Geomorphology 210 (2014) 23–35

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Interaction of geomorphological processes on the north-eastern Tibetan Plateau during the Holocene, an example from a sub-catchment of Lake Donggi Cona

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ARTICLE INFO

Article history:
Received 25 March 2013
Received in revised form 29 November 2013
Accepted 8 December 2013
Available online 19 December 2013

Keywords:
Holocene
Geomorphology
Sedimentology
OSL
Tibetan Plateau
Paleoclimate

ABSTRACT

Geomorphological landforms on a large alluvial fan and neighboring areas on the eastern side of the Donggi Cona show a complex spatial pattern. Sediment availability is an important factor in the formation of these archives and is partly associated with lake level fluctuation. Different sedimentary archives therefore show a similar geomorphological signal while in some cases similar archives are related to different forcing. The chronology of the processes is based on 22 optical stimulated luminescence (OSL) ages obtained from coarse-grained quartz or potassium-feldspar. The base of the alluvial fan formed during the late Pleistocene but deposition of cover sediments on the fan only started at around 7 ka ago. Silty sediments form a thin cover on the uppermost terraces and have been available only during short timespans. Most of the sediments are sandy deposits which form an internal sediment cycle on the fan. They developed throughout the Holocene. Sandy deposits on the footslopes of the neighboring hills have been preserved since the Pleistocene-Holocene transition. Thicker eolian deposits accumulated during the late Holocene. These sediments were washed into the Donggi Cona and formed sandy lake sediments which were susceptible to remobilization during lower lake levels. In combination with drier climatic conditions during the late Holocene these sediments formed small dunes on the fan. Sediments on the alluvial fan are highly active, for which erosion and deposition vary in space and time. The interaction of fluvial and eolian processes is an important part of this dynamic high mountain system.

1. Introduction

Geomorphological landforms and processes are used widely to reconstruct the paleoclimatic evolution, tectonic influence and human impact on the Tibetan Plateau. However, most studies regarding paleoclimate reconstructions focus on one single archive, e.g. eolian deposits (Lehmkuhl et al., 2000; Sun et al., 2007; Lu et al., 2011), fluvial and colluvial sediments (Kaiser et al., 2007), lake sediments (Madsen et al., 2008; Mischke et al., 2008, 2010c; Opitz et al., 2012) or glacial sediments (Lehmkuhl, 1998; Owen et al., 2003; Heyman et al., 2011). Beside the effects of climate change, geomorphological archives often show evidence of tectonic activity and human influence. There is a wealth of publications reconstructing tectonic movements from geomorphological archives on the north-eastern Tibetan Plateau (e.g. Van der Woerd et al., 2002; Fu and Awata, 2007; Guo et al., 2007; Kirby et al., 2007). For several decades an increased human influence on the environment and geomorphological processes has been observed (e.g. Cui and Graf, 2009; Yan et al., 2009). However, recent publications also highlight an anthropogenic influence over the last several thousand years (Miehe et al., 2009; Schlütz and Lehmkuhl, 2009).

Studies focusing on larger sets of different geomorphological archives often deal with large areas and therefore have a low spatial resolution (e.g. Owen et al., 2006). Hardly any work in the area has tried to identify the entire sediment transport pathways on the catchment scale, both spatially and temporally. Information on these sediment cascades will deepen the understanding of the underlying driving forces, such as climatic changes, tectonic and human influences on these systems. This is especially important as geomorphological processes are interacting with each other and internal feedbacks in the system play an important role in the formation and preservation of geomorphological landforms (e.g. Field et al., 2009).

In this paper different geomorphological landforms, surface types and related geomorphological processes of a multicomponent system in the catchment of the Donggi Cona on the north-eastern Tibetan Plateau are identified. The area is a typical example for a complex pattern of sediment storage and transportation which is sensitive to environmental changes in a high altitude semi-arid climate. Eolian, fluvial and lacustrine processes are interacting and result in a spatial and temporal different response of the geomorphological system to the climatic forcing. Timing of the processes during the Holocene is

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http://dx.doi.org/10.1016/j.geomorph.2013.12.014

constrained by 22 optical stimulated luminesces (OSL) ages. The results are combined in a tentative landscape reconstruction and finally in a simple model of the different processes operating during different time-scales. A special focus is set on the complex interaction of sediment archives. Many paleoclimatic reconstructions rely on the interpretation of lake sediments either from the lake itself or from onshore archives such as lake terraces. This study also provides basic information on terrestrial sediment activity, which is relevant for the interpretation of lake sediments.

2. Regional setting

Lake Donggi Cona is located in the Kunlun Shan on the north-eastern Tibetan Plateau (35°18′ N/98°32′ E) at an elevation of 4090 m asl (above sea level) and is probably one of the best studied catchments on the Tibet Plateau. The catchment has a size of 3174 km^2 and is dominated by a WNW-ESE oriented pull-apart basin (Fig. 1). The basin is part of the Tuosu segment of the Kunlun Fault which is one of the major faults on the northern Tibetan Plateau (Yin and Harrison, 2000; Van der Woerd et al., 2002; Fu and Awata, 2007; Guo et al., 2007). The last major earthquake in 1937 (M 7.5) caused several mole tracks which are still traceable at the surface east and west of the lake (Tapponier and Molnar, 1977; Van der Woerd et al., 2002; Guo et al., 2007). The horizontal offset has been estimated to be about 4 m, while the vertical movement was less than 1 m (Van der Woerd et al., 2002; Guo et al., 2007). The surrounding mountains consist of Triassic and Permian lime- and sandstones, as well as of clastic rocks of Permian to Neogene age. The basins are filled by Quaternary sediments (Wang et al., 1998; Wang and Yang, 2004).

