Relative importance of fluvial and glacial erosion in shaping the Chandra Valley, western Himalaya, India

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Although glaciers are often believed to be the principal erosional agents and the cause for increasing topographic relief in mountain belts, quantifying their contribution to long-term erosion and exhumation is challenging. This is particularly true for the Himalaya, where most previous studies have been conducted in arid and internal segments of the orogen, where present-day ice coverage is low, but glacial landforms and deposits are well preserved. In the more humid frontal segments of the High Himalaya, however, where present-day ice coverage is high, evidence for extensive glaciations is more limited, presumably due to vigorous fluvial erosion and mass wasting that quickly removes the depositional and geomorphic evidence of past glacial impacts. Consequently, the geomorphic impact of Himalayan glaciers on Quaternary erosion is debated. Based on observations from the south-eastern margin of the Tibetan Plateau, Korup and Montgomery (2008) recently proposed that repeated advances of temperate tributary glaciers could impede fluvial bedrock incision and thus prevent headward retreat of fluvial knickpoints into the Tibetan Plateau.

To address the influence of Quaternary glaciations on landscape development in the Himalaya, we have chosen the Lahul region, which is located in the Indian part of the NW-Himalaya. This region is transitional between the southern front of the Himalaya, where the bulk of precipitation occurs during summer, and the more arid Trans-Himalaya, where most precipitation occurs during winter. Therefore, the area may be sensitive to fluctuations in the strength of both, the South Asian monsoon (summer precipitation) and the Westerlies (winter precipitation). The Chandra Valley is located in the Lahul area and forms the headwaters of the Chenab River, a major range-parallel drainage in the western Himalaya. Today, the area is characterised by a high number of glaciers, and U-shaped valleys suggest a recent glacial overprint of the topography. Previous work indicates that the Chandra Valley was strongly glaciated during the late Pleistocene, but the geomorphic evidence for maximum glacial extents has been limited and the timing of the older, more extensive glaciations, is poorly constrained. In conjunction with other studies a glaciation history in the NW-Himalaya has been proposed that is asynchronous to the maximum extents of most other northern hemisphere glaciations, with most of the glaciers in the Himalaya having reached their last maximum extent during Marine Isotope stage 3. Therefore, the extent and timing of the Lahul glaciations are still under debate. Beside the pronounced glacial history recognized along the Upper Chenab/Chandra River/Valley, also the course of one of the first order tectonic boundaries of the Himalayan tectonic evolution, the South Tibetan detachment (STD) separating the High from the Tethyan Himalaya, have been proposed to be located in approximation of the study region. STD was active during the early to middle Miocene and is inferred to be inactive now; see Leloup et al. 2010 for a recent review. Close to the surface the STD acts as normal fault also influenced by precipitation that is focused on the orographic and topographic front.

In this study we intend to determine spatial and temporal variations in valley incision through fluvial and glacial erosion on different timescales by combining information obtained from cosmogenic radionuclide (CRN) dating of glacially-carved and striated surfaces, various low-temperature thermochronometers, and morphometric analysis. River profile analyses were conducted using a 90-m-resolution SRTM digital elevation model (DEM). We mapped several important knickzones along the Chandra and Chenab valleys as well as some of their tributaries. This has been combined with glacial landform mapping in the field and on satellite images, with the purpose to identify the extent of glacially carved landscapes.

A most prominent feature in the upper Chandra Valley is a large knickpoint in the present-day channel profile of the Chandra River that is located between Chhattru and Batal at an elevation of ~3900 m asl. Across the knickpoint channel elevations drop by approximately 400 m over a horizontal distance of 11 km. Interestingly, this knickpoint spatially coincides with (1) a large change in cooling ages along the valley; (2) the joining of a tributary where one of the largest glaciers in the entire area is found; (3) a significant lithological break; and (4) a steep climatic gradient that accompanies the northward turn of the valley. Previously published AFT cooling ages are relatively young below 4100 m elevation and to the south along the Beas River. AFT ages increase sharply upstream of the knickpoint in the Chandra River. The lithological break defines the approximate location of the STD and it is unknown, if the observed change in cooling ages, could be explained by displacement along the STD. We found further knickpoints in tributary valleys of the Chandra Valley at around the same elevation of ~3900 m asl. From the available data it can be seen that these valley do not record the same exhumation pattern, but are also oriented parallel to the strike of the orogen. Instead, some of the knickzones also correspond to a lithological break and are located more northward in an environment with less precipitation due to the N-S precipitation gradient.

Our field observations and preliminary CRN data suggest extensive glacial coverage of the upper Chandra Valley. Based on field evidence the minimum ice thicknesses for the main trunk glacier in the Chandra Valley must have been at least 700 m above the present-day valley bottom. This glacier must have existed prior to ~3 ka, based on new cosmogenic ages from glacially striated and polished bedrock ridges. Our data confirm previous glacial chronological work in this area, but show that the late glacial ice in the upper Chandra has been more extensive than previously thought. Furthermore, our cosmogenic ages, together with those of Owen et al. (1996, 1997, 2001, 2008) show that deglaciation of the Chandra Valley must have been rapid and accomplished within 15 ka. The down-valley ice extent was observed until the village of Rape, but our own ice mass-balance modelling and field observations suggest a larger extent. Existing and new cosmogenic data together with the observation of rounded interfluves and glacial striations and deposits at Kunzum La, the pass between the Chandra Valley and the Spiti Valley farther east, indicate that the pass had been either locally glaciated at that same time, or the ice in the Chandra Valley flowed over to the Spiti Valley.

We hypothesize that these observations coincide with the glacially carved surface of the valley, which indicates a minimum altitude of ~4100 m asl for glaciation in the lower Chandra Valley. Using morphometric analysis tools we are able to project and to estimate the original extent of the carved valley. Combining all preliminary results and observations, we hypothesize that glacial carving has been the first-order erosional agent during the Quaternary of all regions in Lahul above an elevation of 4100 m asl. The AFT ages suggest slower erosional exhumation in the more arid upper Chandra Valley. In this context we keep in mind a possible blocking of the valley by the Bara Shigri glacier and therefore the outpacing of the fluvial erosion in the upper part of the Chandra Valley.

The ultimate goal of this study is to better understand the regional erosion pattern within the Chandra Valley, and to possibly determine whether glaciers influenced by local conditions (tectonics, climate), impede or accelerate erosion, and my thus impact the regional geomorphic evolution of the Tibetan plateau margin and other morphotectonic provinces. For that we also plan to investigate the exhumation history in the Chandra Valley in a more detailed manner by thermochronology and the interpretation of brittle structures. This would allow testing exhumation in relation to the activity of the South Tibet Detachment (STD) and the evolution of knickpoints.

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