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Hot springs of Demchok, Ladakh, India

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In this study, two thermal springs are reported from the Demchok area in Ladakh, India. These are characterized by water having low total dissolved solids (TDS) content (~250 mg/l) as well as high pH (9.5) and surface temperature (75°C). Although these hot springs and their medicinal properties are known to locals, they have not been scientifically studied. Relatively low TDS despite high temperature could be due to sluggish ion-exchange processes in the geothermal reservoir. Such a situation might have developed because of the high water-to-rock ratio and/or smaller residence time of the geothermal fluid in the reaction zone.

Keywords: Geothermal zone, hot springs, ion-exchange process, medicinal properties, water–rock ratio.

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HOT springs with conspicuously high solute concentrations compared to local groundwater occur in geothermal anomalous zones[1–3]. Prominent geothermal zones are present in seven major provinces of India, characterized by different litho-tectonic settings. According to the Geological Survey of India (GSI), there are about 350 hot springs in these geothermal provinces[4–6]. The Himalayan Geothermal Province (HGP), stretching for over 1500 km at altitudes between 1500 and 4500 m amsl, consists of more than half of all the thermal resources in India[4,7]. Within the HGP, geothermal zones are particularly predominant in the Union Territory of Ladakh, India, the most important geothermal areas being in the Puga Valley, Chumathang and Nubra valley[2] (Figure 1). Puga and Chumathang thermal springs have been the subject of detailed geothermal exploration by the Geological Survey of India (GSI) since 1973 when the Puga multipurpose project was carried out[8,9]. Here, hot springs discharge water at 84–87°C (boiling point of water at an elevation of 4000–4400 m amsl), and some of the thermal zones, including shallow wells, provide evidence of subsurface boiling[9]. Only preliminary exploratory studies have been taken up to date in the Nubra Valley. Subduction tectonism and shallow crustal melting are the primary reasons for high geothermal gradient anomalous heat flow (>180 mW/m^2) in the geothermal province of Ladakh[7,10].

Located about 300 km southeast of Leh, the district headquarters and the capital of Ladakh, Demchok is well known for the occurrence of hot springs and their medicinal properties. These hot springs are roughly the same altitude as those at Puga, i.e. 4400 m amsl. The Demchok hot springs can be reached after about 10–12 h of a strenuous drive along the left bank of the River Indus or via the Loma–Hanle–Umling La road (the highest motorable La or pass at an altitude of 5790 m amsl).

Ladakh Granitoid Complex of Cretaceous to Tertiary age overlain by Quaternary deposits occurs in the Demchok thermal spring area[11,12] (Figure 1). These hot springs occur in two clusters. One cluster consists of two hot springs, viz. HS-DEM-01 and HS-DEM-02 with surface discharge temperatures of 74°C and 75°C respectively (Table 1), just 10°C less than the local boiling point of water (84°C) at the given altitude (Figure 2). HS-DEM-02 shows minor leakage of thermal waters from a small stagnant pond (Figure 2), while discharge from HS-DEM-01 is estimated to be around 5 litre/min. The other cluster is located at Amchi's village (residents of Demchok) and consists of numerous hot springs with medicinal properties. These hot springs are controlled by Amchis (local healers) and are accessible only on some specific occasions. These springs are used to treat skin diseases, digestive issues, pain healing, etc. The low ionic content in these hot springs accounts for their balneological importance. During this study, the second cluster could not be visited despite our best efforts.

Table 1 shows the results of the chemical analysis of water from these hot springs and non-thermal waters. Water

