Kinematic evolution of the Greater Himalayan Sequence, Annapurna-Dhaulagiri Himalaya, central Nepal

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The channel flow model for the Himalayan orogen suggests that the Greater Himalaya Sequence (GHS) represents a partially molten, rheologically weak, mid-crustal channel, bound above and below by rigid continental crust (Beaumont et al., 2001). Extrusion and exhumation of the channel requires coeval ductile shearing on the underlying, reverse-sense, Main Central Thrust Zone (MCTZ) and the overlying, normal-sense, South Tibetan Detachment System (STDS) (see Godin et al., 2006 for a review). The vertical distribution of strain across the GHS is one aspect of the channel flow model that has yet to be investigated. Here, we present the first quantified vertical strain profile for the GHS produced from crystallographic preferred orientation (CPO) measurements of rocks collected through the Annapurna-Dhaulagiri Himalaya, central Nepal. By combining this data with observed macro- and microstructural deformation fabrics identified in the field and in thin sections, we reveal the kinematic evolution of the GHS. Results suggest that the GHS in this area was not rheologically weak enough to sustain mid-crustal channel flow and cooled prematurely to form a rigid 'channel plug'. Consequently, the increased rheological strength of the GHS later resulted in post-peak metamorphic reverse-sense shearing on the STDS. These interpretations highlight the importance of melt distribution and rheology as controls on crustal scale deformation during orogenesis.

With increasing strain, the degree of alignment of minerals, and thus CPO strength, in a rock also increases. As such, CPO strength in deformed rocks provides a proxy for relative strain magnitude (e.g. Bunge & Morris, 1982). CPOs are measured via electron back scattered diffraction (EBSD), from samples collected along a N-S transect through the Kali Gandaki Valley, in the Annapurna-Dhaulagiri Himalaya of central Nepal. Intensity, I (Lisle, 1985) which is used to describe the strength of each CPO fabric is calculated for each sample and stratigraphically arranged into a single plot to produce the first quantified relative strain magnitude profile for the GHS and bounding units. Additionally, deformation temperatures are estimated from microstructures and accompanying metamorphic mineral assemblages in thin sections (e.g. Stipp et al., 2002), and from identification of the active crystal slip-systems in CPO fabrics (e.g. Lister et al., 1978). Combining deformation temperature estimates with the quantified strain profile reveals the thermo-tectonic evolution of the GHS in the Annapurna-Dhaulagiri Himalaya and provides a unique data set to test the validity of the channel flow model for the GHS in this region.

Along the strain profile, variations in I show that relative strain magnitudes are greatest in the bounding shear zones above and below the amphibolite facies mid-crustal rocks of the Upper GHS.
These high strain zones correspond to the MCTZ and STDS. Within these shear zones, I decreases incrementally, away from the Upper GHS towards the over- and underlying tectonic units of the Tethyan Himalayan Sequence (THS) and Lesser Himalayan Sequence (LHS). Deformation microstructures and metamorphic mineral assemblages in these shear zones also indicate a gradual decrease in estimated deformation temperatures from ~500ºC to ~300 ºC away from the Upper GHS. In both the THS and LHS, relative strain magnitudes and estimated deformation temperatures are low (<300-400 ºC). Notably, within the amphibolite facies mid-crustal rocks of the Upper GHS, estimated deformation temperatures are high (~600-700 ºC), however, shear fabrics are rarely observed and CPO intensity is low. This suggests that these rocks have undergone little deformation whilst at the conditions suitable for mid-crustal flow. Furthermore, evidence of sillimanite grade retrogression and extensive annatexis and leucogranite production, which is commonly observed in the GHS elsewhere in Nepal (e.g., Everest

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region - Searle et al., 2003; Makalu region - Streule et al., 2010; Manaslu region - Larson et al., 2011), also appears to be absent or severely lacking in the Annapurna-Dhaulagiri Himalaya.

Synthesis of these results suggests that the GHS exposed in the Kali Gandaki Valley may not have been rheologically weak enough to sustain mid-crustal channel flow (c.f. Beaumont et al., 2001). It is proposed that premature cooling of the GHS below sub-solidus temperatures effectively froze the GHS to produce a rigid channel ‘plug’, preventing significant mid-crustal flow. This was subsequently followed by post-peak metamorphic reverse-sense shearing on the STDS, possibly due to the increase in strength gained by the GHS during its cooling. These observations and interpretations provide an insight into the mid-crustal processes that occur during continental collision and imply that the channel flow model cannot sufficiently explain kinematic evolution of the GHS in the Annapurna-Dhaulagiri Himalaya. Significantly, these results demonstrate that crustal melting and rheology play an important role during the kinematic development of orogenic belts.

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