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Holocene climatic change and the nomadic Anthropocene in Eastern Tibet: palynological and geomorphological results from the Nianbaoyeze Mountains

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ABSTRACT

Our study provides detailed information on the Lateglacial landscape and vegetation development of Tibet. Based on a suite of geomorphological and palynological proxy data from the Nianbaoyeze Shan on the eastern margin of the Tibetan Plateau (33°N/101°E, 3300–4500 m asl.), we reconstruct the current state as a function of climate history and the longevity of human influence. Study results constrain several major phases of aeolian sedimentation between 50–15 ka and various glacier advances during the Late Pleistocene, the Holocene and the Little Ice Age. Increased aeolian deposition was primarily associated with periods of more extensive glacial ice extent. Fluvial and alluvial sediment pulses document an increase of erosion starting at 3926 ± 79 cal yr B.P., coinciding with cooling (Neoglacial) and a growing anthropo-zoogenic influence. Evidence for periglacial mass movements indicate that the late Holocene cooling started at around 2000 cal yr B.P., demonstrating increased surface activity under the combined effects of human influence and climate deterioration. The onset of peat growth generally depended on local conditions that include relief, meso-climate and in more recent times also on soil compaction due to animal trampling. We distinguish three initiation periods of peat growth: 12,700–10,400 cal yr B.P. for flat basins inside last glacial terminal moraines; 7000–5000 cal yr B.P. for the main valley floors; and 3000–1000 cal yr B.P. for the higher terrace surfaces.

The Holocene vegetation history started with an open landscape dominated by pioneer shrubs along braided rivers (<10,600–9800 cal yr B.P.), followed by the spreading of conifers (*Picea*, *Juniperus*, *Abies*) and *Betula*-trees accompanied by a successive closing of the vegetation cover by Poaceae, Cyperaceae and herbs (9800–8300 cal yr B.P.). First signs of nomadic presence appear as early as 7200 cal yr B.P., when temperatures were up to 2 °C warmer than today. Forest remained very patchy with strong local contrasts. During the following cooling phase (5900–2750 cal yr B.P.) the natural vegetation was transformed by nomadic grazing to *Bistorta*-rich *Kobresia pygmaea*-pastures. Modern nomadic migration routes were established at least 2200 years ago. Overgrazing and trampling led to the shrinking of *Bistorta* and the spreading of annual weeds. Short-lived cold events (8000, 6200, 3500 cal yr B.P.) impacted on the vegetation only temporarily.

As the transformation of the natural Poaceae-rich vegetation into *Kobresia*-pastures modified the influence of the Tibetan Plateau ("hot plate") on the monsoon system, our data even point to an early start of a nomadic (!) Anthropocene nearly 6000 years ago. Against the background of a very long grazing history, modern Tibet must be seen as a cultural landscape.

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1. Introduction

The Tibetan Plateau and bordering mountains occupy an area of ca 2.2×10^6 km^2. With an average elevation of more than 4500 m asl and the largest glaciated area outside the Polar Region it plays an important role in regional and global atmospheric circulation. The Plateau and the bordering mountain ranges are influenced by five major climatic systems: the mid-latitude westerlies, the South and East Asian monsoons, the Siberian high-pressure system and the El Niño Southern Oscillation (ENSO). The relative importance of each system as a moisture and heat source varies throughout the region, with the eastern fringe of Tibet and the southern slopes of the Himalaya being the wettest (e.g. Böhner, 1996). The interplay of atmospheric forces over the plateau and their relationship to the broad climate shifts of the Pleistocene and

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Holocene periods are important for understanding the dynamics of global change (Ruddiman and Kutzbach, 1989; Prell and Kutzbach, 1992). One of the most direct effects of the high altitude and aridity of the Tibetan Plateau is the atmospheric warming in spring and summer enhancing monsoon dynamics.

For a long time scientists have considered vegetation distribution and dynamics in the remote and sparsely populated parts of the Tibetan Plateau as a result of climatic influences only, thereby neglecting the possible role of human influence (Guo, 1993; Fang et al., 2002). Even pollen spectra of surface samples have been analyzed in terms of the recent climate only (Shen, 2003; Shen et al., 2006) and fossil pollen spectra are interpreted primarily as indicative of past climate change (Gasse et al., 1991, 1996; van Campo and Gasse, 1993; van Campo et al., 1996; Liu et al., 1998; Lingyu et al., 1999; Shen et al., 2006; Herzschuh et al., 2006b).

No doubt, the vegetation history of Tibet reflects climatic changes with correlations to global patterns (Gupta et al., 2003; Hong et al., 2003; Feng et al., 2006; Herzschuh, 2006; Yu et al., 2006), but development and species composition of the vegetation is not less sensitive to herbivores. The impact of grazing, trampling and fences on the vegetation is shown by many ecological studies in several parts of High and Central Asia (Li et al., 1984; Tsuyuzaki et al., 1990; Holzner and Kriechbaum, 2000; Fernandez-Gimenez and Allen-Diaz, 2001; Du et al., 2004; Shang and Long, 2005; Wei et al., 2005; Miehe et al., 2006, 2008). Human utilization as a driving factor for landscape development is a global phenomenon resulting in largely domesticated ecosystems (Kareiva et al., 2007). Even naturally appearing vegetation is often not pristine (Willis et al., 2004). With the development of the Tibetan nomadic culture the natural grazing system with only wild herbivores was transformed over thousands of years into a more and more anthropo-zoogenic system, leading to the dominance of domesticated herds. This was already highlighted through the work of Thelaus (1992) and Frenzel (1994) who used palynological data from the Zoige Basin 100 km NW of the Nianbaoyeze Shan to date the onset of nomadic influences to at least 4500 cal yr B.P. (Thelaus, 1992) and 5800 cal yr B.P. (Frenzel, 1994). Based on a variety of ecological and palaeoecological sources the essential role of the Tibetan nomads in the history of vegetation and landscape has been found in several studies (Miehe et al., 1998, 2006, 2007, 2008; Kaiser et al., 2006, 2008). The present ecosystems are a snap shot of thousands of years of co-evolution of plants, animals and humans under the specific climatic conditions of the Tibetan Plateau (Miller, 1999a,b; Tolvanen, 2001). During the last half of the 20th century the ecological equilibrium has undergone vast changes through livestock grazing (Miller, 2005). It is worth to stressing that anthropo-zoogenic vegetation changes have feedbacks with the climate system as well (Li et al., 2002; Du et al., 2004).

