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An Analysis of the Hot Spring Activity of the Manikaran Area, Himachal Pradesh, India, by Geochemical Studies and Tritium Concentration of Spring Waters

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ABSTRACT

The Manikaran region, where the hottest springs in India with temperatures up to 97°C manifest and mild geyser activity and large discharges occur, has been considered as one of the potential areas for exploration of geothermal energy.

The concentration of dominant cations and anions indicates Na-Ca-HCO_3-Cl type of thermal water with major constituents following the order $Na>Ca>K>Mg<Cl<HCO_3$. Minor quantities of metallic trace elements, namely, Ag, Cu, Ni, Sr, and Zn, have also been detected.

On the basis of the sodium, potassium, and calcium content of the nonboiling spring water, the reservoir temperature is estimated as 195°C, whereas consideration of SiO_2 content and enthalpies of nonboiling and quartz solubilities at selected temperatures indicates a probable aquifer temperature of about 200°C, and the fraction of cold water mixing with hot water as 0.60.

The tritium concentration in hot spring water is low, 14 to 58 Tritium Units (TU), compared to the high tritium value of 103 TU of the water of Parbati River, which drains the area. The concentration of tritium in the spring water is higher than that of the pre-bomb tritium levels for 30°N (10 TU). This indicates shallow circulation with short turnover time for the spring water or mixing of deep thermal waters with surface water. Considering the latter and using the estimated cold water fraction, the tritium concentration of the deep unmixed hot water has been inferred. From this it can be concluded that the deep water in the hot aquifer has a very long residence time.

LOCATION OF SURFACE MANIFESTATIONS

Manikaran (Lat. 32°02′N., Long. 77°25′E.) is a small village situated in North-Western Himalayas in the Kulu district of Himachal Pradesh at an elevation of 1700 m on the right bank of the Parbati River, which is a tributary of the Beas River. Hot springs occur at various places in the Parbati valley. The main group of hot springs are located in the Manikaran-Kasol area and at Khirganga, located about 15 km upstream. The majority of the hot springs, with temperatures varying from 41 to 97°C, are located on the right bank of the river. The hottest springs emerge at Manikaran.

In the Manikaran area, the occurrence of hot springs, deposits of travertine, and thermal alterations of quartzite along joints and fractures are common features of the area. The hot springs are confined to several clusters, spreading along a distance of about 1.3 km beside the Parbati River (Fig. 1). The hottest cluster is situated near the Harihar Temple which, being a pilgrimage shrine as well, attracts many tourists. The most spectacular spring in this cluster issues like a geyser near the bank of the Parbati with steam escaping for 25 to 30 seconds at two-minute intervals. As soon as the pressure of the steam decreases, the water discharge from the spouts increases. The maximum height to which the water rises from the spouts is about 50 cm. Also, at another location near the temple, the spring water shoots to about a metre at an angle of about 45°. There are two more locations on the Manikaran terraces where water spouts and steam escapes under pressure. Many other comparatively lower-temperature springs emerging from the river terrace deposit, which overlies quartzite, are also located in the Manikaran area (Gupta, 1974). The thickness of the terrace deposit as estimated by electrical soundings is about 25 m (Gupta et al., 1973). As the quartzite is blanketed by the river deposits, most of the springs on the terrace emerge through these deposits. Hot springs issuing from the joint planes in the quartzite are seen at other locations. One cluster of springs with a temperature range from 41 to 55°C is also situated along the Brahmaganga River near its confluence with the Parbati River. Practically all the springs emit CO_2 and H_2S.

Geological Setting

The rock types exposed in the area are a sequence of thick massive quartzite with subordinate phyllites belonging to the Precambrian metasedimentary system. The other rocks seen in the area are granite-gneiss, quartz-mica-schists,

