How old is pastoralism in Tibet? An ecological approach to the making of a Tibetan landscape

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ABSTRACT

The Tibetan highlands host one of the world's largest pastoral ecosystems, but the evolutionary impact of the Tibetan nomadic livestock economy on the environment has not yet been investigated. Despite this grazing impact, the vegetation of the Tibetan highlands is widely believed to be natural. Our ecological approach to reconstructing the making of a pastoral environment uses the present composition of the plant cover as a baseline. Today's prevailing plant functional types are grazing weeds highly adapted to grazing. The first pollen record of grazing weeds can thus be assumed to mark the onset of pastoralism, supposedly with goats and sheep introduced from the Middle East and the endemic large bovid of the yak, domesticated in the Tibetan highlands. This study represents the first attempt to determine the age of pastoralism with the help of palynomorphs using the indicator-species approach. This is independently corroborated 1) by the synchronous occurrence of pollen clumps indicating disturbance effects from trampling and 2) the precipitous decline of forest pollen on the eastern declivity of the highland during the mid-Holocene climatic optimum. As all pollen core sites currently have a climatic potential of forest as demonstrated by fruiting and progenitive forest relicts, it is suggested that early livestock holders continued to burn these forests to obtain pastures. The charcoal record supports this conclusion. It is hypothesized that the making of a pastoral environment in the Tibetan highlands started around 8.8 ka cal BP during the mid-Holocene climatic optimum. As the pattern of arboreal pollen decline at these sites contrasts with δ^{13}C, δ^{18}O, TOC content, C/N ratio, and ostracod assemblages that are independent of rangeland management decisions of early pastoralists, we may conclude that pastoralists took advantage of the mid-Holocene climatic optimum to convert forests into high-yield pastures. Using pollen clumps as a proxy for herbivore load suggests a tenfold higher amount of livestock than of wildlife before the introduction of pastoralism. In contrast to pastoralism in arid environments of the Old World's desert belt, pastoralists in the eastern Tibetan highlands created their own environment transforming forests and tall grassland into the present golf course-like pastures.

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1. Introduction

1.1. Does the question matter?

Tibet is nothing but a grazing land (Ward, 1947). This statement by one of the most experienced early European travellers in Tibet underscores the role of the world's largest highlands as host to one of its largest pastoral ecosystems. The age of Tibetan pastoralism, however, is virtually unknown. The main grazing areas of the southeastern plateau are dominated by vast, golf course-like Cyperaceae mats covering approx. 450,000 km² (Fig. 1). The area of this vegetation type roughly demarcates the northern extension of the monsoon climate. Despite its remoteness and low population density, the Tibetan pastoral ecosystem gains supra-regional importance due to its importance as a huge, intensive and elevated heat source with strong, sensitive surface heating in the surface layers in summer (Duan and Wu, 2005) as well as in winter (Blanford, 1884; Kuhle, 2001) or in general (Webster et al., 1998). Any changes in surface properties thus affect the radiation feedbacks of the plateau, with global consequences. The plateau is thus of more than just regional palaeo-ecological or anthropological interest, and the crucial question of how long the environmental impact of humans has had global feedback effects (see Gaillard et al., 2000) is most probably nowhere more rewarding than in Tibet (Cui et al., 2006, 2007). Therefore the answer to the question of the age of pastoralism in Tibet can be seen in the wider context of investigations attempting to shed light on the

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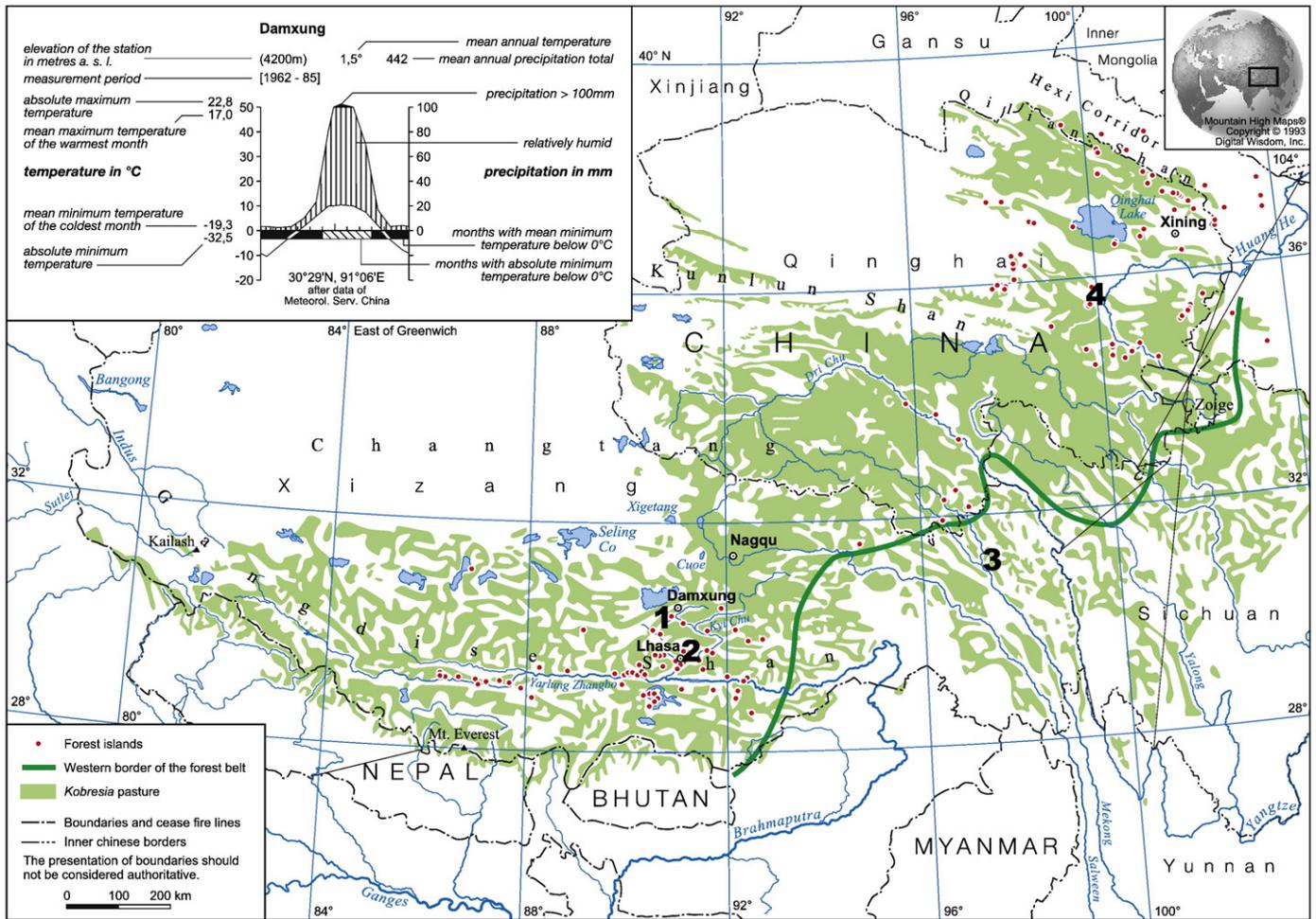E-mail address: miehe@staff.uni-marburg.de (G. Miehe).

Fig. 1. Location of the drilling site (1) in the *Kobresia* pastures of the Tibetan highlands (after Miehe et al., 2008c) with isolated forest relicts (black dots, after Miehe et al. subm.) and the climatic diagram of Damxung (after Miehe et al., 2001). Archaeological sites: Qugong (2), Karuo (3), Zongri (4).

dawn of the 'Anthropocene' (Crutzen and Stoermer, 2000; Ruddiman, 2003). Despite overwhelming field evidence and increasing archaeological evidence of early human presence (e.g. Brantingham et al., 2007), there is a persistent mainstream belief that the vegetation of the Tibetan highlands is natural (e.g. Ni Jian, 2000; Song et al., 2004). Our own surveys of the last two decades, however, allow us to confirm with certainty Ward's statement that the pastures of Tibet are synanthropic replacing forest and grassland. The question is since when? In searching for an answer, we link current ecological indicator values of plants with palynological and pedological analyses. This is new for Tibet and was made possible only by the cooperation of palaeo-ecology (F. Schlütz and La Duo), biogeography (G. and S. Miehe) and pedology (K. Kaiser).

1.2. The pastoralism state of the art

In the Old World's desert belt, migratory systems of the majority of nomadic societies are an adaptation to the unreliable forage resources of an arid environment. In this part of the Tibetan Plateau, pastoralism in contrast is an adaptation to a cold environment at elevations above the limit of cultivation. Thus, apart from hunting, mobile livestock keeping of sheep, goats, and yak forms the sole means of livelihood.

The yak was of highest importance in the valorization of the plateau and without yaks the Tibetan nomadism would never have been possible (Ekvall, 1968; Zhao and Zhou, 1999; Rhode et al., 2007). A seasonal shifting of pasture areas is essential, because food harvest is low due to the climatic deficits. At the transition between the

equilibrium system of the humid eastern plateau and the non-equilibrium system of the semiarid alpine steppes in the northwest, pasture shifting may also be constrained by regional shifts of the precipitation regime. In this area, *Kobresia schoenoides* swamps offer the only possibility for the survival of the herds during winter and early spring. Additionally *K. schoenoides* and *Urtica hyperborea* are cut as winter-feed (Behrendes, 2008). The study area has always been a major centre of pastoralism (Clarke, 1998). Up to the late sixties of the 20th century, the whole area was occupied by nomadic or semi-nomadic herders.

Up until the Chinese accession to power, migratory herders formed part of the semi-feudal tribute system being hereditarily tied to certain grounds and the respective feudal landowner, while the herds were owned by the respective households. Butter represented the main tribute, supplemented by meat, skins, pelts, wool, animals and salt. Any surplus remained the families' property (Goldstein and Beall, 1991). Mobile cattle ranching formed a complex social system, and the herders, despite their dependencies, were involved in the decision processes regarding livestock production (Sheehy et al., 2006).

Since being taken over by the People's Republic of China, the mobile cattle ranching system has been transformed several times. These transformations took place in different regions at different times and with varying intensity (Levine, 1998; Yeh, 2004). The process was accompanied by various programs to increase production (Sue, 1990; Goldstein and Beall, 1991; Clarke, 1998; Levine, 1998; Wu, 1999), the destruction of traditional trading systems (Foggin and Smith, 1996), sedentarisation programs (Goldstein et al., 1990; Levine,

1998; Yeh, 2003; Bauer, 2005), as well as a shift in herd compositions and reduction of livestock densities (Wu, 1999; Ho, 2001; Sheehy et al., 2006).

Most of the herders of the Tibetan highlands now live in permanent dwellings situated in the winter and springtime grazing areas (Sheehy et al., 2006). The traditional, predominately seasonal mobility is now frequently hampered by ground fencing and privatization. While in some regions possible sidelines are utilized, in other regions cattle ranching has been abandoned completely (Wu, 1999; Yeh, 2003).

1.3. The grazing ecology state of the art

Even if we take it for granted that the southeastern Tibetan Plateau is a pastoral ecosystem, it remains uncertain whether the present species composition and dominant plant life forms are exclusively caused by livestock. Large herds of wild yak, Tibetan gazelles, antelopes, Tibetan wild ass (kiang), Marco Polo sheep (argali) and blue sheep (bharal) co-existed with livestock until the 1950s (Schaller,1998). Thus, Tibetan pastures could have been similarly influenced by wildlife as is assumed for African savannas (McNaughton, 1984), North American grasslands (Craine and McLauchlan, 2004), the tundra of northeastern Siberia (Zimov et al., 1995) or Ireland (Bradshaw and Mitchell, 1999). Their immense numbers may have grazed in a similarly selective way to today's livestock when managed in a free range grazing system. The effect could be the same, a long-lasting selection process, skimming off the preferred forage plants and conferring advantage on disliked plants and those too small to be bitten off.

