3 Environmental characteristics of the Upper and Middle Orkhon Valley, Mongolia

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Summary

The Upper and Middle Orkhon Valley in Mongolia refers to the area adjacent to the former capital Karakorum. It is suggested that cultural and societal development during historic and prehistoric times has interacted with landscape evolution in this region. Thus, knowledge on the environmental characteristics and their temporal and spatial changes may help to understand the time-variant human activities.

The area of interest is located in a sensitive ecosystem characterized by extreme environmental conditions that constitute many constraints for the mainly agrarian society. Here, we give a review on these environmental settings and address their temporal changes. Furthermore we give insight into paleoenvironmental archives and their significance for the analysis of environmental reconstruction of the history of the area of interest.

3.1 Introduction

The Orkhon Gol (Orkhon River) in central Mongolia is one of the most important drainages of the Khangay Mountains. Its upper and middle courses constitute not only a vein of present livelihoods but also represent major axes of migration and settlements during historic and prehistoric times (Bemmann *et al.*, 2008). Hence, various archeological studies have been conducted in this area during the last decade.

Throughout time the environmental settings and their changes have always been a crucial factor in the rise and fall of human settlement dynamics. Thus, in order to understand the societal and cultural evolution in this area of interest detailed knowledge on its environmental controls and their spatio-temporal changes is required.

Here, we present an overview on the environmental characteristics of the Upper and Middle Orkhon Valley based on results gained during field campaigns between 2004 and 2006, environmental data analysis and literature reviews. Many environmental features, however, are only poorly documented in the 'Western' literature mainly due to Mongolia's remoteness and historical isolation from the rest of the world.

3.2 Area of interest

The area of interest is located in the Arhangay and Övörhangay province. It encompasses the region between 47°00' to 47°53'N and 102°15' to 103°08'E and comprises elevations between 1210 m and 2350 m a.s.l. (Fig. 3.1, 3.2). The term Upper Orkhon Valley refers to the part of the river course located in the steeply intersected northern declivity of the Khangay Mountains where fluvial processes of bedrock detachment prevail.

A sudden change to a predominance of gravel and sand accumulation occurs where the Orkhon River exits the Khangay Mountains and constitutes the Middle Orkhon Valley (Fig. 3.2). Loosing its transport capacity due to rapid decrease in downward slope and, thus, flow velocity the river accumulated a vast fan. At the apex of this fan the medieval Mongolian capital Kharkhorin (Harhorin, Qara Qorum) is located. From here the present river course meanders in the western part of the Middle Orkhon valley until its confluence with Tamir River nearby Lake Ugii Nuur.

In the east of the Middle Orkhon Valley the Chögschin Orkhon River (Old Orkhon River) drains the eastern part of the Khangay Mountains and flows into Lake Ugii Nuur. Ugi Nuur is a quasi-endorheic freshwater lake, predominantly fed by the Chögschin River, only episodically showing outflow when the lake has high water levels. During these phases the alluvial plain between the Orkhon River and the lake is flooded by lake water and drainage happens via Orkhon River (Fig. 3.2).

