Geophysical Research Abstracts,
Vol. 10, EGU2008-A-05235, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-05235
EGU General Assembly 2008

Glaciation and landslide history around the Annapurna, Nepal, based on 10Be surface exposure dating

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We applied 10Be surface exposure dating to glacial deposits, landslides and terraces in the Kali Gandaki and the Marsyandi Valley around the Annapurna, Nepal, in order to provide some numerical age control concerning the landscape history and to allow a quantification of the geomorphological processes involved. Three boulders from the Dhampu-Chooya landslide deposits near Lete and Tatopani, which were previously interpreted to be of glacial origin, yielded exposure ages of 4.9 $\pm$ 1.2, 4.3 $\pm$ 0.7 and 4.3 $\pm$ 0.8 ka. A several hundred meter high terrace further downstream at the confluence of the Miristi Khola is dated to 2.2 $\pm$ 1.7 and 2.2 $\pm$ 0.6 ka, respectively, and could be a remnant of a massive debris flow related to the failure of a landslide dam upstream. Exposure ages around 30 ka from a terrace several hundred meters above the Dhampu-Chooya landslide deposits document an earlier massive blocking of the main valley, the Takkhola-Mustang Graben, which was most likely caused by glaciers descending from the Dhaulagiri and Nilgiri massifs.

In the Dudh Khola, a tributary of the Marsyandi Valley, moraines are preserved and could be dated to the Little Ice Age (0.1 $\pm$ 0.1 ka), the Neoglacial (1.8 $\pm$ 0.6 and 1.5 $\pm$ 0.4 ka) and into the Early Holocene ($>$ 7.7 $\pm$ 1.0 ka). This is in good agreement with other glacial chronologies from Nepal. Particularly the Early Holocene glacial advances show that not only temperature, but also increased monsoonal precipitation

affects glacial mass-balances. During the Last Glacial Maximum ($\sim$20 ka) climate conditions were likely drier than today and the extent of glaciation was rather limited. Moraines in the steep Marsyandi Valley are not preserved, but exposure ages ($>60 \pm 8$ ka) at Bahundanda (1400 m) show that glaciers did not reach that far down.

In general, our results corroborate earlier findings that extreme geomorpholocial activity, including catastrophic events like landslides and debris flows, played a crucial role in landscape history around the Annapurna. Dating results indicate that catastrophic events were not necessarily related to deglaciation, but also occurred during the Holocene. Similar catastrophic events today would cause substantial human and economic damage and therefore constitute substantial geohazards.