Multi-proxy analysis of colluvial deposits: Archaeopedological reconstruction of land use practices in southwestern Germany

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Abbreviations

ABR site:	Middle Bronze Age settlement site 'Anselfingen Breite' (Hegau, southwestern Germany)
^{14}C dating:	AMS radiocarbon dating
B5CA/B6CA ratio:	Pentacarboxylic acid to mellitic acid ratio
BC:	Black carbon
BCE:	Before current epoch
BPCA:	Benzene polycarboxylic acid
CAS:	Complex Adaptive Systems
$CaCO_3$:	Calcium carbonate
CE:	Current epoch
CIA:	Chemical index of alteration
C_{mic}:	Microbial biomass carbon
C/N ratio:	(Soil organic) carbon to nitrogen ratio
CRC:	Collaborative Research Centre
EBA:	Early Bronze Age
Fe_d:	Iron released by dithionite-citrate extraction
Fe_o:	Iron released by the ammonium-oxalate extraction
Fe_t:	Total iron
FUE site:	Prehistoric site at the Fürstenberg mountain (Baar, southwestern Germany)
LBA:	Late Bronze Age
LUA site:	Middle Bronze Age settlement site 'Leutkirch Untere Auen' (Westallgäu, southwestern Germany)
MBA:	Middle Bronze Age
NAP:	Non-arboreal pollen
OSL dating:	Optically stimulated luminescence dating
PAH:	Polycyclic aromatic hydrocarbon

POR:	Pedogenic oxide ratio
Py-FIMS:	Pyrolysis-field ionization mass spectroscopy
RA:	ResourceAssemblage
RC:	ResourceComplex
SPD:	Summed probability density
SOC:	Soil organic carbon
Urease/C_{mic} ratio:	Urease to microbial biomass carbon ratio
WUT site:	Middle Bronze Age settlement site 'Winterstetten Urlauer Tann' (Westallgäu, southwestern Germany)
XRD:	X-ray diffraction
XRF:	X-ray fluorescence

Abstract

This thesis aims at achieving a better understanding of past human-land interaction by following an interdisciplinary approach, which includes the (sub-)disciplines of soil sciences, archaeology, archaeobotany and archaeozoology. The decipherment of past human-land interaction entails the identification of resources that were significant for the cultural development of prehistoric societies in southwestern Germany.

The theoretical superstructure of this thesis is based on the Favor-Disfavor dichotomy, which classifies landscapes as 'favourable' and 'unfavourable' based on its suitability for agricultural purposes. The application of the concept of ResourceCultures and the framework of Complex Adaptive Systems attempts to refine this one-dimensional interpretation of past human-land interaction.

For this study, multi-proxy analyses of multi-layered colluvial deposits in the area surrounding prehistoric settlements at the Baar, in the Hegau (both favourable) and in the Westallgäu (unfavourable) are performed. These multi-proxy analyses are utilized to reconstruct the colluvial deposition history based on ages from optically stimulated luminescence dating (OSL) and radiocarbon (AMS ^{14}C) dating. The resulting colluvial chronostratigraphy is then synchronized with the local archaeological record. Pedogenic properties, such as the soil organic carbon (SOC) and calcium carbonate ($CaCO_3$) content, as well as pH values, grain size distributions, X-ray fluorescence (XRF) and pedogenic iron oxides are analysed to support the (chrono)stratigraphy of colluvial deposits. In this context, the identification of former land surfaces, based on varying intensities of soil formation and weathering processes, is of major interest. The investigation of soil microstructure is applied to identify human permeation of colluvial deposits (e.g., accumulation of charcoal, identification of plough marks). Land use proxies such as the analysis of phytoliths, charcoal spectra, black carbon (BC), polycyclic aromatic hydrocarbons (PAHs), urease enzyme and microbial activities, faecal biomarker (e.g., sterols, stanols and stanones) and heavy metals from colluvial samples are used to gain insights into prehistoric land use practices. The local archaeological record, as well as offsite pollen data, complement the dataset.

At the prehistoric site of Fürstenberg, the analysis of colluvial deposits provide information on land use practices, such as wood procurement and livestock husbandry, between the Late Bronze Age and the Early Iron Age. At the Middle Bronze Age (MBA) settlement site of Anselfingen, the sedimentation history confirms the beginning of soil erosion during the MBA. From the MBA colluvial horizons, land use practices, such as arable farming (e.g., ploughing, manuring and cultivation of cereals), forest management (wood procurement and forest pasture) and livestock husbandry, can be reconstructed. The land use practices are complemented by the investigation of onsite charred archaeobotanical remains and animal bones from archae-

ological structures. Archaeological structures further contribute to a detailed understanding of MBA land use practices in the Hegau. Offsite pollen data, from nearby peat bogs, allows for a regional interpretation and suggests that the identified onsite and near-site vegetation change and land use practices were characteristic for the north-western Alpine foreland. At the two sites in the Westallgäu, land use areas are attributed to nearby MBA settlement sites. Based on the depositional history, the beginning of soil erosion is dated to the MBA, with up to 90 cm of eroded soil column within few hundreds of years. Land use practices, such as livestock husbandry and heavy metal processing, appear to be likely at the Westallgäu sites.

The acquired data support the interpretation of colluvial deposits as archives for the reconstruction of past land use practices in the areas surrounding prehistoric settlement sites. The data also show that, especially during the Middle Bronze Age in the Hegau, an elaborated land management was established to maintain the landscape and the subsistence economy. The results derived from the colluvial deposits and the local archaeological records of the two sites in the Westallgäu suggest that settlement communities must have already existed in the MBA, even if these sites are considered less favourable than sites in the Hegau and at the Baar in terms of agricultural practices.

In summary, the multi-proxy analysis of colluvial deposits contributes to better understanding of prehistoric land use practices in the areas surrounding prehistoric settlements. Land use proxies from specific colluvial horizons, that can be correlated to the local archaeological record and offsite pollen data, provide in-depth insights into past human-land interactions in southwestern Germany. The ResourceCultures concept and Complex Adaptive System framework provide a more detailed understanding of prehistoric farmers and their efforts to maintain subsistence economy.

Zusammenfassung

Ziel der vorliegenden Arbeit ist es, Mensch-Umwelt Interaktionen im Umfeld prähistorischer Siedlungen zu rekonstruieren. Hierzu wird ein interdisziplinärer Forschungsansatz genutzt, der (Teil-)Disziplinen der Bodenkunde, Archäologie, Archäobotanik und Archäozoologie vereint.
Den theoretischen Überbau dieser Arbeit bildet die Gunst-Ungunst-Dichotomie, die Landschaften aufgrund ihrer Eignung für landwirtschaftliche Zwecke als ‚günstig' oder ‚ungünstig' bewertet. Dieser eindimensionalen Interpretation von Landschaft und ihrer inhärenten Mensch-Umwelt Interaktionen wird mit den Konzepten der RessourcenKulturen und der Komplex Adaptiven Systemen (*engl.* Complex Adaptive Systems) begegnet, um das Verhalten prähistorischer Gesellschaften umfassend zu untersuchen. Die Identifikation von materiellen und immateriellen Ressourcen, die für die Entwicklung prähistorischer Gesellschaften in Südwestdeutschland von Bedeutung waren, steht im Fokus der Arbeit.
Als zentraler Aspekt der vorliegenden Arbeit werden mehrschichtige Kolluvien mithilfe von multi-proxy Analysen entschlüsselt. Die untersuchten Kolluvien befinden sich im Umfeld prähistorischer Siedlungen auf der Baar, im Hegau (beide als günstige Landschaften angenommen) und im Westallgäu (als ungünstig angenommen). Der multi-proxy Ansatz umfasst die Rekonstruktion der Sedimentationshistorie auf Basis von Radiokohlenstoffdatierungen an Holzkohlen (^{14}C) und der Datierung von Sedimenten durch die Messung der Optisch Stimulierten Lumineszenz (OSL). Die abgeleitete Chronostratigraphie kolluvialer Ablagerungen kann mit der lokalen Chronologie archäologischer Aufzeichnungen korreliert werden. Die Chronostratigraphie, die verschiedene kolluviale Horizonte und alte Oberflächen umfasst, wird durch die Untersuchung von pedogenen Eigenschaften, wie dem Gehalt an organischem Kohlenstoff (SOC), an Kalziumkarbonat, dem pH-Wert, der Korngrößenverteilung, pedogenen Eisenoxiden und Verwitterungsindizes unterstützt. Bodenmikromorphologische Untersuchungen werden genutzt, um menschliche Einflüsse auf den Boden nachzuweisen (z.B. Anreicherung von Holzkohlen, Überprüfung von Pflugspuren). Landnutzungs-Proxies, wie Phytolithen, Holzkohlespektren, Verbrennungsrückstände von schwarzem Kohlenstoff (*engl. black carbon*, BC), Polyzyklische Aromatische Kohlenwasserstoffe (PAK), die Aktivität von Urease und mikrobielle Aktivität, fäkale Biomarke und Schwermetalle wurden verwendet um Aussagen zu Landnutzungspraktiken im Umfeld prähistorischer Siedlungen zu treffen. Die lokalen archäologischen Aufzeichnungen sowie Daten von offsite Pollenprofilen ergänzen den Datensatz.
Auf der Grundlage des interdisziplinären Ansatzes und des vielfältigen Methodenspektrums konnten die Phasen der Sedimentation mit menschlichen Besiedlungsphasen synchronisiert werden. An der prähistorischen Fundstelle am Fürstenberg (Baar) wurde ein mehrschichtiges Kolluvienprofil am Südwest gelegenen Hang untersucht und gibt Aufschluss darüber, dass vorwiegend Landnutzungspraktiken wie Holzbeschaffung und Viehhaltung während der Spätbronzezeit und

der frühen Eisenzeit vorlagen. An der mittelbronzezeitlichen Fundstelle bei Anselfingen (Hegau) kann aufgrund der Sedimentationshistorie eine erstmals einsetzende Bodenerosion während der Mittleren Bronzezeit beobachtet werden. Aus den entsprechenden kolluvialen Horizonten lassen sich Landnutzungspraktiken, wie Ackerbau (z.B. Pflügen, Düngen und Getreideanbau), Forstwirtschaft (z.B. Hutwald, Mittelwald) und Viehhaltung, rekonstruieren. Die Analyse von verbrannten Getreideresten und Tierknochen aus archäologischen Befunden aus der Siedlung ergänzt und bestätigt die aus den Kolluvien rekonstruierten Landnutzungspraktiken. Auf Basis von zwei Pollenprofilen werden die für die mittelbronzezeitliche Siedlung in Anselfingen lokalen Landnutzungspraktiken in einen regionalen Kontext gesetzt. Im Umfeld der beiden Siedlungsfundstellen im Westallgäu können die Standorte der untersuchten kolluvialen und alluvialen Bodenprofile als der Siedlungen angehörigen Landnutzungsareale interpretiert werden. Die Chronostratigraphie zeigt auch hier eine beginnende Bodenerosion in der Bronzezeit, wobei an einem Profil anhand von OSL-Altern die Sedimentation von bis zu 90 cm Bodenmaterial beobachtet werden konnte. Landnutzungspraktiken, wie z.B. Metallverarbeitung und Viehhaltung, werden durch die entsprechenden Proxies angezeigt.
Auf Basis der erhobenen Daten kann gezeigt werden, dass Kolluvien als Archive zur Rekonstruktion prähistorischer Landnutzungspraktiken geeignet sind. In der Umgebung dokumentierter Siedlungsplätze, können Kolluvien als Landnutzungsflächen interpretiert werden. Für die Mittelbronzezeit im Hegau konnte ein ausgefeiltes und umfassendes Landmanagement nachgewiesen werden. Im Westallgäu deuten die archäologischen und archäopedologischen Ergebnisse darauf hin, dass trotz der scheinbar ‚ungünstigen' Landschaft schon während der Bronzezeit diese Region besiedelt gewesen sein muss.
Zusammenfassend wird in dieser Arbeit das analytische Potential von Kolluvien erweitert, um Landnutzungspraktiken im Umfeld prähistorischer Siedlungen zu abzuleiten. Landnutzungs-Proxies, die in kolluvialen Horizonten konserviert sind, können mit archäologischen Aufzeichnungen und offsite Daten aus Pollenprofilen korreliert werden, um ein möglichst detailreiches Bild zu prähistorischen Mensch-Umwelt Interaktionen zu erhalten. Die Konzepte RESSOURCEN-KULTUREN und Komplex Adaptive Systeme zeigen sich als hilfreiches Rahmenwerk um archäopedologische und archäologische Forschungsfragen umfassend zu bearbeiten.

List of included publications

Manuscript I: Scherer, S., Deckers, D., Dietel, J., Fuchs, M., Henkner, J., Höpfer, B., Junge, A., Kandeler, E., Lehndorff, E., Leinweber, P., Lomax, J., Miera, J.J., Poll, C., Toffolo, M.B., Knopf, T., Scholten, T., Kühn, P.: *What's in a colluvial deposit? Perspectives from archaeopedology,* Catena, https://doi.org/10.1016/j.catena.2020.105040, 2021.

Manuscript II: Scherer, S., Höpfer, B., Deckers, K., Fischer, E., Fuchs, M., Kandeler, E., Lechterbeck, J., Lehndorff, E., Lomax, J., Marhan, S., Marinova, E., Meister, J., Poll, C., Rahimova, H., Rösch, M., Wroth, K., Zastrow, K., Knopf, T., Scholten, T, and Kühn, P: *Middle Bronze Age land use practices in the north-western Alpine foreland – A multi-proxy study of colluvial deposits, archaeological features and peat bogs*, SOIL, 2021.

Manuscript III: Höpfer, B., Deckers, K., **Scherer, S.**, Scholten, T., Kühn, P., Knopf, T.: *Mittelbronzezeitliche Siedlungsfunde aus Engen-Anselfingen (Lkr. Konstanz, Baden-Württemberg): erste Einblicke in Struktur und Organisation der Siedlung,*, in: K.-H. Willroth (Hrsg.), Elemente bronzezeitlicher Siedlungslandschaften, Studien zur Nordeuropäischen Bronzezeit 5, 2021.

Manuscript IV: James, B.R., Teuber, S., Miera, J.J., Downey, S., Henkner, J., Knopf, T., Correa, F., Höpfer, B., **Scherer, S.**, Michaelis, A., Wessel, B., Gibbons, K., Kühn, P., Scholten, T.: *Soils, Landscapes, and Cultural Concepts of Favour and Disfavour within Complex Adaptive Systems and ResourceCultures. Human-Land Interactions during the Holocene,* Ecology & Society, 2021.

Further publications

Höpfer, B., Werner, S., **Scherer, S.**, Schmid, D., Scholten, T., Kühn, P., Knopf, T.: *Talsiedlung - Höhensiedlung - Bestattungsplatz? Weitere Forschungen zur bronzezeitlichen Besiedlung des Westallgäus bei Leutkirch,* Archäologische Ausgrabungen in Baden-Württemberg 2019, 24-27, 2020.

Höpfer, B., **Scherer, S.**, Schmid, D., Hermann, J., Scholten, T., Kühn, P., Knopf, T: *Archäologische und bodenkundliche Untersuchungen zur bronzezeitlichen Besiedlung des westlichen Allgäus bei Leutkirch,* Archäologische Ausgrabungen in Baden-Württemberg 2018, 31-35, 2019.

Manuscript in prep.: Scherer, S., Höpfer, B., Fuchs, M., Kandeler, E., Lehndorff, E., Lomax, J., Marhan, S., Poll, C., Rahimova, H., Knopf, T., Scholten, T., Kühn, P.: *Bronze Age land use derived from colluvial deposits and archaeological records at two sites in the Westallgäu*, in preparation.

1 Introduction

1.1 The role of soils in prehistory

Survival strategies and cultural development have always depended, and still depends, on soil as a key resource for the direct and indirect food supply of all species (Blum et al., 2006). Nevertheless, modern societies around the globe have reached new forms of soil degradation through soil erosion, loss of soil cover and fertility, salinification, acidification, soil compaction and sealing and exploitation of natural areas (Montgomery, 2007; Gomiero, 2016). In consequence, some societies are at risk of losing soil as a resource for their subsistence strategies and cultural development (Abrahams, 2002). The study of soils and societies in the past can offer possibilities to perceive the importance of soils as a key resource of daily life (Dearing et al., 2006).

Human occupation has altered terrestrial ecosystems and vegetation patterns since the Late Pleistocene and Early Holocene (Ellis, 2011). In Central Europe, the transition from a society of hunter and gatherers to a society of sedentary subsistence farmers was marked by the arrival of people from the Linear Pottery Culture (5500-5000 BCE) (Lüning, 1988) and implied a tighter dependency between humans and soil (McNeill et al., 2010; Boivin, 2004). Thus, a greater necessity was required to dealing with soil as a fundamental aspect of daily life, including the application of agricultural practices and the establishment of settlement infrastructures, traditions and religious rituals. According to Edgeworth et al. (2015), this change in human survival strategies could mark the beginning of the Anthropocene, a new geological epoch with global-scale human-induced impacts on terrestrial ecosystems.

In a study by Bogaard (2004), the nature of early farming in Central and Southeast Europe was examined, and showed that there were already different agricultural systems during the Neolithic. According to McNeill et al. (2010), the success of prehistoric agriculture rested on the challenge of resolving long-term nutrient loss, which is an integral part of an open soil cycle. The nutrients that were removed from the soil by the harvest must be returned to it. Indeed, prehistoric manure practices with animal and/or human faeces have been assumed by several authors (e.g., Bogaard, 2004; Bakels, 2018; Styring et al., 2017). In addition, the emergence and distribution of ards and traction-ploughs during the Neolithic and Bronze Age may have improved soil tillage and productivity (Bishop, 1936; Tegtmeier, 1987). Generally, the higher abundance of Neolithic settlement remains in Europe in loess covered areas has been interpreted as an intentional human decision making process with soil fertility as a significant component (Gradmann, 1948; Ryzner and Owczarek, 2020). Contrasting evidence of Neolithic settlement remains and land use activity in less fertile soil landscapes could therefore show evidence of continuous improvement of agricultural tillage practices, which enabled settlers to colonize these

areas (Miera et al., 2019). The driving factors responsible for these developments – distribution of knowledge, social pressure, climatic changes, and physio-geographical site characteristics – can only be assumed; nonetheless, soils must have been perceived in the prehistory as a fundament for food supply with soil as a key component in ensuring the subsistence economy.
Soils in prehistory were also part of traditional and religious practices. One example is the use of soil for manufacturing traditional artefacts, such as ceramic vessels and sculptures, or for earth work in the context of burials (Salisbury, 2012). The diachronic differences in pottery manufacture, which are used for the modern classification of archaeological periods, indicate that soils were part of the cultural identity. Another example is the use of soils for building burial mounds, which were an integral part of religious practices. Burial mounds, which were also a significant feature of the 'Tumulus Culture' (Middle Bronze Age, 1600-1250 BCE) in the northwestern Alpine foreland or the 'Hopewell Culture' (300 BCE – 500 CE) in central and southern Ohio, testify impressively to the use of soils in prehistoric rituality. This is not only because of their still distinctive appearance in modern landscapes, but also because of their elaborated internal structures, created by layering different sediments of different grain sizes with other organic and inorganic raw materials (Milner, 2005; Torbrügge, 1959).
The dependence of prehistoric survival strategies and subsistence economies on soil is obvious, as many land use practices are directly related to soils. However, it is difficult to investigate whether prehistoric use of soil was intentional or unintentional and whether soils were perceived as an integral entity of a holistic system of the natural and cultural landscape. An approximation to the prehistory rationality can be reached with help from the hybrid discipline of ethnopedology, which evolved through the collaboration of natural and social sciences and investigates the relations between humans and soils (e.g., Barrera-Bassols and Zinck, 2003; Pauli et al., 2016). Based on ethnopedolgical research, an elaborated but locally limited soil knowledge has been observed at different parts of the world, which is similar to that of modern soil sciences (Pauli et al., 2016). In many cases, soils are used practically and ritually, with emphasis on the conservation of soils as a resource. However, taking indigenous communities as an example, they are often limited to marginal landscapes with scarce resources, while the richer soils are devoted to large-scale, mechanized agriculture that produces goods for our industrialized societies and promotes soil degradation (Barrera-Bassols and Zinck, 2003). In order to reduce the risk of modern soil degradation on a global scale, looking to the perception of soils by small-scale famers, as outlined by Pauli et al. (2016) and Wahlhütter et al. (2016), may allow a break with common unsustainable thought patterns. Rather than seeing soil as an external medium in the cycles of capitalism and profiteering, the perception of soil should be more holistic with soils "as a key part of their [famers] identity" (p.8, Pauli et al., 2016).

