

MID-HOLOCENE LANDSCAPE DEVELOPMENT
IN THE CARPATHIAN REGION
PASTORALISM, CLIMATE AND THEIR INTERDEPENDENCIES

by

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Inaugural Dissertation
to obtain the academic degree
Doctor rerum naturalium in Geography

submitted to the Department of Earth Sciences
of Freie Universität Berlin

Berlin 2016

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Date of disputation

June 20, 2016

Für Soyoung und Karl

ACKNOWLEDGMENTS

This thesis was financially, technically and scientifically supported by the German Research Foundation (DFG) funded *Cluster of Excellence 264 "Topoi"*.

I would like to express my great appreciation to my supervisor Prof. Dr. Brigitta Schütt for her valuable advices in realising this thesis. Prof. Schütt supported this work not only as co-author and by improving the presented papers, she also helped to adjust working approaches when stagnation impended. Furthermore, I want to thankfully acknowledge my second supervisor Prof. Dr. Schier for establishing the research project this thesis is part of. Without his efforts to integrate the different studies this thesis would not have been achieved.

As part of the larger research project, Ana Grabundzija, Chiara Schoch and Christian Küchelmann conduct studies that contribute archaeological and archaeozoological information to the project. I thank you very much for appreciating our mutual research topic – the woolly sheep. You were great support in developing general aspects of the research approach and it was always beneficial to commonly ruminate on past pastoralism.

Fieldwork and laboratory analyses were only feasible due to the energetic support of Dr. Daniel Knitter, Tina Gerl, Stefanie Bachmeier, Gerhárd Golen and René Hahn. I also warmly thank my co-author Dr. Anna Dobos for contributing her great scientific expertise to the fieldwork and the related paper. Furthermore, I cordially thank Dr. Judit Koós and her colleagues from the Herman Ottó Múzeum in Miskolc for kindly providing valuable archaeological data.

The meta-analysis of published pollen data realised in this thesis required arduous data extraction. In this, I obtained invaluable help from Tina Gerl and Stefanie Bachmeier to whom I want to give much thanks. Once again, my great appreciation goes to Dr. Daniel Knitter who was always available when technical problems occurred in the course of data processing. Besides, conceptual discussions with Daniel and his methodological advices have always been of fruitful value for the project designs.

Developing this thesis would not have been as rewarding without my colleagues from the Institute of Geography at the Freie Universität Berlin and my fellows from the Dahlem Research School. I warmly thank Julia Meister, Johanna Seidel, Tina Michel, Jun.-Prof. Dr. Wiebke Bebermeier, Moritz Nykamp, my office mate Michael Thelemann, Thusitha Wagalawatta, Torsten Klein and all colleagues not mentioned by name for encouraging conversations and joyful barbecue sessions. Special thanks go to Dr. Jan Krause for his patient support in all organisational and administration issues.

My very personal thanks go to my family. I warmly thank my parents and brothers who are an unquestioning support during hard times. In the end I want to express my deepest gratitude to my wife Soyoung Park. You supported the development of this thesis by your encouraging attitude to life in all its facets. This is what makes keep on keeping on so gladsome.

ABSTRACT

This thesis was developed in the context of the Topoi Research Group A-4 "*Textile Revolution*" which is part of the Research Area A of the *Cluster of Excellence Topoi*. The central research question of the group focuses on the emergence and spread of early wool economies. The single research projects included in the group target different aspects related to wool processing.

In this thesis changes of Holocene environmental dynamics related to increasing pastoral activities are investigated. The research project includes two independent studies on Holocene environmental change in the Carpathian region. The regional and supra-regional scales are addressed with a standardised meta-analysis of published pollen data. The local scale is addressed by investigating fan deposits of tributary valleys in the Bükk Mountain foreland in northern Hungary. A precedent study reflects the conceptual and thematic integration of the different research projects within the group. This gives implications for a constructive contribution to the interdisciplinary research approach. Increment value due to the integration of different scientific fields may only be obtained if basic parameters of the single projects are thoroughly aligned and specific understanding of the different research objects is transparent.

Results of the data evaluation imply an increase of herding activities in the course of the Chalcolithic and Early Bronze Age periods. In the South Carpathians, increased herding indication is evident for the Early Chalcolithic, whereas in northern Hungary grazing impact increases only during the Late Chalcolithic – Early Bronze Age transition. This is synchronous with enhanced sediment deposition in the Bükk Mountain foreland. However, grazing impact was overall low and significant land degradation due to pastoral activities are not implied by the data.

ZUSAMMENFASSUNG

Diese Dissertation wurde im Kontext der Topoi Forschergruppe A-4 "*Textile Revolution*" verfasst. Die Forschergruppe ist Teil des *Exzellenz Clusters Topoi*. Die zentralen Forschungsthemen der Gruppe sind die Entstehung und Ausbreitung früher Wollverarbeitung. In den einzelnen Forschungsprojekten werden unterschiedliche Aspekte die mit früher Wollverarbeitung einhergehen untersucht.

In dieser Arbeit werden Holozäne Umweltveränderung untersucht, die im Zusammenhang mit intensivierter Tierhaltung stehen. Die Arbeit umfasst zwei unabhängige Studien in denen Holozäne Landschaftsdynamiken im Karpatenraum sowohl auf regionaler und überregionaler, als auch auf lokaler Skale untersucht werden. Die überregionale Skale wird mittels einer Metaanalyse publizierter Pollendaten analysiert. Die Untersuchungen auf lokaler Skale stützen sich auf Analysen von Schwemmfächersedimenten und geomorphologischen Kartierungen im südlichen Vorland der Bükk Berge in Nordungarn. Dem vorangestellt ist eine Betrachtung der konzeptionellen und thematischen Integration der verschiedenen Forschungsprojekte innerhalb der Gruppe. Daraus werden Implikationen für die konstruktive Umsetzung eines gemeinsamen Ansatzes abgeleitet. Ein ergebnisorientierter Mehrwert kann nur erreicht werden wenn grundlegende Parameter der Einzelprojekte gut abgestimmt werden und das jeweilige Verständnis der Forschungsobjekte kommuniziert wird.

Die Ergebnisse der Datenanalysen weisen darauf hin, dass sich Weideaktivitäten während des Chalkolithikums und der Frühen Bronzezeit verstärkten. In den Südkarpaten verstärken sich Beweidungsanzeichen bereits während des Frühen Chalkolithikums, während in Nordungarn Hinweise auf verstärkten Beweidungsdruck erst während des Übergangs vom Späten Chalkolithikum zur Frühen Bronzezeit auftreten. Dies passiert zeitgleich mit gesteigerter Sedimentablagerung im südlichen Vorland der Bükk Berge. Die Beweidungseffekte waren jedoch insgesamt gering und die Daten weisen nicht darauf hin, dass gesteigerte Viehhaltung innerhalb des untersuchten Zeitraums mit signifikanter Landschaftsdegradation einher ging.

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INTRODUCTION

This thesis was developed in the context of the Topoi Research Group A-4 *Textile Revolution* which is part of the Research Area A of the *Cluster of Excellence Topoi*. The central research aim of the Topoi Research Area A is the investigation of past human-environment interactions in the light of emerging innovations. The superordinate research topic of the group A-4 is the advent and spread of wool processing during the mid-Holocene. The idea of emerging sheep wool production and related textile economies, propagating as revolutionary innovation from West Asia towards Central Europe refers to Sherratt's concept of the "Secondary Products Revolution" (Sherratt, 1981, 1983b). The projects comprised in the research group target different aspects connected to the advent of early wool production. Similarly, different scientific disciplines are represented in the research group: Archaeological studies aim to trace changes of spinning and weaving techniques by investigating spindle whorls and loom weights. Furthermore, evidence for wool use is compiled as reflected by iconographic finds and textile-related objects such as needles, combs and buttons. Archaeozoological studies investigate bone assemblages to estimate the relative importance of sheep compared to other animals and to construct herd structures and biometric measures. Cuneiform texts from the Late Uruk to Ur III periods (5200 – 4000 cal BP) are studied to reveal details about specialized wool economies in Mesopotamia.

In this thesis changes of environmental dynamics related to increasing pastoral activities are investigated. On the one hand this topic forms an independent approach rooted in the well established research context of deciphering Holocene human-environment interactions. On the other hand it fits well into the concept of the research group which is designed to elucidate spatial and temporal aspects of emerging wool economies. Finally, the project embodies the link between socio-economic progress of past humans and the natural environment affected by, as well as affecting this progress. By this, the central focus of the Topoi Research Area A is integrated into the group.

1.1 PROJECT BACKGROUND

The reconstruction of causes, triggers and effects of Holocene landscape development is a major concern of earth sciences. In this, the integration of archaeological and geographical disciplines has become increasingly important in the last decade in order to include a more differentiated view on the role of prehistoric human beings (Verstraeten, 2013). Accordingly, the superordinate question of this thesis emerges from the archaeological sciences: In 1981, Sherratt introduced the model of the "Secondary Products Revolution". For the first time he integrated archaeozoological and archaeological data to develop the narrative of the use of secondary animal products such as milk, wool and traction. He dated the start

of this process to c. 6000 BP and postulated a propagation as complex package from West Asia towards northwest. The model quickly gained attention in the research community and focus was put on spatial and temporal differentiation of the process. This led to the modern understanding of different secondary animal products emerging from West Asia and spreading towards Central Europe with temporal and spatial variability rather than as a revolutionary package (Greenfield, 2010). However, exact spatio-temporal trajectories of propagating use of secondary animal products are poorly understood. The Topoi research group A-4 was created to shed light on the complex of one of these secondary animal products, i.e. sheep wool.

1.2 OBJECTIVES

The objectives of this thesis are to evaluate the impact of early herding activities on the landscape and to contribute to the comprehensive research complex of the spread of the wool-bearing sheep and early wool economies. For the extension of sheep husbandry from mere meat production towards additional wool production implies increasing grazing pressure on the landscape exerted by larger herds. These objectives are addressed in three different studies:

- The intricacy of investigating the spread of early wool economies implies basic integration of different research fields. A common project design is required and it is coercively necessary to find a mutual scientific language. This aspect is reflected in Schumacher et al. (2016b): *Near Landscapes of the Textile Revolution*. The paper addresses the integration of geographic research into an archaeological research context by reference to the spread of early wool processing and benefits and limitations are discussed. Crucial aspects inherent to such a complex topic are pointed out as e.g. scale-dependencies and variable significance of archives and proxies.
- Conceptual implications for the project design as outlined in Schumacher et al. (2016b) refer to temporal and spatial scales of environmental change. Supra-regional landscape development is investigated in Schumacher et al. (2016a): *Mid-Holocene Vegetation Change and Herding-related Interferences in the Carpathian Region*. The study comprises a meta-analysis of published palynological data from the Carpathian region to trace herding activities during the mid-Holocene. Independent data on climate change and comprehensive data on prehistoric settlement activities are included to evaluate the significance of the respective factors affecting the vegetation dynamics. Early Chalcolithic herding indications in the South Carpathians are synchronous with the presumed advent of intensified wool production, whereas increased herding indication in northern Hungary dates to the Late Chalcolithic and Early Bronze Age periods. The overall grazing pressure, however, was rather low and severe land degradation did not occur.
- On the local scale a geomorphological case study on Holocene landscape development was conducted in Schumacher et al. (accepted): *Holocene valley incision in the southern Bükk foreland – climate-human-environment interferences in*

northern Hungary. The Holocene formation of the middle course of the Hór valley was reconstructed based on GIS- and laboratory analyses. The results indicate rather climate-controlled than human-related landscape development during the Holocene. Nonetheless, increased sediment deposition at c. 4800 cal BP is related to human activities in the area and corresponds to increased herding indication as derived from Schumacher et al. (2016a).

In chapter 6 conceptual aspects of the research approach and its relation to the theoretic approach of Topoi Research Area A are discussed. The results of the studies are reflected in the light of variable landscape resilience and varying sensitivity of environmental archives and proxies for past landscape change. Finally, the role of pastoral activities in Holocene landscape development is summarised briefly.

1.3 EARLY HUMAN IMPACT ON THE LANDSCAPE – A STATE OF THE ART

Holocene landscape development took place in the interplay of climate influences and the impact of human activities. Both sets of variables exerted their influences with fluctuating intensities and spatial and temporal variability. The search for imprints of past human activities on the one hand, and climate fluctuations on the other hand is a long-lasting research topic in environmental and earth sciences. The emphasis of the human role affecting landscape development increased with progressing availability and awareness of data on prehistoric and historic settlement activities (Bintliff, 2002). The inclusion of different scientific disciplines was enhanced and research concepts underwent important changes: the independence of the different disciplines and their research targets was promoted, as well as the necessity for integrated and interdisciplinary approaches was realised (Verstraeten, 2013) (see section 2.1). Today, a myriad of case studies on vegetation development, climate fluctuations and sediment fluxes give evidence about Holocene environmental dynamics. Similarly, the knowledge about past human societies, their socio-economic strategies and cultural behaviour has enormously increased. Improved dating techniques contribute to increasing reliability of temporal relations between natural and socio-cultural processes. Elaborate scientific methods including isotope analyses of animal bones and dental enamel, or analyses of DNA from plants, bacteria and domestic mammals extracted from lake sediments give valuable insights in past human activities and their impact on the environment. Reviews comprising larger numbers of case studies give regional overviews about the spatio-temporal development of human-environment interactions (e.g. Dotterweich, 2008; Dreibrodt et al., 2010; Dusa et al., 2011; Kalis et al., 2003; Notebaert and Verstraeten, 2010). Additionally, modelling human-environment interactions contributes to the understanding of interdependencies between the involved variables (Barton et al., 2012; Wainwright, 2008). The following section gives an overview about approaches and techniques applied to trace human impacts on the landscape.

1.3.1 *Traces of past agro-pastoral activities*

Pollen, fungal spores and charred plant remains are well preserved in wet environments such as lakes, mires, peat bogs, or oxbow lakes. Palynological studies contribute to the understanding of Holocene vegetation development and human-environment interferences since several decades (e.g., Bakker et al., 2012; Behre, 1981, 1990; Bottema and Woldring, 1990; Prentice et al., 1996; Willis, 1997; Willis et al., 1997). The thematic focus of case studies reaches from reconstructing succession processes and regeneration phenomena of particular species (e.g. Finsinger et al., 2006; Magri, 2008; Peglar, 1993) to deducing past land use practices (e.g. Behre, 2002; Feurdean et al., 2009; Magyari et al., 2012; Willis, 1997). Primary indicator species such as *Secale*, *Hordeum* are used to infer on plant cultivation, whereas secondary indicator species such as *Plantago lanceolata*, *Rumex acetosa*, *Polygonum aviculare*, *Urtica*, etc. are understood to represent vegetation disturbance by animal grazing and trampling (Behre, 1981, 1990; Bottema and Woldring, 1990; Magyari et al., 2012). In addition, coprophilous fungal spores give evidence about the presence of animals and are used to infer on past grazing pressure (e.g. Geantă et al., 2014; Hausmann et al., 2002; Thöle et al., 2016). Palynological richness and rate of change are statistical measures that are adduced to support evidence of herding-related vegetation disturbance (Birks and Line, 1992; Huntley, 1992; Milchunas and Lauenroth, 1993; Schütz et al., 2003). Canonical correspondence analysis can be used to investigate the role of human activity impacting the vegetation (Birks et al., 1988). The high-dimensional data set of a pollen sequence is reduced to a lower-dimensioned space with eigenvectors accounting for the variance in the data. Studies have shown that plant species indicating human activity scored on the first eigenvector and thus account for the highest explanatory value of vegetation change (Kerig and Lechterbeck, 2004; Lechterbeck, 2008; Lechterbeck et al., 2009). However, the investigation of pollen data do not allow to infer on land degradation processes beyond vegetation disturbance.

1.3.2 *Traces of past land degradation and relation to human activities*

In contrast to pollen data, sediment sequences from terrestrial archives are used to assess past soil erosion and the involved factors. Comprehensive dating of the deposits and reference to archaeological data reveal temporal relations between human activity and phases of increased sediment accumulation (e.g. Bork, 1998; Fuchs, 2007; Fuchs et al., 2004; Förster and Wunderlich, 2009; Houben et al., 2006; Seidel and Mäkel, 2007; Superson et al., 2014). Yet, soil erosion and human activity can not be linked causally. The combination of pollen data and geochemical records extracted from the same sediment archive is a useful method to relate evidence of past human activities as reflected in vegetation disturbances and rates of detrital sediment flux to the archive (Bajard et al., 2016; Giguët-Covex et al., 2011; Silva-Sanchez et al., 2014; Wick et al., 2003). Molecular markers such as plant lipids and isotope data ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) of organic remains give further information on vegetation dynamics presumably related to human activities (Massa et al., 2012; Simonneau et al., 2013). Similarly, carbon isotope analyses of herbivore bone

collagen allows to infer on pasture strategies (Doppler et al., 2015). Finally, DNA from plants, bacteria and domestic mammals extracted from lake sediments give direct evidence of cultivated plant taxa and herded animal species (Giguët-Covex et al., 2014).

1.3.3 *Potential human activities and their environmental impact*

All mentioned approaches have in common that the investigated environmental archives have limited spatial representativity. Bauer (2014) presents an approach that aims to investigate a large spatial scale waiving to acquire elaborate proxy data. Space born visible, short-wave infrared and near infrared data (ASTER) are used to develop soil distribution maps displaying the classes “soil” and “bare rock”. Large-scale data on prehistoric settlement activities are included to assess the spatial variability of settlement density. The relation between surface properties (soil, bare rock) and settlement density (low, high) are evaluated in a regression model and compared to the relevance of other variables such as slope and elevation. The explanatory value of the archaeological record for the land surface properties appeared to exceed the explanatory values of all other investigated variables.

Fischer-Kowalski et al. (2014) present a fundamentally different approach towards the assessment of past human impact on the landscape. The authors follow an inverse line of argumentation and do not target an explicit site or study area but refer to a generalized theoretical scenario. The starting point of their considerations is the human agency at a given time. Human impact on the environment is then modelled interpreting the formula:

$$I = P * A * T$$

introduced by Ehrlich et al. (1971) with I = impact: human pressure on the environment, P = population: human population numbers, A = affluence: energy, material available per person, T = technology: technologies used to acquire the consumed energy. The variable population is differentiated in three modes of subsistence namely “the hunting and gathering mode”, “the agrarian mode” and “the fossil fuel-based industrial mode” and their calculated partial pressure on the environment is added. Running this model with estimated input data for the time period 1950 BP – 450 BP revealed that the increase of human pressure due to population growth was doubled considering affluence. Of course, this can only be understood as qualitative description of *de facto* human impact. Nonetheless, modelling human-environment interactions may help to understand interrelations between the different system components (e.g. Barton et al., 2012; Lemmen et al., 2011; Wainwright, 2008; Wainwright and Millington, 2010).

1.3.4 *Past human impact in the Carpathian region*

For the Carpathian region knowledge about past human-environment interactions is comparably scarce. Well-dated case studies from the region mainly focus on Holocene vegetation development in the Carpathian mountain range. Few

studies investigate terrestrial sediment archives and consider sediment geochemistry to infer on past soil erosion. For the Neolithic period human-induced vegetation changes are recorded in northern Hungary (Bácsmegi et al., 2012; Gardner, 2002; Magyari et al., 2008, 2012; Medzihradszky, 2001, 2005; Willis, 1997; Willis et al., 1995). In the course of the Bronze Age period human impact becomes more pronounced (Gardner, 2002; Magyari et al., 2008, 2012). Sümegi (1999) finds weak human impact around an oxbow lake in north-eastern Hungary for the Chalcolithic period, whereas significant human interferences start only with the onset of the Iron Age. Low and unspecific human-related vegetation disturbances are evident in the Apuseni Mountains (Feurdean and Willis, 2008; Feurdean et al., 2009), the East Carpathians (Fărcaș et al., 2013) and the South Carpathians (Tanțău et al., 2003, 2006, 2009). However, between 4000 – 3000 cal BP the vegetation appears to be affected by human activity throughout the Carpathian Mountain range (Feurdean, 2005; Feurdean and Willis, 2008; Feurdean et al., 2009; Fărcaș et al., 2013; Geantă et al., 2014; Magyari et al., 2009; Tanțău et al., 2003, 2006, 2009, 2011, 2014). For an extended literature review and discussion of prehistoric human-environment interferences see section 4.2.

1.4 REGIONAL SETTING

The spatial focus of the Topoi Research Group A-4 extends from today's Iran in the southeast to the Carpathian region including Hungary in the northwest (Figure 1 a). While the southeastern parts of the study area provide valuable archaeozoological, archaeological and textual sources, studies on Holocene landscape development in the context of human activities are scarce. Particularly, the preservation of pollen as proxies for herding-related vegetation changes are poor under arid and semi-arid climate conditions. Thus, the spatial focus for studying past grazing impact on the environment was put on the Carpathian region (Figure 1 b). Here, a substantial number of case studies was published in the past 15 years providing pollen, charcoal and geochemical data with high temporal resolution. Besides, archaeological research has a long history in the region (Chapman et al., 2009; Duffy et al., 2013; Gyucha et al., 2011; Kalicz, 1994; Sherratt, 1982, 1983a). The overlap with the study areas focused by the archaeozoological and one of the archaeological projects is a key to achieving mutual benefit of the interdisciplinary project.

The sites included in the meta-analysis are located in a variety of landscape types including the montane to sub-alpine Carpathian Mountain range, the montane and colline areas of the north Hungarian mid-mountains, the colline areas of the Transylvanian Basin and the lowlands of the Great Hungarian Plain (Figure 1, Table 1). Considered separately, the area is large enough to address spatio-temporal trajectories of herding signals. Furthermore, the integration of different natural environments allows to question herding strategies and the significance of environmental archives and evaluated proxies.

The southern Bükk foreland (Bükkalja Foothill area) in northern Hungary was selected to conduct a case study investigating the Holocene development of a particular landscape section. The study area comprises the middle course of the

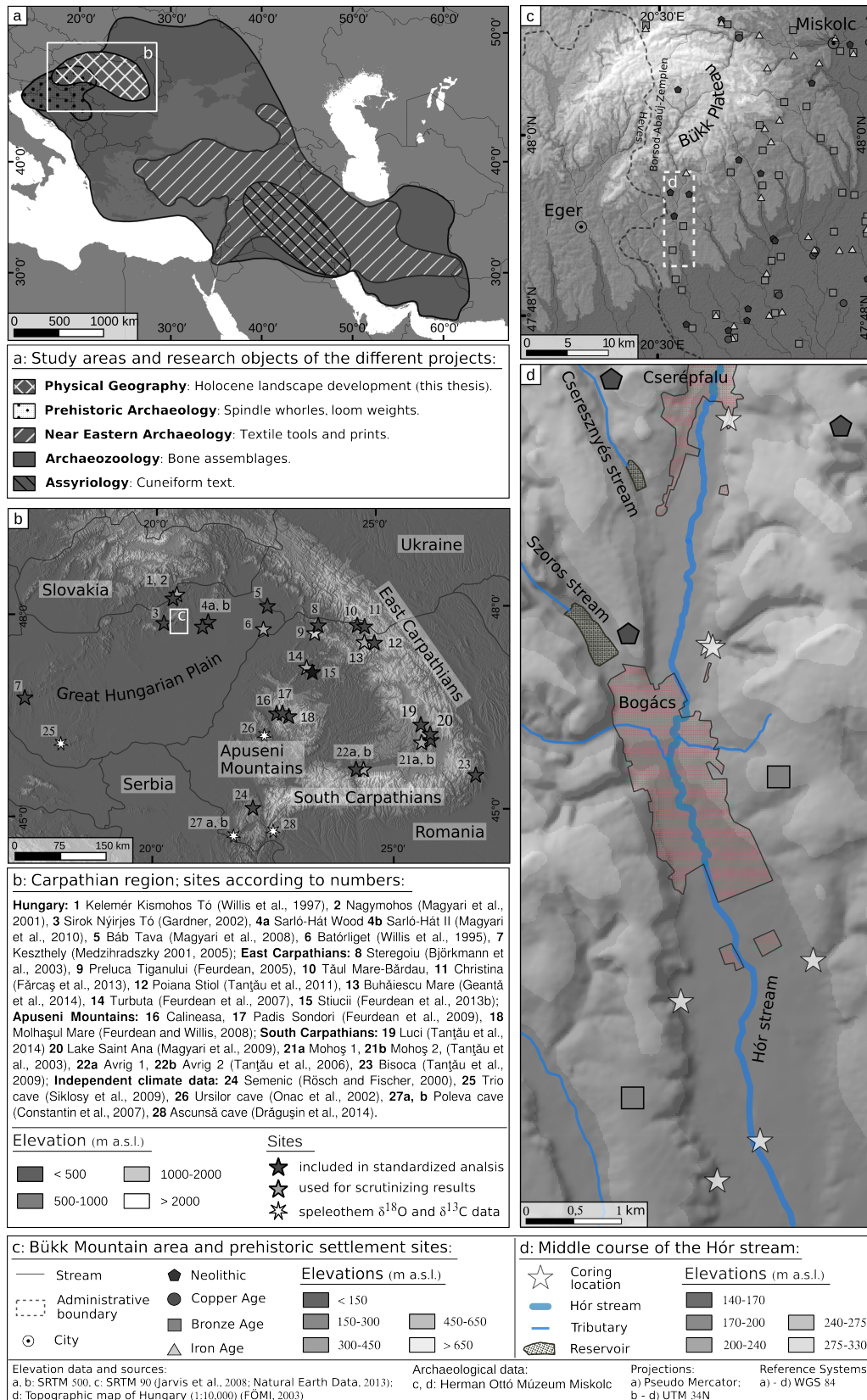


Figure 1: (a) Study areas covered by the different projects of the Topoi Research Group A-4; (b) Study area of the regional scale meta-analysis with included sites; (c, d) Overview and detailed map of the case study area at local scale.

Table 1: List of sites included in the meta-analysis, providing data on Holocene vegetation development (Table taken from Schumacher et al., 2016a).

| Map code | Site | Location | Region ^b | Depositional environment | Surface area (ha) | Investigated Proxies ^c | Sampling interval (cm) | References |
|------------------|---------------------|------------------|---------------------|------------------------------|--|-----------------------------------|------------------------|---|
| 1 | Kelemér Kismohos Tó | 48.3371; 20.4256 | 1 | Peat bog in depression | 0.9 | Multi Proxy | 8 | Willis et al., 1997; Braun et al., 2005 |
| 2 ^a | Nagymohos | 48.3404; 20.4308 | 1 | Peat bog in depression | 1.4 | Multi Proxy | 3 | Magyari et al., 2001 |
| 3 | Sirok Nyírjes Tó | 47.9391; 20.1872 | 1 | Peat bog in crater | 6.3 | Multi Proxy | 2-4 | Gardner, 2002 |
| 4a | Sarló-Hát Wood | 47.9608; 21.1659 | 1 | Oxbow lake | c. 30 (core taken from close to the shore) | Pollen, Charcoal/C _{org} | 4 | Magyari et al., 2010 |
| 4b | Sarló-Hát II | 47.9608; 21.1659 | 1 | Oxbow lake | c. 30 (core taken from close the basin center) | Pollen, Charcoal/C _{org} | 4 | Magyari et al., 2010 |
| 5 | Báb-Tava | 48.1859; 22.4822 | 1 | Oxbow lake | 5 | Pollen, Charcoal/C _{org} | 4 | Magyari et al., 2008 |
| 6 ^a | Batórliget | 47.7725; 22.2689 | 1 | Marsh land | c. 3.5 | Multi Proxy | 2 | Williset al., 1995 |
| 7 | Keszthely | 46.7705; 17.1973 | 1 | Mire/marsh land | NA | Pollen | 5 | Medzihradsky, 2001; 2005 |
| 8 | Steregeiu | 47.8133; 23.5447 | 2 | Silt up crater lake | 0.5 | Pollen | 2.5 | Björkmann et al., 2003 |
| 9 | Preluca Tiganului | 47.8230; 23.5419 | 2 | Peat bog in crater | 1 | Pollen | 2.5 | Feurdean, 2005 |
| 10 | Tăul Mare-Bărdau | 47.8333; 24.6000 | 2 | Peat bog in cirque | 0.8 | Pollen | 10 | Fărcaș et al., 2013 |
| 11 | Christina | 47.8333; 24.6166 | 2 | Peat bog in cirque | 0.1 | Pollen | 10 | Fărcaș et al., 2013 |
| 12 | Poiana Știol | 47.5856; 24.8165 | 2 | Peat bog in cirque | 2.6 | Pollen | 5 | Tanțău et al., 2011 |
| 13 ^a | Buhăiescu Mare | 47.5884; 24.6431 | 2 | Glacial lake | 0.9 | Pollen, Charcoal/C _{org} | 2 | Geantă et al., 2014 |
| 14 ^a | Turbuta | 47.2564; 23.3123 | 2 | Palaeo-lake | 1.5 | Pollen, Charcoal/C _{org} | 2 | Feurdean et al., 2007 |
| 15 | Stiucii | 46.9678; 23.9029 | 2 | Lake | 38 | Pollen, Charcoal/C _{org} | 2-10 | Feurdean et al., 2013b, 2015 |
| 16 | Călineasa | 46.5632; 22.8167 | 3 | Infilled doline | 1 | Pollen, Charcoal/C _{org} | 2 | Feurdean et al., 2009 |
| 17 | Padiș Sondori | 46.5983; 22.7323 | 3 | Infilled doline | 1 | Pollen, Charcoal/C _{org} | 2 | Feurdean et al., 2009 |
| 18 | Molhașul Mare | 46.5899; 22.7641 | 3 | Peat bog | 8 | Pollen, Charcoal/C _{org} | 4 | Feurdean and Willis 2008 |
| 19 | Luci | 46.2969; 25.7375 | 4 | Peat bog in crater | 120 | Pollen | 5 | Tanțău et al., 2014 |
| 20 | Lake Saint Ana | 46.1285; 25.9008 | 4 | Crater lake | 19.3 | Multi Proxy | 4 | Magyari et al., 2006; 2009 |
| 21b ^a | Mohoș 1 | 46.1337; 25.9046 | 4 | Peat bog in crater | 80 | Pollen | 5 | Tanțău et al., 2003 |
| 21b | Mohoș 2 | 46.1337; 25.9046 | 4 | Peat bog in crater | 80 | Pollen | 5 | Tanțău et al., 2003 |
| 22a | Avrig 1 | 45.7142; 24.3947 | 4 | Peat bog in depression/oxbow | 10 | Pollen | 5 | Tanțău et al., 2006 |
| 22b ^a | Avrig 2 | 45.7142; 24.3947 | 4 | Peat bog in depression/oxbow | 10 | Pollen | 5 | Tanțău et al., 2006 |
| 23 | Bisoca | 45.5333; 26.8166 | 4 | Peat bog | 1.5 | Pollen | 5 | Tanțău et al., 2009 |
| 24 | Semenic | 45.1800; 22.0594 | 4 | Peat bog | NA | Pollen, Charcoal/C _{org} | 2 | Rösch and Fischer, 2000 |

^a sites were not included in standardized analysis because of extended hiatus, poor age depth modelling, or lack of proxy data.

^b Regions according to numbers: 1 Hungary, 2 Eastern Carpathians, 3 Apuseni mountains, 4 Southern Carpathians.

^c All studies provide pollen data; the term multi proxy refers to studies additionally providing at least charcoal and geochemical data.

Hór valley located at the interface between the lowlands of the Great Hungarian Plain and the steep slopes of the Bükk mountains (Figure 1 c, d). Information on the coring locations are summarised in Table 2. Here, a wide range of ecological environments in close vicinity provide various resources for diverse economic activities (Sherratt, 1982). Three Neolithic and two Bronze Age settlements are evident in the study area. Furthermore, four of the sites included in the meta-analysis of the review are situated within 50 km distance.

Table 2: List and general characteristics of the analysed corings (Table taken from Schumacher et al., [accepted](#)).

| Coring | Latitude | Longitude | Elevation (m a.s.l.) | Sequence length (cm) | Valley number | Coring position* |
|---------|-------------|-------------|-------------------------|-------------------------|------------------|---------------------|
| Coll 04 | 47°56′10.6″ | 20°32′15.0″ | 205 | 750 | 1 | fan, west |
| Coll 05 | 47°54′56.4″ | 20°32′6.0″ | 183 | 300 | 4 | fan, west |
| Coll 07 | 47°54′55.5″ | 20°32′8.0″ | 183 | 700 | 4 | fan, west |
| Coll 08 | 47°51′59.9″ | 20°32′11.8″ | 146 | 500 | 17 | fan, east |
| Coll 09 | 47°52′13.1″ | 20°32′32.6″ | 143 | 300 | - | alluvial plain |
| Coll 10 | 47°53′12.6″ | 20°32′58.0″ | 163 | 700 | 8 | fan, east |
| Coll 11 | 47°52′58.8″ | 20°31′53.5″ | 159 | 900 | 11 | fan, east |

* sedimentation environment, exposition of the catchment

1.4.1 The Carpathian Region

The Carpathian region can be structured into an extended basin area in the west and in the center and an encompassing mountain belt (Figure 1 b). The basin comprises the Great Hungarian Plain and the Transylvanian Basin. In the Great Hungarian Plain, loess and sand covered Pliocene sediments dominate where Phaeozems, Chernozems, Cambisols and Vertisols have developed. In the river flood plains Holocene alluvial fills are prevalent. On extended sandy areas Arenosols have developed (ESDB, 2004; Gaertner et al., 1969). In the Transylvanian Basin Miocene sediments prevail on which mainly Luvisols have developed. Locally, Phaeozems are prevalent and along the river courses Fluvisols are found (ESDB, 2004; Gaertner et al., 1969). The mountain belt comprises the West Carpathians in Hungary and Slovakia, the East Carpathians in the Ukraine and Romania and the South Carpathians in Romania. The outer zone consists of Cretaceous, Eocene and Paleocene flysch. The inner zone is built up from Precambrian metamorphic rocks in the south and Cenozoic effusive rocks in the east. Furthermore, granitic, basic and ultrabasic intrusions are found in the Apuseni Mountains and in the West Carpathians (Gaertner et al., 1969; Rădulescu and Săndulescu, 1973). Cambisols and Podzols dominate in the mountain range and are complemented by Andosols on Cenozoic volcanic rocks. At exposed positions and in summit areas Leptosols are found (ESDB, 2004).

Elevations vary between <100 m a.s.l. in the Great Hungarian Plain and >1900 m a.s.l. in the East Carpathians. These large orographic differences determine the major climatic conditions of the study region: mean annual precipitation

ranges between 550 – 600 mm y^{-1} in the Great Hungarian Plain and increases to 1500 – 1600 mm y^{-1} in the East Carpathians. With increasing altitudes mean annual temperatures decrease from 9.5 – 11.5 °C in the lowlands of Hungary to 0 – 2 °C at the high levels of the Eastern Carpathians (Anonymous, 1960 cited in Okołowicz, 1977, p. 108; Stoenescu, 1960a,b). The basin situation and increasing continentality contribute to pronounced dryness and to a marked yearly temperature amplitude in the central lowlands of the Pannonian Plain and towards the east (Okołowicz, 1977, p. 77). However, also different macro weather situations prevail for the different areas of the Carpathian region, with the westerlies controlling rainfall in its northern part from April to November. The oceanic air masses transport moisture and have mitigating effects on the mean temperatures. Towards the south, the subtropical high gains importance during summer and causes region-wide temperature maxima in the southeast of the Carpathian region. Especially between October and April, Adriatic lows bring Mediterranean influences to the Pannonian Plain (Weischet and Endlicher, 2000, p. 136).

General pattern of vegetation are controlled by the climatic and orographic conditions. In the East and South Carpathians, the natural vegetation is broadleaved deciduous and mixed deciduous and conifer forests, complemented by thermophilous mixed deciduous broadleaved forests in climatically favoured areas. In the floodplains, wet-land communities complement the vegetation composition. Summit areas are characterized by nemoral-montane open woodlands, sub-alpine, alpine and subarctic communities. In the colline and montane area of the north Hungarian mid-mountains the natural vegetation is composed of thermophilous mixed deciduous broadleaved forests, deciduous broadleaved and mixed broadleaved and conifer forests. In the lowlands of the Great Hungarian Plain and the Transylvanian Basin forest steppe and vegetation communities of floodplains prevail and are complemented by fen forests and swamps in waterlogged areas (Bohn et al., 2004).

1.4.2 *The Southern Bükk Foreland*

The southern Bükk foreland represents the transition between the Tisza lowlands in the south and the Bükk Mountains in the north (Figure 1c). The Tisza lowlands are located between 80 – 90 m a.s.l. and belong to the Great Hungarian Plain. The Bükk Mountains reach elevations around 950 m a.s.l. and belong to the Inner West Carpathians. The study area comprises the c. 9 km long middle course of the Hór valley. The town Bogács splits the study area in a northern and a southern part. In the north, the study area includes the Cserépfalu basin and extends to the town Cserépfalu; in the south, it is delimited by an artificial lake. Within the study area the valley bottom ranges between 140 – 200 m a.s.l. and the tops of the valley flanks reach 180 – 260 m a.s.l. Mean annual precipitation amounts to c. 630 mm y^{-1} . Mean monthly temperatures range between c. 22 °C in the warmest month and c. -2 °C in the coldest month with mean annual temperatures of c. 9.5 °C (Anonymous, 1960 cited in Okołowicz, 1977, p.108).

The Bükkalja Foothill area consists of Eocene and Oligocene limestones, marls and clay formations, Miocene rhyolitic tuff and ignimbrite series and Quater-

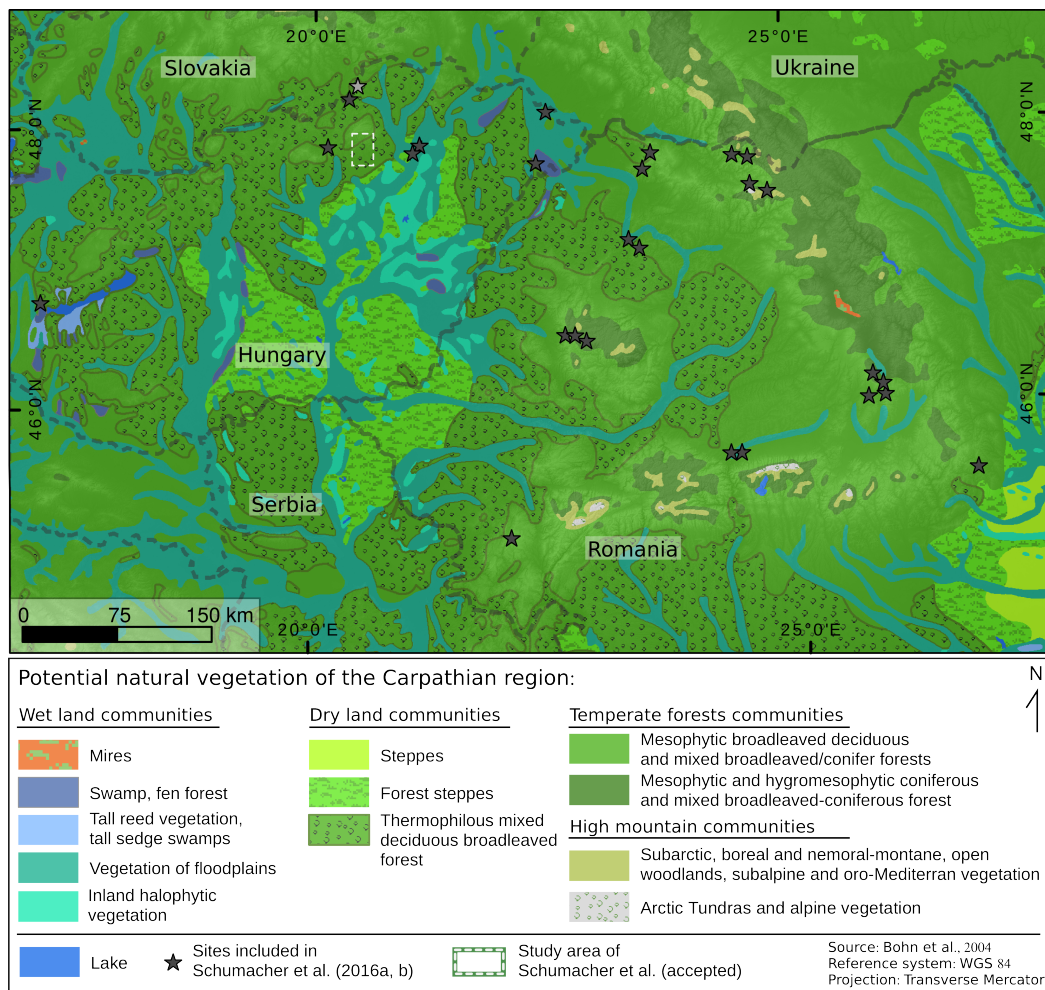


Figure 2: Potential natural vegetation of the Carpathian region

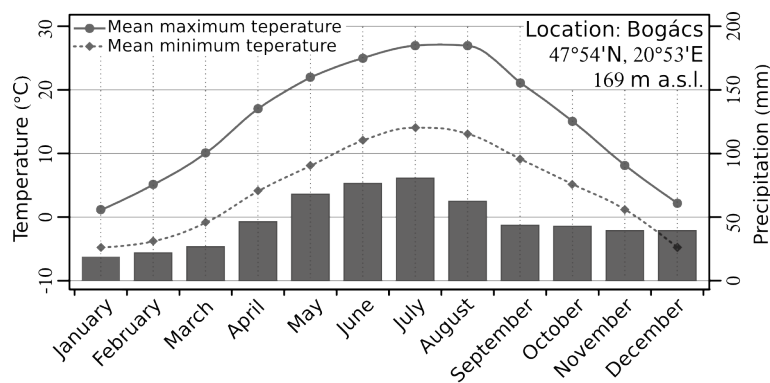


Figure 3: Climate diagram at Bogács; data from World-Weather.com.

