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Dry periods on the NE Tibetan Plateau during the late Quaternary

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ABSTRACT

Environmental conditions on the Tibetan Plateau are changing rapidly. This study reconstructs late Quaternary environmental changes on the northeastern Tibetan Plateau based on sand deposits. The study area is located close to the present maximum extent of the East-Asian summer monsoon and is likely to register shifts in monsoon extent. Furthermore, different sediment deposits are available that allow reconstruction of sediment pathways between the different archives. Sediment deposition in the catchment is dominated by deposition of sand. Sandy deposits in the form of dune fields and sand sheets are widespread on the northeastern Tibetan Plateau and are an important archive for paleoclimatic reconstruction. This study shows that sand deposits on the northeastern Tibetan Plateau are local phenomena that still bear the sedimentological and geochemical fingerprint of their source materials. Reconstruction of transport processes in the local sediment cascade shows that local sand deposits are the main source of Tibetan mountain loess.

Six long sections were sampled and analysed for their geochemical and sedimentological characteristics, showing that both sand and loess deposits have a local source. A special focus was placed on the manganese concentration and the related environmental implications. In several sections, an increase in Mn concentration from 318 ± 44 to 878 ± 294 ppm was found, independent of concentrations in Fe and organic compounds. Since the increase in Mn is caused by solid Mn^{3+} and Mn^{4+} alone, it is interpreted as increased dust input. The synchronicity with climatic variations on the northeastern Tibetan Plateau confirms the climatic interpretation of the variations in Mn. Sand and dust transport both took place around 11 ka, followed by a period of fixation or even erosion of sediments. Although increased sand transport in the catchment already started around 3 ka, the increased dust input did not take place before 0.7 ka. Therefore, the Mn concentrations are interpreted as an indication of increased dust transport during the very late Holocene, related to colder and drier circumstances during that time.

The use of manganese as a proxy for dust is a valuable addition to the toolbox of paleoclimate reconstruction, since it is a direct proxy of dust in deposits. However, further validation and testing should be performed before general acceptance of Mn as a paleoclimate proxy in terrestrial sediments.

1. Introduction

The mean elevation of the Tibetan Plateau of 5000 m a.s.l. strongly influences the behaviour of atmospheric systems in central Asia (An et al., 2001; Boos and Kuang, 2010). The present atmospheric circulation in Asia is dominated by the westerly and monsoon wind systems (Nilson and Lehmkuhl, 2001; Sun et al., 2008). The onset of the monsoon system dates back to 6–8 Myr, based on red-clay deposits (i.e. Qiang et al., 2001) or isotopic studies, pollen, micro-organisms and loess deposits (summarized by Molnar, 2005). The evolution of the monsoon system related to the plateau uplift was described by An et al. (2001). The dominance of the different atmospheric systems varied over the past millennia, as was been recorded in Chinese loess deposits (e.g. Lu et al., 2004; Sun et al., 2008), in speleothem records from Dongge Cave (e.g. Kelly et al., 2006) and Hulu Cave (e.g. Rholing et al., 2009) and in glacial records (i.e. Yang et al., 2006, 2009). Environmental conditions on the Tibetan Plateau are changing rapidly (Qiu, 2008; Schwalb et al., 2010), as indicated by desertification (Xue et al., 2009), deglaciation (Qiu, 2008) and thawing of permafrost (Qiu and Cheng, 1995; Yang et al., 2010). Investigation of past changes is needed to gain insight in future changes. Study of past climate conditions on the Tibetan Plateau up to now mainly focused on distribution and timing of Pleistocene glaciations (e.g. Lehmkuhl, 1997a; Kuhle, 1998; Owen et al., 2003) and study of lake archives (Lehmkuhl and Haselein, 2000; Wang

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et al., 2002; Ji et al., 2005; Herzschuh et al., 2006; Shen et al., 2006; Mischke et al., 2010a, 2010b; among many others). A study summarizing several lake records on the Tibetan Plateau (Wischnewski et al., 2011) showed that there are no common regional patterns of moisture development during the Holocene on the Tibetan Plateau. However, many lacustrine studies describe a cooling trend for the Holocene (Lehmkuhl and Haselein, 2000; Wang et al., 2002; Ji et al., 2005; Herzschuh et al., 2006; Shen et al., 2006; Mischke et al., 2010a, 2010b). Some studies suggest a dry middle Holocene, but this signal might be asynchronous for the Tibetan Plateau as a whole (An et al., 2006). For example, data from Tang et al. (2000) and Zhao et al. (2011) suggest a warmer and moister middle Holocene, whereas on the central Tibetan Plateau, a general cooling trend was found (Herzschuh et al., 2006).

Variations in atmospheric circulation are the driving force behind changes in moisture availability (Chapin et al., 2008). Moisture availability influences the sediment availability in the catchment (Mischke et al., 2008) by changing the stability of the soil by influencing the vegetation cover (Nield and Baas, 2008).

The effects of climatic variations are enhanced by human impact (Klinge and Lehmkuhl, 2003; Kaiser et al., 2007; Miehe et al., 2009). Human impact has influenced the landscape of the Tibetan Plateu for a long time. Zhang and Li (2002) suggest that the area around Lhasa was already inhabited 20,000 years ago. The first indications of pastoralism are dated to the early or middle Holocene (Miehe et al., 2006, 2009; Schlütz and Lehmkuhl, 2009). Since the 1980s, the impact of grazing is increasing significantly, especially close to roads and major cities (Klinge and Lehmkuhl, 2003. Kaiser et al. (2009) suggest that a distinct portion of late Holocene sands in southern Tibet are older sands that are reactivated by grazing. Shifting sands that mainly result from over-exploration are a significant problem in central Tibet (Liu and Zhao, 2001). These recent environmental changes contribute to increasing sediment mobility on the Tibetan Plateau during the Holocene and hinder reconstruction of the paleoclimatic situation. More precise dating of the onset of human impact on the Tibetan Plateau is therefore crucial, to decipher the contribution of both climatic and human impact on the sedimentary record, as both influences can create comparable signals in the sedimentary record.