1.2 Concepts for the interpretation of past human-land interactions

Past human-land interactions are recognized as the interplay of various resources that enabled cultures to develop and thrive (Bartelheim et al., 2015). Various concepts exist, which are used to interpret past human-land interactions (Miera, 2020). Three of them, which have been recently reviewed in the publication of James et al. (accepted) (manuscript IV), are outlined in the following with regard to their suitability for studying past human-land interactions:

Favor-Disfavor

Since the early 20th century, the Favor–Disfavor concept has provided a simplistic perspective on the physical landscape regarding its suitability for past land use. The concept assumes environmentally-deterministic factors, such as climate, topography and soils, to be most applicable for the assessment of landscapes being favourable or unfavourable for human purposes (Schliz, 1906; Schumacher, 1922). The human occupation of 'favourable' loess covered regions serves as prominent example for the Favor–Disfavor dichotomy and the characteristics of loess – silty, calcareous, good nutrient and water balance – have explained past settlement patterns in Central Europe for a long time (Wolff, 1913). This rationality implies agriculture to be the driving factor of human-decision making and neglects the significance of other relevant resources for prehistoric settlers. In addition, and most notably, this binary dichotomy classifies past landscapes according to modern thought patterns and predefines landscapes within static terms. Whether prehistoric settlers made use of the same economic rationality or were driven by other stimuli to assess their landscapes is not reflected in the Favor–Disfavor concept (Miera, 2020).

Recent studies have emphasized the limitations of the classification into favourable and unfavourable landscapes using only environmentally-deterministic factors. In southwestern Germany the regions of the Swabian Jura, the Black Forest and the Westallgäu are considered typically 'unfavourable' areas by the terms of the Favor-Disfavor dichotomy, due to their elevation, climatic conditions and the distribution of shallow and unfertile soils. Despite this, Miera (2020) reported ritual sites on the plateau of the Swabian Jura from the Late Bronze Age (LBA) and Iron Age, while Henkner et al. (2018b) dated the beginning of human occupation of the Black Forest to the Younger Neolithic. Furthermore, the recently discovered Middle Bronze Age (MBA) settlements in the Westallgäu (see section 4.3.3) provide evidence of early human-land interaction in unfavourable areas (Höpfer et al., 2020).

ResourceCultures

To refine the one-dimensional perception of resources exclusively as raw material, scholars of the Collaborative Research Centre (CRC) 1070 at the University of Tübingen work on a more holistic perspective of (past) human-land interactions and the related resources. In terms of

the CRC 1070, a resource is not a fixed object of research, but a category of analysis, which is used to study cultural phenomena from different perspectives. By asking "What cultural and social practices turn something into a resource?" (p. 14 Hardenberg et al., 2017), it becomes obvious that resources are not predefined nor do they intrinsically exist as such, rather they must be perceived and valuated from an interpretivist stance. In this framework, resources are both tangible (e.g., various raw materials) and intangible elements (e.g., knowledge, power, traditions), which promote socio-cultural dynamics and cultural developments. Furthermore, the effect of individual resources can only be examined when studying a resource network, the so called ResourceComplex (RC). In these networks the relevant tangible and intangible resources interact with each other and gain and lose importance based on human rationality. In that sense, RCs are culturally constructed and reflect the necessities of societies between the poles of natural landscapes and cultural identities for a defined period. As perceptions may change over time, and with them the meaning of individual resources within ResourceComplexes, a momentum was added to the interplay of different resources and designated as ResourceAssemblages. Finally, social-cultural developments on contingent temporal and spatial scales are compared to explain the rise and fall of societies, their sustainable and short-lived character, migration processes and the human occupation of favourable and unfavourable landscapes within the framework of ResourceCultures (Bartelheim et al., 2015; Hardenberg et al., 2017).

In light of past human-land interactions, different scenarios are conceivable for the conceptual application of ResourceCultures. Returning to Miera (2020): The Swabian Jura, which is considered unfavourable for agricultural practices, has been reassessed and the occurrence of ritual sites provides a non-environmentally-deterministic explanation for the human occupation of these areas. Furthermore, the transition from hunter and gatherer societies to sedentary farmers may have supplied a change in human perception. Regions that were considered unfavourable due to the scarcity of wild game, may have been favourable in terms of crop growth and settlement activity. Moreover, the settlement locations along physical-geographical nodal points (e.g., lakes, rivers), which guaranteed advantages for the trade of tangible resources such as raw materials, but also promote the exchange of knowledge as an intangible resource, may have played a significant role in the perception of landscapes in early societies (James et al., accepted) (manuscript IV).

Complex Adaptive Systems

Similar to the concept of ResourceCultures, the framework of Complex Adaptive System (CAS) includes a holistic perspective on (past) human-land interactions. The CAS framework, however, avoids an exclusively anthropogenic interpretivist approach to describing changes in (past) human-land interaction, and instead assumes a system-level approach with unique and non-deterministic properties among human and non-human agents. These system properties are (1) emergent properties, (2) domination by non-equilibrium states, (3) scale in space and

time, (4) feedback relationships and (5) regime shifts (Downey et al., 2016). Considering that the CAS framework was initially developed for studying social and natural systems and designed to meet their chaotic and unpredictable character (Castellani, 2013), the interpretation of past human-land interaction may also benefit from this approach. In this context, (1) emergent properties could describe incipient innovations such as the usage of new cultural technologies. The bronze sickle, the cultivation of spelt and a cattle-pulled plough could have been emergent properties, which marked the transition between the Neolithic and Bronze Age periods in Central Europe (Falkenstein, 2009). If nature is perceived as a chain of entropic processes, a constant input of energy is required to maintain (2) non-equilibrium states. However, both natural (e.g., climate deterioration, natural disaster) and anthropogenic properties (e.g., social pressure, wars) may emerge and limit the input of energy which leads to a system change with entropy as a dominant player. System maintenance and change can perform on (3) various spatial and temporal scales including past and present local settlement communities and their interrelation to regional and supraregional areas as well as to global interactions as they have occurred due to long-distant trading. Emerging properties, and presumably system changes, entail (4) feedback relationships in unpredictable directions. The establishment of new crops and cultural technologies during the Bronze Age may have led to a higher food security, the possibility of different sowing and harvesting times, the expansion of agricultural activities throughout the year, and the requirement of post-harvesting techniques and storing capacities (Scherer et al., submitted). If system thresholds are exceeded by the continuous emergence of properties and feedback relationships, (5) regimes may shift to another non-equilibrium state. In the northwestern Alpine foreland the occurrence and abandonment of settlements at the lakeshores of Lake Constance, at the transition between the Neolithic and Bronze Age periods, can be quoted as a suitable example for regime shifts. In this context, climate deterioration has been reported to have altered the hydrological balance of the lakes in the Circum-Alpine region with influence on the corresponding settlement behaviour (Menotti, 2009). Related migration processes to higher elevated areas reflect this regime shift as there was no opportunity to maintain the former non-equilibrium state.

In summary, the integration of different concepts for the interpretation of past human-land interactions opens up the possibility of a deeper understanding of how people may have acted in the past and what motives may have been used for decisions that triggered the changes we observe today. The integration of different concepts also promotes a departure from modern values and thought patterns, and it additionally stimulates the interdisciplinary research necessary for the holistic interpretation of past human-land interactions.

1.3 Colluvial deposits: Definitions, relevance, interpretation

Colluvial deposits (also *colluvium* or *colluvisol*) are variously defined in the literature (see reviews of Zádorová and Penížek, 2018; Miller and Juilleret, 2020). Common to most of these definitions is that colluvial deposits are heterogeneous sedimentary deposits rich in organic matter resulting from gravitational processes such as water soil erosion and mass movements. These hillslope processes are most effective in open landscapes with sparse vegetation cover on the soil surface (French, 1992). In Central Europe, an increased occurrence of open landscapes is assumed since the emergence of sedentism in the Early Neolithic (Ellis et al., 2013). Hence, the human contribution to the formation of colluvial deposits, as possible trigger of soil erosion and sedimentation processes, must be considered (Leopold and Völkel, 2007; Pietsch and Kühn, 2017; Van der Meij et al., 2019). In this thesis, the author refers to colluvial deposits as sedimentary archives that result from human-induced soil erosion and sedimentation processes. The relevance of colluvial deposits as archives for the sedimentation and climate history (Lang and Hönscheidt, 1999; Dreibrodt et al., 2010a), phases of past pedogenesis and land use (Kadereit et al., 2010; Lang et al., 2003) have been emphasized within the last few decades. Colluvial deposits are widely found in landscapes and have a high spatial and textual resolution due to their proximal position to the sediment sources and their information on the paleosurface, post-depositional soil formation processes and local land use (Dreibrodt et al., 2010b). Therefore, colluvial deposits can be considered as key archives storing proxies for phases of sedimentation and land use on a local scale. The extrapolation of sedimentation and land use phases to a regional scale has been applied in several studies and allows the characterization of main phases of colluvial deposition and slope stability (e.g., Dotterweich, 2008; Henkner et al., 2018a; Kappler et al., 2019).

For the interpretation of colluvial deposits, the differentiation between geomorphodynamically stable and instable phases is fundamental (Rohdenburg, 1970). Geomorphodynamically stable phases are characterized by low colluvial deposition but an increased natural succession of vegetation and pedogenesis. In contrast, phases of geomorphodynamic instability show an increased formation of colluvial deposits, which is related to upslope soil erosion processes (Botha et al., 2016). The activity of such slope systems is dependent on local landscape sensitivity, climate and land use history, soil erodibility, sediment texture and transport capacity (James, 2018). However, the formation of multi-layered colluvial deposits is characterized by non-linear processes as described in the cascade model by Lang and Hönscheidt (1999). The cascade model implies a temporal offset between the sediment source and the deposition of the colluvial deposit at the downslope position. Along the hillslopes, eroded sediments can be trapped in natural and anthropogenic sinks for a certain amount of time before a renewed sediment mobilization occurs. However, the cascade model does not take into account the erosion of downslope ac-

cumulated colluvial deposit or a reworking of a stable land surface by land use practices (e.g., ploughing). For the absence of certain phases of colluvial deposition, these processes must be considered (Lang and Hönscheidt, 1999; Van der Meij et al., 2019).

The stratigraphic and chronostratigraphic decipherment of multi-layered colluvial deposits is crucial for all subsequent interpretations (Pietsch and Kühn, 2017). The numerical dating of individual colluvial horizons by AMS radiocarbon (^{14}C) measurement of charcoal and the optically stimulated measurement (OSL) of sediments provides a temporal framework of the local sedimentation and land use history (Fuchs and Lang, 2009; Schroedter et al., 2013). OSL ages from colluvial deposits can be interpreted as the age of (human-induced) sediment deposition after bleaching of the mineral grains during the transport along the slope. However, a recent study by Van der Meij et al. (2019) proved the effects of post-depositional processes such as soil tillage on the depositional ages and proposed to use modelled stabilization ages of colluvial deposits to increase the accuracy of depositional ages. ^{14}C ages are more closely related to human activity as the production of charcoal is forced by anthropogenic combustion processes. However, the suitability of ^{14}C ages from charcoal derived from colluvial deposits for the interpretation of the sedimentation history is challenging since different input pathways of charcoal into the soil and post-depositional *in-situ* translocation processes along the soil column must be considered (Henkner et al., 2018a).

As main drivers for the formation of colluvial depositions, natural (e.g., climatic anomalies, wildfires, heavy rain events) and anthropogenic disturbances (e.g., slash and burn agriculture, ploughing) have been controversially discussed (e.g., Crombé et al., 2019; Kołodyńska-Gawrysiak et al., 2018; Dreibrodt et al., 2020). In a recent study, Dreibrodt et al. (2020) reported a correlation between phases of colluvial deposition and global and regional climatic anomalies in the Central Ukraine, while a correlation between phases of colluvial deposition and land use, as indicated by nearby Middle Neolithic remains, was not observed. However, it is generally assumed that since the Late Holocene, human impact on the terrestrial ecosystem has increased and has mostly surpassed climate as the dominant driver for the formation of colluvial deposits (Poréba et al., 2019; Van Loo et al., 2017; Nykamp et al., 2020) and "we [humans] have now become arguably the premier geomorphic agent sculping the landscape" (p. 843: Hooke, 2000).

Despite the correlation between phases of colluvial deposition and human occupation, the human contribution to the formation of colluvial deposits is vague and mainly assumed from the local archaeological record and chronostratigraphy (e.g., Kappler et al., 2018; Henkner et al., 2018b; Feeser et al., 2019; Lang, 2003; Van der Meij et al., 2019). Clear indications to specific land use practices, that may have triggered soil erosion and sedimentation processes, have been less frequently reported (Ponomarenko et al., 2020; Emadodin et al., 2011). Especially at sites with aerobic soil conditions, where the preservation of local land use proxies is limited due to weathering processes and microbial degradation (Jansen and Wiesenberg, 2017), colluvial de-

posits can be considered as key archives for the reconstruction of past human-land interaction within and at areas surrounding archaeological settlements (Scherer et al., accepted; Scherer et al., submitted) (manuscript I and II).

2 Objectives

This thesis is part of the Collaborative Research Center 'SFB 1070 ResourceCultures' of the University of Tübingen. The project B02 "Favor-Disfavor? Development of Resources in Marginal Areas" focuses on the investigation of Bronze Age (2200-800 BCE) settlement activities in relation to the sedimentation history at three sites in southwestern Germany. The general goal is the interpretation of human movements into and from favourable/unfavourable landscapes in the light of different resources. In this regard, the driving factors of human movements, the availability and possible perception of resources in a defined landscape unit and the soil, as a key resource for past human-land interaction, are of major interest.
With regard to the definition of colluvial deposits as sedimentary archives resulting from human-induced soil erosion and sedimentation processes, the multi-proxy analysis of multi-layered colluvial deposits is the focus of this work. The applied archaeopedological reconstruction of land use practices from colluvial deposits comprises an interdisciplinary approach including data from soil sciences, archaeology, archaeobotany and archaeozoology. The investigation of colluvial deposits with respect to site formation history, paleoenvironment, phases of sedimentation and land use (changes), within archaeological settlement sites (onsite) and in their surrounding (near-site), were synchronized with the local and regional cultural chronology to provide in-depth insights into Bronze Age subsistence strategies in southwestern Germany.
In detail, this thesis focuses on (the):

Multi-proxy analysis of colluvial deposits

(i) Assessment of the state-of-the art analytical potential of colluvial deposits for the reconstruction of past land use practices (manuscript I, II, in prep.).

(ii) Extending the analytical potential of colluvial deposits with respect to the interpretation of land use practices as trigger of past soil erosion and sedimentation processes (manuscript I, II, in prep.).

Archaeopedological reconstruction of past land use practices in favourable and unfavourable landscapes

(iii) Multi-proxy analysis of a multi-layered colluvial deposit at the prehistoric site of Fürstenberg (Baar) against the background of the local archaeological record and regional phases of colluviation (manuscript I).

(iv) Multi-proxy analysis of colluvial deposits, archaeological features and peat bogs in the northwestern Alpine foreland (Hegau) (manuscript II).

(v) Multi-proxy analysis of colluvial deposits against the background of the local archaeological record of two sites in the Westallgäu (manuscript in prep.).

Cultural-historical relevance for the Bronze Age in southwestern Germany

(vi) Assessment of human movements and cultural shifts between the study areas, which are related to Bronze Age traditions and innovations and provide insights into the cultural-historical environment of the Bronze Age in southwestern Germany (manuscript II, III, in prep.).

(vii) Interpretation of identified Bronze Age resources in terms of the concepts of the Collaborative Research Center SFB 1070 ResourceCultures (manuscript II, IV).

3 Study area

3.1 Physical geographical setting

The study area is in southwestern Germany and comprises the landscape units Baar, Hegau and Westallgäu (Fig. 3.1). With regard to the Favor–Disfavor dichotomy, the Hegau is considered as a favourable landscape (German: *Altsiedellandt*, *Gunstraum*) compared to the Baar and Westallgäu; this is mainly based on climatic conditions and elevation, but also reflected in the regional archaeological records (Krahe, 1958; Mainberger et al., 2010). Notably, in the previous project phase the Baar was considered favourable in comparison to the landscape units of the Black Forest and Swabian Jura. This change in favourability underlines the relative nature of the Favor–Disfavor dichotomy.

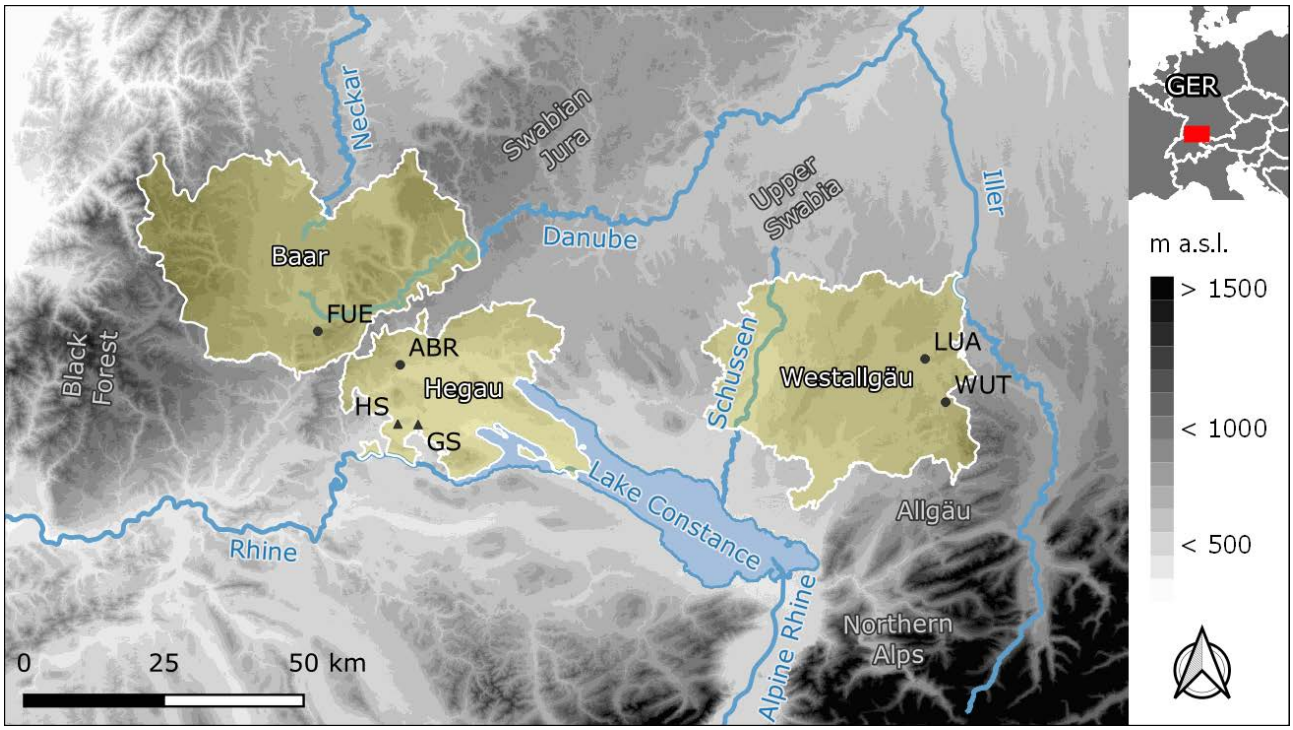

Figure 3.1: Study area (Baar, Hegau, Westallgäu in southwestern Germany) with the archaeological sites (black dots) and the pollen profiles (black triangles). FUE: Fürstenberg site, ABR: Anselfingen site, LUA: Leutkirch site, WUT: Winterstetten site, HS: Hartsee peat bog, GS: Grassee peat bog. Coordinates are shown in UTM 32N reference system; EPSG 25832.

