fluid. The reason for higher Ca (and also HCO_3) values observed in borehole discharges may now be explained. These samples have been collected from the funnel-shaped opening within the carbonate-deposit developed around the borehole. There is a distinct possibility that higher Ca and HCO_3 contents in borehole discharges are due to re-dissolution of pre-deposited carbonates and therefore are fortuitous.

The simple model of Tapoban hot water system thus demonstrates that water-rock interaction in an inert rock like quartzite has resulted in no major changes in the chemistry of thermal fluids. An increase in SiO_2 content is the only reliable indication of temperatures attained by the fluid at deepest level (reservoir). The recharge zones of thermal discharges are located at altitudes of 1000 to 1500 m above discharge sites from where meteoric water descends to levels of about 1000 m above m.s.l. At such levels temperature well in excess of 100°C is expected by virtue of normal geothermal gradient.

Systems, such as that of Tapoban, characterised by normal gradient heating are likely to have their hydrological system spread over relatively large area covering several kilometres. Their thermally anomalous area, encompassing the zone of upflow of thermal fluids, however, tends to be much smaller (Fig. 1).

In view of copious discharge of 55 l s^{-1} from hot springs and boreholes at Tapoban, which has been sustained for over 15 years, relatively small upflow zone having a volume of < 1 km^3 must be highly permeable. It is probably this characteristic of Tapoban-like systems, which makes their geophysical demarcation possible to some extent.

Tapoban, for the preponderance of hot fluids of very low TDS content (which are of drinking quality, as far as major ion chemistry is concerned) is a unique hot water system ideal for development as a tourist complex

5. ACKNOWLEDGEMENT

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