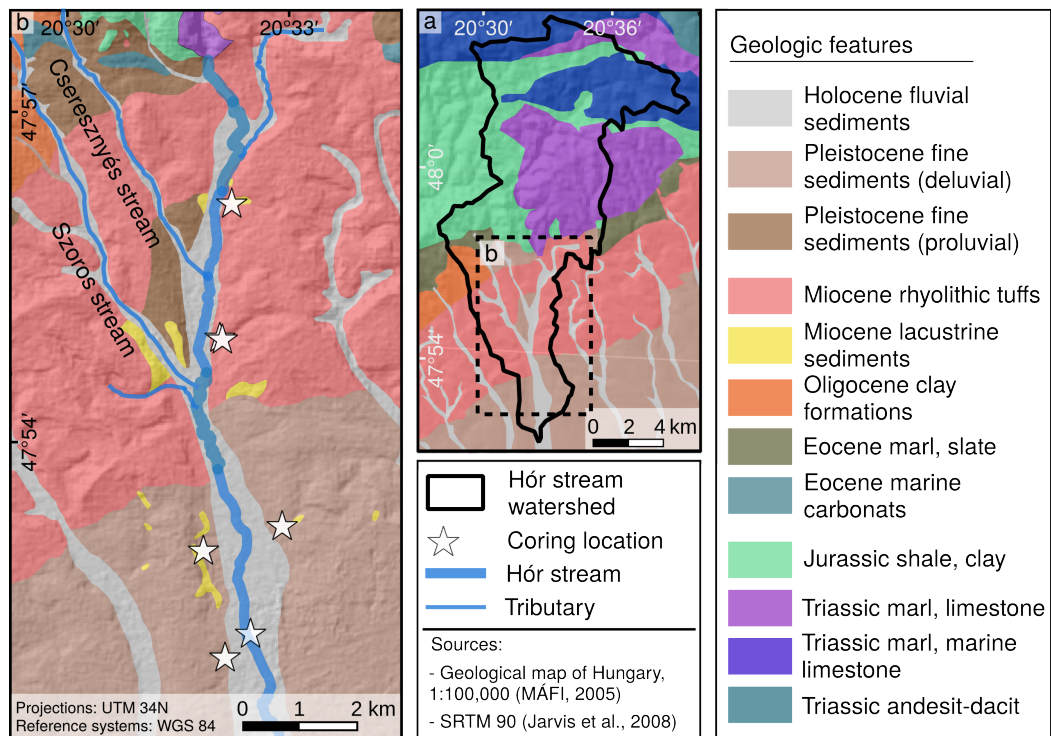


Figure 4: Geologic map of the Bükk Mountains. (a) Generalized overview; (b) study area covering the middle course of the Hór River.

nary sediments (Figure 4). In the northern part of the study area Miocene rhyolitic tuffs prevail, whereas the southern part of the study area is characterised by Quaternary sediments. The volcanic landforms were eroded during the Tertiary and twofold pediment surfaces developed: the development of the older pediment surface dates to the Miocene period (8 – 5.5 Ma) while the younger pediment developed during the transition from Pliocene to Pleistocene periods (2 – 1.8 Ma) (Dobos, 2001; Hevesi, 1986; Hevesi, 1990; Martonné Erdős, 2000; Pinczés, 1968, 1980). During the Rhodan orogeny (5.5 – 3 Ma) the older pediment was uplifted and dissected by tectonic fault lines; following these fault lines, a south-oriented drainage system developed (Balogh, 1963; Pinczés, 1955). As part of this major drainage system the Hór stream and its tributaries (the Cseresznyés and Szoros streams) formed the Cserépfalu basin. Today, in the study area the older pediment is mostly eroded and only represented by few hilltops. The younger pediment represents the basis for Pleistocene valley incision (Dobos, 2002). Remnants of two Pleistocene fluvial terraces and a Holocene terrace can be found on the surface. During glacial periods periglacial climatic conditions dominated in the area and slopes and valleys were affected by mass movements, gelisolifluction and frost activities. During interglacial periods chemical weathering, soil formation and linear erosion prevailed. During the end of the 18th century and the first half of the 19th century, the bottom of the Hór valley was drained and several stream branches dried up and disappeared. Nowadays, vineyards, forests and arable lands are characteristic for the Bükkalja foothill area.

1.4.3 *Prehistoric settlement development between the Neolithic and the Early Iron Age periods*

Research on prehistoric cultural development in the Carpathian region has a long tradition. The complex research history resulted in a variety of regional terminological and chronological inconsistencies. Often several names are used for the same material culture, or various cultures are differentiated, while others designate them to one culture with different regional groups (Daicoviciu et al., 1972; Gimbutas, 1965, e.g.). Since a detailed compendium of the cultural development in the Carpathian region would go far beyond the scope of this chapter only a rough overview of the most important cultures will be presented in the following.

NEOLITHIC The earliest agro-pastoral communities that immigrated from the southern Balkan into the Carpathian basin belonged to the Körös culture (Kalicz, 1970, 18 ff). The people spread towards eastern Hungary and lived in stratified tell-like settlements practising crop rotation. The settlements were located in the Tisza lowlands (Sherratt, 1982), often along rivers and streams reaching up to several 100 m in length (Kalicz, 1970, p. 18). In this, their life style resembled the ways of living known from the Mediterranean and contrasted the habits of synchronous cultures in western Hungary. Here, the Transdanubian Linear Pottery culture was influenced by the central European Linear Pottery culture: Large families lived in longhouses practising slash-and-burn cultivation which was connected to regular shifts of the settlement locations (Kalicz, 1970, p. 27). People of the Transdanubian Linear Pottery culture inhabited the area from the Danube bend to the hills of Gödöllő and Nógrád (Kalicz, 1970, p. 31). Synchronous with the Körös culture in Hungary, the Criș culture spread over most of the Romanian territory (Daicoviciu et al., 1972). As in Körös communities, the settlements were located in the lowlands in the vicinity to streams and people cultivated einkorn wheat (*Triticum monococcum*), herded various domesticates and produced woven textiles. However, occupation of settlements were only short-term (Daicoviciu et al., 1972).

The Körös culture was followed by the Middle Neolithic Alföld Linear Pottery culture that emerged in eastern Hungary around 7300 cal BP (Sherratt, 1982). By c. 7200 cal BP, material culture had differentiated and settlements expanded further to the north-east where the Bükk culture developed. Besides the fertile lowlands, people now occupied the mountainous areas along the valleys of small streams and settled in formerly uninhabited regions. Trade was greatly expanded between mountain areas and sites in the Great Hungarian Plain, and less wild resources were used but cattle husbandry became increasingly important (Sherratt, 1982). At the same time, late groups of the Alföld Linear Pottery culture persisted in the Great Hungarian Plain and the Szakálhát group established even further south (Kalicz, 1970, p. 28). Nuclear families lived in small houses and settlements were rather small, while tell-like settlements were abandoned and settlement locations were shifted regularly (Kalicz, 1970, p. 29). In southern Hungary and the northern Balkans, the Vinča culture established around 7500 cal BP and lasted

until c. 6300 cal BP (Kaiser and Voytek, 1983). People lived in open and large settlement sites, as well as in tells. Manufacture of subsistent and non-subsistent products was intensified, going along with economic specialisation and social differentiation (Kaiser and Voytek, 1983).

During the Middle and Late Neolithic, the Theiß culture spread along the Tisza river to the north and north-east replacing the Alföld Linear Pottery and the Bükk cultures (Kalicz, 1970, 41 ff). Around 6800 cal BP, the Hérpaly-Csőszhalom group established in the lowlands and the sites at the mountain fringe were abandoned (Sherratt, 1982). The settlement structure became more centralised again and people lived in tell-like settlements practising crop-rotation and herding cattle while also controlling the mountain areas and importing metal resources (Kalicz, 1970; Sherratt, 1982). People often settled in protected locations such as small river islands, or narrow peninsulas (Kalicz, 1970, p. 53). Simultaneously, the Lengyel culture followed the Transdanubian Linear Pottery culture (Kalicz, 1970, p. 55). People often settled on elevated locations and houses were similar to the ones known from the Theiß culture.

In southern Transylvania, the Criş culture was followed first by the Dudeşti culture and around 7000 cal BP by the Boian culture (Daicoviciu et al., 1972; Renfrew, 1971). Settlement occupation was still short-term and socio-economic structures did not differ much from the Criş culture.

COPPER AGE A major change occurred around 6700 cal BP, when in the southern Carpathian region the Gumelniţa culture appeared, contemporaneous with the Karanov V period, while in the highlands of central Transylvania, the Petreşti culture developed (Renfrew, 1971): Long-term occupation of settlement sites led to stratified settlement mounds and emerging wealth of the people is reflected in increasing importance of cattle husbandry and the occurrence of copper weapons, tools and jewellery in the archaeological material; additionally, textile production gained increasing importance (Daicoviciu et al., 1972). However, wild animals still seem to have played an important role in the diet as indicated by the bone assemblages from the Gumelniţa tell site Pietrele (Benecke et al., 2013). This period lasted until c. 6000 cal BP when the Coţofeni culture appeared in the region immigrating from the steppe regions east of the Carpathians (Champion et al., 1984, 154 ff; Daicoviciu et al., 1972). The economic strategy of these people was based on cattle herding and their appearance marked the transition to the Early Bronze Age in the southern Carpathian region (Champion et al., 1984, 154 ff; Daicoviciu et al., 1972).

In Hungary the transition from the Neolithic to the Copper Age is represented by increasing importance of animal herding and a change of settlement structures towards short-term occupation of settlement locations while the tells vanished (Kalicz, 1970, p. 60; Sherratt, 1982). In eastern Hungary, this development went along with the emergence of the Tiszapolgár culture around 6400 cal BP (Sherratt, 1982) which was followed by the Bodrogheresztúr culture (Kalicz, 1970, p. 60). The exploitation of metal resources from the mountains brought economic wealth, and important trade routes run through the region (Sherratt, 1982). During the Late Copper Age, again strong cultural changes occurred in the Great Hungarian

Plain: The Baden cultural complex ousted the Bodrogkeresztúr culture around 5500 cal BP and expanded to the whole Carpathian Basin (Kalicz, 1970, 72 ff; Renfrew, 1971; Sherratt, 1981). The plough and probably the cart appeared in the region and arable farming became more important again (Kalicz, 1970, p. 72; Sherratt, 1981). Open and unfortified settlements prevailed in the lowlands, while settlements in the mountainous regions were often fortified by earth walls (Kalicz, 1970, p. 72).

BRONZE AGE The beginning of the Bronze Age in the Carpathian region is characterised by a differentiation of the material culture into a number of units with a variety of ceramic styles and forms of artefacts; this is interpreted to be the result of a mixing of people and an increase of metallurgy and trade (Gimbutas, 1965, p. 185). While in Transylvania the Late Copper Age Coţfeni culture contained already many Kurgan elements from east of the Carpathians, the succeeding Otomanians were descendants of the Kurgan people (Gimbutas, 1965, 187 f). The Otoman culture emerged around 4000 cal BP in the region and successively spread towards north-west. Long-term settlements were located on elevated spots, or river islands with natural protection and in addition, almost all settlements were fortified by ditches. (Gimbutas, 1965, pp. 200, 202).

Synchronous with the Otoman culture in Transylvania, the Pecica culture developed in south-eastern Hungary and north-western Romania representing large-scale cultural unity (Gimbutas, 1965, p. 188). In northern Hungary, the Early Bronze Age (c. 4800 cal BP) is characterised by the reappearance of tells, often with fortified character. Between c. 4000 – 3450 cal BP the Hatvan and the Füzesabony cultures established in the region (Fischl et al., 2012; Gimbutas, 1965, 196, 200 ff). Similar to the Otomanians, people settled on elevated locations in the Tisza alluvial plain such as levees and islands, as well as along the streams draining the Bükk mountains. Here, elevated fringes of the alluvial plains and hilltops were settled (Fischl et al., 2012; Gimbutas, 1965, p. 202). During the Late Füzesabony around 3500 cal BP, elements of the European Tumulus culture appeared (Gimbutas, 1965, p. 195). The Hatvan culture ended with the appearance of the Otomanians which is traceable in the change of settlement styles, burial rites and the pottery: While Hatvan people lived in large family houses and buried their dependants in urns, the Otomanians lived in small houses, produced finer ceramics and inhumed their dependants (Gimbutas, 1965, p. 200).

EARLY IRON AGE During the end of the Bronze Age, cultural uniformity in western and central Europe is represented by the Urnfield culture and these people also influenced the cultural development of the Carpathian region (Champion et al., 1984, p. 271). In Romania, the Noua culture developed during the beginning of the 3rd millenium BP with a variety of regional groups. These people lived in unfortified settlements (Champion et al., 1984, p. 273) practising arable farming in the river valleys (Gimbutas, 1965, p. 219).

In northern Hungary, the Bronze Age tell sites vanished between c. 3000–2300 cal BP, and ceramic discard in the region lacks. Nevertheless, increasing charcoal records and decreasing arboreal pollen indicate stronger forest burning than in

the Late Bronze Age (Chapman et al., 2009; Magyari et al., 2010). While arable farming remained important, increased pollen occurrence of secondary indicator species as e.g. *Plantago lanceolata*, *Artemisia*, Gramineae indicate increasing significance of animal herding (Chapman et al., 2009; Magyari et al., 2010).

1.4.4 Land use change in the Carpathian region during the modern era

Large scale land use changes in the Carpathian region during the past 250 years were reconstructed by Munteanu et al. (2014): The authors reviewed 66 case studies reporting on land cover changes at 102 study sites in total. While the area of agricultural land expanded at the expense of forest and grassland during the Austro-Hungarian Monarchy – from 37 % in 1853 to 60 % in 1913 (*KSH Agricultural long time series and censuses*) – it constantly declined thereafter. In the second half of the 19th century large scale river- and floodplain regulations were implemented along the Tisza river in Hungary (Ihrig, 1973 cited in Pinke, 2014). The Tisza river was shortened by 38 % and by this, c. 25 % of the Hungarian territory was protected from regular inundation (Kiss et al., 2008; Rakonczai and Kozák, 2011, and citations therein). Most of this newly reclaimed land was used as cropland leading to an enormous increase of the Hungarian economy (Pinke, 2014). Before, farming in the Great Hungarian Plain was mainly based on animal husbandry (Bellon, 2003 cited in Pinke, 2014). Pinke (2014) argues that these strong river regulations failed in terms of their socio-economic effects, since about one third of the Hungarian population being smallholders and agroproletarians impoverished, while few landowners and decision makers gained power and wealth.

The change from forest decrease to woodland expansion occurred in most regions between the two world wars (1920 – 1940) (Munteanu et al., 2014; *KSH Agricultural long time series and censuses*). Only during the socialist time period (1945 – 1990) agricultural land use increased on fertile soils in Hungary. Overall, the direction of changes at the large spatial scale is rather stable over time and only the magnitude differs between periods, with higher rates of change during the last 30 years when abandonment of agricultural land was accelerated. Socio-demographic, economic and institutional factors, such as decline of the rural population, emigration towards western Europe and bankruptcy of large agricultural enterprises had much stronger effects on the land use development than climate variability (Munteanu et al., 2014).

Nowadays, c. 28 % of the Romanian territory are covered by woodland, while 61 % are used as agricultural land (EEA – European Environment Agency, 2013; MMEDIU – Ministry of Environment, 2013) (Figure 5). In Hungary c. 24 % of the land are woodland while only 12 % of the Great Hungarian Plain are forested (Bóday, 2014) and 47 % of Hungary are covered by agricultural land. Between 1980 and 2010, agricultural land in the Carpathian region decreased (Munteanu et al., 2014; Müller et al., 2009) while the forested area in Romania and Hungary did not change much in size (Griffiths et al., 2014). In both countries however, coniferous and mixed forests decreased in favour of deciduous forests. While in Hungary c. 92 % of the woodland consist of deciduous forests, in Romania c. 50 % of the woodland are coniferous and mixed forests (Griffiths et al., 2014). Forest

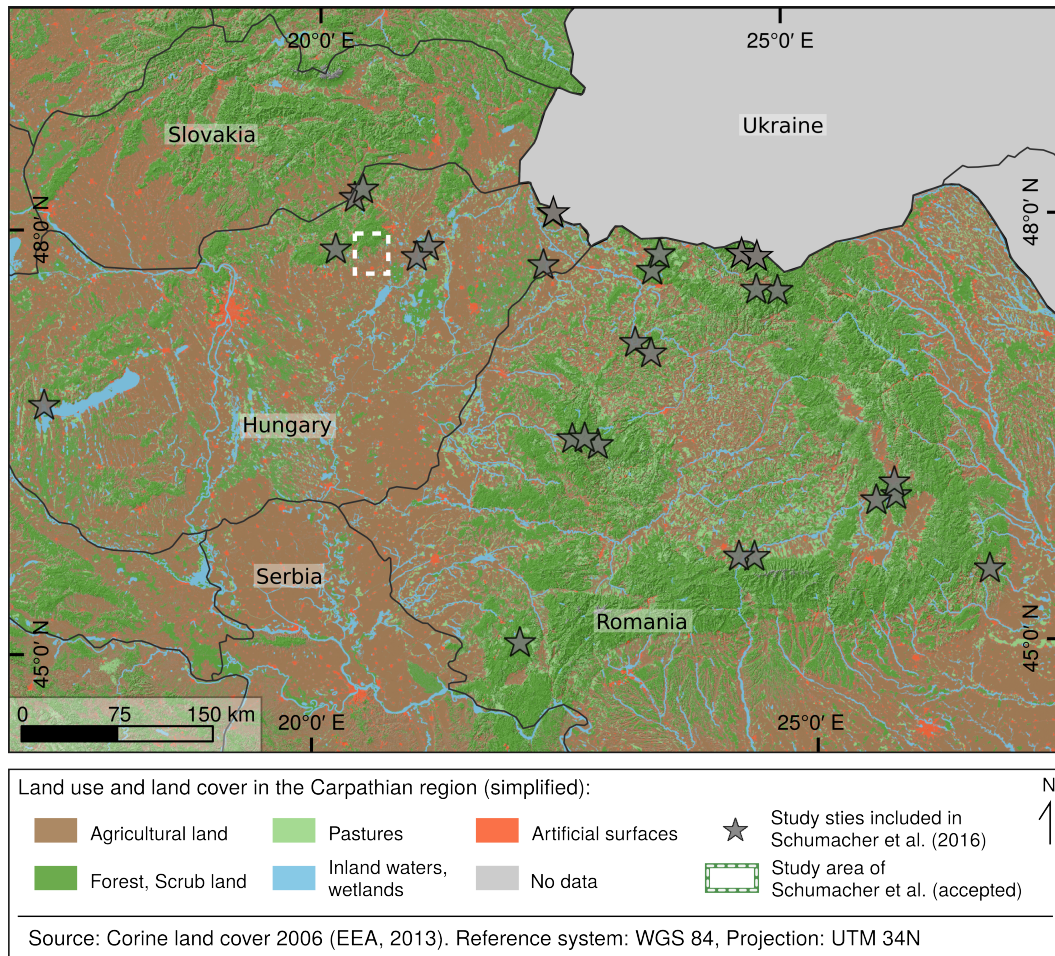


Figure 5: General land use/land cover in the Carpathian region.

disturbances are much stronger in newly forested areas compared to old forests that already existed in 1860. This is most probably due to natural disturbances that have stronger effects on planted spruce and poplar forests than on (semi-) natural old mixed forests. While the former are often planted in less favourable environments and are more prone to e.g. windthrow, the latter are more resilient against natural disturbances (Munteanu et al., 2015).

In the recent years, increase of mountain forests is due to nature conservation policies (Munteanu et al., 2015). In agreement to this, abandonment of agricultural land in southern Romania in the post-socialist period can most often be observed in hilly and particularly in the mountainous areas (Müller et al., 2009). In the lowlands, mostly isolated patches of cropland were abandoned and there is a tendency towards homogeneity of the cropland over time (Müller et al., 2009).

EXPLORING LANDSCAPE DEVELOPMENT - INTERDISCIPLINARITY INHERITED?

2.1 INTRODUCTION

Landscapes may be understood as territories shaped by natural factors such as relief, soils, vegetation, climate, as well as human constructions and interferences with environmental processes (Förster et al., 2013). A second dimension of the human role comes into play if it is considered that landscapes are always denoted as such by human beings (Förster et al., 2013; Greider and Garkovich, 1994). The landscapes that emerge from the human perception of an environmental segment may vary significantly depending on the respective individual observing the scenery (Greider and Garkovich, 1994). Thus, the term landscape conveys the relation between human being and natural environment in its many facets (Förster et al., 2013). Similarly, the investigation of landscapes and their development implies the integration of different scientific disciplines. However, approaches to create increment value from the integration of different disciplines are on debate for decades (Boulden, 2012; Butzer, 1975, 1982; Gladfelter, 1977; Huckleberry, 2000; Meier, 2012; Rapp and Hill, 2006; Verstraeten, 2013). Gladfelter (1977) emphasizes that an interdisciplinary research approach requires cooperative collaboration from project conception, through execution to data interpretation. Although he sees archaeology as the central discipline in his research, he underlines the benefit that lies in the *questions* asked by other disciplines rather than in the *answers* other disciplines are able to give. Verstraeten (2013) illustrates the significant conceptual changes that palaeoenvironmental research has been undergone during over 20 years of exploring past landscape development around Sagalassos, south-west Turkey: The research design developed from an archaeology-focused approach in which geographical sub-disciplines were seen as subordinate instruments, towards a concept of integrated coequal disciplines.

During the Landscape Archaeology Conference that was held in Rome in 2014, the session “Bridging the Gap” picked up this issue hosting a number of contributions that focus on the integration of humanities and sciences in the context of investigating the past. In the course of this debate, Schumacher et al. (2016b) shed light on the role of geographic research within interdisciplinary research of the Topoi Research Group A-4 “Textile Revolution”. It is illustrated how the geo-specific questions posed on the hypothesis of emerging wool economies bridge the gap between archaeological and geographical disciplines. Important aspects of the overall research design are addressed, as well as drawbacks and pit falls of the chosen approach. Furthermore, implications for the design of the geographical approach are derived.

2.2 PAPER 1: NEAR LANDSCAPES OF THE TEXTILE REVOLUTION

Schumacher, M., Schier, W., Schütt, B. (2016): Near Landscapes of the Textile Revolution. eTopoi. Journal for Ancient Studies, Special Volume 4, 162-187.

Abstract

It was between the Late Neolithic and the Early Bronze Age when wool was introduced as raw material for textile production. It is expected that this innovation had a comprehensive effect on the socio-economic life of people and their environment. However, little is known about spatio-temporal trajectories of the process and the environmental influences it actually had. The approach presented demonstrates how such a comprehensive and complex research question may be operationalised. Decomposition of the overall process and gathering of information from different fields allows to reconstruct particular aspects of the phenomenon and their diachronic change. Subsequent synthesis enables addressing the overall question. This paper focuses on the role of landscape within the process of wool sheep introduction. Besides covering the particular approach to reconstruct herding-related landscape changes it is shown how deeply different disciplinary approaches are interconnected. Finally, difficulties and constraints of data integration are addressed.

Keywords

Chalcolithic; Early Bronze Age; Carpathians; human-environment interaction; grazing impact.

2.2.1 *Background*

The use of wool for textile production is a several thousand years old practice. In Mesopotamia vegetal fibres have already been replaced by wool fabrics around 5000 cal BP as documented by cuneiform texts (Waetzoldt, 1972). Yet the initial shift in economic strategies may have taken place much earlier: The domestication of wild sheep and goats in eastern Mesopotamia occurred at least between c. 11,000 and 10,500 cal BP (Zeder, 2008). Chessa et al. (2009) provide genetic evidence for the origin of wool-bearing sheep in south-west Asia and a further spread towards Europe, Africa and the rest of Asia. Sherratt (1981) links the introduction of wool-bearing sheep to a complex socio-economic transition process which he calls the “Secondary Products Revolution” taking place during the Chalcolithic period. Even though chronological coherence of this process has been revised the view of a post-Neolithic advent of wool production is commonly accepted (Greenfield, 2010). However, little is known about the temporal and spatial spread of wool as a common raw material and triggers and effects of this innovation are still rather vague. The widespread introduction of the wool-bearing sheep and of woolly textiles constitutes a complex of issues which is connected to a variety of research fields. Hence, the interdisciplinary research project “Textile

Revolution” was established in which the disciplines of archaeozoology, prehistoric archaeology, Near Eastern archaeology, Assyriology and physical geography cooperate to seize these interrelations. Data from different regions between West Asia and Central Europe are compiled to trace temporal and spatial aspects of the introduction of wool-bearing sheep and to infer causal dynamics and socio-environmental effects of the process (Figure 6 a): Bone assemblages and particular bone measures give information about exploited animal species and may allow conclusions on herd structures and preferably produced products. Predominant culling of subadults indicates meat production whereas herding of adult animals indicates the use of secondary products. Here, the predominance of female animals indicates milk production whereas prevailing male animals may be an indicator for wool production (Payne, 1973). These compiled qualitative and semi-quantitative data provide direct information on sheep herding and indirect information on wool production. However, it is not possible to infer numbers about the scale of wool production and environmental causes and effects. Prehistoric textile finds as direct evidences are extremely rare because of the rapid decay of the material. In contrast, textile tools such as loom weights and spindle whorls are normally well preserved. Changes of shape and measures of these tools may relate to changes of production processes indicating the start of wool production (Rooijakkers, 2012). Unfortunately, the link between certain shapes of textile tools and types of processed fibres is not very strong. However, state of preservation and abundance of finds may allow to infer socio-economic information e. g. on the scale of textile production, or division of labor. Iconographic representations of livestock and textile-related scenes such as production processes may provide information on the use of wool fabrics (Vila and Helmer, 2014). However, it is hard to differentiate between scenes of very particular practices and scenes of everyday life. Hence, such data do not provide information on scales of production and presumably connected effects on the environment. Written sources are the most precise information about ancient textile production. Exact numbers of herd sizes and amounts of produced textiles are documented in cuneiform texts from Ancient Mesopotamia (Green, 1980). Unfortunately, such sources are scarce and only available for a small region and a short time window and reflect only certain parts of foremost elite and institutional strata of ancient society.

The possibility of using the wool of sheep may have induced changes in husbandry including exploitation of formerly unused marginal areas and might have triggered changes in non-sedentary subsistence strategy. Assuming that increasing wool production required intensified sheep husbandry implies that landscape dynamics were increasingly affected by grazing impacts. Increasing grazing pressure ultimately leads to land degradation due to vegetation disturbance and subsequent soil erosion (Belsky and Blumenthal, 1997; Milchunas and Lauenroth, 1993). However, it is a difficult task to precisely attribute human-induced landscape changes to certain palaeo-environmental proxies and to distinguish them from climatically triggered processes. Deducing prehistoric grazing impact of particular animals from palaeo-environmental proxies alone, however, is impossible. Nevertheless, the hypothesis that the introduction of wool-bearing sheep led to increasing landscape disturbances can be tested using geoscientific methods. This

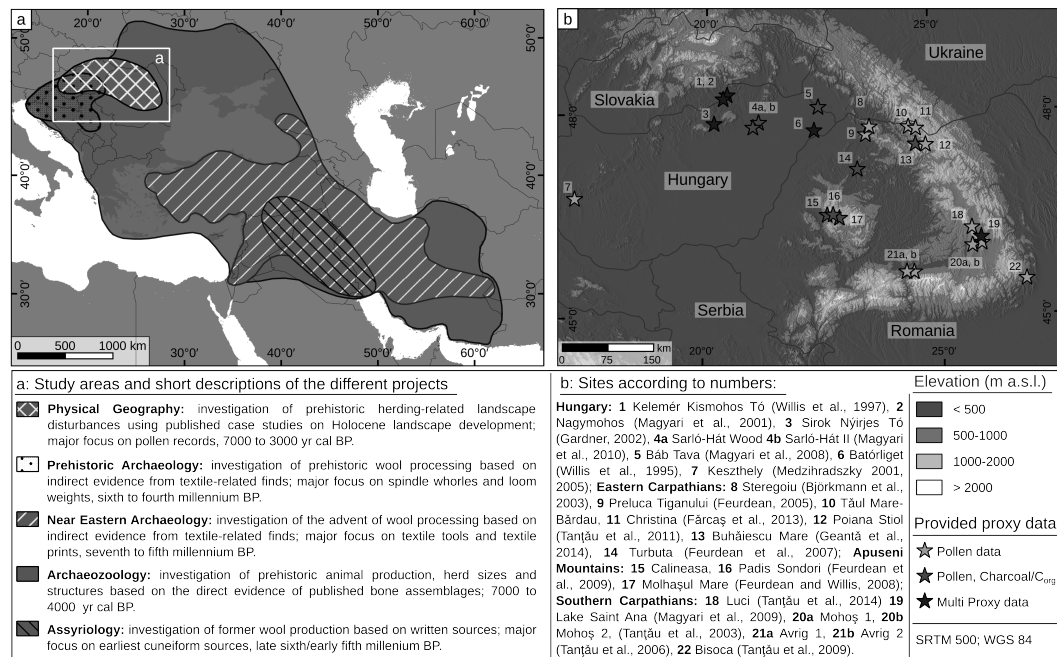


Figure 6: Study regions and sites included in the review (see also Tab. 3).

addresses the quantitative aspect of the introduction of wool-bearing sheep and contributes to spatial and temporal aspects of the process.

To investigate the prehistoric grazing impact the spatial focus was put on the Carpathian region (Figure 6 b). Studies on prehistoric settlement history and cultural development in the Carpathian region have a long research tradition (e.g., Chapman et al., 2009; Duffy et al., 2013; Kalicz, 1994; Sherratt, 1982, 1983a). Parsons presents extended considerations about the transformation processes in the Great Hungarian Plain during the Late Chalcolithic (Parsons, 2011) and studies on ^{87}Sr - ^{86}Sr -ratios in dental enamel of animals and humans provide information on the mobility of people and animals for the post-Neolithic period (Giblin et al., 2013; Giblin, 2009; Hoekman-Sites and Giblin, 2012). Holocene vegetation development in the region is documented by a number of well-dated pollen records. While Holocene landscape development and human-environment interactions in the eastern Mediterranean, as well as in central Europe have been extensively discussed most recently (Dotterweich, 2008; Dreibrodt et al., 2010; Duser et al., 2011; Notebaert and Verstraeten, 2010), Holocene environmental history of the Carpathian region is discussed only regionally (Magyari et al., 2012; Willis, 1997), or with significantly different thematic foci (Feurdean et al., 2012). Considering case studies from the Carpathians on a large scale allows to address spatio-temporal trajectories within the region, as well as to relate them to the south-eastern and north-western adjacent regions.

The introduction of wool-bearing sheep and the use of wool for textile production pose integrated questions requiring the integration of aspects referring to social as well as to natural dynamics. Information on herding practices and on the use of wool itself may rather be inferred from archaeozoological, archaeological and textual evidences. However, the assessment of environmental conditions

controlling the herding activities and natural dynamics reacting to the changing socio-economic practices are by default addressed by geoscientific work. Hence, to elucidate human-societal-natural interactions such as feed back mechanisms between the natural environment and the spread of wool-bearing sheep and wool as the predominant raw material for textile production, it is inevitable to integrate different disciplines from the humanities as well as from natural sciences. In the presented paper the approach addressing the environment-related aspects of the introduction of the wool-bearing sheep is illustrated. Here, the role of the environment is reflected as well as the adoption and operationalisation of the approach is addressed, rather than results of the project.

2.2.2 *The role of landscape*

Animal herding is directly interlaced with environmental as well as socio-economic conditions: Different natural environments provide habitats of alternating suitability for sheep grazing. People arrange different types of land use within a cultivated area based on economic considerations relating environmental conditions and transport costs (Thünen, 1921). Simultaneously, grazing habits of sheep influence the spatial aspects of herding activities. It is hard to evaluate the significance of the different factors determining prehistoric herding patterns. In particular, human habits, decisions and herding practices are difficult to reconstruct for prehistoric times. Therefore, the role of landscape can only be assessed based on general assumptions about the suitability of landscapes for grazing, grazing habits of sheep and theoretical considerations about land use patterns.

Impact of grazing on the landscape

Environmental factors such as climate, relief, hydraulic regime and vegetation are part of a complex system controlling the suitability of regions for sheep herding and affect the intensity of resulting landscape dynamics; sensitivity and sustainability of landscapes control the thresholds for their reactions. Climatic extreme events, frequently occurring as regional phenomena may trigger landscape reactions abruptly. However, thresholds change in correspondence to changing environmental factors and husbandry. Additionally, the effect of grazing pressure on the degradation of the landscape might occur with a time lag: while increased grazing intensity enhances the vulnerability of landscape and increases risks of soil degradation and soil erosion, the onset of soil degradation and soil erosion processes depends on the occurrence of extreme weather events – drought, storm or rainfall – which exceed thresholds to trigger earth surface processes (e.g., Church and Slaymaker, 1989; Hoffmann et al., 2008, 2010; Verstraeten et al., 2009). Woodland grazing generally inhibits rejuvenation of trees and gives relative advantage to species of primary forests that are able to grow from the stump (Kalis et al., 2003). Generally, overall plant species richness increases on grazed areas (Schütz et al., 2003). Impacts of grazing on vegetation and soils on a global scale are discussed by Milchunas and Lauenroth (1993). They conclude that plant species composition shows fast and net primary production shows moderately fast reactions on grazing while the soil nutrient pool reacts slowly, with a consid-

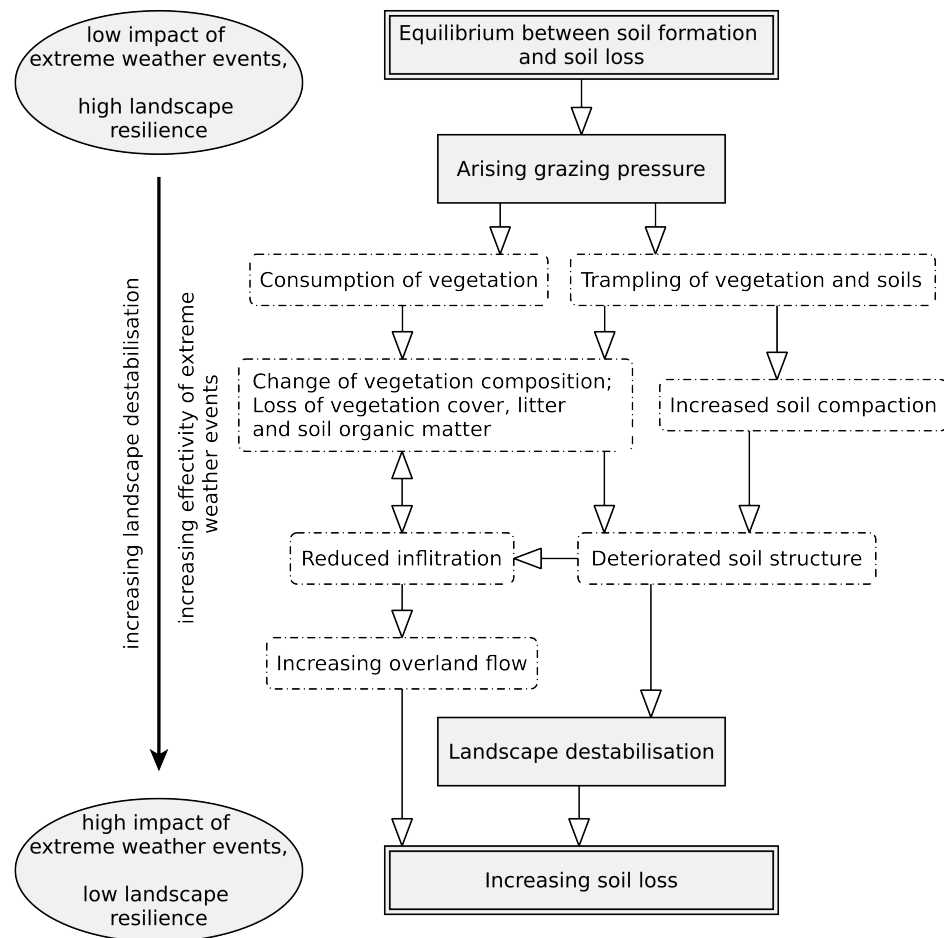


Figure 7: Schematic process of landscape degradation due to grazing (modified after Belsky and Blumenthal, 1997)

erable time-lag on grazing. The most productive sites show the greatest reduction in net primary production and forests display a generally positive change of net primary production when grazed. Livestock grazing leads to soil compaction and loss of vegetative cover. Subsequently, deteriorated soil structure, decreasing infiltration rates and increasing overland flow enhance soil erosion (Figure 7, (Belsky and Blumenthal, 1997)). However, the impacts of annual weather fluctuations and long-term climatic cycles may exceed herding impacts masking the grazing effects in the sediment archives (Hyder, 1975; Milchunas and Lauenroth, 1993; Wilson, 1989). Succession processes on sites with poor soils, tending to soil and nutrient loss appear to be slower than in sink areas where eroded soils are accumulated (Risch et al., 2001). It can be summarized that increasing grazing pressure leads to both, subsequent and synchronous environmental reactions: alteration of vegetation composition is followed by a decrease of vegetation cover and physical and chemical soil deterioration enhances erosion processes.

Grazing habits of sheep affecting grazing patterns

In general, sheep prefer herbal vegetation whereas goats favor buds and young leaves of trees. However, both may easily adapt to different environmental conditions (Evangelou et al., 2011). Summarising, a variety of case studies Gordon et al. (2004) document that the complex spatial patterns of herbivore grazing are controlled by the distribution of preferred vegetation. These mechanisms are structured by higher levels of constraints such as distance to water and shelter. On coniferous forest range, sheep prefer rich meadows and forests instead of heath land and poor forests, whereas fallow land is most favored (Warren and Myrsetrud, 1991). In an Atlantic mountain area of northern Spain sheep prefer grassland instead of heathland and forest (Mandaluniz et al., 2009). On extensive grassland in north-western Germany, drier and nutrient poor areas are preferred instead of moist and productive habitats (Putfarken et al., 2008). Seasonal differences in grazing patterns are mainly related to changing resource supply (Evangelou et al., 2011, 2014). During the night sheep are usually kept in pens where they use to ruminate (Evangelou et al., 2011, 2014; Loridas et al., 2011). In accordance, mountain sheep living in the wild attend shelters such as forests and exposed areas during the night; upper slopes of drainage basins instead of valley bottoms are preferred grazing areas and precipitous slopes and exposed areas are essential escape terrains (Gionfriddo and Krausman, 1986). This distinctly variable and a circadian rhythm following behavior of sheep living in the wild suggests that for people using simple means of animal keeping a partly vagrant life might have been more suitable for sheep keeping than a sedentary way of life.

Socio-economic aspects of spatial grazing patterns

Following the classic model of agricultural land use it can be assumed that land consuming economic activities are carried out in the more marginal areas of a settlement whereas labor intensive activities are concentrated immediately around a settlement (Thünen, 1921). Ihse (1995) documents that such agricultural structures outlasted for several hundreds of years in southern and central Sweden. With the land use intensification during the younger Funnel Beaker culture in northern Germany around 5000 cal BP animals were no longer kept in pens close to houses but woodland pasture started in more distant areas. Finkelstein and Gophna (1993) report economic differentiation in the Highlands of Palestine for the Chalcolithic and Early Bronze Age when animal husbandry was concentrated in sparsely populated frontier zones of the highlands; furthermore, the authors consider the occupation of marginal caves during the Chalcolithic to point to the importance of pastoral activities. These examples indicate the significance of peripheral regions for the reconstruction of prehistoric grazing activities.

Implications for the project design

Vegetation reacts more sensitive to grazing pressure than soil stability (Belsky and Blumenthal, 1997; Milchunas and Lauenroth, 1993) and the occurrence of indicator species is more clearly linked to herding impact than soil erosion (Behre, 1981; Bottema and Woldring, 1990; Magyari et al., 2012). Therefore, published pollen

records were chosen as the major source of information to trace prehistoric grazing activities and related landscape disturbances. If available, charcoal and geochemical data are included in the discussion of the pollen data. Grazing habits of sheep and socio-economic considerations imply to choose pollen archives that are located in a certain distance from settlement areas. This meets the fact that sediment archives providing well preserved pollen records such as peat bogs or mountain lakes are often located in unsettled environments. However, it has to be considered that these sediment archives often provide only pollen from local source areas. Therefore, impacts of herding activities few kilometres away might not be represented in the archives any more. The temporal resolution and accuracy of the different data sets vary, as well as the spatial representation is heterogeneous. Furthermore, different numbers of proxies indicating herding-related landscape disturbances are published for the different sites. This implies a standardisation of the data as well as a standardized evaluation of prehistoric grazing pressure using a consistent set of proxies. In addition, a temporal and spatial generalisation of the results allows to trace large-scale spatio-temporal trajectories of prehistoric herding indication.