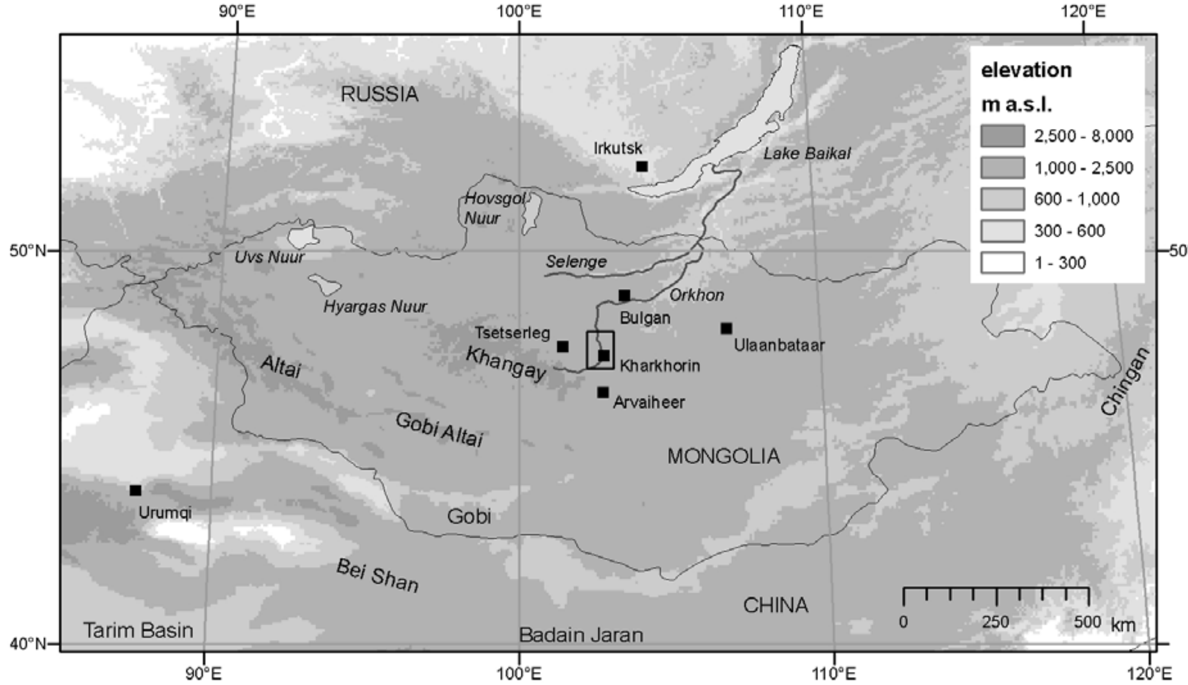

Figure 3.1: Location of the area of interest (black outline). Elevation values are based on GTOPO30 (Projection: Eckert IV, Graticule: WGS84).

3.3 Environmental characteristics

Mongolia's exogenically driven environmental characters (e.g. climate, soils, vegetation and drainage) exhibit a strong zonal gradient determined by the planetary settings (Haase, 1983). Thus, the mean annual precipitation sum decreases from 300-400 mm in the north to 100 mm and less in the south (Barthel, 1983). Mainly governed by effective moisture supply vegetation pursues this trend. Taiga forests in the north pass over into forest steppe followed by steppe, desert steppe and the Gobi desert in southward direction (Gunin *et al.*, 1999).

Breaks in the zonal trend of the environmental settings may be caused by several local or regional peculiarities, however, the most important factor is elevation. In general, an increase in elevation causes a change in climate: with increasing elevation mean air temperature decreases while precipitation sums usually increase. The latitudinal extent of the study site is relatively low. However, parts of the area of interest are located in the Khangay Mountains. Hence, to characterize the environmental setting altitudinal zones