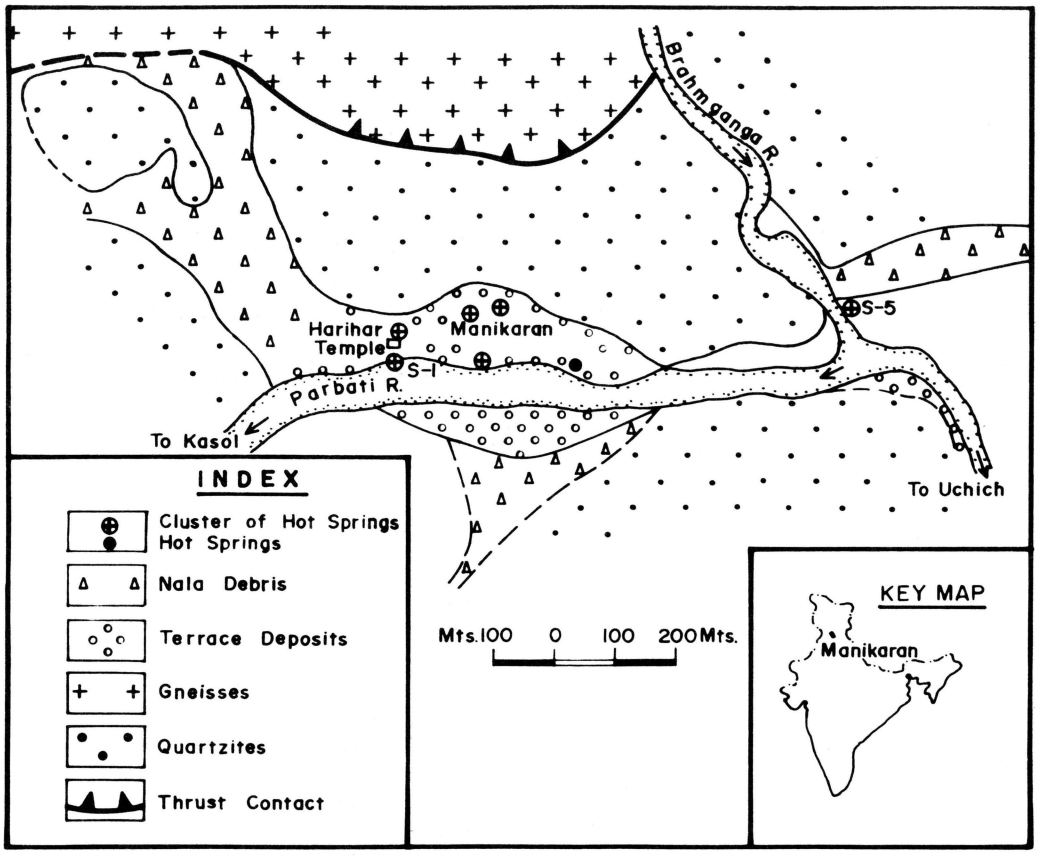


Figure 1. Main geological features of the Manikaran hot springs area.

mica-schists, and basic intrusive rocks. The quartzite is well jointed and, along with phyllites, dips in a northeastern direction from 30 to 50 degrees (Sehgal, 1973). The Parbati River has cut a deep gorge for a considerable length approximately normal to the strike of the formations. Chlorite and mica schists and gneisses directly overlie the massive quartzite phyllite group at Manikaran. The quartzite is uraniferous and contains a few other radioactive minerals. Silver mineralization has also taken place in the shear zones in the Manikaran phyllites and quartzites. Ancient silver mines have been noticed in the vicinity of the Manikaran area.

Between Manikaran and Uchich, which is located upstream of Manikaran, the contact between the schists and the underlying quartzites runs in a northwestern direction and then swings to the west, downstream from Manikaran. Upstream from Manikaran, at a distance of about 2 km, the schists are exposed near the river level. The contact between these two groups is a major thrust contact. This thrust contact probably forms a part of the central Himalayan thrust, which is an extensive feature related to Cenozoic folding in the Himalayas.

HOT SPRING AND RIVER WATER CHEMISTRY

Water samples from five hot springs and the Parbati River were collected and have been analyzed for their chemical constituents. The chemical analysis data and the weight ratios of important cations and anions are given in Table 1 and Table 2, respectively. The waters are of a mildly alkaline nature with pH 7.3 to 7.6. It seems that the pH value in the waters is under control by HCO_3^- reaction. CO_2 was detected in the gases bubbling out of the springs.

The analysis shows that there is a predominance of Na^+, Ca^{++} HCO_3^-, and Cl^- ions in the spring waters while Mg^{++} is present in very moderate concentration. NaCl and $NaHCO_3$ are the dominant groups in the water. The concentration of dominant cations and anions indicates that the spring waters are of Na-Ca-HCO_3-Cl type. The dissolved solids (TDS) are present only in low concentrations and vary from 390-609 mg/liter. Consideration of the variations of spring temperatures and estimated alkali reservoir temperature indicates mixing of deep hot waters with cold shallow waters. Keeping this in view, it has been estimated that the TDS of the deep hot water is likely to be over 1000 mg/liter. The presence of SO_4 ions could be due to the interaction of deep thermal water with granites and gneisses containing traces of sulfur (Barth, 1950).