Evidence of ancient grazing landscapes

Evidences on Holocene landscape conditions and landscape processes in general are provided by environmental archives. However, attributing distinct causes to certain processes in landscape dynamics is highly difficult (Bintliff, 2002; Butzer, 2005; Fuchs, 2007; Kalicki et al., 2008; Kalis et al., 2003). Even if catchment configuration is rather simple and the area is archaeologically well investigated, it is hard to directly relate phases of soil erosion to particular human activities as they might appear with a time lag due to the appearance of the triggering extreme weather event (Fuchs et al., 2004). Phases of landscape destabilisation and soil erosion during prehistoric times are commonly attributed to enhanced field cultivation rather than to animal husbandry (Dreibrodt and Wiethold, 2015). It is therefore not assumed that intensified herding activities during prehistoric times were intense enough to trigger large-scale soil erosion. However, increasing grazing pressure increased the exposure of the landscape to erosion processes and, thus, concurring with extreme weather events might have affected increased erosion rates. On the basis of sediment texture alone a differentiation between soil sediments mobilized due to husbandry from those mobilized due to intensive grazing is not possible. Therefore, the data compilation mainly focuses on studies on Holocene vegetation development, whereas studies on prehistoric soil erosion are considered secondarily.

Increasing grazing pressure is directly reflected in density and composition of the vegetation cover (Milchunas and Lauenroth, 1993). Pollen, the most appropriate proxy to reconstruct vegetation composition, are preferentially preserved under anoxic conditions. Therefore, most archives providing long sequences of pollen data are lakes, peat bogs, oxbows or waterlogged depressions (Bernabo and Webb, 1977; Buczkó et al., 2009). Representativity of pollen archives is rather variable. The reliability of the determination of a source area is related to basin

size and type of pollen; wind as well as surface runoff control transport distances and directions of pollen transport (Bradshaw, 1988).

Indicator species may be used to infer environmental conditions and human impacts, although, the natural vegetation of the investigated site always has to be considered (Behre, 1981; Bottema and Woldring, 1990; Magyari et al., 2012). *Polygonum aviculare* and *Plantago major/media* represent ruderal vegetation and *Plantago lanceolata* and *Rumex acetosa/acetosella* represent pasture and meadow communities; these four species are commonly interpreted as indicators for animal herding (e.g., Behre, 1981; Bottema and Woldring, 1990; Feurdean et al., 2010; Magyari et al., 2012; Marinova et al., 2012). The Transylvanian lowlands were covered by extensive forests during the Early and the Middle Holocene (Feurdean et al., 2015). Therefore, it can be assumed that the surroundings of the included sites were naturally forested during the timeslice of interest. Percentages of arboreal and non-arboreal pollen may indicate quantitative vegetation composition representing human impact on vegetation cover (Bradshaw, 1988; Feurdean, 2005). Although arboreal-non-arboreal pollen ratios are not the most appropriate values to trace human impact they are the most used ones (Kalis et al., 2003). Assuming that grazing significantly alters species composition of a given vegetation community and inducing an increase of plant species, statistical measures such as “rate of change” (Huntley, 1992) and “palynological richness” (Birks and Line, 1992) are suitable indicators for potentially herding-related human impact. Charcoal concentrations and charcoal accumulation rates indicate the importance of forest fires; here microscopic charcoal represents regional fires and macroscopic charcoal indicates local and extra-local fires (Whitlock and Larsen, 2001). Including climate proxies into the analysis, human induced woodland burning can be distinguished from natural forest fires (e.g., Feurdean et al., 2012).

2.2.3 Material

The study is based on a compilation of data from published case studies. Articles included deal with sedimentary archives where human impact and especially herding triggered processes were identified (Table 3). Identifying triggers which released landscape processes as they can be reconstructed from sediment archives underlies high uncertainties. The degree to which proxies indicating human impact are emphasized may depend on the objective of the particular case study. Thus, to compare results of a variety of case studies the primary data have to be evaluated and a re-evaluation will be necessary to assess the published interpretations. Above it has to be considered that the significance of indicator species may vary according to the environmental settings of the site (Behre, 1981; Bottema and Woldring, 1990; Magyari et al., 2012). High temporal precision is required to allow a diachronic and spatially comparative analysis of landscape development. Thus, the focus was put on sediment sequences from wetlands such as peat bogs, mountain lakes and drainless hollows providing sufficient pollen conservation and reliable age-depth modelling. Furthermore, a coherent temporal basis of the proxy data is required. ^{14}C ages were recalibrated using IntCal13 (Reimer et al., 2013) and linear age-depth models were calculated applying Clam 2.2 (Blaauw,

2010; R-Core-Team, 2014). In case a published age-depth model was modified according to a more plausible stratigraphy it was incurred. However, temporal resolution of data records inherently may vary within a particular sediment sequence as well as the quality of temporal representation of different sediment sequences is not homogeneous. Thus, despite precise age depth modelling only tendencies of environmental changes can be inferred from the data and quantitative information is not derived. In order to facilitate the inter-site comparison of results proxy values were summarized and mean values were calculated for 500 years time slices.

Secondary indicator species such as *Plantago lanceolata*, *Plantago major/media*, *Polygonum aviculare* and *Rumex acetosa/acetosella* were extracted as proxies indicating animal herding (Behre, 1981; Bottema and Woldring, 1990; Magyari et al., 2012). Arboreal pollen values were considered as indicators for the density of canopy cover, condoning a high degree of uncertainties due to the large variety of influencing factors (Gaillard et al., 2010). Nevertheless, since sheep prefer open herbaceous grounds (Evangelou et al., 2011; Warren and Mysterud, 1991) it was assumed that increasing herding activities are related to decreasing canopy cover due to woodland cutting and maintained by browsing. Therefore, the analysis was conducted on the basic assumption that with intensified herding pollen values of indicator species increase whereas arboreal pollen values decrease. Both proxies were combined in a fuzzy rule-based system and degrees of herding probability were obtained for 500 years time slices (Schumacher et al., 2016a). In addition, available proxies allowing to infer palaeo-environmental conditions such as “rate of change” (Huntley, 1992), “palynological richness” (Birks and Line, 1992), charcoal accumulation rates (Whitlock and Larsen, 2001) or geochemical indicators (Boyle, 2001; Mackereth, 1965; Meyers and Teranes, 2001) were used to validate the results. Spatial representativity of the data is highly variable. Although the majority of included sites are small and reflect local pollen rain, the contribution of extra-local and regional pollen cannot be excluded. To level out this spatial inaccuracy sites were aggregated to trans-regional areas achieving a frame for the spatial comparison of the data (Figure 9).

2.2.4 Traces of Prehistoric Grazing Pressure

Literature review

Palynological case studies from the Carpathian Basin focus on different aspects of Holocene environmental dynamics such as post-glacial succession processes, climate fluctuations, geomorphological processes shaping landscape and human impact. None of the case studies identifies explicitly human-triggered landscape degradation processes for the mid-Holocene. Referring to modern pollen assemblages the pollen records covering prehistory imply that mid-Holocene grazing impact in the Carpathian region was all over low; even if it is assumed that indicated vegetation disturbance was the result of human impact rather than of climate influences. Nevertheless, at 19 out of 23 included sites authors identify human presence and various economic activities such as animal husbandry, peasant farming and woodland management (Figure 8): During the Late Neolithic,

Table 3: List of included sites for assessing mid-Holocene grazing impact on the landscape in the Carpathian region (see also Figure 6 b).

| Map code | Site | Location | Region* | Depositional environment | Proxies** | References |
|----------|---------------------|------------------|---------|------------------------------|-----------------------------------|---|
| 1 | Kelemér Kismohos Tó | 48.3371; 20.4256 | 1 | Peat bog in depression | Multi Proxy | Willis et al., 1997; Braun et al., 2005 |
| 2*** | Nagymohos | 48.3404; 20.4308 | 1 | Peat bog in depression | Multi Proxy | Magyari et al., 2001 |
| 3 | Sirok Nyírjes Tó | 47.9391; 20.1872 | 1 | Peat bog in crater | Multi Proxy | Gardner, 2002 |
| 4a | Sarló-Hát Wood | 47.9608; 21.1659 | 1 | Oxbow lake | Pollen, Charcoal/C _{org} | Magyari et al., 2010 |
| 4b | Sarló-Hát II | 47.9608; 21.1659 | 1 | Oxbow lake | Pollen, Charcoal/C _{org} | Magyari et al., 2010 |
| 5 | Báb-Tava | 48.1859; 22.4822 | 1 | Oxbow lake | Pollen, Charcoal/C _{org} | Magyari et al., 2008 |
| 6*** | Batórliget | 47.7725; 22.2689 | 1 | Marsh land | Multi Proxy | Willis et al., 1995 |
| 7 | Keszthely | 46.7705; 17.1973 | 1 | Mire/marsh land | Pollen | Medzihradsky, 2001; 2005 |
| 8 | Stereoiu | 47.8133; 23.5447 | 2 | Silt up crater lake | Pollen | Björkmann et al., 2003 |
| 9 | Preluca Tişanului | 47.8230; 23.5419 | 2 | Peat bog in crater | Pollen | Feurdean, 2005 |
| 10 | Tăul Mare-Bărdau | 47.8333; 24.6000 | 2 | Peat bog in cirque | Pollen | Fărcaş et al., 2013 |
| 11 | Christina | 47.8333; 24.6166 | 2 | Peat bog in cirque | Pollen | Fărcaş et al., 2013 |
| 12 | Poiana Ştiol | 47.5856; 24.8165 | 2 | Peat bog in cirque | Pollen | Tanţău et al., 2011 |
| 13*** | Buhăiescu Mare | 47.5884; 24.6431 | 2 | Glacial lake | Pollen, Charcoal/C _{org} | Geantă et al., 2014 |
| 14*** | Turbuta | 47.2564; 23.3123 | 2 | Palaeo-lake | Pollen, Charcoal/C _{org} | Feurdean et al., 2007 |
| 15 | Călineasa | 46.5632; 22.8167 | 3 | Infilled doline | Pollen, Charcoal/C _{org} | Feurdean et al., 2009 |
| 16 | Padiş Sondori | 46.5983; 22.7323 | 3 | Infilled doline | Pollen, Charcoal/C _{org} | Feurdean et al., 2009 |
| 17 | Molhaşul Mare | 46.5899; 22.7641 | 3 | Peat bog | Pollen, Charcoal/C _{org} | Feurdean and Willis 2008 |
| 18 | Luci | 46.2969; 25.7375 | 4 | Peat bog in crater | Pollen | Tanţău et al., 2014 |
| 19 | Lake Saint Ana | 46.1285; 25.9008 | 4 | Crater lake | Multi Proxy | Magyari et al., 2006; 2009 |
| 20a | Mohoş 1 | 46.1337; 25.9046 | 4 | Peat bog in crater | Pollen | Tanţău et al., 2003 |
| 20b | Mohoş 2 | 46.1337; 25.9046 | 4 | Peat bog in crater | Pollen | Tanţău et al., 2003 |
| 21a | Avrig 1 | 45.7142; 24.3947 | 4 | Peat bog in depression/oxbow | Pollen | Tanţău et al., 2006 |
| 21b | Avrig 2 | 45.7142; 24.3947 | 4 | Peat bog in depression/oxbow | Pollen | Tanţău et al., 2006 |
| 22 | Bisoca | 45.5333; 26.8166 | 4 | Peat bog | Pollen | Tanţău et al., 2009 |

* regions according to numbers: 1 Hungary, 2 eastern Carpathians, 3 Apuseni mountains, 4 southern Carpathians.
** all studies provide pollen data; the term *multi proxy* refers to studies additionally providing geochemical data.
*** data do not cover the whole study period from 7000 to 3000 yr cal BP due to hiatus.

human activities are evident throughout the study area, except in the Apuseni Mountains, where the data do not cover this period. In Hungary, Late Neolithic agricultural activities are indicated at the sites Báb-Tava (Magyari et al., 2008) and Keszthely (Medzihradzsky, 2005). Besides arable farming also herding activities are indicated at Sarló-Hát Wood (Magyari et al., 2012). In the Eastern and in the Southern Carpathians, unspecific human activities are mentioned by the authors (Fărcaș et al., 2013; Tanțău et al., 2003, 2006). Between 6500 and 4500 cal BP human activities are largely reduced throughout the study area: at the sites Sarló Hát Wood and Bisoca impact of grazing and agricultural activities are evident (Magyari et al., 2012; Tanțău et al., 2009), whereas at the sites Báb-Tava, Keszthely, Tăul Mare-Bărdau, Christina, Călineasa, Molhașul Mare and Avrig only low and unspecific human activities are indicated (Feurdean and Willis, 2008; Feurdean et al., 2009; Fărcaș et al., 2013; Magyari et al., 2008; Medzihradzsky, 2005; Tanțău et al., 2006). During the Bronze Age human impact becomes increasingly significant. At least low anthropogenic activities are evident throughout the study area, except at the sites Mohoș and Keszthely where no human impact is indicated. In Hungary grazing activities are inferred at three sites (Gardner, 2002; Magyari et al., 2008, 2012). In the Eastern Carpathians, the Apuseni Mountains and in the Southern Carpathians herding impact is indicated at one site each (Feurdean et al., 2009; Geantă et al., 2014; Tanțău et al., 2009). At all other sites human impact is related to arable farming, or authors do not mention specific activities.

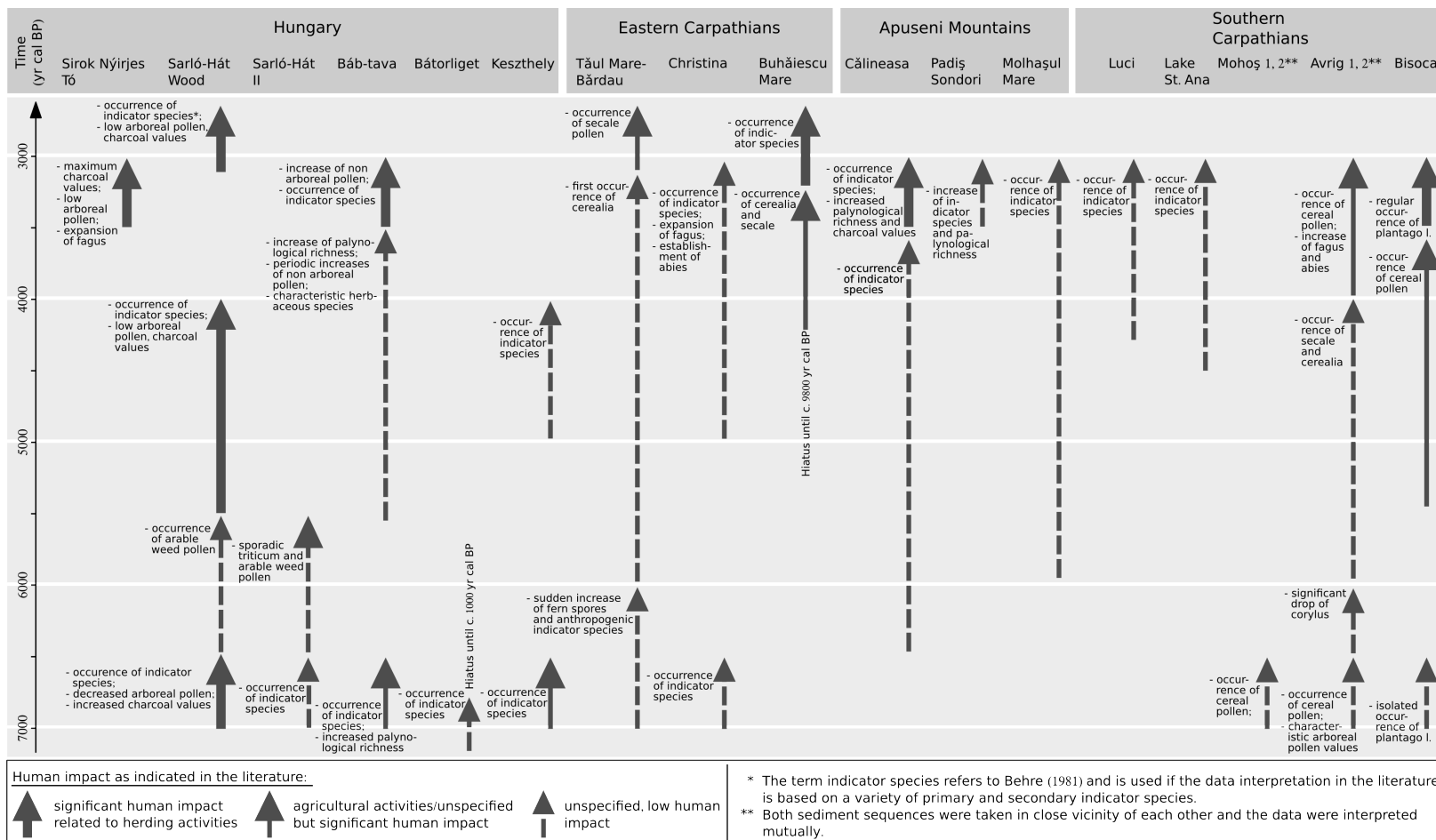
Source criticism

This general overview is in accordance to the commonly accepted view that human activities during the Late Neolithic led to changes in landscape dynamics, whereas during the Chalcolithic human impact on the landscape was less significant and with the onset of the Bronze Age increasing human activities again triggered landscape disturbance (Bintliff, 2002). However, not all included case studies focus on human impact on Holocene environmental dynamics and the consideration of indicators for human activities is not homogeneous. Hence, the compilation of published information on human landscape disturbance produces neither a region-wide consistent view about prehistoric human activities in general nor about herding activities in particular. The application of a standardized model inferring probabilities of prehistoric herding activities based on pollen data, however, gives a large-scale coherent idea of possible grazing impact. Though, it is admitted that not all the details of the particular case studies can be considered. It is not assumed that a re-evaluation and synthesis of the case studies proposes phases of herding-related degradation processes for any of the studied regions. Yet, by re-evaluating all published data with a uniform thematic focus and using a standardized procedure, prehistoric herding activities can be traced uniformly for the study region.

Displaying the results of the fuzzy model

The main aspects of the standardized fuzzy model can be summarized as follows: During the Late Neolithic moderate human impact is evident throughout

Figure 8: Indication of human impact as reported in the included case studies.



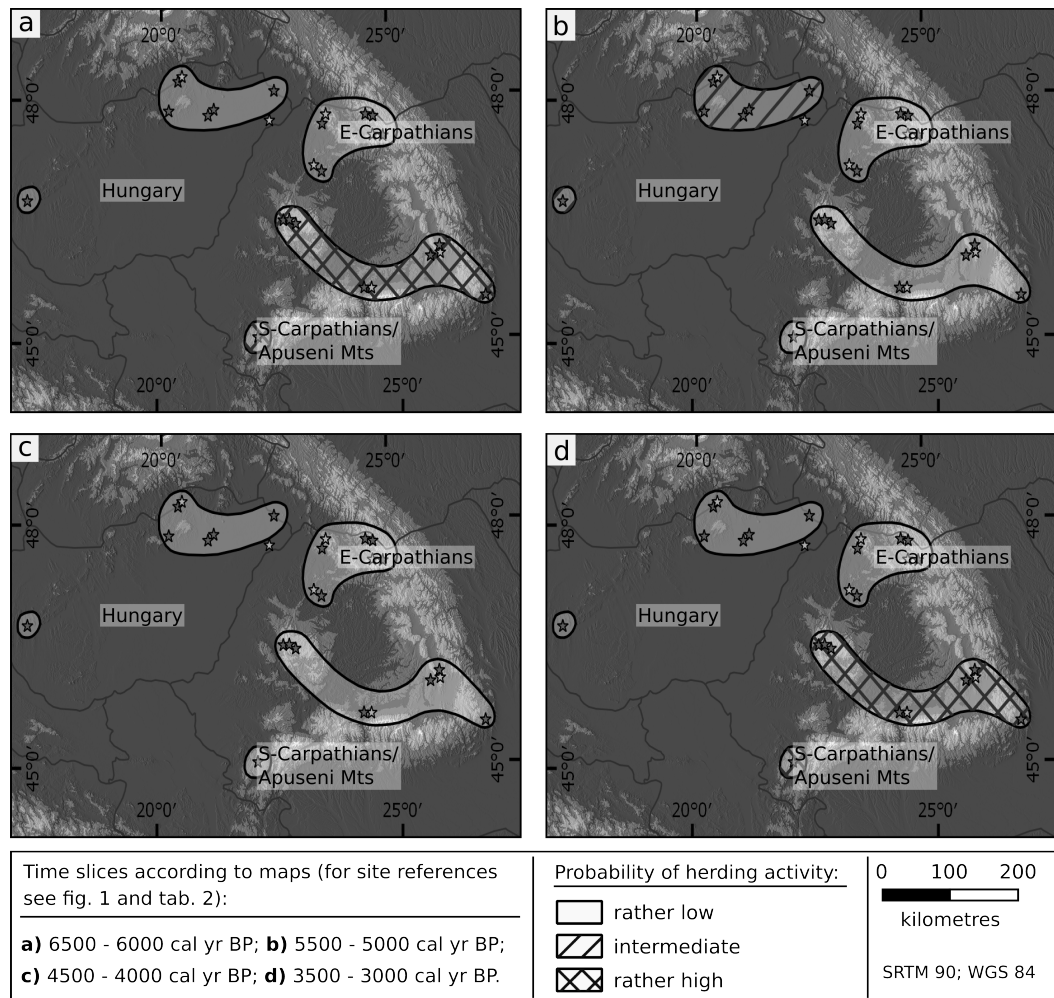


Figure 9: Probability of grazing activities in the Carpathian region as inferred from pollen data of published case studies; note that indicated regions do not correspond to catchment areas of the sites.

the study area; with the start of the Chalcolithic period probability of herding impact increases significantly in the southern Carpathians and Apuseni Mountains (Figure 9 a) and drops abruptly during the transition from Chalcolithic to Bronze Age (Figure 9 b); during the Middle Bronze Age herding indication is all over rather low (Figure 9 c) while for the Late Bronze Age a high probability of herding impact is evident (Figure 9 d) (Schumacher et al., 2016a). Marinova et al. (2012) find similar evidences for human impact in the palynological and anthracological records of northern Bulgarian sediment sequences: after a first grazing impact during the Late Neolithic an expansion of light-demanding and riparian trees during the Early Chalcolithic indicates increasing impact of grazing. During the transition from Chalcolithic to Bronze Age there is almost no indication for human impact besides low evidence for pasture activities; between 5200 and 4200 cal BP indication for pastoralism again increases and between 3400 and 3200 cal BP (Marinova et al., 2012) identify strong evidence for human impact as represented by pollen assemblages.

In contrast, in northern Hungary there is almost no indication for herding impact during the Early Chalcolithic (Figure 9 a), whereas the Middle and Late Chalcolithic are characterized by increased herding (Figure 9 b). An east-oriented trajectory of herding impact is indicated from Lake Balaton towards the Upper Tisza valley for the period between 5500 and 3000 yr cal BP. According to that, Sherratt describes increasing settlement activities to the east beginning from c. 5500 BP (Sherratt, 1982, 1983a). The sites in the eastern Carpathians are located mostly at sub-alpine altitudes. Pollen records of the sediment sequences indicate locally and temporally differing events of vegetation disturbance. This points to vegetation disturbance due to local human activities. The archives in the eastern Carpathians are situated at marginal locations several tens of kilometres away from known prehistoric settlements. Assuming that vegetation disturbances were caused by human activities this suggests a vagrant rather than a sedentary way of life. However, due to the high elevation of the sites vegetation may have reacted more sensitive to disturbances than the vegetation represented by the pollen records from lowland sites. Therefore, indication of herding impact in this region is rather equivocal compared to sites at lower altitudes in the southern Carpathians and northern Hungary.

Summarizing, it can be stated that the presumed start of wool production between the Late Neolithic and the Early Bronze Age did not have significant impact on landscape dynamics; however, herding-related disturbance of the vegetation cover can be assigned to the relevant time frame. Even though the introduction of wool-bearing sheep might have been of revolutionary character for the socio-economic life of contemporaries pronounced degradation effects were not connected with this process.

2.2.5 *Disentangling the Textile Revolution – an inherent bridge between disciplines?*

Data synthesis

The thematic complex of the project holds strong potential for integrated research across humanities and natural sciences. To disentangle the complex process of the introduction of wool-bearing sheep and connected socio-economic as well as environmental changes, data from different fields and of different quality and scales need to be set in relation. Generating these diverse data was achieved by realising interdisciplinary research forming a coherent synergy. General parameters of the investigations such as chronological and spatial foci were determined during the conception phase and have been commonly adjusted during the research. This allowed performing coherent research projects within the different scientific fields, as well as it ensured a constructive data synthesis. Specific aspects related to the introduction of the wool-bearing sheep and to the advent of wool production are addressed by the different projects. Results for the Balkan region, such as shifts of general morphological parameters of spindle whorls will be set in relation to types of textile imprints, the representation of sheep in bone assemblages and the indication of herding-related vegetation disturbance. For Western Asia, the occurrence of sheep-related iconographic representations will be related to written evidence of wool production and both will be compared to the amount of

identified sheep species as derived from bone assemblages. Results of the data synthesis from one region may be transferred to another region. E.g., information derived from the combination of wool-, or sheep-related iconographic representations and particular shapes of spindle whorls with detailed information from cuneiform texts, may allow a more accurate interpretation of the same type of proxies from other regions. Similarly, probability of herding activities as derived from pollen records will be supported by information on sheep husbandry as derived from bone assemblages and by information about textile production as derived from textile tools. It is the thematic framework of the introduction of wool-bearing sheep which constitutes the bridge between the different disciplines and respective projects, rather than the complexity of a very particular research issue requiring interdisciplinary research. The results of the independent research projects are coalesced and mutually interpreted to produce a general output of increment value.

Limits of the approach

The holistic approach of the project inherits certain limits: The large-scale use of wool as raw material for textile production was not a local phenomenon orderly spreading towards the adjacent and farther regions but proceeded with regional and temporal variation (Greenfield, 2010). It is therefore important to consider large spatial and temporal scales to reveal processes and mechanisms of this innovation. Large-scale investigations are subject to drawbacks such as significant reduction and generalisation of the data on-hand to be able to cope with the amount of available information. Furthermore, the availability of data becomes more and more heterogeneous with increasing scales of the studied areas and time periods. These problems propagate the more disciplines are comprised within the project. Hence, site specific details may often not be considered and information about wool processing or herding activities provided by the sources of one discipline may lack the support by information from sources of other disciplines. Therefore, the data synthesis will focus on general trends, rather than on local and detailed processes.

Particular obstacles are inherent to the task of addressing landscape reaction to prehistoric grazing pressure. While it is a commonly accepted view that the exploitation of sheep for wool production started between the Late Neolithic and the Early Bronze Age (Greenfield, 2010), thresholds of landscape reaction to human activity are highly variable. Hence, land degradation due to large scale wool production and related grazing pressure might have taken place long after the introduction of wool processing; namely when carrying capacities of grazed landscapes were reached and grazing impact could not be compensated any more. Even though the introduction of wool production may have been of revolutionary character regarding socio-economic aspects, the impact of related animal herding on the landscape seems to have started only after 3000 cal BP (Schumacher et al., 2016a). Furthermore, spatial representation of landscape conditions derived from the different archives are variable and sites with good pollen preservation such as mountain lakes and peat bogs are often situated in far distance from archaeological sites. If the sites are small and represent only the local vegetation composition,

signals of herding-related landscape disturbances from adjacent areas suitable for animal herding, such as gently inclined valley slopes, might not be recorded in the sediments. Thus it is possible that the *de facto* landscape disturbance connected to the introduction of wool processing was stronger than it is indicated in the included sediment records. Nevertheless, by following a semi-quantitative approach the probability of prehistoric herding activities during the time of the presumed advent of wool production could be traced on a trans-regional scale.

ACKNOWLEDGMENTS This study was kindly supported by the financial, technical and scientific help of the Excellence Cluster Topoi of the *Deutsche Forschungsgemeinschaft* (DFG). We gratefully acknowledge the two anonymous reviewers for their constructive comments on an earlier version of this manuscript.

MATERIAL AND METHODS

The investigation of different spatial scales as it is implied for studying past herding activities and their impact on the landscape requires the application of various methodological approaches (Schumacher et al., 2016b, chapter 2.2). The supra-regional scale is addressed performing a meta-analysis of published data on Holocene environmental change. Pollen data was re-evaluated applying a standardized fuzzy model in order to trace herding-related vegetation changes during the Mid-Holocene (chapter 4). Here, comprehensive data compilation reflects regional and supra-regional trajectories of human-vegetation interference at the expense of accounting for site-specific developments. Therefore, a case study was performed by applying field-, laboratory- and GIS-methods to study Holocene landscape development on the local scale (chapter 3.2).

3.1 META-ANALYSIS OF PUBLISHED DATA ON PAST VEGETATION CHANGE

Except for four sites, studies included in the meta-analysis provide continuous pollen records throughout the Holocene; data on charcoal accumulation are available for 15 sediment sequences and geochemical data are available for five sediment sequences (Figure 1 b, Table 1). All data sets included are supported by reliable chronological information.

The archives from which the sediment sequences were taken have mostly surface areas of less than 6 ha in size. Five of the included sites have archives with a surface area of 10 ha, 20 ha, 30 ha, 40 ha, 80 ha and 120 ha, respectively. To precisely specify the relevant pollen source area of a given archive it is necessary to consider type of pollen, vegetation patterning, surrounding relief and local wind systems (Bradshaw, 1988; Bunting et al., 2004). Simulations for archives with surface areas of up to 20 ha situated in a mostly forested landscape in Denmark result in relevant pollen source areas of <3000 m distance around the respective basin (Hellman et al., 2009). To reconstruct regional vegetation composition data from several archives with relatively large surface areas (>48 ha) within the respective area have to be integrated (Sugita, 2007). Thus, the results of the meta-analysis do not refer to area-wide conditions but reflect local human-environment interferences that are comprised at regional scale.

As vegetation composition relates to climate development as well, the investigation of human induced prehistoric vegetation changes requires the consideration of Holocene climate conditions. Published speleothem $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ records were included as independent proxies for Holocene climate development (Figure 1 b). Data from the National Archaeological Record of Romania were used to assess the proximity between environmental archives used and prehistoric settlement sites (INP, 2013). All locations denoted in the data base as settlements or fortified sites (in total 2102) were included in the assessment.

Linear age-depth models for each sediment sequence were calculated using Clam2.2 (Blaauw, 2010; R-Core-Team, 2014) with IntCal13 calibration curve (Reimer et al., 2013) to improve the temporal precision and consistency of the different data sets. In case a published age-depth model was modified according to a more plausible stratigraphy, it was adopted. From the pollen records secondary indicator species such as *Plantago lanceolata*, *Plantago major/media*, *Polygonum aviculare* and *Rumex acetosa/acetosella* were selected as proxies for herding activities (Behre, 1981; Bottema and Woldring, 1990; Magyari et al., 2012) and data were extracted from published pollen diagrams. Being aware of the large variety of factors influencing pollen composition, arboreal pollen values were considered as indicators for the density of canopy cover (Bradshaw, 1988; Kalis et al., 2003).

To infer probabilities of herding-related landscape disturbance, these data were combined by applying a standardized evaluation procedure (Figure 10). The data were aggregated to 500 year time slices and different degrees of herding probability were assigned. The evaluation procedure followed a semi-quantitative approach based on the assumption that increasing abundance of indicator species pollen and decreasing arboreal pollen values respectively, indicate a higher probability of herding-related landscape disturbance. First, values of indicator species were summarized and mean values were calculated for 500 year time slices. To facilitate the comparability between the different records, arboreal pollen values were z-transformed using the base period 7000 to 3000 cal BP and mean values were calculated for each time slice. Subsequently, semi-quantitative classes of herding intensity were obtained by combining the data in a fuzzy rule-based system using the R-package *frbs* with *frbs.gen* function and Mamdani model (R-Core-Team, 2014; Riza et al., 2014).

In the first step of the fuzzy combination the values of each data set were classified into three classes namely “no”, “low”, “intermediate” pollen values of indicator species and “low”, “moderate”, “high” arboreal pollen values. Break values for membership functions were defined in relation to the range of each data set to level out different degrees of sensitivity of the different sites. Rules for the combination of proxies were formulated assuming that arboreal pollen values are a weaker indicator for herding impact than pollen of indicator species.

The combination of the classified proxies resulted in ordinal scaled classes of herding probability: class 0 represents no herding indication, classes 1 – 3 represent increasing degrees of herding probability (Figure 10). For each data set classes of herding probability were assigned to the 500 year time slices. In total, data sets from 20 sites were included in the standardized evaluation procedure. Data from sediment sequences with extended hiatus or low dating confidence were excluded in order to optimize inter-site comparability. Further proxies allowing to infer palaeoenvironmental conditions such as “rate of change” (Huntley, 1992), “palynological richness” (Birks and Line, 1992; Feurdean et al., 2013b), charcoal accumulation rates (Whitlock and Larsen, 2001) or geochemical indicators (Boyle, 2001; Mackereth, 1965; Meyers and Teranes, 2001; Schütt, 2004) were not available for all the case studies included. These additional data were considered for critically scrutinizing the results of the standardized evaluation procedure and plausibility check.

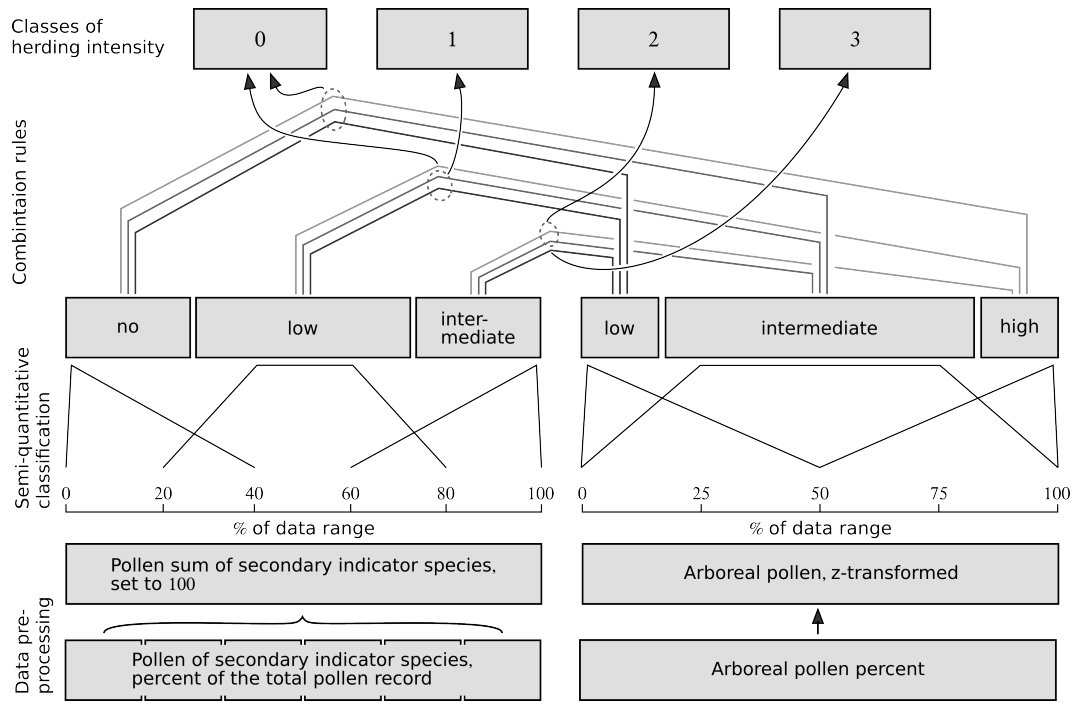


Figure 10: Flow chart of the standardised fuzzy model applied to derive semi-quantitative classes of herding intensities.

The degree to which human activities are reflected in a pollen archive depends, amongst others, on the distance between the archive and the locations where human activities have impacted the landscape. Distances between pollen archives and locations where humans affected the landscape are hard to assess. Prehistoric settlement sites indicate locations of former concentrated human activities, although animal herding in particular may have been practised in more distant areas. Homogeneous, large-scale data on prehistoric settlement activities were available only for the territory of Romania (INP, 2013). Therefore, proximity of the included sediment archives from prehistoric settlement sites was consistently approximated exclusively for the sediment archives located within the country borders. Since detailed information on timing of the settlement sites was inconsistent, temporal resolution of the data sets derived is coarse and refers only to the Neolithic, Chalcolithic and Bronze Age. Furthermore, no distinction was made between different types or sizes of settlements. Mean linear distances between the sediment archives and the 10, 20 and 50 nearest settlement sites each were calculated as approximate values for the marginality of the sediment archives.

3.2 FIELD WORK AND LABORATORY ANALYSES

Local Holocene environmental dynamics were investigated in the Bükkalja Foothill area, northern Hungary. Along the middle course of the Hór valley sediment cores were extracted from five fans deposited by tributary valleys. Additionally, one sediment core was extracted from the alluvial plain of the Hór valley (Figure 1 d). Coring locations were recorded using a handheld GPS de-

vice with 5 m accuracy. The cores were obtained using a percussion hammer (Wacker® BHF 30 S) with a core diameter of 5 cm. The sediment sequence Coll 01 was extracted with an open steel rod and sediments were photographed, described and subsampled in the field. All remaining sediment sequences were obtained using closed plastic liners and photographs, sediment description and subsampling were done in the Laboratory for Physical Geography of the Freie Universität Berlin.

The sediment analyses were conducted in the Laboratory of Physical Geography at the Freie Universität Berlin. Volume-specific magnetic susceptibility of the closed sediment cores was measured in 4 cm intervals using a Bartington MS2 System. After core opening sediment sequences were documented by photographs and described macroscopically displaying stratigraphical units. Fines of the cores (<2 mm Ø) were sampled in 10 cm intervals and from every stratigraphical unit, respectively. Sediment colour was determined applying parallel a Munsell soil colour chart and a Minolta CM 2500d spectrophotometer displaying colours in the CIE colour space (Lab-system). Content of coarse rock fragments, grain size composition, sediment compaction, soil wetness and carbonate content were estimated following the German Soil Survey Instructions (Ad-Hoc-AG, 2005). Water content of the samples was determined by drying the samples at 105 °C for at least 4 hours measuring difference in weight before and after the drying process. Contents of volatile substances were determined as step-wise loss on ignition (LOI mass-%) of the dried samples (105 °C) at 550 °C and 900 °C with a minimum heating period of 4 hours for each procedure. pH values of the sediments were measured for a solutions of 1 g of dried sediment digested in 2.5 ml 0.01 M KCl solution using a Hanna checker device (HI 98127) with 0.1 pH resolution. Total carbon content (TC mass-%) was measured applying a dry combustion using LECO TruSpec CHN 1000 analyser and total inorganic carbon (TIC mass-%) was measured applying a Woesthoff Carmograph C-16; total organic carbon (TOC) was computed building the difference of total carbon and total inorganic carbon. Twelve samples of charred plant remains were extracted and analysed using AMS dating in the Radiocarbon Laboratory Poznan. The radiocarbon dates were calibrated using Calib Rev 7.0.2 (Stuiver and Reimer, 1993) and IntCal13 calibration curve (Reimer et al., 2013).

A digital elevation model (DEM) of the study area with 16 m*16 m ground resolution was derived from the 1:10,000 topographic map (FÖMI – Institute of Geodesy, 2003) using the “Topo to Raster” tool of ArcGIS 10.0. Tributary valley incisions and their geometric characteristics such as drainage area, stream length, mean stream gradient and mean width-depth ratio were determined on the basis of the DEM and applying QGIS 2.10. A geomorphological map of the study area was created on the basis of Dobos (2012) supplemented by field mapping and the analysis of the 1:10,000 topographic map. Data on prehistoric settlement sites were kindly provided by the Herman Ottó Múzeum, Miskolc.

THE REGIONAL SCALE – GRAZING-RELATED VEGETATION CHANGES IN THE CARPATHIANS

4.1 INTRODUCTION

Case studies investigating past human-environment interactions provide detailed information on the development of particular environmental conditions or socio-economic behaviour (see chapter 1.3). The results mostly reflect local conditions around the studied site. However, tracing the impact which the emergence and spread of prehistoric wool economies had on the environment inherently requires the consideration of large spatial scales, as well (Schumacher et al., 2016b, chapter 2.2). The integration and reliable comparison of case studies from a larger region requires accurate age-depth modelling of the investigated sediment sequences. Furthermore, it is important to consider the different research foci of the included case studies. E.g. if reconstructing the post-Pleistocene vegetation succession would be the main research target of a given case study it is rather likely that signs of early human impacts on the vegetation development is neglected than if the focus lies on tracing Neolithic human activities.

Considering these constraints, the following study was designed to trace prehistoric grazing impact on the regional and supra-regional scale. The study contains a literature review compiling evidence of prehistoric human-vegetation interferences. A standardised meta-analysis of the published data is performed to trace early grazing impact.