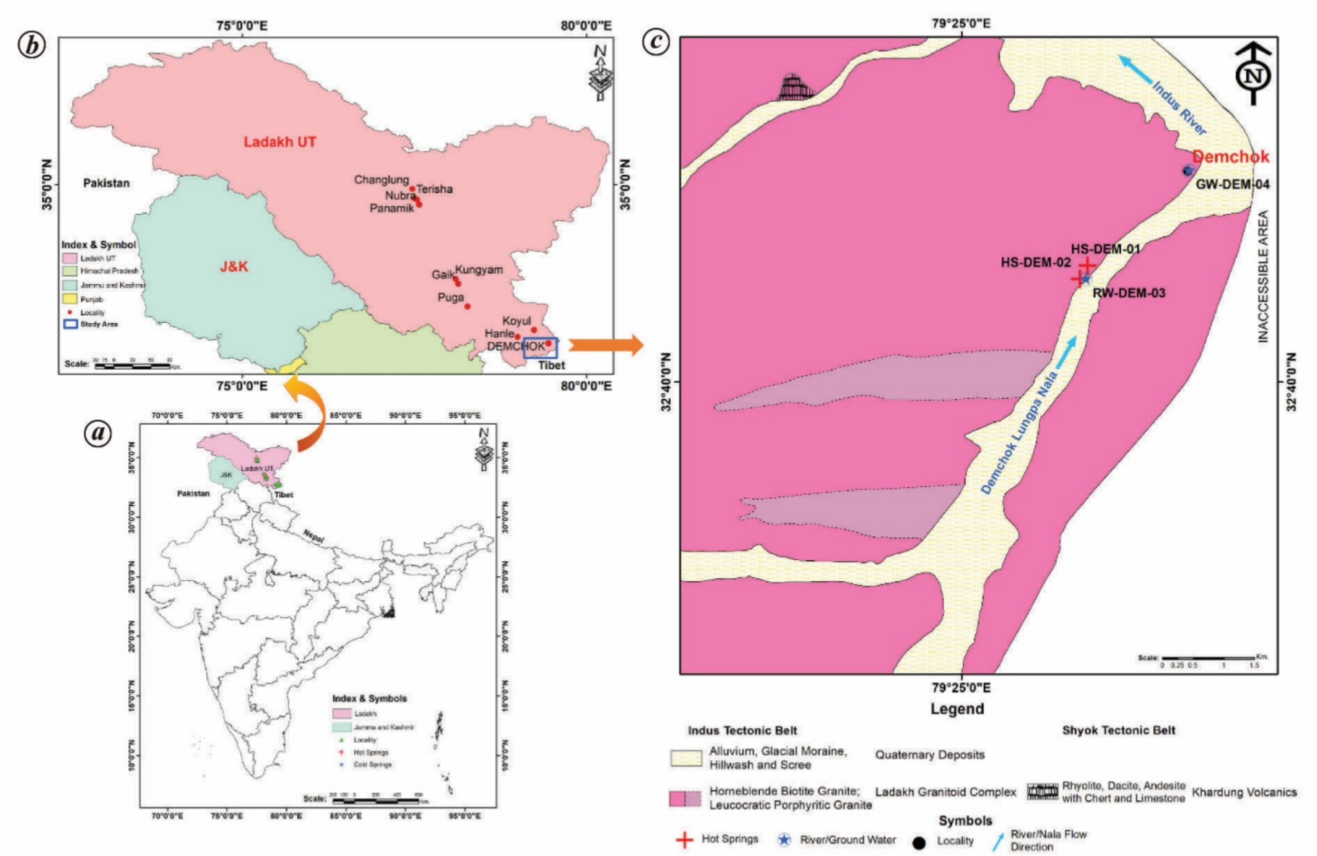

Figure 1. (***a***, ***b***) Location of geothermal resources in India with special emphasis on the Ladakh Himalayas. (***c***) Demchok area in the southeast extreme of Ladakh, overlain by Quaternary deposits resting on Ladakh granitoid complex.

Table 1. Chemical analysis of principal ions (mg/l) in hot and cold spring water samples of Demchok geothermal field, Ladakh, India

Sample ID	Sample type	Temperature (°C)	pH	TDS	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	SiO_2	CBE (%)
HS-DEM-01	Hot spring	74	9.5	244	6	10	23	2	38	12	25	22	106	0
HS-DEM-02	Hot spring	75	9.4	262	6	10	26	2	46	12	30	18	112	–2
RW-DEM-03	River water	12	7.4	75	5	5	4	1	29	0	5	8	18	5
GW-DEM-04	Groundwater	15	7.6	136	4	10	10	2	56	0	11	15	28	–1

samples were collected in 500 ml HDPE (high-density polypropylene) bottles for major cation and anion analysis. The samples were also collected in 60 ml bottles for SiO_2. A 60 ml sample was also collected in another bottle and acidified with Suprapur HNO_3. This latter sample was used for analysing rare earth and trace elements by ICPMS. Physico-chemical parameters such as pH, salinity and electrical conductance were measured onsite using a calibrated water analyzer (Systronics, India). For pH, three-point calibration was carried out utilizing buffers with pH values 4.01, 7.01 and 10.01. Similarly, the EC probe was calibrated using three standard solutions with EC values 84, 1413 and 5 mS/cm respectively. Total hardness, Ca^{2+}, Mg^{2+}, and total alkalinity were determined onsite using standard titrimetric techniques with 0.02 (M) EDTA and 0.02 (N) H_2SO_4 solutions[13]. Total dissolved solids (TDS) values given in Table 1 are the sum of all major cations and anions. Silica and SO_4^{2-} were estimated using a UV spectrophotometer (Thermo UV330, India). Cl^- was determined by argentometric titration, while Na^+ and K^+ were estimated using a flame photometer (Systronics). Rare earth and trace elements were analysed using ICPMS (Varian 820 MS ICPMS). The accuracy of the analysis was confirmed by the fact that the ionic charge balance error was less than 5%.

