Quantified vertical strain profile through the Greater Himalayan Sequence, Annapurna-Dhaulagiri Himalaya, central Nepal

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Determining the kinematic evolution of the Greater Himalayan Sequence (GHS), which forms the metamorphic core of the Himalayan orogen, represents the central focus of all models of Himalayan orogenesis (e.g. Beaumont et al., 2001; Webb et al., 2007; Faccenda et al., 2008). Whilst much is known about the geothermobarometric evolution of the GHS, the spatial and temporal distribution of strain within the GHS is less well understood. This is largely due to the difficulty of finding reliable strain markers within high grade metamorphic rocks, as they are often overprinted during late stage static recrystallisation. Here, we present the first quantified vertical strain profile for the GHS derived from crystallographic preferred orientation (CPO) data from samples collected in the Annapurna-Dhaulagiri Himalaya of central Nepal. We explore interpretations of this profile and their implications for models of Himalayan orogenesis, and also look at the wider implications for our understanding of crustal scale deformation within continental collision zones. We further assess the strengths and weaknesses of this approach and its applicability to other settings.

CPO describes the degree of crystal alignment of a selected mineral in a rock with respect to an external reference frame such as sample or geographic coordinates. With increased crystal plastic strain, the degree of mineral alignment, and thus CPO strength, increases. As such, CPO strength in deformed rocks provides a proxy for relative strain magnitude (e.g. Bunge & Morris, 1982). An advantage to this approach is that deformation-related CPOs can be resilient to late-stage static recrystallisation, a process commonly observed in deformed rocks that can overprint and remove geometric strain markers such as shape preferred orientations. Here, we use electron back scattered diffraction (EBSD) to measure CPOs of bulk mineral assemblages in samples collected along a N-S transect through the Kali Gandaki Valley and neighbouring foothills, in the Annapurna-Dhaulagiri Himalaya. We use the Intensity parameter, *I* (Lisle, 1985), calculated from the eigenvalues of the orientation distribution functions used to define each CPO to quantify CPO fabric strength. Whilst there are numerous parameters available to describe CPO strength (e.g. *strength parameter, c*, Woodcock, 1977; *J-index,* Bunge & Morris, 1982; *PGR index,* Vollmer, 1990; *misorientaion index*, Skemer et al., 2005) we graphically demonstrate that the intensity parameter, I is the most suitable parameter to use as a proxy for relative strain magnitude. By plotting values of I against the relative structural/stratigraphic height of the samples from which they are derived, we have produced the first vertical strain profile for the whole of the GHS and bounding units that shows changes in relative strain magnitudes across the sample transect. Furthermore, as *I* is calculated from the *c*-axis CPOs of all major mineral phases (quartz, calcite, dolomite, mica and feldspar) we may also explore how deformation partitions into specific mineral phases in different polymineralic rocks.

Along the strain profile, variations in I demonstrate that relative strain magnitudes are greatest in the bounding shear zones above and below the GHS. These high strain zones correspond to the reverse-sense Main Central Thrust Zone (MCTZ) at the base of the GHS and the normal-sense South Tibetan Detachment (STDS) at the top of the GHS. Within these shear zones, I decreases incrementally, away from the GHS towards the over- and underlying tectonic units of the Tethyan Himalayan Sequence (THS) and Lesser Himalayan Sequence (LHS), respectively. Pairing CPO data with deformation temperatures derived from deformation microstructures and metamorphic mineral assemblages (e.g. Stipp et al., 2002) shows how deformation migrated outwards away from the GHS as it cooled during extrusion/exhumation. Within the amphibolite facies rocks of the GHS, I is low and shear fabrics are rarely seen, whilst

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estimated deformation temperatures are high (~600-700 ºC). This suggests that these rocks have undergone little deformation whilst at conditions suitable for mid-crustal flow and instead suggest that the GHS has exhumed as a rigid body with little internal deformation, facilitated by ductile to brittle shearing at its margins.