4.2 PAPER 2: MID-HOLOCENE VEGETATION DEVELOPMENT AND HERDING-RELATED INTERFERENCES IN THE CARPATHIAN REGION

*Schumacher, M. Schier, W. Schütt, B. (2016): Mid-Holocene vegetation development and herding-related interferences in the Carpathian region. Quaternary International 415, 253–267.
DOI: <http://dx.doi.org/10.1016/j.quaint.2015.09.074>*

Abstract

The paper comprises data from 27 case studies to assess large-scale human-vegetation interferences in the Carpathian region during the Mid-Holocene. The main focus is put on herding-related vegetation changes and climate influences are addressed. The publications reviewed are based on sediment sequences which provide ¹⁴C-dated pollen records, charcoal and geochemical data. Based on a semi-quantitative approach pollen of secondary indicator species and arboreal pollen values were combined in a fuzzy model to assess the intensity of herding-related vegetation changes. The model was applied for 20 selected case

studies. The data from the remaining seven sites as well as geochemical and charcoal data were used to validate the results of the standardized evaluation. Speleothem $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ records from Hungary and Romania were used as independent proxies to align Holocene climate development. The results were regionalised and trends of herding-related vegetation change are presented for the Southern Carpathians and Apuseni Mountains, for the Eastern Carpathians and for Hungary. Mean distances between included archives and prehistoric settlement sites were calculated as indicator for the marginality of the environmental archives. In all regions, absolute values for herding indication are low. Phases of changing herding impact on the landscape can be observed for the Southern Carpathians and Apuseni Mountains as well as for Hungary. In the Southern Carpathians and Apuseni Mountains increased herding activities can be traced for the Early Chalcolithic and the Late Bronze Age. The first phase is contemporary with an intensification of the use of secondary products. In Hungary herding impact is in accordance with prehistoric settlement development. Widely increased herding indications date to the Late Chalcolithic and the Early Bronze Age. In the Eastern Carpathians, interference of climate influences and human impacts occurred.

Keywords

Chalcolithic; Early Bronze Age; Herding impact; Fuzzy rule-based systems; Secondary products revolution

4.2.1 Introduction

The Holocene was a period of climatic changes occurring at multiple spatial and temporal scales (Mayewski et al., 2004). At a spatially generalized millennial timescale three periods can be distinguished: a deglaciation period between 11700 and 7000 BP, a warm period between 7000 and 4200 BP and a cool period between 4200 and 250 BP; these periods of relatively stable temperature conditions were interrupted by cold phases at a multi-decadal to multi-centennial timescale (Wanner et al., 2011). However, the Holocene climate development was not uniform across Europe. Davis et al. (2003) show that southern Europe was characterised by cool and moist climate during the Mid-Holocene.

During the Early and the Mid-Holocene, the first farmers spread from the eastern Mediterranean into the Balkans and further towards northwestern Europe introducing agro-pastoral land use practices (Bogucki, 1996). Although the general spatio-temporal trend of this cultural development is northwest oriented, the introduction of Neolithic and post-Neolithic innovations did not uniformly progress but spread with geographic and temporal variability (Bogucki, 1996). Both, climate influences as well as human activities affected landscape development (Bintliff, 2002; Butzer, 2005). In correspondence to the variable nature of these impacts, pace and intensity of landscape development and related sedimentation processes varied though time (e.g. Dotterweich, 2008; Dreibrodt et al., 2010; Dusaar et al., 2011; Notebaert and Verstraeten, 2010). However, the differentiation between climatically triggered and human-driven landscape changes

remains challenging (e.g. Dotterweich et al., 2013; Dusar et al., 2012; Fuchs, 2007; Kalicki et al., 2008; Schütt, 2006). Phases of erosion processes accelerated due to human impact can most often only be related to settlement activities in general (e.g. Dreibrodt et al., 2014; Fuchs et al., 2004; Notebaert et al., 2014). Furthermore, varying landscape sensitivity as well as time lags between triggering climate events or human impacts and corresponding landscape reactions may induce rather vague cause-effect linkages (Dusar et al., 2012; Schütt, 2006).

Examining settlement strategies, next to the exploitation of primary products such as cereals and meat, the use of secondary products gained continuously in importance after introduction. The concept of the “Secondary Products Revolution” suggests an increasing use of secondary products from animals such as wool, milk and labour during the Chalcolithic (Sherratt, 1981). While the different secondary products appeared with regional and temporal variations, significant impacts on cultures came with their large scale and contemporary application (Greenfield, 2010). Increasing use of animal products is based on increasing importance of livestock husbandry and implies generally increasing grazing pressure. Furthermore, new subsistence strategies might have triggered changing land use patterns, as formerly unused marginal areas were now exploited by pastoral farmers (Finkelstein and Gophna, 1993). Increasing mobility of pastoral farmers may be connected to the changing economic strategy (Arbuckle, 2012).

Increasing grazing pressure is reflected in the vegetation cover first: species composition reacts sensitively to grazing, while net primary production reacts with a slight time-lag and the soil nutrient pool reacts with a long time-lag to grazing (Milchunas and Lauenroth, 1993). Woodland grazing generally constrains the rejuvenation of trees: this leads to a relative support of species of primary forests that are less light-sensitive and able to grow from the stump (Kalis et al., 2003). Moderate grazing pressure leads to an increase of overall plant species richness (Schütz et al., 2003). Intensified livestock grazing leads to soil compaction and decrease of vegetative cover; subsequently, destabilized soil structure and increasing overland flow enhance soil erosion (Belsky and Blumenthal, 1997). However, the onset of soil erosion processes appears dependent on the magnitude of rainfall events, where the critical threshold is determined by the landscape sensitivity.

While it is hard to retrace the whole cause-effect structure linking certain triggers to landscape forming processes, herding-related changes of the vegetation cover are represented in pollen records. *Polygonum aviculare* and *Plantago major/media* representing ruderal vegetation and *Plantago lanceolata* and *Rumex acetosa/acetosella* representing pasture and meadow communities (Behre, 1981) are commonly interpreted as indicators for animal herding, although it is important to consider the natural vegetation of the investigated site (Magyari et al., 2012). Percentages of arboreal pollen relate to tree canopy (Bradshaw, 1988) and the arboreal/non-arboreal pollen ratio is the most frequently used proxy to trace human impact on the vegetation cover, although it is not the most appropriate one (Kalis et al., 2003). It can be assumed that species composition of a given vegetation community significantly changes due to grazing pressure (Milchunas and Lauenroth, 1993) and that the number of plant species increases (Schütz et al., 2003). In consequence, statistical measures such as rate of change (Huntley, 1992)

and palynological richness (Birks and Line, 1992) can be used as indicators for potentially herding-related human impact (Feurdean et al., 2013b). Records of microscopic charcoal represent the importance of regional fires, whereas macroscopic charcoal records indicate the importance of local and extra-local fires (Whitlock and Larsen, 2001). Human induced woodland burning may be distinguished from natural forest fires if independent climate proxies are included in the analysis (e.g. Feurdean et al., 2012).

Holocene vegetation development in the Carpathians is documented by a number of well-dated pollen records. Furthermore, studies on prehistoric settlement history and cultural development in the region have a long research tradition (e.g. Chapman et al., 2009; Duffy et al., 2013; Kalicz, 1994; Parsons, 2011; Sherratt, 1981, 1982, 1983a,b).

The presented study is based on a review comprising published case studies on Holocene vegetation dynamics in the Carpathian region. Aims of the study are 1) to point out spatio-temporal differences of climate variation and human activity impacting Holocene vegetation dynamics in the region; 2) to characterize herding-related landscape changes within the area and in relation to the southeastern and northwestern adjacent regions, and 3) to relate the vegetation development in the region to the model of cultural development that assumes abruptly increasing animal herding during the Mid-Holocene.

4.2.2 *Study site*

The sites which are comprised in this review are located within a variety of landscape types including the Great Hungarian Plain, the north Hungarian mid-mountains, the Transylvanian Basin as well as different altitude levels of the Carpathian Mountain range. Elevations vary between <100 m a.s.l. in the Great Hungarian Plain and >1900 m a.s.l. in the Eastern Carpathians. These large orographic differences determine the major climatic conditions of the study region: mean annual precipitation ranges from 550 to 600 mm y⁻¹ in the Great Hungarian Plain and increases to 1500 – 1600 mm y⁻¹ in the Eastern Carpathians. With increasing altitudes mean annual temperatures decrease from 9.5 – 11.5 °C in the lowlands of Hungary to 0 – 2 °C at the high levels of the Eastern Carpathians (Anonymous, 1960 cited in Okołowicz, 1977, p. 108; Stoenescu, 1960a,c). The basin situation and increasing continentality contribute to pronounced dryness and to a marked yearly temperature amplitude in the central lowlands of the Pannonian Plain and towards the east (Okołowicz, 1977, p.77). However, also different macro weather situations prevail for the different areas of the Carpathian region, with the westerlies controlling rainfall in its northern part from April to November. The oceanic air masses transport moisture and have mitigating effects on the mean temperatures. Towards the south, the sub-tropical high gains importance during summer and causes region-wide temperature maxima in the southeast of the Carpathian region. Especially between October and April, Adriatic lows bring Mediterranean influences to the Pannonian Plain (Weischet and Endlicher, 2000, p. 136).

The research sites included in this review were assigned to four regions: Southern Carpathians including the southern part of the Eastern Carpathians, Apuseni Mountains, Eastern Carpathians and Hungarian low lands and mid-mountain ranges (Figure 11). Climate, vegetation and relief characteristics of the areas are outlined briefly in the following, and specifications of the included sequences and references are summarized in Table 4.

In the Southern Carpathians, eight sites were included which are situated at elevations between 400 and 1400 m a.s.l. (Figure 11, sites 19-24). In the lower areas annual precipitation averages 600 mm y⁻¹ with mean annual temperatures of 8 – 9 °C; at higher elevations mean annual precipitation exceeds 1000 mm y⁻¹ with mean annual temperatures of 2 – 4 °C (Stoenescu, 1960b,c). Broadleaved deciduous forests and mixed deciduous and conifer forests form the natural vegetation around the selected sites. In the lowlands wet-land communities of the floodplains complement the vegetation composition, and above ~1000 m a.s.l. coniferous and mixed broadleaved-coniferous forests prevail (Bohn et al., 2004).

For the Apuseni Mountains three sites were included which are situated within an area with a radius of ~5 km at around 1300 m a.s.l. (Figure 11, sites 16-18). Mean annual precipitation in the area amounts up to 1200 mm y⁻¹ with annual average temperatures of 4 – 6 °C (Stoenescu, 1960b,c). The natural vegetation is formed by coniferous and mixed broadleaved-coniferous forests. The summit areas of the Apuseni Mountains are characterized by nemoral-montane open woodlands and sub-alpine communities (Bohn et al., 2004).

From the Eastern Carpathians, six sites were selected located at elevations between 700 and 1600 m a.s.l. (Figure 11, sites 8-13) and two sites located in the Transylvanian Basin at c. 250 m a.s.l. (Figure 11 sites 14, 15). Mean annual precipitation at the sites in the Gutai Mountains (700 – 750 m a.s.l.) varies between 800 and 1000 mm y⁻¹ with mean annual temperatures of 8 °C (Stoenescu, 1960b,c) (Figure 11, sites 8, 9). Here, the natural vegetation is broadleaved deciduous and mixed broadleaved conifer forests which is complemented by thermophilous mixed deciduous broadleaved forests in climatically favoured areas (Bohn et al., 2004). In the Maramureş Mountains (1500 – 1600 m a.s.l.) mean annual precipitation amounts up to 1400 mm y⁻¹ falling mostly as snow; mean annual temperatures vary between 0 and 2 °C (Stoenescu, 1960b,c) (Figure 11, sites 10-13). In the highest areas the natural vegetation is formed by alpine and subarctic communities. In the northern Transylvanian lowlands (Figure 11, sites 14, 15) mean annual precipitation ranges between 650 and 700 mm y⁻¹ with mean annual temperatures of 8.5 °C; mean monthly temperature varies between -2 and 18 °C (Stoenescu, 1960b,c). The natural vegetation is composed of thermophilous mixed deciduous broadleaved forests, deciduous broadleaved and mixed broadleaved and conifer forests; the floodplains are dominated by wet-land communities (Bohn et al., 2004).

In the northern and western part of the Carpathian region selected sites are located in the mid-mountain ranges of northern Hungary (Figure 11, sites 1-3), in the lowlands of the Pannonian Plain (Figure 11, sites 4-6) and at the western shore of Lake Balaton (Figure 11, site 7). Mean annual precipitation ranges from 600-700 mm y⁻¹ in the northern mid-mountains to 500 – 550 mm y⁻¹ in the lowlands

Table 4: List of sites providing data on Holocene vegetation development included in the review.

| Map code | Site | Location | Region ^b | Depositional environment | Surface area (ha) | Investigated Proxies ^c | Sampling interval (cm) | References |
|------------------|---------------------|------------------|---------------------|------------------------------|--|-----------------------------------|------------------------|---|
| 1 | Kelemér Kismohos Tó | 48.3371; 20.4256 | 1 | Peat bog in depression | 0.9 | Multi Proxy | 8 | Willis et al., 1997; Braun et al., 2005 |
| 2 ^a | Nagymohos | 48.3404; 20.4308 | 1 | Peat bog in depression | 1.4 | Multi Proxy | 3 | Magyari et al., 2001 |
| 3 | Sirok Nyírjes Tó | 47.9391; 20.1872 | 1 | Peat bog in crater | 6.3 | Multi Proxy | 2-4 | Gardner, 2002 |
| 4a | Sarló-Hát Wood | 47.9608; 21.1659 | 1 | Oxbow lake | c. 30 (core taken from close to the shore) | Pollen, Charcoal/C _{org} | 4 | Magyari et al., 2010 |
| 4b | Sarló-Hát II | 47.9608; 21.1659 | 1 | Oxbow lake | c. 30 (core taken from close the basin center) | Pollen, Charcoal/C _{org} | 4 | Magyari et al., 2010 |
| 5 | Báb-Tava | 48.1859; 22.4822 | 1 | Oxbow lake | 5 | Pollen, Charcoal/C _{org} | 4 | Magyari et al., 2008 |
| 6 ^a | Batórliget | 47.7725; 22.2689 | 1 | Marsh land | c. 3.5 | Multi Proxy | 2 | Williset al., 1995 |
| 7 | Keszthely | 46.7705; 17.1973 | 1 | Mire/marsh land | NA | Pollen | 5 | Medzihradsky, 2001; 2005 |
| 8 | Steregeiu | 47.8133; 23.5447 | 2 | Silt up crater lake | 0.5 | Pollen | 2.5 | Björkmann et al., 2003 |
| 9 | Preluca Tiganului | 47.8230; 23.5419 | 2 | Peat bog in crater | 1 | Pollen | 2.5 | Feurdean, 2005 |
| 10 | Tăul Mare-Bărdau | 47.8333; 24.6000 | 2 | Peat bog in cirque | 0.8 | Pollen | 10 | Fărcaș et al., 2013 |
| 11 | Christina | 47.8333; 24.6166 | 2 | Peat bog in cirque | 0.1 | Pollen | 10 | Fărcaș et al., 2013 |
| 12 | Poiana Știol | 47.5856; 24.8165 | 2 | Peat bog in cirque | 2.6 | Pollen | 5 | Tanțău et al., 2011 |
| 13 ^a | Buhăiescu Mare | 47.5884; 24.6431 | 2 | Glacial lake | 0.9 | Pollen, Charcoal/C _{org} | 2 | Geantă et al., 2014 |
| 14 ^a | Turbuta | 47.2564; 23.3123 | 2 | Palaeo-lake | 1.5 | Pollen, Charcoal/C _{org} | 2 | Feurdean et al., 2007 |
| 15 | Stiucii | 46.9678; 23.9029 | 2 | Lake | 38 | Pollen, Charcoal/C _{org} | 2-10 | Feurdean et al., 2013b, 2015 |
| 16 | Călineasa | 46.5632; 22.8167 | 3 | Infilled doline | 1 | Pollen, Charcoal/C _{org} | 2 | Feurdean et al., 2009 |
| 17 | Padiș Sondori | 46.5983; 22.7323 | 3 | Infilled doline | 1 | Pollen, Charcoal/C _{org} | 2 | Feurdean et al., 2009 |
| 18 | Molhașul Mare | 46.5899; 22.7641 | 3 | Peat bog | 8 | Pollen, Charcoal/C _{org} | 4 | Feurdean and Willis 2008 |
| 19 | Luci | 46.2969; 25.7375 | 4 | Peat bog in crater | 120 | Pollen | 5 | Tanțău et al., 2014 |
| 20 | Lake Saint Ana | 46.1285; 25.9008 | 4 | Crater lake | 19.3 | Multi Proxy | 4 | Magyari et al., 2006; 2009 |
| 21b ^a | Mohoș 1 | 46.1337; 25.9046 | 4 | Peat bog in crater | 80 | Pollen | 5 | Tanțău et al., 2003 |
| 21b | Mohoș 2 | 46.1337; 25.9046 | 4 | Peat bog in crater | 80 | Pollen | 5 | Tanțău et al., 2003 |
| 22a | Avrig 1 | 45.7142; 24.3947 | 4 | Peat bog in depression/oxbow | 10 | Pollen | 5 | Tanțău et al., 2006 |
| 22b ^a | Avrig 2 | 45.7142; 24.3947 | 4 | Peat bog in depression/oxbow | 10 | Pollen | 5 | Tanțău et al., 2006 |
| 23 | Bisoca | 45.5333; 26.8166 | 4 | Peat bog | 1.5 | Pollen | 5 | Tanțău et al., 2009 |
| 24 | Semenic | 45.1800; 22.0594 | 4 | Peat bog | NA | Pollen, Charcoal/C _{org} | 2 | Rösch and Fischer, 2000 |

^a sites were not included in standardized analysis because of extended hiatus, poor age depth modelling, or lack of proxy data.

^b Regions according to numbers: 1 Hungary, 2 Eastern Carpathians, 3 Apuseni mountains, 4 Southern Carpathians.

^c All studies provide pollen data; the term multi proxy refers to studies additionally providing at least charcoal and geochemical data.



Figure 11: Area of investigation with included case studies; map codes correspond to numbers given in Table 4 and Figures 12 and 13.

(Anonymous, 1960 cited in Okołowicz, 1977, p. 108). Mean annual temperatures amount to 9.5 – 10 °C, with mean temperatures of the warmest and the coldest month of 20 – 23 °C and -3 to -1 °C. The natural vegetation in the colline and mountainous areas is formed by thermophilous mixed deciduous broadleaved forests. In the lowlands vegetation communities of floodplains and forest steppe prevail and are complemented by fen forests and swamps in waterlogged areas (Bohn et al., 2004).

4.2.3 *Methods*

Data base

Except for four sites, studies included in this review provide continuous pollen records throughout the Holocene; data on charcoal accumulation are available for 15 sediment sequences and geochemical data are available for five sediment sequences (Figure 12 and 13). Selection criteria for included sites refer to the time period covered and the dating quality of the sediment sequences. In case a sediment sequence was supported by less than three reliable dates within the period of interest, or the interval for dating samples exceeded 2 m, it was not included in the analysis. The archives from which the sediment sequences were taken have mostly surface areas of less than 6 ha in size. Five of the included sites have archives with a surface area of 10 ha, 20 ha, 30 ha, 40 ha, 80 ha and 120 ha, respectively. To precisely specify the relevant pollen source area of a given archive it is necessary to consider type of pollen, vegetation patterning, surrounding relief and local wind systems (Bradshaw, 1988; Bunting et al., 2004). Simulations for archives with surface areas of up to 20 ha situated in a mostly forested landscape in Denmark result in relevant pollen source areas of <3000 m distance around the respective basin (Hellman et al., 2009). To reconstruct regional vegetation composition data from several archives with relatively large surface areas (>48 ha) within the respective area have to be integrated (Sugita, 2007). Therefore, the presented results do not refer to area-wide conditions but reflect local human-environment interferences that are comprised at regional scale. As vegetation composition relates to climate development as well, the investigation of human induced prehistoric vegetation changes requires the consideration of Holocene climate conditions. Published speleothem $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ records were included as independent proxies for Holocene climate development (Figure 11). Data from the National Archaeological Record of Romania were used to assess the proximity between environmental archives used and prehistoric settlement sites (INP, 2013). All locations denoted in the data base as settlements or fortified sites (in total 2102) were included in the assessment.

Data processing

The assessment of landscape development requires a diachronic approach of data analysis. However, the reliability of a diachronic data analysis depends on the temporal precision and consistency of the different data sets. Therefore, the timescales of the data were unified by calculation of linear age-depth models for each sed-

iment sequence using Clam2.2 (Blaauw, 2010; R-Core-Team, 2014) with IntCal13 calibration curve (Reimer et al., 2013). In case a published age-depth model was modified according to a more plausible stratigraphy, it was used.

From the pollen records secondary indicator species such as *Plantago lanceolata*, *Plantago major/media*, *Polygonum aviculare* and *Rumex acetosa/acetosella* were selected as proxies for herding activities (Behre, 1981; Bottema and Woldring, 1990; Magyari et al., 2012) and data were extracted from published pollen diagrams. Being aware of the large variety of factors influencing pollen composition, arboreal pollen values were considered as indicators for the density of canopy cover (Bradshaw, 1988; Kalis et al., 2003). By applying a standardized evaluation procedure these data were combined to infer probabilities of herding-related landscape disturbance. The data were aggregated to 500 year time slices and different degrees of herding probability were assigned. The evaluation procedure followed a semi-quantitative approach based on the assumption that increasing abundance of indicator species pollen and decreasing arboreal pollen values respectively, indicate a higher probability of herding-related landscape disturbance. First, values of indicator species were summarized and mean values were calculated for 500 year time slices. In order to facilitate the comparability between the different records, arboreal pollen values were z-transformed using the base period 7000 to 3000 cal BP and mean values were calculated for each time slice. Subsequently, semi-quantitative classes of herding intensity were obtained by combining the data in a fuzzy rule-based system using the R-package frbs with frbs.gen function and Mamdani model (R-Core-Team, 2014; Riza et al., 2014). In the first step of the fuzzy combination the values of each data set were classified into three classes namely “no”, “low”, “intermediate” pollen values of indicator species and “low”, “moderate”, “high” arboreal pollen values. Membership functions were defined accordingly (Figure 14). To level out different degrees of sensitivity of the different sites, break values for membership functions were defined in relation to the range of each data set. Rules for the combination of proxies were formulated assuming that arboreal pollen values are a weaker indicator for herding impact than pollen of indicator species (Table 5). The combination of the classified proxies resulted in ordinal scaled classes of herding probability: class 0 represents no herding indication, classes 1 to 3 represent increasing degrees of herding probability (Table 5, Figure 14). For each data set classes of herding probability were assigned to the 500 year time slices. In total, data sets from 20 sites were included in the standardized evaluation procedure. Data from sediment sequences with extended hiatus or low dating confidence were excluded in order to optimize inter-site comparability. Further proxies allowing to infer palaeo-environmental conditions such as “rate of change” (Huntley, 1992), “palynological richness” (Birks and Line, 1992; Feurdean et al., 2013b), charcoal accumulation rates (Whitlock and Larsen, 2001) or geochemical indicators (Boyle, 2001; Mackereth, 1965; Meyers and Teranes, 2001; Schütt, 2004) were not available for all the case studies included. These additional data were considered for critically scrutinizing the results of the standardized evaluation procedure and plausibility check.

The degree to which human activities are reflected in a pollen archive depends, amongst others, on the distance between the archive and the locations where hu-

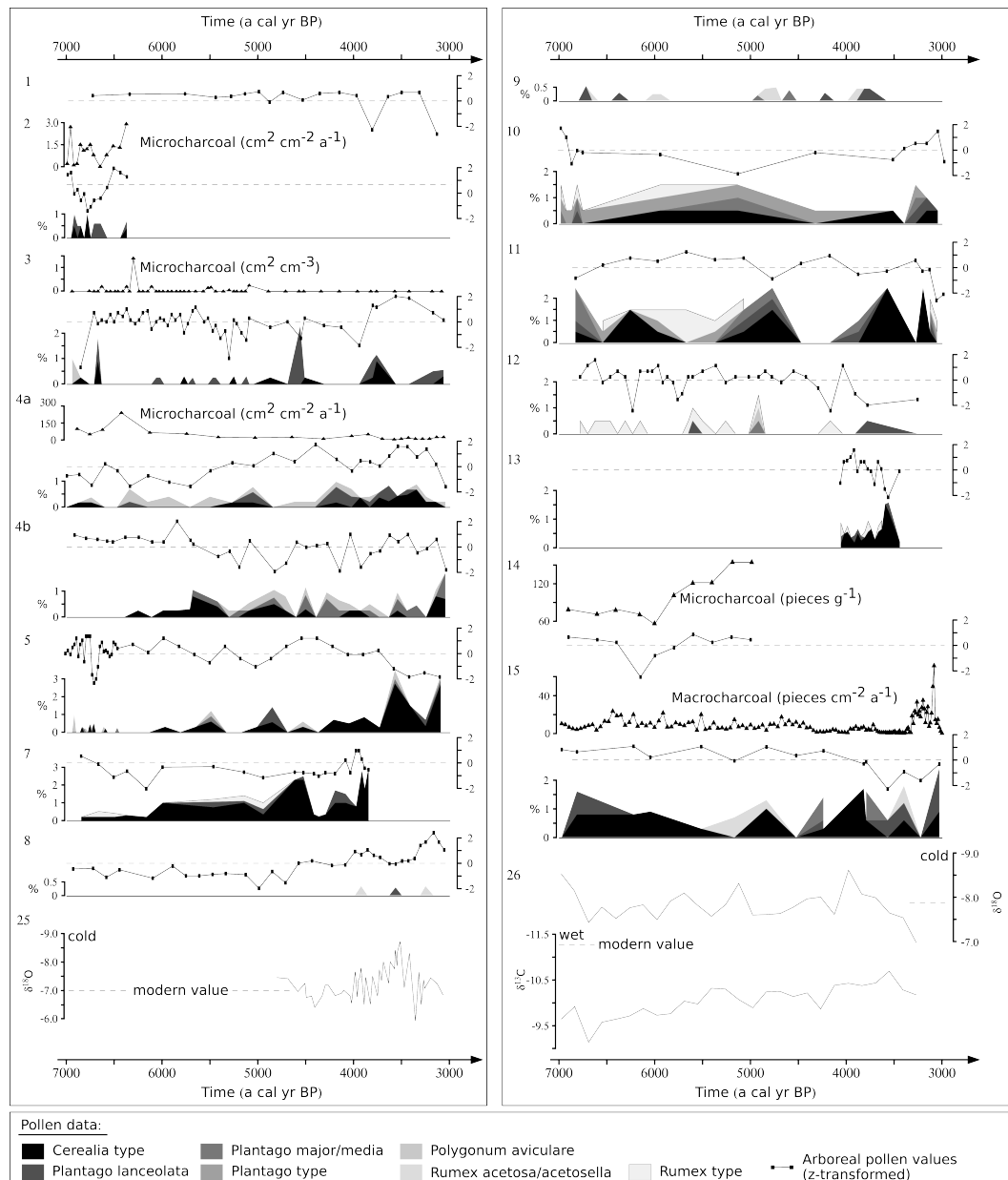


Figure 12: Pollen of secondary indicator species, arboreal pollen values and charcoal data from included sites located in Hungary (left) and Eastern Carpathians (right); arboreal pollen values (%) were z-transformed based on the period of interest. Speleothem $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ data are used as independent proxies for climate development. Numbers correspond to the map codes given in Figure 11 and Table 4.

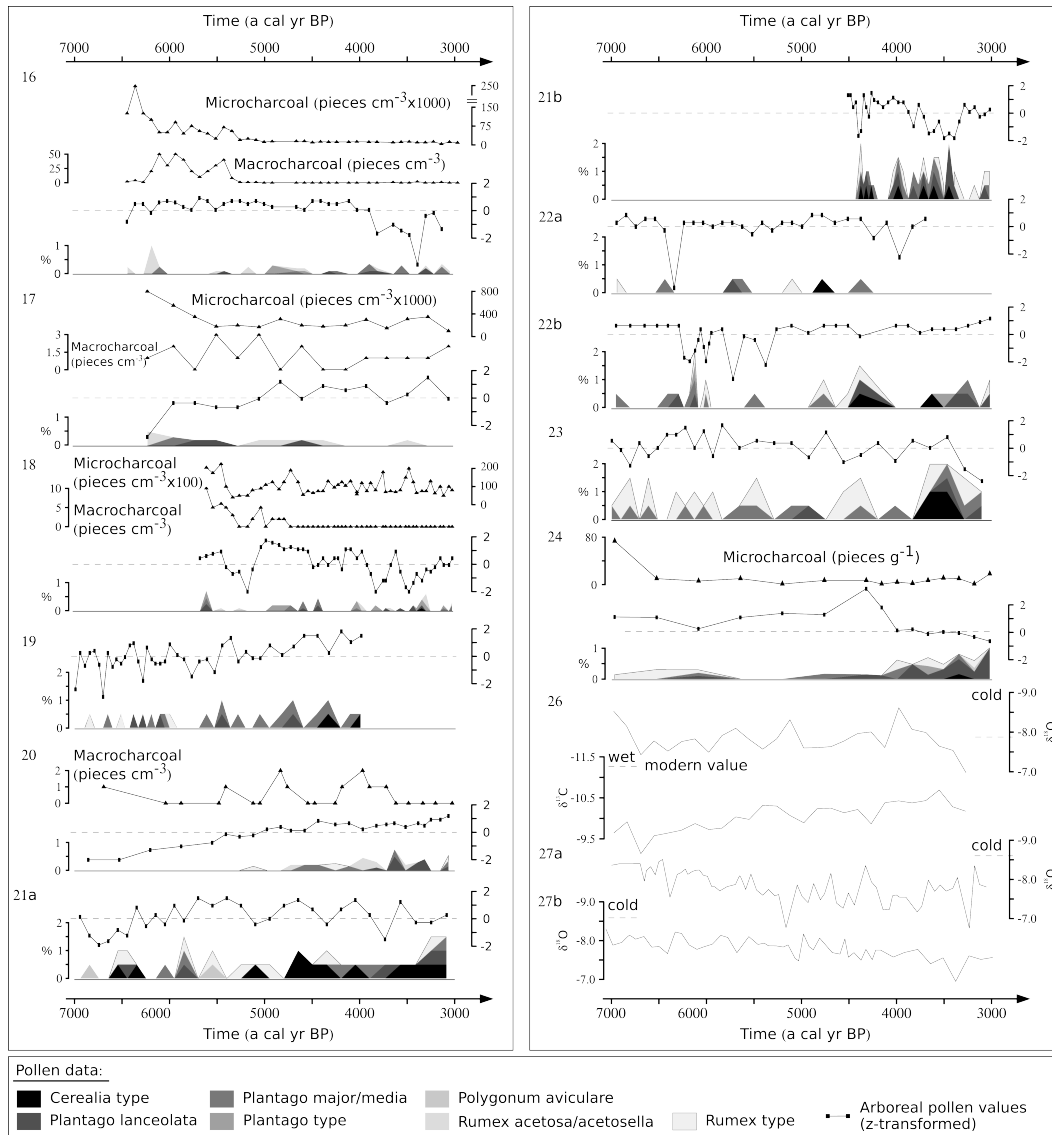


Figure 13: Pollen of secondary indicator species, arboreal pollen values and charcoal data from included sites located in the Apuseni Mountains and Southern Carpathians; arboreal pollen values (%) were z-transformed based on the period of interest. Speleothem $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ data are used as independent proxies for climate development. Numbers correspond to the map codes given in Figure 11 and Table 4.

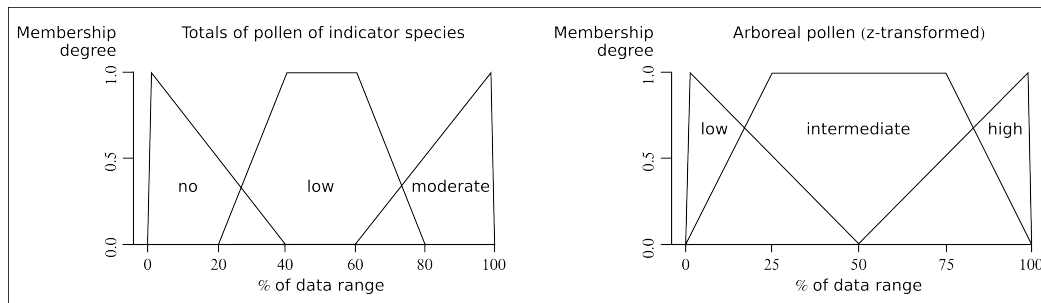


Figure 14: Membership functions for the two proxies: pollen of indicator species (left) and z-transformed arboreal pollen values (right). General break values are given in % of the respective data ranges.

Table 5: Fuzzy rules combining the two proxies pollen of indicator species and arboreal pollen values to obtain classes of probability of herding impact.

| Rule number | Proxy 1: Indicator pollen | Combined with | Proxy 2: Arboreal pollen | Leads to | Class of herding probability |
|-------------|---------------------------|---------------|--------------------------|----------|------------------------------|
| 1-3 | No | + | High/intermediate/low | -> | 0 |
| 4 | Low | | High | | 0 |
| 5, 6 | Low | | Intermediate/low | | 1 |
| 7, 8 | Moderate | | High/intermediate | | 2 |
| 9 | Moderate | | Low | | 3 |

man activities have impacted the landscape. Distances between pollen archives and locations where humans affected the landscape are hard to assess. Prehistoric settlement sites indicate locations of former concentrated human activities, although particularly animal herding may have been practised in more distant areas. Homogeneous, large-scale data on prehistoric settlement activities were available only for the territory of Romania (INP, 2013). Therefore, proximity of the included sediment archives from prehistoric settlement sites was consistently approximated exclusively for the sediment archives located within the country borders. Since detailed information on timing of the settlement sites was inconsistent, temporal resolution of the data sets derived is coarse and refers only to the Neolithic, Chalcolithic and Bronze Age. Furthermore, no distinction was made between different types or sizes of settlements. Mean linear distances between the sediment archives and the 10, 20 and 50 nearest settlement sites each were calculated as approximate values for the marginality of the sediment archives.

4.2.4 Results and discussion

Preliminary remarks

The attribution of particular triggers to processes of landscape change using palaeo-environmental proxies is subject to high uncertainties. Furthermore, different objectives of case studies lead to inconsistent interpretation of proxies related to human-induced landscape change. Therefore, if case studies are compiled incurring published interpretations, comparison of results may be difficult. To avoid such bias we chose a standardized procedure for evaluating palaeo-environmental proxies. However, if results are re-evaluated using a standardized procedure, site-specific details may be omitted and interpretations may only provide rough tendencies. Significance of indicator species may vary according to environmental conditions of site surroundings (Behre, 1981, 1990; Bottema and Woldring, 1990; Magyari et al., 2012). Since detailed information was not available for all reviewed sites, the standardized algorithm presented here does not weight indicator species. Only arboreal pollen values are considered as of lower significance for herding impact than pollen of indicator species.

In none of the reviewed case studies from the Carpathian Basin human-triggered land degradation was found for the period between the Neolithic and the Bronze Age, no matter if the focus of the study was put on post-glacial

succession processes, climate fluctuations, or particularly human influences on landscape changes. Nevertheless, human presence was identified at several sites; in some cases also particular kinds of economic activities were specified such as animal husbandry, peasant farming and woodland management (e.g. Feurdean et al., 2009; Gardner, 2002; Magyari et al., 2010; Magyari et al., 2008; Tanțău et al., 2006, 2009). Likewise, the standardized re-evaluation of the case studies presented in this review does not propose phases of herding-related land degradation. Instead, categories of Mid-Holocene herding indication as resulted from the standardized fuzzy analysis should be understood as graded likelihoods of animal husbandry. Figure 15 shows the number of sites representing the different categories of herding probability for each time slice and grouped by region. For the two regions located in Romania, where large-scale data on prehistoric settlement sites were available, mean distances between the archives and the 10, 20 and 50 nearest settlement sites are displayed. Figure 16 shows generalized results of the standardized evaluation for each time slice.

Southern Carpathians and Apuseni Mountains

Eleven of the palaeo-environmental research sites included in the review are located in the Southern Carpathians including the southern part of the Eastern Carpathians and in the Apuseni Mountains (Figure 11, Table 4: sites 16-24); out of this number nine sites were included in the standardized evaluation procedure. Three main characteristics of the palaeo-environmental development result from the standardized evaluation: a distinctively increased probability of herding activities is evident for the Early Chalcolithic, documented by two sites showing herding probability of class 3, one site of class 2 and three sites of class 1. A clearly decreased herding indication is evident for the late Chalcolithic (5500 – 5000 cal BP) with one site each showing herding probability of class 1 and 2; the late Bronze Age is characterized by strong herding indication with two sites of class 3, three sites of class 2 and two sites of class 1. For the Neolithic and Early and Middle Bronze Age, slight herding impact is indicated locally at four sites.

LATE NEOLITHIC – CHALCOLITHIC In accordance with the results of the standardized evaluation for the Late Neolithic and the Early Chalcolithic, isolated occurrence of *P. lanceolata* and alterations of vegetation composition at the site Bisoca between 7200 and 6700 cal BP are interpreted as an indication for vegetation disturbance, triggered either by climatic or human influences (Tanțău et al., 2009). For the pollen sequence 1 from the sediments extracted at the site Mohoș a decline of mixed oak forests and few cereal occurrences point to human activities between 7200 and 7000 cal BP (Tanțău et al., 2003), while strongly alternating arboreal pollen values and occurrences of secondary indicator species between 6500 and 6000 cal BP are not considered by the authors. The pollen sequence 1 from the sediment record of the site at Avrig peat bog indicates Late Neolithic human impact as represented by the isolated occurrence of *P. lanceolata* as well as cereal pollen (Tanțău et al., 2006). Low herding activities result from the fuzzy analysis at the Semenici site between 7000 and 6000 cal BP and increased charcoal values indicate synchronous woodland burning (Rösch and Fischer, 2000). Con-

trarily, in the sediments from Lake St. Ana and Luci, located ~5 km and 20 km distance from the Avrig peat bog, respectively, neither pollen nor charcoal or chemical data indicate any human activities during the Late Neolithic (Magyari et al., 2006, 2009; Tanțău et al., 2014). However, increased allogenic Al, Mg, Mn, Ca and S concentrations in the sediment record from Lake St. Ana dating to approximately 5500 cal BP point to an increased material input as for instance originating from soil erosion (Magyari et al., 2009). Although isolated occurrences of indicator species are evident from 5200 cal BP onwards, Magyari et al. (2006) refer to human induced vegetation changes only since 4700 cal BP. In the sediments from the Luci site in c. 20 km distance to Lake St. Ana isolated occurrences of pollen of secondary indicator species occurred already during the Chalcolithic (Tanțău et al., 2014) whereas the authors refer to human impacts only since 4300 cal BP.

The sediment sequences available from the study sites in the Apuseni Mountains do not cover the Late Neolithic period, and sampling intervals from the sediment sequences of the Padiș Sondori site provide only roughly resolved chronological data. Early Chalcolithic herding activities as indicated by the fuzzy analysis are corroborated by peaks in micro- and macro-charcoal records of the Călineasa and Padiș Sondori sites, although, macro-charcoal values for the latter are overall low (Feurdean et al., 2009). However, authors refer to $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ records from Ursilor Cave (Onac et al., 2002) and consistently argue that vegetation changes are due to climatic alteration. Nevertheless, it has to be scrutinized whether such high charcoal values may only be due to natural forest fires during the Holocene Climatic Optimum. Other records from the Carpathians do not show synchronous charcoal peaks, although climatically triggered forest burning should be visible at larger spatial scales, whereas localized occurrence of charcoal peaks point to regional triggers such as human activities (Carcaillet, 1998). For the transition from the Chalcolithic to the Bronze Age (5500 – 5000 cal BP) the results of the standardized evaluation indicate markedly reduced herding probability throughout the area. Micro- and macro-charcoal records from Molhașul Mare (Feurdean and Willis, 2008) and Călineasa (Feurdean et al., 2009) sites decrease, whereas arboreal pollen concentrations in the sediments from Molhașul Mare site increase rapidly after c. 5200 cal BP, reaching maximum values around 5000 cal BP. Synchronously, *Fagus* became the dominant taxon in the area which is sometimes regarded to be initiated by human influence, especially in marginal regions (e.g. Bradshaw et al., 2010; Magri, 2008; Tanțău et al., 2003, 2006, 2011). Overall, this phase is characterized by vegetation recovery and landscape stability which is in accordance with a warmer phase as indicated by the speleothem $\delta^{18}\text{O}$ record from the Ursilor cave, dated to 5500 – 5200 cal BP (Onac et al., 2002). Compared to the periods before and after, the speleothem $\delta^{18}\text{O}$ records from Pol-ea cave indicate a relatively warm phase (Constantin et al., 2007).

