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Multi-decadal periods of enhanced aeolian activity on the north-eastern Tibet Plateau during the last 2ka

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A R T I C L E I N F O

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A B S T R A C T

The north-eastern Tibetan Plateau is regarded as key area for the understanding of the Holocene paleoclimate in central Asia. During the last decade a special emphasis has been placed on multi-decadal to millennial scale climate fluctuations, especially in the context of the recent climate change. However, most reconstructions are based on lake sediments, tree rings and speleothems whereas only little information from terrestrial archives is included. This study presents multi-decadal scale climate fluctuations based on optical stimulated luminescence (OSL) ages from aeolian sediments from three catchment areas. Six phases of enhanced aeolian accumulation during the last 2000 years, each lasting around 80–200 years were identified. The first three phases (1630–1725 CE, 1450–1530 CE and 1250–1350 CE) occurred during the Little Ice Age; the other three (750–950 CE, 390–540 CE, 50–225 CE) during the so-called dark ages cooling. Aeolian processes were strongly reduced during the medieval climate anomaly. A comparison with other proxy records indicates that the formation of aeolian archives on the north-eastern Tibetan Plateau during the late Holocene is facilitated by cool and dry climate conditions during times of weaker Asian Summer Monsoon and probably enhanced westerlies. The results show that short term climate fluctuations can be reconstructed from non-continuous and heterogeneous terrestrial archives in a semi-arid environment, provided a sufficient number of OSL ages from aeolian sediments is available.

1. Introduction

Multi-decadal to millennial scale climate variations have gained increasing interest in the recent years (e.g. Mayewski et al., 2004; Wanner et al., 2011; Pages 2k Consortium, 2013). Frequent climate fluctuations during the Holocene have been recorded in marine sediments (Bond et al., 1997, 2001; Jennings et al., 2002; de Vernal and Hillaire-Marcel, 2006), lake sediments (Noren et al., 2002; Jones et al., 2006; Geirsdóttir et al., 2013; Hildebrandt et al., 2015), speleothemes (Fleitmann et al., 2003; Wang et al., 2005; Dykoski et al., 2005; Zhang et al., 2008; Baker et al., 2015) or glacial deposits (Denton and Karlén, 1973; Solomina et al., 2015) in many regions around the world. The understanding of the causes and consequences of these short term climate fluctuations are crucial in the context of the recent warming. However, global reconstructions of temperature and precipitation revealed no coherent results for the entire Holocene (e.g. Mayewski et al., 2004; Wanner et al., 2011) and indicate substantial spatial and temporal differences for the last 2000 years (PAGES 2k Consortium, 2013).

The north-eastern Tibetan Plateau (TP) has been identified as an especially climate sensitive region due to its location at the northern boundary of the Asian summer monsoon (Indian Summer Monsoon and East Asian Summer Monsoon) and the mid-latitude westerlies (e.g. Böhner, 2006; Chen et al., 2010; Henderson et al., 2010; An et al., 2012) (Fig. 1). Previous climate reconstructions mainly focused on the timing and strength of the monsoonal influence in the area during the entire Holocene (Herzschuh, 2006; An et al., 2012; Wang et al., 2014a). During the global last glacial maximum (gLGM) and Lateglacial times the influence of the moisture bearing Asian summer monsoon was weak. During the early and middle Holocene the Asian summer monsoon reached its maximum and declined during the late Holocene (Wang et al., 2008, 2010; Liu et al., 2015). These long term climate changes are related to orbital variations leading to changes in summer insolation at low latitudes which in consequence drive the Asian monsoon system (Kutzbach, 1981; Shi et al., 2011; Sun et al., 2015). During times of a weaker monsoon the influence of the westerlies

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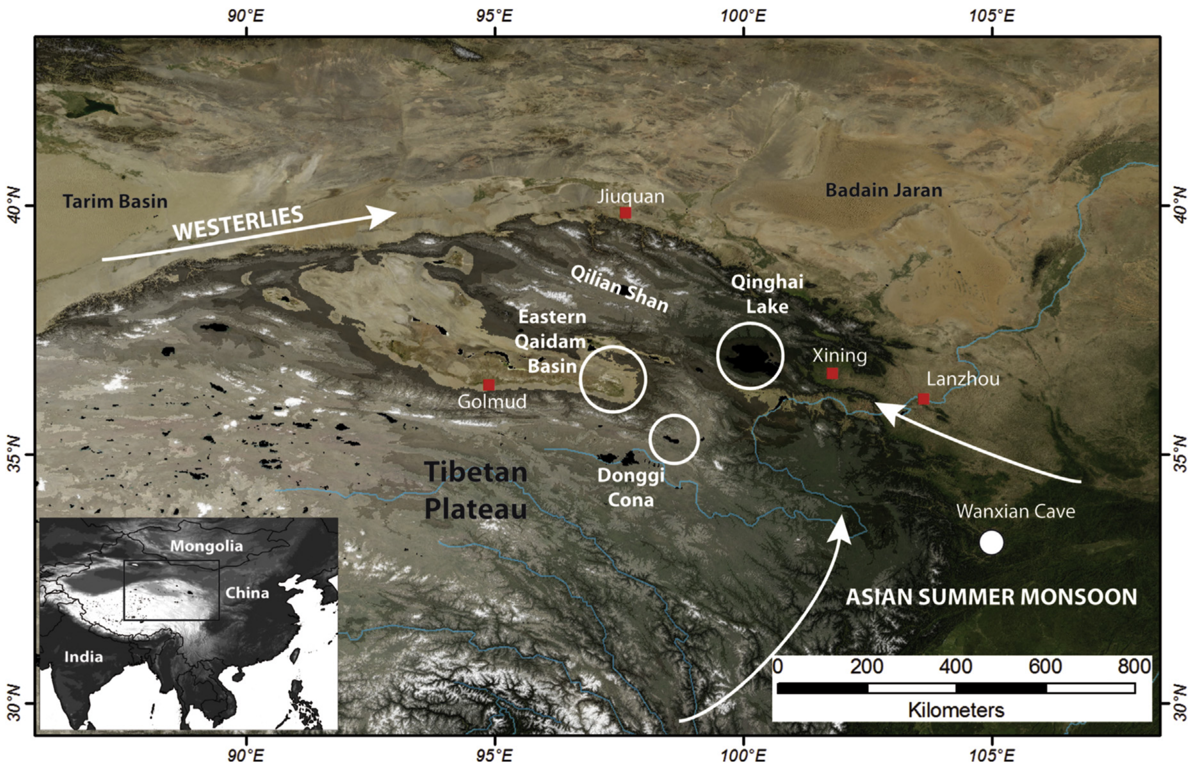