A further ambiguity is to what extent the current grazing levels of livestock exceed the historic grazing impact of large wild herbivores. To date we have no tools that can provide even a rough estimation for our area. The postulation of a tenfold larger livestock load of a pastoral system for the plateau compared with wildlife like in African savannas remains purely speculative, following Oesterheld et al. (1992, Fig. 1).

1.4. The archaeological state of the art

Domestication preceded pastoralism, yet the origin and age of pastoralism in general is still a matter of dispute (Scholz, 1995). For the larger parts of the Old World's desert belt the consensus is that migratory livestock economy ("nomadism") diverged from sedentary agricultural livestock keeping societies (Scholz, 1995). In Central and High Asia, however, we cannot rule out the possibility that migratory complex foragers were the first to select the yak for domestication. To date it remains totally unknown if and when Tibetan pastoralism evolved from agricultural sedentary societies or from complex foragers. Moreover, nearly all archaeological determinations of early domesticates in China are doubtful (Flad et al., 2007). However, palaeolithic tools from the Changtang, although of uncertain ages (including 30 ka cal BP, 24.2 to 15.8 ka cal BP, 8.2 to 6.4 ka cal BP, Brantingham et al., 2007) provide evidence of human presence possibly even during the Last Glacial Maximum. It is thus probable that humans have been present for any climate-driven environmental changes since then. These earliest forager groups might have had an impact on the environment through hunting techniques including fire, yet the supposed desert steppes of the LGM (Shen, 2003; Herzschuh et al., 2006a) probably did not have enough biomass to carry fire. Thus, the earliest human-induced changes may not be expected before the onset of a humid monsoon-driven climate with closed vegetation cover, be it forb-rich grassland, thickets or closed forest. In contrast to the archaeological evidence of humans on the plateau and the connected fire record, there is to date not a single piece of evidence to determine the age of pastoralism on the Tibetan highlands.

Of the four domestic animals of Tibetan pastoralism (sheep, goat, horse, yak), the first two were introduced from the Middle East. The

pathways and timing of the introduction are however completely speculative (Flad et al., 2007; Aldenderfer, 2007). Horses had been domesticated in the grasslands of Central Asia (Parzinger, 2006), possibly including those areas which are today under Chinese administration (Flad et al., 2007). The yak, the most important animal of Tibetan pastoralism, is endemic and was most probably domesticated here too. The archaeological record, however, has proven to be soberingly scant (Olsen, 1990) and conclusions from molecular evidence are complex (Guo et al., 2007).

Archaeo-zoological findings from the highlands proper are lacking to date. The earliest, albeit doubtful archaeo-zoological evidence of domesticates stems from an area near Xian from a sedentary economy dating back to 6.9–5.8 ka cal BP (Flad et al., 2007: 185). The site is approx. 4000 m lower than our study site and 1800 km farther to the east. Closer to the highlands, remains of the Zongri culture have been found near the middle reaches of the Huang He in Xinghai County (Fig. 1:4) approx. 2500 m lower than our study site and 1000 km to the northeast. The sedentary Neolithic site, dated between 5.6 and 4.0 ka cal BP, contained sheep and bovids, but again the identification has been questioned (Flad et al., 2007: 182). The best known Neolithic site in Tibet is Karuo (Fig. 1:3; Chayet, 1994; Aldenderfer and Zhang, 2004; Flad et al., 2007), 1100 m lower than our site on the eastern declivity near Qamdo and 600 km to the east, which is dated between 5.1 and 3.5 ka cal BP. The report, however, does not list sheep or goats, only unidentified bovids. The second Neolithic site known from Tibet is a sedentary settlement as well, only 90 km south of our site and 600 m lower, at 3680 m in the northern outskirts of Lhasa (Fig. 1:2), dated between 3.75 and 3.1 ka cal BP. It is the only site so far with a reliable sheep record and a record of domesticated yak (Flad et al., 2007). Summing up, we must say that there is not a single archaeological record of pastoralism from the highlands proper; reliable records of domesticates have only been found in the valleys of the southern and eastern declivity, and all date to 4 ka cal BP or later.

1.5. The palynological state of the art

The palynological evidence is ambiguous because it records only secondary effects of pastoralism, i.e. changes in the vegetation cover caused by humans and grazing livestock. In most cases this relates to forest clearing by fire in order to gain luxuriant grassland for livestock grazing. It has been possible to reconstruct the making of the agropastoral landscape in Europe by means of comprehensive ecological, palynological and archaeological knowledge using the "Indicator-Species Approach" (Behre, 1981; Berglund, 1991; Gaillard, 2007). In general, an in-depth reconstruction of Tibet's environmental past has been hindered by a limited knowledge of pollen and Non Pollen Palynomorphs. This is especially true for the determination of human indicator pollen. Only recently have pollen clumps been included in the analyses. Pollen clumps have hitherto been interpreted as being a product of climatic conditions. Herzschuh et al. (2006a: 115) see pollen clusters only in the climatic context of unfavourable growing conditions as suggested by Demske and Mischke (2003). By contrast, Schlütz in Schlütz and Lehmkuhl (2007) considers mechanical stress by trampling and grazing to be the main factor causing pollen clumps in turf profiles.

Palynological analyses from the Tibetan Plateau have so far only been used to confirm, at a regional level, the widely accepted climate-driven environmental changes of the younger Quaternary (e.g. Kelts et al., 1989; Sun and Chen, 1991; Yan et al., 1999; Tang et al., 2000; Shen, 2003; Shen et al., 2005; Herzschuh et al., 2006a,b; Wu et al., 2006; Herzschuh, 2007; Zhu et al., 2008). The only exceptions are two pollen diagrams from the outer northeastern declivity (Zoige basin) at 3500 m (Thelaus, 1992; Frenzel, 1994). They concede a human-caused decrease of arboreal pollen after 4 to 5 ka cal BP. Charcoal particles are not considered. Recently, Ren (2007) discussed a forest decline after 6 ka cal BP which may have been caused predominantly by humans.

Superimposed effects of climate and humans were suggested as explanations for the forest decline in the eastern Tibetan Plateau, Inner Mongolia and the Loess Plateau after 2 ka cal BP (Zhao et al., 2007).

In the treeline ecotone of arid southern High Asia the forest pollen decline between 5.7 and 5.4 ka cal BP, followed by first appearance of human indicator pollen, was described for the Hindu Kush of northern Pakistan (36°23'N/73°07'E; Miehe et al., 2009.), central northern Nepal (28°49'N/83°51'E; Miehe et al., 2009.) and for Lhasa in the Transhimalaya of southern Tibet (29°40'N/91°04'E; Miehe et al., 2006). In all three sites the present hedgehog-like open dwarf shrublands replace *Pinus wallichiana* and *Juniperus* forests or woodlands. Concomitant with the forest pollen decline, spores of forest ferns disappeared and *Riccia* spores appeared, which stand for liverwort carpets sealing open soil surfaces. So far the following human indicator pollen were determined: *Acantholimon, Eremurus* (Hindu Kush), *Plantago depressa*-type, *Convolvulus arvensis*-type, *Malva*-type, *Erodium, Cyananthus, Stellera chamaejasme, Bupleurum*-type (Nepal), *Ceratostigma, Pterocephalus, Erodium, Malva*-type, *Tribulus, Stellera chamaejasme* (Lhasa). The earliest archaeo-zoological evidence of domesticates from the site in Nepal is approx. 4000 years more recent (v.d. Driesch et al., 2000). Around Lhasa the earliest domesticates are approx. 1200 years (Flad et al., 2007) and earliest barley 1500 years younger (Fu et al., 2000) than our palynological evidence. We cannot exclude earlier human presence at either site. Both sites can be classified as a sedentary agro-pastoral economy. The only attempt so far to interpret *Tribulus* as human indicator pollen in order to calibrate the age of nomadic husbandry was undertaken in southern Mongolia (Miehe et al., 2007a). Our estimation of at least 5 ka cal BP precedes the archaeological evidence from Tuva in the forest steppe ecotone of southern Siberia (Okunev: Parzinger, 2006) by 1000 years.

1.6. The anthracological state of the art

Another line of evidence supporting early human impact comes from paleosol records of tree charcoal (*Picea, Juniperus*; Kaiser et al., 2007) in present-day rangelands of the northeastern Tibetan plateau suggesting the replacement of forests by grassland since 10 ka cal BP. In general the charcoal record does not necessarily witness the human impact, although the connection between human presence and fire is strongly supported by the fire history of islands before and after the arrival of the first humans (Kershaw, 1986; Burney, 1993; Ogden et al., 1998; Burney and Burney, 2003). Moreover the meteorology of Tibet speaks does not corroborate lightning (see below: climate and weather), the Tibetan flora has no pyrophytes, and forests have not recovered since then according to the pollen record (Yan et al., 1999; Herzschuh et al., 2006b). Thus intentional fire clearing of forests is the most plausible explanation. Foragers may have used fire for hunting purposes followed by early pastoralists who were in need of predator-free rangelands. The common forest islands surrounded by treeless pastures in the eastern declivity of the plateau (Fig. 1) can be considered to be further evidence of forest potential or the effectiveness of the tool of fire (Miehe et al., 2008a) meaning that the climate would allow forests if forest growth were not suppressed by humans.

2. Environmental setting

2.1. Relief and climate

The area of investigation (Fig. 1) is located in the southern ecotone between the northern Tibetan highland pastures ('Changtang') and the agricultural oases of arid southern Tibet. The core site (30°23'N/90°53'E, 4250 m) is a Cyperaceae swamp, used as winter pasture for yak near the village of Nindung Xiang, below a rocky hill which has on its southern exposure an isolated open juniper woodland (Fig. 2). This grove is worshipped by the local Buddhists and is known to be the northernmost outpost of trees towards the treeless Changtang. The site is located in the centre of a broad valley stretching over 150 km SW/NE (Fig. 3, left). The 4 to 10 km broad valley bottom ranges between altitudes of 4200 and 4500 m. Towards the northwest, an almost closed glaciated mountain range ('Nyenquentangla Shan') with several summits higher than 7000 m towers over the valley (see Fig. 3). Towards the southeast, mountain massifs around 5000 m give way to three tributary rivers of the Kyi Chu (Lhasa River), thus belonging to the Yarlung Zhangbo/Brahmaputra catchment. Farther to the north and behind the Nyenquentangla Shan stretches the arid Central Asian closed basin drainage system.

The present day climate of the area is moderately continental (see Fig. 1, Climatic diagram of Damxung, 20 km northeast of the core site): During summer (June to August) mean monthly temperatures reach 10 °C; the mean monthly maximum of the warmest month is 17.0 °C. In December and January mean monthly temperatures drop down to −10 °C. The soil remains frozen on level sites like the extensive swamps of the valley between October and April. The mean minimum