The average silica content was 110 mg/l. Alkaline waters dissolve hydrated silica through proton abstraction, forcing it to achieve geochemical equilibrium[10]. It has been deduced carbonate ion in high-pH waters is primarily responsible for the dissociation of silicic acid in geothermal

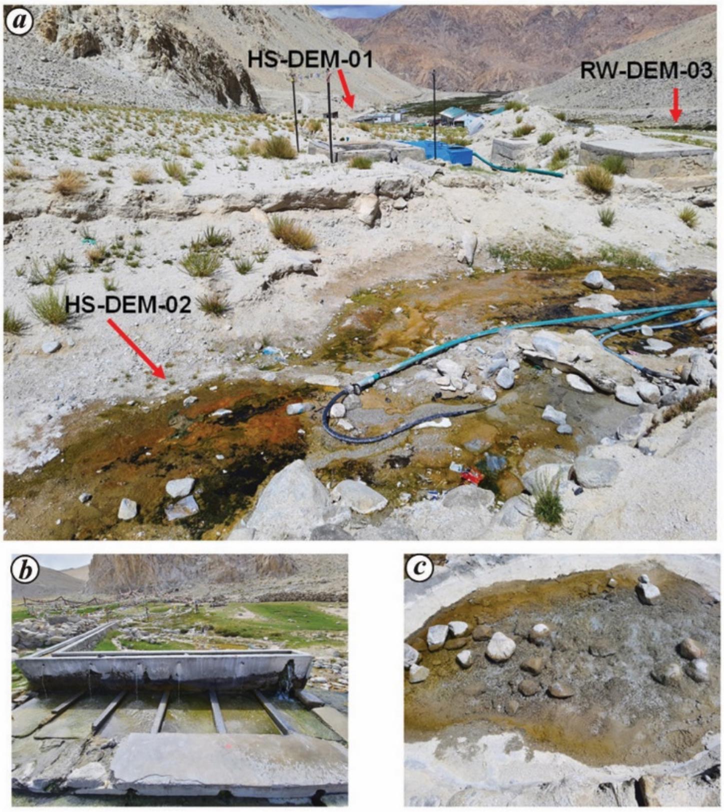

Figure 2. (***a***) Panoramic view of hot spring locations and Lungpa nala water of the Demchok geothermal field. (***b***, ***c***) Location of thermal springs: (***b***) HS-DEM-01 and (***c***) HS-DEM-02.

fluids[10]. This could be a reason for the relatively high silica content over other ions in thermal waters. As silica is assumed to be in geochemical equilibrium with thermal waters, the reservoir temperature of the Demchok geothermal springs has been estimated as ~125°C from silica geothermometry[1–4]. Na–K Giggenbach (1988) and K–Mg Giggenbach (1986) geothermometers predict anomalously high (~221°C) and low (~34°C) reservoir temperatures. Such inconsistencies can be predicted in terms of poor Na, K and Mg contents in thermal waters and varying rates of equilibrium of plagioclase and orthoclase with thermal waters[2,5,14,15]. Silica concentration in the geothermal fluid is highly vulnerable to reduction on account of various reservoir processes such as precipitation, boiling causing increase in fluid pH and mixing of ascending geothermal fluid with local groundwater. Therefore, the reservoir temperature determined using silica concentration may be considered minimum, and the actual reservoir temperature may be higher. The relatively high pH of the geothermal fluid may be attributed to the dissociation of HCO_3^- to CO_3^{2-}, and ionic exchange between ascending geothermal fluid through silicic rocks and clays.

The hydrochemistry of the Demchok geothermal springs is strikingly different from other important thermal springs of Ladakh like the Puga Valley, Chumathang and Nubra Valley. Extraordinarily low TDS value (~260 mg/l) is a characteristic feature of the Demchok thermal spring waters compared to Puga and other springs of Ladakh (TDS > 1000 mg/l)[4,8]. These springs have lower reservoir temperatures (~125°C) compared to those of Puga, Chumathang (~180°C) and Nubra Valley (~147°C), as estimated from silica thermometry.

Table 1 shows that water–rock interactions between the geothermal fluid and reservoir rocks for acquiring solutes are sluggish, as indicated by low Na^+ and K^+ concentrations, despite the reservoir temperature being more than 100°C and the rock being granite. However, a silica concentration of >100 mg/l suggests granite source[16]. There is a possibility that the Demchok geothermal prospect is characterized by a relatively high water-to-rock ratio and/or smaller residence time of the geothermal fluid in the reaction zone.

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