BRONZE AGE For the first half of the Bronze Age period, the standardized evaluation indicates slight herding activities. Similarly, pollen data from sequence 1 at Avrig peat bog show cycles of increasing and decreasing *Carpinus betulus* pollen between 5000 and 4000 cal BP, pointing to human woodland management (Tanțău et al., 2006) that might be connected to herding activities. Towards the end of the

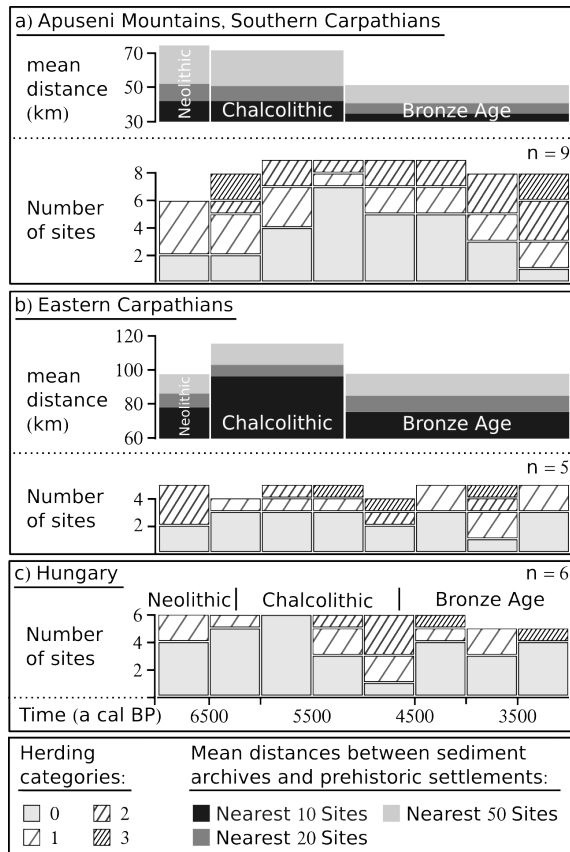


Figure 15: Categories of herding impact as resulted from the fuzzy analysis: results are aggregated for three sub-regions of the study area; mean distances between sediment archives and 10, 20 and 50 nearest settlement sites each for Neolithic, Chalcolithic and Bronze Age are illustrated (archaeological periods after Arnold and Greenfield (2006) and Görsdorf and Bojadziev (1996)).

Bronze Age, probability of herding activities increases throughout the area. For the period between 3500 and 3000 cal BP results of the standardized analysis indicate extensively increased probability of grazing impact. This is corroborated by data from the Bisoca site, where herding activities are indicated and accompanied by the occurrence of cereal pollen and increased concentration of *Fagus* pollen (Tanțău et al., 2009). In the sediments from Lake St. Ana increased allo-genic Al, Mg, Mn, Ca and S concentrations around 4500 cal BP point to an increased input of detritals as originating from soil erosion (Magyari et al., 2009). This might be triggered by human induced changes in vegetation cover starting around 4700 cal BP (Magyari et al., 2006). Macro-charcoal values rise slightly between 4000 and 3500 cal BP and *Fagus* pollen increase around 3400 cal BP while *Carpinus betulus* pollen decrease. Simultaneously, detrital input increases from 3800 cal BP onwards, explained by Magyari et al. (2009) as the consequence of higher surface runoff under beech forest. In the sediments from sequence 2 of the Mohoš site, increased *Fagus* pollen concentration at 3500 cal BP coincides with the occurrence of cereal pollen (Tanțău et al., 2006) and increased herding probability as deduced from the fuzzy analysis (Figure 16). Increased *Fagus* pollen concentration in the sediments from sequence 1 of the Avrig site dates to 4400 and 4100 cal BP (Tanțău et al., 2006). Subsequently, an increase of herding probability can be stated for the period between 4000 and 3000 cal BP. This is corroborated by the regular occurrence of *P. lanceolata* in the sediments of the adjacent sequence 2 of the Avrig site (Tanțău et al., 2006). Additionally, Tanțău et al. (2006) deduce small human impact from the first occurrence of *Secale* pollen and a synchronous

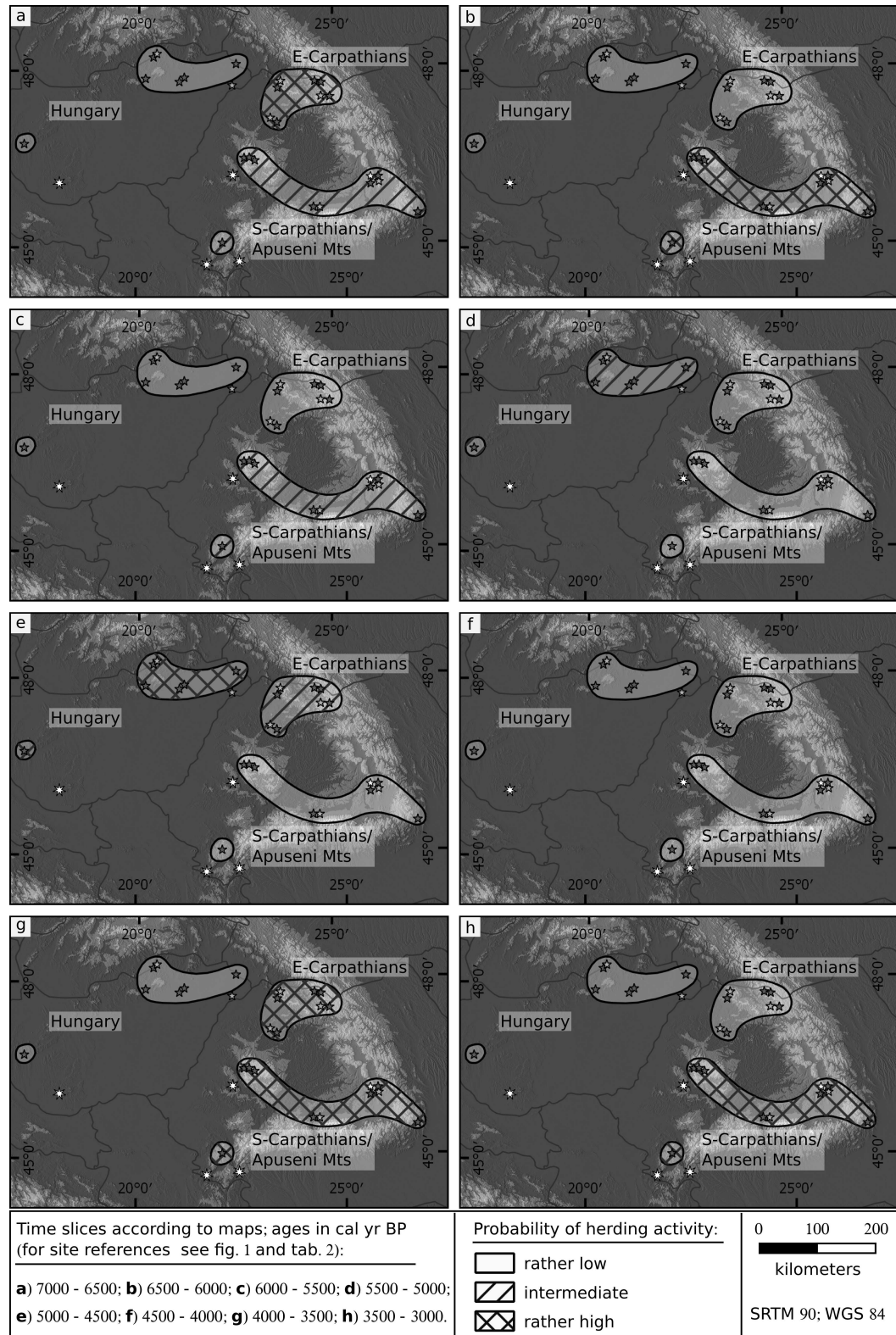


Figure 16: Probabilities of grazing activity aggregated to 500 year time slices as resulted from the standardized evaluation of pollen data; note that indicated regions do not correspond to catchment areas of the sites.

abrupt drop of *Carpinus betulus* pollen concentration from ~50% to ~30%. Increasing herding activities during the Late Bronze Age (4000 – 3000 cal BP) result from the fuzzy analysis of the data from the Semenice site and a synchronous drop of arboreal pollen and a local peak of the charcoal values corroborate this evidence (Rösch and Fischer, 2000). In the sediments from the Luci site pollen of *P. lanceolata* and *Rumex* increase slightly between 5000 and 4000 cal BP and first *cerealia* pollen occur at 4300 cal BP (Tanțău et al., 2014). *Fagus* becomes the dominant tree species only after 4000 cal BP. Drăgușin et al. (2014) present $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ records from the south-western Carpathians indicating climate-hydraulic changes around 3200 cal BP. Although the deduced change in precipitation seasonality and yearly temperature amplitude may currently not be further specified, signals of human impact may interfere with climatically induced vegetation disturbance and vegetation resilience may be reduced. Contrarily, an increase in land use intensity and the resulting increase in surface runoff might pretend a drier phase with reduced infiltration and soil moisture. *Fagus* expansion may be favoured by such climate alteration (Feurdean and Willis, 2008; Feurdean et al., 2009). A warm phase between 3500 and 3000 cal BP is also indicated by the speleothem $\delta^{18}\text{O}$ records from the Poleva cave (Constantin et al., 2007).

In the sediments from the Călineasa site arboreal pollen concentrations significantly decrease after 4000 cal BP, although charcoal concentrations remain at negligible amounts (Feurdean et al., 2009). Nevertheless, increased *Fagus* pollen concentrations date to c. 3150 cal BP and Feurdean et al. (2009) suggest that seasonal pasturing and small scale forest burning may have started in the area around 3500 cal BP. In the sediments from the Molhașul Mare site peaks of micro-charcoal concentration at 3750 and 3500 cal BP correspond to decreased arboreal pollen concentrations. Pollen of indicator species for grazing occur regularly between 4000 and 3000 cal BP (Feurdean and Willis, 2008).

Temporal information on prehistoric settlement sites as provided by the data from the National Archaeological Record of Romania is distinctively less than for the reviewed sediment sequences (Figure 15). Mean distances between the origin of the sediment sequences and the surrounding settlements constantly decrease from the Neolithic to the Bronze Age period. However, the first distinct rise in herding probability coincides with the beginning of the Chalcolithic when mean settlement distances decrease only slightly. In contrast, significantly reduced distances between sediment archives and settlement sites during Bronze Age are reflected in herding probability not until the end of the Bronze Age.

Eastern Carpathians

Holocene environmental changes in the Eastern Carpathians and the Transylvanian Lowlands are documented by sediment sequences from eight sites (Figure 11, Table 4, sites 8-15) while a reliable standardized evaluation of the data was only possible for five sites. Results of the fuzzy combination of pollen data do not show clearly consistent and distinct phases of alternating herding probability (Figure 15). For the Late Neolithic, as well as for the Late Middle Bronze Age the number of sites showing indicators for herding in their sediments exceed the number of sites indicating no herding. For the Early Chalcolithic and the Middle

and Late Bronze Age herding probability is markedly reduced. The standardized evaluation implies Late Neolithic herding activities around the sites Tăul Mare-Bărdau and Christina; simultaneously, corresponding sediment sequences show low concentrations of cereal pollen (Fărcaș et al., 2013). Accordingly, the authors suggest first evidence of human activities in the area between 7050 and 6000 cal BP. Concentration of *Fagus* pollen increases slightly before 5000 cal BP which in the case of the Tăul Mare-Bărdau site is accompanied and in the case of the Christina site is followed by grazing indication and occurrence of cereal pollen. For the sediment sequence from the Poiana Știol site, located in c. 30 km distance to the sites Tăul Mare-Bărdau and Christina, the standardized evaluation indicates grazing activities around the site already during Late Neolithic and Early Chalcolithic periods. However, Tanțău et al. (2011) do not confirm human impact before increasing *Fagus* pollen concentration in the Late Bronze Age sediments occur. Instead, the authors suppose earlier changes in vegetation composition to be climatically driven. This is corroborated by the $\delta^{18}\text{O}$ record from Ursilor cave (Onac et al., 2002) implying a cool phase from 6800 to 5000 cal BP which was interrupted by a warmer phase from 5500 to 5200 cal BP. This climate development is reflected in vegetation disturbances at the Christina site around 6000 and 5000 cal BP (Fărcaș et al., 2013) and reduced herding probability between 5500 and 5000 cal BP. Although the sediment record from the Buhăiescu Mare site ~13 km from the Christina site shows a substantial hiatus between 9800 and 4000 cal BP, occurrences of *P. lanceolata*, *Rumex* and *cereal* pollen suggest small scale human activities at least beginning from 4000 cal BP (Geantă et al., 2014). *Fagus* pollen occur in the sediments from 4000 cal BP and slightly increase in concentration in the overlying sediments.

The sediment sequences from the Steregoiu (Björkman et al., 2003) and Preluca Tiganului sites (Feurdean, 2005) are located at 750 m a.s.l. and c. 100 km to the west of the Buhăiescu Mare site. The sediment sequence from the Preluca Tiganului site is not supported by a sufficient number of numerical dates for the period of interest but the age-depth model is based on the adjacent sequence of the Steregoiu site. Therefore, the pollen record was not included into the standardized fuzzy analysis. However, pollen of indicator species were occasionally found in the sediments dating to 7000 and 6000 cal BP (Feurdean, 2005). For the period from 5500 to 5000 cal BP no pollen of indicator species for grazing could be recorded, which is in accordance with the regional trend as resulting from the standardized evaluation. From 5000 cal BP onwards pollen of indicator species occur regularly in the sediments from the Preluca Tiganului site, although not in large quantities. Reduction of woodland diversity, increased concentration of *Fagus* pollen and slight increase of e.g. *Artemisia*, *Urtica*, *Rumex acetosa/acetosella* pollen between 4800 and 4200 cal BP at the Preluca Tiganului site and between 4000 and 3500 cal BP at the Steregoiu site are linked to woodland openings that may have been used as meadows and pastureland (Feurdean and Astalos, 2005). This is in agreement with the standardized evaluation procedure of the data from Steregoiu site indicating moderate grazing probability between 4000 and 3500 cal BP. However, this transformation of vegetation composition may also be influenced by climate fluctuations (Feurdean, 2005).

For the same time period increased herding indication results from the standardized evaluation procedure of the data from the Stiucii site in the Transylvanian lowlands. Here, Feurdean et al. (2015) find a significant decline of forest cover between 4700 and 3700 cal BP and synchronous occurrences of pollen of secondary indicator species. The opening of the woodland is interpreted as resulting from increased human activities rather than climate deterioration. Lake level reconstructions for the same time period indicate a pronounced moist phase (Feurdean et al., 2015). However, the shift from warm-temperate deciduous broadleaf woodland to forest steppe at c. 3700 cal BP was also influenced by drier conditions around the lake (Feurdean et al., 2015). For the Late Bronze Age low herding probability results from the standardized evaluation. This is supported by rising charcoal accumulation rates from c. 3300 cal BP onwards which indicate increased woodland burning due to human activities as well as natural forest fires (Feurdean et al., 2013a). The Turbuta site is located c. 60 km northwest from the Stiucii site. Here, the sediment record shows a reliable age-depth-model from Younger Dryas to 5000 cal BP (Feurdean et al., 2007). Although there is no human impact implied by the pollen record, micro-charcoal concentrations locally peak around 5000 cal BP. Synchronously, concentrations of inorganic carbon peaks and lithology is characterized by an increase of minerogenic compounds while concentrations of organic carbon and organic matter is reduced.

Mean distances between locations of sediment archives and prehistoric settlement sites in the eastern Carpathian region increase from the Neolithic to the Chalcolithic. This coincides with a decrease in number of sites indicating herding activities. Compared to the Neolithic slightly lower distances between sediment archives and prehistoric settlement sites are evident for the Bronze Age. Abundance of sites indicating herding activities fluctuates during the Bronze Age which is hard to relate to settlement distances because of the poor temporal resolution of the data sets for settlement sites pattern. Overall distances are approximately twice as high compared to the Southern Carpathians and Apuseni Mountains. Small-scale differentiated quality and quantity of vegetation change imply that effects of climate deterioration were interconnected with human impacts of different intensities. If vegetation disturbance is supposed to be triggered by herding transhumance would be more likely than sedentarism in the lowlands, even though local wind systems may transport pollen from lower elevations to sub-alpine sites (Bradshaw, 1988).

Hungary

Data from six sites located in northern and western Hungary are included in the standardized evaluation (Figure 11, Table 4, sites 1, 3-5, 7). Two additional sites are added for regional comparison of the results. Results of the standardized evaluation imply first low-impact herding activities at larger scales around the transition from the Chalcolithic to the Bronze Age and its spatial expansion during the Early Bronze Age. During the Middle and Late Bronze Age as well as during the Late Neolithic, herding indication was locally restricted, although partly intensified; during the Chalcolithic it was largely reduced. Discussing prehistoric human impact upon northeastern Hungarian landscapes on a regional scale, Willis (1997)

concludes that the comparatively intense human impact during the Neolithic led to a shift towards park-like landscapes in eastern and central Hungary. In contrast, northern Hungary remained forested but underwent a change in the composition of tree species. Contrarily, the standardized evaluation of pollen data implies only locally restricted low grazing impact for the Neolithic, whereas during the Chalcolithic herding indication is largely missing. At the transition from the Neolithic to the Chalcolithic tells vanished and smaller settlements spread over larger areas (Sherratt, 1983a). This went along with the spread of slightly complex societies and gradually increasing spatial interactions (Giblin et al., 2013; Giblin, 2009; Schier, 2005). However, herding practices did not change significantly and upland areas were not yet used for grazing (Hoekman-Sites and Giblin, 2012). Late Neolithic human impact on the landscape such as forest clearing and grazing is recorded in the sediments of the sequence SH-Wood from the Sarló Hát site for the period between 7000 and 6500 cal BP (Magyari et al., 2010; Magyari et al., 2012). The sequence was taken from the bank of an oxbow lake of the Tisza river close to Neolithic settlement sites representing local conditions. However, sediments of the sequence SH-II which was extracted in c. 90 m distance from the bank of the oxbow lake indicate first regional grazing activities during the transition from the Chalcolithic to the Bronze Age (Magyari et al., 2010; Magyari et al., 2012). Pollen records from the Batórliget site indicate the occurrence of *P. lanceolata* and *Rumex* already around 7000 cal BP and increased charcoal concentrations dating to 7200 cal BP imply forest burning (Willis et al., 1995). In the sediments from the Báb Tava site Middle to Late Neolithic human activities correspond to coppicing (Magyari et al., 2008). Human impact during the Neolithic is also implied in the sediment sequence from the Nagymohos site by the occurrence of *P. lanceolata*, changing composition of tree species and increased charcoal concentrations (Magyari et al., 2001). Furthermore, deposition of soil sediments due to soil erosion is revealed by increased minerogenic contents and local peaks of K and Al concentrations. The pollen record from the adjacent Kelemer Kis-Mohos-Tó site does not support the interpretation of a human induced destabilization of landscapes during prehistoric times (Willis et al., 1997). However, the increase of charcoal concentrations and the increased concentration of *Fagus* and *Carpinus betulus* pollen around 5500 cal BP indicate forest burning which might be connected to grazing activities (Willis, 1997). Braun et al. (2005) discriminate regional erosion phases based on the chemical composition of the sediment sequence from Kelemer Kis-Mohos-Tó. They assume overall stable morphodynamic conditions between 9300 and 2800 cal BP with a short phase of decreased stability between 5000 and 4200 cal BP. This might be interpreted as a delayed reaction to the regional decrease in vegetation cover as observed by Willis (1997) for the end of the preceding millennium.

For northern Hungary, the standardized evaluation reveals a spatio-temporal trajectory of Post-Neolithic herding impacts which seems to be east-oriented. For the Keszthely site at the western shore of Lake Balaton a first phase of herding impact is indicated between 5500 and 4500 cal BP (Medzihradsky, 2005). At the Sirok Nýirjes Tó site increased herding probability is indicated between 5000 and 4500 cal BP (Gardner, 2002). After c. 3900 cal BP forest recovers and Gardner (2002)

argues for undisturbed environmental conditions referring to simultaneous propagation of *Fagus* and continued abundance of *Quercus*, as well as stabilization of *Corylus* and the expansion of *Carpinus betulus*. Similarly, the standardized evaluation of the data from the SH-Wood sequence at the Sarló Hát site implies the beginning of herding activities in the immediate surroundings of the site between 5500 and 5000 cal BP and an increasing herding probability between 5000 and 4500 cal BP. Subsequently, *Fagus* expands around 4000 cal BP. Data of the SH-II sequence from the Sarló Hat site indicate an increased probability of herding activities at regional scale between 4500 and 4000 cal BP which is underpinned by increased charcoal concentrations in the sediments (Magyari et al., 2010). For the easternmost sediment record extracted at the Bab-Tava site, the results from the standardized evaluation point to a distinctly increased grazing probability between 3500 and 3000 cal BP which was accompanied by land cultivation as indicated by an increase in cereal pollen concentration and by the expansion of *Fagus* (Magyari et al., 2008). Nevertheless, intermediate grazing probability is indicated already for the period between 5000 and 4500 cal BP which corresponds to the results from the Sirok Nyírjes Tó and Sarló Hát sites. In accordance with that, Sümegi (1999) documents low human impact in northeastern Hungary from the Chalcolithic onwards whereas marked vegetation clearance did not start before the Iron Age. This is also in agreement to Hoekman-Sites and Giblin (2012) who state significantly increased herd sizes for the Late Bronze Age and Early Iron Age. In addition, during the Middle to Late Bronze Age intensified use of animal products was accompanied by a gradually increasing variability of $^{87}\text{Sr}/^{86}\text{Sr}$ -ratios in dental enamel of animals and humans which suggests that mobility of people increased (Giblin et al., 2013; Hoekman-Sites and Giblin, 2012). However, a slow increase of mobility of people is assumed and it is not yet clear at which spatial scale transhumance was practised. For the central Balkan Arnold and Greenfield (2006) state strong changes in land use practices already for the Chalcolithic period. (Sherratt, 1982, 1983a) describes increasing eastward spreading settlement activities beginning from c. 5500 cal BP and an increasing amenity of the Carpathian Basin as a whole and its adjacent uplands. However, Parsons (2011) stresses that it is still debatable if migration processes are sufficient to explain the spread of innovations like the use of secondary animal products.

In the Körös Basin basic economies shifted towards large-scale animal husbandry during the Late Bronze Age (Gyucha et al., 2011) and settlements developed with increasing distance from water courses (Bökönyi, 1974; Kemenczei, 2001; Szabó, 1996, cited in Gyucha et al., 2011). Authors relate this to the need for extended relatively dry areas for animal herding. On the other hand, the speleothem $\delta^{18}\text{O}$ record from the Trio cave in southern Hungary documents a climatic deterioration around 3600 cal BP (Siklósy et al., 2009). Increased water availability due to cooler and moister weather would have allowed the colonization of areas further away from perennial water courses. Furthermore, such climate development might have contributed to the contemporary expansion of *Fagus* around the sites of low elevation (Gardner, 2002; Magyari et al., 2010; Magyari et al., 2008). However, the fact that vegetation disturbance follows an east-oriented spatio-temporal trajectory rather than showing an area-wide decline around 3600 cal BP

implies that human-induced environmental disturbance played a significant role in Holocene vegetation history.

4.2.5 *Conclusions*

Spatio-temporal patterns of Holocene vegetation dynamics in response to human impacts and climate development in the Carpathian region were investigated by reviewing case studies on Holocene vegetation development. The assumption that increasing animal husbandry during the Secondary Products Revolution impacted vegetation composition in the region was targeted in particular. To evaluate probability of animal herding a standardized fuzzy model was developed by combining pollen based herding indicators. The results of the standardized evaluation show obvious patterns for the Southern Carpathians including the southern part of the Eastern Carpathians and the Apuseni Mountains, where herding related impact on the vegetation is clearly evident for the Early Chalcolithic, as well as for the Late Bronze Age, whereas the Late Chalcolithic and the transition to the Bronze Age are characterised by distinctly reduced herding probability (Figure 16). Increased herding probability during the Late Bronze Age is corroborated by increasing pollen richness which is related to herding activities (Feurdean et al., 2013b). In Hungary increased herding probability is evident for the transition from Chalcolithic to Bronze Age and for the Early Bronze Age. These general results are confirmed by several case studies focusing on Holocene human-environment interactions (Magyari et al., 2010; Magyari et al., 2001, 2006, 2008; Tanțău et al., 2009). In the Southern Carpathians and Apuseni Mountains increased herding indication during the Early Chalcolithic corresponds to the timing of the Secondary Products Revolution (Greenfield, 2010). Studies from southwestern Bulgaria reveal similar results (Marinova et al., 2012). In Hungary the spatio-temporal trajectory of herding indication is east-oriented, while widely increasing herding indication dates to the Early Bronze Age. In the Eastern Carpathians phases of increased and reduced herding probability are spatially not as consistent. This could be due to intensified sensitivity of vegetation to climate controls and interference with human impacts.

Even though it was possible to examine large scale spatio-temporal trajectories of herding impact on the vegetation in the Carpathian region, it must be stated that referring to modern pollen assemblages records from prehistoric times suggest that Mid-Holocene grazing impact was overall low. However, the distances between included sediment archives and prehistoric settlement sites vary largely and therefore, intensity of human impact is likely to be reflected to alternating degrees. Included archives from the Carpathian mountain range are mostly situated at considerable distance from presumably preferred pasture areas and it is highly possible that anthropogenic disturbance was greater than records imply (compare Magyari et al., 2012). In order to foster the relation between vegetation disturbance and herding activities it would be necessary to include reliably dated archaeozoological data from the region. Furthermore, the consideration of textile-related archaeological finds such as textile tools, textile imprints and

iconographic objects will contribute to elucidating the relation between intensified animal husbandry and vegetation dynamics during the Mid-Holocene.

ACKNOWLEDGMENTS This study was kindly supported by the financial, technical and scientific help of the “TOPOI - Cluster of Excellence” Project from the DFG. We gratefully acknowledge Angelica Feurdean and an anonymous reviewer for their constructive comments on an earlier version of this manuscript. Furthermore, we cordially thank Angelica Feurdean for the contribution of valuable raw data from the Stiucii site.

THE LOCAL SCALE – VARIABLES OF LANDSCAPE DEVELOPMENT

5.1 INTRODUCTION

The regional-scale investigation of herding-related vegetation changes successfully revealed spatio-temporal patterns of herding indication within the Carpathian region (Schumacher et al., 2016a; chapter 4.2). However, grazing impact on the environment appeared to be overall low, affecting only the vegetation cover in the way that herding activities are indicated by characteristic vegetation changes. Severe land degradation due to grazing pressure did not occur. Besides others, underrepresentation of herding-related land degradation may be due to a) spatial discrepancy between exerted grazing pressure and investigated environmental archives, or b) climate-driven environmental changes that mask grazing effects in the sedimentological record.

In northern Hungary, significant herding activities are evidenced for the Late Chalcolithic and the Early Bronze Age periods (Gardner, 2002; Magyari et al., 2010; Magyari et al., 2001, 2008, 2012; Medzihradszky, 2001, 2005; Willis et al., 1995, 1997). Due to flat surroundings of the sites, or restricted catchment sizes most analysed sediment sequences do not contain allochthonous detrital material, and thus, fail to give evidence about grazing-induced soil erosion. Taking up these findings the following case study was conducted aiming to investigate Holocene landscape development in the interplay between climate variability and human activities. The middle course of the c. 60 km long Hór stream was selected and sediment sequences from five alluvial fans deposited by secondary tributaries were extracted. The study area is situated in the Bükkalja foothill area which forms the transition between the Tisza lowlands and the Bükk mountains. Neolithic and Bronze Age settlement sites are evident within the studied valley section and the morphology of the landscape indicates susceptibility to external impacts – be it of climatic or anthropogenic nature.

5.2 PAPER 3: HOLOCENE VALLEY INCISION IN THE SOUTHERN BÜKK FORELAND: CLIMATE-HUMAN-ENVIRONMENT INTERFERENCES IN NORTHERN HUNGARY

Schumacher, M., Dobos, A., Schier, W., Schütt, B. (accepted): Holocene valley incision in the southern Bükk foreland: climate-human-environment interferences in northern Hungary. Quaternary International. DOI: <http://dx.doi.org/10.1016/j.quaint.2016.10.021>

Abstract

Prehistoric human settlement activities in northern Hungary have been well studied for several decades. Recent studies from the Great Hungarian Plain provide evidence of human impact starting as early as in the Neolithic (c. 8200 cal BP). Archaeological records suggest that with establishment of the Baden culture (c. 5500 cal BP), settlements were moved from Tisza River towards the northern mountainous area. Although Quaternary landscape development of the Bükk Mountains is well studied, Holocene human environment interactions in particular, have not been focused on so far. Here, we present Holocene landscape history around Bogács in the southern Bükk mountain foreland. Sediment records were sampled from fans of secondary tributaries in the middle course of the Hór valley. Morphology of the tributary valleys suggests different incision phases with older forms and less human impact in the northern part of the studied valley section (type 1) and younger forms and stronger human impact in the southern part (type 2). However, ^{14}C dates from the fan of a type 2 valley in the southern part suggest initial incision between 9000 – 8000 cal BP, whereas human activity is not reflected in the sediments. In the fan sediments of a type 1 tributary in the northern part of the studied valley section, daub was found in the context of deposits dated to 3000 cal BP. Here, thickness of Holocene sediments suggest significant soil erosion.

It can be summarised that post-Pleistocene valley incision was restricted to short periods of extreme climate conditions during the Early- to Mid Holocene. Human activities did not contribute to initial valley incision. Nevertheless, human activities seem to have enhanced soil erosion in the catchments of type 1 tributaries.

Keywords

Stream morphology; Fan development; Late Pleistocene-Early Holocene transition; Late Neolithic; Bronze Age

5.2.1 *Introduction*

Holocene landscape development over decadal scales is an intensely discussed research topic in the environmental sciences. It is commonly accepted that climate changes as well as human activities influenced landscape formation and

that the different factors interfere and feed back on each other (e.g. Bintliff, 2002; Fuchs, 2007; Kalicki et al., 2008; Kalis et al., 2003; Leigh et al., 2016; Leopold and Völkel, 2007; Sümegi et al., 2002; Zielhofer et al., 2008). Extensive reviews reveal large-scale overviews over Holocene soil erosion processes in Central and Eastern Europe and the Eastern Mediterranean (Dotterweich, 2008; Dreibrodt et al., 2010; Dusaar et al., 2011; Notebaert and Verstraeten, 2010). Comprising a variety of case studies, Schumacher et al. (2016a) demonstrate spatio-temporal trajectories of herding related vegetation disturbances within the Carpathian region during the Mid-Holocene. The differentiation of causes and triggers of landscape formation is often a crucial issue, although most difficult to approach. Only if a variety of information such as archaeological sources and different environmental archives are integrated, the importance of the different factors may be evaluated (e.g. Dreibrodt et al., 2014; Fuchs et al., 2004; Kuzmin and Rakov, 2011; Leigh et al., 2016; Magyari et al., 2012; Mandel et al., 2014; Murphy et al., 2014; Tonkov et al., 2014). It is essential to carefully choose the study area with respect to significance of the environmental archives, as well as the availability of archaeological data in the regional surroundings.

Studies from the Great Hungarian Plain and northern Hungary provide evidence of human impact starting as early as in the Neolithic: First indication of forest management and changes in vegetation composition are reported for c. 7000 cal BP (e.g., Bácsmegi et al., 2012; Gardner, 2002; Jakab et al., 2009; Magyari et al., 2008, 2012; Willis et al., 1995). Early Holocene phases of increased input of minerogenic material predate intensified settlement activities, and point to climatically triggered processes; material input that is attributed to human induced soil erosion processes seems to have occurred only in the course of the Bronze Age and Iron Age (Braun et al., 2005; Sümegi, 1999). However, the studied environmental archives are either located in the flat lowlands in close vicinity to the River Tisza, or in the hilly mountain foreland in closed depressions with small catchments. Both areas are not affected by intense material fluxes such as soil erosion and, therefore, are not particularly suitable to study human driven soil deterioration. In contrast, alluvial fans deposited by tributary valleys provide externally visible sediment archives while small catchment areas and simple configuration of drainage networks ensure close connection between sediment source and deposits (Fuchs, 2007; Leigh et al., 2016). Human activities such as land clearance enhance surface runoff and soil erosion. Even in areas of generally low morphodynamics, stronger rainfall events might lead to fan deposition in the channel foreland where before human impact the same rainfall event might not have left visible marks. However, extreme rainfall events lead to intense surface runoff and soil erosion that is enhanced by human activities in the respective catchment (e.g. Borrelli et al., 2013; Dotterweich et al., 2013; Dreibrodt et al., 2010; Döhler et al., 2015). In the Bükk foreland (Bükkalja) and especially in the middle course of the Hór valley, several simply configured drainage systems and well accessible sediment archives provide good opportunities to study Holocene sedimentation dynamics. The pre-Holocene landscape development is well studied (Dobos, 1997; Dobos, 2012; Hevesi, 1986; Hevesi, 1990; Pinczés, 1955, 1968, 1980) providing an excellent basis for the understanding of Holocene landscape processes.

Human settlement activities in northern Hungary are evidenced already for the Palaeolithic (Adams, 2009, and citations therein). With establishment of the Baden culture (c. 5500 cal BP), settlements increasingly moved from Tisza River to the northern mountains area and here, the Bükk Mountains and their foothills were preferred, rather than the adjacent Mátra Mountains (Sherratt, 1982, 1983a). The diversity of landscape types in close vicinity provided resources for a range of economic activities (Sherratt, 1982): sites in the lowlands give indications for arable farming and cattle raising, whereas sites at higher elevations point to goat and particularly sheep keeping. Settlement patterns changed from larger nucleated settlements towards dispersed and smaller settlements (Sherratt, 1983a). This shift was accompanied by a less intense but spatially extensive mobility of the people pointing to an economic transformation towards intensified pastoralism (Giblin, 2009). During the Bronze Age (c. 4700 – 3000 cal BP), people predominantly settled on the ridges of the hilly Bükk foreland and the Tisza lowlands became important settlement areas again (Fischl et al., 2012; Kalicz, 1968; Sherratt, 1982 and citations therein).

With focus on the middle course of the Hór valley, available information on prehistoric settlement activities and sediment archives suitable to decipher past erosion processes allow to investigate the following three points:

- I) When did the tributary valleys incise into the flanks of the Hór valley and which factors triggered their initial incision?
- II) How did the tributary valleys develop during the Holocene and which factors affected the Holocene valley evolution?
- III) How can the roles of climate and human activity be evaluated?

5.2.2 Regional Setting

Landscape characteristics

The study area comprises the middle course of the Hór valley that is located in the Bükkalja foothill area, south of the Bükk Mountains in northern Hungary (Figures 17, 18). The Hór stream is c. 33 km long and has a drainage area of c. 208 km². Valley density of the Hór catchment is c. 0.7 km/km². In the upper reaches, the stream formed a v-shaped valley that incised deeply into the Bükk plateau. In the middle and the lower reaches, the Hór stream is meandering, however, most sections are regulated and artificially straightened. The stream represents a nivo-pluvial regime with peak discharge during the thawing period in spring and after erratic precipitation in autumn. Calculated peak discharge north of the town Bogács amounts to $Q_2=37 \text{ m}^3/\text{s}$ and is expected to occur every 50 years (written communication by the North-Hungarian Water Directorate, 2015). Two tributaries join the Hór stream between the towns Cserépfalu and Bogács. The Cseresznyés stream in the north contributes c. 6 % to the catchment draining into the area of interest and the Szoros stream contributes c. 11 % (Figure 17 b). The present drainage configurations differ from those during the Late Pleistocene and Early Holocene periods due to stream captures in the lower southern Bükk Mountains

(Pinczés, 1955; Székely, 1958), and it can be assumed that the discharge of the Cseresznyés and the Szoros streams was significantly higher in former times.

The studied valley section is c. 9 km long. The town Bogács splits the study area in a northern and a southern part (Figure 18 a). In the north, the study area extends to the town Cserépfalu; in the south, it is delimited by an artificial lake. Within the study area, the valley bottom ranges between 140 – 200 m a.s.l. and the tops of the valley flanks reach 180 – 260 m a.s.l. To the north, the Bükk Mountains reach elevations around 950 m a.s.l., and the southern adjacent Tisza lowlands are located at c. 80 – 90 m a.s.l. elevation. Mean annual precipitation amounts to c. 630 mm (meteorological station: Bogács at 47°54'N, 20°53'W; reference time period: 1896-1955). Mean monthly temperatures range between c. 22 °C in the warmest month and c. -2 °C in the coldest month with mean annual temperatures of c. 9.5 °C (Anonymous, 1960 cited in Okołowicz, 1977, p.108).

Regosols, Leptosols and Cambisols developed on the hilltops and the upper slopes of the study area, and at foot slope position colluvic Regosols occur. In the alluvial plain of the Hór valley, Chernozems dominate while Phaeozems occur on the edges of the plain. Locally, Fluvisols and Arenosols occur (Kocsis et al., 2015; MÉM-NAK, 1983; Sisák et al., 2015).

The Bükkalja foothill area was forested until the middle of the 19th century and the valley bottoms were frequently flooded. This area was covered by swamps and alluvial forests. During the end of the 18th century and the first half of the 19th century, the bottom of the Hór valley was drained, and several stream branches dried up and disappeared. The slopes and hill tops were still forested and locally used as pastures (Timár et al., 2006). Nowadays, the flood plain and the gentle flanks of the Hór valley are used as arable land and the steeper slopes of the Hór valley and the deeply incised tributaries are forested. The moderately steep slopes and the hilltops are used as vineyards.

Geology and Pre-Holocene landscape evolution

The Bükkalja foothill area consists of Miocene rhyolitic tuff and ignimbrite series and Quaternary fine sediments (Figure 18 b). Locally, Eocene and Oligocene limestones, marls and clay formations occur. Miocene rhyolitic tuffs prevail in the northern part of the study area, whereas the southern part of the study area is characterised by Quaternary sediments. The volcanic landforms were eroded during the Tertiary and two pediment surfaces developed: the development of the older pediment surface dates to the Miocene period (8 – 5.5 Ma) while the younger pediment developed during the transition from Pliocene to Pleistocene periods (2 – 1.8 Ma) (Dobos, 2000; Hevesi, 1986; Hevesi, 1990; Martonné Erdős, 2000; Pinczés, 1968, 1980). During the Rhodan orogeny (5.5 – 3 Ma) the older pediment was uplifted and dissected by tectonic fault lines; following these fault lines, a south-oriented drainage system developed (Balogh, 1963; Pinczés, 1955). As part of this major drainage system, the Hór stream and its tributaries (the Cseresznyés and Szoros streams) formed the Cserépfalu basin. Today, in the study area the older pediment is mostly eroded and only represented by few relict hilltops. The younger pediment was dissected by the south-oriented drainage system during the Pleistocene (Dobos, 2002; Pinczés, 1955). Remnants of two Pleistocene fluvial

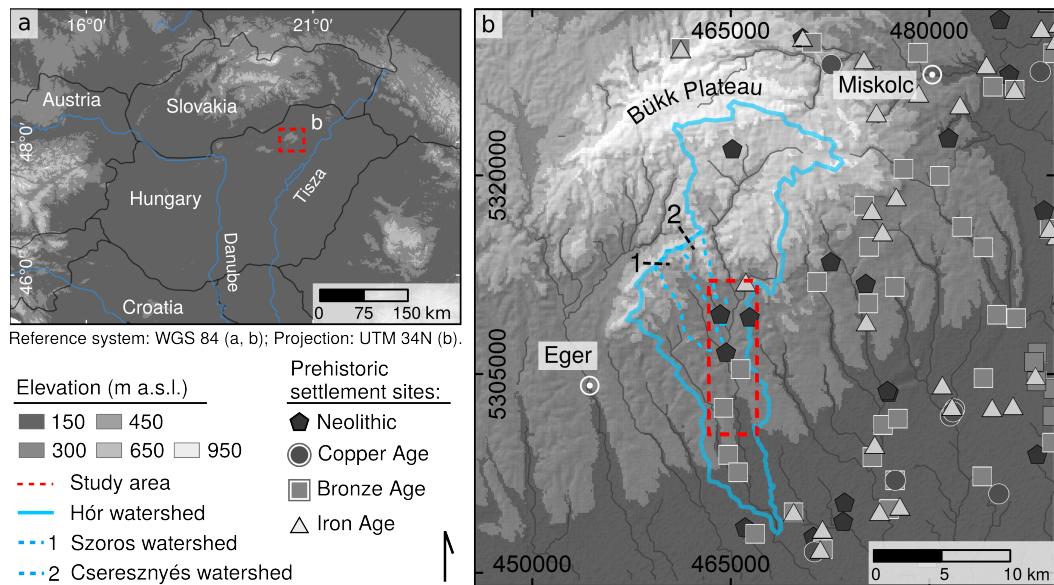


Figure 17: (a) Regional overview of the study area. (b) Overview of the Bükk Mountains and the Bükkalja foothill area with known prehistoric settlements (raster and vector data from Jarvis et al. (2008) and Natural-Earth-Data (2015); archaeological data provided by Herman Ottó Múzeum Miskolc).

terraces can be found at 25 – 30 m and at 10 – 15 m above the valley bottom and a Holocene terrace of 1 m height has developed in the alluvial plain (Dobos, 2012). During glacial periods, periglacial climatic conditions dominated in the area and slopes and valleys were affected by mass movements, gelisolifluction and frost activities. During interglacial periods, chemical weathering, soil formation and linear erosion prevailed (Dobos, 2012).