Fig. 2. Sacred grove of the northern most *Juniperus tibetica* (1) trees. With dwarf shrubs of *Juniperus pingii* var. *wilsonii* (2) and *Caragana versicolor*, ca. 100 m east of the drilling site. Foothills of the Nyenquentangla Shan in the background. Photo: G. Miehe, Sept. 2002.
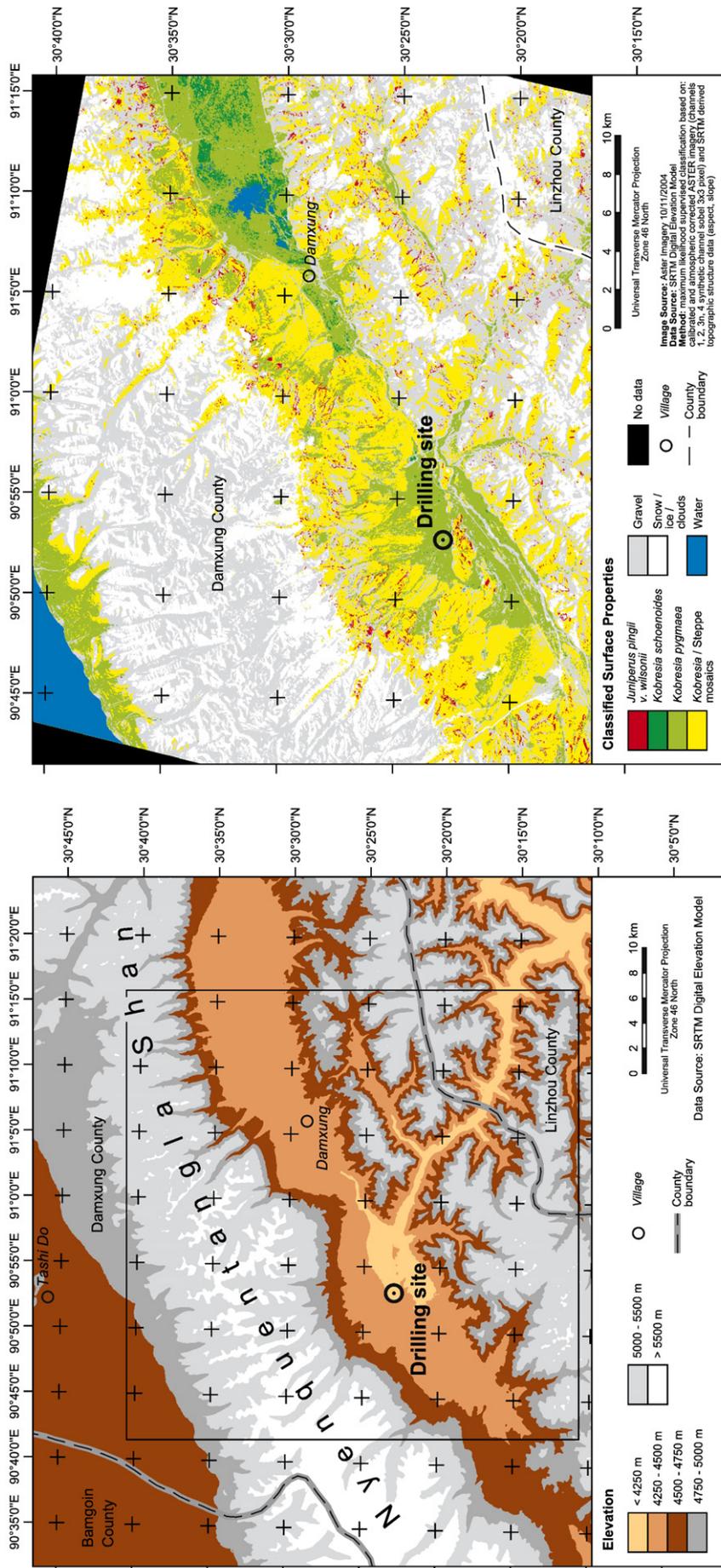
Fig. 3. The relief and the vegetation units of the study area. Draft C. Reudenbach, 2008.

temperature of the coldest month is − 19.3 °C. Frost occurs all year round and can occur even during summer nights. Nights are colder in the valley due to cold air pooling. During winter the valley is most probably under the influence of the Siberian high pressure system. Apart from the autochthonous daily valley wind system, the drainage towards the south connects the valley with the valley wind system of the Yarlung Zhangbo and the forest-covered valleys of the south-eastern Himalaya. During summer southeasterly monsoon winds prevail, while the wall-like Nyenquentangla largely protects the valley against strong westerlies during winter. The area has a clear summer monsoonal rainfall maximum, in total 442 mm/a. Roughly during the last two decades precipitation increased significantly from September to May and decreased from June to August (Xu et al., 2007). Advective rainfall of several days with slush occurs, yet convective rainfall or hail is common during afternoon thunderstorms, leaving slopes covered by patches of hail which melt the following day. Year to year deviations of precipitation totals are high (Morrill, 2004). Therefore the area can be classified as a transition between equilibrium and non-equilibrium systems (Vetter, 2005). On average, snowfall during winter is weak and snow cover lasts only a few days especially on sunny slopes. Periodic heavy snowfalls (like in March 1997) can, however, cause heavy losses of livestock and small mammals. Such disturbances with intermediate frequency may play a role in the debate about the state of equilibrium of the ecosystem.

2.2. Vegetation

The pastoral ecosystem of the study area includes four main vegetation types (Fig. 3, right).

The drilling site itself is in a *Kobresia schoenoides* (Cyperaceae) swamp with a hummock-like structure (Fig. 4). Swamps of this type represent the largest azonal biome of the plateau with a surface area of approx. 80,000 km^2 (Miehe and Miehe, 2000). *K. schoenoides* is an extremely robust sedge reaching 80 cm in height. It provides indispensable winter pastures for yak herders. Under the present level of grazing pressure it is rarely found in its natural habit but often grazed to the ground and unable to flower. When grazing pressure is too high the tall sedges are often replaced by mat-forming *Carex sagaensis* and *Kobresia pygmaea*. The drier parts of the turf hummocks are then colonized by matted *Leontopodium pusillum* and *Astragalus strictus*. The salinity of the habitat is indicated by *Triglochin* spp., *Puccinellia* spp. and *Glaux maritima*.

Fig. 5. Golf course-like *Kobresia pygmaea* pasture. The sedge covers 98% and is 2 cm high. 30°48'N/92°35'E, 4750 m. Photo: G. Miehe, July 2004.

These swamps are part of the *Kobresia pygmaea* belt of the southeastern Tibetan plateau, stretching over 1400 km between the Qilian Shan (38°N) in the north and the Inner Himalaya valleys of Nepal and Bhutan (28°N) (Miehe, 1990; Atlas of Tibet Plateau, 1990; Zhou, 2001). Their distribution range is unique in High Asia, because *Kobresia pygmaea* forms south-facing pastures deep down to 4000 m in the forest belt of the southeastern declivity, or to 3000 m in the northeast and up to 5960 m on the north slope of Mt. Everest (Miehe, 1989). Those pastures are dominated by one of the smallest Cyperaceae endemic to High Asia (Dickoré, 1995) growing not taller than 2 to 3 cm. They are found on all exposures and relief positions. The key to the success of this vegetation type is that the dominant plant species have their main above-ground phytomass beyond the grazing reach of larger herbivores.

The dominant structural patterns of *Kobresia* pastures in the near surroundings of our study site (Fig. 3, right) are 1) golf course-like mats with a closed cover of *Kobresia pygmaea* (Figs. 5 and 2) pastures with a mosaic of isolated *Kobresia*-covered turf sods surrounded by rosette plants and cushions growing in open sand and gravels (Fig. 6). Closed golf course-like *K. pygmaea* pastures form carpets of 2 to 3 cm thick sedge mats covering more than 90%, and consist of only 8 to 10 mostly tiny rosette species (e.g. *Thalictrum alpinum, Potentilla*

Fig. 4. *Kobresia schoenoides* swamps with yaks. Overgrazing and trampling induces the increase of mat-forming *Carex sagaensis* and *Kobresia pygmaea*. Near Damxung, 4250 m. Photo G. Miehe, July 2004.

Fig. 6. An alpine turf cover of *Kobresia pygmaea* separated into sods (1). The turf cliffs are undermined by pika (2). The open soil is colonized by endemic pioneer plants (3). 30°48'N/92°35'E, 4750 m. Photo G. Miehe, July 2004.

saundersiana, Aster flaccidus, Primula walshii, Pedicularis spp., *Cortiella caespitosa*). Mosses (mostly Pottiaceae) cover less than 5%, there are virtually no lichens. The mosaic type is the most common in our area. The turf is mostly separated by polygonal cracks or turf cliffs. The open humic soil between the remaining turf sods is colonized by rosettes (e.g. *Lancea tibetica, Lagotis brachystachya, Potentilla bifurca, Microgynoecium tibeticum, Przewalskia tangutica Persicaria glacialis, Microula tibetica, Lasiocaryum densiflorum*), cushion plants and a few tiny grass tufts. These pioneer communities have a high percentage of endemic monotypic genera. Patches of tall, partly unpalatable forbs (e.g. *Aconitum gymnandrum, Rheum* spp., *Urtica hyperborea*), are common. Rosette and cushion plants and small graminoids of the alpine steppe (e.g. *Stipa purpurea, Saussurea graminea* v. *ortholepis, Androsace tapete, Carex montis-everestii*) are obviously invading the turf sods where *K. pygmaea* no longer covers the turf. These mosaics can be regarded as transitional to the more arid alpine steppe biome of the northwestern highlands. They appear to arise from the destructive impacts of abiotic processes like desiccation (Shen, 2003; Wu et al., 2006) and frost heaves, along with biotic impacts of soil-dwelling small mammals (pika) and the impact of livestock through grazing, trampling and wallowing.

Open dwarf shrublands of *Juniperus pingii* var. *wilsonii* are found along the eastern foothills of the Nyenquentangla Shan between 4300 and 4800 m on sunny exposures (SW to SE) on sandy soils and between rock cliffs. They are never found on densely rooted turfs or sites with stagnant water. They consist of patches of *Juniperus pingii* var. *wilsonii* up to 10 m in diameter and 1.3 m tall. The percent cover of those patches ranges between 70 and 90%. They are surrounded by open soil with species of degraded pastures (e.g *Stellera chamaejasme, Euphorbia* spp., *Iris* spp., *Artemisia moorcroftiana, A. tridactyla, Astragalus monbeigii, Dracocephalum* spp., *Heteropappus* spp., *Pedicularis alaschanica*), tall grasses (e.g. *Pennisetum flaccidum, Elymus brevisubulatus*), species of the alpine steppe and tiny, annual, ruderal rosette plants (e.g. *Microula* spp., *Lasiocaryum* spp., *Eritrichium* spp., *Chenopodium nepalense, Axyris prostrata*).

Juniperus tibetica trees are very rare in the area. Our site hosts the northernmost trees in Tibet (Miehe et al., 2008a). Local oral tradition recognizes this site as the last remnant of once extensive juniper forests in the valley. The trees are 3 to 4 m tall, fruit poorly and have a high proportion of dead wood.

2.3. Sediments and soils

There are no specific soil data available from the study area around the core site. Thus only general information, sporadic observations by

the authors and local pedological studies from adjacent sites with similar relief properties can be used representatively for characterization purposes. According to the Atlas of Tibet Plateau (1990), the study area pedologically belongs to a transitional zone from the 'cold calcic soils' (mostly Kastanozems) of southern Tibet to the 'cold felty soils' (mostly Cambisols and Gleysols) of central Tibet. Dominant rocks, which form the soil surface only at cliff locations, screes and eroded sites, are Palaeozoic metamorphics and Carboniferous and Jurassic sediments. Granites occur only locally. Almost the entire area is covered by a thin layer of silty loess, which was deposited mainly during the Late Pleistocene–Early Holocene period (Lehmkuhl et al., 2002; Kaiser et al., 2008). Additionally, morainic, fluvial-lacustrine, colluvial and peaty sediments form the soil substrates. Extensive wetlands cover the valley ground forming Gleysols, Fluvisols and Histosols, mostly with a thin peat covering layer (under 1 m thick). At relatively dry sites Cambisols prevail, supplemented by Leptosols, Chernozems and Fluvisols. At higher altitudes (>4800 m) signs of permafrost are found.

A common pedological feature of both relatively dry *Kobresia pygmaea* and wet *K. schoenoides* sites is the presence of topsoil horizons rich in rhizogenic organic matter creating so-called turfs (also named sods). In the adjacent Nagqu area (approx. 4500 m, about 140 km to the northeast), the turfs are enriched by living (dominant portion) and dead root biomass (Kaiser et al., 2008). In terms of humus forms (Green et al., 1993), *Kobresia pygmaea* turfs can be classified as Rhizomulls. *Kobresia schoenoides* turfs, however, can be classified as Rhizo-Hydromors. Below-ground remains from of are the most frequent macroremains in the turf. Only a few pollen types of vascular plants occur (predominantly sedges and grasses). Large amounts of microscopic charcoal (indeterminate) are present. Macroremains extracted from the turfs predominantly have negative AMS ^{14}C ages, giving evidence of a modern turf genesis. Bulk-soil datings from the lowermost section of the turfs have a Late Holocene age covering approx. the last 2000 years. The development of *Kobresia pygmaea* turfs was most probably caused by an anthropo(zoo) genetically initiated growth of sedge mats replacing former grass-dominated vegetation. Thus the turfs result from the transformation of pre-existing topsoils comprising a secondary penetration and accumulation of roots. *Kobresia schoenoides* turfs, by contrast, are characterised by a combined process of peat formation and penetration/accumulation of roots probably representing a (quasi) natural wetland vegetation. The integration of pedogenic, chronological and biogeographical aspects as well as the present day geomorphic processes is shown in the model of turf genesis for *Kobresia pygmaea* sites and *K. schoenoides* sites (Fig. 7). A till-loess sequence was used for an exemplary *Kobresia pygmaea* site, whereas a till-gyttja-peat sequence was taken for an exemplary *Kobresia schoenoides* site. The chronology of the first three stages in each case is an approximation and thus hypothetical. Information on timing of depositional and pedogenic processes from neighbouring areas as well as large-scale overviews have been integrated (see Kaiser, 2007). A further uncertainty concerns the questions whether there was actually a phase of peat formation without involvement of *Kobresia schoenoides* and when the assumed process of combined peat formation (deposition of amorphous organic matter) and root penetration/accumulation actually started.

