GEOCHEMISTRY AND ORIGIN OF GEOTHERMAL SYSTEMS OF NORTHWEST HIMALAYA

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SUMMARY - Out of a total number of 112 hot spring localities of Northwest Himalaya, 14 typical geothermal areas have been selected for this study. Puga, Chhumathang, Changlung, Tapri and Beda are better prospects with temperatures definitely in excess of 110°C. Very dilute solutions discharging at boiling temperature and Na-HCO_3 type fluids are typical of Himalayan geothermal systems. There are indications that hydrothermal activity has migrated northwards during the last 10^6 years.

1. INTRODUCTION

Systematic geothermal studies, initiated in India by the Geological Survey of India in 1973 identified 340 hot spring localities. Out of these, 112 are confined to the northwestern part of the Himalaya (Ravi Shanker, 1991). Deep incision of rocks by Himalayan streams has facilitated emergence of hot springs mainly along the valleys.

The selection of hot springs for the present study was difficult. *An* attempt has been made to have the best possible representation of different types of Himalayan hot springs using the parameters such as surface and reservoir temperatures, lithological considerations, geographical attributes and concentration levels of dissolved constituents.

Table-1 lists 14 geothermal areas located in 9 river valleys. Although, published literature is available on thermal discharges of Nubra valley (Absar *et* al., 1991), Indus valley (Ravi Shanker et al., 1976), Parbati valley (Giggenbach et al., 1983) and Satluj valley (Absar et al., 1996a), this work is the first attempt to present a consolidated picture of geochemical and genetic aspects of northwest Himalayan geothermal systems.

2. SURFACE FEATURES

Some geothermal areas have one or two thermal manifestations only while others have groups of hot springs. Thermal discharge from individual areas varies from < 2 $l\,s^{-1}$ at Galhar, Pulga and Vashist to > 100 $l\,s^{-1}$ at Manikaran. More than 100 springs at Puga have a cumulative discharge of 30 $l\,s^{-1}$. The surface temperature of discharges ranges from about 30°C to local boiling point (84°C at Puga and 94°C at Manikaran, Tapoban and Beda). Most of the thermal discharges deposit carbonate on the surface. Mounds and ridges of carbonate are particularly well developed at Puga, Chhumathang, Manikaran, Tapoban and Beda. At Puga, a thermally anomalous area is covered by sublimates consisting of borax, sulphur and avogadrite (Ravi Shanker *et al.*, 1976; Ravi Shanker, 1991).

3. GEOCHEMISTRY

Figure 1 is a simple SiO_2 - TDS plot on which 5 of the geothermal areas fall away **from** the normal trend. At Pulga, TDS has apparently increased by processes other than water - rock interaction. Relatively high TDS values at Changlung and Beda may be attributed to high HCO_3 - content of > 1700 mg l^{-1} in these thermal discharges. Chhumathang and Tapri systems plotting to the left of the normal trend may have been affected by near-surface dilution.