Metallic trace elements have also been quantitatively determined in the spring waters by use of an atomic absorption spectrophotometer. Minor quantities of the elements Co, Cu, Sr, Ni, Ag, and Zn have been detected and their quantities are given in Table 1.

A Na-K-Ca geothermometer (Fournier and Truesdell, 1973) has been used for the estimation of temperature in the geothermal reservoir for the Manikaran area. This has been calculated using the chemical data of four nonboiling springs from the area. The value varies from 186 to 202°C with 195°C as the average value.

MIXING OF THERMAL AND COLD WATERS

The appreciable difference between the subsurface reservoir temperatures, as inferred by geochemical thermome-

Table 1. Chemical analysis of Manikaran hot spring and Parbati River waters, in mg/liter.

Description	Manikaran hot springs (1)	(3)	(4)	(5)	Parbati River
Temperature °C	97.0	75–92	81.0	45.0	13.0
pH value at 30°C	7.3	7.4	7.35	7.6	7.2
Sp. cond. at 25°C in micromhos/cm	878.2	871.1	892.5	606.9	47.0
TDS	555.0	609.0	510.0	390.0	33.0
Li	1.1	1.0	0.8	0.6	ND
Na	94.0	76.0	88.0	53.0	7.0
K	21.0	19.0	18.0	15.0	3.0
Ca	36.0	32.0	32.0	30.0	6.0
Mg	10.0	10.0	11.0	10.0	3.0
Fe	0.04	0.05	0.05	0.07	ND
Co	0.014	ND	ND	0.018	ND
Cu	0.019	0.028	0.0095	ND	ND
Sr	0.135	0.135	0.140	0.133	ND
Ni	0.0018	0.0023	0.0009	0.0018	ND
Ag	0.01	0.01	0.01	0.01	ND
Zn	0.12	0.125	0.127	0.121	0.122
B	1.0	1.5	2.0	1.0	ND
SiO_2	120.0	115.0	120.0	110.0	ND
F	1.0	0.5	0.5	1.0	0.5
Cl	123.0	100.0	104.0	64.0	1.0
SO_4	45.0	48.0	45.0	46.0	ND
HCO_3	177.0	188.0	175.0	177.5	58.0

Note: ND means Not Determined.

Table 2. Weight ratios of the important constituents in Manikaran hot spring waters.

Description	Hot springs 1	3	4	5
K:Na	0.22	0.25	0.20	0.28
Li:Na	0.012	0.013	0.011	0.011
F:Cl	0.008	0.005	0.005	0.016
B:Cl	0.008	0.015	0.019	0.016
HCO_3:Cl	1.44	1.88	1.68	2.76
SO_4:Cl	0.36	0.48	0.43	0.72
(Ca+Mg):(Na+K)	0.40	0.44	0.41	0.59
Na:Ca	2.61	2.37	2.75	1.77
Ca:Mg	3.60	3.20	2.99	3.00
Cl:SO_4	2.73	2.08	2.31	1.39

tery, and the observed temperatures of the hot springs of an area having high discharges can be explained by the mixing of deep water with shallow cold water. At Manikaran, the temperature and chloride content of the hot springs show large variations. This indicates mixing of deep hot water with cold water. The fraction of shallow cold water mixing with deep thermal water has been estimated independently from such parameters as temperatures of hot springs, estimated reservoir temperature, and mean annual temperature of the area, and also has also been estimated from the combined approach of enthalpy, measured dissolved silica of hot springs and surface cold waters, and the data on the solubility of quartz at elevated temperatures as given by Morey, Fournier, and Rowe (1962).

Considering the average annual temperature of the Manikaran area to be 10°C, the average temperature of nonboiling springs to be 80 to 90°C, and the reservoir temperature to be 195°C (as estimated by Na-K-Ca geothermometery), the fraction of cold water mixing with deep thermal water comes out to be 0.62 to 0.57. While making use of the enthalpy of water, the solubility of quartz at various temperatures, and the temperature and SiO_2 content of nonboiling springs, the mixing fraction has been calculated according to the following relationships:

$$E_{spring} = E_{hot}\,X + E_{cold}\,(1 - X) \tag{1}$$

$$Si_{spring} = Si_{hot}\,X + Si_{cold}\,(1 - X) \tag{2}$$

where E = Enthalphy of water
Si = Silica content of spring water, deep hot water, and surface cold waters.
X = Fraction of deep thermal water present in the spring water.

