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Western extension of the Himalayan geothermal belt

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INTRODUCTION AND TECTONIC SETTING

The Himalayan Geothermal Belt (HGB) was first defined by Tong and Zhang (1981). It has been described as a 3000 km long belt with at least 600 hot and warm springs, stretching from the Pamir terrain through Tibet into Yunnan (Hochstein and Regenauer-Lieb, 1998). Hochstein and Yang (1995) described the main characteristic features of the geothermal systems and the magnitude of heat transfer by fluids within the central and eastern parts of the HGB (Figure 1).

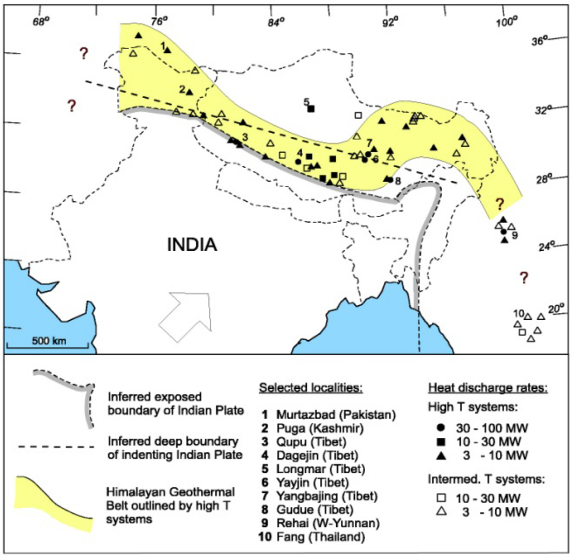

Figure 1. The Himalayan Geothermal Belt (modified from Hochstein and Yang 1995).

The Himalaya is commonly divided into four tectonic provinces that can be followed for at least 2400 km along almost the entire orogenic belt (Figure 2):

1. The Himalayan Foreland (composed of the Muree and Siwalik Formations of Miocene to Pleistocene molassic sediments, products of the erosion of the Himalaya). The foreland formations are thrust over the Quaternary alluvium along the Main Frontal Thrust (MFT).

2. The Lesser Himalaya (composed mainly of Precambrian detrital sediments and some granites and acid volcanics) thrust over the Subhimalaya along the Main Boundary Thrust (MBT). The Lesser Himalaya often appears in tectonic windows.

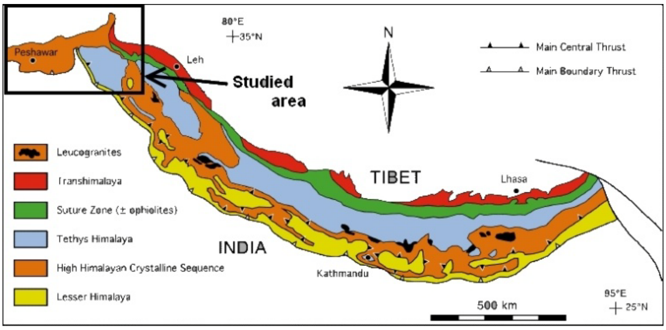

Figure 2. The Himalayan tectonic provinces (after Le Fort, 1988).

3. The High Himalaya encompassing the areas with the highest topographic relief is commonly separated into four zones:

- The High Himalayan Crystalline Sequence (HHCS), a major 30 km thick nappe of mostly Proterozoic to early Paleozoic medium- to high-grade metamorphic sequence of metasediments thrust over the Lesser Himalaya along the Main Central Thrust (MCT); the HHCS is in places intruded by granites of Ordovician and early Miocene.
- The Tethys Himalaya (TH) consist of ca 100 km wide synclinorium of weakly metamorphosed, intensely folded and imbricated sedimentary formations of almost complete Paleozoic and Mesozoic sequence.
- The Nyimaling-Tso Morari Metamorphic Dome, NTMD formed of greenschist and eclogitic metamorphic rocks as the northern extension of the TH in the Ladakh region.
- The flysch and turbiditic Lamayuru and Markha (LMU) Late permian to Eocene formations of the northern continental slope of the Indian Plate.

4. The Indus Suture Zone (ISZ) is the actual zone of collision between the Indian Plate and the Transhimalaya Karakoram-Lhasa Block. It represents the northern limit of the Himalaya. The Transhimalaya Karakoram-Lhasa Block is the South-Eurasian active continental margin of the Andean type volcanic arc.

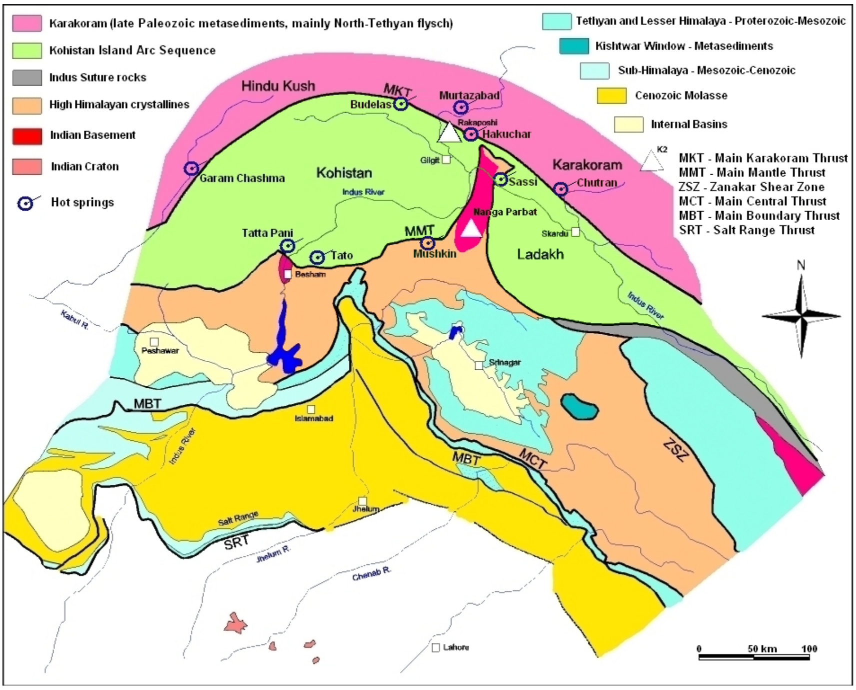

Figure 3. Geology of Western Himalaya (adapted from Edwards et al. 1997).

