Deformation Temperatures and Flow Vorticities Near the Base of the Greater Himalayan Crystalline Sequence, Sutlej Valley and Shimla Klippe, NW India

Richard D. Law[1], Donald W. Stahr III[1], Talat Ahmad[2], Santosh Kumar[2]

[1] Department of Geosciences, Virginia Tech., Blacksburg, VA 24061, U.S.A., rdlaw@vt.edu
[2] Department of Geology, University of Delhi, Delhi 110007, India

We report new flow-vorticity and deformation-temperature data from near the base of the Greater Himalayan Series (GHS) exposed in the Sutlej River section and Shimla klippe of NW India (Figure 1), focusing on variation in these parameters traced from foreland to hinterland positions.

The Sutlej River section trends approximately WSW-ENE and in map view extends for approximately 100 km between the westernmost map position of the Main Central thrust (MCT) and the Sangla Detachment (a strand of the South Tibetan Detachment System). The section is oriented oblique to the pervasive NNE-SSW to NE-SW trending mineral stretching lineation in the GHS, assumed to indicate transport direction, and, traced from WSW to ENE, more hinterland structural positions are progressively exposed. However, regional scale NW-SE trending folding and subsequent erosion has resulted in formation of a structural window in the center of the Sutlej River section with low-grade Lesser Himalayan Sedimentary Series rocks and higher-grade Lesser Himalayan Crystalline Sequence rocks being exposed beneath the antiformally folded MCT (Figure 1). This allows us to examine exposures of the GHS that are at similar structural distances above the mapped position of the MCT, but in progressively more hinterland positions traced from WSW to ENE. Additionally, the Shimla klippe, located to the SW of the Sutlej River section, allows us to examine outcrops of the GHS that occupy a more foreland position than those exposed along the Sutlej.

At the western end of the Sutlej River section exposures of mylonitic granite and quartzite located at structural distances of 350-900 m above the MCT were described by Grasemann and others (1999) in the first quantitative study of flow vorticities reported from the Himalaya. This study, which employed the

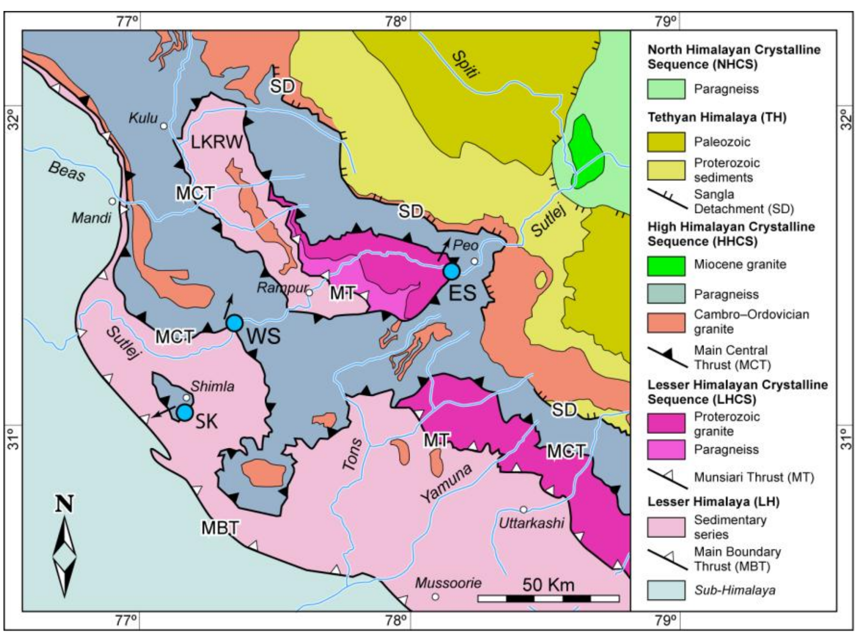

Figure 1. Geologic map of the structural units in the Sutlej River area; circles indicate the three areas referred to in text: WS – western Sutlej section, ES – eastern Sutlej section, SK – Shimla klippe. Average trend of mineral stretching lineation for the three localities indicated by arrows. LKRW – Larji-Kullu-Rampur Window. Modified from Wiesmayr and Grasemann (2002).

Rxz strain ratio / quartz c-axis method of Wallis (1992), indicated that penetrative deformation close to the base of the GHS involved a general shear (combined pure and simple shear, where pure shear has mean kinematic vorticity number Wm = 0 and simple shear has Wm = 1). However, due to uncertainty in the strain values employed, only semi-quantitative estimates of flow vorticity could be made. We have re-examined some of these exposures using the rigid grain and oblique grain shape / quartz c-axis fabric methods of Wallis (1992). Our rigid-grain data indicate flow vorticities in the Wm = 0.73–0.81 range (47-40% pure shear; 53-60% simple shear component), confirming the basic conclusion of a general shear reached by Grasemann and others (1999) in their pioneering study. Our oblique grain shape / quartz c-axis fabric data indicate higher Wm values and hence higher simple-shear components. The data from the western Sutlej section indicate higher simple-shear components than generally recorded close to the base of the GHS in the Everest and Annapurna regions of eastern-central Nepal (Jessup and others, 2006; Larson and others, 2009), but are similar to Wm estimates recorded by Carosi and others (2007) from western Nepal.