Solving for X from equations (1) and (2)

$$X = \frac{E_{spring} - E_{cold}}{E_{hot} - E_{cold}} \tag{3}$$

$$X = \frac{Si_{spring} - Si_{cold}}{Si_{hot} - Si_{cold}} \tag{4}$$

Enthalphy, or total heat content, and the concentration of silica in water are functions of temperature. Using these functions and equations (3) and (4), values of X and temperature were calculated earlier. Recently, however, a simple graphic procedure as suggested by Fournier and Truesdel (1974) has been adopted. In this graphic procedure, using equations (3) and (4), the values of X are calculated for a set of enthalphies at different temperatures and also for a set of solubilities of quartz at various temperatures up to 300°C. The point of intersection of the curves representing the above-mentioned variations provides the fraction of deep thermal water present in the spring waters and the probable reservoir temperature. By this method the estimated fraction of deep hot water present in the spring waters turns out to be 0.35 to 0.46, with an average value of 0.4 for the

three springs S_2, S_3, and S_4 of the Manikaran area. Thus an average value of 0.60 of the fraction of cold water mixing with deep thermal water is in agreement with that found by temperature considerations only. The spring S_1 in which boiling occurs has not been considered. Also the mixing fraction for the spring S_5 has not been estimated as the spring emerges from sand and gravels and may have picked up extra silica. The aquifer temperature as obtained by this method varies from 190 to 210°C with a mean of about 202°C.

TRITIUM MEASUREMENTS

A few water samples representing hot springs and surface water were analyzed for their tritium content. The water samples are converted to methane gas, and tritium activity was measured using an Oeschger gas proportional counter. Table 3 gives the result of tritium analyses, and the values are reported in tritium units. One tritium unit (TU) is defined as one atom of tritium per 10^{18} atoms of hydrogen. The tritium contents of hot springs are found to vary from 14 TU to 58 TU as against concentrations of 103 TU and 173 TU for the surface streams. The value of 173 TU corresponds to snow-melt water originating at higher altitudes, probably having more of a contribution of the precipitation of 1963-64, which had a peak tritium concentration. The concentration of 103 TU corresponds to the Parbati River in general.

The concentration of tritium in spring water is higher than that of the pre-bomb tritium levels for 30°N (5 to 10 TU), which could be due to shallow circulation with a short turnover time before the meteoric water emerges as spring water or to the mixing of deep thermal waters with surface waters. It has been shown above that the Manikaran spring waters are of a mixed type, that is deep thermal waters emerging from joints and fissures become mixed with cold waters at shallow depths. The variation of the tritium concentrations of various springs (Table 3) also indicates the latter possibility. There is an inverse relationship between the tritium contents and the temperature of springs. This indicates a lesser degree of mixing for the springs having high temperatures. The chloride contents of various spring waters also show a similar behavior. The mixing model, taking the general mixing fraction of shallow cold water with deep thermal water to be 0.6, indicates no tritium in deep thermal waters, thus pointing out that the deep thermal waters in the hot aquifer have a long residence time. The long residence time for the Manikaran thermal waters also shows the probability of a large subsurface reservoir. The long residence time for thermal waters can also be understood in view of the slow movement of water in the subsurface. Long periods of time (>20 years) can easily be required for the meteoric water to percolate to depths and flow out. The tritium contents of drill-hole waters measured in another potential geothermal field at Puga (Gupta and Sukhija, 1974) also show dead water (tritium-free) at depth. Thus tritium-free water at greater depths in the Manikaran reservoir, as inferred from the mixing model, appears quite logical.

Table 3. Concentration of tritium and chloride in waters of the Manikaran area.

Description	Temperature °C	Cl mg/liter	Tritium concentration (TU)
Manikaran Hot Spring			
Cluster No. S-1	97	123	14
Cluster No. S-3	75–92	100	37
Cluster No. S-4	81	104	58
Cluster No. S-5	45	64	56
Parbati River water	13	1	103
Cold water from the hill	11	—	173

CONCLUSIONS

The analysis of geochemical and tritium data indicates that:

1. The deep thermal water of the Manikaran area mixes predominently with shallow cold water before emerging as spring water. The fraction of deep hot water present in the spring water is of the order of 0.4.
2. Considering the mixing model, the tritium concentration in deep thermal water is inferred to be negligibly small, thus indicating a large residence time for thermal waters.
3. The reservoir temperatures as estimated by a Na-K-Ca geothermometer and by a mixing model turn out to be 195°C and 202°C respectively. This shows a great possibility for multipurpose utilization of thermal water of the Manikaran area.

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