20 Ma of lateral mass transfer around the western Himalayan syntaxis

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The thermodynamic evolution of an orogen can be subdivided into three stages depending on the relative rates of energy accumulation and dissipation. The first stage is mainly driven by plate tectonic forces and results in vertical thickening of the lithosphere. The present vertical thickening trajectory has been mapped using stress tensor inversion of earthquakes and runs from the western syntaxis via Tien Shan and NE Tibet to the eastern syntaxis (Schill et al. 2004a). After this first phase of energy accumulation, interplay of accumulative and dissipative processes dominates the second stage (Hodges et al. 2001). During the third stage the dominance of energy dissipation leads to the degradation of the orogen. The absolute deformation caused by one of these tectonic regimes depends among others on its temporal activity.

The regional configuration of forces in the India-Asia collision zone is characterized by a rotational compressional system caused by the counterclockwise indentation of the Indian plate (Patriat and Achache 1984) and a related extensional regime represented by the eastward extrusion of the Tibetan plateau (Tapponnier and Molnar 1977). In the frontal part of the collision zone, the Himalayan mountain belt, crustal thickening and potential energy dissipation are in equilibrium over time (Hodges et al. 2001). The frontal extrusion developed near the Oligocene to Miocene boundary and is limited by the South Tibetan detachment system (STDS) to the north and the Main Central Thrust (MCT) to the south (Hodges et al. 1996), while crustal thickening occurs mainly at the southern front of the Himalayan arc south of the MCT. To the north the former distal shelf of the Indian plate, the Tethyan Himalayas, represents the transition between the frontal and the E-W extrusion of the upper crust of the Tibetan plateau in the central and eastern part of the orogen. In this transition zone and further to the N in southern Tibet a dichotomy of the tectonic regime is indicate, e.g., by paleomagnetic data (Schill et al. 2004b, Schill et al. 2001) and the distribution of boiling springs (Hochstein and Regenauer-Lieb, 1998). Both information set reveal extrusion features in the central and eastern part indicated by the a large right lateral shear zone in the transition zone (Schill et al. 2004b) and a slip line solution for the observed heat lines (Hochstein and Regenauer-Lieb 1998). Around the western syntaxis stress tensor inversion (Schill et al. 2004a) and paleomagnetic investigation (Klootwijk et al. 1985) indicate a compressional regime with oroclinal bending around the syntaxis. The tectonic regimes are separated by the Karakoram fault. Both, Neogene tectono-morphologic evolution and geothermal data reveal that the present tectonic setting in southern Tibet and the Himalayas with frontal and lateral extrusion has been operational for about 10-20 Ma (Hodges et al. 2001, Hochstein and Regenauer-Lieb 1998).

From a thermodynamic point of view, oroclinal bending can be considered as lateral mass transfer without influence on the potential energy budget of the collision zone. Since no vertical thickening is involved, oroclinal bending is attributed to the second stage of orogeny. In order to investigate the transition between the first and second stage in the compressional part of the collision zone, we present a compilation of present rotation rates deduced from GPS measurements and the late-orogenic rotation pattern since 40-50 Ma deduced from paleomagnetic results. The evaluation of different correlations between both provides new constraints on the stability and the onset of oroclinal bending.

The Quaternary to present rotation pattern in the India-Asia collision is deduced from a joint inversion of Quaternary strain rates and 238 GPS velocities for a self-consistent velocity field (Holt et al. 2000). For equidimensional crustal blocks rotation rates can be calculated after Lamb (1987). This rotation pattern is characterized by counterclockwise and clockwise rotation rates of up to 10^{-16} rad/sec west and east of the Nanga Parbat Haramosh syntaxis, respectively.

The post-collisional rotation pattern is best represented by secondary remanence directions carried mainly by pyrrhotite with remanence acquisition ages between 50 and 40 Ma (Schill et al. 2002, Schill et al. 2001, Klootwijk et al. 1983). The acquisition age of secondary pyrrhotite remanences with a Curie temperature of ~325 °C and a formation temperature of >200 °C to 350 °C is deduced from $^{40}K/^{39}Ar$ and $^{40}Ar/^{39}Ar$ cooling ages with a closing temperature of about 300 °C and dated to 40 to 50 Ma. The paleo-rotation pattern in the Tethyan Himalayas in respect to the Eurasian plate is dominated by clockwise rotations W of the Nanga Parbat-Haramosh syntaxis. To the E, the counterclockwise rotation of NW Kashmir is supported by the Pliocence rotations in the Peshwar basin (Burbank and Tahirkheli 1985). This rotation pattern in conjunction with the rotations south of the Tethyan Himalayas (Klootwijk et al. 1985) pinpoints oroclinal bending around the western syntaxis. The remanence acquisition age provides the maximum age of rotations due to oroclinal bending. The consistency of the paleo-rotation pattern with the present rotation directions deduced from GPS measurements points to a long term stability of the rotation processes.

Linear extrapolation of the rotation rates from Quaternary strain rates and GPS measurements to the remanence acquisition time describe a linear correlation with the observed paleomagnetic rotations with a coefficient of determination of R^2=0.60. Since the age of remanence acquisition represents a maximum age for oroclinal bending, the rotation patterns of paleomagnetic results and GPS measurements have been calculated for different ages in 5 to 10 Ma steps between the remanence acquisition age and 5 Ma. At 20 Ma the correlation between the expected rotations from GPS measurements and the paleomagnetic rotations reveal a linear fit with a gradient a=1. Assuming a stable rotation velocity, this gradient indicates that the oroclinal bending related rotations initiated 20 Ma ago. The fact that the linear fit runs approximately through the origin minimizes the influence of earlier rotation processes on the absolute rotational motion. This implies that the onset of lateral mass displacement occurred at about 20 Ma, which can be considered the transition age from the first to the second stage of orogeny in the compressional part of the collision zone. The timing of onset of oroclinal bending is consistent with the right-lateral motion at the southern end of the Karakoram fault since about 23 Ma (Lacassin et al. 2004) and the onset of doming in the Nanga Parbat-Haramosh massif in the Miocene (Schneider et al. 2001).

The inferred age of transition between stage 1 and 2 of orogeny of about 20 Ma is a Himalayan-wide event, which is reflected in onset of frontal extrusion and oroclinal bending in the extensional and compressional part of the orogen, respectively.

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