Baar

The Baar is a depression between the granite basement of the Black Forest to the west and the limestone escarpment of the Swabian Jura to the east. The present landscape is characterized by steep slopes formed by the Danube River and its headwater streams Brigach and Breg. The Baar comprises the geology of the German Trias, including sedimentary rock from

the Buntsandstein, Muschelkalk and Keuper (Siegmund, 2006). Loess sediments, which were relocated by periglacial processes, are covering the slopes (Kösel and Rilling, 2002). Cambisols, Stagnosols and Regosols are the dominant Reference Soil Groups according to WRB 2015 (IUSS Working Group, 2015) and mainly developed from periglacial layers with varying amounts of local rocks. The average elevation is 750-800 m a.s.l., the mean annual air temperature 7-8 °C and the precipitation about 850 mm.
In the southeastern part of the Baar, the prehistoric site of Fürstenberg (FUE site) was chosen for the archaeopedological reconstruction of diachronic land use practices (see Fig. 4.2 in section 4.3.1). The FUE site is located on a Zeugenberg of the Swabian Jura and has an elevation of 918 m a.s.l.. The slopes of the Fürstenberg mainly consist of limestones from the late Jurassic and clay-rich sediments from the early Jurassic. Along the slopes, several multi-layered colluvial deposits have been described by Henkner et al. (2017).

Hegau

The Hegau is part of the northwestern Alpine foreland and extends between the southern decline of the Swabian Jura ridge to the north and the lakeshores of Lake Constance to the south. The landscape is characterized by two main lowland areas, as a prolongation of the two arms of Lake Constance from southeast to northwest, and by filled volcanic vents, which are remains of the tertiary volcanism. Geologically, the tertiary sediments of the Younger Juranagelfluh and of the Hegau volcanism (phonolite, basalt, porphyry) as well as the quaternary glacial and glacio-fluvial deposits (gravel, (terminal) moraines) of the Würm glaciation dominate the study area (Schreiner, 2008; Geyer et al., 2011). Soil substrates are mainly redeposited sediments and weathered bedrock from the Younger Juranagelfluh, the Würmian glacial and glaciofluvial deposits (mainly gravels, sand, silt) and tertiary porphyry (Deckentuff). Cambisols, Luvisols, Phaeozems and Calcaric Regosols, which developed on different substrates and with different stagnic and vertic features, are dominating the Reference Soil Groups according to WRB (IUSS Working Group, 2015). The average elevation is 500-550 m a.s.l., the mean annual air temperature is 7.5-8.5 °C and the precipitation is between 700 and 800 mm.
In the northwestern Hegau, the study site 'Anselfingen Breite' (ABR site) is located in and around an excavation area close to the modern village of Anselfingen and has an average elevation of 520 m a.sl. (see Fig. 2 in manucscript II). The ABR site is located on glaciofluvial deposits next to the outer young terminal moraine of the Würmian glaciation (Äußere Jungendmoräne). The multi-layered colluvial deposits at the eastern foot slope positions of the Hohenhewen mainly developed from the sediments and weathered bedrock from the Younger Juranagelfluh and the volcanic material (mainly basalt) from the Hohenhewen. The buried soils developed from clay rich Würmian fluvioglacial deposits. The two palynological sites Hartsee (HS) and Grassee (GS) are bogs in the western part of the Hegau and developed from kettle holes, which remained after the glacier's retreat.

Westallgäu

The Westallgäu is located northeast of the Lake Constance basin. The landscape was mainly shaped by the eastern part of the Rhine-valley glacier and is characterized by glacial forms such as ground and terminal moraines, drumlins, and gravel deposits as well as by lakes and bogs, which developed after the glacier's retreat. Geologically, the quaternary glacial and fluvioglacial sediments of the Würm glaciation dominate the study area with the occurrence of sediments of the Riss glaciation (Donau-Iller-Lech Platte) and the upper freshwater molasse restricted to the northern and eastern part of the study area, respectively (Geyer et al., 2011). Glacial tills, which originated from the northern (calcareous) and central (crystalline) Alps, are the soil substrate with varying amounts of gravel, sand and silt. Cambisols, Luvisols, Stagnosols and Calcaric Regosols, developed from the glacial deposits of the Würmian or Riss glaciation, dominate the Reference Soil Groups, according to the WRB (IUSS Working Group, 2015). On average, the elevation is 650-700 m a.s.l., the mean annual temperature is 6-7 °C and the precipitation is 1200 mm.
The study site 'Leutkirch Untere Auen' (LUA site) comprises an excavation area and its surrounding in the northern part of the city Leutkirch im Allgäu (see Fig. 4.7 in section 4.3.3). The excavation area is located on the lower terrace gravel deposits of the Rhine-valley glacier near the Eschach River and has an average elevation of 650 m a.s.l.. The colluvial/alluvial profiles are in the floodplain area of the Eschach River, underneath the lower terrace edge, with varying influence of alluvial loam and eroded glacial deposits. One colluvial profile is located in a paleochannel of the Eschach River and developed from the sediments of the lower terrace gravel deposits.
The excavation at the study site 'Winterstetten Urlauer Tann' (WUT site) was conducted upon a spur of the 'Wuchzenhofener Platte' (715 m a.s.l. in average), which mainly consists of gravel deposits of Riss glaciation. The colluvial profiles are at the eastern edge of the floodplain area of the Eschach River and mainly developed from relocated slope deposits with varying amounts of sediments of the upper freshwater molasse and glacial till. The colluvial profiles are located in the surrounding area of a documented Middle Bronze Age settlement and burial mounds (see Fig.4.13 in section 4.3.3).

3.2 Climate and vegetation history

The transition between the Younger Dryas and the Praeboreal chronozone (9.600-8700 BCE) marked the beginning of the Holocene and was characterized by a strong increase in the mean annual temperatures of about 6 °C (Mills, 2013). The rise in temperature enabled the widespread reforestation of the tundra with shrubs, dwarf shrubs (e.g., *Salix, Betula, Juniperus*) and woodlands (e.g., *Pinus Sylvestris, Betula alba/pendula*), which mainly appeared as open and non-densely vegetated areas (Behre, 2006).

During the Boreal chronozone (8700-7300 BCE), the temperature rise continued, and the open pine and birch woodlands were successively suppressed by mixed-oak forest communities predominately consisting of *Quercus*, which were associated with *Ulmus, Tilia* and *Alnus*. The spread of *Corylus* during the Early Boreal was restricted by the spread of mixed-oak forests communities (Litt et al., 2009).
During the Atlanticum (7300-3700 BCE) the Holocene reached its thermal optimum with overall humid conditions and rising sea levels (Mills, 2013). This climatic trend was interrupted by cooling events like the 8.2 ka event, which lasted about 160 years and was probably triggered by the ice saddle collapse in North America (Matero et al., 2017). In Central Europe, the Atlantic chronozone is palynologically characterized by the establishment of deciduous forest communities, which are dominated by thermophilous calciphilous beech forests (*Fagus sylvatica*) and sessile oak (*Quercus petraea*)-beech forests (*Luzula luzuloides*) with a rich and diverse shrub and herb layer (Bohn et al., 2003). These presumably dense woodlands were initially disturbed by the arrival of the people of the Linear Pottery Culture (5500-5000 BCE) (Kerig and Lechterbeck, 2004; Lechterbeck, 2001).
The Subboreal chronozone (3700-450 BCE) was characterized by slightly lower temperatures and an increase in aridity compared to the preceding Atlanticum (Mills, 2013). Palynologically, *Tilia* and *Ulmus* lost importance in the mixed oak forests. During this period, it is especially the rapid decline of *Ulmus*, the so called 'Elm Decline', that serves as a marker of the past. However, whether the 'Elm Decline' was climate-driven or the result of anthropogenic influences on vegetation patterns has been controversially discussed (Kearney and Gearey, 2020; Grosvenor et al., 2017). In addition, the spread of *Fagus sylvatica* and *Carpinus betulus* was a characteristic of the Subboreal vegetation development (Pott, 1997).
The Subatlantic chronozone (since 450 BCE) opened with a warm period but was generally cooler and more humid than the preceding Subboreal. The averaging climate trend of the Subatlanticum was interrupted by several temperature peaks and declines. The 'Roman Climatic Optimum' around 100 BCE to 200 CE, which is considered a multi-decadal dry event, and the 'Little Ice Age' (1400-1850 CE), which culminated as a global cooling event towards the end of the 16th century CE, were significant climatic changes during the Subatlanticum (Grove, 2012; Bini et al., 2020; Wanner et al., 2008).
To better understand the patterns of regional vegetation change at the study area, main differences in the vegetation history of palynological records at the Baar, in the Hegau and in the Westallgäu are presented (Baar: Plattenmoos, Sudhaus et al. (2006); Hegau: Lake Steißlingen, Lechterbeck (2001); Eusterhues et al. (2002); Kerig and Lechterbeck (2004); Westallgäu: Großer Ursee, Rösch et al. (2020); Tab. 3.1). The Plattenmoos is a raised bog about 20 km northwest of the FUE site, at the transition between the Black Forest and the Baar. The Lake Steißlingen developed from a kettle hole after the last glacier retreat and is about 15 km southeast of the excavation area at the ABR site. The Großer Ursee, which also originated from a kettle hole,

is about 7 km southwest of the WUT site and about 10 km south of the LUA site.
The first palynological difference between the pollen archives are observed during the Boreal. Around Lake Steißlingen, there was a stronger advance of *Corylus*, while the spread of mixed oak forest was more distinct at the Plattenmoos and Großer Ursee. A high occurrence of natural fires was observed at the Plattenmoos site up until the Boreal, while similar observations have not been reported at the Lake Steißlingen and Großer Ursee. The significant occurrence of *Trapa natans* (water chestnut) is remarkable at the Großer Ursee and has not been observed in the pollen archives of the Baar and Hegau. The flourishing of the water chestnut is limited by water temperature below 20 °C during the summer term (Gams, 1926). During the Atlanticum, *Fagus* arrived earlier, but developed slower around the Großer Ursee compared to Lake Steißlingen. Conifer species such as *Picea* and *Abies* had a greater impact on the vegetation patterns of the Plattenmoos and Großer Ursee compared to Lake Steißlingen. In comparison to the Hegau region, *Quercus* and *Corylus* were never dominant after *Fagus* declined at the two sites of the Baar and Westallgäu. There, declines in *Fagus* were often accompanied by peaks in *Betula*. Around Lake Steißlingen, human impact on the vegetation is first observed with the arrival of the people from the Linear Pottery Culture (5500-5000 BCE). In the Plattenmoos and Großer Ursee record, human impact prior to the Hallstatt (800-450 BCE) and Latène period (450-15 BCE), respectively, is not documented.

3.3 Phases of colluvial deposition and land use

The history of colluvial deposition and related land use activities in Central Europe has been frequently discussed in the recent decades (e.g., Dotterweich, 2008; Henkner et al., 2018a; Dreibrodt et al., 2010b; Dotterweich, 2013). Even when considering the local validity of hillslope processes and the limitation of ^{14}C and OSL dating in the context of colluvial deposits, a supraregional trend of phases of colluvial deposition and land use can be demonstrated.
In most cases, evidence of Neolithic land use, which derives from archaeological records and ^{14}C ages, are contrasting with the absence, or very weak presence of Neolithic colluvial deposit (Dotterweich, 2008; Dreibrodt et al., 2010b; Henkner et al., 2018a). However, distinct phases of Neolithic soil erosion have been documented by Zádorová et al. (2013) and Poréba et al. (2019). During the Early and Middle Bronze Age, soil erosion appeared to be low, while there is a consensus on the first phase of widespread colluvial depositions occurring in the Late Bronze Age (Henkner et al., 2018a; Dotterweich, 2008; Dreibrodt et al., 2010b). The increase in Late Bronze Age colluviation intensity continued until the Roman period with peaks during the Early and pre-Roman Iron Age (Dreibrodt et al., 2010b; Henkner et al., 2018a). For the Roman period, the records of sedimentation history are contradictory. Dotterweich (2008, 2013) documented a peak in soil erosion and deposition during the end of the Roman period, while Henkner et al. (2018a) and Dreibrodt et al. (2010b) have not observed the formation of corresponding colluvial horizons. However, the lack of evidence of colluvial deposition during the Early, or

Table 3.1: Summarized palynological records of the Plattenmoos (Sudhaus et al., 2006), Lake Steißlingen (Eusterhues et al., 2002; Lechterbeck, 2001) and Großer Ursee (Rösch et al., 2020).

Plattenmoos (Baar) (Sudhaus et al., 2006)	**Lake Steißlingen (Hegau)** (Lechterbeck, 2001; Eusterhues et al., 2002)	**Großer Ursee (Westallgäu)** (Rösch et al., 2020)	CE / BCE
Alternating phases of natural succession (*Fagus, Abies*) and human impact (landscape opening, cereal pollen, promotion of *Junglans* and conifer), agricultural activity since Roman Period (15 BCE)	Alternating phases of natural succession (advance of *Fagus*) and human impact (landscape opening, NAP increase, advance of *Quercus* and *Corylus*)	Alternating phases of natural succession (advance of *Fagus*) and human impact (landscape opening, advance of *Betula*)	Subatlanticum (since 450 BCE)
Mixed forest (*Abies*, *Fagus*); advance of *Corylus*, first human impact (Hallstatt Period, 800-450 BCE)	Advance of *Corylus*; decline in *Fagus* in the first half; major human forest clearances (pile dwellings); trans-regional *Fagus* advance with inter-ruptions by *Corylus*; agricultural activity since Early Bronze Age (2100 BCE)	Alternating phases of *Fagus*; permanent human occupation since Latène Period (450-15 BCE); advance of *Quercus*, *Corylus;* increase in NAP, charcoal	Subboreal (3700-450 BCE)
Dominance of mixed oak forests; spread of *Picea* from the Swabian Jura; *Picea* and mixed oak forests suppressed by spread of *Fagus* and *Abies* from the Black Forest	Thermophilus deciduous forests (*Quercus*, *Fraxinus*, *Alnus*, *Corylus, Tilia*); mixed oak forests at drier soils; decrease in *Pinus*; advance of *Fagus;* first human impact (Linear Pottery Culture, 5500-5000 BCE)	Thermophilus deciduous forest; slight advance of *Fagus*, *Abies, Picea*; slow Elm decline until 2000 BCE; weak human impact since Final Neolithic (2500 BCE); slight advance of cereal pollen	Atlanticum (7300-3700 BCE)
Spread of mixed oak forests (*Quercus, Fraxinus, Alnus, Corylus, Tilia, Acer*); advance of *Corylus* and *Pinus*; decline of natural fires	Fast spread of *Corylus* (up to 70 % of the pollen sum); slow spread of mixed oak forest with a dominance of *Quercus, Ulmus*	Spread of mixed oak forests (*Quercus, Fraxinus, Acer, Tilia*); decrease in *Pinus*; since Boreal occurrence of *Trapa natans*	Boreal (8700-7300 BCE)
Strong advance of *Betula*; mixed birch and pine forests*;* slight advance of *Corylus*, *Ulmus*, *Quercus*; strong impact of natural fires	Strong advance of *Betula*; mixed birch and pine forests; slight advance of *Corylus*, *Ulmus*, *Quercus*	Strong advance of *Betula*; mixed birch and pine forests; slight advance of *Corylus* and *Ulmus*	Praeboreal (9600-8700 BCE)

the entire, Roman period contrasts the generally accepted increase in corresponding land use activities (Van Lanen et al., 2018). During the Migration period and Early Middle Ages, weak colluviation is generally reported, while an increase in colluviation during the High and Late Medieval Ages seems to have been accompanied by a more intensive land use (Henkner et al., 2018a; Dreibrodt et al., 2010b; Dotterweich, 2013). Especially in the first half of the 14th century, soil erosion intensity has been reported to be 10 to 100 times higher than the preceding periods (Dotterweich, 2008). Since the industrialized Modern Times, a continuous colluvial deposition has been observed.
Since the formation of colluvial deposits is strongly influenced by climatic conditions, landscape topography, relief, soil substrate and human phases of occupation, a regional overview of the colluvial deposition history seems appropriate for the evaluation of the study sites of the Baar, Hegau and Westallgäu.

Baar

A regional distribution of colluvial deposits at the Baar has been reported by Henkner et al. (2017) with seven main phases of colluvial depositions. According to Henkner et al. (2017), the first phase of colluvial deposition appeared during the Younger Neolithic and is interpreted as a result of colder and wetter climatic conditions. The second phase occurred during the Middle Bronze Age and contrasts the local archaeological record. However, it remains questionable whether a single OSL age and several ^{14}C ages were sufficient to delineate a main phase of colluvial deposition, even when soil erosion and sedimentation processes were climatically favoured. The third and fourth phase of colluvial deposition corresponds to the Late Iron Age and Roman period and could have been a consequence of climatic disfavor and an increase in land use activity by Romans, respectively. After the low soil erosion and sedimentation of the Migration period and Early Middle Ages, the intensity of colluvial deposition increased continuously and has almost doubled since the High Middle Ages, compared to the preceding periods. Henkner et al. (2017) reported further peaks at the end of the 12th and 15th century.

Hegau

Phases of colluvial deposition in the Hegau were reported by Höpfer et al. (2016), Vogt (2014), Maier and Vogt (2000) and Dieckmann (1995) around the lakeshores of Lake Constance and at sites further inland by Schulte and Heckmann (2003) and Schulte and Stumböck (2000). In the areas further inland, Early Neolithic occupation has been documented by ^{14}C ages, while the corresponding colluviation is lacking. Schulte and Heckmann (2003) and Schulte and Stumböck (2000) assumed that Early Neolithic land use was small-scale and did not contribute to significant colluvial deposition. During the Middle Neolithic, local phases of colluvial deposition have been documented close to a settlement site near the Hohentwiel volcano hill (Schulte and Stumböck, 2000). Between the Middle Neolithic and Late Bronze Age, a hiatus of about 3000 years has been observed with no or low colluvial deposition, while since the Late Bronze

Age widespread soil erosion and sedimentation processes, with the occurrence of corresponding colluvial horizons and sediment input into bogs, are observable (Schulte and Heckmann, 2003; Schulte and Stumböck, 2000; Dieckmann, 1995). However, whether phases of colluvial deposition after the Late Bronze Age are lacking or are not investigated in the inner Hegau, is not evident from these studies.
Phases of colluvial deposits in the vicinity of Lake Constance are documented since the Late and Final Neolithic (Höpfer et al., 2016; Vogt, 2014; Maier and Vogt, 2000; Dieckmann, 1995). However, the local archaeological record provides evidence of human occupation prior to these periods, which is interpreted to mean that Early and Middle Neolithic land use did not lead to significant soil erosion and sedimentation processes. With the onset of the 'pile dwelling' settlements at Lake Constance, the first phase of colluvial deposition is documented likely because of population growth (Vogt, 2014). During the Early Bronze Age, a remarkable increase in colluviation intensity is observed, which can be related to a modified and intensified land use activity as documented by plough traces (Vogt, 2014). For the Middle and Late Bronze Age a decrease in soil erosion and sedimentation is detected, which is associated with a lack of human settlements on the shores of Lake Constance (Menotti, 2009). For the Early Iron Age, similar rates of sedimentation have been documented as for the Early Bronze Age, which contrasts the lack of documented settlement remains in the vicinity of Lake Constance (Vogt, 2014). The intensity of colluvial deposition was continuous during the Late Iron Age, whereas no or only weak colluviation is known for the Roman period and the Migration period. Since the Early Medieval Ages, the intensity of soil erosion and sedimentation processes have increased and have continued into the industrialized Modern Times.