Neolithic – Iron Age settlement history

A general overview of Neolithic and Copper Age settlement history in northern Hungary is presented by Sherratt (1982): Around 7300 cal BP, the region became an important settlement area for the first time, when the Middle Neolithic Alföld Linear Pottery culture emerged (Sherratt, 1982). The settlements were located in the Tisza lowlands, and by c. 7200 cal BP, material culture had differentiated, and small cultural groups had developed in the foreland of the Bükk mountains. Trade was greatly expanded between mountain areas and sites in the Great Hungarian Plain, and less wild resources were used but cattle husbandry became increasingly important. With establishment of the Szakálhát period, settlements expanded further to the mountains, and bone finds, as well as camp sites located in caves indicate herding activities. Around 6800 cal BP, the sites at the mountain fringe were abandoned, and the Hérpaly-Csőszhalom group established in the lowlands. This period lasted c. 300 – 400 years. People lived in tell sites herding cattle while also controlling the mountain areas and importing metal resources.

At the beginning of the Copper Age around 6400 cal BP, the Tiszapolgár culture emerged in the northern Great Hungarian Plain. While people still settled close to larger rivers avoiding the mountain fringes, the tells vanished. However, cattle

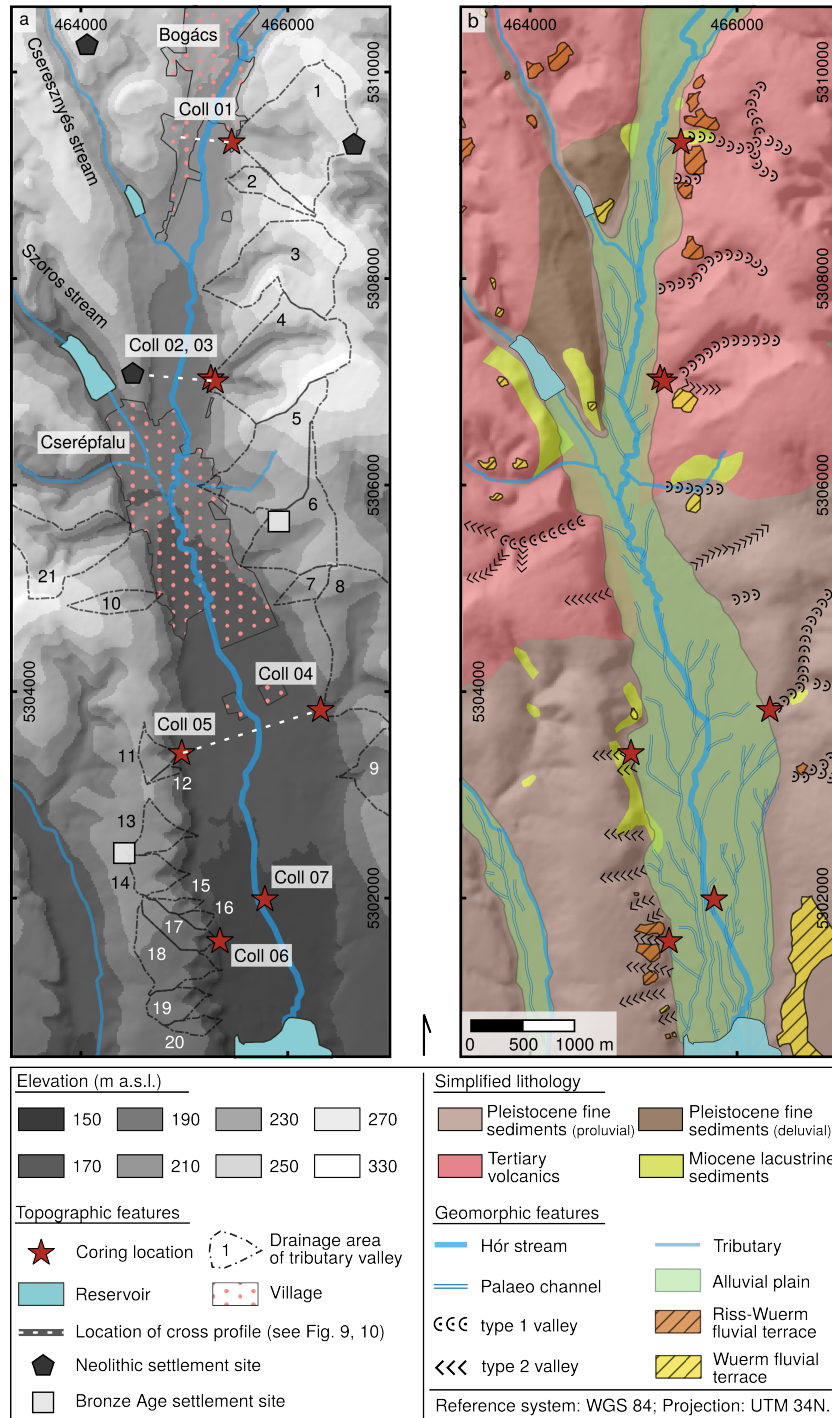


Figure 18: (a) Topographic map of the study area with coring locations and known prehistoric settlements; (b) Geomorphological map and geologic features of the study area. Data sources: topographic map, 1:10,000 (FÖMI – Institute of Geodesy, 2003); geological map, 1:100,000 (Dobos, 2012; MÁFI – Institute of Geology, 2005); archaeological data provided by Herman Ottó Múzeum Miskolc.

herding remained important, and the exploitation of metal resources from the mountains brought economic wealth, and important trade routes run through the region. The most important cultural break occurred with the appearance of the Baden culture around 5500 cal BP. The plough and probably the cart appeared in the region (Sherratt, 1981), and people occupied the edges of the Great Hungarian Plain expanding their settlements to the uplands, as well.

During the Early Bronze Age around 4800 cal BP, tells reappeared in the region, often with fortified character. Between c. 4000 – 3450 cal BP, the Hatvan and Füzesabony cultures established in the region (Fischl et al., 2012; Gimbutas, 1965, 196, 200 ff). People settled on elevated locations in the Tisza alluvial plain such as levees and islands, as well as along the streams draining the Bükk mountains. Here, elevated fringes of the alluvial plains and hilltops were settled (Fischl et al., 2012; Gimbutas, 1965, p. 202). In the Bükkalja foothill area, often several village-like settlements were located in c. 5 – 10 km distance along the same stream (Figure 17 b; Fischl et al., 2012).

Little is known about the life style of Early Iron Age people in the region. Between c. 3000 – 2300 cal BP, the Bronze Age settlements were abandoned, and ceramic discard in the region lacks. Nevertheless, increasing charcoal records and decreasing arboreal pollen at the Sarló-Hát site (c. 40 km east of the study area) indicate stronger forest burning than in the Late Bronze Age (Chapman et al., 2009; Magyari et al., 2010). While arable farming remains important, increased pollen occurrence of secondary indicator species as e.g. *Plantago lanceolata*, *Artemisia*, Gramineae indicate increasing significance of animal herding (Chapman et al., 2009; Magyari et al., 2010).

5.2.3 *Material and methods*

Field work

Along the middle course of the Hór valley, sediment cores were extracted from five fans deposited by tributary valleys. Additionally, one sediment core was extracted from the alluvial plain of the Hór valley (Figure 18). Coring locations were recorded using a handheld GPS device with 5 m accuracy. The cores were obtained using a percussion hammer (Wacker® BHF 30 S) with a core diameter of 5 cm. The sediment sequence Coll 01 was extracted with an open steel rod whereas all remaining sediment sequences were obtained using closed plastic liners.

Sediment analysis

Photographs of the sediment sequences, sediment description, subsampling and sediment analyses were done in the Laboratory for Physical Geography of the Freie Universität Berlin (only the sediment core Coll 01 was documented and sampled in the field). Volume-specific magnetic susceptibility (magnetisability) of the closed sediment cores was measured using a Bartington MS2C System. Low frequency measurements (0.565 kHz) were done in 4 cm intervals. After core opening sediment sequences were described macroscopically displaying strati-

Table 6: List of AMS ^{14}C datings.

| Lab code | Sediment core | Sample depth (cm) | Laboratory remark | ^{14}C age BP | range (a) | a cal BP | 2-sigma range | Probability |
|-----------|---------------|-------------------|-------------------|------------------------|-----------|----------|---------------|-------------|
| Poz-59732 | Coll 01 | 306 | 0.5 mgC | 2900 | 35 | 3054 | 110 | 93.1 |
| Poz-59733 | Coll 01 | 351-354 | 0.3 mgC | 4250 | 60 | 4876 | 92.5 | 51.3 |
| Poz-59734 | Coll 01 | 476 | 0.4 mgC | 330* | 40 | 395 | 90 | 95.4 |
| Poz-59735 | Coll 01 | 599 | 0.8 mgC | 12,200 | 60 | 14,037 | 212 | 92.1 |
| Poz-61867 | Coll 02 | 178 | | 6220 | 35 | 7069 | 60 | 54.8 |
| Poz-61865 | Coll 03 | 86 | | 2900 | 30 | 3018 | 65 | 82.9 |
| Poz-61866 | Coll 03 | 165 | | 6125 | 35 | 7042 | 116 | 98.6 |
| Poz-61870 | Coll 05 | 199 | | 8170 | 40 | 9085 | 69.5 | 72.3 |
| Poz-61871 | Coll 05 | 271 | 0.13 mgC | 7640 | 100 | 8446 | 163 | 95.1 |
| Poz-61873 | Coll 05 | 533 | 0.8 mgC | 28,880 | 310 | 32,865 | 866 | 100 |
| Poz-61868 | Coll 06 | 234-235 | | 7390 | 100 | 8199 | 184 | 100 |
| Poz-61869 | Coll 06 | 279 | 0.6 mgC | 7410 | 50 | 8261 | 103 | 97.6 |

* unreliable result due to contamination, date was rejected

graphical units. Fines in the cores ($d < 2$ mm) were sampled in 10 cm intervals and from every stratigraphic unit, respectively. Sediment colour was determined with a Munsell soil colour chart and a Minolta CM 2500d spectrophotometer displaying colours in the CIE colour space (Lab-system).

Content of coarse rock fragments ($d \geq 2$ mm), grain size composition, sediment compaction, soil wetness and carbonate content were estimated following the German Soil Survey Instructions (Ad-Hoc-AG, 2005). The nomenclature of the soil texture was incurred from the U.S. Field Book for Describing and Sampling Soils Water (Schoeneberger et al., 2012). content of the samples was determined by drying the samples at 105°C for at least 4 hours measuring difference in weight before and after the drying process. Contents of volatile substances were determined as step-wise loss on ignition (LOI mass-%) of the dried samples (105°C) at 550°C and 900°C with a minimum heating period of 4 hours for each procedure. Sediment pH values were measured for solutions of 1 g of dried sediment digested in 2.5 ml 0.01 M KCl solution using a Hanna checker device (HI 98127) with 0.1 pH resolution. Total carbon content (TC mass-%) was measured applying a dry combustion using LECO TruSpec CHN 1000 analyser and total inorganic carbon (TIC mass-%) was measured applying a Woesthoff Carmograph C-16; total organic carbon (TOC) was computed building the difference of total carbon and total inorganic carbon. Twelve samples of charred plant remains were extracted and analysed using AMS dating in the Radiocarbon Laboratory Poznan (Table 6). The radiocarbon dates were calibrated using Calib Rev 7.0.2 (Stuiver and Reimer, 1993) and IntCal13 calibration curve (Reimer et al., 2013) and 2-sigma confidence intervals were used as age reference.

GIS analysis and archaeological data set

A digital elevation model (DEM) of the study area with 16 m*16 m ground resolution was derived from the 1:10,000 topographic map (FÖMI – Institute of Geodesy,

2003) using the “Topo to Raster” tool of ArcGIS 10.3. Slope gradients of the Hór valley flanks and drainage areas of the tributaries were determined on the basis of the DEM and applying the “Slope” and the “Watershed” tools of ArcGIS 10.3. Stream length, mean stream gradient, mean depth and mean top width of the tributaries were determined using QGIS 2.10. To determine mean depth and mean top width of the tributaries DEM-derived cross-sectional profiles were drawn every c. 150 – 250 m between the valley outlet and the headwater area and the valley depth was defined as the vertical distance between the top of the lower valley flank and the valley bottom; the valley width was defined as the horizontal distance between the top of the lower valley flank and the opposite valley side (20). Valley depth and width were determined for each cross-sectional profile along a single tributary and mean values were calculated for each tributary valley. In case of branched valleys every branch was considered and included in the calculation. Finally, mean width-depth ratios (WDR) were calculated for each tributary.

The tributary valleys were grouped automatically according to drainage area and valley length applying the k-means algorithm of Hartigan and Wong (1979) implemented in the R-package “stats” (R-Core-Team, 2014). Statistic variables used refer to the standard deviation (SD), arithmetic mean (μ), coefficient of determination (r^2) and the p-value (p).

A geomorphological map of the study area was created on the basis of Dobos (2012) supplemented by field mapping and the analysis of the 1:10,000 topographic map. Data on prehistoric settlement sites were kindly provided by the Herman Ottó Múzeum, Miskolc.

5.2.4 Results

Geomorphological analysis

Morphology along the flanks of the valley of the Hór stream shows locally significant differences: in the northern part of the study area, the slopes with western exposure show inclinations of up to 16° and elevations of the left valley flank amount to 60 – 90 m above the alluvial plain. The right valley flank is weakly delineated and dissected by the Szoros and the Cseresznyés streams and due to this, the slopes with eastern exposure are not considered here. In the southern part of the study area, the west-facing slopes are more gentle with inclinations below 12° and elevations of 50 – 60 m above the alluvial plain. In contrast to this, the east-facing slopes have inclinations of $8 - 20^\circ$, and elevations of 45 – 55 m above the alluvial plain.

The size of the drainage areas is strongly correlated to the valley length ($r^2=0.88$), and two types of tributary valley incisions can be differentiated (Table 7, Figure 19): the first group (incision type 1; $n=8$) is represented by the first two clusters of the k-means cluster analysis (R-Core-Team, 2014) and can be characterised by comparably long valleys (mean=1513 m, SD=617) with relatively large drainage areas (mean=79 ha, SD=28). The second group (incision type 2; $n=13$) is represented by the third k-means cluster and is characterised by clearly shorter valleys (mean=308 m, SD=107) and smaller drainage areas (mean=12 ha,

Table 7: Morphological characteristics and descriptive statistics of the valley types 1 and 2.

| | Drainage area (ha) | | Length (m) | | Top width (m) | | Depth (m) | | Width-depth ratio | | Inclination (m * m ⁻¹) | |
|------|-----------------------|----|------------|-----|------------------|-----|-----------|-----|----------------------|----|---------------------------------------|------|
| mean | 79* | 12 | 1513 | 308 | 292 | 122 | 15.9 | 6.9 | 27 | 20 | 0.06 | 0.12 |
| SD | 28 | 7 | 617 | 107 | 51 | 51 | 7 | 4 | 10.5 | 8 | 0.02 | 0.05 |
| min | 47 | 2 | 669 | 131 | 213 | 37 | 6.6 | 2.2 | 11 | 12 | 0.03 | 0.06 |
| max | 138 | 30 | 2422 | 486 | 394 | 190 | 28 | 15 | 47 | 41 | 0.09 | 0.25 |

* italic numbers refer to type 1 valleys (n=8); other to type 2 valleys (n=13).

SD=7). Student's t-tests resulted in significant differences between the two valley types with $p_{\text{valley length}}=0.0006$ and $p_{\text{drainage area}}=0.0002$.

Mean top width and mean valley depth of type 1 incisions range between c. 245 – 394 m and 6.6 – 28 m, respectively, with mean width-depth-ratios of 27 (SD=11; Table 7, Figure 20). Mean inclination of the valley bottoms is 0.06 m * m⁻¹ (SD=0.02). The channels tend to bifurcate, and several gullies and rills incise the channel walls. Type 2 valleys are characterised by mean top width and mean valley depth between 36.5 – 190 m and 2.2 – 15 m, respectively, with mean width-depth-ratios of 20 (SD=8). Mean inclination of the valley bottoms amounts to 0.12 m * m⁻¹ (SD=0.05). The morphological characteristics of the tributary valleys are in accordance with field observations. The wider and deeper incisions suggest a rather mature development stage (Horton, 1945), and except for one case (valley 21), all type 1 valleys are located exclusively on the west-facing slopes. In contrast, less deep and rather narrow incisions indicate younger development stages (Horton, 1945), and all except of two (valleys 2, 7) are located on the east-facing slopes (Figure 18 a).

Sedimentological record

The numbering and order of presentation of the sediment cores follow the spatial order of the drilling locations from north to south. First, the sediment sequences located on the left bank of the Hór valley and corresponding to type 1 valleys are described (Coll 01 – Coll 04), followed by the cores corresponding to type 2 valleys (Coll 05 – Coll 06, both located on the right bank of the Hór valley); finally, the core taken from the alluvial plain of the Hór stream is presented (Coll 07). Lithological features of the different units are described for each sediment sequence, and main characteristics of bulk chemical parameters are pointed out. TIC values are overall negligibly low and are not reported in the sediment description. Stratigraphic models of the cores Coll 01, Coll 04 and Coll 05 are depicted on Figures 21 – 23 while the stratigraphic models of all other sediment sequences and descriptive statistics of the laboratory analyses can be found in the supplementary material.

Core loss occurred due to material compaction during the drilling process in the cases of the Coll 01, Coll 03 and Coll 06 sediment sequences. The sections of core loss are treated as no data since it is not possible to specify the sediment deformation during the compaction process. An AP horizon of 20 – 50 cm thickness is found at the top of all sediment sequences.

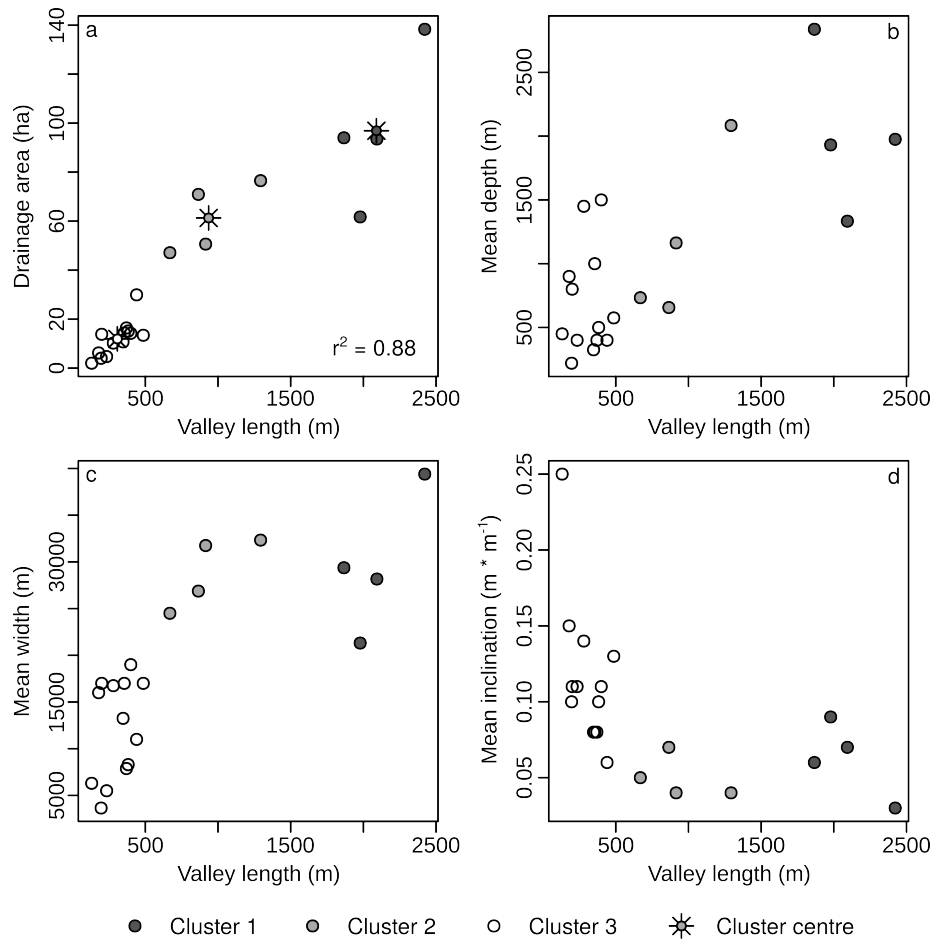


Figure 19: Scatter plots of the morphological characteristics of tributary valleys: clusters were derived by applying the k-means algorithm Hartigan and Wong (1979) on the variables drainage area and valley length (a); clusters 1 – 2 represent type 1 valleys, cluster 3 represents type 2 valleys.

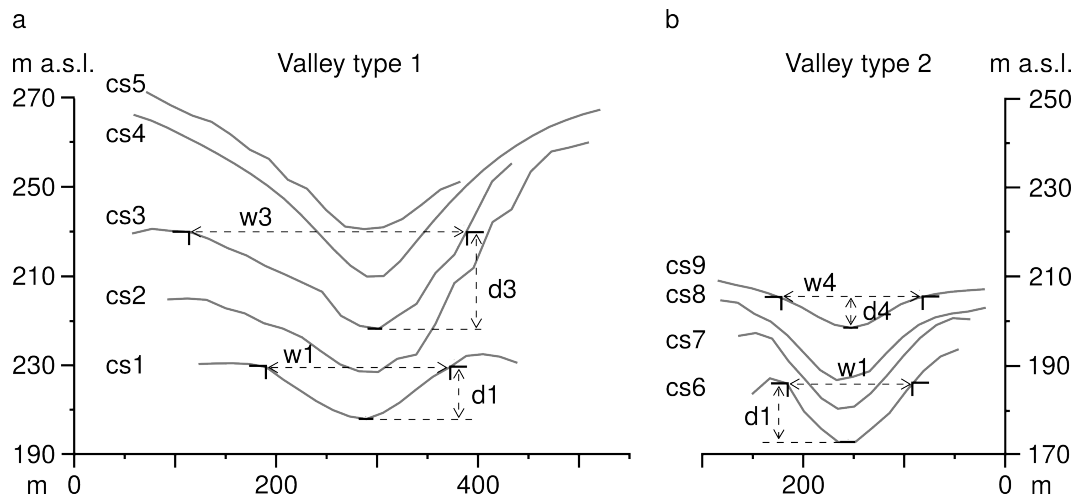


Figure 20: (a) Series of cross-sectional profiles from valley 3 (cs1 – cs5) representing the morphology of valley type 1; (b) Series of cross-sectional profiles from valley 11 (cs6 – cs9) representing the morphology of valley type 2 (see Figures 18 a, 19). For further explanation of valley depth (d) and top width (w) measurements refer to the text.

CORE COLL 01 The northernmost sediment core Coll 01 was obtained from a fan assigned to valley type 1, located on the left bank of the Hór valley. The sediment sequence has a total thickness of 740 cm and can be divided into seven units (Figure 21).

The basal unit 1 is formed by homogeneous silt loam with low amounts of fine-grained, coarse clasts ($d \leq 5$ mm). Unit 2 consists of coarse gravel ($d \leq 25$ mm; 667 – 656 cm depth) and sandy loam with high contents of fine-grained slate debris ($d \leq 10$ mm; 656 – 605 cm depth). Unit 3 (605 – 412 cm depth) is formed by a layer of dark, homogeneous clay loam that is widely free of coarse clasts. Due to technical reasons, the unit is interrupted by overlying material (576 – 539 cm) which was displaced during the drilling process. The upper c. 40 cm of the unit form a gradual transition towards the overlying unit 4. Unit 4 (412 – 350 cm depth) consists of light coloured, homogeneous clay loam containing low amounts of coarse clasts. Unit 5 (350 – 178 cm depth) is composed of clay loam with high amounts of angular rock fragments ($d \leq 15$ mm) at the basis. Very high amounts of rounded coarse clasts ($d \leq 40$ mm) are found between 310 – 294 cm depth. Towards the top of the unit amounts of rock fragments decrease. Daub was found in 343 – 336 cm, 306 cm, 278 – 273 cm and in 232 – 178 cm depth. Unit 6 (178 – 76 cm depth) consists of silt loam with low amounts of fine-grained, angular rock fragments ($d \leq 5$ mm) occurring in the upper part. High amounts of daub occur throughout the unit. Unit 7 (76 – 41 cm depth) consists of sandy clay loam and small amounts of fine-grained, angular rock fragments ($d \leq 5$ mm) occur throughout the whole unit.

TOC values are low ranging between 0.39 – 2.24 mass-% ($\mu=0.93$ mass-%, $SD=0.44$, $n=46$). In unit 3 TOC values peak with 1.7 mass-% at c. 470 cm depth ($\mu=1.16$ mass-%, $SD=0.29$, $n=12$). Manganese streaks indicate recent hydromorphic alterations from 391 cm depth upwards. Manganese concretions occur between 300 – 220 cm depth.

Four samples were dated by AMS dating: the basis of unit 3 (599 cm depth) was dated to $14,037 \pm 213$ cal BP (Poz-59735), while another sample taken in 476 cm depth (395 ± 90 cal BP; Poz-59734) seemed to be contaminated and was rejected. The top of unit 4 was dated to 4876 ± 93 cal BP (354 – 351 cm depth; Poz-59733) and in 306 cm depth (unit 5) a sample gave an age of 3054 ± 111 cal BP (Poz-59732).

CORES COLL 02, 03 The Coll 02 sediment sequence has a total thickness of 700 cm and was extracted close to the present drainage line from the vertex of the fan. The sediment sequence can be divided into three units.

Unit 1 (700 – 526 cm depth) consists of homogeneous, highly compacted sandy loam that is free of coarse clasts. Unit 2 (526 – 455 cm depth) consists of a basal gravel layer in a matrix of sandy clay loam and an overlying compacted sand layer with high contents of fine- and coarse-grained, angular and very angular rock fragments ($d \leq 30$ mm). Between 475 – 466 cm depth and 483 – 481 cm depth, amounts of coarse clasts are strongly reduced. Unit 3 (455 – 20 cm depth) consist of a layer series with grain size distributions alternating between loamy sand and clay loam and varying contents of angular and very angular rock fragments

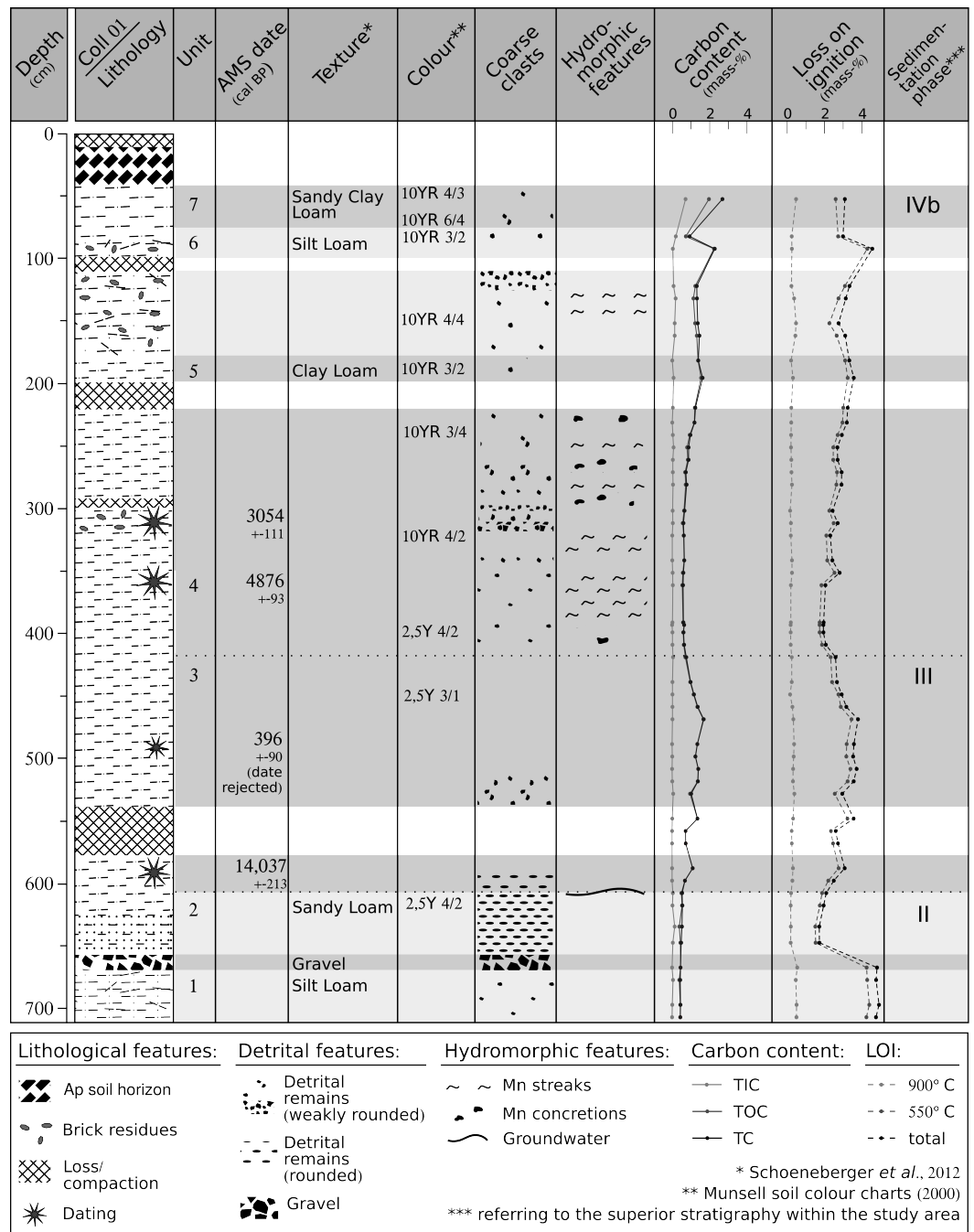


Figure 21: Stratigraphic units and geochemical and geophysical characteristics of the Coll 01 sediment sequence (Mn = manganese, LOI = Loss on ignition, TOC = total organic content, TIC = total inorganic content, TC = total carbon).

($d \leq 20$ mm). The thickness of the different layers varies between 1 to 40 cm. Small amounts of daub occur at 177 cm and 135 – 130 cm depth.

TOC values peak at 1.1 mass-% ($\mu=0.5$ mass-%, $SD=0.2$, $n=32$) at 161 cm depth, and the magnetic susceptibility ranges between $5 - 118 * 10^{-5}$ SI peaking at $498 * 10^{-5}$ SI in 476 cm depth ($\mu=50 * 10^{-5}$ SI, $SD=68 * 10^{-5}$, $n=191$). Hydromorphic alterations of the sediments are indicated by manganese concretions and bleached patches between 650 – 550 cm, 500 – 430 cm, 330 – 311 cm and at 130 cm depth, and manganese streaks occur around 200 cm depth. A charred plant particle found at 178 cm depth was dated to 7069 ± 60 cal BP (Poz-61867).

The Coll 03 sediment core has a total length of 300 cm and was extracted from a more distal position of the fan c. 15 m northwest. The sediment sequence can be divided into two units. Unit 1 (300 – 246 cm depth) consists of fine- and coarse-grained, mostly rounded rock fragments ($d \leq$ mm) in a matrix of sandy loam, silty clay, silty clay loam and silt loam. The overlying unit 2 consists of silt loam (246 – 231 cm, 156 – 80 cm depth), loam (231 – 156 cm depth) and clay loam (80 – 20 cm depth) and contains only low amounts of mostly angular, coarse clasts ($d \leq 20$ mm). Daub was found at 195, 180, 140 – 130, 125 and 100 – 40 cm depth.

TOC values are overall low ($\mu=0.12$ mass-%, $SD=0.04$, $n=10$), and the magnetic susceptibility averages at $48 * 10^{-5}$ SI ($SD=16 * 10^{-5}$, $n=75$). Samples for AMS dating were taken from 165 cm depth (7042 ± 116 cal BP; Poz-61866) and from 86 cm depth (3018 ± 65 cal BP; Poz-61865).

CORE COLL 04 The sediment core Coll 04 has a total length of 700 cm and consists of mostly homogeneous, carbonate free loam and silt loam. The sediment sequence can be divided into four units (Figure 22).

Unit 1 (700 – 656 cm depth) consists of homogeneous, highly compacted clay loam that is free of coarse rock fragments. Unit 2 (656 – 471 cm depth) consists of a series of alternating fine-grained sand, loamy sand and silt loam layers. The content of coarse clasts is low, and the fragments are fine-grained and angular to rounded ($d = 2 - 10$ mm). A layer of coarse-grained, rounded gravel ($d \leq 30$ mm) is deposited between 595 – 576 cm depth with a 2 cm thick intercalated sand layer. Unit 3 (471 – 271 cm depth) and unit 4 (271 – 20 cm depth) consist of homogeneous silt loam and loam. Unit 3 contains very low amounts of mostly rounded, fine-grained slate debris and tuff residues ($d \leq 2$ mm) whereas unit 4 lacks coarse clasts.

TOC values range between 0.4 – 1.1 mass-% ($\mu=0.6$ mass-%, $SD=0.2$, $n=27$), and the magnetic susceptibility is overall low averaging at $34 * 10^{-5}$ SI ($SD=7 * 10^{-5}$, $n=129$). Hydromorphic alteration of the material is indicated throughout the whole sediment sequence by manganese concretions, manganese streaks and bleached patches. Due to a lack of organic rich material, none of the units could be dated by AMS measurement.

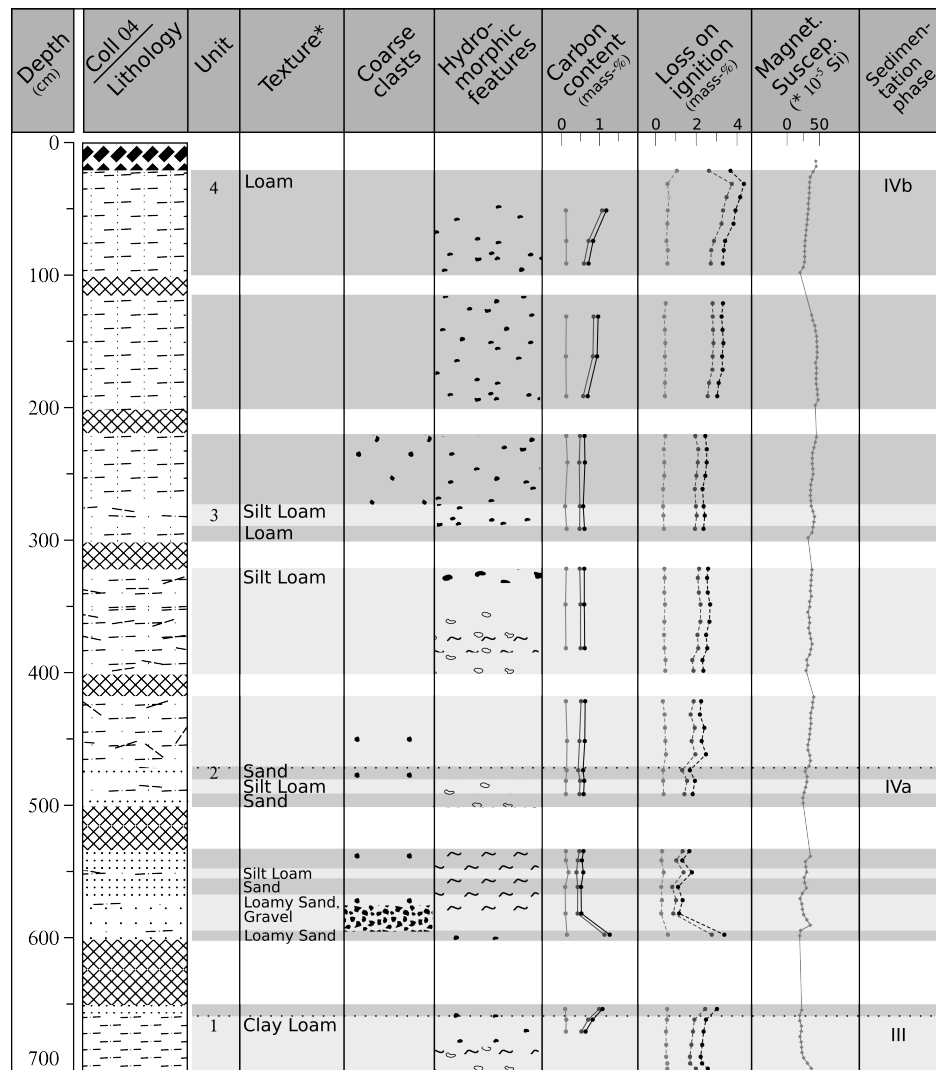


Figure 22: Stratigraphic units and geochemical and geophysical characteristics of the Coll 04 sediment sequence (please note that the legend is the same as in Figure 21).

CORE COLL 05 The sediment core Coll 05 was extracted from a fan deposited by a tributary of the Hór stream belonging to valley type 2. The tributary discharges the western flank of the Hór valley. The extracted sediment sequence has a total thickness of 900 cm and can be divided into seven units (Figure 23).

Unit 1 (900 – 820 cm depth) consists of homogeneous, loosely bedded, fine-grained sand, and the material lacks coarse rock fragments. Unit 2 (820 – 715 cm depth) is composed of angular and rounded, coarse gravel and fine-grained rock fragments ($d \leq 40$ mm). Amounts of fine textured material are negligible in the basal 20 cm whereas increased amounts of loamy sand are present in the upper 85 cm. Unit 3 (700 – 525 cm depth) is composed of sand, silty clay loam, silt loam and silt. The material is moderately compacted, and the basal 65 cm are free of coarse clasts. The upper 110 cm contain very low amounts of mostly rounded rock fragments ($d \leq 15$ mm). Unit 4 (500 – 350 cm depth) consists of homogeneous, fine-grained deposits. The basal clay layer is superimposed by a silty clay section

(471 – 372 cm depth) and an overlying silty clay loam section. The material is compacted and coarse clasts mostly lack. Only in the upper 50 cm, low amounts of very angular, fine gravels occur ($d \leq 10$ mm). Unit 5 (300 – 240 cm depth) is composed of 15 finely stratified layers of clay-, silt- and sandy loam, with alternating contents of mostly rounded coarse clasts. The rock fragments vary greatly in size and amount ($d > 3$ mm, < 40 mm). The thickness of the individual layers ranges between 1 – 9 cm ($\mu=4$ cm), and the deposits are highly compacted. Unit 6 (200 – 120 cm depth) shows a similar structure like unit 5: it consists of a sequence of 10 layers but in contrast to unit 5, layer thickness range between 3 – 14 cm ($\mu=8$ cm). The deposits are also highly compacted. Daub occurs in 192 cm and in 128 cm depth. Unit 7 (93 – 20 cm depth) consists of silt loam in the lower part and clay loam in the upper part. The material contains low amounts of fine-grained, rounded and moderately rounded coarse rock fragments ($d \leq 10$ mm). In the upper part, well rounded gravel occurs ($d \leq 30$ mm), and daub occurs in 29 cm depth.

TOC values average at 0.63 mass-% (SD=0.35, $n=24$) with peak values of up to 1.1 – 1.5 mass-% in unit 4 and at the basis of unit 5 (290 – 370 cm depth). The magnetic susceptibility averages at $62 \cdot 10^{-5}$ SI (SD= $58 \cdot 10^{-5}$, $n=178$) and shows increased values in unit 4 ($\mu=170 \cdot 10^{-5}$ SI, SD=57, $n=30$). Recent hydromorphic alterations of the material are indicated below 500 cm depth by manganese concretions and bleached patches, and above 500 cm depth manganese streaks occur with varying abundance.

Three charcoal samples were taken from the sediment sequence for AMS dating: the top of unit 3 (533 cm depth) was dated to $32,865 \pm 867$ cal BP (Poz-61873), the lower part of unit 5 (271 cm depth) was dated to 8446 ± 163 cal BP (Poz-61871), and the basis of unit 6 (199 cm depth) was dated to 9085 ± 70 cal BP (Poz-61870).

CORE COLL 06 The core Coll 06 was extracted from a fan deposited by a tributary draining the western flank of the Hór valley at the most downstream part of the study area. The sediment sequence has a total thickness of 500 cm and can be divided into four units.

Unit 1 (500 – 426 cm depth) consists of homogeneous, moderately compacted silt loam that is free of coarse rock fragments. Unit 2 (400 – 190 cm depth) consists of homogeneous, compacted clay loam. The basal 20 cm represent the transition from unit 1 consisting of silt loam and the material lacks coarse clasts. Between 300 – 190 cm depth, low amounts of fine-grained, rounded rock fragments occur ($d \leq 2$ mm). For unit 3 (190 – 80 cm depth), data lack due to a gap within the drilling profile. Only the uppermost 20 cm are documented and consist of a compacted, coarse-grained gravel layer ($d \leq 4$ mm). Unit 4 (80 – 50 cm depth) consists of compacted clay loam with low amounts of fine-grained, rounded rock fragments ($d \leq 3$ mm).