WESTERN EXTENSION OF THE HGB

Geothermal manifestations at the west end of the HGB are limited to hot springs (Figure 3) associated exclusively with the still active Main Karakoram Thrust (MKT) and the Main Mantle

Thrust (MMT). The MKT separates the Paleozoic metasediments, consisting of turbidities and flysch of the early Tethyan geosynclinorium (Hindukush and Karakoram) in the north, from the Kohistan Island Arc constructed on the ocean floor during late Jurassic and Cretaceous times. The MMT separates the Kohistan Island Arc formation from the HHCS granitoids, divided into peraluminous collisional granites of Proterozoic, Pan-African and Palaeozoic periods and Himalayan alkaline granites of Carboniferous-Triassic extensional regime (Syed Shahid Hussain, 2005).

Although overthrust faults are usually tightly sealed with cataclastic or mylonitized breccias such as the MMT (Dipietro et al., 2000; Singh, 2003), thus rendering them impervious to groundwater flow, yet unquestionably the two overthrusts serve as a conduit to the ascending thermal water. Yousafzai et al. (2008) concluded that the topography-driven pressure along these faults from the highest ridges to the north of the study area may attain a maximum of 25 MPa as compared to the tectonic stress of 90 MPa computed by Lisa et al. (1997). Thus, it would seem that the overall tectonic pressure within the basin is high enough to overcome this obstacle. Indeed, Yousafzai et al. (2008) have demonstrated in their numerical model for ground water flow in the area an existence of excess pressure head along the two fault-lines commensurate with the elastic response to the tectonic stress of 90 MPa. Moreover, a substantial amount of heat is presumably generated by frictional movement along these faults (Todaka et al., 1988).

The Nanga Parbat Haramosh Massif

During the last 10 m.y., the Nanga Parbat Haramosh Massif in the northwestern Himalaya (Figure 3) has been intruded by granitic magmas, has undergone high-grade metamorphism and anatexis, and has been rapidly uplifted and denuded. Chamberlain et al. (1995, 2002) suggested on the basis of their isotopic studies that the rapid uplift of the massif created a dual hydrothermal system, consisting of a near-surface flow system dominated by meteoric water circulating through shear zones and a system of faults and fractures within the upper 5–6 km of the crust, while the deeper brittle/ductile hydrothermal system consists of unconnected magmatic/metamorphic volatiles/fluid inclusions. Craw et al. (1997) concluded that the geothermal system within the upper 5-6 km can be further divided into deep liquid-dominated zone following a boiling-point relationship down to 3 km, overlaying a deeper zone of dry steam with fluid densities from 0.36 to as low as 0.07 g/cm^3.

Water-dominated systems

Manzoor et al. (2005) determined that the thermal waters of the Northern Pakistan originate from the meteoric recharge. They have in general low concentrations of dissolved solids and are neutral to slightly alkaline, usually dominated by Na-HCO_3. They found the Murtazabad Hot Springs yielding “mixed waters” with equilibrium temperature of the thermal end-member is in the range 185°C–225°C. However, the equilibrium temperature range indicated by the $\delta^{18}O(SO_4\text{-}H_2O)$ geothermometer is 130°C–185°C. Narrower ranges were found for the springs of Tatta Pani, where the equilibrium temperatures determined by the Na-K, K-Mg and quartz geothermometers yield reservoir temperatures in the range 100°C–130°C, and the $\delta^{18}O(SO_4\text{-}H_2O)$ geothermometer indicates equilibrium temperatures around 150°C. Somewhat higher reservoir temperatures were obtained for Tato Springs where the silica and cation geothermometers suggested equilibrium temperatures in the range of 175°C–200°C, while the $\delta^{18}O(SO_4$-$H_2O)$ geothermometer indicated equilibrium temperatures of 170°C.

Yousafzai et al. (2010) investigated chemical composition of water sampled from Garam Chashma Hot Springs and about 70 ground water wells located between SRT in the south and beyond MKT in the north. They found that large number of the groundwater wells and springs located in proximity of the MMT and MKT yielded water at a significantly elevated temperature over the local mean annual air temperature. While Garam Chashma is renown for discharging water at the "balmy" 67°C, many water wells used for either irrigation or domestic use yielded ground water with the temperatures in excess of at least 6°C over the local mean annual air temperature. They found a significant correlation between that temperature excess and several hydrochemical anomalies, notably elevated silica, boron and strontium concentrations for the sampled springs and water wells. They concluded that the thermal and hydrochemical anomalies result from admixture of the deep thermal water along the faultlines and entering into the shallow aquifer taped by the water wells. They demonstrated such mixing systems using Piper (1944) trilinear diagrams. Yousafzai et al. (2010) estimated the source reservoir temperature using silica and various cation geothermometers obtaining widely ranging temperatures. However, by assumming the mixing system indicated by several bivariate chemical concentration and orifice temperatures they narrowed down the range of 116°C–155°C. Also, the reservoir temperature calculated using Mg-Li falls within this range.

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