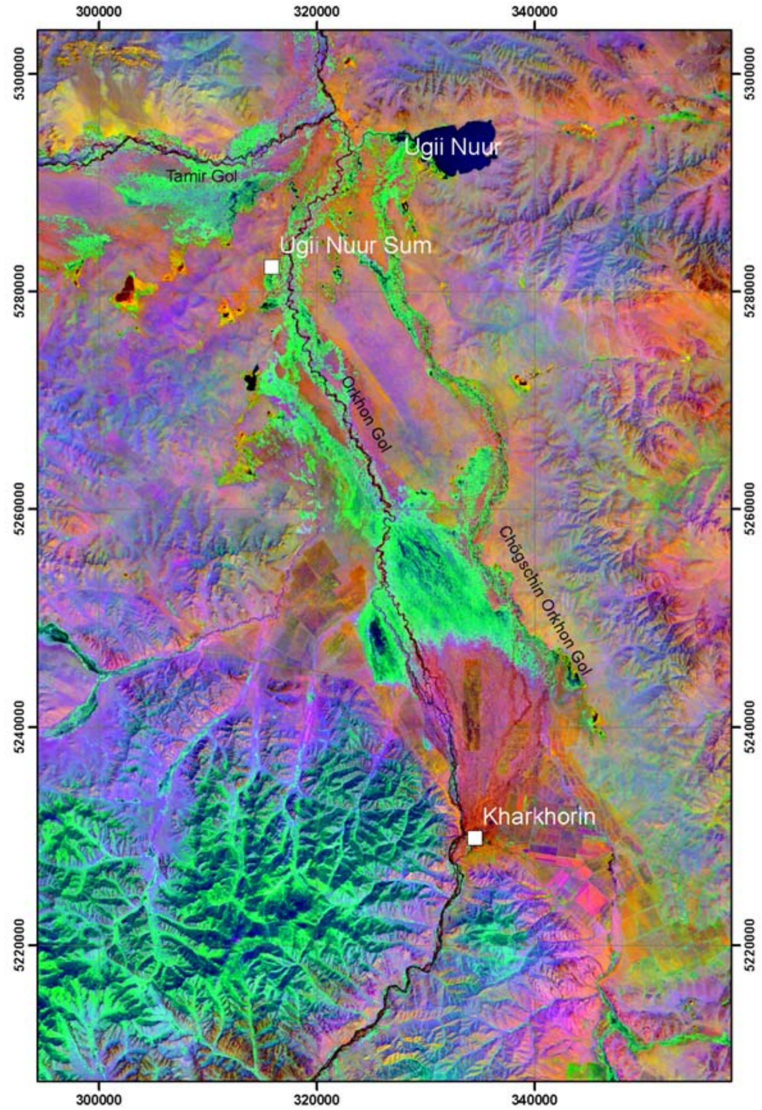

Figure 3.2: First three principal components (PC) of Landsat ETM+ imagery (22 July 2002, R-PC1, G-PC2, B-PC3, Projection: UTM 48T, WGS84). Information in the second PC (green) can be correlated with vegetation.

have to be taken into account.

3.3.1 Geology

Geological maps of Mongolia reveal a variety and complexity of rock types and structures covering the time span from Precambrian to Quaternary. This diversity is due to successive terrane accretions to the Siberian Craton and consequent structuring during the Early and Late Palaeozoic. These structures were repeatedly reactivated during the Mesozoic and

Figure 3.3: Landscape characteristics in the Upper and Middle Orkhon Valley. a) Exposition dependent Larix siberica in the northern declivity of the Khangay Mountains and the Middle Orkhon Valley. b) Basalts in the Upper Orkhon Valley. c) Tertiary weathering of granites in the Upper Orkhon Valley. d) Lake Ugii Nuur.

Tertiary responding tectonic activity in western and central China, probably triggered by the Himalayan orogeny and Tibetan Plateau uplift (Traynor and Sladen, 1995, and several authors therein).

The area of interest comprises several stratigraphical units from the Proterozoic and Cambrian ($>$ 50 Ma BP) to present. Oldest units can be found in the southeast and northwest of the Middle Orkhon Valley along a southeast-northwest stretching zone and composed of high grade metamorphic rock (mainly schists). Attached to this zone Devonian sediments are intermitted by plutonites and intrusions. The ridges of the Khangay Mountains are largely composed of Devonian to Mid-Permian sediments of marine facies that were subsequently orogenetically elevated, folded and ruptured in the response to compressional tectonics in southern Mongolia (Akademiya Nauk, 1990; Sladen and Traynor, 2000; Walther, 2005).

In the course of this tectonic activity but also during the Varisciden folding of the Khangay Mountains various plutonites and dikes formed and were exhumed by erosional processes during the Cenozoic. Induced by uplift widespread erosion and sedimentation processes in the mountain foreland and intramontane basins occurred from Triassic to early Jurassic (Traynor and Sladen, 1995). Rifting and synrift deposition resulted in the formation of an extensive belt of Late Jurassic to early Cretaceous basins especially in southern and eastern Mongolia (Sladen and Traynor, 2000). Remnants of Jurassic thin layered, highly fissile lacustrine mudstones surrounding Ugii Nuur and in the Middle Orkhon Valley may be attributed to this period. In the vicinity of Ugii Nuur reddish conglomerates are exposed that can be attributed to the late Cretacious and Tertiary and testify fluvial dynamics with high bedload transport as documented by pebble beds and channel bar sandstones (Traynor and Sladen, 1995).

From Tertiary to present tectonic faulting was accompanied by intensive volcanism depositing flood basalts in the Upper Orkhon Valley and in the east of Ugii Nuur (Walther, 2005). Along the Middle Orkhon Valley thick deposits of Quaternary unconsolidated debris and fluvial pebble and sand accumulations predominate. Variability in discharge caused the forming of fluvial terraces (Fig. 3.4) traceable on both sides of the Middle Orkhon Valley. Glaciation only played a minor role during the Pleistocene and was limited to the elevations higher than 3000 m a.s.l. (Lehmkuhl and Lang, 2001).

3.3.2 Climate

Analysis and description of local or regional climatic characteristics is restricted by the scarce data availability regarding both temporal and spatial resolution. Moreover, data quality is often poor. In order to characterize the regional climate data from the NOAA National Climate Data Center Global Historical Climate Network for the station Arvaiheer (1813 m a.s.l.) and Bulgan (1210 m a.s.l.) is used (Fig. 3.1).

