Types of processes in crustal channels evidenced by along-strike variations in the tectonic style of the Himalayas and by numerical models

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Along-strike variations in Himalayan tectonic style suggest that ductile extrusion of the Greater Himalayan Sequence (GHS) is more complicated than predicted by simple channel-flow models (e.g., Beaumont *et al.,* 2001, *Nature,* 414, 738-42). For example, high-temperature (>800°C) and moderate- to low-pressure (4-7 kbar) assemblages characterise the upper tectonic level of the GHS in several regions of the central and eastern Himalaya. In these areas, out-of-sequence thrusts separate the upper GHS from a lower tectonic level with peak conditions of 700-800°C at pressures up to 12 kbar. Based on recent model results, we suggest that the two levels of the GHS may represent sequentially exhumed parts of a hot mid-crustal channel, with the upper tectonic level possibly corresponding to an extruded dome.

In central Bhutan, cordierite-sillimanite gneisses and migmatites are thrust over garnet-staurolite schist along the conspicuous, out-of-sequence, Kakhtang thrust. In the hanging wall, leucogranite in the roof of the Monlakarchung-Kula Kangri pluton has been dated at 12-13 Ma (Edwards & Harrison 1997, *Geology* 25, 543-546), the youngest known in the Himalaya. Beneath the pluton, the Kakhtang thrust cuts the main foliation and metamorphic isograds in the GHS. Leucogranite dykes deformed by the thrust with ca. 14-15 Ma intrusion and cooling ages document rapid exhumation of the hanging wall associated with late Miocene shearing along the Kakhtang thrust. Quartz textures indicate syn-thrusting amphibolite facies (≥650°C) conditions in the hanging wall and greenschist facies conditions in the footwall. Garnet zoning in footwall schists suggests growth with increasing pressure (Davidson *et al.* 1997, *J. Metam. Geol.* 15, 593-612). These schists, which can be correlated with Neoproterozoic sediments found further south in klippen of the South Tibetan Detachment (Grujic *et al.* 2003, *EPSL* 198, 177-191), point to significant displacement that progressively diminishes to east and west along the trace of the Kakhtang thrust. In central Bhutan, the thrust and the foliation are steep and locally overturned, outlining a non-cylindrical, recumbent, south-facing antiform. In its frontal part, the steep foliation is overprinted by a sub-horizontal crenulation cleavage which is likely co-kinematic with north-directed shear bands in the detachment at the roof of the leucogranite pluton. Together, these textures are consistent with flattening of a hot structure (upper GHS) during southward thrusting beneath the Tethyan cover and over the previously exhumed lower GHS.

Recent models for the tectonic evolution of large hot, orogens (Beaumont *et al. JGR*, in press) demonstrate that channel flows can be accompanied by the development of domes and hot fold nappes. These structures may be exposed by extension of the overlying upper crust, or may be extruded as part of the channel and exposed by erosion. Models with the latter type of development exhibit structures similar to those described above. In particular, overthrusting of the dome or nappe at high structural levels in the channel creates an out of sequence Kakhtang-like thrust with the dome/nappe arched above it. Such structures are produced without the need to appeal to low-viscosity or low-buoyancy enclaves; it therefore is uncertain whether the observed leucogranite sheets are an active or passive part of the system.

Comparisons between observations and model results suggest that the GHS is likely to be structurally and metamorphically more complex than predicted by the simple 'toothpaste-like' extrusion of a channel. Along-strike variability in GHS tectonic style may provide evidence of the types of processes seen in the numerical models. Moreover, the process of dome extrusion above a mid-crustal channel provides an additional mechanism for out-of sequence thrusts in the cores of hot collisional orogens.