Such observations suggest that current channel flow models (e.g. Beaumont et al., 2001) that invoke extensive mid-crustal flow of the GHS may not be applicable to the GHS of the Annapurna-Dhaulagiri Himalaya. The channel flow model for the Himalayan orogen suggests that the GHS represents a rheologically weak, mid-crustal channel driven laterally southwards and towards the surface, by the overburden of the Tibetan Plateau and the underthrusting of the Indian lower crust. Whilst there is good evidence to support the occurrence of channel flow elsewhere in the Himalaya (e.g., Everest region - Searle et al., 2003; Makalu region - Streule et al., 2010; Manaslu region - Larson et al., 2011), the weak CPO observed in the GHS of the Annapurna-Dhaulagiri Himalaya, combined with a lower than average volume of partial melting and a marked absense of sillimanite grade metamorphism suggests that channel flow did not play a significant role in the extrusion and exhumation of the GHS in this area.

The technique outlined here, presents a new approach for unravelling the structural evolution of mid-crustal terranes in situations where visual strain markers are hard to find. The observations and interpretations made from this study provide a new insight into the kinematic evolution of the Himalayan orogen and into the crustal proccesses that occurr during continental collision. Further work should be carried out to develop this technique further and to explore its usefulness and applicability to other settings.

References

Beaumont, C., Jamieson, R. A., Nguyen, M. H. and Lee, B. 2001, Himalayan tectonics explained by extrusion of a low-viscosity crustal channel coupled to focused surface denudation. Nature, 414, 738-742.

Bunge, H. J. and Morris, P. R., 1982, Texture analysis in materials science: mathematical methods, 593 pp, Butterworths, London.

Faccenda, M., Gerya, T. V. and Chakraborty, S., 2008, Styles of post-subduction collisional orogeny: Influence of convergence velocity, crustal rheology and radiogenic heat production. Lithos, 103, 257-287.

Larson, K. P., Cottle, J. M. and Godin, L., 2011, Petrochronologic record of metamorphism and melting in the upper Greater Himalayan sequence, Manaslu–Himal Chuli Himalaya, west-central Nepal. Lithosphere, 3, 379-392.

Lisle, R. J., 1985, The use of the orientation tensor for the description and statistical testing of fabrics. Journal of Structural Geology, 7, 115-117.

Searle, M. P., Simpson, R. L., Law, R. D., Parrish, R. R. and Waters, D. J., 2003, The structural geometry, metamorphic and magmatic evolution of the Everest massif, High Himalaya of Nepal-South Tibet. Journal of the Geological Society, 160, 345-366.

Skemer, P., Katayama, I., Jiang, Z. and Karato, S.-I., 2005, The misorientation index: Development of a new method for calculating the strength of lattice-preferred orientation. Tectonophysics, 411, 157-167.

Stipp, M., Stunitz, H., Heilbronner, R. and Schmid, S. M., 2002, The eastern Tonale fault zone: a 'natural laboratory' for crystal plastic deformation of quartz over a temperature range from 250 to 700 degrees C. Journal of Structural Geology, 24, 1861-1884.

Streule, M. J., Searle, M. P., Waters, D. J. and Horstwood, M. S. A., 2010, Metamorphism, melting, and channel flow in the Greater Himalayan Sequence and Makalu leucogranite: Constraints from thermobarometry, metamorphic modeling, and U-Pb geochronology. Tectonics, 29, TC5011.

Vollmer, F. W., 1990, An application of eigenvalue methods to structural domain analysis. Geological Society of America Bulletin, 102, 786-791.

Webb, A. G., Yin, A., Harrison, T. M., Celerier, J. and Burgess, 2006, The leading edge of the Greater Himalayan Crystalline complex revealed in the NW Indian Himalaya: Implications for the evolution of the Himalayan orogen. Geology, 35, 955-958.

Woodcock, N. H., 1977, Specification of fabric shapes using an eigenvalue method. Geological Society of America Bulletin, 88, 1231-1236.