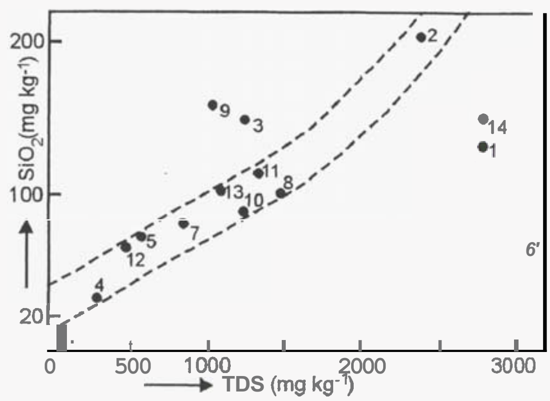

Figure 1. Silica-TDS plot. Numbers relate to geothermal areas listed in Table-1

Table-1 Chemistry of Thermal Discharges of Northwest Himalaya

Hot Spring Locality	Temp °C	Chemical Constituents (mg l^{-1})										
		HCO_3	Cl	SO_4	F	Ca	Mg	Na	K	B	SiO_2	TDS me l^{-1}
Nubra Valley												
1. Changlung	65	1805	115	174	12.5	27	1	690	50	11	133	2800
Indus Valley												
2. Puga (borehole)	120	704	447	156	15	2	0.2	618	81	150	207	2380
3. Chhumathang	83	290	113	258	10	3	0.2	355	21	38	152	1250
Chenab Valley												
4. Galhar	60	112	30	72	6	14	'	56	4	1	35	300
Parbati Valley												
5. Manikaran (borehole)	94	187	130	35	0.8	51	3.3	93	21	3	75	600
6. Pulga	44	1011	1080	34	6.5	13	3	1040	70	17	70	3200
Beas Valley												
7. Vashist	59	300	163	62	12.5	14		210	13	5	80	850
8. Kalath (Borehole)	40	548	391	28	4	46	7	370	28	1	100	1500
Satluj Valley												
9. Tapri	73	288	145	117	11	28	2	240	23	6	160	1050
10. Karchhan	44	303	208	348	6	103	11	260	45	13	87	1250
Alaknanda Valley												
11. Badrinath	55	112	485	22	1.6	70	13	490	37	19	115	1350
12. Tapoban (borehole)	94	278	12	27	0.5	42	26	15	8	1	69	480
Bhagrathi Valley												
13. Gangnani	61	739	90	36	8	28	6	280	25	5	102	1300
Mandakini Valley												
14. Be&	94	1708	139	109	2.2	4	0.2	700	55	13	150	2800

Relative concentrations of cationic solution components (Fig. 2) indicate that transformation of dilute solutions such as those of Tapoban, Manikaran and Galhar, to Puga-Chhumathang type fluids is accompanied by the addition of Na. The processes which may increase the Na-content of geothermal solutions are water-rock interaction, dissolution of salts and mixing of formation waters or brine. Puga, Chhumathang and Beda plot close to the Na-K line, corresponding to K/Na equilibrium temperatures of 200 to 250°C implying addition of Na from rocks at elevated temperatures. At Pulga, plotting close to Beda, Na content, which is higher than that of even Puga, has probably been attained not through water-rock interaction alone. Addition of Ca in a fluid similar to that of Tapri, on the other hand, has resulted in an apparent decrease in Na content of Karchham hot spring, making it plot close to dilute geothermal fluid of Manikaran. Kalath, Tapri, Badrinath and Gangnani clustering in the middle of Na-K-Ca plot represent an intermediate stage in generation of alkali-rich, relatively high temperature systems from fluids similar to those at Tapoban and Manikaran.

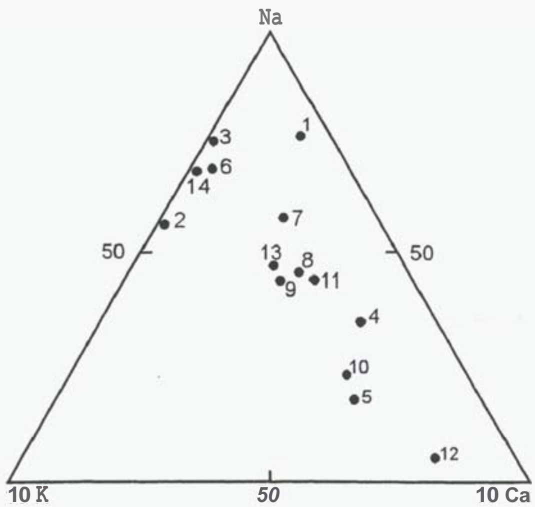

Figure 2. Na-K-Ca plot showing relative concentration of major cations. High temperature systems (2, 3, 14) develop by addition of Na to Ca-rich meteoric waters through water-rock interaction

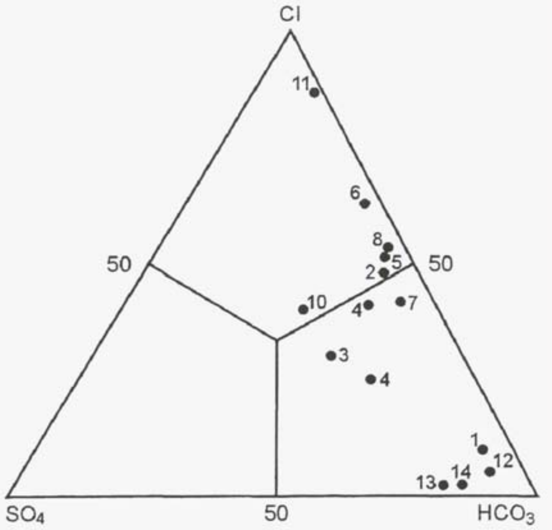

Figure 3. Relative concentration of the three major anions. There are no acid-sulphate waters. HCO_3 rich fluids (1, 12, 13 and 14) are typical of NW Himalaya.

On the Cl-SO_4-HCO_3 plot (Fig. 3), 4 types of waters are broadly identified, which are Cl-type (Badrinath), **HCO_3-type** (Changlung, Tapoban, Gangnani, Beda), HCO_3-Cl type (Puga, Manikaran, Pulga, **Vashist,** Kalath, Tapri) and relatively SO_4-enriched waters (Chhumathang, *Galhar,* Karchham).