TOC values average at 1.21 mass-% (SD=0.41, $n=14$), and reach a local maximum of 1.7 mass-% in 361 cm depth (unit 2). In 364 cm depth (unit 2), the magnetic susceptibility peaks at $239 \cdot 10^{-5}$ SI ($\mu=117 \cdot 10^{-5}$ SI, SD= $76 \cdot 10^{-5}$, $n=71$). Hydromorphic alteration of the material is indicated by bleached patches,

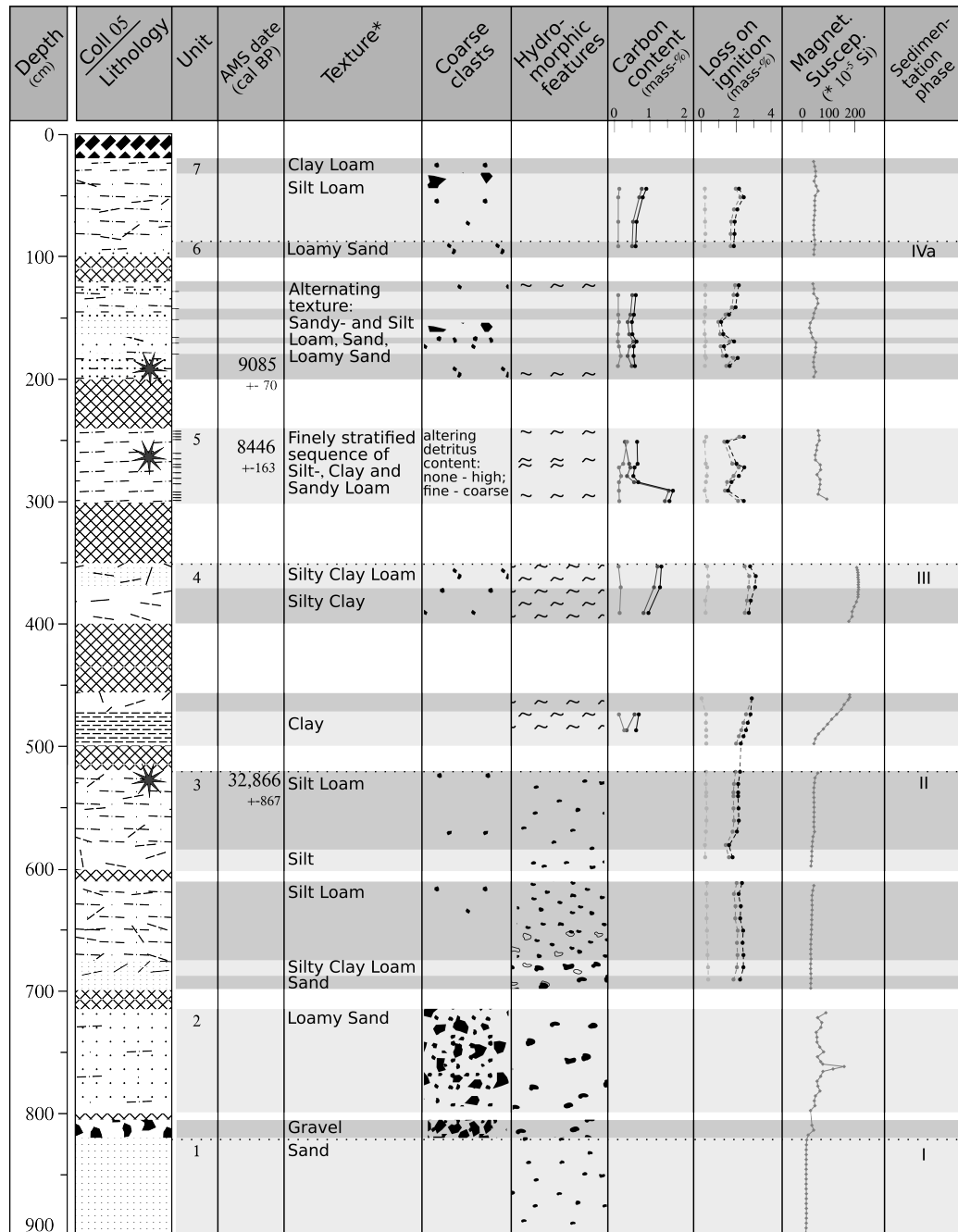


Figure 23: Stratigraphic units and geochemical and geophysical characteristics of the Coll 05 sediment sequence (please note that the legend is the same as in Figure 21).

manganese streaks and manganese concretions between ca. 500 – 430 cm and 300 – 200 cm depth.

Within the upper part of unit 2, two charcoal samples revealed ^{14}C ages dating to 8261 ± 103 cal BP in 279 cm depth (Poz-61869) and 8198 ± 184 cal BP in 234 – 235 cm depth (Poz-61868).

CORE COLL 07 The sediment core Coll 07 was obtained from the alluvial plain close to the Hór stream, 400 m north of the Coll 06 sequence. The sediment sequence has a total thickness of 300 cm and can be divided into four units.

The basal unit 1 (300 – 280 cm depth) is formed of very angular, coarse-grained gravel ($d \leq 50$ mm) and low amounts of sandy matrix material. The gravel mainly consists of limestone. Unit 2 (280 – 213 cm depth) is composed of silty clay loam and silt loam and is rich in coarse-grained, very angular limestone gravel ($d \leq 70$ mm) and fine-grained, rounded slate debris ($d \leq 3$ mm). Unit 3 (200 – 135 cm depth) consists of slightly to moderately compacted silty clay loam and coarse clasts are mostly missing. Unit 4 (135 – 11 cm depth) is composed of compacted silt loam and loam containing low amounts of fine-grained, rounded rock fragments ($d \leq 10$ mm). Due to a lack of datable material, the sediments are not supported by any numeric chronology.

The magnetic susceptibility is overall low averaging at 39×10^{-5} SI ($SD=17 \times 10^{-5}$, $n=67$). TOC values range between 0.4 – 2.2 mass-% ($\mu=1.3$ mass-%, $SD=0.6$, $n=15$). In 245 cm depth TIC values peak at 1.5 mass-% ($\mu=0.3$ mass-%, $SD=0.4$, $n=15$) due to the occurrence of limestone gravel. Hydromorphic features such as manganese concretions and manganese streaks occur between ca. 380 – 250 cm and 90 – 40 cm depth.

Geochronology

The chronological model is based on 11 radiocarbon datings of charcoal pieces from the Coll 01, Coll 02, Coll 03, Coll 05 and Coll 06 sediment sequences (Table 2, Fig. 8). The AMS dates span the period from the last glacial period to the Late Bronze Age (c. 33,000 – 3000 cal BP). The datings are not equally distributed over the study period, and it is not possible to calculate sedimentation rates for any of the sediment sequences. Seven samples contained less than 1 mg C, and their ages need to be treated carefully. One age was rejected due to contamination of the sample. Nonetheless, the ages support each other and fit well into the chronological model.

Three dates from the Coll 01 and the Coll 06 sediment cores correspond to a phase of low-energy sedimentation during the Late Pleistocene and Early Holocene (c. 14,000 – 8000 cal BP). Two samples from the Coll 05 sediment core gave inverted ages dating to 8446 ± 163 cal BP (Poz-61871) and 9085 ± 70 cal BP, however, the sediment context resembles a sequence of repeated sedimentation events at foot slope position, and the reversal of sediment profiles in such situations is plausible (Lang and Hönscheidt, 1999). Human related sediment deposition is indicated by daub fragments and was dated to c. 4800 and c. 3000 cal BP by two samples from the Coll 01 sediment core. In the Coll 02 and the Coll 03 sediment cores, daub was found in the context of charcoal pieces dating to

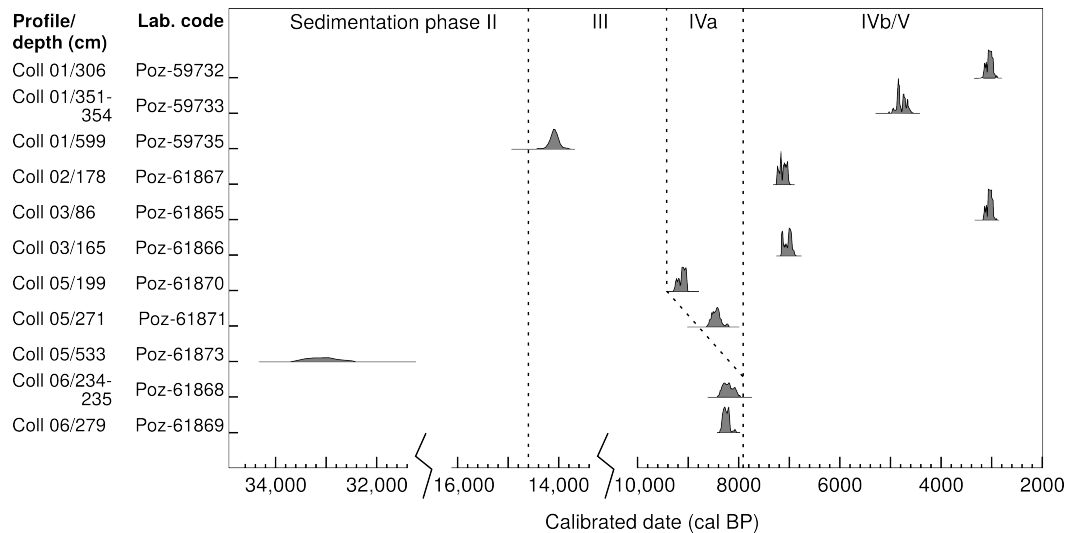


Figure 24: Age model of the sediments in the middle Hór valley and sedimentation phases according to the core records (see Tables 6, 8).

c. 7000 cal BP. This suggests that the dated plant particles were charred well before their deposition at the coring location.

5.2.5 Discussion

The development of the tributary incisions can be reconstructed by relating the different sedimentation phases of the sampled sediment sequences. Implications for the development of the Hór valley itself are addressed in section 5.2.5 The Coll 05 core presents the most complete sediment sequence and is used as reference for the other records. The total of 11 ^{14}C dates informs a chronology of the sedimentation phases: phase I dates to the pre-Pleistocene period, phase II dates to the Pleistocene, phase III dates to the Late Pleistocene – Early Holocene transition and phases IVa, IVb and V date to the Holocene (Table 8, Figure 24). Phase V occurs only in the Coll 07 sequence, which was extracted from the alluvial plain of the Hór stream. Unfortunately, no datable material was present in these sediments. Thus, the phase Is not discussed separately.

Pre-Pleistocene and Pleistocene sediments and corresponding landscape development

Phase I is present in the Coll 02 and Coll 05 sediment sequences and consists of homogeneous sand and sandy loam that is free of organic material, carbonates and coarse clasts. The magnetic susceptibility shows mean values below $10 \cdot 10^{-5}$ SI. In the Coll 05 sediment core, a charcoal piece was found c. 300 cm above phase I dating to the Pleistocene ($32,866 \pm 867$ cal BP, Poz-61873), and the boundary between the sandy phase I and the overlying material is very sharp, indicating significantly different sedimentation environments. It is therefore assumed that phase I corresponds to lacustrine sedimentation during the Miocene which is supported by the geological map (MÁFI – Institute of Geology, 2005).

Table 8: Summarising overview of the sedimentation phases I – V as occurring in the sediment sequences from the studied fans.

| Phase | Characteristics | Depositional environment | Age |
|-------|---|---------------------------------------|--|
| I | - homogeneous fine-grained sand, sandy loam; - carbonate free; - very low magnetic susceptibility | lacustrine deposition | Miocene |
| II | - sand, loam; - high amounts of coarse- and fine-grained gravel; - peak values of magnetic susceptibility; - free of organic content | fluvial/fan deposition | Pleistocene |
| III | - homogeneous blackish-brown silty clay, silty clay loam, clay loam; - increased TOC contents, magnetic susceptibility; | low-energy fluvial deposition | Late Pleistocene – Early Holocene (c. 14,000 – 8000 cal BP) |
| IVa | - stratified sequence of 7 – 15 layers; - strongly varying amounts of coarse clasts; - partly occurring daub | event-related fan deposition | c. 9000 – 8000 cal BP |
| IVb | - silt loam, clay loam; - reduced amounts of coarse clasts; - no significant peaks of carbonate content or magnetic susceptibility | fan deposition | Mid- to Late Holocene |
| V | - <i>exclusively found in sediment sequence Coll 07 and not considered in the discussion</i> | <i>presumably alluvial deposition</i> | <i>presumably Holocene</i> |

The Pleistocene phase II consists of sandy and loamy material with varying content of coarse rock fragments. The phase is present in all core records, except the Coll 04 sediment sequence. The basis of the Pleistocene phase II, however, can be identified with certainty only in the sediment sequences of Coll 02 and Coll 05 where the underlying Miocene material is present. Here, the basal section of phase II consists of coarse debris in a matrix of loamy sand and sandy clay loam, and the magnetic susceptibility shows peak values of up to $498 \cdot 10^{-5}$ SI which can be explained by the occurrence of ferrimagnetic minerals originating from volcanic rocks (Liu et al., 2012). High amounts of coarse gravel reflect high-energy processes (Hjulstrom, 1939; Inman, 1949) which is indicative for a braided river environment during the Weichselian high glacial period (e.g. Mol et al., 2000; Mol, 1995, 1997; Vandenberghe, 2002), or may be related to slope failures under periglacial conditions that prevailed in the area during the Pleistocene (Dobos, 2012).

The upper unit of the Pleistocene phase II dates to $32,866 \pm 867$ cal BP (Poz-61873) in the Coll 05 sequence and consists of silt, silt loam and silty clay loam containing low amounts of fine-grained coarse rock fragments. This indicates low-energy material transport rather than sediment deposition related to intense valley incision. Furthermore, the accumulation of silty material may be related to loess deposition, which is reported from the Tokaj region for the period between 40 and 32 ka BP (Sumegi and Hertelendi, 1998). Soil creeping and frost movements led to reworking of the material, downslope transportation and mixing with slate debris, calcareous gravel and rhyolitic tuffs (Dobos, 2012) explaining the occurrence of coarse clasts. Similar material can be found in the adjacent Coll 06 sediment sequence between c. 430 – 500 cm depth (Figure 26 c).

The Coll 02 sediment sequence was extracted from above the apex of the fan based upon poor material sorting (Hjulstrom, 1939; Inman, 1949) and sedimentation of highly heterogeneous layers. An exact localisation of the upper boundary of the Pleistocene sedimentation phase I is therefore not possible. In the adjacent Coll 03 sediment sequence, the deposits contain high contents of coarse gravels between 300 – 245 cm depth indicating high-energy material transport and Pleistocene deposition (Dobos, 2012; Hjulstrom, 1939; Inman, 1949). The boundary to the overlying loamy material (dated to 7042 ± 116 cal BP in 165 cm depth; POZ-62866) marks a sharp transition and is interpreted as the Pleistocene – Holocene boundary. This boundary corresponds to a depth of c. 275 cm in the Coll 02 core (Figure 25). Here, the underlying material consists of layers of different thickness and varying amounts of coarse clasts in clayey to sandy matrices, which is characteristic of fan deposition (Blair and McPherson, 1994; Bull, 1972; Calvache et al., 1997). A charred plant remain extracted at 178 cm depth dates to 7069 ± 60 cal BP (POZ-61867) proving Holocene deposition. Assuming the Pleistocene – Holocene boundary at c. 275 cm depth the thickness of Pleistocene fan deposits amounts to c. 200 – 250 cm. This is in accordance with the type 1 morphology of the corresponding valley.

In the Coll 01 sediment sequence, the Pleistocene phase II is formed by homogeneous silt loam and an overlaying debris layer, and in the upper section, it consists of sandy loam with high amounts of fine-grained, rounded slate debris. Here, the basis of the overlying phase III was dated to $14,037 \pm 213$ cal BP (POZ-59735) indicating Late Pleistocene or earlier origin of the upper part of phase II (Figure 25 b). The high contents of coarse clasts point to sedimentation during high-energy material transport (Hjulstrom, 1939; Inman, 1949), and the deposition of (Late) Pleistocene fan material is in accordance with the type 1 morphology of the corresponding valley.

Intense incision of type 1 valleys during the (Late) Pleistocene corresponds to regional vegetation development and climate conditions as reported for the Upper Weichselian: based on mollusc faunas of Hungarian loess profiles, Krolopp and Sümegi (1995) reconstruct a cold and arid period between c. 23,500 – 18,000 cal BP, interrupted by a humid temperate phase between c. 21,500 and 20,000 cal BP. Similarly, Sümegi and Krolopp (2002) present malacological data and model simulations that indicate a cold and dry phase during the Upper Weichselian around 21,500 cal BP. Accordingly, pollen records from the Nagy Mohos Tó site in c. 60 km distance indicate a decline of the forest cover, while several herbaceous taxa such as Poaceae, Artemisia, Chenopodiaceae increase (Magyari et al., 1999; Sümegi and Krolopp, 2002). These vegetation changes and climate conditions lead to increased overland flow and thus enhance valley incision. In agreement, Gábris et al. (2012) find an incision phase in the Middle Tisza River during the Last Glacial Maximum (LGM) between 23,000 and 19,000 cal BP.

Sediments and landscape formation of the Pleistocene – Holocene transition and the Holocene

LATE PLEISTOCENE – HOLOCENE LOW-ENERGY SEDIMENT DEPOSITION
Sedimentation phase III represents Late Pleistocene – Early Holocene homo-

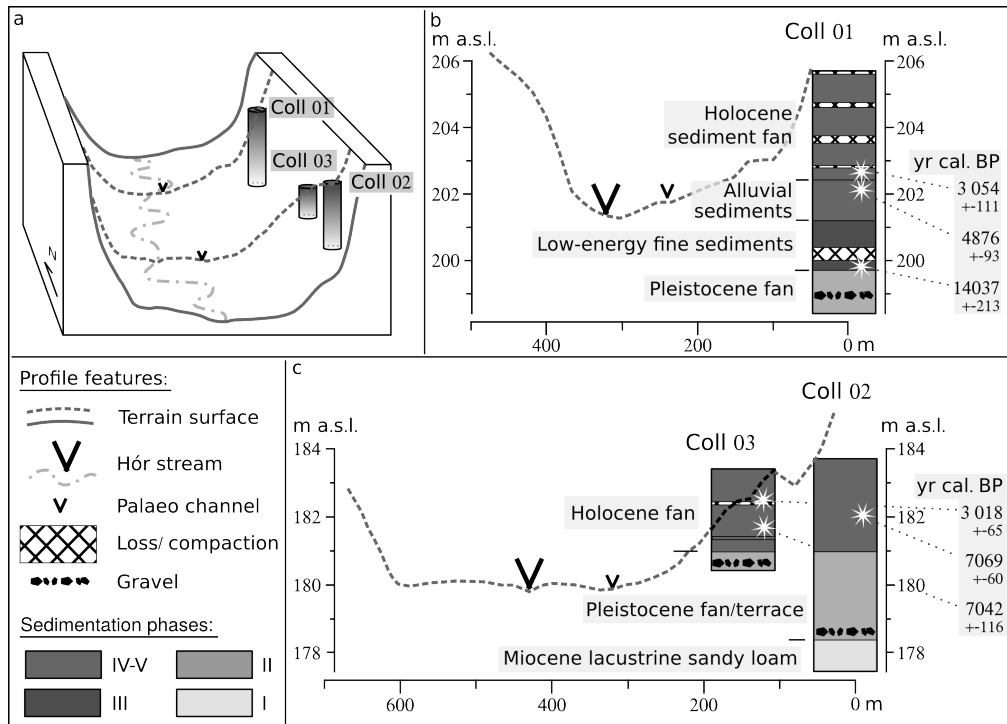


Figure 25: (a) Relief model of the northern part of the study area with coring locations; (b, c) Cross-sectional profiles through the Hór valley and generalised stratigraphy of the sediment sequences of Coll 01 – Coll 03. Vertical and longitudinal scales of the cross-sectional profiles are consistent.

geneous blackish-brown silty clay, silty clay loam and clay loam with increased magnetic susceptibility values and TOC contents. This points to low-energy sediment deposition as e.g. in an abandoned meander (Hjulstrom, 1939; Inman, 1949; Paasche et al., 2004; Snowball et al., 2002; Spring and Bazylinski, 2006). The phase is 150 – 200 cm thick and contains only few coarse rock fragments. The phase is present in the cores Coll 01, Coll 06 and Coll 05 and possibly forms the basis of the Coll 04 sediment sequence. In the core Coll 01 the basis of the phase was dated to 14,037 ± 213 cal BP (Poz-59735). In the core Coll 06 two ^{14}C ages from the upper part of the phase date to 8199 ± 185 cal BP (Poz-61868) and 8261 ± 103 cal BP (Poz-61869), consistent with respect to the stratigraphy.

In the cores Coll 06 and Coll 05 high magnetic susceptibility values are in contrast to all other phases (except the gravel layers of the Pleistocene phase II) where the magnetic susceptibility remains broadly below 100×10^{-5} SI. Since only the volume-specific magnetic susceptibility was measured, the values may be biased due to the strong material compaction during the drilling process. However, the basal sediments of the Coll 04 sequence were similarly compacted without showing increased magnetic susceptibility values. Increased magnetic susceptibility of fine substrates may be the result of soil forming processes, or the effect of burning (Mullins, 1977). However, neither Early- to Mid Holocene soil development resulting in up to 150 cm thick humous A-horizons is reported for the study region (Dobos, 2012), nor is intensified large-scale burning evidenced from environmental archives in c. 25 – 40 km distance (Gardner, 2002; Magyari et al., 2010;

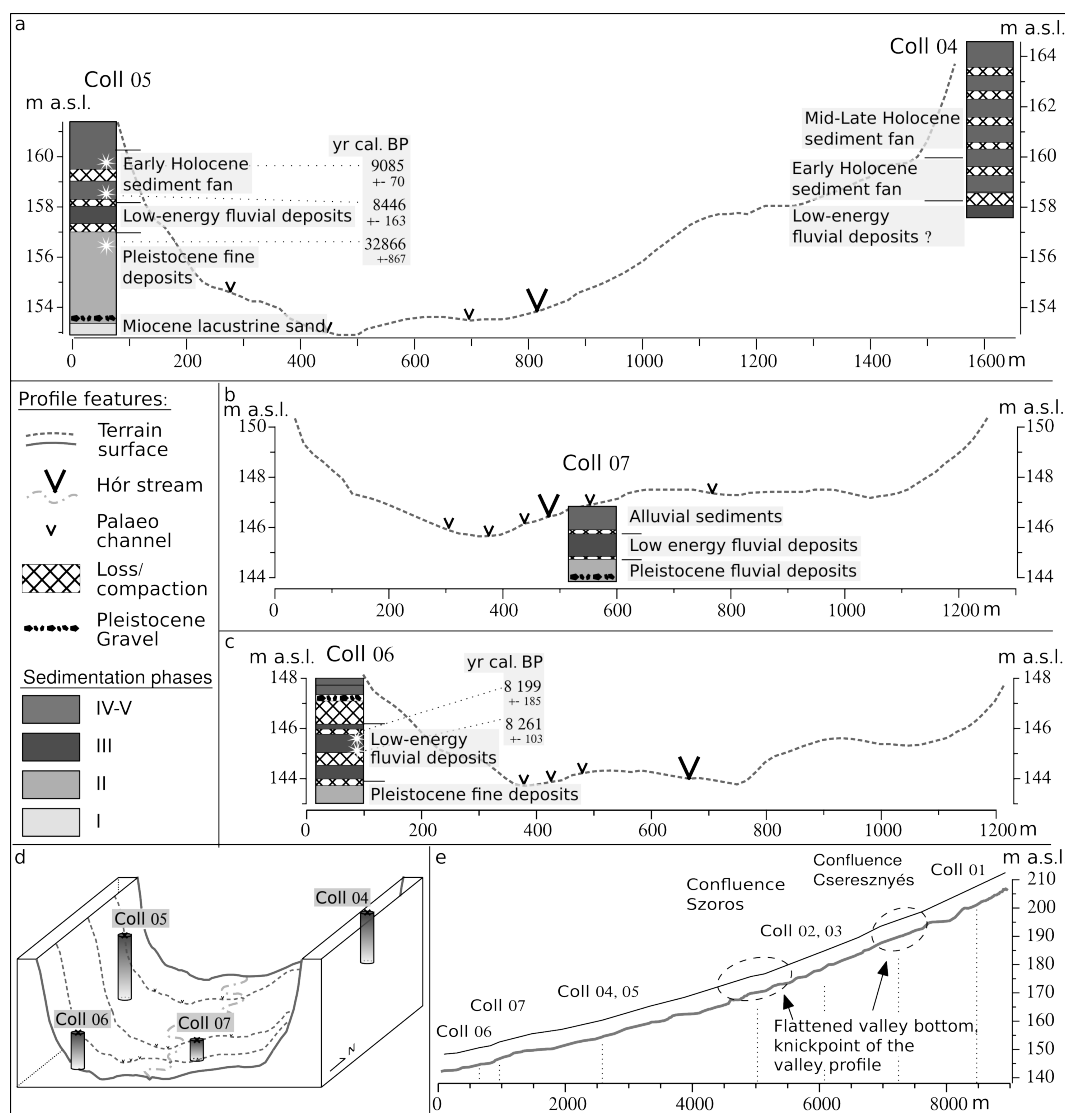


Figure 26: (a – c) Cross-sectional profiles through the Hór valley and generalised stratigraphy of the sediment sequences Coll 04 – Coll 07; (d) Relief model of the southern part of the study area with coring locations; (e) Longitudinal profile of the studied section of the Hór valley. Vertical and longitudinal scales of the cross-sectional profiles are consistent.

Magyari et al., 2012). Enrichment of minerogenic ferrimagnetic material such as magnetite originating from felsic volcanic rocks may lead to increased magnetic susceptibility of alluvial sediments (Liu et al., 2012). Furthermore, increased magnetic susceptibility may be due to magnetotactic bacteria with highest concentrations found at the oxic-anoxic transition of sediments or a water column (Spring and Bazylnski, 2006). Enrichment of organic material stimulates the reproduction of magnetotactic bacteria resulting in increased magnetic susceptibility (Paasche et al., 2004; Snowball et al., 2002; Spring and Bazylnski, 2006). Although, these results were demonstrated for lake sediments, low-energy deposition in an abandoned channel may have led to similar processes so that slightly increased TOC values are reflected by increased magnetic susceptibility values.

The occurrence of phase III in the Coll 07 sequence is in accordance with the drilling location (c. 60 m distance from the Hór stream) where a slight depression indicates the presence of a palaeochannel. Here, increased TOC contents are not associated with increased magnetic susceptibility values as observed in the Coll 06 and Coll 05 sequences.

The basal 40 cm of the Coll 04 sediment sequence consist of clay loam typical of phase III. The upper boundary of the section is located on the same level as the upper boundary of phase III of the opposing Coll 05 sediment sequence (Figure 26 a). However, neither the available colour values, magnetic susceptibility, nor TOC data are in accordance with the records of phase III of the other sediment sequences which may be due to the incompleteness of the record. Therefore, the material cannot be assigned reliably to phase III.

The sedimentation phase III, as reconstructed from the ^{14}C ages of Coll 01 and Coll 06, started latest during Late Pleistocene and ended in the Early – Mid Holocene. However, for the Coll 01 sequence the end of the low-energy deposition could not be dated. The basis of phase III within Coll 01 corresponds to the transition from a braided to a meandering river system in the Middle Tisza region (Kasse et al., 2010; Figure 27). At that time the climate became warmer and more humid, and the vegetation developed from steppe to forest steppe and open forests (Kasse et al., 2010; Krolopp and Sümegei, 1995; Sumegi and Hertelendi, 1998). Nonetheless, discharge of rivers in the Great Hungarian Plain was still several times higher than today (Kasse et al., 2010; Sümegehy and Kiss, 2011). The river system did not react to climate deterioration during the Younger Dryas but large meanders persisted (Kasse et al., 2010). During the Pleistocene-Holocene transition, discharge was reduced due to the development of deciduous forest. Meander dimensions of the Tisza river decreased and the river started to incise, forming a fluvial terrace of up to 4 m height until nowadays (Kasse et al., 2010). Based on pollen transfer functions, Mauri et al. (2015) reconstructed Holocene climate anomalies for Europe in comparison to conditions around 100 cal BP. For northern Hungary and the time slice 9500 – 8500 cal BP, this hint-cast climate model shows strongly decreased precipitation surplus (Figure 27 j). Accordingly, phase III is assumed to reflect abandoned channels of a braided river system that were frequently affected by flood events. With reducing discharge during the Early Holocene, the low-energy sediment deposition ended. In the case of the

Coll 05 sediment sequence the phase ended before c. 9100 cal BP and in the case of the Coll 06 sediment sequence it happened after c. 8200 cal BP.

HOLOCENE FAN DEPOSITION In various cores alternating layers of clay loam, silt loam and loamy sand with varying amounts of fine- and coarse-grained, mostly not rounded rock fragments occur, summarised to the Holocene sedimentation phase IVa. This points to alternating low- and high-energy sedimentation (Hjulstrom, 1939; Inman, 1949) that is characteristic of event-related, cyclic fan deposition (Blair and McPherson, 1994; Calvache et al., 1997; Constante et al., 2011). The sedimentation phase IVa is most clearly identifiable in the Coll 05 sediment sequence where it can be divided into two sections: the underlying section consists of 15 distinct layers that have thicknesses between 1 and 9 cm and the overlying section consists of 10 layers with thicknesses between 3 and 14 cm. Two samples of organic material from the phase revealed ^{14}C ages that are inverse in respect to the stratigraphy dating to 8446 ± 163 cal BP (Poz-61871) and to 9085 ± 70 cal BP (Poz-61870). The distinct stratification of the layers clearly relates to erosion events (Blair and McPherson, 1994; Calvache et al., 1997) and the inversion of sediment profiles at the footslope of a small scale catchment is plausible (Lang and Hönscheidt, 1999). The valley that corresponds to the studied fan is directed towards a small saddle. This suggests that the incision is associated to a former road, as it often can be observed all over Europe (e.g. Dotterweich, 2008; Dotterweich et al., 2013; Gábris et al., 2003; Nykamp et al., 2016; Vanwallegheem et al., 2003).

The Bronze Age Hatvan tell site Bogács-Pázsag puszta is located in close vicinity on a hilltop between the Coll 05 and the Coll 06 sediment sequences (Figure 18 a; Fischl et al., 2012; Koós, 1991), suggesting a relation between valley formation and prehistoric human activities. The earliest signs of human woodland management in northern Hungary date to c. 8000 cal BP (Willis et al., 1997) and to the early 8th millennium BP (Gardner, 2002; Magyari et al., 2001, 2012), and settlement density in the Bükkalja foothill area increased at the transition from the Chalcolithic to the Bronze Age around 5500 cal BP (Sherratt, 1982). However, the calibrated ^{14}C ages that were obtained from sedimentation phase IVa predate these activities and human triggered valley incision cannot be assumed. Instead, it is suggested that the valley incised due to a short-term erosive climate event. The absolute dates point to a relation to the 8.2 ka cold event. Although it is assumed that the climate deterioration between 8300 and 8100 cal BP was not very pronounced in the Pannonian region (Constantin et al., 2007; Drăguşin et al., 2014), the geochemical record of the Kelemér Kismohos Tó site located in c. 60 km distance to the north shows peak Al and K concentrations around 8150 cal BP, indicating a short-term enhanced sediment input from the catchment (Braun et al., 2005). For the same period, a short-term decline of *Corylus* (hazelnut) pollen and a contemporaneous increase of *Tilia* (lime) pollen are reported for the Sirok Nyírjes Tó site in c. 25 km distance to the west (Gardner, 2002) and for the Nagymohos Tó site in c. 60 km to the north (Magyari et al., 2001). Around the Kelemér Kismohos Tó site *Betula* (birch) reoccurred at the expense of *Corylus* (Willis et al., 1997). Furthermore, *Filicales* (order of polypod ferns) show local peaks in the records of the

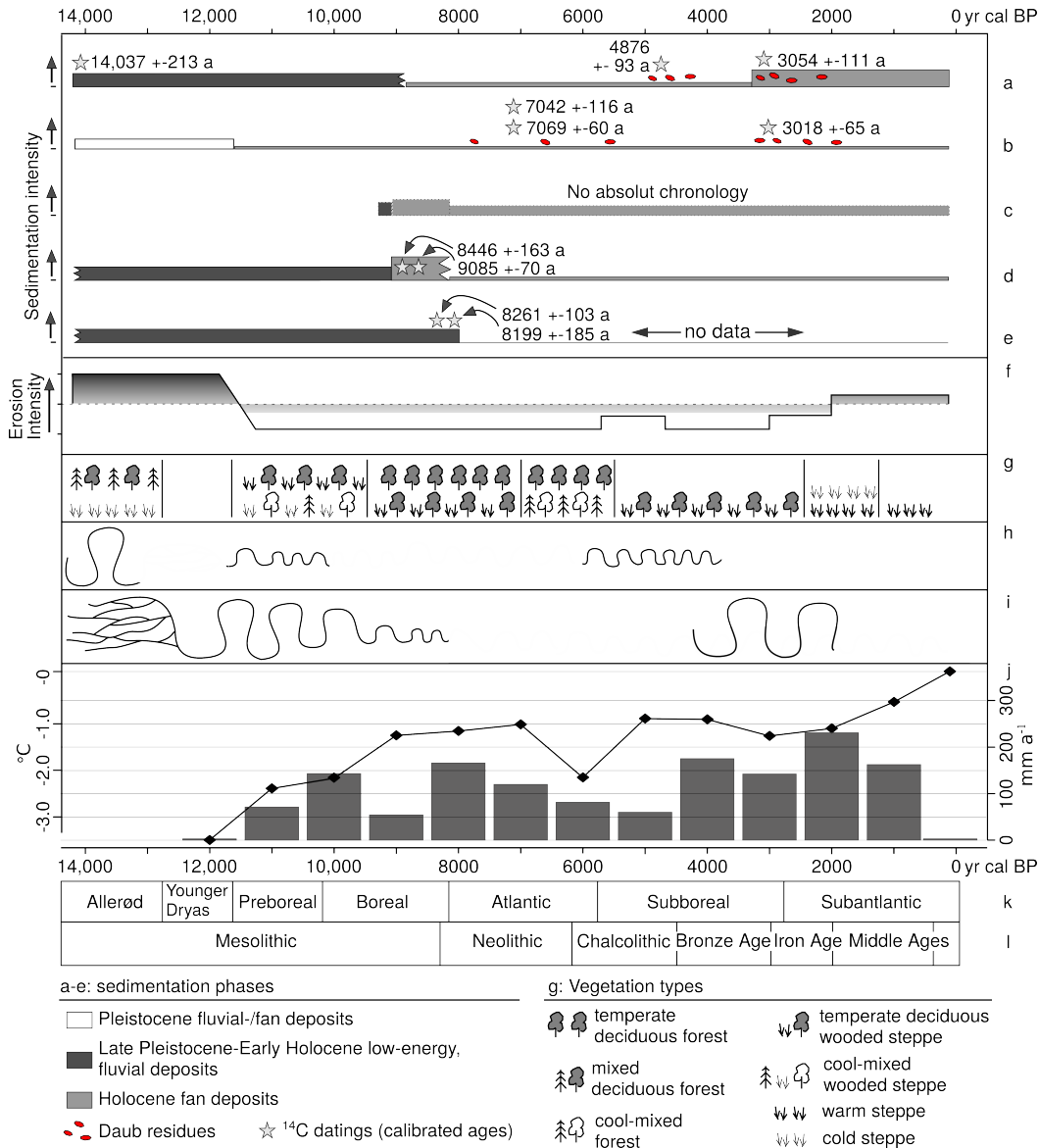


Figure 27: Synthesis of Late Pleistocene and Holocene sedimentation dynamics, vegetation and river development and climate conditions. (a – e) sediment record (this study); (f) erosion intensity at Kelémer Kismohos Tó site (Braun et al., 2005); (g) biomes in the region of the Sárlo-hát site (Gábris and Nádor, 2007; Magyari et al., 2010); (h) fluvial activity on and around the Sajo-Hérnad alluvial fan (Gábris and Nagy, 2005); (i) river style development of the Tisza River (Gábris et al., 2012; Gábris and Nádor, 2007; Kasse et al., 2010); (j) Holocene mean precipitation and temperature anomalies for the study region (Mauri et al., 2015); (k) climate periods (Gábris and Nádor, 2007); (l) archaeological periods (Willis et al., 1998).

Sirok Nyírjes Tó and the Nagymohos Tó sites. These environmental disturbances point to climate anomalies that may also be related to intensified short-term soil erosion as evidenced for the studied valley 11 (core Coll 05).

In the Coll 04 sediment sequence that was extracted from the left flank of the Hór valley, the basis of sedimentation phase IVa is presumed to be located on the same absolute height as in the opposing Coll 05 sediment sequence (Figure 26 a). A 130 cm thick sequence of seven alternating sand, loamy sand and silt loam layers containing varying amounts of coarse clasts corresponds to the lower section of phase IVa of the Coll 05 sequence. Unfortunately, no datable material was found, limiting any chronological correlation between the deposits of the Coll 04 and the Coll 05 sediment sequences.

The overlying sedimentation phase IVb corresponds to Holocene deposits consisting of clay loam and silt loam with overall strongly reduced contents of coarse clasts; only within the Coll 02 and Coll 03 sediment sequences, the phase shows coarser material and debris contents are increased. An event-related sedimentation during phase IVb can not be observed, but low-energy transport and deposition conditions are indicated (Hjulstrom, 1939; Inman, 1949). In the Coll 05 sediment sequence, the phase has a shallow thickness of c. 90 cm. In accordance to that, the corresponding valley shows a morphology of type 2, which is indicative for a young development stage (Horton, 1945). It is therefore suggested that during the last 8000 years, morphodynamics in the respective catchment were related only to short-distance material transport, while sediment output from the catchment did not occur, thereby preserving the morphological appearance of the valley. This parallels patterns in geochemical records of the Sirok Nyírjes Tó site (Gardner, 2002), and the Kelemér Kismohos Tó and Nagymohos Tó sites (Braun et al., 2005; Magyari et al., 2001; Willis et al., 1997; Figure 27 f). Also for the Bátorliget site in the upper Tisza region, decreasing inwash of allogenic material is indicated for the period between 9000 – 5000 cal BP (Sümegei, 1999) and Magyari et al. (2010) found a warm and dry phase after 8100 cal BP. Similarly, pollen-based climate reconstructions for the region show gradual warming and decreasing precipitation (Mauri et al., 2015; Figure 27 j).

However, e.g. Fuchs et al. (2011) report on Holocene short-distance sediment transport within a meso-scale river catchment (97 km²) in northern Bavaria, Germany, where the sediment budget results in 58 % of the sediments being stored at foot- and on-slope position within the catchment. This suggests that the de facto Holocene soil erosion in the present catchment may have been stronger than implied by the deposits of the Coll 05 sediment core, extracted at the valley outlet.

In the Coll 04 sediment sequence phase IVb has a thickness of c. 470 cm. The homogeneity of the deposits and the lack of coarse clasts suggest low-energy and constant material transport rather than rapid sedimentation of large amounts of material during climatic extreme events (Hjulstrom, 1939; Inman, 1949). The sediments lack any proxies for human presence suggesting low impact of human activities in the catchment. However, material indicating human presence, such as sherds and daub, may have remained within the catchment.

The Coll 03 and Coll 02 sediment sequences were taken upslope the apex of the fan where runoff intensity from the tributary valley is naturally high, and there-

fore, the material shows overall high contents of detrital material (Bull, 1972, and citations therein). This hampers the distinction between Pleistocene and Holocene sediments. However, the absolute dates that were obtained from the sediment sequences support the findings suggested by the other sediment records: between 178 and 86 cm depth three samples of organic material taken from both sequences date to 7069 ± 60 cal BP (Poz-61867), to 7042 ± 116 cal BP (Poz-61866) and to 3018 ± 65 cal BP (Poz-61865). This indicates increased Pleistocene material deposition and reduced sedimentation during the Holocene which relates to significant valley incision during the Late Pleistocene and Early Holocene and to decreased sediment output from the catchment during the Mid- and Late Holocene.

The sediments of the Coll 01 sequence point to Holocene environmental dynamics that differ from those indicated by the remaining sediment sequences: phase IVa is missing, whereas phase IVb shows a thickness of c. 400 cm. The cross-sectional profile suggests that alluvial sediments may have contributed to the deposits (Figure 25 b). At depths of 350 cm and 300 cm two samples of organic material were dated to 4876 ± 93 cal BP (Poz-59733) and 3054 ± 111 cal BP (Poz-59732). Daub was found in association with the upper date and above, between c. 170 – 100 cm depth. This clearly indicates human presence in the area matching the archaeological evidence as reported by Koós (1991) and Fischl et al. (2012). As in the case of the Coll 04 sediment sequence, the valley that is associated with the Coll 01 sequence shows a type 1 morphology, suggesting initial valley incision during the Pleistocene. Phase IVb shows similar thickness in both sequences. However, the catchment area contributing to the Coll 01 sequence covers only 94 ha in comparison to the one contributing to the Coll 04 sequence covering 138 ha. This supports the assumption that human interference led to increased soil erosion in the catchment of the Coll 01 sequence since the Late Copper Age/Early Bronze Age (around c. 5000 cal BP), when settlement activities increased in the region (Fischl et al., 2012; Sherratt, 1982).