2.4. Wildlife

At the current time, wild ungulates are very rare in our area. Today the most important remaining wild mammals are by far the pika (*Ochotona curzoniae*), an endemic, soil-dwelling, territorial, winter-active lagomorph species that weighs 150 to 200 g (Smith and Foggin, 1999; Pech et al., 2007). Pikas inhabit the *Kobresia* pastures in large numbers especially in the most degraded pastures around settlements. Pika-infested sites with open soil are typically colonized by a
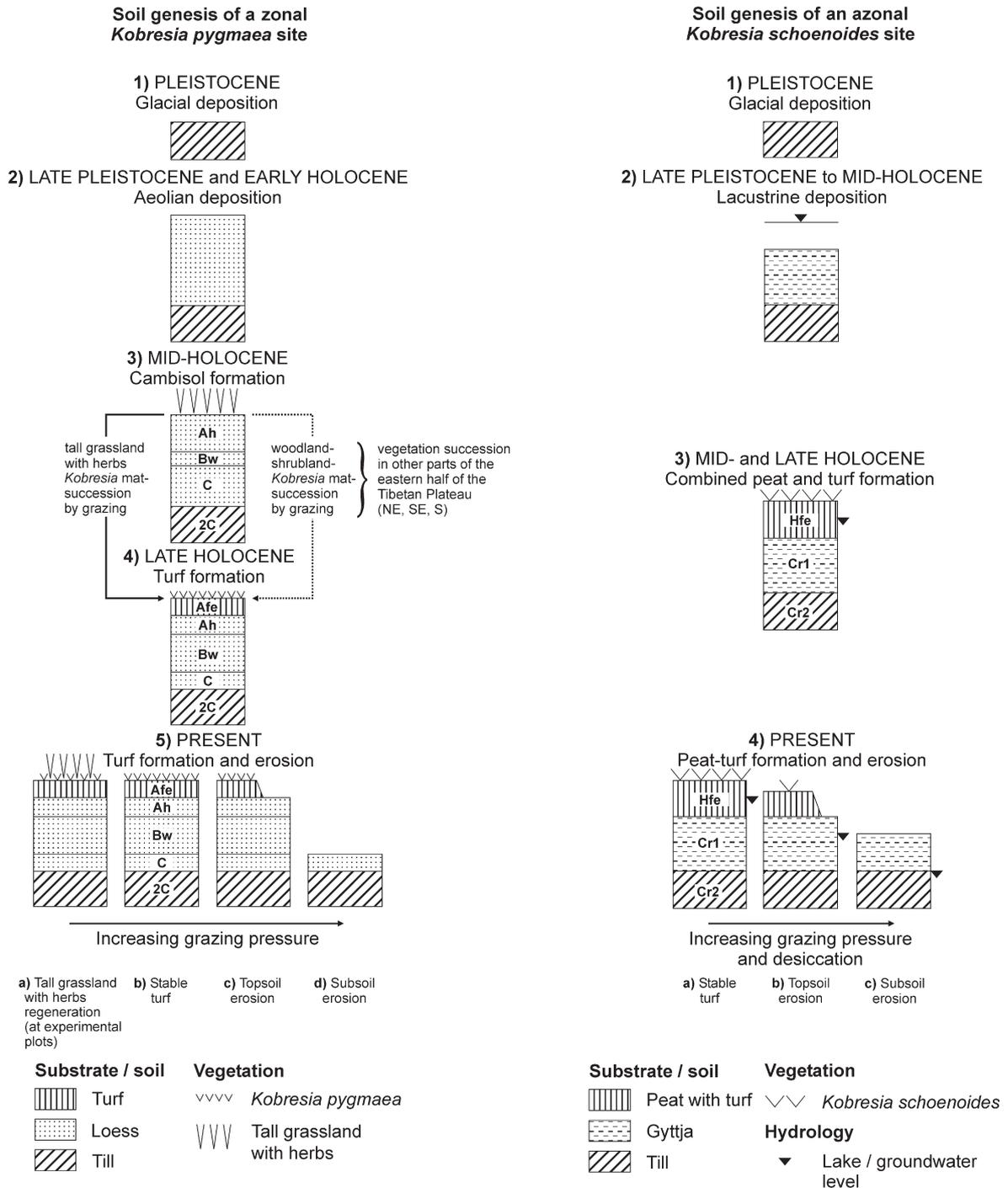
Fig. 7. Model of soil genesis of zonal *Kobresia pygmaea* pastures and azonal *Kobresia schoenoides* swamps of the southeastern Tibetan highlands (Nagqu area between 4200and 4700 m), after Kaiser et al., 2008.

set of endemic Tibetan annual or biennial rosette plants which are classified as disturbance indicators.

3. Materials and methods

The Damxung pollen core is 190 cm long. It was obtained in 2003 in the course of the 'First Lhasa-Marburg University Partnership Programme Joint Expedition'. Samples were prepared according to standard protocols using hydrofluoric acid (Erdtman, 1960; Moore et al., 1999). For our attempt to reconstruct the making of the Tibetan landscape, the "Indicator-Species Approach" (see Gaillard, 2007) is essential. Our baseline assumption is that the present and the past

species' ecological indicator values (e.g. Behre, 1981, Ellenberg et al., 1991, Gaillard, 2007) are comparable. Our vegetation records in High Asia since 1976 are an indispensable pre-requisite for using this approach. Only a very few pollen grains of human indicator pollen are considered to be sufficient in order to reconstruct human impact. Pollen and spores were identified using the pertinent literature as well as a reference collection of 4500 samples (Schlütz, 1999). Naming of types followed Beug (2004) but was modified wherever necessary to reflect regional taxa. Information on the indicator value of the types is found in Beug and Miehe (1999), Schlütz (1999) and Miehe et al. (2006). Based on our own vegetation records and the use of the regional floras (Wu, 1983–1987; Liu, 1996–1999) supplemented by
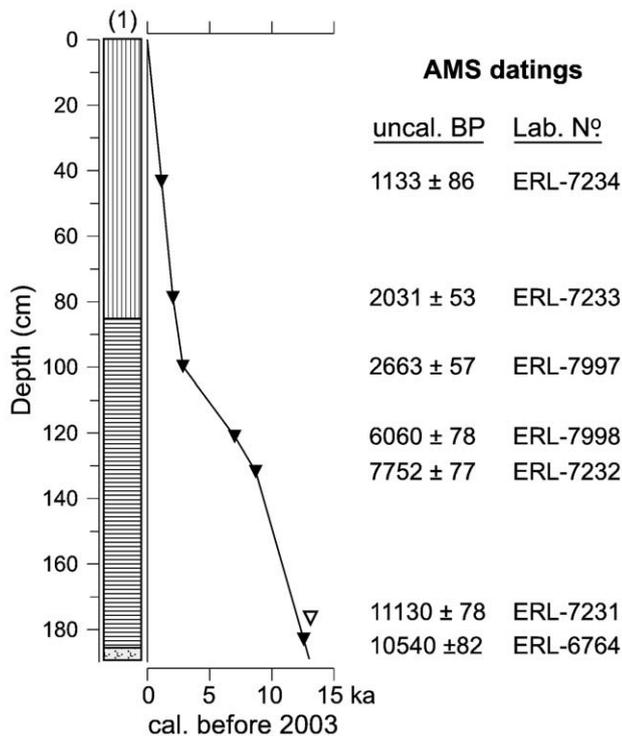
Fig. 8. Age-depth model of the profile Damxung using linear interpolation. Given are the dating results and identification numbers (ERL = Erlangen). The reverse age of ERL-7231, possibly influenced by reworked material, was excluded from the model. Sedimentology (1) from top to base: Cyperaceae peat, Cyperaceae peat with layers of (peaty) detritus mud, sandy humic silt with grus.

revisions in the course of the "Flora of China" (Wu and Raven, 1994 ff.) we are able to attribute a large number of pollen types to distinct species. In some cases these are monospecific genera (e.g. *Stellera*) or the sole species of a genus recorded here, while other species of the genus can be excluded by means of habitat preferences. In addition to pollen and the usual spores, non-pollen palynomorphs (NPP) were included especially in recent profiles; these take into account spores of coprophilous fungi (Aptroot and van Geel, 2006, v. Geel et al., 2003, v. Geel and Aptroot, 2006) as well as spore masses of smut fungi (Vánky, 1994). For the significance of pollen clumps see above and Schlütz and Lehmkuhl (2007).

In the pollen diagrams prepared with the programme C2 (Juggins, 2003) only a selection of types has been portrayed. Percentage values were calculated using the pollen of terrestrial plants minus Cyperaceae as a total sum. The base value was generally set at 250–280 pollen grains, and in the Holocene section of the Damxung profile at least 330 pollen grains. Different scales were adopted for the sake of better legibility. Non-coloured cross-hatching indicates 10-fold percentage values. Due to the recorded ecological changes, the pollen diagram is divided into six local pollen zones ("LPZ"). Ages are based on six AMS-datings of pollen fractions (Schlütz et al., 2007, Morgenroth et al., 2000). Linear sediment accumulation was assumed when extrapolating the calibrated age (www.calpal-online. deCaLPal2005_SFCP).

Interpretation of the pollen diagrams is aided by an understanding of the ecology of the component plant species. The *Artemisia*/ Chenopodiaceae ratio, for instance, is useful in arid environments to describe shifts from humid (A) to arid (C) conditions as are found in the alpine deserts of western Tibet (v. Campo van et al., 1996). In the humid alpine and montane pastures of the eastern plateau, however,

it could be misleading. Here, no fewer than 40 species of *Artemisia* are present with representatives in nearly all treeless plant communities, prevailing in highly degraded pastures or wastelands and during early primary successions of river gravels and lake shores. Similarly, Chenopodiaceae are part of the flora of the alpine steppe, but are also present in humid environments and constitute the main component of wastelands around permanent or seasonal settlements. Thus, we came to the same conclusion as Frenzel (2002: 369), that "at least in central and eastern Tibet the *Artemisia*/Chenopodiaceae pollen-ratio does not seem to unequivocally inform about past major vegetation types". The same is true of Brassicaceae. *Saussurea* and *Thalictrum* are similarly ambiguous: *Saussurea* has more than 100 species in the highlands and is common in all plant communities; *Thalictrum* spp. are present in the alpine steppe, in juniper woodlands and in most of the successional stages of the *Kobresia pygmaea* ecosystem. The Cyperaceae, however, pose the greatest challenge. *Kobresia schoenoides*, *Blysmus compressus* and *Carex sagaensis* form the azonal wetlands of the plateau, closest to the drilling sites. *K. pygmaea* dominates the zonal golf course-like pastures of the southeastern highlands. The alpine steppe of the northwest, like other Central Asian arid biomes, consists largely of *Carex* spp. To use *Artemisia*/Cyperaceae ratios (Shen, 2003; Herzschuh, 2007) would thus ignore the ecology of these taxa.