The effect of dissolution of two Ca-species, calcite and **$CaSO_4$ has** been assessed on the Ca-HCO_3-SO_4 plot (Fig. 4) Dissolution of calcite may be considered possible only at **Manikaran**, Tapoban,

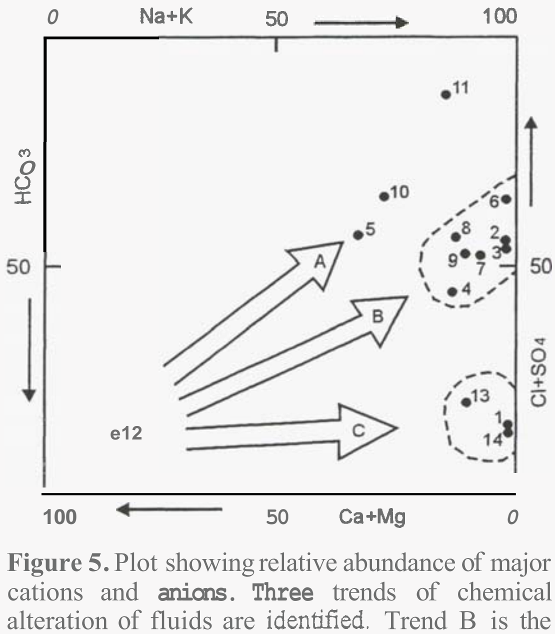

Figure 5. Plot showing relative abundance of major cations and anions. Three trends of chemical alteration of fluids are identified. Trend B is the normal trend of water-rock interaction. Fluids, such as 5, 12 and 1, 13, 14 are typical of NW Himalaya.

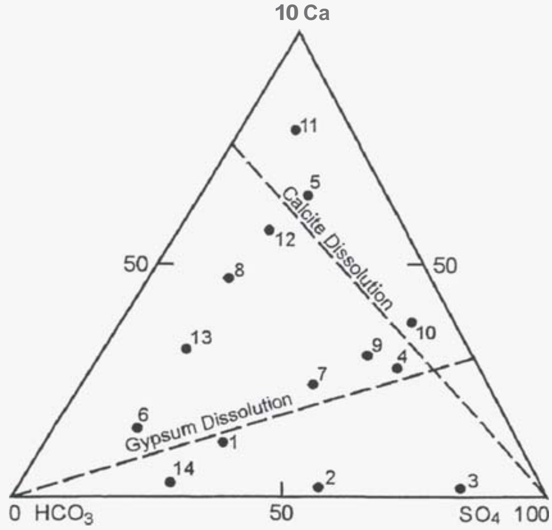

Figure 4. Ca-HCO_3-SO_4 plot with calcite an gypsum dissolution lines. In some of the areas, there are suggestions that calcite or *gypsum* or both ar being taken in to solution.

Tapri and Karchham. Sulphate dissolution, on the other hand, is suggested at Changlung, **Vashist,** Tapri, Karchham and Galhar.

As depicted in Figure **5,** three major trends of chemical alteration of Ca-Mg-HCO_3 type meteoric water (represented here by the Tapoban fluid) are identified. Most of the areas plotting in the middle of the **Cl+SO_4** line have attained their chemistry predominantly by water-rock interaction at elevated temperatures (trend B). As mentioned earlier, for at least two areas, *i.e.* Galhar and Pulga plotting in this field, the influence of dissolution of chemical species is probably more than that of exchange with the rocks. At Pulga, subsurface dissolution of NaCl *can* not be ruled out (Table-1). High HCO, content may point to dissolution of carbonates. However, under such a situation, the bulk of Ca may have been removed in the form of hydrothermal minerals. Changlung, Gangnani and Beda (trend C) plot below the main cluster, mainly because of the large addition of HCO_3 resulting in $HCO_3 >> Cl+SO_4$. The only Na-Cl type fluid, that of **Badrinath,** suggests gradual acquisition of NaCl through intermediate compositions similar to that of Manikaran (trend A).