Westallgäu

In comparison to the Baar and Hegau, the history of colluvial deposition in the Westallgäu is much less investigated. The only exception is a pedological study in the surrounding area of Lake Degernsee, where remains of a Younger Neolithic settlement have been documented. In a multi-layered colluvial profile more than 2m of colluvial deposit was described with a cultural layer burying a full developed Cambisol. In the cultural layer, an accumulation of charcoal was observed with ^{14}C ages from the Early Bronze Age. Younger charcoals in the overlaying horizons indicated an intensive colluvial deposition until the Early Medieval period (Vogt, 2016).

4 Results and discussion

4.1 Analytical potential of colluvial deposits for the reconstruction of past land use practices (Manuscript I, II, in prep.)

The analytical potential of colluvial deposits has been used to investigate research questions concerning the (sub-)disciplines of soil sciences (Kühn et al., 2017; Zádorová et al., 2015; Kadereit et al., 2010), geomorphology (Fuchs and Lang, 2009; Fuchs et al., 2010; Van der Meij et al., 2019), geoarchaeology (Wilkinson et al., 2006; Cremeens et al., 2003; Küster et al., 2011) and archaeopedology (Pietsch and Kühn, 2017; Devos et al., 2009; Henkner et al., 2017). Depending on the research question, colluvial deposits are subject to a variety of methodological approaches; however, for the most part they are investigated using multi-proxy approaches. Multi-proxy approaches are especially important for geoarchaeological and archaeopedological studies, which comprise the investigation of archaeological research questions using soil scientific and archaeobotanical methods (Pietsch and Machado, 2014; Owens et al., 2016). In this context, the distinction between geoarchaeology and archaeopedology is mainly based on the perspective on the investigated soils and sediments. While geoarchaeologists study human-modified *sediments* within an excavation and its surrounding area (onsite and near-site), archaeopedologists focus on (onsite, near-site and offsite) *soils*, which provide information on site formation history, paleoenvironmental conditions and land use practices that may have changed over time (Pietsch and Kühn, 2017). Although the analytical approaches of both sub-disciplines overlap, it is the perspective on the research environment and the research focus that matters.

In a study by Pietsch and Kühn (2017), several field and lab methods for soil description and analysis have been listed (cf. Tab. 1 in Pietsch and Kühn (2017)). These methods were considered relevant for answering research questions in an archaeopedological context. However, progress in biogeochemical research has enabled the expansion of the analytical potential of colluvial deposits and includes methods that were previously limited to the study of subaqueous archives (e.g., lacustrine or peat bogs). From a methodological point of view, this thesis aims to refine the list of methods applied to colluvial deposits through identifying methods that can potentially contribute to a better understanding of the nature and intensity of past human-land interactions (see Tab. 4.1).

As already described by Pietsch and Kühn (2017), deciphering the stratigraphy of colluvial deposits is fundamental to understanding the soil formation history and, additionally, provides the basis for soil sampling. The concept of 'boundary A' can help to distinguish between buried soils that developed *in-situ* and colluvial soils that were mainly relocated from upper slope po-

sitions (Edgeworth et al., 2015). A colluvial stratigraphy is also supported by the analysis of calcium carbonate content ($CaCO_3$), soil organic carbon content (SOC), grain size distribution and pH. These soil parameters can support or question the stratification and thickness of individual colluvial horizons, the identification of former land surfaces and the transition between colluvial deposit and buried soil observed in the field. Information on weathering processes, the status and intensity of weathering, the formation of pedogenic iron (hydr)oxides and the presence or absence of certain clay minerals and iron (hydr)oxides is provided by the analysis of X-ray fluorescence (XRF), X-ray diffraction (XRD), and the analysis of pedogenic oxides.
A temporal framework of numerical ages can be added to the relative stratigraphy by using optically stimulated luminescence (OSL) dating of sediments and AMS radiocarbon (^{14}C) dating of charcoal fragments from colluvial sediments. These numerical dating approaches have been successively reported in several studies (e.g., Fuchs and Lang, 2009; Schroedter et al., 2013; Fuchs et al., 2010; Kappler et al., 2018; Henkner et al., 2018a) and allow the temporal framework of colluvial deposits to be synchronized with archaeological periods and potential phases of local human occupation, as indicated by nearby settlements (Kadereit et al., 2010; Kittel, 2015).
However, the question of which land use practices triggered soil erosion and colluvial deposition is mainly assumed from the chronostratigraphy and local archaeology. In many cases, land use practices such as deforestation and soil tillage are mentioned as possible triggers of soil erosion, but supporting evidence is missing (e.g., Schulte and Stumböck, 2000; Henkner et al., 2017; Feeser et al., 2019; Van der Meij et al., 2019). This gap can be filled by analysing land use proxies from colluvial deposits, which provide detailed insights into past land use practices in the areas surrounding nearby settlements. These land use proxies are preserved in colluvial deposits by continuous sedimentation that protects them from being degraded by weathering processes and microbial turnover (Scherer et al., submitted). Hence, colluvial deposits can be considered one of the key archives for human-land interactions (Pietsch and Kühn, 2017).
A few studies have begun to include the analysis of archaeobotanical and biogeochemical proxies from colluvial deposits for the reconstruction of past land use practices (Ponomarenko et al., 2020; Pietsch and Machado, 2014). For example, Ponomarenko et al. (2020) investigated colluvial deposits in western Russia and found seven phases of colluvial deposition and stabilization that chronologically matched the local phases of human occupation. Besides the sedimentological data that supported the phases of soil erosion, they were able to reconstruct different Medieval land use systems (e.g., swidden agriculture and permanent fields) by analysing charcoal and pollen assemblages from colluvial deposits. Another multi-proxy study of colluvial deposits revealed promising insights into the land use history of the area surrounding the Great Temple of Yeha in Tigray (Ethiopia) (Pietsch and Machado, 2014).

Table 4.1: Methods and their relevance for the analysis of colluvial deposits in the context of archaeopedology

Method	Relevance	References
Soil description	Number and thickness of colluvial horizons; identification of soil formation processes, former land surfaces and human impact; transition between colluvial horizons and buried soil;	Ad-Hoc-AG-Boden (2006), Mnusell-Soil-Color-charts (2000)
Grain sizes, SOC, $CaCO_3$, pH	Buried soils: status of soil formation; colluvial horizons: support of described stratigraphy, (e.g., differentiation between individual colluvial horizons, former land surfaces and soil formation)	Blume et al. (2000), Sparks et al. (2020)
X-ray fluorescence (XRF)	Calculation of weathering indices (e.g., chemical index of alteration, CIA): status and intensity of weathering	Nesbitt and Young (1982), Buggle et al. (2011)
X-ray diffraction (XRD)	Identifiation of different iron oxides and clay minerals: (past) soil formation	Bergmann et al. (1998), Ufer et al. (2012a,b),
Pedogenic oxide ratios (POR)	Fe_d/Fe_t ratio: Status on the activity of weathering of primary silicates; Fe_o/Fe_d ratio: Information on the iron release from primary minerals and formation of Fe (hydr)oxides	Schwertmann (1964), Mehra and Jackson (2013), Baumann et al. (2014)
Micromorphology	Investigation of soil microstructure; differentiation between buried soils and colluvial horizons; identification of anthropogenic features (e.g., charcoal, hints for ploughing)	Stoops et al. (2003), Lewis (2012)
Optically stimulated luminesence dating (OSL)	Dating of sediment samples; chronostratigraphic framework of sedimentation history; last date of minerals being exposed to sunlight (date of sedimentation?; date of last human influence through tillage?)	Fuchs and Lang (2009), Fuchs et al. (2010), Van der Meij et al. (2019)
AMS radiocarbon (^{14}C) dating	Dating of organic soil material (charcoal, SOM); identificationof human impact (e.g., deforestation by using fire); can be related to ^{14}C ages of nearby settlements	Schroedter et al. (2013), Vogt (2014)
Archaeological finds	Support the chronostratigraphic framework by OSL and ^{14}C dating; identification of human impact beyond settlement areas	Höpfer et al. (2016), Miera et al. (2019)

Method	Relevance	References
Anthracological determination of charcoal	Proxy for local woody vegetation composition (natural vs. modified by humans); supports ^{14}C dating by considering the 'old wood effect'	Schweingruber (1990), Schroedter et al. (2013), Jansen and Nelle (2014)
Phytolith analysis	Proxy for past woody and non-woody vegetation composition (natural vs. modified by humans); support the theory of 'landscape openess'; information on agricultural practices (conc. of inflorescence phytoliths) and paleoenvironment	Twiss et al. (1969), Piperno (2006), Meister et al. (2017)
Polycyclic aromatic hydrocarbon (PAH)	Proxy for past fire events; information on combustion processes (complete vs. incomplete), on fire condensates vs. *in-situ* accumulation of PAHs, on fire temperature, on fuel source (PAH ratios)	Yunker et al. (2002), Bläsing et al. (2016), Kappenberg et al. (2019a), Tan et al. (2020)
Black carbon, Benzene polycarboxylic acid (BPCA)	Proxy for past fire events; information on fire intensity and temperature	Glaser et al. (1998), Brodowski et al. (2005), Wolf et al. (2013), Kühn et al. (2017)
Urease activity to microbial biomass C ratio (urease/C_{mic})	Proxy for the past input of urea into soils; urease as stable enzyme over millennia (stabilized through urease-organo-mineral complexes); C_{mic} as proxy for current microbial activity; high levels of urease/C_{mic} in greater soil depths: past (human-induced) eutrophication	Kandeler and Gerber (1988), Zantua and Bremner (1977), Chernysheva et al. (2015)
Faecal biomarker (sterols, stanols, stanones)	Proxy for past input of animal and human faeces into soils; differentiation between herbivorous and omnivorous faeces	Birk et al. (2012), Bull et al. (1999), Prost et al. (2017)
Heavy metal analysis	Proxy for human-induced heavy metal input; differentiation between geogenic background, atmospheric input and direct anthropogenic input	Nölte (2020), Young (2013), Dreibrodt et al. (2009), Henkner et al. (2018b)

Based on the colluvial (chrono-)stratigraphy, several buried soils could be attributed to cultural and climatic periods. Even though the phytolith assemblages did not provide insights into cereal cultivation, it did reveal a climatic trend towards increased aridity within younger horizons, which was most likely accompanied by a change in vegetation composition and an opening of the landscape. This climatic change undoubtedly affected human-land interactions in the study area during the Middle Neolithic.

Table 4.1 lists several methods to reconstruct land use practices from colluvial deposits. Most of these methods are well established in the disciplines of geoarchaeology and archaeobotany (e.g., analysis of phytoliths and anthracological determination of charcoals). Despite the preservation of biogeochemical and archaeobotanical proxies is more limited in colluvial deposits than in subaqueous archives, the case studies described in section 4.3.1, 4.3.2 and 4.3.3 support the application of these land use proxies in the context of colluvial deposits.

The anthracological determination of charcoal provides information on the local history of vegetation change since the aerial transport of charcoal only affects fragments < 1 mm and can therefore be neglected (Whitlock and Larsen, 2001). Since at least the Late Holocene, changes in woodland vegetation have been increasingly accompanied by human influence. For example, Jansen and Nelle (2014) reconstructed Early Neolithic woodland composition in northern Germany which they then related to the land use of the Funnel Beaker Culture (4000-2800 BCE). In particular, the increase in *Corylus* in the charcoal assemblages was related to a higher anthropogenic influence, as *Corylus* indicates an increased openness of the landscape. The comparison of local charcoal assemblages from colluvial deposits or archaeological structures with offsite pollen data from nearby peat bogs and lakes can help to put the local vegetation record into a regional context (Dreibrodt et al., 2009) (see also section 4.3.2).

The analysis of phytoliths from soil samples can give further insights into past vegetation patterns by differentiating woody (dicotyledons) and non-woody vegetation (monocotyledons). Phytoliths are well preserved in colluvial deposits once sedimentation continues and phytolith turnover is reduced (Cabanes et al., 2009). This is mainly because degradation by microbes, plant roots and mineral weathering processes is highest at the soil surface. Nevertheless, depositional and post-depositional processes, as well as humid soil conditions often lead to a state of preservation that only allows for a differentiation between monocotyledonous and dicotyledonous morphotypes (Scherer et al., accepted). Phytoliths, therefore, provide information on the level of landscape openness (e.g., concentration of grass phytoliths), while the assignment to cereal species remains challenging in areas of Central Europe compared to dryland sites (Lehnhardt et al., 2019). However, the identification of lower concentrations of inflorescence parts of monocotyledonous morphotypes, combined with other proxies, such as onsite charred archaeobotanical remains, allows for detailed insight into vegetation history and related agricultural practices (Scherer et al., submitted; see also section 4.3.2).

Pyrogenic black carbon (BC), which is mainly studied through benzene polycarboxylic acids

(BPCAs) or polycyclic aromatic hydrocarbons (PAHs), is ubiquitously distributed in the environment as a result of natural and artificial fires (Kappenberg et al., 2019b; Goldberg, 1985). Since fire has been an integral part of past human societies long before sedentism, the residue of natural and human-induced burning processes can be used as a proxy for biomass burning (Oros and Simoneit, 2001a,b). The total amount of BC to soil mass or SOC gives hints about the occurrence and intensities of fires. The fire temperature, which might be helpful for distinguishing between natural and anthropogenic combustion, can be deduced by the analysis of BPCAs and PAHs (Wolf et al., 2013). The calculation of source-specific PAH ratios further provides information on the fuel source (Kappenberg et al., 2019a; Yunker et al., 2002, 2015). This information on past fire regimes is helpful for the reconstruction of wildfires and artificial burnings which were an integral part of past societies' efforts to modify and maintain their landscape. The analysis of black carbon from colluvial deposits was performed by Kühn et al. (2017) from a loess-paleosol-colluvium sequence in central Germany. They found high concentrations of BC in soil horizons formed during the Late glacial period and Atlantic period, which they interpreted as evidence for wildfires and anthropogenic fires, respectively. The relatively low B5CA/B6CA ratios further indicated high fire temperatures and burning of biomass. In another study by Tan et al. (2020), the PAH patterns of a loess-paleosol-sequence in Eastern China were investigated to decipher fire regimes since the Late Holocene. They were able to correlate PAH fluxes not only to the fire intensity (derived through the analysis of BC), but also to phases of human occupation. Both BPCAs and PAHs from colluvial deposits have the potential to contribute to a refined understanding of past land use practices which were accompanied by the use of fire and most probably occurred in the catchment areas of past settlements (see sections 4.3.1, 4.3.2 and 4.3.3).

The past input of urea into the soil can be assessed with the urease to microbial biomass carbon ratio (urease/C_{mic}). Urea in the soil may originate from past and recent input of animal faeces as well as from the degradation of the soil necromass (mainly nucleic acids). However, in greater soil depths, the reduction of both currently active microorganisms and of urease enzyme activities is expected; therefore, higher urease/C_{mic} ratios in greater soil depths can be interpreted as formerly eutrophicated areas associated with past land use practices such as livestock husbandry and manuring. The sustainable preservation of urease enzymes in the soil environment is due to their affinity to organo-mineral complexes, which protect them from being metabolized by microorganisms (Zantua and Bremner, 1977; Skujiņš and McLaren, 1969). Urease activity has mainly been used in a geoarchaeological context as a proxy for livestock husbandry and manuring. For example, Chernysheva et al. (2015) and Reinhold et al. (2017) analysed urease activities from cultural layers within settlement remains in the Caucasus region (Russia). They identified areas with increased urea input into soils, which they attributed to either cattle pens or organic fertilization. The analysis of urease activities, and the urease/C_{mic} ratios, from colluvial deposits have been reported for the first time in the case studies presented

in this thesis (see section 4.3.1, 4.3.2 and 4.3.3). It was remarkable that the urease/C_{mic} ratios also peaked in soil depths with overall low SOC levels, which further underlines the high stability of urease in greater soil depths over millennia (section 4.3.2). The urease/C_{mic} ratio can be considered a reliable proxy for past urea input into the soil as the result of past land use practices and, within a multi-proxy approach, it contributes to a refined understanding of the nature and the spatial distribution of land use practices, such as livestock husbandry or manuring.

The research of faecal biomarker (e.g., sterols, stanols and stanones) has progressed in recent decades, and the analysis of lipids in soils derived from animal metabolisms has been established as a part of the soil scientific methodological spectrum and of (geo)archaeological research (Lauer et al., 2014; Prost et al., 2017; Bull et al., 2003) (see section 4.3.1, 4.3.2 and 4.3.3). In particular, 5ß-stanols, which mainly originate from microbial reduction of their molecular precursors (Δ^5-sterols) during omnivorous digestion processes, can be used as proxy for human and pig faeces (Birk et al., 2011). With a higher occurrence of (epi)-5ß-stigmasterol, herbivorous faeces are indicated. The differentiation between herbivorous and omnivorous faeces is further supported by the calculation of source-specific steroid ratios and the analysis of bile acids, which can even provide information at the level of species (Prost et al., 2017). In previous studies, Lauer et al. (2014) and Simpson et al. (1999) were able to identify organic manuring in the areas surrounding Neolithic and Roman settlements.

The processing and trading of metals have been a central aspect of prehistoric societies in Central Europe and were important for the production of tools for land use as well as for objects in the context of ritual practices (Höppner et al., 2005; Radivojević et al., 2019; Pernicka, 2014). The analysis of heavy metals from colluvial deposits have been frequently conducted to provide information on past metal processing in and around past settlements (Dreibrodt et al., 2009; Henkner et al., 2018b). However, the comparison of the geogenic background and the additional atmospheric or direct input by anthropogenic contamination in colluvial horizons often indicates a correlation between heavy metals and other soil parameters (e.g., $CaCO_3$, see manuscript II). This is fairly site dependent since the geological background can also vary on a local scale. Nonetheles, when considering the statistical range of heavy metals for a single profile reflecting the geogenic background, heavy metal analysis can contribute to the identification of past heavy metal contaminations associated with prehistoric settlement (manuscript in prep.).

Based on the methods for the analysis of colluvial deposits published by Pietsch and Kühn (2017), the analytical potential of colluvial deposits can be extended by such proxies that contribute to the reconstruction of past land use practices. These proxies allow insights into certain types of land use, which may have triggered soil erosion and sedimentation processes, and provide information on the utilization of land use areas in the surrounding of documented settlements.

4.2 Phases of colluvial deposition and land use at the Baar, in the Hegau and in the Westallgäu (Manuscript I, II, in prep.)

The stratigraphic and chronostratigraphic deciphering of colluvial deposits based on OSL and ^{14}C ages is fundamental for the reconstruction of the phases of colluvial deposition and related land use practices of nearby settlements (Kittel, 2015). This temporal framework of colluvial deposition can be linked to local archaeological records and provides detailed information on the history of past human-land interactions (Scherer et al., accepted).

For the determination of phases of colluvial deposition at the Baar, in the Hegau and in the Westallgäu, a total of 43 colluvial profiles with an average of five colluvial horizons per profile can be used. The thickness of colluvium and of the colluvial horizons was highest in the Hegau, and higher in the Westallgäu than at the Baar. Most of the profiles were described and most of the samples for analysis were taken at the Baar (Tab. 4.2); however, it should be noted that the study of colluvial deposits at the Baar included a larger catchment area and thus a higher number of colluvial profiles, since the previous phase of the B02 project focused on the investigation of colluvial deposition and land use dynamics on the level of landscape units (see Henkner et al., 2017; Henkner, 2018). The studies of colluvial deposits in the Hegau and in the Westallgäu were designed to investigate phases of colluvial deposition in smaller catchment areas, but in tighter relation to local archaeological sites; this must be taken into account when evaluating differences and similarities for phases of colluvial deposition and land use at the Baar, in the Hegau and in the Westallgäu on the basis of the available data.