According to the classification concept of Köppen (Kottek *et al.*, 2006) the climate in

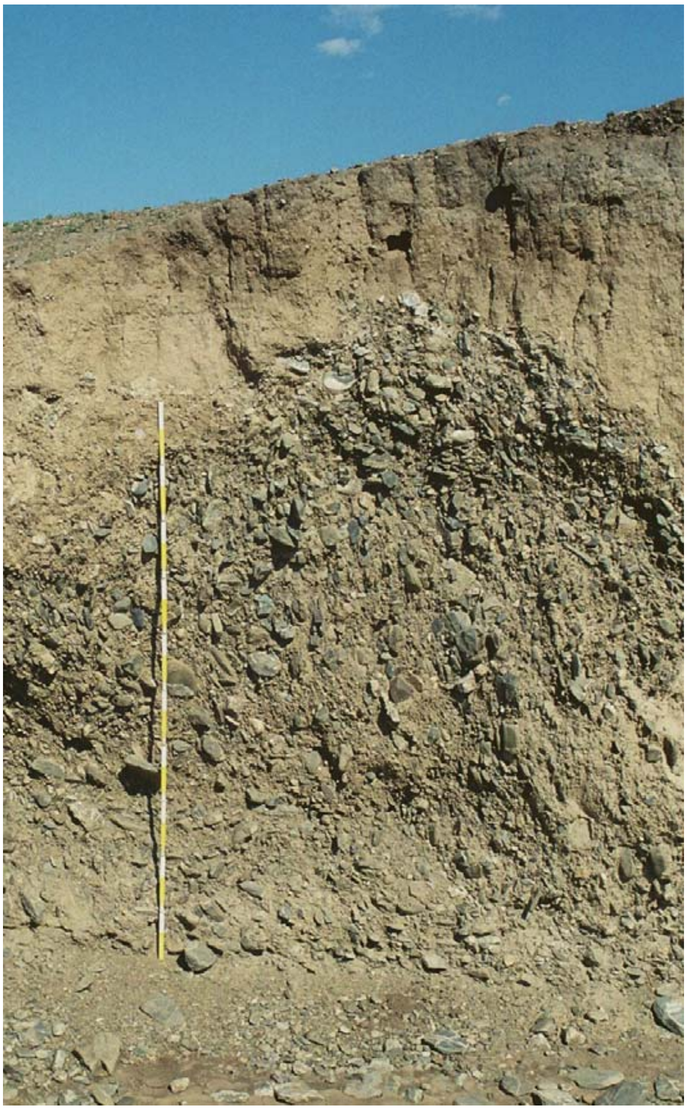

Figure 3.4: Outcrop of the Orkhon terrace close to Kharkhorin exhibits fluvial deposits composed of basalt pebbles which are cryoturbatically reworked and covered by aeolian silts and sands (Photo: Steffen Möller).

the area of interest can be described as BSk climate in the south and as Dwc climate in the north. Climate is controlled by the extreme continentality and the large scale circulation patterns resulting in strong seasonality both in air temperature and precipitation. Annual precipitation amounts average 209 and 314 mm and mean annual temperature is ca. 1.5 and −1.4°C in Arvaiheer and Bulgan, respectively.

During the winter months the predominance of the Siberian High causes unhindered outgoing heat radiation and the subsequent cooling results in mean January air temperatures below −25°C. Minimum daily temperatures may even exceed -40°C especially below temperature inversions developing in basins and valleys (Barthel, 1983). Due to the stable Siberian high precipitation during winter remains low and snow cover rarely exceeds 10 cm.

Prevailing west winds influence the Mongolian climate during the summer months. Monthly July air temperature averages around 15°C but maximum daily temperature may exceed 35°C. July is the wettest month of the year, too, but there is a strong interannual variation in monthly rainfall amounts (Fig. 3.5c, d) (Gunin *et al.*, 1999). Rainfall is mainly short and intense and often linked to heavy thunderstorms that may occur several times per day. Data on rainfall duration is unavailable but own field observations suggest that rainfall events hardly exceed three hours.

Results of an estimation of recurrence intervals of daily precipitation amounts are shown in Fig. 3.5e and f. The daily rainfall magnitude-frequency relationship was modeled using the approach proposed by Ahnert (1986). Visually the logarithmic function fits the observational data well, however, for larger precipitation amounts (¿ 30 mm/day) there is an increase in uncertainty of the model due to scarce observational data for these extreme events. According to this model statistically every 1 (5, 10, 30) years a daily rainfall of 25 mm (38, 43, 52 mm) can be expected in Arvaiheer. It is assumed, however, that these values are underestimated because wind-induced undercatch, wetting loss and evaporation loss cause a precipitation amount bias that is especially strong in forests and prairies (Zhang *et al.*, 2004).