IMPLICATIONS FOR THE LATE PLEISTOCENE AND HOLOCENE DEVELOPMENT OF THE HÓR VALLEY In the Coll 07 sediment sequence, Pleistocene coarse debris forms the basal 90 cm. The upper boundary of these deposits is located 2 m below the recent alluvial surface. Assuming similar conditions 1.5 km north, at the transect between Coll 05 and Coll 04, this would indicate c. 5 m of vertical erosion of the Hór stream (Figure 26). In the Coll 04 and the Coll 05 sequences the top of the Late Pleistocene – Early Holocene low-energy deposits (phase III) is located c. 500 cm above the actual alluvial surface. This points to significant incision of the Hór stream after channel abandonment. In the record of the Coll 06 sediment sequence, the boundary between the Pleistocene debris and the phase III deposits is located at the level of the current alluvial surface. This implicates that removal of the Pleistocene material occurred before the low-energy material deposition and Holocene incision was much less intense than at the position of the Coll 04 and Coll 05 sequences. Extended stable conditions at the position of the Coll 06 sequence are reflected by c. 2 m thick phase III sediments, whereas in the Coll 05 sequence only 1 m of phase III material was found. At the position of the Coll 02 and Coll 03 sequences, the cross-sectional profile indicates the removal of at least

100 cm of Pleistocene debris (Figure 26 c). In contrast, the cross-sectional profile at the position of the Coll 01 sequence does not indicate Holocene valley incision, since the upper boundary of phase III is found on the same level as the recent alluvial surface (Figure 26 b).

These differences may be explained by the confluences of the Hór stream and the Szoros stream located between the Coll 02/Coll 03 and the Coll 04/Coll 05 sequences and of the Hór stream and the Cseresznyés stream located slightly north of the Coll 03/Coll 02 sequences. Today, the catchments of the Szoros and the Cseresznyés streams cover c. 11 %, respectively c. 6 % of the catchment area draining into the area of interest. However, drainage configurations during the Late Pleistocene and Early Holocene is assumed to have been significantly different from today due to stream captures in the lower southern Bükk Mountains (Pinczés, 1955; Székely, 1958). In former times, the two streams may have contributed a significantly higher proportion to the discharge. Figure 26 e shows the smoothed profile of the Hór stream valley bottom within the section of interest, as derived from the DEM based on the 1:10,000 topographic map. It is evenly straight to slightly concave with a mean inclination of c. 0.7 %. At the confluence with the Cseresznyés stream and even more clearly visible at the confluence with the Szoros stream, the Hór valley shows transitions from higher to lower gradients. This points to downstream incision and lowering of the alluvial level while the upstream section of the valley did not adjust to the lowering of the erosion basis due to insufficient runoff during the Holocene. In consequence, slight knees are visible in the Hór stream profile at the positions of the joining tributaries (Horton, 1945). Aggradation of the Hór valley is also reflected in the sediments of the Coll 01 sequence upstream of the confluences.

5.2.6 Conclusions

We investigated alluvial fans that were deposited by first-order-tributaries of the Hór stream in the area of Cserépfalu and Bogács in northern Hungary. Morphology of the tributary valleys suggests different incision phases and different valley evolution processes.

- (I) On the eastern flank of the Hór valley, long valleys (700 – 2000 m) with large catchment areas (47 – 138 ha), wide width-depth-ratios (11 – 47) and gentle valley bottom inclinations ($0.03 - 0.09 \text{ m} \cdot \text{m}^{-1}$) prevail (type 1) and are related to initial incision during the Pleistocene. This could be evidenced by the sediment records of the respective alluvial fans (cores Coll 01 and Coll 02) containing 100 – 250 cm thick sandy and loamy deposits with high amounts of coarse rock fragments. These fan deposits indicate intense fluvial erosion under periglacial conditions and in the Coll 01 core overlying sediments of low-energy deposition date to the Late Pleistocene.
- (II) The western flank of the Hór valley is characterised by short valleys (131 – 486 m) with small catchment areas (2 – 30 ha), narrow width-depth-ratios (12 – 41) and steep valley bottoms ($0.06 - 0.25 \text{ m} \cdot \text{m}^{-1}$) (type 2). Here, silty Pleistocene sediments with low contents of coarse rock fragments

rather indicate soil creeping and intense Pleistocene valley incision is not very likely.

- (III) The Holocene evolution of the type 1 valleys shows a differentiated scenario: In the Coll 01 sediment sequence (valley 1), 400 cm of Holocene deposits indicate significant soil erosion during the Holocene. Daub residues found in these sediments relate sediment deposition to human activities in the catchment. This is supported by two ^{14}C ages relating the daub containing sediments to the Copper Age (around c. 5000 cal BP), when settlement density increased in the region (Sherratt, 1982) and to the Late Bronze Age/Early Iron Age Periods (around c. 3000 cal BP), when human-related landscape disturbance became more pronounced (Chapman et al., 2009; Magyari et al., 2010; Sümegi, 1999). Besides, a Neolithic settlement site is located on the hilltop above the valley and two other Neolithic, respectively Iron Age settlements are located in c. 2.5 km distance.

Valley 08 (Coll 04) shows a similar setting and although the sediment sequence could not be supported by a numerical chronology, the stratigraphy indicates c. 500 – 600 cm thick Holocene sediments. This is in accordance with two Bronze Age settlement sites located within 2.5 km distance, although, no indication for human activities was found in the fan deposits.

In contrast, at the valley 4 (Coll 02, Coll 03), Holocene deposits are only 170 – 220 cm thick, indicating reduced Holocene soil erosion, while a Neolithic and a Bronze Age settlement site are located within 2 km distance. This may be related to the shape of the catchment which has steep slopes and a mean width-depth ratio of 11 and thus was probably less intensely used for arable farming.

- (IV) The shape of type 2 tributary valleys indicate major incision during the Mid- to Late Holocene. At the valley 11 (Coll 05 sediment sequence), alternating layers of fine and coarse deposits that date to c. 9000 – 8000 cal BP point to event-related and climate-triggered valley incision. The underlying silty loam dates to the Pleistocene (around c. 33,000 cal BP) and indicates low-energy transport processes, rather than intense valley incision. The overlying sediments are only 100 cm thick and daub residues do not occur. This suggests that here, major incision occurred during the Early-/Mid Holocene, while Late Holocene soil erosion was weak and although a Bronze Age settlement site is located on the hill top within 1 km distance, human activities do not seem to have lead to valley incision.
- Based on these findings, it can be stated that the initial incision of large tributary valleys on the left side of the Hór valley dates to the Pleistocene, while Holocene valley incision was restricted to short periods of time and triggered by rare climatic extreme events during the Early-/Mid Holocene. Sediment output from tributary catchments to the Hór valley that can be related human activities, occurred only from the large catchments on the left valley side. Human-triggered soil erosion that may be reflected by short-

distance material transport within the catchments cannot be addressed by this study.

ACKNOWLEDGMENTS This study was kindly supported by the financial, technical and scientific help of the Cluster of Excellence Exc 265 "TOPOI". We cordially thank two anonymous reviewers and the guest editor of this issue for valuable comments, helping to substantially improve an earlier version of this manuscript.

5.2.7 *Supplementary material**Coring characteristics*

Table 9: General characteristics of the analysed corings.

| Coring | Latitude | Longitude | Elevation (m a.s.l.) | Sequence length (cm) | Valley number | Coring position* |
|---------|-------------|-------------|-------------------------|-------------------------|------------------|---------------------|
| Coll 04 | 47°56'10.6" | 20°32'15.0" | 205 | 750 | 1 | fan, west |
| Coll 05 | 47°54'56.4" | 20°32'6.0" | 183 | 300 | 4 | fan, west |
| Coll 07 | 47°54'55.5" | 20°32'8.0" | 183 | 700 | 4 | fan, west |
| Coll 08 | 47°51'59.9" | 20°32'11.8" | 146 | 500 | 17 | fan, east |
| Coll 09 | 47°52'13.1" | 20°32'32.6" | 143 | 300 | - | alluvial plain |
| Coll 10 | 47°53'12.6" | 20°32'58.0" | 163 | 700 | 8 | fan, east |
| Coll 11 | 47°52'58.8" | 20°31'53.5" | 159 | 900 | 11 | fan, east |

* sedimentation environment, exposition of the catchment

5.2.8 *Statistics of laboratory analyses*

Table 10: Descriptive statistics of the laboratory sediment analyses.

| Core/ Unit | Depth (cm) | TOC (mass-%) | | TIC (mass-%) | | Sample count | MS (*10 ⁻⁵ SI) | | Sample count |
|---------------|---------------|--------------|------|--------------|------|-----------------|---------------------------|-----|-----------------|
| | | mean | SD | mean | SD | | mean | SD | |
| Coll o1 | 700-0 | 0.06 | 0.11 | 0.93 | 0.44 | 46 | - | | 0 |
| 7 | 76-41 | 0.72 | NA | 1.97 | NA | 1 | | | |
| 6 | 178-76 | 0.13 | 0.06 | 1.32 | 0.5 | 6 | | | |
| 5 | 350-178 | 0.04 | 0.02 | 0.91 | 0.32 | 13 | | | |
| 4 | 412-350 | 0.02 | 0.01 | 0.59 | 0.04 | 6 | | | |
| 3 | 605-412 | 0.02 | 0.02 | 1.16 | 0.29 | 12 | | | |
| 2 | 667-605 | 0.06 | 0.05 | 0.46 | 0.06 | 4 | | | |
| 1 | 740-667 | 0.02 | 0.02 | 0.43 | 0.03 | 4 | | | |
| Coll o2 | 700-0 | 0.12 | 0.02 | 0.51 | 0.18 | 32 | 50 | 68 | 191 |
| 3 | 455-20 | 0.12 | 0.02 | 0.56 | 0.19 | 25 | 35 | 18 | 112 |
| 2 | 526-455 | 0.14 | 0.02 | 0.35 | 0.01 | 3 | 166 | 109 | 30 |
| 1 | 700-526 | 0.12 | 0.02 | 0.35 | 0.03 | 4 | 9 | 9 | 43 |
| Coll o3 | 300-0 | 0.12 | 0.04 | 0.95 | 0.4 | 10 | 48 | 16 | 75 |
| 2 | 246-20 | 0.13 | 0.05 | 1.01 | 0.37 | 9 | 53 | 14 | 56 |
| 1 | 300-246 | 0.11 | NA | 0.4 | NA | 1 | 32 | 10 | 14 |
| Coll o4 | 700-0 | 0.12 | 0.02 | 0.59 | 0.21 | 27 | 34 | 7 | 129 |
| 4 | 271-20 | 0.12 | 0.01 | 0.69 | 0.21 | 8 | 38 | 7 | 51 |
| 3 | 471-271 | 0.11 | 0.02 | 0.49 | 0.02 | 7 | 36 | 3 | 41 |
| 2 | 656-471 | 0.12 | 0.03 | 0.56 | 0.27 | 10 | 27 | 4 | 24 |
| 1 | 700-656 | 0.12 | 0.01 | 0.61 | 0.13 | 2 | 24 | 6 | 11 |
| Coll o5 | 900-0 | 0.14 | 0.06 | 0.63 | 0.35 | 24 | 62 | 58 | 173 |
| 7 | 93-20 | 0.11 | 0.02 | 0.62 | 0.13 | 4 | 42 | 4 | 18 |
| 6 | 200-120 | 0.11 | 0.03 | 0.44 | 0.06 | 8 | 39 | 8 | 22 |
| 5 | 300-240 | 0.18 | 0.09 | 0.72 | 0.53 | 7 | 58 | 11 | 15 |
| 4 | 500-350 | 0.16 | 0.06 | 0.81 | 0.37 | 5 | 170 | 57 | 30 |
| 3 | 700-525 | NA | NA | NA | NA | 0 | 33 | 6 | 42 |
| 2 | 820-715 | NA | NA | NA | NA | 0 | 61 | 28 | 26 |
| 1 | 900-820 | NA | NA | NA | NA | 0 | 9 | 1 | 20 |
| Coll o6 | 500-0 | 0.11 | 0.02 | 1.21 | 0.41 | 14 | 117 | 76 | 71 |
| 4 | 80-50 | 0.12 | 0.01 | 1.75 | 0.1 | 2 | 62 | 1 | 7 |
| 3 | 190-80 | 0.12 | 0.01 | 0.98 | 0.06 | 2 | 41 | 18 | 5 |
| 2 | 400-190 | 0.1 | 0.01 | 1.29 | 0.29 | 8 | 173 | 49 | 41 |
| 1 | 500-426 | 0.14 | 0.05 | 0.56 | 0.07 | 2 | 32 | 3 | 18 |
| Coll o7 | 300-0 | 0.33 | 0.41 | 1.29 | 0.64 | 15 | 39 | 17 | 67 |
| 4 | 135-11 | 0.13 | 0.03 | 1.58 | 0.49 | 6 | 52 | 10 | 26 |
| 3 | 200-135 | 0.12 | 0.01 | 1.77 | 0.24 | 4 | 31 | 10 | 17 |
| 2 | 280-213 | 0.73 | 0.53 | 0.54 | 0.2 | 5 | 23 | 7 | 17 |
| 1 | 300-280 | NA | NA | NA | NA | 0 | 53 | 24 | 6 |

5.2.9 Stratigraphy of coring Coll 02

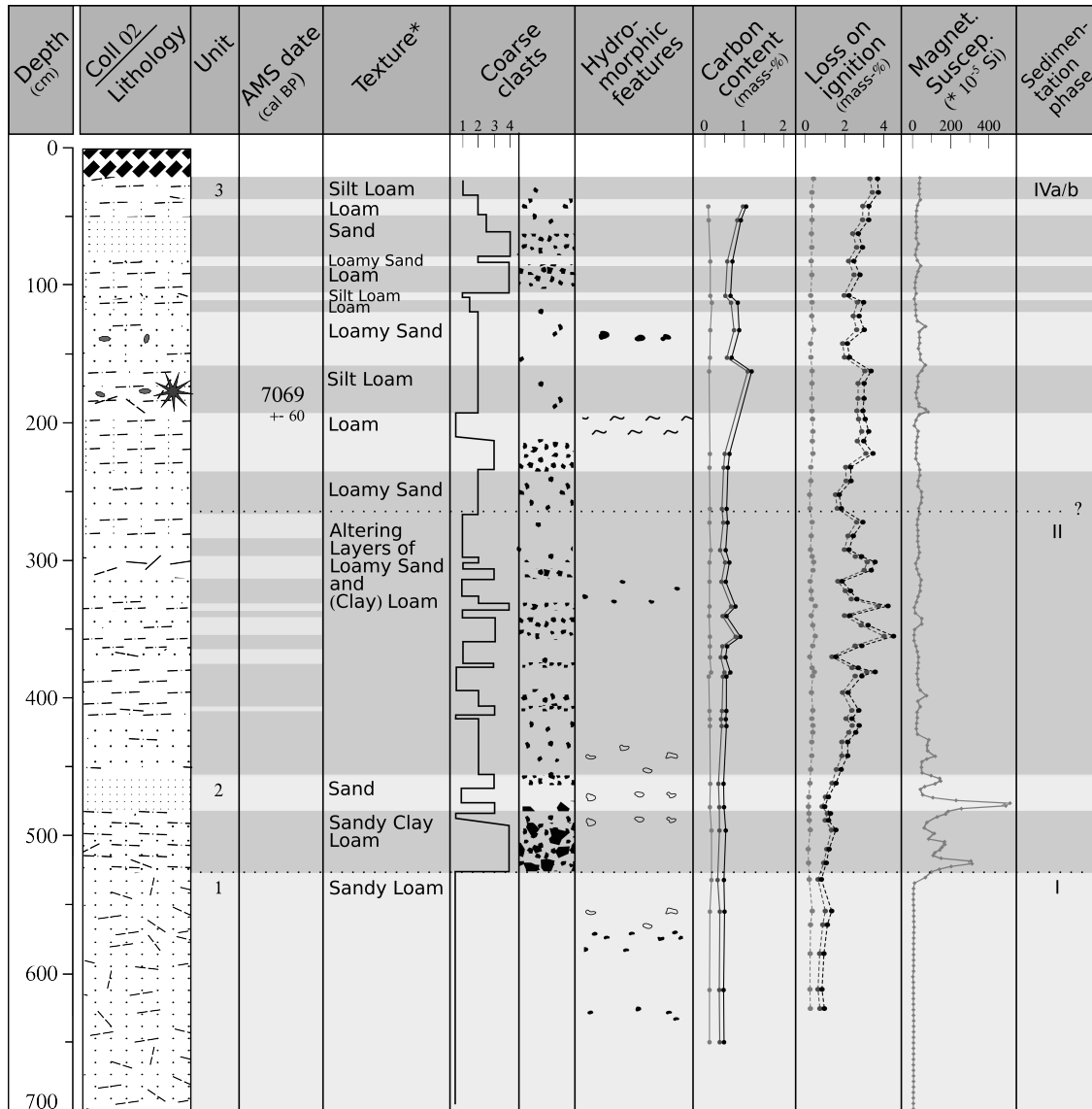


Figure 28: Stratigraphic units and geochemical and geophysical characteristics of the Coll 02 sediment sequence (please note that the legend is the same as in Figure 21).

5.2.10 Stratigraphy of coring Coll 03

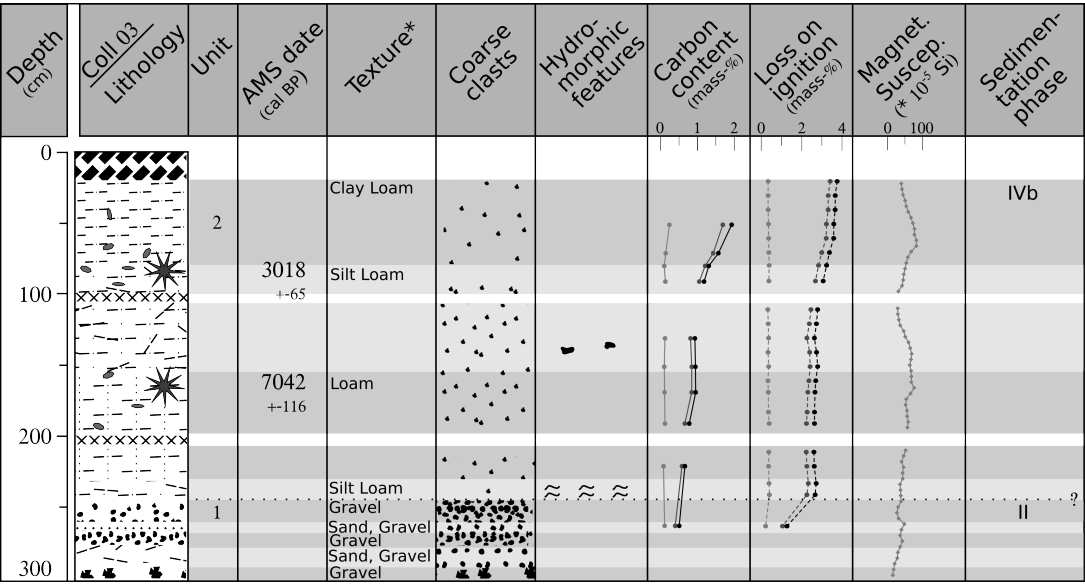


Figure 29: Stratigraphic units and geochemical and geophysical characteristics of the Coll 05 sediment sequence (please note that the legend is the same as in Figure 21).

5.2.11 Stratigraphy of coring Coll 06

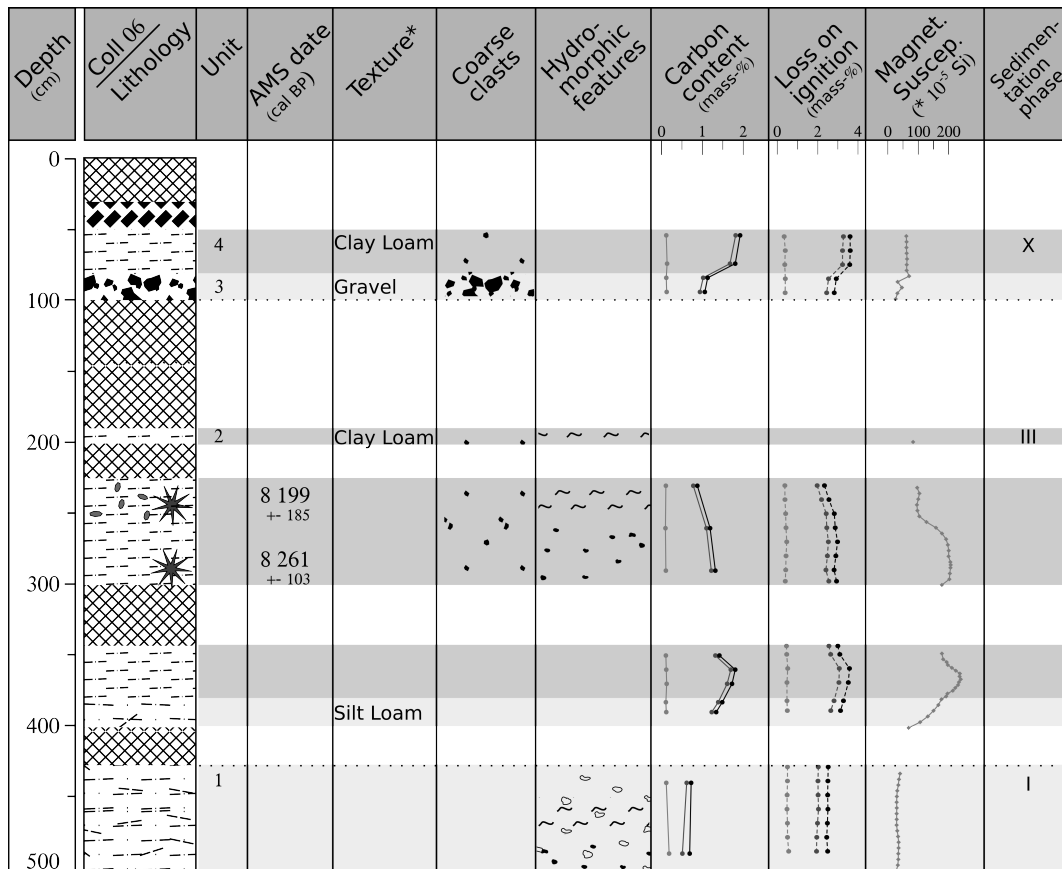


Figure 30: Stratigraphic units and geochemical and geophysical characteristics of the Coll 06 sediment sequence (please note that the legend is the same as in Figure 21).

5.2.12 Stratigraphy of coring Coll 07

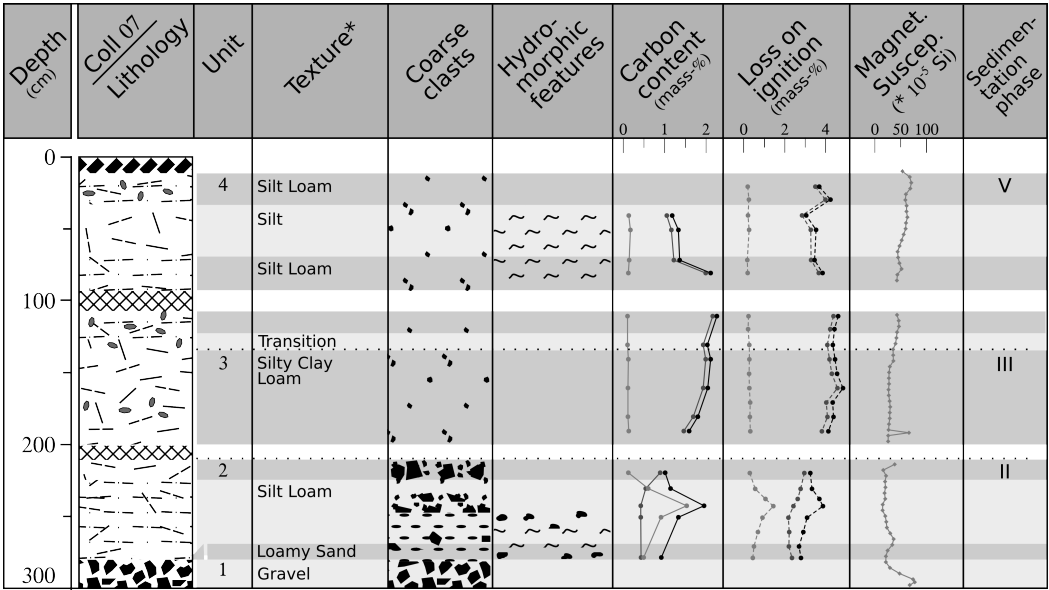


Figure 31: Stratigraphic units and geochemical and geophysical characteristics of the Coll 07 sediment sequence (please note that the legend is the same as in Figure 21.

SYNTHESIS

This thesis aims to investigate herding-related disturbances of the natural environment during the Holocene. The project is based in the Topoi Research Group A-4 “*Textile Revolution*”. In a conceptual paper, the role of geographic investigations within the context of archaeological research is analysed. These reflections pave the way to designing two independent studies on Holocene environmental change and give important implications for integrating data from the different sub-projects in the group. The two studies investigate herding-related landscape change on regional and supra-regional, as well as on local scales. The following sections present central aspects of the studies and results are integrated. First, the entrenchment of this study in the conceptual approach of the superordinate research project is resumed. Subsequently, the relevance of scale-dependencies for integrating the results are outlined. The sensitivity of landscapes, environmental archives and proxies for environmental change are addressed being crucial factors for the determination of past human-landscape interferences. Finally, it is concluded that the emerging use of secondary animal products did not went along with large-scale landscape disturbances in the study area, but landscapes seem to be resilient enough to withstand early grazing pressure.

6.1 THE INTEGRATION OF DISCIPLINES

Investigating emergence and spread of early wool economies holds strong potential for beneficial interdisciplinary research. Mutual conception of general project parameters such as chronological and spatial foci, as well as consistent nomenclatures of studied regions and cultural complexes were fostered throughout the project. Based on this, coherent studies within the different disciplines were conducted, both as independent research projects and as entangled strands of a superordinate project. Conclusively, it is the thematic framework, i.e. the advent of wool production, which is the integrating link between the different disciplines. This leads to different kinds of pitfalls compared to multidisciplinary studies that apply a number of elaborate methods to solve a complex but spatially and temporally well delineated question. In the latter case there is the risk of ranked acceptance between the disciplines and misinterpreted results of a “low-ranked” investigation may be applied to answer a “high-ranked” question (Verstraeten, 2013). The approach applied here faces marked heterogeneity concerning the quality, significance and spatial representativity of the compiled data (see chapters 2.2.1, 2.2.5). In consequence, the interdisciplinary data synthesis will rather address general trends than spatially and temporally explicit details of spreading wool economies.

Since the sub-projects constitute independent research projects rooted in different scientific fields understandings of the mutually studied objects diverge fol-

lowing discipline-specific concepts. This implies a reflection – and finally a basic agreement – on how a common language can enable the interdisciplinary discourse. The functional interrelations between the different research spheres and the single research objects therein can be illustrated by the conceptual model of Fischer-Kowalski and Erb (2006), called the socio-ecological model. The model was adopted by Knitter (2015) to make it beneficial to the conceptual discussion within the Topoi Research Area A (Figure 32). Although the model provides a comprehensive theoretical framework to integrate disciplines from the humanities, as well as from the sciences, a mutual application of the model requires a common understanding of the used terminology which appears to be a sensitive problem. The problem diminishes if the model is applied to illustrate the mere relation between the geographical approach and the superordinate project. Figure 32 shows the socio-ecological model after Fischer-Kowalski and Erb (2006) (as modified by Knitter, 2015) and the specific rendering according to the context of this thesis. Terms in white correspond to the version of Knitter (2015) and black terms represent the specific understanding which this thesis is based on. The material sphere is the main focus of the applied approach containing *de facto* investigated components. On the contrary, the immaterial sphere comprises aspects which affect the studied components more or less directly: Herding practices determine nature and intensity of related landscape disturbances and consequently influence the visibility of herding impact in the environmental record. E.g., wood pasture, pollarding and transhumance would rather imply grazing impacts in forested and marginal regions such as hilly and mountainous uplands and accordingly, herding-related environmental proxies would occur in lake sediments and peat bogs of the respective areas (Magyari et al., 2012; Schumacher et al., 2016b). Pasture feeding around the settlement and forage crop use, however, affects the immediate surrounding of permanent settlements (Dai et al., *in press*). In contrast, the development of elaborate breeding techniques has inferior consequences for sheep-landscape interrelations.

Employing the socio-ecological model within the Topoi Research Group A-4 facilitates the reflection about interrelations between the different research objects. The model points out the relevance of scale-dependencies if it is applied to specific questions, although it does not directly illustrate relations between different spatial and temporal scales.

6.2 THE INTEGRATION OF SCALES

The way in which aspects of the immaterial sphere affect the investigated objects inherent to the material sphere indicates the importance of a multi-scale investigation, both, in spatial and temporal terms. This challenge was approached by conducting a meta-analysis of published data on the supra-regional scale and a sediment-based case study on the local scale. The socio-ecological model applied here is not capable of illustrating these infinitely variable dimensions but refers to interrelations under stationary and time-bound conditions. In a similar way, investigating the effects of past herding activities on the supra-regional scale went along with data generalization ignoring site-specific details, whereas

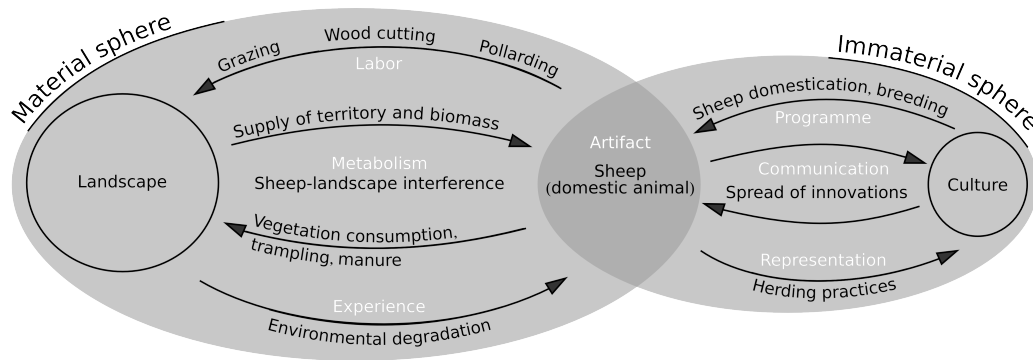


Figure 32: Socio-ecological model displaying the functional interrelations between research spheres and objects involved in this thesis (Fischer-Kowalski and Erb, 2006; Knitter, 2015, after).

the sediment-based case study may inherently refer only to the local scale. Nevertheless, the results of both studies may be set in relation due to the diachronic approaches and the spatial vicinity of the study regions. Climate-controlled valley incision in northern Hungary dates to c. 8200 cal BP (Schumacher et al., [accepted](#), see chapter 5), while low human impact in the area during the Late Neolithic (Magyari et al., 2012; Schumacher et al., 2016a, see chapter 4.2.4) is not reflected in the sedimentary records. Around 4800 cal BP valley incision appears to be related to human impact (Schumacher et al., [accepted](#), see chapter 5.2.5). In accordance, the meta-analysis of published pollen data indicates increased herding activities in northern Hungary between 5000 – 4500 cal BP. The timing of human-related valley incision corresponds also to the east-directed propagation of herding-related vegetation disturbance as indicated by the literature-based meta-analysis (Schumacher et al., 2016a, see chapter 4.2.4): Figure 33 shows the Holocene climate development after Mauri et al. (2015) (a), the development of the studied fans (c) and the single results of the meta-analysis for the included sites from northern Hungary (c). Here, the intensity of sediment accumulation shows temporal relation to pollen-based herding indication rather than to climate development. Short-term climate deterioration around 8200 cal BP causing enhanced valley incision, is not reflected by the climate hindcast due to the low temporal resolution of the model by Mauri et al. (2015). Nevertheless, long-term precipitation decrease between 8500 – 4500 cal BP and pronounced cooling between 5500 – 4500 cal BP possibly play a role in increased sedimentation around 4800 cal BP, as well.

The approach applied to integrate results referring to different spatial scales may not go beyond adducing temporal relations between the different deduced processes. This is a common limitation in reconstructing past human-environment interactions (see chapter 1.3). Nevertheless, the results of the sediment-based case study fit well to the general idea of propagating herding activities as resulted from the large-scale analysis. A stronger relation between herding activities and climate effects, respectively, and increased valley incision requires detailed archaeological and archaeozoological investigations in close vicinity to the studied sediment archives.

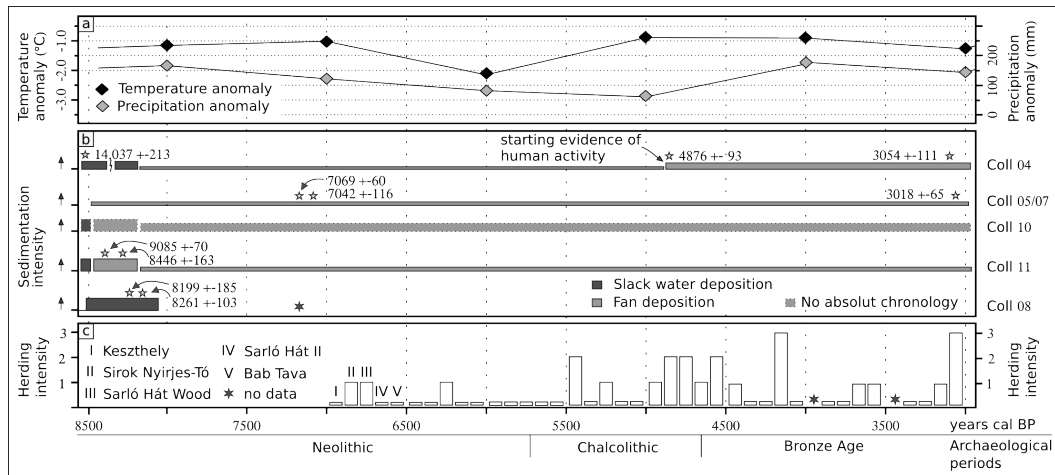


Figure 33: a: Holocene climate anomalies for northern Hungary after Mauri et al. (2015); b, c: Results of the case studies

6.3 SENSITIVITY OF LANDSCAPES, ARCHIVES AND PROXIES

Besides scale-effects complicating the evidence of past herding impact on the landscape, it is the sensitivity of the investigated landscape, environmental archive and proxy that crucially affects the representativity of the results. Landscape sensitivity can be expressed as the relation between the magnitude of processual change in the landscape and the magnitude of response to that change which can be understood as change of the landscape itself (Brunsden and Thornes, 1979; Usher, 2001):

$$S(\text{sensitivity}) = (\text{magnitude of process change}) / (\text{magnitude of landscape response})$$

In this case, landscape can be understood as a system that is subject to certain variability within a stable state A. If a certain threshold of process magnitude is exceeded, the system adopts another stable state B (Usher, 2001). In the case of increasing grazing pressure successional states may be represented by: state A = undisturbed landscape; state B = changing vegetation cover, beginning soil compaction (i.e., with increasing grazing intensity: increase of species richness, increasing presence of primary forest vegetation, occurrence of ruderal vegetation on compacted soils, reduction of net primary production); state C = loss of vegetation cover, decrease of species richness, soil degradation; state D = development of heath land on severely degraded soils (Bennett et al., 1992; Milchunas and Lauenroth, 1993; Schumacher et al., 2016b; Thöle et al., 2016, see chapter 2.2.2). Landscape descriptors such as geologic conditions, soils, relief or climate determine the sensitivity of a landscape (Usher, 2001). Rich soils and foot slope positions e.g., enhance vegetation resilience and it is more likely, that the landscape returns from state B to state A if grazing pressure is reduced again (Feaser et al., in press; Risch et al., 2001). In contrast, vegetation on *a priori* nutrient poor soils growing under unfavourable climate conditions – e.g. open forests on Shetland, consisting of *Betula*, *Corylus avellana*, *Juniperus communis*, mixed with tall-herb

communities – reacts more sensitive to grazing impacts and it is more likely that the landscape reaches a state from which a return to a less degraded state is impossible (Bennett et al., 1992).

Here, it must be stated, that landscape sensitivity is strongly related to the spatial and temporal scale under consideration (Thomas, 2001). Similarly, this holds true in respect to the sensitivity of environmental archives and proxies reflecting past environmental change. Colluvia and lake sediments receiving material input from small catchment areas with direct hillslope coupling react more sensitive to local disturbances than alluvial plains from large river basins which reflect environmental changes on large spatial and temporal scales (Dreibrodt et al., 2010; Hinderer, 2012). Pollen records reflect vegetation conditions and thus, are more sensitive to herding pressure than geophysical and geochemical data from terrestrial (or aquatic) sediment archives which may be used to trace soil erosion (Milchunas and Lauenroth, 1993).

Varying landscape sensitivity was a significant problem for designing the standardized meta-analysis to trace past herding activities (Schumacher et al., 2016a, see chapter 4.2.3). It was approached by classifying pollen data of indicator species in relation to the data range of the respective record. Arboreal pollen data were z-transformed on the basis of the considered time period. Different sensitivities of archives and proxies became obvious with integrating results from the meta-analysis of north Hungarian pollen data and sedimentological evidences as derived from the case study. While low human activities are reflected in the pollen data already for the Neolithic, increased sedimentation related to human activities dates only to the Late Chalcolithic, when also vegetation disturbance appears to be stronger (Figure 33).

6.4 THE ROLE OF PASTORALISM IN THE LIGHT OF HOLOCENE LANDSCAPE DEVELOPMENT

The theory of the *Secondary Products Revolution* points out the great relevance of increasing animal husbandry in the course of beginning wool production, milk use and employment of draught animals during the mid-Holocene (Bökönyi, 1974; Sherratt, 1981). Greenfield (2010) reviews the further research effort undertaken to specify spatial and temporal spread of the different innovations. He concludes that intensified wool production started in West Asia and Europe during the Chalcolithic period, likewise. Specialized wool economies, however, developed in Central and Northern Europe not before the Roman Age.

The results of the studies included in this thesis support this general development. Low Neolithic herding impact is indicated throughout the study area, whereas intensified herding indication dating to the Chalcolithic appears earlier in southern Romania than in northern Hungary. The occurrence of herding indicators at agriculturally marginal sites is in accordance to the evidence of early transhumant pastoralism in the central Balkans (Arnold and Greenfield, 2006). This is corroborated by recent studies revealing Neolithic through Bronze Age herding activities in the Mountain Alps (Kothieringer et al., 2015; Thöle et al., 2016), whereby related soil erosion did not increase significantly before the Late

Iron Age (c. 2500 cal BP) (Bajard et al., 2016; Giguët-Covex et al., 2011; Giguët-Covex et al., 2014). At Lake Belau in the lowlands of northern Germany, landscape opening, intensified soil degradation and minerogenic material input is related to woodland grazing and dates to the Late Bronze Age and pre-Roman Iron Age periods (2650 – 1950 cal BP) (Dreibrodt and Wiethold, 2015). However, sediment accumulation related to human activity in the Bükkalja foothill area is evident around 4800 cal BP. This is synchronous with increased herding indication at nearby sites (Magyari et al., 2010; Magyari et al., 2012) and subsistent shifts in the larger region (Giblin et al., 2013; Hoekman-Sites and Giblin, 2012). In Germany, colluvial sediment deposition as reviewed by (Dreibrodt et al., 2010), peaks locally between 4500 – 4300 cal BP. However, given the scarcity of data-based causal links between past herding activities and land degradation processes, drivers such as climate variability and arable farming need to be considered likewise.

Finally, it must be pointed out that early herding activities can not clearly be linked to widespread land degradation in the studied region. It is rather indicated that overall, landscapes of the temperate zone have been resilient enough to sustain early herding pressure. Nevertheless, early herding activities can be traced in environmental records. By this, a contribution was made to the clarification of spatial and temporal dynamics of early wool economies.

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APPENDIX

A.1 CURRICULUM VITAE

To protect the privacy of the author, the curriculum vitae is not included in the online version of this dissertation.

Aus Gründen des Datenschutzes ist der Lebenslauf in der Online-Version der Dissertation nicht enthalten.

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EIDESSTATTLICHE ERKLÄRUNG

Hiermit erkläre ich, dass ich die Dissertation "*Mid-Holocene Landscape Development in the Carpathian Region - Pastoralism, Climate and their Interdependencies*" selbständig angefertigt und keine weiteren als die angegebenen Quellen und Hilfsmittel verwendet habe.

Ich erkläre, dass ich diese Dissertation in keinem anderen Promotionsverfahren, sondern erstmalig am Fachbereich Geowissenschaften der Freien Universität Berlin vorgelegt habe. Der Inhalt der dem Verfahren zugrunde liegenden Promotionsordnung ist mir bekannt.

Berlin, January 20, 2017

Paul Martin Park (geb.
Schumacher)