The summed probability densities (SPDs) show the OSL and ^{14}C ages within their statistical ranges from colluvial deposits and buried soils for the study areas of the Baar, the Hegau and the Westallgäu (Fig. 4.1). In the Hegau and the Westallgäu, the oldest OSL signals were from buried subsoil horizons and date to the transition of the Praeboreal to the Boreal and to the Older Atlantic chronozone. At the Baar, similar observations were made with OSL signal from colluvial deposits that date to the Older Praeboreal and Older to Middle Atlantic chronozone. In Central Europe, it is assumed that human influence on the landscape during the Early to Middle Holocene was lower than in the succeeding periods (Bailey and Spikins, 2008; Bogaard et al., 2017); therefore, we interpret the OSL ages from the buried subsoils and colluvial horizons mainly as the result of naturally-induced bleaching processes such as tree throw or bioturbation by soil fauna (Bateman et al., 2007).

At the Baar (a), the beginning of major colluviation was dated to the Younger Neolithic (Fig. 4.1: red arrow), which is more than 2000 years earlier than the study areas of the Hegau (b) and Westallgäu (c). However, Neolithic colluvial deposits are not widespread in the study area but restricted to the sites of Magdalenenberg and Fürstenberg. At the Fürstenberg, approximately

Table 4.2: Number of colluvial profiles and samples taken and field descriptions at the Baar, in the Hegau and in the Westallgäu on the basis of the preceding and current funding phase of the B02 project (CRC 1070).

	Baar	**Hegau**	**Westallgäu**	**total**
Soil profiles	26	8	9	43
Bulk samples	402	279	236	917
Micromorphological samples	93	54	39	186
Microbiological samples	-	209	217	426
Anthracological samples	213	268	206	687
OSL samples	50	45	31	126
AMS ^{14}C charcoal samples	47	57	44	148
Pollen profiles	-	2	-	2
				mean ± sd
Thickness of colluvium	158 ± 57	249 ± 36	201 ± 50	203 ± 48
Thickness of colluvial horizons	108 ± 55	180 ± 46	162 ± 51	150 ± 51
Colluvial horizons per profile	3 ± 2	6 ± 1	6 ± 1	5 ± 1

50 cm of colluvial deposition were described which could be related to a nearby Neolithic settlement and to a higher degree of landscape openness (Scherer et al., accepted). From the Neolithic colluviation, Henkner et al. (2017) deduced the first main phase of colluvial deposition at the Baar. In the Hegau and the Westallgäu, Neolithic OSL signals mainly derived from buried subsoils and topsoils, which could indicate early soil tillage (Scherer et al., submitted). In the literature, Neolithic colluviation appears to be site-dependent, with soil substrate and local human impact as the main drivers of soil erosion and sedimentation. For example, Neolithic soil erosion has often been reported at loess-covered sites in Central and Eastern Europe (e.g., Lang et al., 2003; Poréba et al., 2019; Zádorová et al., 2013), while Neolithic evidence of soil erosion was, for example, lacking for the Weichelian glacial sediments in northeastern Germany (Kappler et al., 2018).

With the beginning of the Bronze Age, a higher probability of OSL ages was determined in the Hegau and Westallgäu. The first main phases of colluvial deposition in these areas were documented for the Middle Bronze Age (MBA), which could be related to corresponding settlement remains. At the study site of Anselfingen (Hegau), approximately 30 cm of sediment was accumulated during the MBA (see section 4.3.2), whereas at the study site of Winterstetten (Westallgäu) up to 85 cm of colluvial deposition could be documented (see section 4.3.3). At the Baar, similar observations were reported by Henkner et al. (2017), mainly based on the occurrence of MBA ^{14}C ages and a single OSL age dating to the end of the MBA period. Whether or not a main phase of colluvial deposition can be deduced from these data should at least be critically questioned, especially when considering the challenges of ^{14}C chronologies in redeposited sediments (Henkner et al., 2018a). Phases of colluvial deposition during the MBA were described by several soil scientist at different locations in Central Europe (e.g., Kittel, 2014;

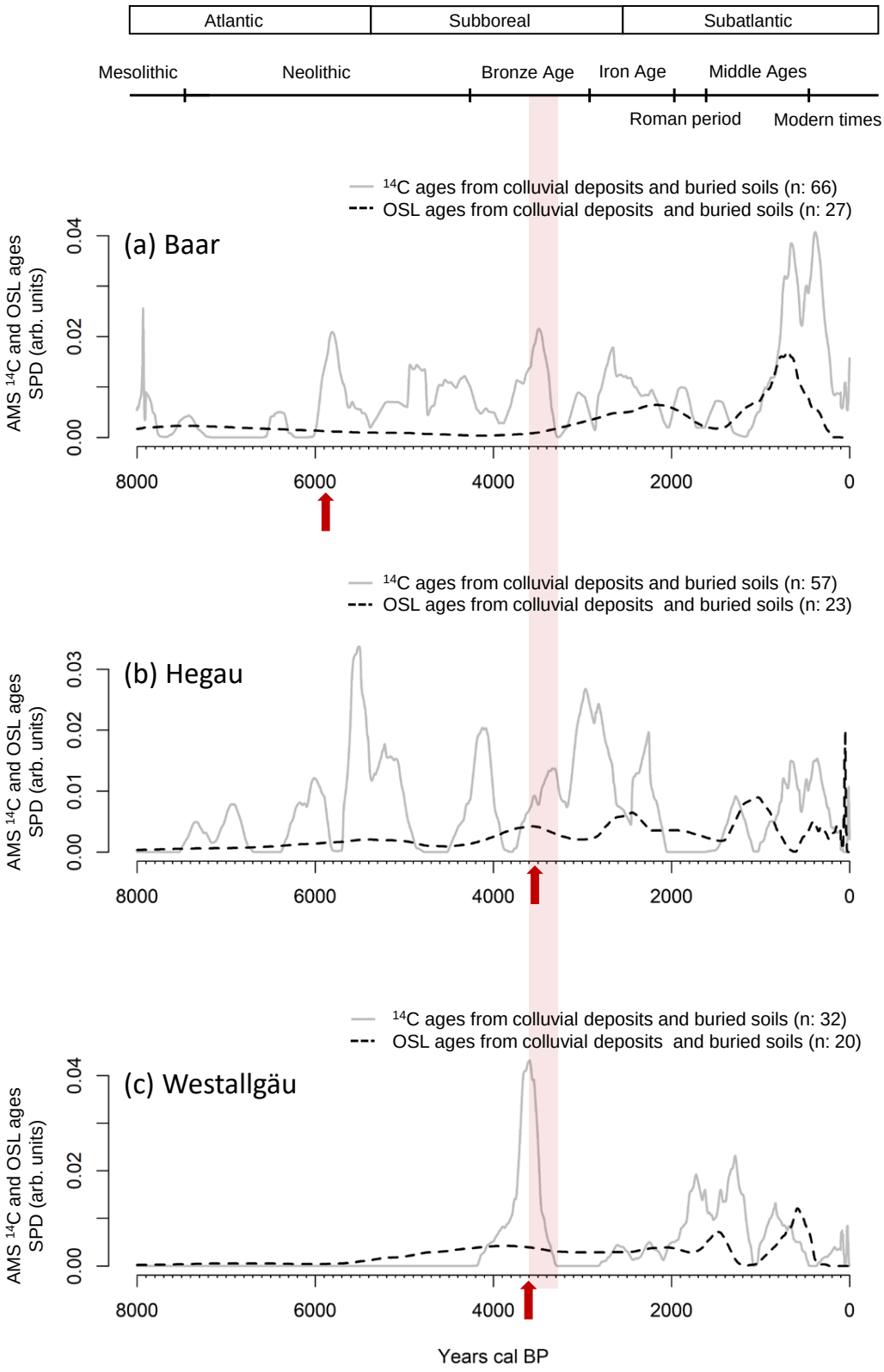

Figure 4.1: Summed probability densities (SPDs) of AMS ^{14}C and OSL ages from colluvial deposits and buried soils (a) at the Baar, (b) in the Hegau and (c) and in the Westallgäu. Red arrow: Beginning of colluviation according to the concept of boundary A (Edgeworth et al., 2015). Red bar: Time range of the Middle Bronze Age, which was the main focus of the investigations in manuscript (II, in prep.)

Henkner et al., 2018b; Mäckel et al., 2003; Lang et al., 2003) and seem to reflect a phenomenon that occurred on a supra-regional scale and was no longer as dependent on the soil substrate as during the Neolithic. Areas lacking MBA colluviation could be the result of missing human occupation or a certain form of land use (Dreibrodt et al., 2009; Vogt, 2014). Dreibrodt et al. (2009), for example, documented several phases of colluvial deposition since the Late Neolithic in northern Germany, and explained the absence of Bronze Age colluvial horizons with the presence of corresponding burial mounds which could have led to a stabilization of the soil surface.

During the Iron Age, phases of colluvial deposition were described at the Baar, in the Hegau and the Westallgäu. Henkner et al. (2017) used the climate as narrative to explain increased sedimentation rates at the Baar, as the Iron Age coincided with a phase of increased humidity and low temperatures (Jäger, 2002). However, human occupation during the Iron Age, which continuously increased from the Bronze Age, should also be considered when assessing possible triggers of colluviation at the Baar (Miera, 2020). In the Hegau, colluvial deposition during the Iron Age was accompanied by increasing rates of sedimentation (Scherer et al., submitted) and could be related to the corresponding settlement remains of the Anselfingen site (Ehrle et al., 2018). Human occupation and related land use activities may have also been responsible for the phases of colluviation during the Iron Age in the Westallgäu; however, both the sedimentation history and human occupation of the Westallgäu are poorly investigated, and archaeological evidence beyond the Neolithic period is rare (Höpfer et al., 2019). In the literature, it is generally assumed that the Iron Age was a period of major colluviation, mainly caused by intensive land use activities (Dotterweich, 2008; Dreibrodt et al., 2010b). Unfavourable climatic conditions may have additionally contributed to increased levels of soil erosion and sedimentation as suggested by Henkner et al. (2017).

Phases of colluviation also occurred during the Roman period, although the intensity decreased significantly. This is confirmed by the negative slopes of the SPD curves at the transition from the Iron Age to the Roman period. At the three study areas, phases of colluvial deposition during the Roman period could be explained by the regional and local archaeological records (Ehrle et al., 2018; Miera, 2020; Meyer, 2010), because during the Early Subatlantic chronozone the 'Roman optimum' is considered a phase of climatic favor, and therefore, cannot be held responsible for increased sedimentation rates (Bini et al., 2020). In other parts of Central Europe, the colluvial record is contradictory for the Roman period, with the presence and absence of sedimentation being viable at the regional and local scale (see section 1.3).

In the Westallgäu, there is a remarkable phase of colluvial deposition during the Migration period, which is based on OSL ages from the Leutkirch and Winterstetten site (see section 4.3.3). In contrast, comparable phases of sedimentation have not been documented at the Baar and in the Hegau. A possible explanation for increased sedimentation rates in the Westallgäu during the Migration period could be the preceding and pronounced peak in ^{14}C ages, which indicates

an intensified human impact in the form of deforestation. In the literature, the Migration period is suggested as phase of geomorphodynamic stability without or with only minor colluvial deposition (Henkner et al., 2018a; Dreibrodt et al., 2010b; Dotterweich, 2013).
Since the beginning of the Middle Ages, colluviation continuously increased, with major peaks in the High Middle Ages (Hegau) and Late Middle Ages (Baar, Westallgäu) (see also Dotterweich, 2008). These phases of sedimentation confirm intensified land use activities, as most of the European villages and cities were founded during the Medieval period (Fehring, 1987). Corresponding peaks in ^{14}C ages from the colluvial horizons at the Baar, Hegau and Westallgäu are in line with a higher anthropogenic impact.
The SPDs of ^{14}C ages indicate phases of human occupation, and related land use activities, at least since the arrival of the first settlers in Central Europe in the Early Neolithic (Price et al., 2001; Bogaard, 2004). These phases of increased anthropogenic influence were probably accompanied by deforestation on different scales and by subsequent soil tillage for guaranteeing subsistence economies. At the Baar and in the Hegau, ^{14}C ages from charcoal that go back to the Early Neolithic correspond to the local and regional archaeological record (Ehrle et al., 2018; Miera, 2020). However, the absence of Neolithic ^{14}C ages from charcoals in colluvial horizons and buried soils in the Westallgäu is remarkable and in contrast to the available data from the BELAVI ('Beyond Lake Villages') project. According to archaeological, as well as onsite and offsite archaeobotanical data, the scholars from the BELAVI project dated the first phase of human occupation in the Westallgäu to the end of the Middle Neolithic (4400-4300 BCE). Around 3700 BCE the intensity of human occupation was highest and corresponds to phases of human-land interaction at nearby Lake Constance (Ebersbach et al., 2019; Mainberger et al., 2019). However, this contrast in ^{14}C ages underlines the local character of human occupation and land use reflected in the colluvial deposits. Another difference in ^{14}C ages is observable from the Late Bronze Age to the end of Late Iron Age (Latène period). During these phases, human occupation at the Baar and in the Hegau is confirmed through several peaks in ^{14}C ages, while in the Westallgäu contemporaneous ^{14}C ages are missing. Since the occurrence of archaeological remains in the Westallgäu is poorly investigated, the causes of the absence of ^{14}C ages cannot be exclusively assessed; however, climatic deterioration with an increase in humidity and a decrease in temperatures might have contributed to a lower charcoal production rate (Jäger, 2002).
Besides the individual reflection of SPDs, either on the basis of OSL or ^{14}C ages, a general observation can be made when observing both curves simultaneously. In case of a sufficient number of ages given for a certain period, the peaks in OSL and ^{14}C ages are temporally shifted in a way that peaks in ^{14}C ages precede peaks in OSL ages. This can be especially observed at the Baar since 50 BCE (2050 BP), in the Hegau since 1800 BCE (3800 BP) and in the Westallgäu since 200 CE (1800 BP) (see Fig. 4.1). Assuming that the anthropogenic influence has continuously increased since the Neolithic – excluding local phases of decline in human

occupation – the peaks in ^{14}C ages could indicate a higher intensity of charcoal production as a result of land use practices such as deforestation and landscape maintenance (e.g., slash and burn agriculture). These land use practices were accompanied by removing the vegetation cover on the soil surface to prepare the soils for tillage and crop cultivation. Once deforestation has begun, and land use change was initiated, soils along hillslopes were more prone to water soil erosion processes. During these phases of increased colluviation, an open landscape, with overall low charcoal-production rates, can be assumed; however, the temporal gap of approximately 200 years between the ^{14}C and OSL peaks must be explained since soil erosion and sedimentation processes undoubtedly commenced right after the landscape was opened. There are two possible explanations: (1) Assuming that phases of human-land interaction and natural succession were alternating, several phases of matured forest ecosystems have occurred since the Neolithic; hence, the so-called 'old wood effect' must be considered and could bridge the gap of several hundred years between OSL and ^{14}C ages. To overcome this limitation, the anthracological determination of charcoals before dating is crucial! (2) when using OSL dating for the reconstruction of phases of colluvial deposition, the OSL signal determines the last bleaching of mineral grains by sunlight. Whether the last bleaching occurred during the erosional transport along the hillslope, or during the last phase of soil tillage (e.g., ploughing at the foot slope positions) can not be exclusively assessed; therefore, Van der Meij et al. (2019) proposed to use modelled OSL ages in agrarian landscapes that include human impact as a potential driver of last mineral bleaching. This could potentially explain the temporal gap between OSL and ^{14}C ages – and also their interdependence – with the ^{14}C ages dating to the beginning and the OSL ages to the ending of human impact.

In summary, the OSL and ^{14}C chronologies, combined with the local and regional archaeological records, allow for a detailed overview of the phases of colluvial deposition, land use and human occupation at the Baar and at the study sites of Anselfingen (Hegau), Leutkirch and Winterstetten (Westallgäu). Even if the data sets cover different catchment area sizes, a general idea of the human-land interaction in the study areas is given. In terms of the Favor-Disfavor dichotomy, a differentiation between the Westallgäu and the study areas of the Baar and Hegau is observable, with the initial phase of land use, as given by ^{14}C ages, being much younger compared to the Baar and Hegau. This indicates that the Westallgäu was much later occupated than the areas of the Baar and the Hegau. However, this is diametrically opposed by the local archaeological records gained in the BELAVI project (Ebersbach et al., 2019; Mainberger et al., 2019). It is also remarkable that colluviation began approximately 2000 years earlier at the Baar compared to the Anselfingen site, while at both sites Neolithic settlement remains and corresponding ^{14}C ages were documented (Ehrle et al., 2018). In the end, phases of colluvial deposition during the Late Holocene cannot be independently interpreted from the local archaeological record. Conversely, the combination of the analysis of colluvial deposits and local archaeological records provide in-depth information on past human-land interactions,

which would not be possible on a single disciplinary level.

4.3 Archaeopedological reconstruction of land use practices from colluvial deposits in southwestern Germany

One goal of this thesis is the interpretation of human behaviour in favourable and unfavourable landscapes in the light of different resources. Therefore, three case studies were designed to study land use practices in the areas surrounding (Middle Bronze Age, MBA) settlements in southwestern Germany. The first case study comprised the multi-proxy analysis of a multi-layered colluvial profile close to the prehistoric site of Fürstenberg (Baar, section 4.3.1). In this case study, a diachronic investigation of phases of colluvial deposition, pedogenesis and land use practices were synchronized with the local archaeological record of the Fürstenberg site. The second case study dealt with the reconstruction of onsite and near-site land use practices from colluvial deposits and archaeological features at the well-documented settlement site of Anselfingen (Hegau, section 4.3.2). In this case study, a multi-proxy approach was applied to gain detailed insights into the MBA land use practices and corresponding vegetation changes in the northwestern Alpine foreland, which were compared to offsite pollen signals from two peat bogs. In the third case study, two MBA sites were investigated in order to evaluate human occupation in the Westallgäu, where archaeological and archaeopedological evidence is so far scarce (section 4.3.3). Again, data acquired through a multi-proxy approach to several colluvial profiles was synchronized with the local archaeological record to provide insights into MBA human-land interaction in the Westallgäu. In consideration of the Favor-Disfavor dichotomy, the three study areas were conclusively compared regarding the occurrence and intensity of certain land use practices as well as human occupation during the Middle Bronze Age (section 4.3.4).

4.3.1 Case study I: Multi-proxy analysis of a multi-layered colluvial profile at the prehistoric site of Fürstenberg (Baar) (Manuscript I)

The guiding question of the manuscript I 'What's in a colluvial deposit?' focused on refining the analytical potential of colluvial deposits with respect to the reconstruction of prehistoric land use practices. Therefore, the well-dated and multi-layered colluvial profile 'Fue 8', in the area surrounding the prehistoric site of Fürstenberg (FUE site), was diachronically investigated using a multi-proxy approach, which comprised different pedological and biogeochemical analyses.

The Fürstenberg mountain is a so-called 'Zeugenberg' located in southwestern Germany, at the transition area between the Baar and Swabian Jura. The 'Fue 8' profile is embedded into a well-resolved catena at the southwestern slopes of the Fürstenberg, containing three different colluvial profiles and 16 augers (see Fig. 4.2, B). The catena was first investigated by J. Henkner (see Henkner, 2018; Henkner et al., 2017) as part of the previous funding phase of the B02 project. Due to its detailed and pronounced stratigraphy, the 'Fue 8' profile was selected for the multi-proxy approach on a single colluvial deposit. The applied methods were described in detail in manuscript I.

The 'Fue 8' stratigraphy comprised a fully preserved Cambisol which was buried by six colluvial horizons (see Fig. 4.3). These six phases of colluvial deposition occurred through five phases of land use comprising the Early to Younger Neolithic, the Urnfield to Hallstatt period, the Iron to Roman Age, the High Middle Ages, and the pre-modern period. Pre-Neolithic human occupation was not documented at the FUE site, and the charcoal and phytolith assemblages from this period indicate a naturally occurring oak-mixed forest vegetation, which was typical for the Atlantic period in southwestern Germany (Rösch, 1987) (see Fig. 4, Tab. 3 in manuscript I).