The transitional seasons spring and autumn are short and often characterized by strong temperature increases and decreases. During this time frequent occurrence of freezing-thawing cycles is an important factor for physical weathering processes (Fig. 3.5a, b). Due to the ambiguous correlation of the diurnal temperature range and elevation (Geerts, 2003) extrapolation of these results to other altitudinal zones is not possible, yet.

The harsh climate conditions result in many constraints for agricultural activity. Singular weather events, however, even aggravate the problems especially for livestock owners. These events are termed 'Zuds' and belong to the most dramatic catastrophes leading to high economic losses for herders. Zuds generally arise from a sequence of extreme weather

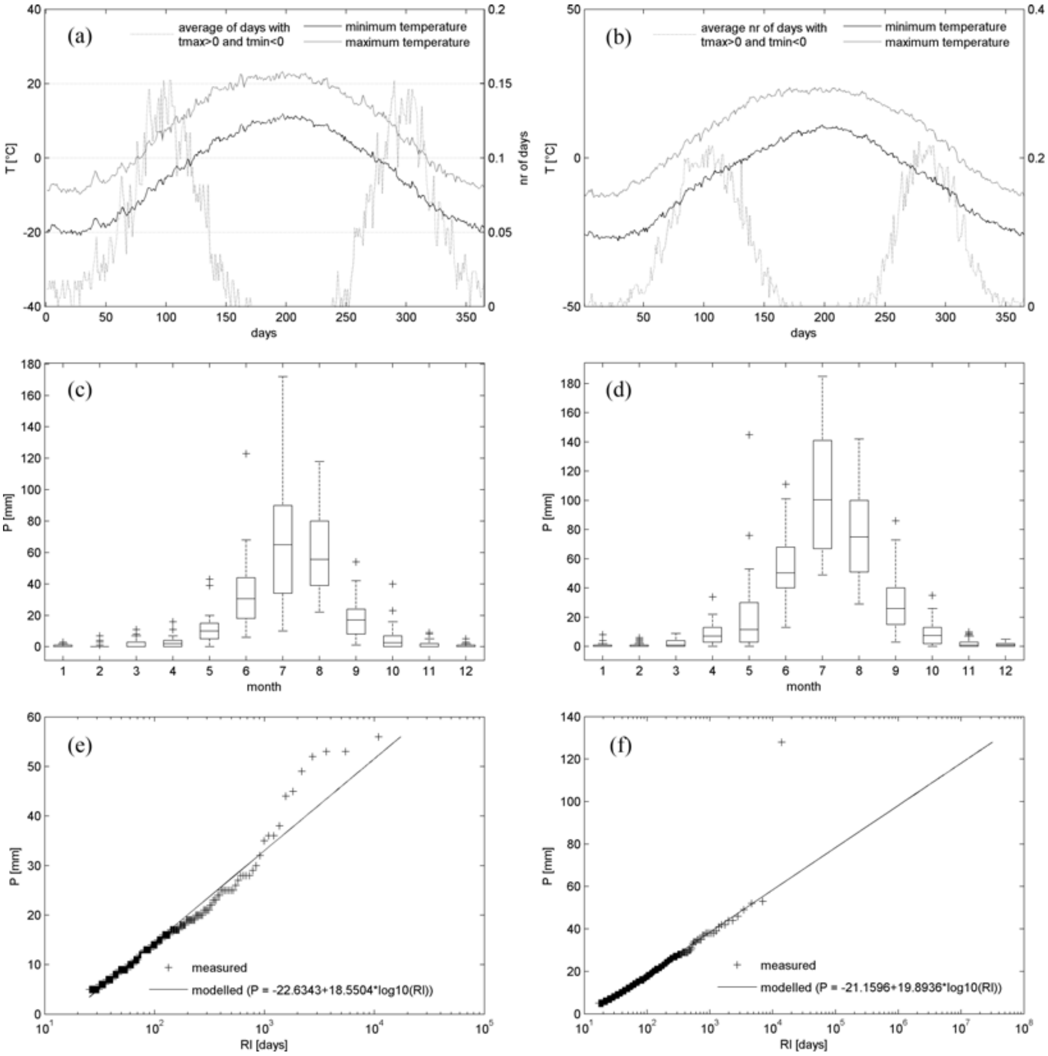

Figure 3.5: Analysis of daily climate station data of Avaiheer (a,c,e)/Bulgan (b,d,f) during 1969/1961 to 1998. (a,b) Seasonal development of mean maximum and minimum daily temperatures and average number of days with maximum temperatures greater than 0°C and minimum temperatures less than 0°C (freezing-thawing cycles). (c,d) Monthly precipitation amounts and variability. (e,f) Recurrence intervals of daily precipitation amounts.

conditions which in combination cause unavailability of nourishments or water for the herds. Starvation and dehydration of the animals during a devilish Zud winter in 1944/45 caused a nationwide livestock reduction of approx. 30%. Two consecutive Zud disasters in 1999-2000 and 2000-2001 resulted in a livestock loss of 29,640 animals in the Arhangay province only (Goroncy, 2006).