Deformation temperatures of the mylonitic granite and quartzite located close to the underlying MCT at the western end of the Sutlej section are estimated at c. 525 °C based on the quartz c-axis fabric opening angle thermometer of Kruhl (1998) and Law and others (2004). These temperature estimates are in good agreement with the observed quartz recrystallization regime (limited grain-boundary migration) in these tectonites. However, both crystallographic fabrics (this study, and Grasemann and others, 1999) and recrystallization microstructures indicate that deformation temperatures increase structurally upwards, reflecting the inversion of metamorphic isograds at the base of the GHS.

Close to the base of the GHS preserved in the Shimla klippe (Figure 1), which occupies a more foreland position than the exposures at the western end of the Sutlej section, quartz fabrics and recrystallization mechanisms (subgrain rotation with minor grain boundary migration) indicate lower deformation temperatures than those recorded in the western Sutlej mylonites. In contrast, plastically deformed and recrystallized quartz-rich tectonites located immediately (< 300 m) above the mapped position of the MCT in the eastern part of the Sutlej River section, and occupying a more hinterland position than the western Sutlej exposures, record the highest deformation temperatures. Deformation temperatures of c. 625 °C are indicated by quartz c-axis fabric opening angles and this is confirmed by microstructural evidence for widespread grain-boundary migration recrystallization. Identical temperatures are estimated by phase-equilibria methods in these tectonites, indicating that penetrative deformation occurred at close to peak temperature and that the high-temperature fabrics have not been pervasively overprinted by later lower-temperature events associated with exhumation. Microstructures needed for quantitative vorticity analysis do not develop, however, at such elevated deformation temperatures.

The tectonic implications of these vorticity and thermal data for internal flow and extrusion/exhumation of the GHS will be discussed.

References

Carosi, R., Montomoli, C. and Visona, D., 2007, A structural transect in the Lower Dolpo: Insights on the tectonic evolution of Western Nepal, Journal of Asian Earth Sciences, 29, 407-423.

Grasemann, B., Fritz, H. and Vannay, J-C., 1999, Quantitative kinematic flow analysis from the Main Central Thrust zone, (NW Himalaya): implications for a decelerating strain path and the extrusion of orogenic wedges, J. Struct. Geol., 21, 837-53.

Jessup, M., Law, R.D., Searle, M.P. and Hubbard, M., 2006, Structural evolution and vorticity of flow during extrusion and exhumation of the Greater Himalayan Slab, Mount Everest Massif, Tibet/Nepal: implications for orogen-scale flow partitioning, in: Law, R.D., Searle, M.P and Godin, L. (eds) *Channel Flow, Ductile Extrusion and Exhumation in Continental Collision Zones*, Geological Society of London Special Publication, 268, 379-413.

Krul, J.H., 1998, Reply: Prism- and basal-plane parallel subgrain boundaries in quartz: a microstructural geothermobarometer, Journal of Metamorphic Geology, 16, 142-146.

Larson, K.P. and Godin, L., 2009, Kinematics of the Greater Himalayan Sequence, Dhaulagiri Himal: implications for the structural framework of eastern Nepal, Journal of the Geological Society, London, 166, 25-43.

Law, R.D., Searle, M.P. and Simpson, R.L., 2004, Strain, deformation temperatures and vorticity of flow at the top of the Greater Himalayan Slab, Everest Massif, Tibet, Journal of the Geological Society, London 161, 305-320.

Wallis, S., 1992, Vorticity analysis in a metachert from the Sanbagawa Belt, SW Japan, J. Struct. Geol., 14, 271-280.

Wiesmayr, G. and Grasemann, B., 2002, Eohimalayan fold and thrust belt: Implications for the geodynamic evolution of the NW-Himalaya (India), Tectonics, 21(6), 1058, doi:10.1029/2002TC001363.

Cite as: Law, R.D., Stahr III, D.W., Ahmad, T. and Kumar, S., 2010, Deformation Temperatures and Flow Vorticities Near the Base of the Greater Himalayan Crystalline Sequence, Sutlej Valley and Shimla Klippe, NW India, *in* Leech, M.L., and others., eds., Proceedings for the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey, Open-File Report 2010-1099, 2 p. [http://pubs.usgs.gov/of/2010/1099/law/].