4. Results

4.1. The pollen record

The LPZ 1 is marked by highest values of *Hippophaë* (up to 22%) and *Thalictrum* (up to 44%), as well as relatively high values of *Myricaria* (2%), *Juniperus* (up to 11%), *Glomus* (14–27%) and clumps of AP and NAP. At the turn to the LPZ 2 values of *Hippophaë*, *Thalictrum* and *Glomus* decrease. In the LPZ 2 the *Halerpestes*/Clematis type (23%) as well as the Cyperaceae (4800%) reaches their highest values. Decreases of the curves of *Myricaria* (below 2%), of *Artemisia* (from about 30 down to 20%) and increasing curves of *Senecio* (from 15 to 30%) and *Bistorta* (from around 5% to over 10%) mark the beginning of LPZ 3. The LPZ 4 is characterized for instance by the decrease of the curves of *Thalictrum*, of the *Senecio* and the *Bistorta* type accompanied by sharp increases in the values of *Rheum* from 1 to 28% and of Cichorioideae from about 0.5 to over 2%. In the LPZ 5 the *Bistorta* curve increases up to over 20% while *Rheum* values are as low as 2%. With the turn to LPZ 6 the *Bistorta* values are below 3% and increasing values are found for the Cichorioideae (up to 30%) and the Gentianaceae (from 2% to 9%).

4.2. Ecological indicator values

The present vegetation patterns and plant indicator values form the basis for our attempts to reconstruct the making of a Tibetan pastoral landscape. Indicator values are attributed according to their present habitat preferences as recorded during our fieldwork of the last 30 years. We largely follow the concept outlined in Ellenberg et al. (1991) and applied for Quaternary sciences (Behre, 1981; Gaillard, 2007).

The following list does not supply information on every spore and pollen type shown in Fig. 8 but only about those relevant for our questions. In many cases we are not yet able to attribute species to certain pollen forms. The list follows the sequence of spores and pollen as given in Fig. 9.

Hippophaë: The altitude of our site restricts the pollen type to *Hippophae tibetana*, a dwarf shrub of 50 cm height in gravel beds of streams and moist open soil.

Fig. 9. Simplified pollen diagram "Damxung" (30°22'N/90°54'E, 4250 m; 190 cm). Selected taxa after Schlütz et al., 2007, changed; pollen sum without Cyperaceae. Maximum value of Cyperaceae is 4800%. Exaggeration factor is 10. Note different scales in lower right part. Charred particles are given as influx.
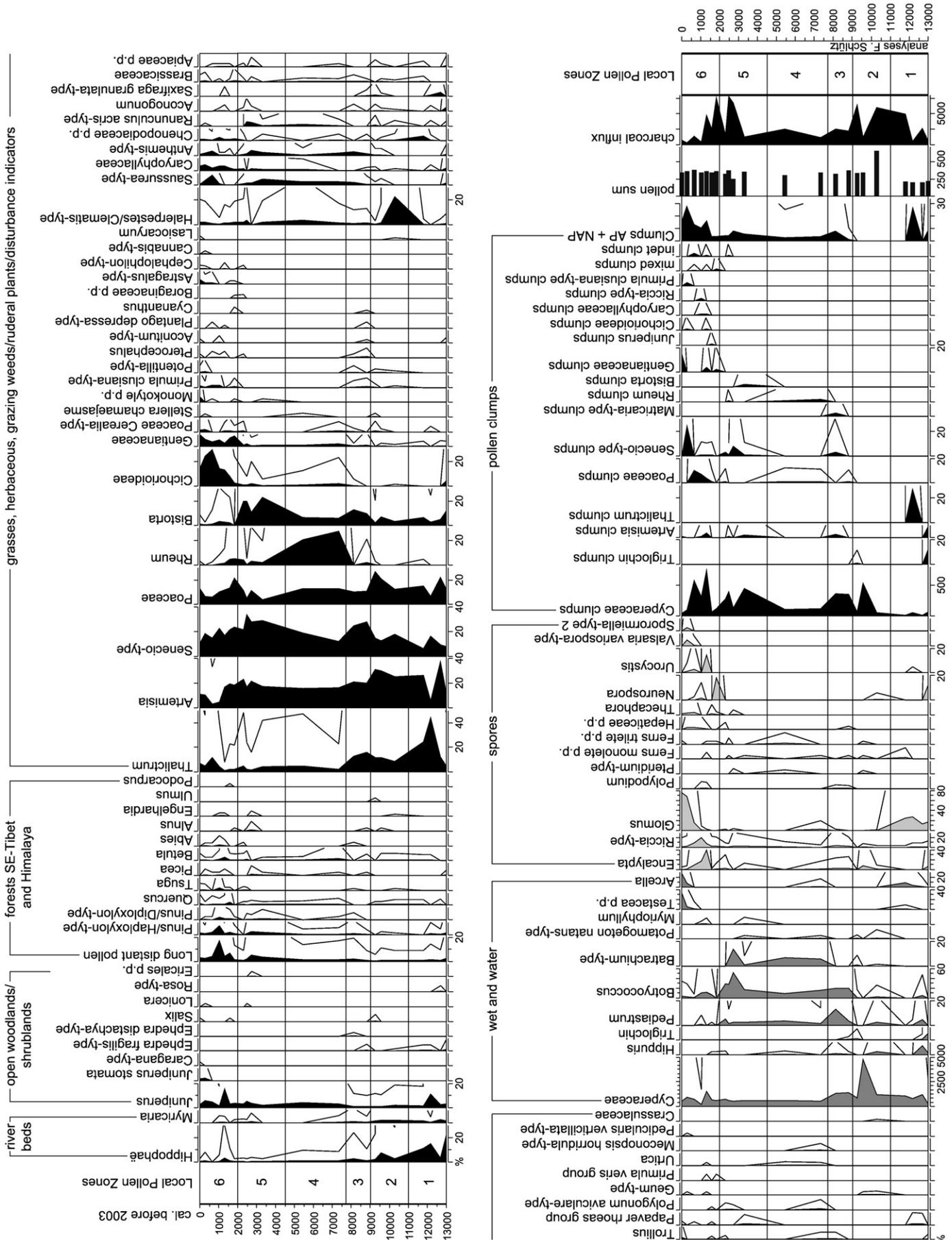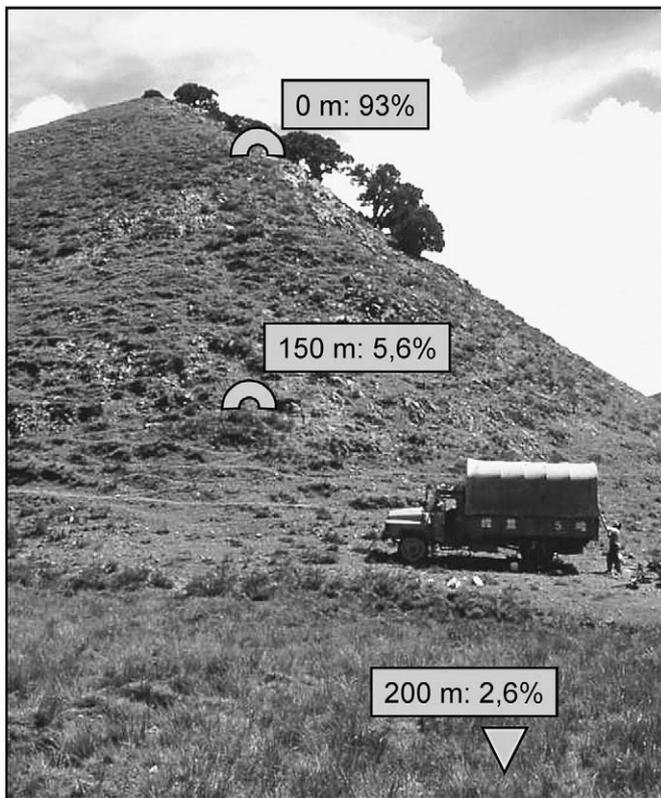
Fig. 10. A 200 m transect of three surface pollen samples between the nearest *Juniperus tibetica* trees and the drilling site. The recorded percentage of juniper are indicated for each sample. Photo and data F. Schlütz 2003, unpubl.

Myricaria: Following our records this can be attributed to *Myricaria prostrata,* a dwarf shrub of gravels along streams. Slightly salt tolerant.

Juniperus: To date we are not able to differentiate between the tree-forming *Juniperus tibetica* and the dwarf shrub of *Juniperus pingii* v. *wilsonii*. Both junipers are restricted to sunny slopes without stagnant water in open soil, screes or rock cliffs. They are never found and obviously never established in the dense tough rhizomull of the *Kobresia* turf. Probably dispersed by birds. *J. tibetica* is a sacred tree for Tibetan Buddhists. The woodland of Figs. 2 and 9 is believed to be the last relics of a former juniper forest widespread in the whole valley. Twigs and bark are used as incense. The shrubby *Juniperus pingii* v. *wilsonii* is used as firewood and incense.

Caragana-type: Two species of thorny dwarf shrubs in the area. *Caragana jubata* is restricted to shady slopes of subalpine altitudes. *Caragana versicolor* is common in juniper woodlands in open soil of sunny slopes.

Ephedra distachya-type: *E. gerardiana* and *E. intermedia* are dwarf shrubs of steep cliffs and open soil. Browsed during winter.

Lonicera: Dwarf shrubs in the south-exposed *Juniperus* woodlands (*Lonicera myrtillus, L. rupicola*), in open soil of wastelands (*Lonicera spinosa*) and north-exposed boulder slopes in *Salix-Betula* woodlands (*Lonicera obovata*).

Rosa-type: *Rosa sericea*, common along trails and in *Juniperus* woodlands.

Ericales p.p.: The only attributable species in the nearest surrounding is *Rhododendron nivale* and *R. anthopogonoides*, forming dwarf thickets on northern slopes. Not browsed, but cut for incense.

Betula: *Betula platyphylla* is the only constituent of forests on shady slopes of the lower Kyi Chu. At present the next birch forests are 80 km away.

Thalictrum: Three species in the area: The 3 to 5 cm tall *Thalictrum alpinum* on hummocks of the *Kobresia schoenoides* swamps

and the zonal *Kobresia pygmaea* pastures; *Thalictrum rutifolium*, 5–15 cm in open sandy soil of open juniper woodlands such as the neighbouring hill of Figs. 2 and 10. *Thalictrum foetidum* of 20 to 50 cm height is common in the tall forb-rich grassland of grazing exclosures (Fig. 11).

Artemisia: 12 species in the area. Annual, perannual scapose and suffruticose species in all habitats with open soil (degraded pastures, pika-infested wastelands, wastelands around settlements, gravels or river beds, glacial forefields, lake shores, even if saline, juniper woodlands and juniper shrublands).

Senecio-type: Uncertain attribution; possibly including two rosette plants of degraded south-facing commons, *Anaphalis xylorhiza, Heteropappus gouldii* and the mat-forming *Leontopodium* spp.

Rheum: Two species. *Rheum pumilum* is common in *Kobresia schoenoides* wetlands, *Rheum inopinatum* is found on mixed open soils and scree slopes of all sorts of habitats.

Bistorta: Attributed to *Bistorta macrophylla*, a character species of humid *Kobresia* pastures between the Qilian Shan (Kürschner et al., 2005) to the Inner Himalayas (Miehe, 1990). The "Vegetation of Xizang" (Zhang, 1988) differentiates a humid subtype of the *Kobresia pygmaea* "meadow" in the eastern part of the distribution area of the *Kobresia pygmaea* pastures. Towards the west *Bistorta macrophylla* retreats to water surplus sites like the *Kobresia schoenoides* swamps or northfacing slopes.

Cichorioideae: Uncertain attribution, perhaps *Youngia simulatrix* or *Cicerbita macrorhiza*. The peak in Cichorioideae pollen is conspicuous during changes with forest pollen decline and synchronous with first appearance of human indicator pollen in the whole of High Asia (Schlütz, 1999; Schlütz in Miehe et al., 2006; Schlütz in Miehe et al., 2009).

Gentianaceae: Uncertain attribution. There are numerous annual tiny *Gentiana* species common in open sandy soil.

Poaceae Cerealia-type: Possibly *Elymus brevisubulatus*, a common wasteland grass, avoided by cattle.