To understand the roles of climate and human impact, we undertook a systematic study using palynological and geomorphological methods on the eastern margin of the Tibetan Plateau, in the Nianbaoyeze Shan region (=Nianbaoyeze Mountains, Fig. 1). Resulting palynological reconstructions allow us to examine the relationship between vegetation, human impact, and climate change. The area of the Nianbaoyeze Shan was selected as this mountain system is situated on the absolute western most limits of modern forests, which stretch from the Chinese lowlands into our study area (Fig. 2). Because of the proximity to the modern forest margin the vegetation in this region is highly sensitive to changing conditions of climate and human influence. Our investigation focuses on geomorphic mapping and the detailed analyses of selected peat cores. The area and study locations of all sections are shown in Fig. 1. The high spatial resolution employed allows us to address the interplay of climate change and human impact during the Holocene in detail.

Geomorphological and palynological records were obtained during several joint Chinese–German expeditions starting in 1991. In addition to geological and geomorphological fieldwork, 16 peat cores were taken from the Nianbaoyeze Shan area ranging in altitude between 3870 and 4170 m asl. Here we present a selection of pollen data that focus on (1) the Holocene vegetation history in altitudes of around 4000 m asl, (2) the interplay of climate and early human influence, (3) the local differentiation of vegetation development in this specific ecotone with forest relicts in alpine sedge mats under nomadic use. We investigated various geo-archives, those that are mostly independent from nomadic land use – such as glacier activity – and those probably heavily influenced by climate change and/or overgrazing, like buried soils.

2. Regional setting

The Nianbaoyeze Shan is the easternmost part of the NW–SW trending Bayan Har Shan. The granite dome of Nianbaoyeze (about 820 km^2 in area, see Fig. 1) is situated at the main water divide of the Huang He and Yangtze River systems. With the highest peak at 5369 m, it rises about 500–800 m above the surrounding peneplain (“main surface” cf. Lehmkuhl and Spönemann, 1994). Pleistocene glacial landforms such as moraines, cirques, and U-shaped valleys are well-developed. Moraines that chiefly consist of granites and widespread granitic erratics from the Nianbaoyeze batholith clearly mark the extent of multiple Pleistocene glaciations. Loess deposits of several decimeters thickness accumulated especially in basins below 3400 m, e.g. the Basin of Aba. The higher areas up to the boundary of alpine meadows between 3500 and 4300 m asl are covered by about 50–60 cm of sandy silt of aeolian origin (Lehmkuhl and Liu, 1994; Lehmkuhl, 1995).

A small modern glacier around the highest summit covers an area of about 5.1 km^2. The present snowline (ELA = equilibrium line altitude) is calculated to be at an average elevation of 5100 m. The climate is controlled by the East Asian and South Asian monsoon from May to October delivering 80% of the total annual precipitation. The very dry winter with a monthly precipitation of less than 10 mm is due to the winter monsoon which in turn is controlled through the Siberian High. For precipitation and temperature distribution in the area see Fig. 3. In general, there is a decrease of annual precipitation from more than 1000 mm at the south-eastern margin of the Tibetan Plateau in the Sichuan Basin towards the west to about 300 mm in Madoi (4272 m asl) on the NW Tibetan Plateau. In the Nianbaoyeze area climate data are limited but local authorities have reported an annual precipitation of 975 mm in the S part and 582 mm in the NW part (Lehmkuhl and Liu, 1994). The average vertical gradient of temperature is about 0.55 °C/100 m (Domrös and Peng, 1988; Böhner, 1996, 2006). On higher areas of the plateau the mean annual temperature (MAAT) is 0.1 °C in Jiuzhi (3629 m asl, NE margin of Nianbaoyeze). Aba (3275 m asl, SE of Nianbaoyeze) is a warmer region (MAAT 3.2 °C) within the coniferous forest zone (Figs. 2 and 3) which was severely decimated by logging after World War II. Agriculture, mainly barley, is practiced to altitudes of up to 3300 m in the Aba Basin. In Jiuzhi there are 10 months of possible snowfall and no frost-free month. The ground surface is frozen for nearly half the year.

The vegetation in Western Sichuan, from the Sichuan Basin towards the Tibetan Plateau, is one the most diverse in the holarctic region (Mutke and Barthlott, 2005). Several centuries of intensive land use have changed the natural vegetation. At lower elevations forests have been converted into agricultural land and in the upper regions into pastures. The number of species decreases with higher altitudes and in a NW direction due to precipitation and temperature reductions. There is a clear differentiation between N- and S-facing slopes due to solar radiation.

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