The Donggi Cona catchment is located close to the limit of the modern Asian summer monsoon (Long et al., 2010) and is therefore likely to register shifts in atmospheric circulation patterns. Furthermore, the Donggi Cona catchment is the ideal field laboratory for reconstruction of sediment transport processes as all sediment archives are present, from glacial to fluvial and from aeolian to lacustrine archives. The sediment transport pathways between different archives in the Donggi Cona catchment were described by IJmker et al. (2012). Study of sediments from the Donggi Cona lake bottom (Dietze et al., 2012) as well as local terrestrial sediments (IJmker et al., in press) shows the dominance of the aeolian sediment transport mode in the catchment. Therefore, this study describes the environmental information that can be gained from aeolian sediments with a special focus on sandy deposits, as the sandy end-members make up 69% of the sediments within our grain size dataset (IJmker et al., in press).

The Tibetan Plateau is bounded by large sand deserts at its northern edge (e.g. Badain Jaran, Taklimakan, Tengger; Yang et al., 2008), but sand on the Tibetan Plateau often represents a more local, small-scale deposit. Wang et al. (1999) described early sand deposition on the Tibetan Plateau as existing since 15 Ma, reaching a maximum impact at 8 and 6–5 Ma. After the late Pliocene, a decreasing impact of sand deposition in favour of more distal dust sources was found. This might be due to changing air circulation patterns as a result of increased Tibetan Plateau uplift around that time (Qiang et al., 2001). Major aeolian dust sources on the Tibetan Plateau are deflation of glacial outwash sediments (Sun et al., 2007), lacustrine sediments and (paleo) rivers (Lehmkuhl, 1997b). Sand on the Tibetan Plateau was studied in a broader sense in combination with loess sediments (Lehmkuhl et al., 2000). He suggested that both sediments are obtained from the same source, but are sorted due to selective transport. This results in sandy deposits within the lower catchments, close to the sediment source, while loess-like deposits are transported further and deposited at higher elevations. Sun et al. (2007) found a contrasting pattern for aeolian deposits in the Yarlung Zhangbo River valley close to Lhasa. They found climbing sand dunes and sheets on windward slopes of the mountains up to a height of 5300 m a.s.l., whereas loess deposits were found at lower elevations. Jin et al. (2007) described three major phases of aeolian sand deposition along the Qinghai-Tibet Highway, being the late Pleistocene, the early Holocene and recently, accelerating since the Little Ice Age (Jin et al., 2007).

The present study investigates the character of sand deposits in a lake catchment on the northeastern Tibetan Plateau. Questions that need answering, are i) do the aeolian sediments in the Donggi Cona catchment have a local or a regional source? ii) does the sedimentary record show indications of temporal variations, pointing towards climate change? iii) which parameters can be used to reconstruct past environmental variations? iv) how do these local variations fit into the regional climate development?

2. Study area

The Donggi Cona lake catchment (Fig. 1) is located on the northeastern Tibetan Plateau (35°18'N, 98°32'E, 4090 m a.s.l.) and is also known as Dongxi Co (Van der Woerd et al., 2002) or Tuoso Hu (Fu and Awata, 2007). The lake is located on the Kunlun Fault, a fault system that allows left-lateral strike-slip movement of the Tibetan Plateau in eastward direction. The Donggi Cona catchment covers 3174 km^2; the lake has a total surface of 229 km^2 and a maximum depth of 92 m (Dietze et al., 2010). The northern and south-eastern part of the catchment are characterised by high relief (elevations up to 5,230 m). U-shaped valleys and moraines point to past glacial activity. At elevations lower than 4800 m a.s.l., V-shaped fluvial valleys are found.

At its south-eastern bank, the lake is bordered by a mountain ridge consisting of Permian carbonate rock. The apex of a large alluvial fan depositing in the direction of the lake, is located at the eastern end of the ridge. The upper fan consists of fluvial gravels with a depth of 2.5 m (Jin et al., 2007) covered with a thin silty to sandy layer (10–100 cm). The lower part of the fan is flat and was part of a former lake (IJmker et al., 2012). Past lake level changes below the present water level were described by Dietze et al. (2010). Higher lake level stands are suggested by several beach ridges, terrace levels and geochemical anomalies (IJmker et al., 2012; Lockot, 2011). The northern border of the alluvial fan is formed by Triassic limestones and sandstones (Wang et al., 2001; Wang and Yang, 2004). These rocks are faulted against Triassic black to green shales and partly overlain by Neogene conglomerates. As a result of the geological situation, the northern banks are consist of mild slopes and alluvial fans, whereas the southern banks consist of steep slopes made up from carbonate rock. The highest peaks in the north-western part of the catchment are formed by Permian intrusions. Outflow from the lake is directed through an artificial channel at the lake's western end. The water level is controlled by a gauge station at the channel entrance that was built during the 1970s. The water is drained towards the endorheic Qaidam Basin.

The lake is located close to the western limit of the East-Asian monsoon system, so the climate is controlled by both monsoon in summer and extra-tropical westerlies and winter monsoon in winter (Domrös and Peng, 1988; An et al., 2001; among others). Local climate conditions were obtained from the climate station at Madoi, 50 km southeast of the lake at 4272 m a.s.l. (measurements from 1958 to 2007, Chinese Meteorological Office, 1984). The area can be