3.3.3 Soils

As in most parts of Mongolia loamy and sandy soils prevail in the area of interest, usually riddled with a considerable amount of detritus or pebbles (Gunin *et al.*, 1999). Besides, hydromorphic soils occur in the vicinity of rivers and lakes. In the slighly rolling hills of the Middle Orkhon Valley and in intramontane basins there is a predominance of Kastanozems in regions below 2000-1700 m a.s.l.. On steep slopes these steppe soils are poorly developed, frequently only a few decimeters thick and formed in debris cover in a sandy to loamy matrix (weathered layer). Much thicker weathered layers can be found in the foothills and valley floors. Parent material of these soils is rich in skeleton which is often layered and shows adjusted pebbles and debris (Fig. 3.6). It is assumed that in these locations an interfingering of autochthonous weathered material and soil sediments (colluvial deposits) prevails. Usually calcrete layers and chalk precipitated on the bottom of debris and pebbles are found in variable depths in the Kastanozem zone (Fig. 3.6) (Haase, 1983; Klinge, 2001) wherever the hydrologic gradient is small enough to allow ascendent soil water movement. Caragana roots penetrating the soil up to two meters demonstrate strong soil rooting.

In the mountainous areas a differentiation of the Kastanozems occurs according to the aspect. Due to a stronger radiation and subsequent increased evaporation soils tend to be drier and lighter in south- and westward inclined slopes while north- and eastward inclined slopes have more favorable moisture conditions (Haase, 1983; Klinge, 2001).

Between 1700 m and 2000-2400 m a.s.l. more humid conditions and stronger exposition to solar radiation lead to a development of A-C-soils with thick humus horizons due to a lack of decomposition of litter (Paratschernosems). Permafrost and the extremely low winter temperatures prevent the dislocation of soluble and promote podzol formation producing patches of Cryotaigasoils (Haase, 1983).

Above 2000 to 2400 m a.s.l. soils constitute of partly thick (up to 80 cm) meadow soils characterized by a distinct humus-rich top soil (Dernosem) above a C-horizon (A-C-soil). Their strong relationship to steppe soils constitutes in high humus contents up to 8 mass-%. They interfinger with peat bogs that develop close to springs and in topographic sinks where ground ice impedes percolation (Haase, 1983).

Figure 3.6: Kastanozem profile developed in a top to bottom sequence of colluvial/alluvial deposits, aeolian fines and slope debris. Below 60 to 70 cm a indurated calcrete horizon has established (Photo: Steffen Möller).

Above 2900 to 3200 m a.s.l. debris and boulders prevail and a development of soil is constrained due to cryoturbatic processes and the lack of vegetation.

3.3.4 Vegetation

The general vegetation pattern of Mongolia follows a zonal, climate dependent sequence (Gunin *et al.*, 1999). Transitions between these zones are rather continuous but often constitute in aspect-dependent vegetation mosaics Hilbig (2000); Dulamsuren *et al.* (2005b).

The study site is mainly situated in the steppe region. The higher elevated regions of the Khangay Mountains can be classified as mountain steppe or mountain forest steppe (Barthel *et al.*, 1962). Here, sparse Larix-populations are mainly restricted to northern exposed slopes above 1350-1400 m a.s.l. (Fig. 3.3a) (Walther and Gegeensuvd, 2005). The sharp contrast to the deforested southern exposed slopes in the mountainous regions is attributed to the different exposition to solar radiation causing favorable moisture, temperature and edaphic conditions (Treter, 1996; Sommer and Treter, 1999). Along the Orkhon River locally riverine forests assembled predominantly of *Ulmus* and *Salix* occur. The slightly rolling plains of the Middle Orkhon Valley are covered by steppe type vegetation which can be subdivided into the three major types *Artemisia*-, *Stipa*- and *Allium*-Steppe.