The first phase of human occupation coincided with the formation of the colluvial horizons M6 and M5 between the Early and Younger Neolithic (5500-3800 BCE). Remarkably, the OSL dated sediments of M6 and M5 were approximately 2000 years older than the corresponding ^{14}C dated charcoals, which ranged from the Late Neolithic to the Late Bronze Age. Since the OSL parameters did not indicate insufficient bleaching of mineral grains, the *in-situ* relocation of charcoals through pedo- and bioturbation processes was considered the driving factor of the observed age inversions. Similar observations were also reported by Vogt (2014) for a colluvial sequence from the area surrounding Lake Constance in southwestern Germany. The phytolith assemblages of horizons M6 and M5 showed a high abundance of grass morphotypes, while the charcoal determinations indicated a natural forest ecosystem mainly consisting of *Quercus*; this suggested that during the Early and Younger Neolithic, a patchy landscape with natural oak-mixed forests and small-scale open areas existed as the result of increasing human influence (Rösch, 1987). Both the analysis of BC and organic matter composition by pyrolysis-field ionization mass spectroscopy (Py-FIMS, see Tab. 4 in manuscript I) indicated that the maintenance of small-scale open areas was supported by the use of fire. Whether livestock was kept at the FUE site in the Early to Late Neolithic period or whether arable land was fertilized with animal faeces cannot be assessed exclusively, since the markers for past urea (urease/SOC) and faecal input (5ß-stanols, (epi)-5ß-stigmastanol) were only weakly represented (see Fig. 4.4).

There was a remarkable hiatus of about 3300 (min) and 4900 (max) years in OSL ages between colluvial horizons M5 and M4 at the 'Fue 8' profile (see Fig. 4.3). This hiatus indicated a geomorphodynamically stable phase without intensive sedimentation but with soil formation processes (increased values of Fe_d/Fe_t and CIA) from the Early to Younger Neolithic (M5) to the

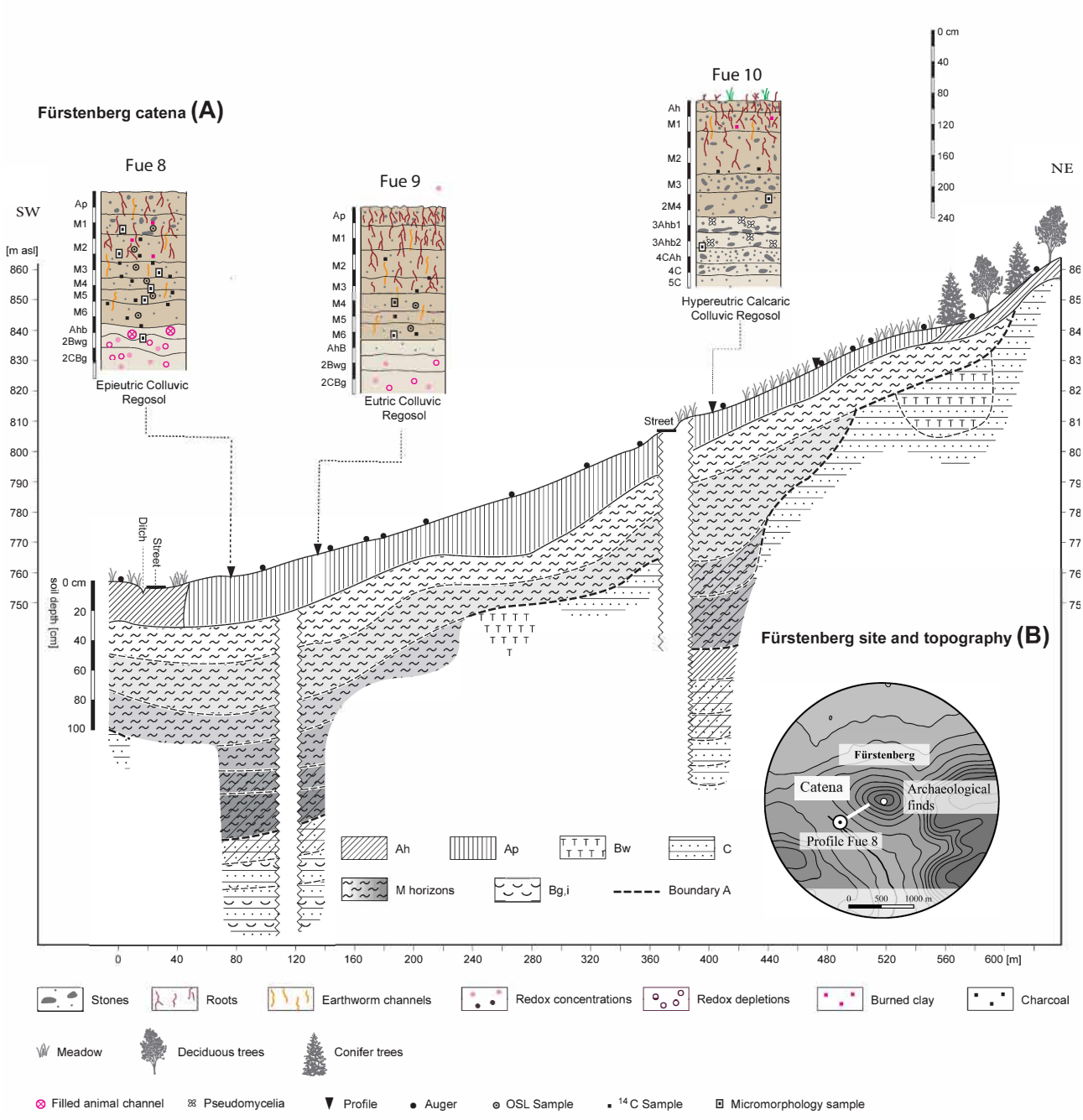

Figure 4.2: Catena and pedostratigraphy of the southwestern slope of Fürstenberg (A); Topography and location of the prehistoric site of Fürstenberg, the catena, and the Fue 8 profile (B); Adapted from (Henkner et al., 2017)

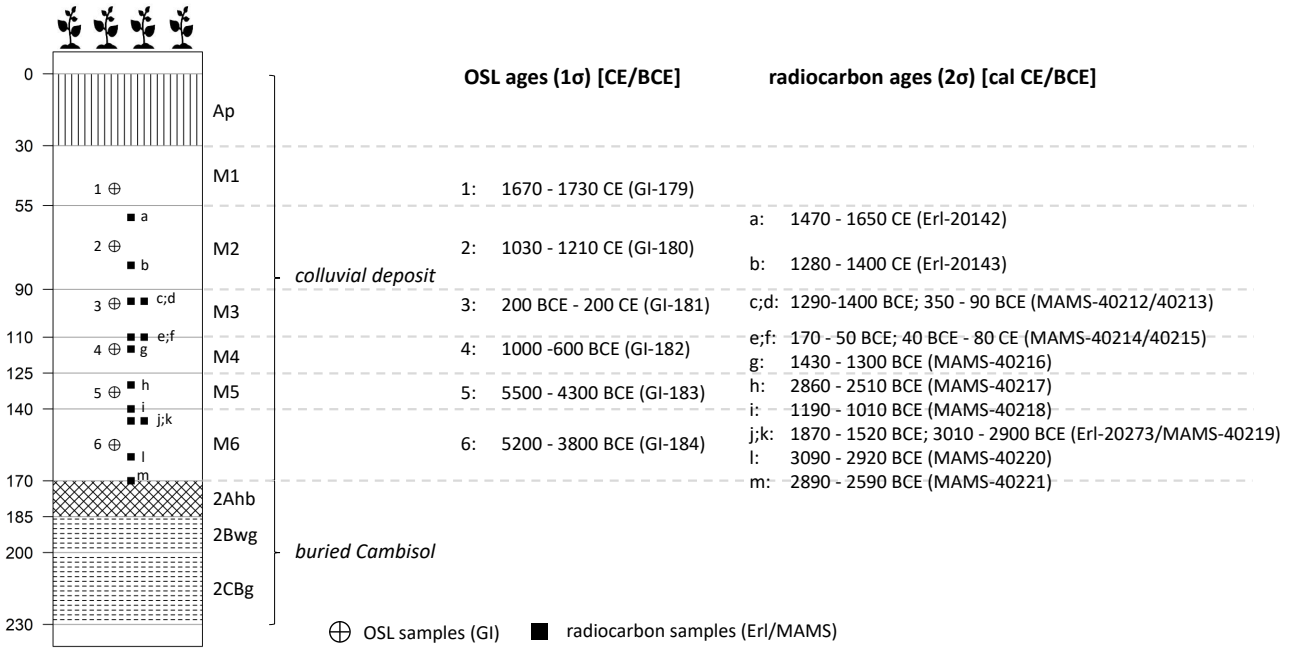

Figure 4.3: Pedostratigraphy, OSL and AMS-^{14}C ages of the Fue 8 profile (Scherer et al., accepted); ^{14}C ages were calibrated with OxCal v4.3.2 after Bronk and Ramsey (2017) using the IntCal13 atmospheric curve according to Reimer et al. (2013); OSL and ^{14}C ages are adapted from (Henkner et al., 2017); ^{14}C samples were analysed in Erlangen (Erl) and Mannheim (MAMS), OSL were are analysed in Gießen. Figure from Scherer et al., accepted.

Urnfield to Hallstatt period (M4) (see Tab. 1 in manuscript I). The ^{14}C dated charcoal from the corresponding soil depths supported this phase of slope stability, suggesting an accumulation of charcoal from the Final Neolithic to the Middle Bronze Age. However, a differentiation between the natural accumulation of charcoal, through wildfires, and the anthropogenic accumulation by land use practices to maintain an open landscape was not achievable by biogeochemical proxies. The local archaeological record indicated a gap in human occupation during the Early and Middle Bronze Age that underlines the relevance of colluvial deposits as the correlate sediments of human-induced soil erosion (Kadereit et al., 2010).

The colluvial deposition of M4 coincided with a phase of human occupation of the FUE site during the Urnfield to Hallstatt period (1000-600 BCE) (see Fig. 4.3). Both the phytolith and the charcoal assemblages showed a distinct change in the vegetation composition during that time. The phytolith data revealed a striking change in the abundances of phytoliths originating from C_4 plants compared to phytoliths originating from C_3 plants, which could be either climatically-driven (from drier to more humid conditions) or the result of a changing land management practices (from e.g., grassland to arable fields). However, the absence of further agricultural proxies, as well as the increasing abundance of *Juniperus*, a peak in the urease/SOC ratio and the occurrence of 5ß-stigmastanols can be interpreted in a way that suggests that livestock husbandry was more likely than arable farming on the southwestern slopes of the Fürstenberg. Moreover, the charcoal assemblages showed an increase of *Fagus*

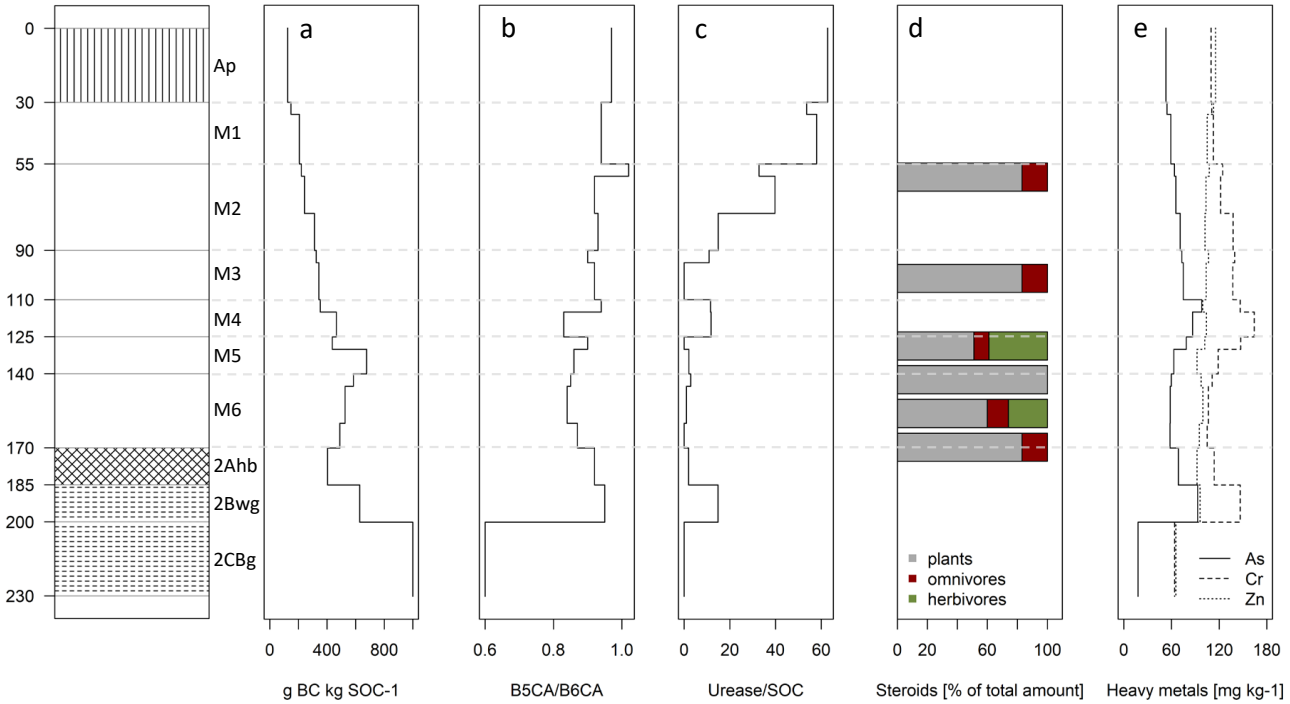

Figure 4.4: Depth functions of black carbon/soil organic carbon ratio (BC/SOC, a), pentacarboxylic acid/mellitic acid ratio (B5CA/B6CA, b), urease/soil organic carbon ratio (Urease/SOC, c), relative amounts of steroid compounds (as % of total amount, d) and heavy metals contents (As = arsenic, Cr = chrome, Ni = nickel, e) (Scherer et al., accepted). All detected steroid compounds are summarized in the compound classes plants (ß-sitosterol), herbivores (5ß-stigmastanol) and omnivores (coprostanol, epicoprostanol, coprostanone) based on their probable input pathway into the soil. Figure from Scherer et al., accepted.

at the expense of *Quercus* during the Urnfield to Hallstatt period, which could suggest a formerly dense forest vegetation before the contemporaneous land use. However, if this was the case, much more effort would have been required to open and prepare the landscape for habitation, effort which could have been accompanied by a more intensive biomass burning. A higher fire intensity during the Urnfield to Hallstatt period was clearly indicated by high BC concentrations and the occurrence of thermally stable organic matter (Py-FIMS). Furthermore, the pentacarboxylic to mellitic ratio (B5CA/B6CA) was < 1 and suggested the occurrence of mostly high temperature (anthropogenic) fires (see Wolf et al., 2013) (see Fig. 4.4).

The formation of M3 (200 BCE-200 CE) could be related to a Roman occupation of the FUE site (see Fig. 4.3). However, Wagner (2015) suggested no intensive Roman land use, since the FUE site can be considered unfavourable due to its exposure to extreme weather events and its limited water supply. This less intensive Roman land use was also reflected in the biogeochemical and archaeobotanical record of the 'Fue 8' profile. The phytolith assemblages still indicated a high occurrence of monocotyledonous morphotypes (e.g., grasses), while the dicotyledonous morphotypes (woody vegetation) increased relative to the underlying horizons.

Together with the charcoal spectra, which still showed high abundances of *Fagus* and *Juniperus*, the analysis indicated a human-modified vegetation. Both the analysis of BC and organic matter composition revealed that the use of fire presumably lost importance during the Hallstatt period (see Fig. 4.4). Moreover, the low levels of urease/SOC, as well as herbivorous/omnivorous markers supported H. Wagner's assumption, that there was a military post on the Fürstenberg during the Roman period (Wagner, 2015).
Two more phases of colluvial deposition were documented in the 'Fue 8' profile; these phases could be attributed to the High Middle Ages (1030-1210 CE) and the pre-modern period (1670-1730 BCE) (see Fig. 4.3). Based on the biogeochemical proxies, the intensity of land use seemed to decrease further during this period (see Fig. 4.4). The archaeobotanical record of charcoal and phytoliths at least documented human presence (high abundance of grass morphotypes, increase in conifers) in the area surrounding the FUE site. However, an overall ubiquitous human presence since the Middle Ages can be assumed in Central Europe (Fehring, 1987) and is supported through the foundation of the Fürstenberg village around 1200 CE (Wagner, 2015).
Summarizing discussion: The multi-proxy approach to the multi-layered colluvial profile 'Fue 8' provided in-depth insights into the phases of colluvial deposition, which can be related to phases of human occupation and land use practices at the prehistoric site of Fürstenberg. Colluvial deposition began during the Neolithic, while corresponding land use proxies mainly reflected changes in local vegetation composition. Between the Final Neolithic and the Late Bronze Age (Urnfield period), a geomorphodynamically stable phase was observed, which coincided with a decreased intensity of human impact but increased pedogenesis Between the Urnfield to Hallstatt period, colluvial deposition commenced again, which was attributed to an Early Iron Age settlement at the FUE site. During that time, land use practices such as livestock husbandry and the use of fire were likely. During the Roman period, colluvial deposition coincided with the Roman occupation of the Fürstenberg, but the intensity of land use low. Further phases of land use were suggested by the formation of colluvial horizons during the High Middle Ages and the pre-modern period, as well as by the increase in conifer species in the charcoal spectra. However, the corresponding land use proxies indicated that at least the southwestern slopes of the Fürstenberg were not affected by a certain type of land use after the Roman occupation.

4.3.2 Case study II: Multi-proxy analysis of colluvial deposits, archaeological features and peat bogs in the north-western Alpine foreland (Hegau) (Manuscript II, III)

This study aimed to reconstruct Middle Bronze Age (MBA) land use practices in the north-western Alpine foreland. Therefore, an interdisciplinary approach, combining the (sub-)disciplines of soil sciences, archaeology, archaeobotany and archaeozoology, was applied. This study fo-

cused again on the multi-proxy analysis of colluvial deposits but also included onsite investigation of charred organic remains and animal bones at the well-documented MBA settlement site 'Anselfingen Breite' (ABR site). The comparison of the results from the onsite and near-site analyses of colluvial deposits and archaeological features with data from two offsite pollen profiles allowed for in-depth insights into MBA land use practices and vegetation changes on a local and regional scale. This study was important because the investigation of onsite and near-site land use practices is limited at sites with aerobic soil conditions due to the weak preservation of biogeochemical proxies, archaeological remains and organic material. However, most of the MBA settlements in the Hegau are found further inland, where subaqueous soil conditions are mostly absent. The analysis of biogeochemical proxies from colluvial deposits can help to overcome this drawback, since the continuous sedimentation impedes degradation by microorganisms and weathering processes, and additionally provides information on the temporal input of the analysed proxies.

At the ABR site, at least nine phases of human occupation were documented; these phases comprise the Younger and Final Neolithic, the Early, Middle and Late Bronze Age, the Hallstatt and Latène period of the Celtic Iron Age, and the Roman period (Ehrle et al., 2018). To date, approximately nine hectares have been excavated, and another four hectares have been explored by trench-prospection. In the surrounding area of the MBA settlement, eight colluvial profiles were located to investigate MBA land use areas (see Fig. 2 in manuscript II). On average, the thickness of colluvial profiles was 180 ± 46 cm, and the transition between colluvial horizons and paleo surfaces, according to the concept of 'boundary A' (Edgeworth et al., 2015), could be observed for every profile. Four colluvial profiles were selected for ^{14}C and OSL dating (see Fig. 4.5), and the applied methods were described in detail in section *2.5 Laboratory analyses* and the corresponding supplement material in manuscript II.

The OSL and ^{14}C ages indicated main phases of colluvial deposition during the MBA, the Iron Age, the Medieval period and the pre-modern times (see Fig. 4.5, and Fig. 4.1 in section 4.2), which could be synchronized with the local archaeological record of the ABR site. Despite the fact that Neolithic land use was indicated by ^{14}C ages and archaeological remains, no or only minor colluviation was observed. Most of the Neolithic OSL signals derived from the paleo surface. The MBA colluvial horizons and former land surfaces in the surrounding area of the ABR settlement site were considered promising archives for studying MBA land use practices in the northwestern Alpine foreland.