Fig. 1. The north-eastern Tibetan Plateau, main atmospheric systems and the three areas with OSL ages for this study (Qinghai Lake, Eastern Qaidam Basin and Donggi Cona). Data source background image: Blue marble next generation – NASA Earth Observatory (Stöckli et al., 2005). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

was presumably stronger (e.g. Porter and An, 1995; Stevens et al., 2007; Jin et al., 2015; Zhu et al., 2015). Beside these orbital induced changes several reconstructions of Holocene climate identified millennial scale variations in the strength of the Asian Summer monsoon in East Asia (Hong et al., 2003; Wang et al., 2005, 2008; Yu et al., 2006; Li et al., 2015) and on the north-eastern TP (Mischke and Zhang, 2010; An et al., 2012; Yang et al., 2014). However, there is still considerable difference between the reconstructed timing of the different short-term events during the late Holocene. This is related to uncertainties in proxy interpretation (e.g. Wischnewski et al., 2011; Yan and Wünnemann, 2014) and problems with the established chronologies. Many reconstructions are based on proxies from lake sediments. Radiocarbon dating on lake sediments from the TP is frequently influenced by the reservoir effect due to the input of old carbon in the hydrological system. The amount of the reservoir effect varies between lakes and even between studies from individual lakes (Long et al., 2011; Hou et al., 2012; Mischke et al., 2013). Therefore further proxies have to be established for the reconstruction of Holocene climate variations on the north-eastern TP (e.g. Li et al., 2015).

Aeolian sediments on the north-eastern TP are a suitable indicator for palaeoclimate reconstructions (Lehmkuhl et al., 2000; Madsen et al., 2008; Liu et al., 2012; Stauch et al., 2012; Yu and Lai, 2012; Stauch, 2015). Aeolian sediments can be dated directly by OSL (optical stimulated luminescence), which captures the timing of the accumulation and burial of the aeolian sediment grains (Wintle, 2008). Palaeoclimate reconstructions from aeolian sediments are mainly based on sedimentological proxies requiring interpolation between the dated parts of the individual sections (Yu et al., 2006; Liu et al., 2013; Lehmkuhl et al., 2014). However, many terrestrial sections on the north-eastern TP are affected by varying accumulation rates and non-continuous accumulation (Qiang et al., 2013; Stauch et al., 2014; Yu et al., 2015) leading to large age uncertainties for the sediments between the obtained ages. This also obstructs in many cases the determination of detailed accumulation rates for individual sections. The number of available OSL ages of aeolian sediments from the north-eastern TP has been rapidly increasing in the recent years. By now, the dataset is large enough to apply a different approach that relies solely on OSL ages, thus avoiding any data interpolation between individual dating points (Lang, 2003; Stauch, 2015).

This study analyses aeolian sediments from different regions of the north-eastern TP for the last 5000 years with a special focus on the last 2000 years. The dataset is evaluated regarding its potential to reveal multi-decadal to multi-centennial climate fluctuations. Subsequently the phases of high and low aeolian accumulation are interpreted in the context of the different forcing mechanisms, such as monsoonal intensity and the strength of the westerlies.

2. Study area

The north-eastern Tibetan Plateau (Fig. 1) is characterized by large intramontane basins at elevations between 3000 and 4000 m above sea level. The surrounding mountains reach elevations of more than 5000 m and are partially glaciated. The formation of the basins started at around 10 to 15 Ma ago (Zhang et al., 2012; Hetzel, 2013). Major fault-lines like the Kunlun fault have a profound influence on the landscape (Van der Woerd et al., 2002; Fu and Awata, 2007). Large earthquakes with magnitudes (M) of more than seven occur (Guo et al., 2007). The present-day climate in the basins is semi-arid with annual precipitation between 160 mm in the eastern Qaidam Basin and 300–400 mm at the Qinghai Lake (Liu et al., 2011; Yu and Lai, 2012), reflecting the reduced influence of the Asian Summer Monsoon from the East to the West. Aeolian