The reasons for the present dominance of steppe vegetation in the area of interest are disputed. Extremely high grazing pressure and unregulated lumbering suggest that the present day vegetation is strongly influenced by human activity since earlier than the Medieval (Hilbig, 2000; Rösch *et al.*, 2005). Fernandez-Gimenez and Allen-Diaz (2001) show that livestock influences plant species composition by defoliation, trampling, nutrient enrichment and depletion over the broader landscape scale. Dulamsuren *et al.* (2005a), however, doubt the general significance of human for producing the north-south pattern of vegetation units in the forest-steppe ecotone by presenting evidence that site conditions like moisture supply and radiation vary in a short spatial range and determine ground vegetation. Furthermore, it has been shown that repeated expansion and retreat of steppe vegetation correlated with decreasing and increasing precipitation since 15 ka BP (Tarasov *et al.*, 2000). Presumably both human activity and climate govern present vegetation dynamics (Gunin *et al.*, 1999).

3.3.5 Drainage

The major drainages are perennial (Orkhon River, Chögschin and Tamir River). Due to highly mobile channels these rivers can be classified as braided in the vast Middle Orkhon Valley. Following the climatic seasonality in precipitation the Orkhon discharge has its maximum during July with a monthly average around 100 qm/s (http://www.sage.wisc.edu/riverdata, 10. Dec 2006).

Figure 3.7: Channel morphology at Ugii Nuur headwater area. The picture was taken one day after a heavy rainfall event. The site shown has a drainage area of around 0.5 km^2.

Episodic run-off during high precipitation events results in the incision of channels into the thick debris cover and locally into bedrock (Fig. 3.7). These channels, however, are rarely connected and do not form a regional drainage network. They are arheic where they enter broader valleys or flat to slightly inclined terrain. In the catchment adjacent to Ugii Nuur it was observed that concentrated surface run-off during high rainfall events rarely reaches the lake but prior infiltrates and disappears subterraneous. Hence, it is suggested that these drainage characteristics are a result of a factor combination of high infiltration in sandy and silty soils and short but intensive rainfall events.

3.4 Geomorphological and paleoenvironmental implications

The environmental characteristics of the Upper and Middle Orkhon Valley presented are the results of endogenic and exogenic processes that vary in space and time. These processes create a huge diversity of materials and landforms that differ in scale and life time (Ahnert, 1996). Thus, landforms and their associated materials offer archives to be analyzed in order to understand the underlying processes of their genesis. As many of these landforms are relic or inactive they allow insight into paleoenvironments and their dating enables their temporal placement. Selected examples of landforms shall clarify this issue in terms of the area of interest.

3.4.1 Lake systems

The water input-output ratio of lakes is an important measure to evaluate the climatic evolution of catchments. Closed-basin lakes react on changes in this ratio by increasing or decreasing water levels and establish a shoreline when the water level restabilizes at a new position Sack (2001); Street-Perrot (1980). Depending on the substratum and speed and type of lake level change altering shorelines can be deduced from beach ridges, beach terraces or cliff edges (Street-Perrot and Harrison, 1985). In Mongolia and northwestern China these landforms have proven to be valuable indicators for paleoenvironmental interpretation (e.g. Grunert *et al.*, 2000; Pachur *et al.*, 1995; Walther, 1998, 1999; Walther *et al.*, 2003; Wünnemann *et al.*, 1998; Wünnemann and Hartmann, 2002). In the Upper and Middle Orkhon Valley only a few lakes exist with Ugii Nuur being the largest. (Walther and Gegeensuvd, 2005) describe for Ugii Nuur the existence of beach ridges in 2.5 and 3.5 m above the present lake level. Yet, as Ugii Nuur is only episodically a closed lake basin and opens in the west towards the Orkhon River, the question on the damming of the lake remains unexplained. Smaller lakes in the Orkhon catchment, however, show strong interannual fluctuations in lake level. Landsat imagery available for 1995 and 1999 show closed water surfaces in the Middle Orkhon Valley close to Ugii Nuur Sum that have vanished in 2001 and 2002.

Besides geomorphological evidences lake systems offer lacustrine sediments that are the definite deposition in a complex storage system and, thus, constitute an answer to the drainage basin's geomorphological reaction to climatic, tectonic or human impacts. The continuity of lacustrine sediments is their big advantage if discrete spatial information is lacking. The signal given by lacustrine sediments is mixed, allowing conclusions on the paleolimnic environment (diatoms, authigenic minerals), paleotemperature (oxygen isotopes of shells and authigenious minerals), the local to regional vegetation cover (pollen) and the overall weathering conditions in the drainage basin (bulk chemistry, clay minerals).