Stellera chamaejasme (Thymelaceae): Most common poisonous grazing weed of humid Central Asia (Liu, S.W. 1996–1999; Grubov, 2001). Avoided by cattle throughout the year. Character species of degraded humid *Kobresia* pastures. Today richly flowering *Stellera* can cover as much as 40% in "*Kobresia* meadows" of the northeastern plateau (Kürschner et al., 2005; Miehe et al., 2008b).

Monokotyle p.p. include monocolpate pollen grains of mostly Liliaceae like *Allium* and *Polygonatum* which cannot be identified at genus level (Beug and Miehe, 1999).

Primula clusiana-type: Out of the two *Primula* species, the tiny rosette of *Primula walshii* is typical for intact *Kobresia pygmaea* golf-courses whereas *Primula tibetica* is a character species of slightly saline wetlands in High Asia.

Potentilla-type The area has 8 species of the "*Potentilla* type": The most important are 1) *Dasiphora parvifolia* a dwarf shrub of open slopes and disturbed sites, often replacing *Juniperus pingii* v. *wilsonii*. 2) *Potentilla anserina* widespread in Tibet in muddy, trampled and slightly saline sites. 3) *Potentilla saundersiana,* 4) *Potentilla sino-nivea* are common in the *Kobresia* pastures and 5) *Potentially bifurca* is a common degradation indicator of the *Kobresia* pastures. We tend to give *Potentilla anserina* the highest probability to represent the *Potentilla*-type.

Pterocephalus (Dipsacaceae): To be attributed to *Pterocephalus hookeri* a rosette plant of south-facing degraded commons.

Aconitum type: Several small species in the wetlands. (*Aconitum naviculare, A. hookeri*) and two tall wasteland species conspicuous in pika-infested sites (*Aconitum flavum*) and fallows or disturbed sites like road sites (*Aconitum gymnandrum*). Avoided by cattle throughout the year.

Plantago depressa-type: Ruderal rosette plant.

Cyananthus (Campanulaceae): The annual *Cyananthus hookeri* form loose mats on open sandy soil of the worst degraded pastures in southern exposures.

Fig. 11. Grazing exclosure in Reting forest: after two seasons of grazing exclosure, *Stipa koelzii* tall grassland overtops the *Kobresia pygmaea* pasture inside the fence. 30°18′N/91°30′E., 4350 m. Photo: G. Miehe, Sept. 1999.

Fabaceae p.p.: Out of the 20 herbaceous species of *Astragalus, A. tribulifolius* and *A. monbeigii* are common in the worst degraded pastures. The poisonous *Astragalus monbeigii* has highest probability to represent this pollen type.

Cephalophilon-type: Out of the annual Polygonaceae widespread common on sandy to silty moist open soil of disturbed sites *Persicaria glacialis* is most common and attains highest probability.

Cannabis-type: *Cannabis sativa* is cultivated in the lower Kyi Chu valley around irrigated fields, 80 km to the south.

Lasiocaryum (Boraginaceae): Two species. Annual small rosettes, abundantly in the wastelands around settlements.

Halerpestes/*Clematis*-type: *Halerpestes tricuspis* in wetlands as well as species of *Clematis* on the neighbouring hill.

Saussurea-type: 18 species in the surrounding area in all plant communities. *Saussurea stella,* and *S. thoroldii* are rosette plants of wetlands, salt tolerant.

Caryophyllaceae: Common flat hemisphaerical cushions in degraded *Kobresia pygmaea* pastures and in the ecotone between the *Kobresia* pastures and the alpine steppe. *Arenaria bryophylla* is the most common species.

Anthemis-type: Covers several genera of the Asteraceae (*Den-* and others, Beug, 2004).

Chenopodiaceae p.p.: Annual ruderal plants of wastelands strongly degraded pastures and burnt areas. *Chenopodium karoi, Chenopodium nepalense, Microgynoecium tibeticum* and *Axyris prostrata* are common in the area.

Ranunculus acris-type: Represents mostly species of *Ranunculus* but also other Ranunculaceae taxa not included in the *Aconitum*-type, *Halerpestes*/*Clematis*- and *Batrachium*-type.

Aconogonum (Polygonaceae): *A. tortuosum,* a tall bushy forb of 20 to 50 cm height, colonizes open soil, typical for yak-wallow sites.

Saxifraga granulata-type: 17 species in the area. *Saxifraga flagellaris* is typical for open soil in disturbed *Kobresia pygmaea* pastures.

Brassicaceae: 26 species in the area. Mostly annual small rosette plants of disturbed sites. *Capsella bursa-pastoris, Hedinia tibetica* are common in wastelands around settlements. *Ptilotrichum canescens, Draba ladyginii, Dontostemon glandulosus* are common in the *Kobresia pygmaea* - alpine steppe ecotone.

Apiaceae p.p.: 27 species in the area. Most common in *Kobresia* pastures are rosette plants closely attached to the ground like *Pleurospermum hedinii, Cortiella caespitosum.*

Trollius: *T. farreri* on hummocks of wetlands.

Papaver rhoeas group: *P. rhoeas* is recorded in the Flora Xizangica as a wasteland plant and agricultural weed.

Polygonum aviculare: Character species of sandy, partly saline wastelands around degenerating swamps and around settlements and fallows.

Geum-type: *Geum* and *Sibbaldia* (Beug, 2004) and possibly other Rosaceae.

Urtica: *Urtica hyperborea* is the only species in the area. Common in wastelands around settlements and livestock resting places, and in patches of open soil in degraded *Kobresia pygmaea* pastures including the open soil in the front of pika burrows with heaps of pika faeces.

Meconopsis horridula (Papaveraceae): Open soil of all plant communities (juniper woodlands, *Kobresia* pastures, scree slopes).

Pedicularis verticillanta type: 26 species in the area, *Pedicularis longiflora* v. *tubiformis* is a character species of slightly saline wetlands in High Asia, *Pedicularis alashanica* is common in sandy dry open soil of sunny slopes in juniper woodlands and dry pastures.

Crassulaceae: 15 species in the area. *Sedum roborowskii* commonly colonizes open sandy soil of wastelands (including the front of pika burrows), *Rhodiola smithii* is a character species of open *Kobresia pygmaea* turf.

Cyperaceae: 64 morpho-types, including hybrid forms in the area. The major annoyance of palynological attempts to reconstruct environmental changes in High Asia is that Cyperaceae are dominant in all major biomes (alpine steppe: *Carex moorcroftii, C. montis-everestii, C. ivanoviae, Kobresia robusta; Kobresia pygmaea* pastures: *K. pygmaea, K. robusta, K. capillifolia, K. royleana, K. nepalensis, K. humilis* etc.; wetlands: *K. schoenoides, Blysmus compressus, Carex sagaensis* etc.).

Hippuris vulgaris: In ponds and lakes, slightly saline up to 5000 m.

Triglochin: Two species, common in saline wetlands.

Pediastrum and *Botryococcus*: Green algae appearing in open water. *Pediastrum* seems to be more common in deeper oligotrophic water (see Shen, 2003).

Batrachium-type: Floating in streams and in ponds, often eutrophic.

Potamogeton natans-type: *P. pectinatus* is the only species in the area with highest records in 5200 m.

Myriophyllum: In ponds up to 5000 m.

Testacea p.p., *Arcella:* The shells of some *Testacea* survive the acetolysis. The *Testacea* live in wet places and on the soil surfaces of water bodies. As they browse bacterial lawns *Testacea* may indicate nutrient input by soil erosion and faeces.

Encalypta: Small moss rosettes of *E. tibetica* commonly growing in moss cushions of Pottiaceae.

Riccia-type: This liverwort spreads on open loamy soils with dense carpets during the rainy season; widespread in communal pastures when the plant cover is reduced to patches.

Glomus: Mycorrhiza fungus. Only when the roots have been exposed by erosion (and by heavy trampling etc.) the spores can be washed into the archive.

Polypodium-type, ferns monolete p.p., ferns trilet p.p.: Due to the aridity of the area ferns are rare. The few spores can be attributed to long distance transport. *Platigyra waltonii* in rock fissures is the only fern in the area.

Pteridium-type: *Pteridium aquilinum* is common in fire disturbed forests and pastures of southeast Tibet (upper limit 3100 m, Wu 1983). The nearest bracken is found in the *Pinus* woodlands 300 km to the east.

Hepaticae p.p.: Spores of Hepaticae except those of the *Riccia*-type.

Thecaphora: Smut fungi infecting host plants of several plant families (Apiaceae, Asteraceae, Boraginaceae, Cyperaceae, Fabaceae, Primulaceae, Vánky, 1994).

Neurospora: Species of the ascomycete genus *Neurospora* grow on charcoal and their spores are therefore indicative of fires (Turner et al., 2001, v. Geel and Aptroot, 2006).

Urocystis: Smut fungi infecting host plants from several families (Brassicaceae, Cyperaceae, Liliaceae, Poaceae, Primulaceae, Ranunculaceae, Rosaceae, Vánky, 1994).

Valsaria cf. *variospora*-type: Ascospores of the *Valsaria* cf. *variospora*-type can be found in peat deposits formed under wet eutrophic conditions (v. Geel and Aptroot, 2006).

Sporormiella-type 2: Lives on dung (Aptroot and van Geel, 2006).

5. Discussion

5.1. Fire history

Although the impact of climate on the vegetation history of the last 13,000 years cannot be denied, it also cannot be ignored that humans were present and altered the vegetation cover using fire, at least where sufficient combustible material was available. However, the charcoal influx of our site is weakest during periods when high water levels and extended wetlands occurred between 8.5 and 2.5 ka cal BP and during the last 1000 years when there was supposedly not enough combustible matter left due to increased grazing pressure since the establishment of the Tibetan empire (Sørensen and Hazod, 2007). We do not wish to categorically rule out the possibility of lightning from the fire record. Meteorological evidence suggests that the probability of natural fires is low, as lightning occurs only during thunderstorms followed by torrential precipitation in the rainy season. Therefore the most parsimonious explanation is not lightning but humans, because wherever humans appeared the fire impact increased dramatically. Even a naturally fire-driven ecosystem like Australia was changed radically when foragers brought fire to the continent (Kershaw, 1986, Fig. 1). The conclusion therefore is that as soon as humans are in the area, lightning cannot be excluded but human-induced fire is more likely. High monsoonal rainfall even seems to be an optimal precondition for the intensity of fire, because the warmer and wetter the climate during the growing season, the more standing dry phytomass there is to be burned during the dry season in winter. This ecological line of argument is possibly corroborated by the charcoal record of Rutok (v. Leeuwen in La Duo et al. as cited in La Duo, 2008), 150 km towards the southeast (29°41'N/92°16'E, 4400 m): There is a significantly high charcoal influx between 11.2 and 7.5 ka cal BP which is widely concomitant with "the time interval between 10–7.5 cal. ka BP (which) is considered optimal for vegetational growth in response to the wet and warm conditions" (La Duo, 2008:27). The increased charcoal record during times of increased summer rainfall is

not necessarily a contradiction — if we admit the possibility that humans burned an increased phytomass during the dry cold season. However, in a palaeoecological case 'smoking gun evidence' cannot be expected. Therefore, we dispense with the most parsimonious explanation and do not exclude the possibility of natural fire categorically. *Pteridium* was not found.

Another pollen diagram (Nienang, 29°43'N/90°42'E, 3948 m, v. Leeuwen in La Duo et al. as cited in La Duo, 2008) shows a high charcoal influx before 9.5 ka cal. BP. Similar to the Damxung site, the charcoal influx is weak during the last 700 years, supposedly due to a lack of combustible matter resulting from strong grazing pressure. The question whether the carbonized particles might be long-distance influx can be at least partly answered by the presence of *Neurospora* spores, which strongly suggest a local fire event. *Neurospora* was recorded both at the very base of the core (13 ka cal BP) and during the last 2 ka. Similar early fire impacts are evident in the far more humid catchment of the Co Qongjiamong site (29°48.77'N/92°22.37'E, 4980 m, Shen, 2003: 150). However, the charcoal record of Co Qongjiamong is not recognized for its environmental significance. Standard fire indicator sporotypes (*Pteridium*) are not included in that profile. Our preliminary conclusion, therefore, is that some sort of human impact is superimposed on the climatic impulse at least as far back as the core reaches, covering the last 13 ka.