The highest elevation is located in the south-eastern part of the catchment (5230 m asl), which is the western extension of the A'nyêmaqên Shan. On the northwestern side of the lake the mountains reach an elevation of up to 5050 m asl, while most areas in the catchment are below 4300 m asl. Remnants of Quaternary glaciations are frequent in the higher parts, consisting of cirques, U-shaped valleys and terminal moraines. No modern glaciations exist in the higher part of the catchment. The nearest presently glaciated mountains are the A'nyêmaqên Shan, about 30 km southeast of the catchment with a maximum elevation of 6282 m asl. During the late Quaternary large valley glaciers developed in this mountain range (Wang, 1987; Lehmkuhl, 1998; Owen et al., 2003). Four terminal moraines have been mapped on the eastern side of the A'nyêmaqên Range. Three of them have been dated by CRN (cosmogenic radionuclides) dating of boulders from moraine crests to around 45 ± 5, 16 ± 3 and 9 ± 3 ka (Owen et al., 2003). The fourth moraine which has not been dated is only 1 km away from the present glacier margin (Owen et al., 2003). Terminal moraines of past glaciations are also preserved in the mountains north of the Donggi Cona. Field observations revealed terminal moraines less than one kilometer away from the present lake shore.

The Donggi Cona is mainly fed by the Dungqu River which is draining the mountains in the south-east of the catchment. Several ancient shore-lines have been recorded below (Dietze et al., 2010) and above the present lake level (Van der Woerd et al., 2002; Mischke et al., 2010b; IJmker et al., 2012a; Dietze et al., 2013).

The area is located at the northern boundary of the Asian summer monsoon (e.g. Morrill et al., 2006). The climate is semi-arid, with mean annual precipitation of 311 mm years^{-1}. More than 50% of the precipitation occurs in summer (June, July and August) and more than 80% from May to September. Thunderstorms resulting in high discharge events occur frequently during this time. Mean temperature for January and July are −15.8 and 7.9 °C. The mean annual temperature is −3.0 °C (Mischke et al., 2010a). Alpine meadows, alpine steppes and *Salix* scrubs on the slopes characterize the vegetation in the catchment (Huang, 1987; Kürschner et al., 2005).

In this study, research focused on a large alluvial fan and the neighboring slopes in the eastern part of the pull-apart basin with an area of 180 km^2 (Fig. 2). The fan stretches for about 20 km in NNW to SSE direction and has a width of 10 km. Lake Donggi Cona is located on the western end of the alluvial fan, while the southern border is formed by a small mountain range consisting mainly of carbonate rocks of Permian age. The maximum altitude of this mountains is 4590 m asl. On the eastern side of the mountain range the Dongqu River enters the basin close to the village of Huashixia at an elevation of 4210 m. To the west an undulating surface borders the fan from the high mountain area. It consists of older gravels which might be related to a former west-to-east flowing paleo-river which drained the whole basin prior to the development of the lake and the reorientation of the river system (Li et al., 2000). An elongated ridge (push-up fold, Van der Woerd et al., 2002) with an elevation of up to 4280 m separates the NE part of the basin. This ridge is located directly on a fault line (Van der Woerd et al., 2002). During the field work, seven steps were observed on its northern side. On the lower slopes small ponds and hills alternate. They might have formed during the Tuosuo Lake earthquake in 1937. The rupture zone is clearly traceable to the east and west of the mountain ridge. The north border of the fan is marked by a mountain range with maximum elevations of 4605 m asl.

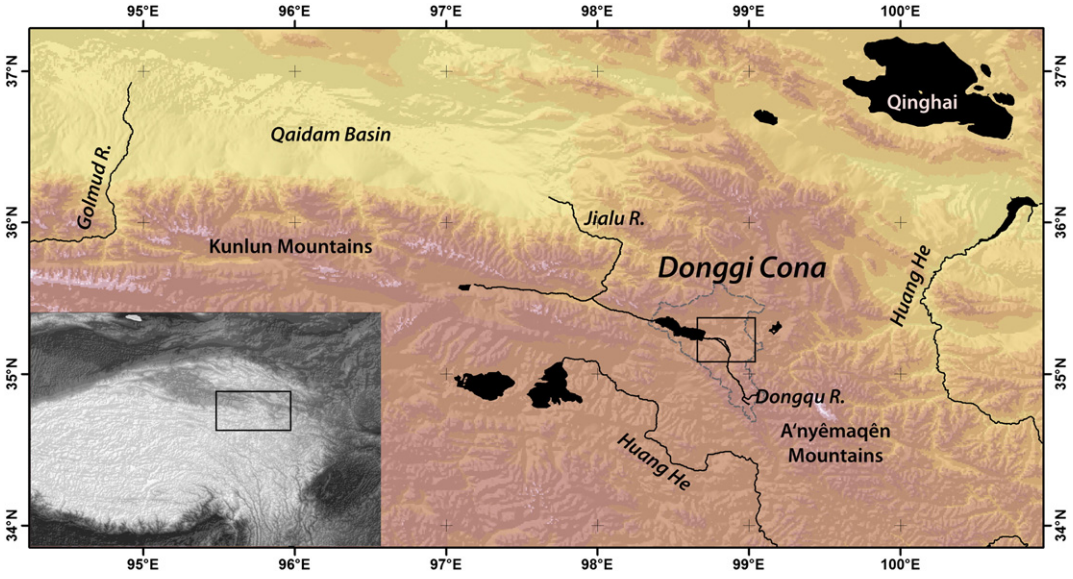

Fig. 1. Overview of NE Tibet. The study area is marked with the black box in the main figure.