In addition to the deposition of allochthonuous detritus, lacustrine sediments are characterized by precipitation of authigenic minerals from aqueous solutions. Precipitation of authigenic minerals is substantially influenced by lake water salinity and its chemical composition, thus, authigenic minerals are particularly of interest for the reconstruction of the palaeolimnic environments. In contrast, the pedogenic minerals (such as clay minerals, oxides) in lacustrine sediments contain information about the synsedimentary environmental conditions in the drainage basin (Schütt, 1998, 2004a).

Lacustrine sediments extracted from Ugii Nuur have been analyzed on organic matter (total organic carbon (TOC)), diatoms and pollen distribution and provide evidence for varying lake levels and moisture supply during the Holocene (Walther and Gegeensuvd, 2005). Pollen profiles of core UGI-3 were analyzed by (Rösch *et al.*, 2005). They suggest increased woodland distribution during the middle Holocene caused by increased precipitation. A subsequent decline of the arbor-nonarbor pollen ratio is interpreted as human induced (Rösch *et al.*, 2005). Further analysis on mineralogical and chemical parameters is currently implemented.

3.4.2 Relief and morphodynamics

However, information on drainage basin geomorphodynamics, on the predominating processes of detrital material flows, magnitude and frequency of these processes and their climatic, tectonic or anthropogenic impulses can only be poorly deduced from lacustrine sediments. In contrast, this information is given by temporally discontinuous, ephemeral sediments to be found inside the drainage basin, such as fluvial and colluvial deposits (e.g., alluvial fans, river terraces), sediments of mass movements etc. However, although they lack temporal continuity, these sediments have the advantage of being spatially discrete.

Periglacial landforms and their spatial occurrence are strongly associated with climate. As noted before there is a strong climatic dependence on elevation that is reflected in the spatial distribution of soils and vegetation. Pekala and Repelewska-Pekalowa (1993) and Lehmkuhl and Lang (2001) determine the present lower limit of active cryoplanation terraces and solifluction forms at 2700-2900 m a.s.l. in the Khangay Mountains. Discontinuous permafrost and smaller but active forms are found as low as 2200 m a.s.l. on northern exposed slopes. Findings of inactive ice-wedges as low as 1400 m a.s.l., however, suggest significant changes of temperature and precipitation during the Pleistocene in the Khangay Mountains (Lehmkuhl and Lang, 2001) that have been previously recognized by Owen *et al.* (1997) and Owen *et al.* (1998) in the Gobi Desert. Glaciation during the Last Glacial Maximum is likely to have never occurred in the area of interest. A depression of the snow line or equilibrium-line altitude (ELA) to 2700-2800 m a.s.l. in the Khangay Mountains is suggested by Lehmkuhl *et al.* (2004) and Lehmkuhl and Lang (2001) which did not affect the area of interest.

Aeolian sediments play an important role in landscape evolution especially during arid periods. In Mongolia they are widespread and occur independently from altitude. Their deposition happened both during the Pleistocene glacial periods and interstadials (Grunert and Klein, 1998; Grunert and Lehmkuhl, 2004; Grunert and Dasch, 2004). However, meteorological observations of dust storms provide evidence for present aeolian activity (Natsagdorj *et al.*, 2003; Dulam, 2005). Reworked fluvial sediments of large rivers and dried out lakes are identified as sources of the wind blown material (Grunert and Lehmkuhl, 2004). In the Upper and Middle Orkhon Valley several dune fields or sand sheets exist, often vegetated by Gramineae achnatherum. Surfaces with strong aeolian accumulation have been identified by a supervised classification of Landsat ETM+ imagery (see figure in Bemmann *et al.* (2008)). The identified regions are located in the vicinity of rivers and in the footzones of hills. Due to the prevalence of WNW wind directions a preponderant occurrence of aeolian sand sheets on south and southeast facing slopes may indicate an orographically induced settling in the wind shadow of mountains.

3.5 Perspective

Cryoturbatic disturbance of periglacial debris, accumulation of material displaced by sheet flow, interfingering fans and aeolian loess-like sedimentation create a relatively uniform geomorphological appearance of terrestrial sedimentary architectures despite their variable processes of origin (Haase, 1983). This uniformity makes it a challenge to unravel the complexity of landscape evolution. An ongoing human interference with landscape forming processes since prehistoric times (Rösch *et al.*, 2005) even complicates this process system. Changes in human activities like lumbering, animal husbandry and cultivation of grains affect the environmental settings and modify geomorphological process intensities. Thus, in order to address the issue of landscape evolution and to understand the interactions with cultural and societal development in the Upper and Middle Orkhon Valley an integrated approach combining physio-geographical and archeological research is required and promising.