Based on the pollen record of Lake Steißlingen, which is about 15 km southeast from the ABR site, thermophilus deciduous forests, comprising the species *Quercus, Alnus, Fraxinus, Ulmus* and *Corylus*, were naturally growing during the Subboreal (Kerig and Lechterbeck, 2004; Eusterhues et al., 2002; Lechterbeck, 2001). However, the charcoal assemblages from the MBA colluvial horizons at the ABR site indicated a distinct dominance of *Quercus* above all other species (see Fig. 6 in manuscript II). A similar observation was made for charcoal spectra from

MBA fireplaces and fire pits at the ABR site (Höpfer et al., accepted, manuscript III). Hence, a human-induced promotion of *Quercus*, for wood procurement and forest pasture (e.g., acorn pigs), was likely. The very good fuel quality of *Quercus*, along with occasionally observed insect holes

within the charcoal fragments and the smaller branch diameters, were interpreted as indicators that wood procurement followed the 'principle of least effort.' The phytolith assemblages from the MBA colluvial horizons further provided information on an increased openness of the landscape surrounding the MBA settlement, with a predominance of monocotyledonous morphotypes. The concentration of dicotyledonous morphotypes was relatively increased in colluvial profiles in the northern surrounding area of the settlement (see Tab. 2 in manuscript II). The use of fire during the MBA was indicated by the PAH patterns predominantly showing the burning of biomass (see Fig. 9 in manuscript II). The high levels of phenanthrene, which point to the occurrence of fire condensates, indicated that combustion processes within a larger catchment area than the ABR site may have contributed to the PAH accumulation in the colluvial profiles. Furthermore, the PAH suites from the colluvial profile within the settlement area (onsite) were more complete than the PAH suites from the colluvial profile at some distance from the settlement area (near-site). This can be interpreted as suggesting that within the settlement a variety of combustion processes such as domestic fires, technical applications (e.g., burning of ceramic and metals) and ritual fires may have contributed to the accumulation of PAHs.

The growing of cereals and other agrarian products was essential for prehistoric societies and guaranteed their nutritional base. In the surrounding area of the MBA settlement, there were several hints of MBA arable farming, even beyond the mere occurrence of colluvial deposits. During field work, a plough horizon was observed, which was buried by 170 cm of colluvial deposit. OSL dating showed that the mineral grains of the plough horizons were last bleached during the MBA, and the corresponding ^{14}C ages additionally indicated an MBA land use (see Fig. 4.5, ABR SA2). Micromorphological analysis supported the occurrence of human disturbances of the soil structure by ards and ploughs in the MBA plough horizons (see Fig. 8 in manuscript II) according to the observation by Lewis (2012). Moreover, the phytolith morphotypes predominately originated from the leaves and stems of the monocotyledonous plants, while the inflorescences of these plants were rarely found. This is likely the result of harvesting the economically valuable part of the cereals. The investigations of onsite charred archaeobotanical remains from archaeological features (fire pits) indicated the occurrence of *Hordeum distichon/vulgare, Triticum dicoccum, Triticum monococcum, Triticum aestivum/turgidum*, and *Triticum spelt*, and comprised the spectrum of cereals typical for the Early and Middle Bronze Age (Rösch et al., 2014) (see Fig. 7 in manuscript II). The post-processing of cereals was indicated by stilted pantries and heat stones found at the ABR site (Höpfer et al., accepted). Stilted pantries have frequently been excavated in the northwestern Alpine foreland and are

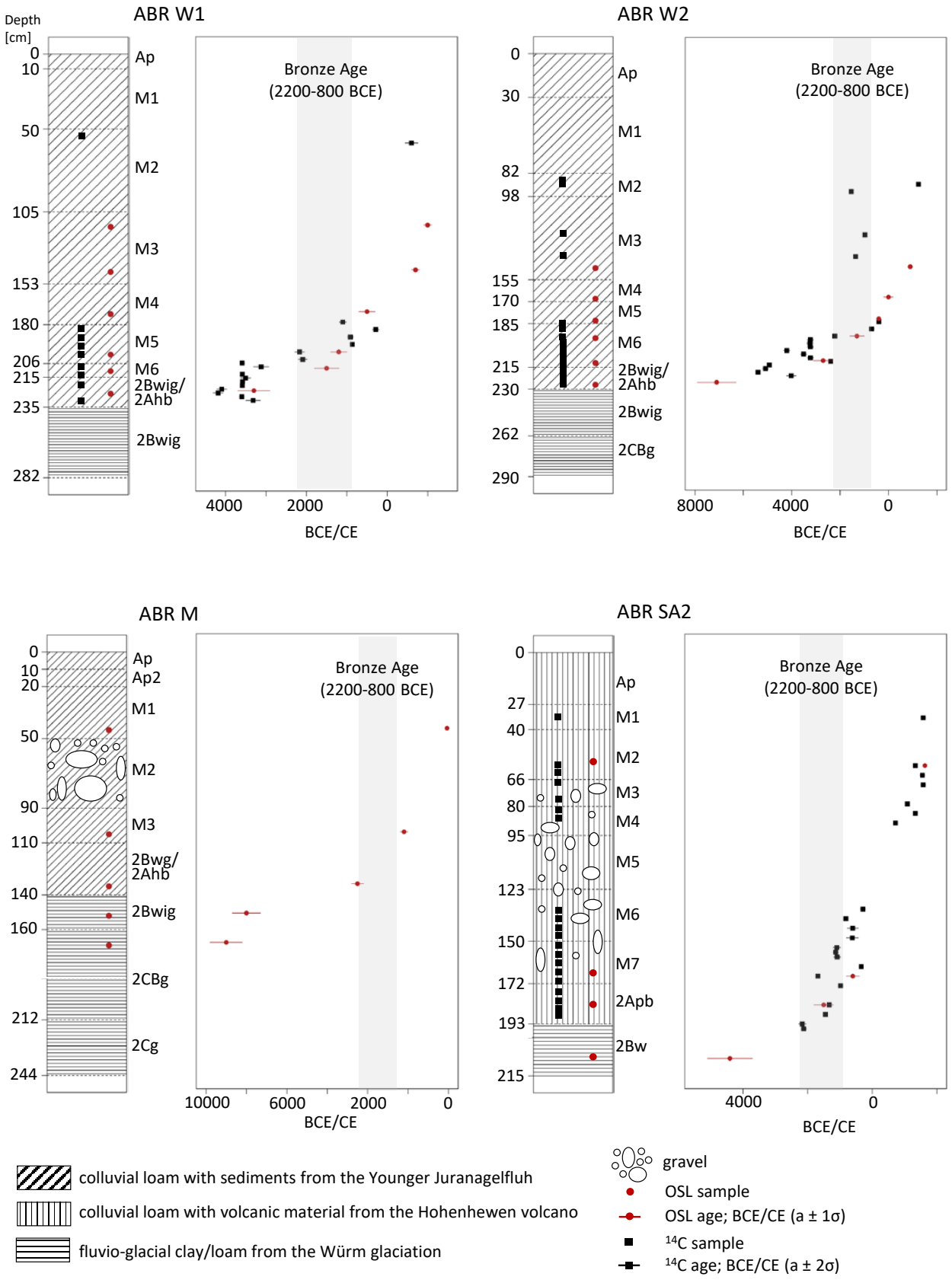

Figure 4.5: Colluvial profiles used for OSL and ^{14}C dating at the ABR site (Scherer et al., submitted). Profile designations are given in bold, colluvial horizons are designated as M. Figure from Scherer et al., submitted.

interpreted as storage facilities (mostly for cereals) (Gnepf-Horisberger and Hämmerle, 2001). Heat stones, which have been frequently found in pit deposits, are most often considered cooking objects, and were probably important for the roasting of cereals or other agrarian products (Lindemann, 2008). Through summing up the indications for arable farming, from colluvial deposits and archaeological features at the ABR site, an elaborated agricultural approach with different sowing and harvesting times, distribution of labor throughout the year and storage opportunities can be deduced; this agricultural elaboration would have guaranteed the food supply and nutritional base for the MBA settlers.

Besides arable farming, livestock husbandry and manuring were probably additional elements of the MBA subsistence economy at the ABR site. Therefore, proxies that provide information on past urea and faecal input can help reconstruct prehistoric farming activities. From the colluvial deposits in the surrounding area of the MBA settlement, urease enzymes and faecal biomarker (sterols, stanols, stanones) were extracted. The newly introduced urease to microbial biomass carbon ratio (urease/C_{mic}) indicated past eutrophicated areas that could be attributed to the MBA (see Fig. 10 in manuscript II). This was further supported by relatively high concentrations of 5ß-stanols, especially in the northern surrounding area of the MBA settlement, which mostly derive from omnivorous faeces (from microbial reductions of their molecular precursors Δ^5-sterols) (see Fig. 11 in manuscript II). In combination with the predominance of *Quercus* and increased abundance of dicotyledonous phytoliths in this area, a forest pasture for pig farming appeared likely. Pig bones excavated from MBA features further confirmed the presence of pigs at the ABR site (see Tab. 3 in manuscript II). The identification of epi-5ß-stigmastanols in the southern surrounding area of the settlement indicated livestock husbandry on fallow land, which could have also contributed to the increased urease/C_{mic} ratios there. However, the occurrence of manuring in Central Europe before the Roman period is still debated (e.g., Bogaard, 2004; Rösch et al., 2014). For example, Tserendorj et al. (accepted) analysed onsite and offsite archaeobotanical data and showed that extensive field-grass-economies without manuring, but with continuous fallow land, were most likely during the Bronze Age. Nevertheless, the increased concentrations of urease as well as 5ß-stanols and epi-5ß-stigmastanols could also indicate the intentional application of manure to MBA fields.

The distribution of heavy metals in the colluvial profiles at the ABR site was mainly positively correlated to soil parameters (e.g., $CaCO_3$) and only a few positive outlier could be identified for the different soil substrates (see Fig. 12 in manuscript II). However, a copper ingot of about 2 kg, which was a trading form of copper and originated most probably from the eastern Alps (Lutz and Pernicka, 2013), at least suggests that metals played a role at the MBA settlement in Anselfingen.

The comparison of the onsite and near-site biogeochemical and archaeobotanical proxies with the offsite pollen data from the two peat bogs Hartsee (Fig. 4.6) and Grassee (see Fig. 13 in manuscript II) revealed similar patterns of vegetation change on a local and regional scale

during the Bronze Age. The remarkable peak of non-arboreal pollen (NAP) between 1500 and 1400 BCE in the Hartsee profile strongly supports MBA disturbances of natural vegetation composition on a regional scale (Fig. 4.6). In the pollen diagram of Hartsee, phases of *Fagus* alternated with phases of microcharcoal peaks, which were then followed by increases in *Quercus* and pollen indicators of agriculture (*Triticum*-type) and pasture (*Plantago lanceolata*). Hence, arable farming and forest management (e.g., forest pasture) were also reflected in the pollen data and were in line with the onsite and near-site archaeopedological records of the ABR site. Summarizing discussion: The interdisciplinary approach, which included the (sub-)disciplines of soil sciences, archaeology, archaeobotany and archaeozoology, provided in-depth insights into MBA land use practices in the northwestern Alpine foreland. The multi-proxy analysis of colluvial deposits and archaeological features showed evidence of MBA land use activities, which undoubtedly triggered the formation of colluvial deposits. The biogeochemical proxies indicated different land use practices such as arable farming, ploughing, possibly manuring, livestock husbandry (in forests and on fallow land) and wood procurement, and were supported by the onsite archaeobotanical and archaeozoological remains from the ABR site. The observed vegetation changes and land use practices were not only observed from the archives studied at the ABR site, but also from the offsite pollen data. Hence, a characteristic landscape during the MBA can be assumed in the northwestern Alpine foreland and a gap in the Middle Bronze Age research beyond the Lake Constance lakeshores in the Hegau can be filled.

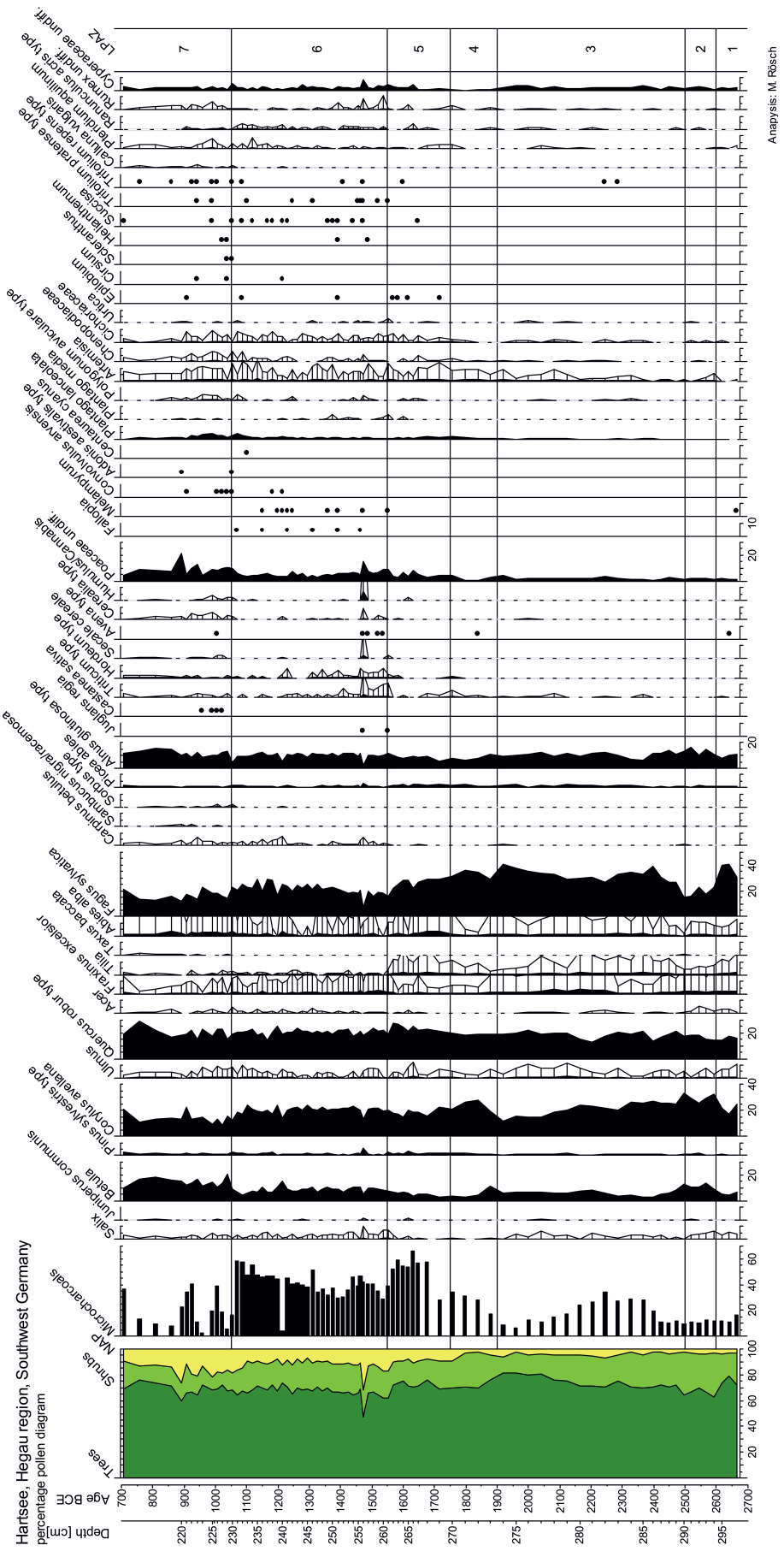

Figure 4.6: Pollen profile of the Hartsee mire. NAP: non-airborne pollen, the samples were investigated in increments of one cm. Figure from Scherer et al., submitted.

4.3.3 Case study III: Bronze Age land use derived from colluvial deposits and archaeological records at two sites in the Westallgäu (Manuscript in prep.)

This study aimed at investigating Bronze Age land use in the Westallgäu, which is generally considered unfavourable due to climatic conditions and topography. Compared to the 'favorable' Hegau, the Westallgäu is on average 200 m higher and has about 500 mm more precipitation (see section 3.1). This disfavor is also reflected in the weakly investigated regional archaeological record (Krahe, 1958) and sedimentation history (Vogt, 2016). The BELAVI project, a trinational cooperation between scientists from Switzerland, Austria and Germany, was the first to start archaeological research on the landscape of the Westallgäu on a regional level. However, there is no evidence of Bronze Age land use in the areas surrounding documented settlements, and, in general, evidence of Middle Bronze Age (MBA) settlement is sparse in the Westallgäu (Mainberger et al., 2010; Mainberger, 2015; Ebersbach et al., 2019).

Colluvial deposits in the surrounding area of the Middle Bronze Age settlement in Leutkirch (LUA site)

The MBA site 'Leutkirch Untere Auen' (LUA site), which is in the northern part of the Leutkirch city, comprised architectural remains, fireplaces with heat stones and shards. These archaeological features were partially excavated during the field campaign of 2018, except for the MBA fireplaces which were excavated during an earlier field campaign organized by volunteers. Four alluvial/colluvial profiles (LKNT 1, LKNT 2, LKNT 3 and LKTT 1) were established in the surrounding area of the settlement to allow insights into the MBA land use areas. Three of these profiles were located in the floodplain area of the Eschach River, underneath the lower terrace edge, while the profile LKTT1 was located in a paleochannel (figure 4.7).
The profiles LKNT 2 and LKTT 1 of the LUA site were selected for numerical dating (Fig. 4.8) due to their pronounced stratigraphy. The profile LKNT 2 was composed of five alluvial horizons, which buried a truncated Cambisol profile. The OSL ages showed a consistent chronostratigraphy with phases of sedimentation during the Early Bronze Age, the Late Bronze Age, the Roman period, and the High Medieval Ages. The corresponding ^{14}C ages indicated phases of land use during the Hallstatt period, the Roman period, and the High Medieval Ages. However, the chronostratigraphy of ^{14}C ages revealed age inversions, which are the result of a high biodiversity and/or mixing processes during the fluvial transport. A high abundance of *Lumbricus terrestris* was observed during field work and is typical in alluvial soils (Bauer et al., 1998). Moreover, ^{14}C ages have been reported to be erroneous for dating alluvial sedimentation events (Blong and Gillespie, 1978), whereas dating approaches such as OSL and cosmogenic nuclides are common techniques for unravelling alluvial chronostratigraphies (Fuchs et al., 2010; Rixhon, 2017). The LKTT 1 profile was composed of five colluvial horizons and showed phases of colluvial deposition during the Middle Bronze Age, the pre-Roman Iron Age, the Migration

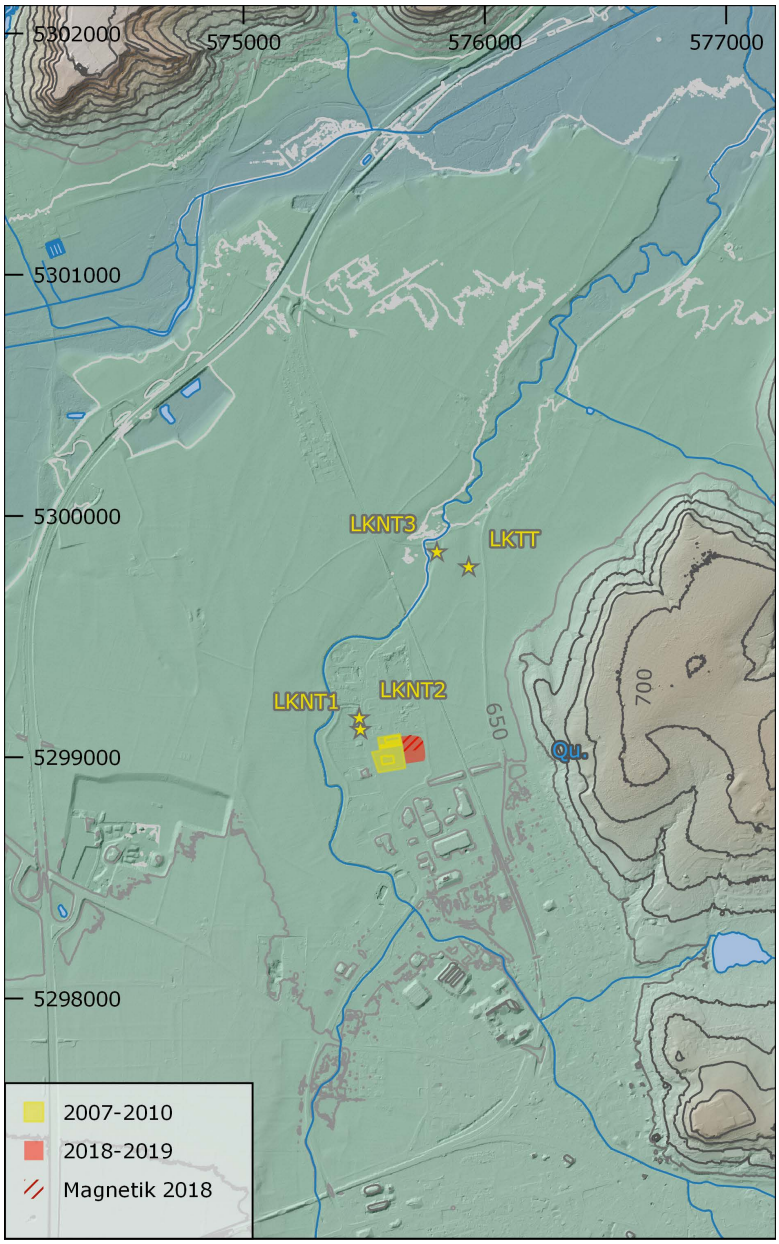

Figure 4.7: Location of the investigated colluvial/alluvial profiles (yellow stars) in the surrounding area of the Middle Bronze Age settlement of the LUA site. The floodplain area of the Eschach River is to the west; the 'Wuchzenhofener Platte' (moraines of the Riss glaciation) to the east. The areas excavated by volunteers (yellow marked) and within this project (red marked) are given. LIDAR credits: Geobasisdaten ©LGL Baden-Württemberg, www.lgl-bw.de, Az.: 2851.9-1/19; (Scherer et al., in prep.).

period, and the Early Medieval Age. Despite the incomplete ^{14}C chronology, the ages derived from ^{14}C and OSL dating matched in the corresponding soil depths. Based on the local archaeological record of the LUA site, the MBA settlement can be dated to the younger part of the Middle Bronze Age (1400-1500 BCE). This can be synchronized with the first phase of colluvial deposition at the LKTT 1 profile and the formation of the M5 horizon (1400 ± 300 BCE).