5.2. Vegetation history

LPZ 1 (13–11 ka cal BP). The zonal vegetation of forb-rich steppe was obviously developed and showed high values of *Thalictrum*, *Artemisia* and Poaceae. Changes in pollen values may be attributed to incisive (climatic) impacts. We suppose that these incisive changes, including higher erosion activity, can be placed in the Younger Dryas. Similar conclusions were drawn for the Rutok site (v. Leeuwen in La Duo et al., as cited in La Duo, 2008). The vegetation cover was probably not closed, allowing transport of *Glomus* spores from the neighbouring hill to the swamp by erosion. Similar, but far stronger indications of erosion processes have only recurred during the last 700 years. The *Aconogonum* record corroborates this conclusion. As this *Glomus* peak lacks any simultaneous record of grazing weeds, in contrast to the sub-recent peak, we may exclude larger wild herbivores as a cause of erosion. Gravel beds of glacial meltwater streams, which serve both as a source of the loess cover (Klinge and Lehmkuhl, 2005) and as a habitat for pioneer dwarf shrubs (*Hippophaë*, *Myricaria*), were more extensive. Shallow ponds, which were possibly slightly saline and existed in a more arid climate than today, have aquatic plants like *Hippuris* and green algae like *Botryococcus*. Higher evaporation rates resulting in saline water may be indicated by the halophytic *Triglochin*. The present Cyperaceae swamp developed quickly after 13 ka cal BP. The junipers on the neighbouring hill were there from the beginning. The molecular evidence of a unique haplotype among recent juniper trees of *J. tibetica* speak in favour of an old relictual forest population at this site or in surrounding areas (Opgenoorth et al., 2009). Around 12.5 ka cal BP the juniper population on the neighbouring hill nearly collapsed and shows a drastically reduced level of pollen production for the next 9000 years. The most parsimonious explanation is fire followed by a *Glomus* peak which points to erosion. The devastating impact on the site favours *Chenopodium nepalense*. We refrain from offering a climate-based explanation for this Chenopodiaceae peak, because the *Haloxylon* type (i.e. *Krascheninnikovia*, syn. *Ceratoides*, syn. *Eurotia*), a representative of the arid Central Asian flora, is missing here. Coinciding with the Chenopodiaceae and *Glomus* peak, four other pollen types occur that can be attributed to open soil or wasteland, namely *Aconogonum*, *Papaver rhoeas* group, *Meconopsis horridula*, and *Elymus brevisubulatus*.

LPZ 2 (11–9 ka cal BP). The zonal vegetation was probably a forb-rich grassland dominated by Poaceae, *Thalictrum*, *Artemisia* and *Bistorta*. It may be convenient to think of these forb-rich grasslands as

broadly similar to a grassland which developed within a few years in a grazing exclosure at the same altitude, only 60 km away (Fig. 11, Schlütz et al., 2007). *Ephedra* is likewise a plausible component in those grasslands as shown in exclosure plots near Lhasa (Miehe unpubl.), but certainly is more common on cliffs of the neighbouring hills. During this time the forb-rich grassland is obviously at its best developed. There is enough dry matter for several major fire events in the zonal grassland, though not necessarily in the swamp itself, because the *Neurospora* values remain weak. The *Kobresia schoenoides* swamp encounters optimal conditions. With the exception of a single disturbance event producing a pronounced peak of Cyperaceae pollen clumps, there is no record of any other disturbance event. The vegetation cover seems to be completely closed (no *Glomus* record) and hailstone or trampling effects are obviously absent (no pollen clumps).

Towards the end of LPZ 2 around 9.2 ka cal BP, *Stellera chamaejasme* pollen occurs for the first time, coinciding with a fire disturbance event that provided open soil for *Aconogonum* and *Elymus brevisubulatus*. The *Potentilla* record can likely be attributed to *Potentilla anserina*. If that is so, then open, muddy, trampled, slightly saline, open patches existed at that time. The earliest pollen record of *Stellera* known so far is slightly older than 20 ka cal BP, and comes from the northeastern plateau ("Thymelaceae", Herzschuh et al., 2006a). Since this core was drilled in a lake, the weak pollen record of this insect-pollinated poisonous weed is not surprising. Two more records of *Stellera* from sites on the eastern declivity of the highlands can probably be interpreted within the context of early human impact. The site 'Hongyuan I' (Zoige basin, Thelaus, 1992, Fig. 10) records "Daphne" around 6.5 ka cal BP, concomitant with a significantly low value for *Picea*. We therefore suggest that human-caused disturbance in forests of that area may have begun 1.5 to 2 ka earlier than concluded by Thelaus (1992: 339). If we compare "Hongyuan I" with the pollen diagram of Yan et al. (1999: Fig. 3) in the immediate vicinity, a drastic decrease of *Abies* pollen around 8818 ± 190 cal BP and of *Picea* pollen around 7592 ± 203 cal BP may corroborate our view. Just 100 km west of "Hongyuan I," the pollen diagram 'Nianbaoyeze 3' (Schlütz in Miehe et al., 2007b) records *Stellera* for the first time also around 7.2 ka cal BP, coinciding with a drop of *Picea* pollen and associated with *Tribulus*, an unequivocal human-indicator pollen. As *Tribulus* is an archaeophyte in the Old Word's desert belt, its occurrence in a humid mountain environment of East Asia can only be explained by cultural impact. Although *Stellera* profits from free-range grazing of livestock and decreases after grazing is excluded (Miehe et al., 2008b), we cannot say with certainty whether the *Stellera* record around 9.2 ka cal BP at our site signifies more than just large herbivore grazing.

Around 9.5 ka cal BP *Pteridium* is recorded. As bracken spores are certainly long-distance dispersed, this record could be attributed to forest fires in eastern or southeastern Tibet. Soon afterwards, a decrease can be noted in the long-distance dispersed arboreal pollen. This is, however, not really surprising, given that fire impact can be traced back to at least 15 ka BP in those forests of the Himalayas (Schlütz and Zech, 2004).

The LPZ 3 (9–7.8 ka cal BP) shows marked changes that are possibly the most important with respect to answering our question. The site was evidently subjected to high water levels, possibly shown by uniquely high *Pediastrum* values (cf. Shen, 2003) and the fact that aquatic plants (*Hippuris*, *Botryococcus*) were favoured at the expense of the *Kobresia schoenoides* hummocks. Higher humidity along with higher temperature is recorded by independent proxies at Cuoe Lake (31°24'N/91°30'E, 4530 m), 120 km to the north (Wu et al., 2006), from Nam Co Lake, just north of the Nyenquentangla Shan (Zhu et al., 2008) and elsewhere on the plateau (Shen, 2003). If this conclusion is correct and we assume a climate-driven cause, we would not expect to see a decrease in pollen production from the zonal vegetation (Poaceae, *Artemisia*) because the grassland should also profit from higher precipitation. The same holds true for significantly increased

pollen clumps, which have so far been explained by adverse climatic conditions (Demske and Mischke, 2003; Herzschuh et al., 2006b). If we refrain from explaining pollen diagrams solely as a product of abiotic impacts, and admit there may be biotic drivers of changes in vegetation (Craine and McLauchlan, 2004; Zimov et al., 1995; Bradshaw and Mitchell, 1999), our line of argumentation is perhaps more parsimonious. In LPZ 3 around 8.8 ka cal BP a set of Tibetan grazing weeds and disturbance indicators appear for the first time (*Pterocephalus hookeri*, *Aconitum gymnandrum*, *Cyananthus hookeri*) together with *Plantago*. Soon afterwards, three other widely known disturbance indicator plants of human-made wastelands (*Polygonum aviculare*, *Meconopsis horridula*, *Urtica hyperborea*) occur for the first time as well. The indicator value of this set is clear: large herbivores now have a stronger impact than ever before. Their grazing pressure causes a significant decrease in the flowering of grasses. As grasses are at present not dominant in the zonal vegetation of the *Kobresia pygmaea* golf courses, but recover and overgrow the *K. pygmaea* as soon as grazing is prevented, (as shown by fenced exclosure plots 60 km east of our site at the same altitude; see Fig. 11), it is likely that these changes can be attributed to grazing impacts. However, the suspected change from taller grassland to golf course-like *Kobresia* pastures is not supported by increased Cyperaceae values; even if it were, the Cyperaceae signal is ambiguous because we cannot differentiate between the pollen production of the swamp (*Kobresia schoenoides*) and that of the zonal vegetation (*Kobresia pygmaea*, *Carex* spp.). Instead, the *Bistorta* pollen curve offers a solution: The increasing pollen values of *Bistorta*, up until a sudden decline around 2.0 ka cal BP, could reflect the development of the pasture type that dominates today. The question is, however, were wildlife or livestock the biotic drivers? To offer an answer, we return to the significantly increased value of pollen clumps. Pollen clumps have only recently been introduced into palaeoecology as grazing indicators (Schlütz and Lehmkuhl, 2007). We now suggest, possibly for the first time, using pollen clumps to elucidate the ratio of wildlife and livestock impact and potentially as a proxy for the age of pastoralism. Tibet's large wild and domestic herbivores have similar weight and hoof size. Therefore, a similar number of game will have an equally damaging effect on flowers producing a similar number of pollen clumps as an equivalent number of livestock. If the number of pollen clumps in surface pollen samples is ten times larger than before the introduction of domesticates, we may conclude that the wildlife was ten times smaller in numbers than today's livestock. This deduction would be in line with the ratio of wildlife and livestock as given by Oesterheld et al., 1992. Wild herbivores were certainly present until the impact stemming from the policies of the Chinese administration became manifest, and we may assume that gazelles, antelopes, bharal, argali, wild yak and wild ass co-existed with livestock until the 1950s.

The date of the earliest livestock influence in our area may be determined using an empirical approach: As grazing weeds dominate today's pastures and the highest levels of grazing weed pollen and pollen clumps have been achieved only in the recent past, the first significant increase of both grazing weed pollen and pollen clumps may mark the onset of pastoralism.

The fact that *Plantago* appears together with the suite of Tibetan grazing weeds, may corroborate our view that livestock have entered the scene. The Rutok pollen diagram (v. Leeuwen in La Duo et al. as cited in La Duo, 2008) has had a continuous *Plantago* record since 7.2 ka cal BP. So far it has never been discussed whether *Plantago* might be an archaeophyte brought to Tibet from the Middle East as supposed for Central Europe, the opposite end of the axis of diffusion of the 'Neolithic Package' (Diamond, 1997). *Plantago* has its diversity centre in the Near and Middle East (Kästner et al., 2001) and its status in Tibet has never been considered before in the context of migration and diffusion, yet the aforementioned Rutok pollen diagram records *Plantago* as early as around 13.5 ka cal BP. In any case, the grazing impact during LPZ 3 was not nearly as strong as it is today or during

the three most recent pollen zones, because the vegetation cover seems more or less intact (weak *Glomus* records) and *Bistorta* flowers are not grazed off as in the more recent past.

LPZ 4 (7.8–4.5 ka cal BP) has reduced Cyperaceae values and a weak fire record. Pollen clumps are present but infrequent. This may be attributable to extensive ponds, indicated by constantly high values of aquatic plants. The junipers of the neighbouring hill seem to have recovered slowly. A synchronous higher sporo-pollen record of *Polygonum aviculare*, Poaceae Cerealia-type, *Glomus*, *Arcella* and *Meconopsis horridula* indicates open soil around 7.2 ka cal BP. This can be interpreted as a disturbance possibly like in the Cuoe catchment 130 km further north, where a "dramatic drop of δ^{13} C, TOC content and the C/N ratio from 7280 to 6750 cal years BP suggests that a severe climatic event probably occurred" (Wu et al., 2006: 337). The *Pteridium* spores can be linked to lower pollen production of the forests in the south and southeast due to intensified fire clearing.

