Geophysical Research Abstracts,
Vol. 11, EGU2009-12017, 2009
EGU General Assembly 2009

Brittle-fault deformation history in the NW Himalaya (Himachal Pradesh, India)

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The Himalayan mountain belt and the Tibetan Plateau are the manifestations of intense crustal shortening and uplift along the southern margin of Eurasia associated with the India-Eurasia collision. While crustal shortening has been focused at lower elevations until the present day along the southern boundary of the Lesser Himalaya and the Siwalik ranges, several generations of both, orogen-parallel and orogen-perpendicular extensional structures have developed. These structures characterize the higher-elevation regions within the Higher and Tethyan Himalaya, suggesting syntectonic extension. In the NW Himalaya (India), extending from the deeply cut gorges of the Sutlej and Spiti rivers to the Garhwal Himalaya, closely spaced young normal faults, focal mechanisms of earthquakes with magnitudes between 5.2 and 6.8, and regional GPS measurements reveal ongoing E-W extension. Surprisingly, and in contrast to other extensional features observed in the Himalaya, this direction is neither parallel nor perpendicular to the NE-SW regional shortening direction.

Here, we present new data obtained from structural geological mapping, fault kinematic analysis of hundreds of brittle faults, and remote sensing spanning the area between the Tso Morari Lake in the Tibetan Himalaya in the north and the mountain front in the Garhwal Himalaya in the south (30°-33°N/77°-79°E). In addition, we integrated published data on extensional phenomena in this region of the Himalaya.

In the Garhwal Himalaya and the Sutlej-Spiti region, we collected and analyzed outcrop-scale brittle fault-planes with displacements of up to several cm. To analyze fault kinematic data (strike and dip of the fault, slip direction and sense of slip) for these micro-faults, we calculated strain axes for approx. 100 outcrop locations using the TectonicsFP program. This data set, as well as field observations on crosscutting relationships, mineralization of fault planes, and correlations with deformation structures in lake sediments, allows us to identify and temporally separate different phases of deformation.

Taken together, this new data allows us to provide a detailed account of the brittle deformation and its temporal evolution. In the southern and western part of our study area, brittle faulting records mainly shortening perpendicular to the strike of the orogen, partly overprinted by normal faulting related to extension, both parallel and perpendicular to shortening. During this stage extensional deformation was associated with strike-slip faulting, mostly observed along reactivated fault planes. In the northeastern part of our study area, we were able to detect at least three extension directions: (1) NW-SE extension is the dominant brittle deformation observed in the Spiti Valley; (2) NE-SW extension associated with the Southern Tibetan Detachment is documented as well in brittle faults. In the vicinity of the Leo Pargil gneiss dome, however, the observed extension is predominantly normal to the NNE-SSW striking long axis of the exhuming dome. (3) Based on cross-cutting relationships, E-W extension is the most recent deformation phase identified throughout the entire study area. The young normal faults overprint all previously formed deformation features. Interestingly, our structural data set of brittle faults suggests, however that ongoing extension is affecting a much larger region towards the south and west than the distribution of seismicity would suggest.

In conclusion, the strain patterns derived from our collected brittle deformation features at a variety of length scales reflect the large regional deformation pattern very well, but also emphasize the relevance of syntectonic extension in a region still dominated by overall shortening, which highlights the role of extensional processes in the Himalaya.