4. RESERVOIR TEMPERATURES

Silica, K-Mg and K-Na thermometries of Giggenbach (1997) have been used. Puga, Chhumathang, Tapri and Beda give temperatures in excess of 150°C by the silica method. Changlung is next with an indicated feed temperature of 140°C. Silica content in all other geothermal areas points to temperatures of 100 to 130°C. K-Mg temperatures are, in general, comparable to those of SiO_2, except in case of Tapri and Tapoban, where the former are far too low probably because of near-surface processes of formation of K-rich clays. Giggenbach *et* al. (1983) have given A SO_4-H_2O temperatures for some of the geothermal areas. For Puga and Chhumathang, these temperatures are similar to those of silica but at Manikaran, Vashist and Kalath they are up to 20°C higher. K-Na thermometry has been applied to Changlung, Puga, Chhumathang, Tapri and Beda which give SiO_2 or K-Mg temperatures in excess of **150°C.** Indicated temperatures are 200 to 250°C. At Puga, at least, there are clear indications that temperatures well above 200°C exist at deeper levels. Most of the bore holes drilled there have ejected huge quantities of silica gel at the time of the first blow-out implying that the estimated SiO_2 temperature of 175°C may be on the lower side. Application of gas geothennometry also suggests temperature in excess of 200°C at Puga (Srivastava *et al.*, 1996).

5. STABLE ISOTOPES STUDY

Stable isotope studies carried out in some of the northwestern geothermal areas are summarised by Giggenbach *et al.* (1983) and Absar *et al.* (1996b). Geothermal areas of Parbati, Beas, Satluj and Alaknanda valleys (Table-1), have their thermal discharges depleted in δD and $\delta^{18}O$ compared to those of the local meteoric water. This peculiar situation is due to the fact that these geothermal areas are recharged from altitudes 2000 to 3000 m above the respective discharge sites and reservoir temperature are not high enough to facilitate ^{18}O-exchange. Although the Puga and Chhumathang systems are also recharged fkom altitudes up to 2000 m above, higher temperatures of 200°C or more in these areas have resulted in discernible positive shift of 1 to 1.5‰ in $\delta^{18}O$ of thermal discharges.

6. ORIGIN AND AGE OF GEOTHERMAL ACTIVITY

One of the characteristic features of northwestern Himalayan geothermal systems is that they occur in crystallines/granitoids to the north of the Main Central Thrust (Fig. 6), which separates Lesser Himalayan sedimentaries/metasedimentaries from Central Crystallines. Interestingly, sulphide occurrences, comprising Cy Pb, Zn, Au, As, Sb mineralisation, often with distinct hydrothermal signatures, occur to the south of MCT. This trans-MCT migration of hydrothermal activity as a result of intracontinental underplating must have occurred during the latest of Himalayan orogenic movements and isostatic adjustments (Ravi Shanker *et al.*, 1996). The fact that recharge areas of Himalayan geothermal systems and circulation patterns might have established only when the Himalaya attained its present - day topography implies that the current phase of geothermal activity may not be older than 10^6 years. Changlung, Puga, Chhumathang, Tapri and Beda are indicated to be hot spots providing the heat source since the trans-MCT migration of hydrothed activity. In most of the other northwest Himalayan geothemal systems, temperatures up to 130°C have been attained by solutions descending down to deeper levels of 3000 to 4000 m under slightly elevated thermal gradient conditions.

7. CONCLUSION

Geothermal activity in northwest Himalaya is probably not older than 10^6 years and is related to northward migration of hydrothermal activity due to underplating. Some of the present-day hot spots and dynamic circulation systems in areas of more than normal heat flow, keep the geothermal activity going.

Thermal gradient heating of solutions to temperatures up to 130°C is best demonstrated by Tapoban, Manikaran, *Galhar* and Vashist systems. At Tapoban and Manikaran, borehole discharges are near drinking quality with boiling temperatures of **94°C.** From this point of view, these thermal discharges are unique in the world.

Bicarbonate-rich solutions of Changlung, *Gangnani* and Beda with Na as the dominant cation are similar to some extent with Kizildere fluid (see Ellis, 1979). However, the latter is exceptionally rich in SO_4. If HCO_3 of these fluids is derived from carbonate rocks, the bulk of Ca and also Mg, might have been involved in the formation of alumino-silicates at deeper levels. Alternatively, there must be an independent source of CO_2. Pulga fluid, one of the most concentrated geothermal solutions in northwest Himalaya has Na ≈ Cl ≈ HCO_3 ≈ 1000 mg l^{-1}. Either the fluid has reacted with a carbonate sequence having pockets of salt (halite) or it represents a diluted brine with CO_2 added to it fkom an unknown source. In the case of the first possibility, Ca may have been consumed in the formation of hydrothermal minerals, as considered plausible for HCO_3-rich waters.

Puga geothermal system, in many respects, resembles the Yangbajing geothermal area in Tibet, China. The similarities between the two are due to comparable reservoir temperatures and similar lithology (see Piovesana et *al.*, 1987).