The LPZ 5 (4.5–2.0 ka cal BP) is obviously the wettest period recorded here, because aquatic plants, including *Myriophyllum*, attain their highest pollen values. This conclusion is in line findings from Nam Co (Herrmann pers. comm.), but contrasts with results from Lake Cuoe that indicated 'unstable conditions against a background of a cooler and drier climate' (Wu et al., 2006: 337). The pollen record of Lake Xigetang (Herzschuh et al., 2006b, Fig. 3), 200 km to the north and situated in the ecotone between *Kobresia pygmaea* pastures and alpine steppe (Zhang, 1988; Noelling, 2006), shows increased Cyperaceae and *Hippophaë* values both of which would support the interpretation of extensive swamps and gravel beds. *Bistorta macrophylla* attains the highest values ever. It is possible that the more humid type of *Kobresia* pasture is at its best. In contrast, this pollen type is weakly present during the last 4500 years around Lake Xigetang (Herzschuh et al., 2006b: Fig. 3).

The LPZ 6 (since 2.0 ka cal BP) is obviously drier because the aquatic plant assemblages decrease. The same trend is obvious around Lake Cuoe (Wu et al., 2006: 338), Lake Nam Co (Zhu et al., 2008), and other parts of the plateau (Shen, 2003).

The last 2.0 ka cal BP show all possible forms of human interference at their highest intensity. Trampling effects of livestock lead to highest pollen clump values recorded, including those of *Juniperus* and stomata of *Juniperus*. The above-mentioned set of disturbance indicators is completed by annual Boraginaceae (i.e. *Eritrichium* and especially *Lasiocaryum munroi*) and *Persicaria glacialis* colonizing open soil. Chenopodiaceae attain their highest values, probably with the tiny annual *Chenopodium nepalense* and with *Axyris prostrata*. The same is true of Brassicaceae (*Hedinia tibetica, Capsella bursa-pastoris, Draba* spp.) becoming dominant on bare soil of wastelands. Poaceae (*Elymus brevisubulatus*) and *Aconogonum* (*tortuosum*) likewise give evidence of prevailing bare soil sites. An increased Cichorioideae curve is in line with similar values during human-induced changes in neighbouring sites of the Himalayas (Schlütz in Miehe et al., 2009.). The most notorious grazing weed of common wastelands around settlements, *Astragalus monbeigii,* increases during the last 1000 years and is at present one of the prevailing flowering plants of zonal sites. The highest pollen values of the *Potentilla* type might be attributable to degenerated wetlands where *Kobresia* hummocks have been destroyed and the trampled muddy soil is colonized by carpets of *Potentilla anserina*. A similar increase in both pollen forms is recorded in Rutok (v. Leeuwen in La Duo et al., as cited in La Duo et al., 2008). Peaks in *Urocystis* and *Thecaphora* indicate unfavourable growth conditions probably brought about by increased trampling.

Around 2.0 ka cal BP *Bistorta* pollen drops to the lowest values ever. This can be seen in an abiotic and biotic context: Along with reduced rainfall, the humid *Kobresia–Bistorta* pasture type retreats towards the east, giving way to Caryophyllaceae cushions (*Arenaria bryophylla*) of the alpine steppe assemblage. Moreover, we can hardly expect *Bistorta* to flower under increased grazing pressure, because taller parts of the rosette are bitten off. It is quite plausible that decreased *Bistorta* values

represent the shift towards the present golf courses which mainly consist of cushions, rosettes and matted plants with the main above-ground phytomass beyond the reach of livestock and especially yak. However, the increased grazing pressure and drier climate weakened the felty turf cover and may have destroyed it on the south side of the hill. The removal of the turf cover improves conditions for the germination of juniper seeds. This is important because Tibetan junipers never establish in densely rooted humic soils, such as rhizomulls (Kaiser et al., 2007), with a closed vegetation such as is found in the *Kobresia* pastures (Miehe et al., 2008c). Thus, a wider distribution of *Juniperus* could have been suppressed by a closed turf of *Kobresia*.

The fire record of LPZ 6 reflects a drastic change in the available biomass left standing during the dry season in winter. Several fire events are recorded between 2.8 and 1.5 ka cal BP, but not later, when simply no combustible matter was available because everything except isolated *Aconitum gymnandrum, Astragalus monbeigii* and *Stellera chamaejasme* had to be used by livestock. A similar conclusion of a weak fire record in the recent past is drawn for the Nam Co (Herrmann pers. comm.).

The last fires, however, initiate a classical sequence of pasture degradation, shown by non-pollen palynomorphs: spores of *Neurospora* testify to the fire event in the surroundings. The destruction of closed plant cover that likely followed gives way to the colonization of carpets of *Riccia* (Hepaticae) sealing the open soil. Increased livestock numbers (indicated by spores of coprophilous *Sporormiella*) probably caused elevated erosion through trampling, which is in turn indicated by the spores of *Glomus*. It seems that erosion was never greater than during the recent past as a result of pastoralism. A similar connection between increased livestock impact and erosion, as indicated by the presence of *Glomus*, can be seen in the Lake Xigetang record (Herzschuh et al., 2006b: 118) during the last 1.4 ka cal BP, although Herzschuh et al. only concede a climatically driven impact. Increased livestock numbers at the Damxung site are likewise demonstrated by *Valsaria variospora*, an indicator of eutrophication of the swamp. At the same time, the thorny shrub *Caragana versicolor* has become so abundant on the neighbouring hill that it is also appearing in the swamp pollen record.

6. Conclusion

Our ecological approach reconstructing the making of a pastoral environment in the Tibetan highlands relies on three arguments hypothetically attributed to humans, 1) the evidence of fire, 2) the presence of a species composition of plant cover that is believed to have developed as a result of free-range grazing of domesticates and 3) the occurrence of pollen clumps introduced here for the first time in the context of human impact on the environment. The fourth line of argument relies on the location of the study site in the diffusion corridor of the "Neolithic Package" (Diamond, 1997): As two of the important domestic animals of Tibetan pastoralism, sheep and goats, had their origins of domestication in the mountains of the Middle East (Ryder, 1983), any record of sheep and goat farther to the east than our site supports the probability that we may expect an earlier sheep or goat record than in the farther East.

1) The evidence of fire is not necessarily absolute proof of human presence and impact. Yet, the probability of lightning as a natural cause can almost certainly be ruled out in Tibet, because thunderstorms occur exclusively during the rainy season in summer and every lightning strike is followed by torrential precipitation. The present day *Kobresia pygmaea* golf courses do not provide enough fuel to carry fire.

However, fire will have no long-term impact either on grasses or herbs, because plants are dormant during the cold fire season, and pollen production during the rainy flowering season will be equally unaffected in the long run. Unlike herbaceous plants, woody plants like shrubs or trees exhibit long-term reduction in pollen production

after fire. This is pivotal for our case because larger areas of the present *Kobresia* pastures of the Tibetan highlands are believed to be occurring in place of forests, as suggested by the presence of isolated forests in Tibetan pastures (see Fig. 1, Miehe et al., 2008a). Therefore, the palaeo-record of fire is important because forests had to be cleared with the help of this tool to gain rangeland. We suggest that the forest pollen decline of several pollen diagrams from the northeastern highlands during the mid-Holocene climatic optimum ("Lake Luan-haizi": 7.9 ka cal BP, Herzschuh et al., 2006b; "Wasong": 7.2 ka cal BP, Yan et al., 1999, Fig. 4; "No 2 pit", 8.8 ka cal BP, Yan et al., 1999, Fig. 3), could have been better explained if the charcoal record had been included in the analyses and human impact had been allowed for. As patterns of arboreal pollen decline at these sites contrast with $\delta^{13}C$ (Yan et al., 1999), $\delta^{18}O$ (Fontes et al., 1996, Gasse et al., 1996), TOC content and C/N ratio (Shen et al., 2005) and ostracod assemblages (Mischke et al., 2005) as independent from rangeland management decisions of early pastoralists, we may conclude that pastoralists took advantage of the mid-Holocene climatic optimum to convert forests into high-yield pastures. Thus, rangeland management decisions of nomads to transform forests into pastures with the help of fire created their own pastoral environment in the eastern Tibetan highlands. This is in contrast to the nomadic lifestyle in the Old World's desert belt which is believed to have passively and sustainably acclimatised to hostile and desiccating environments (Scholz, 1995; Kuper and Kroepelin, 2006).

2) The fact that the present golf course-like structure of the vegetation cover disappears as soon as livestock grazing is excluded, leads us to suggest that the present species composition and the prevailing plant life forms are a result of the selective foraging of livestock managed in free-range grazing. The most parsimonious explanation is that this started with the first pastoralists' impact. However the endemic, wild large herbivores probably have similar selective grazing habits. As the evolutionary time scale of grazing adaptation predates the arrival of domesticates, there is certainly a co-evolutionary impact of wild herbivores and the evolution of plant species and plant functional types adapted to grazing. The presently dominating structure of the pastures with grazing-adapted species prevailing could have been aggravated to the present status by livestock (Stebbins, 1981; Augustine and McNaughton, 1998; Adler et al., 2004).

3) The timing of the first record of the set of Tibetan grazing weeds is synchronous with increased number of pollen clumps. The recent and sub-recent amount of pollen clumps is approx. tenfold higher than those prior to the suggested introduction of pastoralism. Our preliminary conclusion could be that "there is a tenfold difference in herbivore load between them" (Oesterheld et al., 1992: 235). There-fore, the circumstantial evidence allows us to suggest that the development of the present grazing weed dominated vegetation started around 8.8 ka cal BP. It remains uncertain at what point the present *Kobresia pygmaea* golf-courses spread but at least during the last 1000 years.

4) To tackle our question it is necessary to consider our site lo-cation with respect to the centre of the domestication of sheep and goats. Our grazing ecology proxies put the age of pastoralism 5000 years earlier than the oldest confirmed archaeo-zoological records of domesticates in Tibet (Qugong site, Flad et al., 2007: 191), 3500 to 4000 years earlier than for the Ordos Plateau (Zhukaigou site, Flad et al., 2007: 189) and approx. 2800 years earlier than for Hongshan, 330 km to the northeast of Beijing (Guo, 1995; as cited in Parzinger, 2006: 155) in northern China. If the records of sheep near Xian (Linkoucun and Banpo site, Flad et al., 2007: 185) are confirmed, the time lag is reduced to some 2000 years. Archaeological survey data are still sparse and arbitrary, and thus the Qugong site does not necessarily represent the most ancient site of livestock keeping in Tibet. The probability that the Qugong records are younger than the oldest livestock herding in Tibet is underscored by the fact that the domesticates found in northern China or, if reliable, near Xian, are a

greater distance away from the area of earliest domestication in the Middle East. Whichever route is taken, our site is approx. 1800 km closer to the Middle East than Zhukaigou and Xian. As there are no wild species of the tribus *Caprini* known from the Xian site (Schaller, 1977) and if we may exclude that goral have been misidentified as *Caprini*, a record of 'sheep' can only refer to a domestic animal. We therefore may include the Banpo and Linkoucun sheep record with less hesitation into our line of argumentation.

Since it is not known whether the 'Neolithic Package' came to China through the Hexi Corridor (Flad et al., 2007) or along the upper Indus and Yarlung Zhangbo, there are approx. 5400 to 6000 km to be covered. Our site is approx. 1800 km closer to the mountains of southwestern Iran; therefore the distance could be reduced to approx. 4200 km. As the rate of diffusion or migration between the oldest records in the Middle East (Zeder and Hesse, 2000) and our site is not known, it might be helpful to refer to diffusion rates on the European side of the corridor. The distance between southwestern Iran and the Vojvodina (Roberts, 1998, Fig. 5.10) in East Central Europe was covered at diffusion rates of 3 km per year. If we assume similar rates towards the east, our site could have been reached around 8.6 ka cal BP. However, these highly speculative arithmetical scenarios do not consider the time lag posed by the necessity of adapting to high altitudes (Brantingham et al., 2007).

The age of pastoralism in the Tibetan highlands will remain unknown until archaeo-zoological and/or molecular evidence of domesticates can be found. Our ecological approach suggests, however, that the making of a pastoralist environment in the Tibetan highlands started around 8800 years ago. The making of the Tibetan landscape could thus have been contributing to an early greenhouse effect for as long as 8000 years (Ruddiman, 2003).

Acknowledgements

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