Summary

Rivers play a key role in the transfer of mass and energy within the Earth system. They transport huge amounts of water and sediment from the land to the oceans, and they are also a considerable geomorphic agent in most environments. In response to changes in discharge, slope and sediment load, a river can incise or aggrade. These processes are related to climate and tectonics. Present climate change is intensifying the global hydrological cycle by significant changes in precipitation and runoff. How will this global environment change affect the river regimes and, in turn, fluvial geomorphology? The geological past, which has experienced different tectonic-, environmental- and climatic conditions can provide valuable clues to infer these effects. River terraces are typical morphological features of fluvial valleys, recording the fluvial evolution (degradation and aggradation) as a result of climate changes and tectonic movements. In general, the effects of tectonic movements and climate change have been studied separately in studies on fluvial terraces. However, their interplay may result in conflicting, or at least complex, effects on the fluvial process. For instance, fluvial incision may lag behind tectonic uplift while the river may react faster to climatic change. It is challenging to investigate the complex result of the interference of those forcing factors.

The northeastern Tibetan Plateau (NETP) is one of the tectonically most active regions in the world. However, it also experienced drastic climate changes. For example, during the LGM mean annual temperatures were at least 7° less than at present leading to the expansion of glaciers and the initiation of periglacial processes. Thus, geological- and geomorphological records of river evolution in the NETP are ideal for studying the impacts of the coupled effects of tectonic motions and climate changes on fluvial processes.

The general aim of this study is to investigate fluvial incision and sedimentation and terrace morphology and their relationship with climate changes and tectonic movement in the NETP. Several related sub-objectives are:

1) to reconstruct paleoclimatic changes and related landscape evolution using OSL dating; 2) to infer general uplift and deformation processes in the Northeastern Tibetan Plateau (NETP); 3) to investigate in detail the regional correlation of fluvial terrace and morphological evolution and based on this, to study the local tectonic movements. As such, this study reveals an example of fluvial response to climate changes and strong tectonic movements.

To achieve these aims, a large dataset of dated landforms was created for the Huang He and Huang Shui systems. Methods involved morphological
mapping, investigation and analysis of sedimentary structures, lithological properties and micromammalian fossils, and luminescence dating.

One of the studied targets is the Huang Shui catchment. The morpho-tectonic analysis of the Huang Shui catchment shows the presence of one prominent bevelled surface, preliminarily interpreted as a peneplain surface. This surface occurs at c. 2750 m altitude and corresponds with the top of the relict sedimentary fill of large tectonic basins and adjacent summits. After formation of this peneplain, a terrace sequence was formed along the Huang Shui river. The transition of peneplain surface formation to incision was dated as older than 10-6 Ma using the biochronology of micromammalian assemblages from fluvial terraces and the depositional record of the basin fill. The river incision into the former peneplain is attributed to an important uplift event around 10-17 Ma.

This general uplift also caused local fragmentation of the Huang Shui catchment into blocks (kilometers or maximally, a few tens of kilometers) of local extent that have subsided and/or uplifted relative to one another. We speculate that the inferred tectonic motions are related to the transpression movements in NETP as a result of the collision of the Indian and Asian plates. Fluvial deposition of >30 m in the subsiding blocks contrasts with erosion and formation of gorges in the uplifted blocks. The different rates of uplift and subsidence of the individual blocks resulted in the simultaneous development of erosion and accumulation terraces of different sizes within the same catchment, even within the same tectonic block. Terrace deposits are sometimes capped by interglacial soils or soil-derived material and main terrace incision is assumed to occur at the transition to the next cold period.

One of the special studied areas is the interface of the Qilian Mountains and the Menyuan basin. OSL appears to be a valid method to constrain the age of deposits of glacial and fluvial origin, soils and periglacial structures in this area. This area experienced intensive glacial activity during the last glacial cycle, with glacial melt-water systems draining into the Menyuan basin in the NETP. Dating results show glaciers advanced extensively to the foot of the adjacent Qilian Mountains at ~21 ka, in agreement with the timing of the global Last Glacial Maximum (LGM) recorded in Northern Hemisphere ice cores. It is suggested that the factor controlling glacial advance was decreased temperature, not monsoon-related precipitation increase. The areas of the adjacent Menyuan basin occupied by glacio-fluvial deposits experienced continuous permafrost during the LGM, indicated by large cryoturbation features, interpreted to indicate that the mean annual temperature was ≥7 °C lower than at present. Glacio-fluvial systems in the Menyuan basin aggraded and terraces formed

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during cold periods (penultimate glaciation, LGM, and possibly the Younger Dryas) as a response to increased glacial sediment production and meltwater runoff, followed by incision at the transition to the next warm period.

Another specially studied area is at the confluence of Huang Shui and Huang He (Yellow River). The courses of the Huang Shui and the Huang He in this area have developed terrace staircases which are used to infer relative tectonic motions between the individual tectonic segments. The terrace staircases in the different segments are correlated by means of their relative height and OSL dating. At least eight fluvial terraces are present, two of which have been dated by OSL (the sixth and the third ones; -70 ka and -24 ka respectively). The correlated longitudinal terrace profiles show that within the confluence area no distinct relative tectonic movements have taken place since the seventh terrace demonstrating that this area behaved as one large tectonic block. The terrace staircase comparison of this block to areas further upstream (Xining area) and downstream (eastern Lanzhou area) indicates relative tectonic motions with respect to those areas, which must therefore represent different tectonic blocks. The average river incision rate since -70 ka was much higher in the confluence region block than in the up- and downstream blocks, possibly indicating relative uplift of the confluence region.

This relatively strong uplift in the confluence zone gave more space for differentiation within the terrace staircase as a result of climatic changes, leading to 6 terraces formed as a response to small climatic fluctuations (10³-10⁴ year timescale) since the last interglacial. It may be concluded that the stronger the tectonic movement the better the climatic imprint is expressed in the terrace development. On a smaller time scale, two accumulation terraces with thick stacked fluvial deposits (>18 m) which are not related to changes of sediment supply due to other than climatic impact, may indicate relative subsidence in the confluence area relative to the upstream and downstream blocks, occurring at some time between 20 and 70 ka. This indicates changes in relative vertical crustal motions at timescales of tens of thousands of years.

To be concluded about fluvial response to climatic changes, fluvial aggradation occurred during cold periods in general in the NETP, resulting from the increase of sediment supply both in peri-glacial and glacial conditions. In this monsoonal climate region, the resuming vegetation cover reduced sediment supply to the rivers so that rivers progressively incised, reaching only sporadically the previous floodplain at the transition to interglacials. This change in fluvial activity as a response to climatic impact is reflected in the general sedimentary sequence on the terraces from high-energy (braided) channel deposits (at full glacial) to lower-energy deposits of small channels
(towards the end of the glacial), mostly separated by a rather sharp boundary from overlying flood-loams (at the glacial-interglacial transition) and overall soil formation (interglacial). Probably, renewed erosion at the next interglacial-glacial transition was responsible for the absence of interglacial channel deposits. During the next glacial period this fluvial sedimentary series is covered by purely aeolian loess.