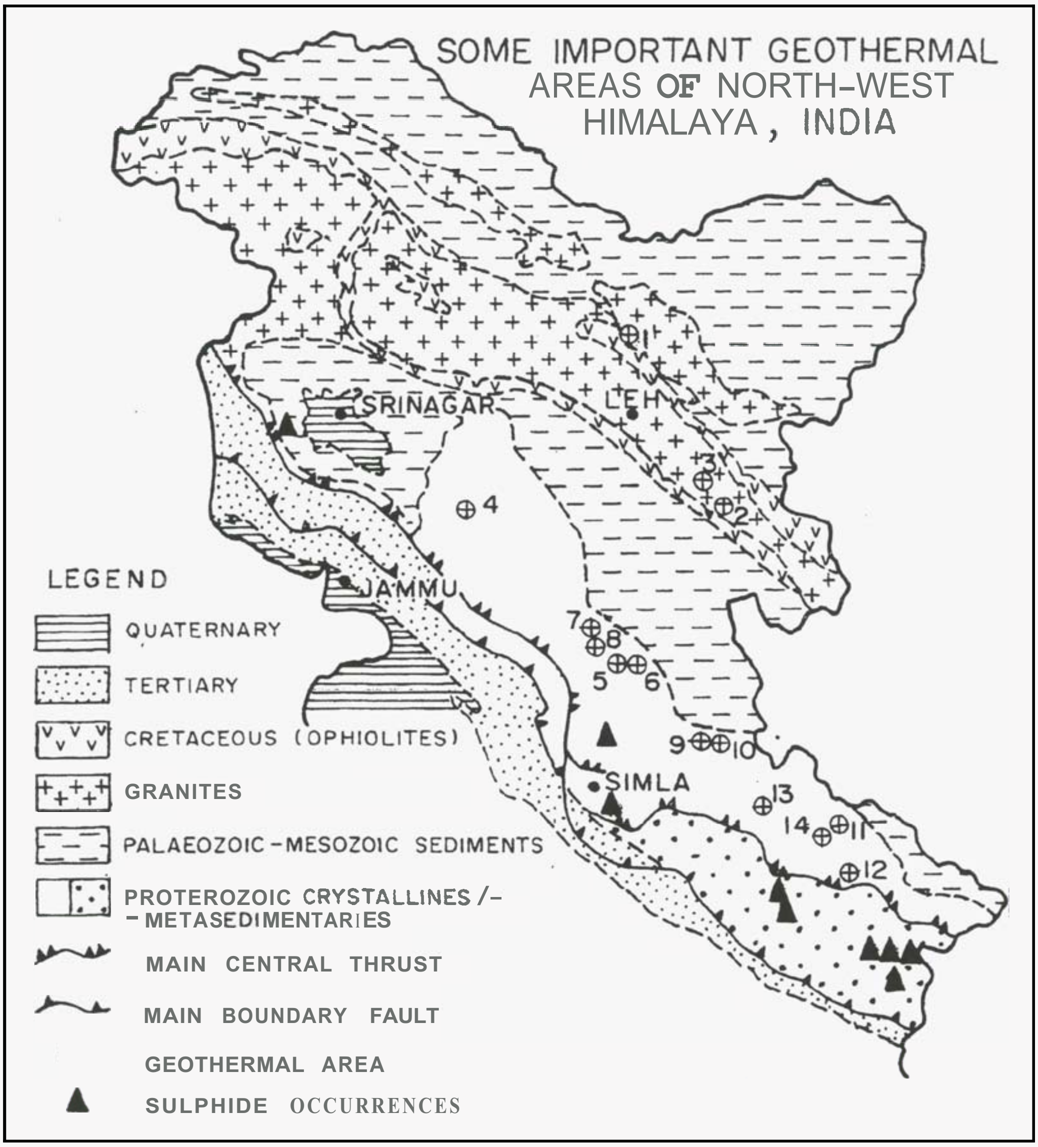

Figure 6. Sketch geological map of NW Himalaya showing locations of geothermal areas listed in Table-1. Also shown are occurrences of sulphide mineralisation. Trans-MCT migration of hydrothermal activity due to underplating has probably occurred during the last 10^6 years.

Puga is definitely the most promising geothermal area in the Indian sub-continent suitable even for electrical utilisation. Other areas where temperatures in excess of 150°C may be encountered are Chhumathang, Changlung, Tapri and Beda. Unfortunately, except for Chhumathang, other areas are relatively inaccessible.

8. ACKNOWLEDGEMENT

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