The slightly older ^{14}C ages in the M5 horizon (1500-1750 BCE) could indicate a phase of

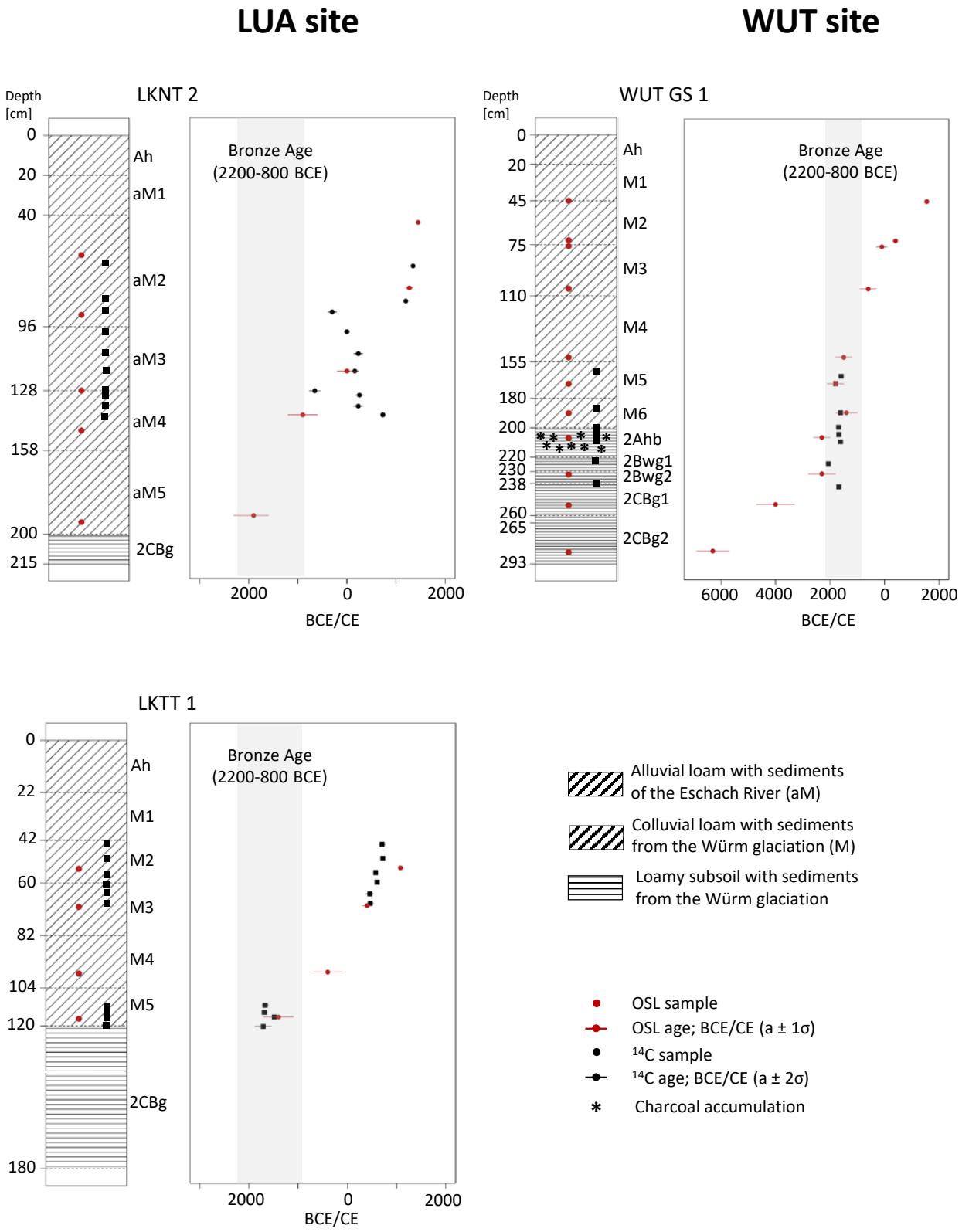

Figure 4.8: Colluvial profiles used for OSL and ^{14}C dating at the LUA and at the WUT site. Colluvial horizons are designated as M (Scherer et al., in prep.).

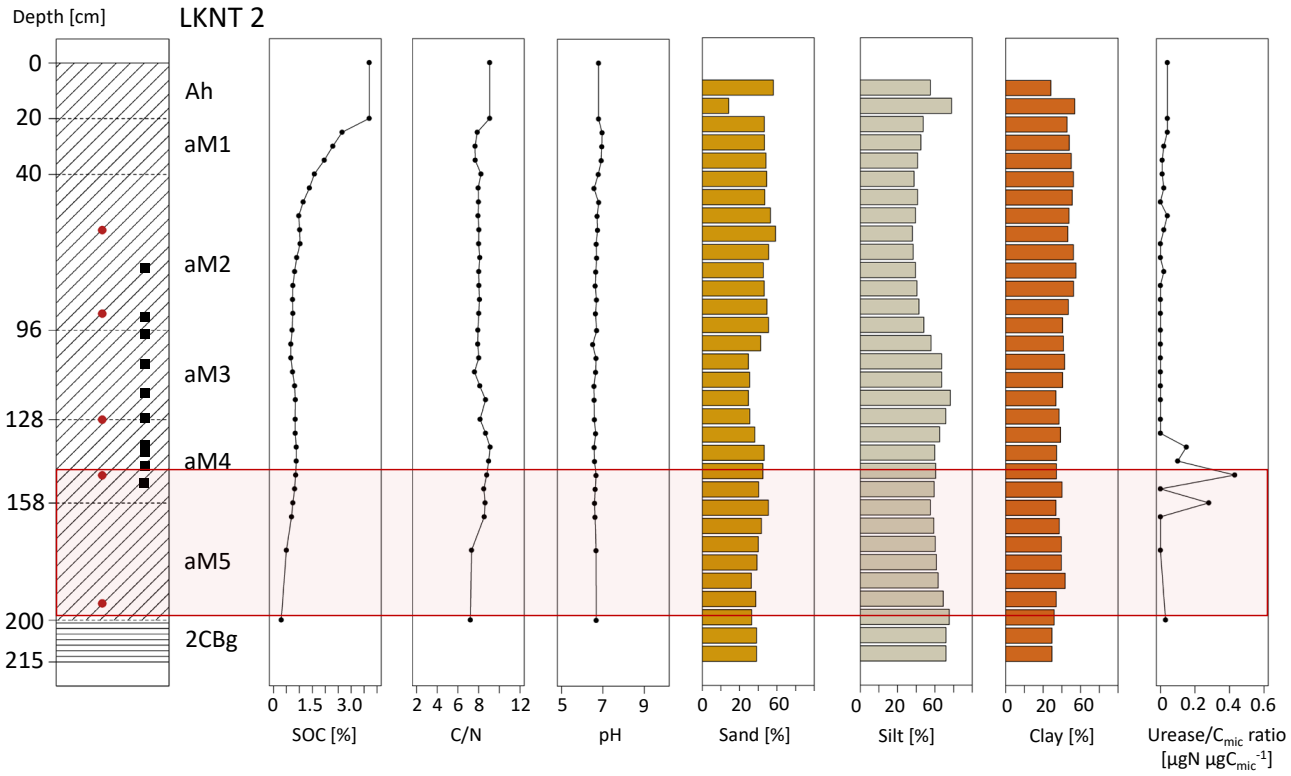

Figure 4.9: Depth functions of soil organic carbon (SOC, in mass-%), carbon to nitrogen ratio (C/N), pH, sand, silt, clay (in mass-%) and urease to microbial biomass ratio (urease/C_{mic}, in μgN μgC_{mic}^{-1}) of the LKNT 2 profile; Red bar: Time range of the Middle Bronze Age, (Scherer et al., in prep.).

landscape opening, which triggered the first phase of colluvial deposition. The temporal gap of 380 (max) and 70 (min) years between the OSL and ^{14}C ages could be explained by the 'old wood effect' (see discussion in section 4.2). The location of the LKTT 1 profile thus indicated land use areas that could be attributed to the MBA settlement of the LUA site. A chronological connection between this MBA settlement and the area of the LKNT2 profile was not achievable by ^{14}C and OSL ages. Nevertheless, the Eschach floodplain may also have served as a land use area, mainly because the lack of sedimentation during the MBA indicated a phase of lower flood activity.

However, the phase of lower flood activity, between the Early and Late Bronze Age, did not lead to detectable soil formation, since the SOC content continuously decreased with greater soil depth, and no accumulation of soil organic matter was observed in the corresponding soil depths (Fig. 4.9). The input and microbial turnover of carbon and nitrogen was also continuous and showed only minor fluctuations along the profile. The urease/C_{mic} ratio peaked in the lower part of M4 and the upper part of M5, and indicated a past input of urea within the Bronze Age. Whether the past eutrophication occurred during the Middle Bronze Age, and was thus related to the MBA settlement, cannot be exclusively assessed. A fireplace with a ^{14}C age from the Urnfield period was excavated during the field campaign and matched the Late Bronze Age OSL age and the formation of the alluvial horizon aM4, indicating a phase of land use during this

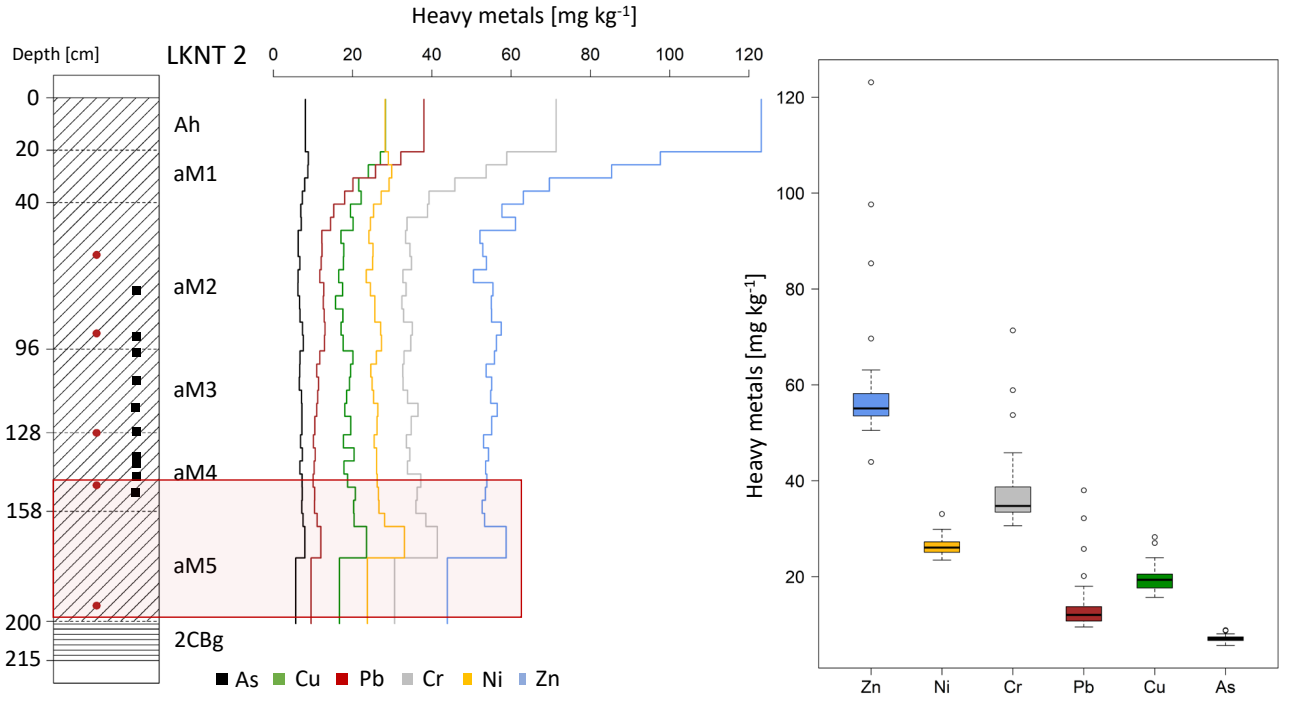

Figure 4.10: Heavy metal (given as mg kg^{-1}) depth function of the LKNT 2 profile (left panel) and heavy metals of the LKNT 2 profile summarized in boxplots (n for all analyzed elements: 32, right panel); boxplots show the median, 25th and 75th percentile (box range), and the 5th and 95th percentile (boxplots whiskers); Zn: zinc, Ni: Nickel, Cr: chrome, Pb: lead, Cu: copper, As: arsenic; Red bar: Time range of the Middle Bronze Age, (Scherer et al., in prep.).

period as well. The heavy metal depth profiles of the LKNT 2 profile showed distinct decreases for all analyzed elements from the soil surface to the aM2 horizon, whereas in greater soil depths the differences in heavy metal contents were within the statistical range (Fig. 4.10). The few positive outliers, which were beyond the 95th percentile of the data, could all be attributed to the aM1 and Ah horizons. This undoubtedly point to recent anthropogenic contamination in the catchment area of the Eschach River, likely the result of both fertilizer application on arable fields and atmospheric deposition. Similar heavy metal depth trends have been reported from a variety of alluvial profiles in Belgium and Luxembourg (Swennen and Van der Sluys, 2002).

The SOC and C/N depth profiles of the LKTT 1 profile showed similar trends to the LKNT 2 profile (Fig. 4.11). The only exception is a slight increase in the upper part of M4 indicating soil organic matter accumulation due to a phase of slope stability between the pre-Roman Iron Age and the Migration period. The urease/C_{mic} ratio revealed a continuously decreasing trend with greater soil depth. The smaller peaks, from 60 cm onwards, were statistically not significant and could thus not be interpreted with respect to past eutrophication events. The grain size distribution was continuous at the LKTT 1 profile and indicated only a slight inverse gradient of the sand and silt percentages. Hence, the sedimentation processes must have been similar

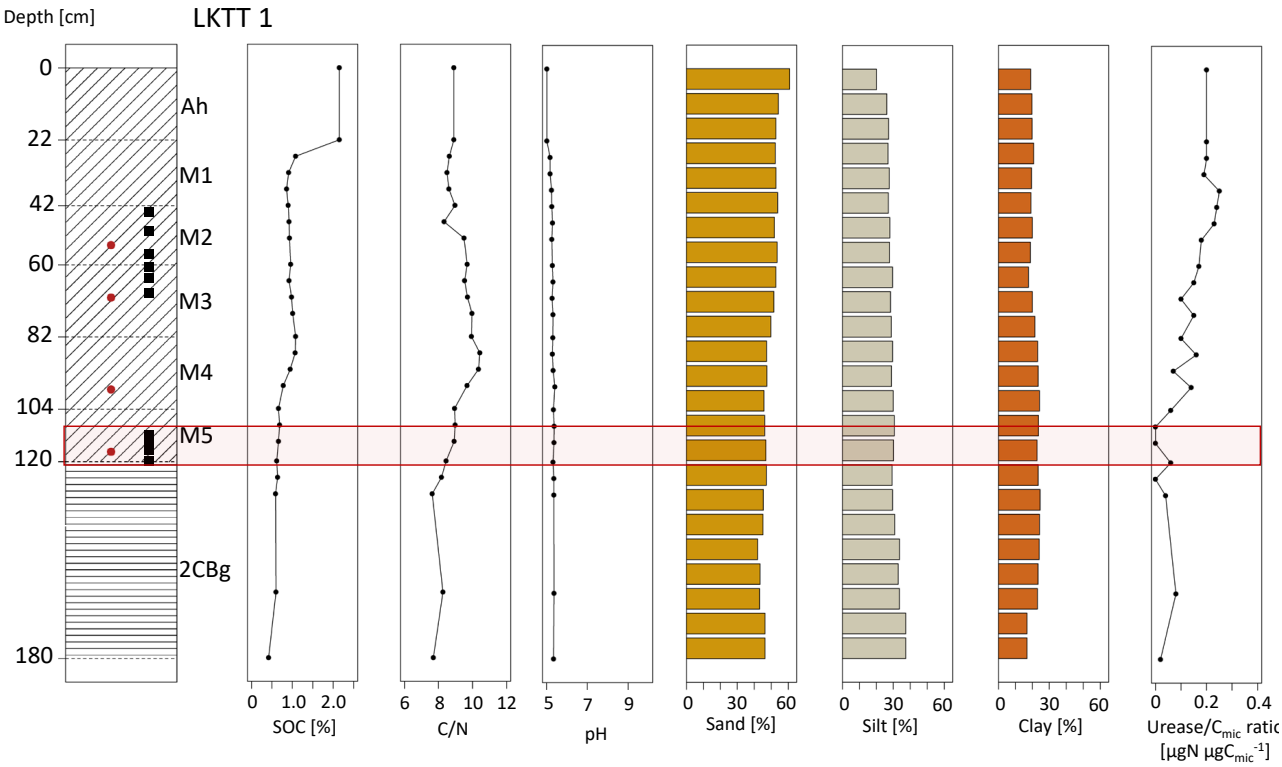

Figure 4.11: Depth functions of soil organic carbon (SOC, in mass-%), carbon to nitrogen ratio (C/N), pH, sand, silt, clay (in mass-%) and urease to microbial biomass ratio (urease/C_{mic}, in μgN $\mu gC_{mic}{}^{-1}$) of the LKTT 1 profile; Red bar: Time range of the Middle Bronze Age, (Scherer et al., in prep.).

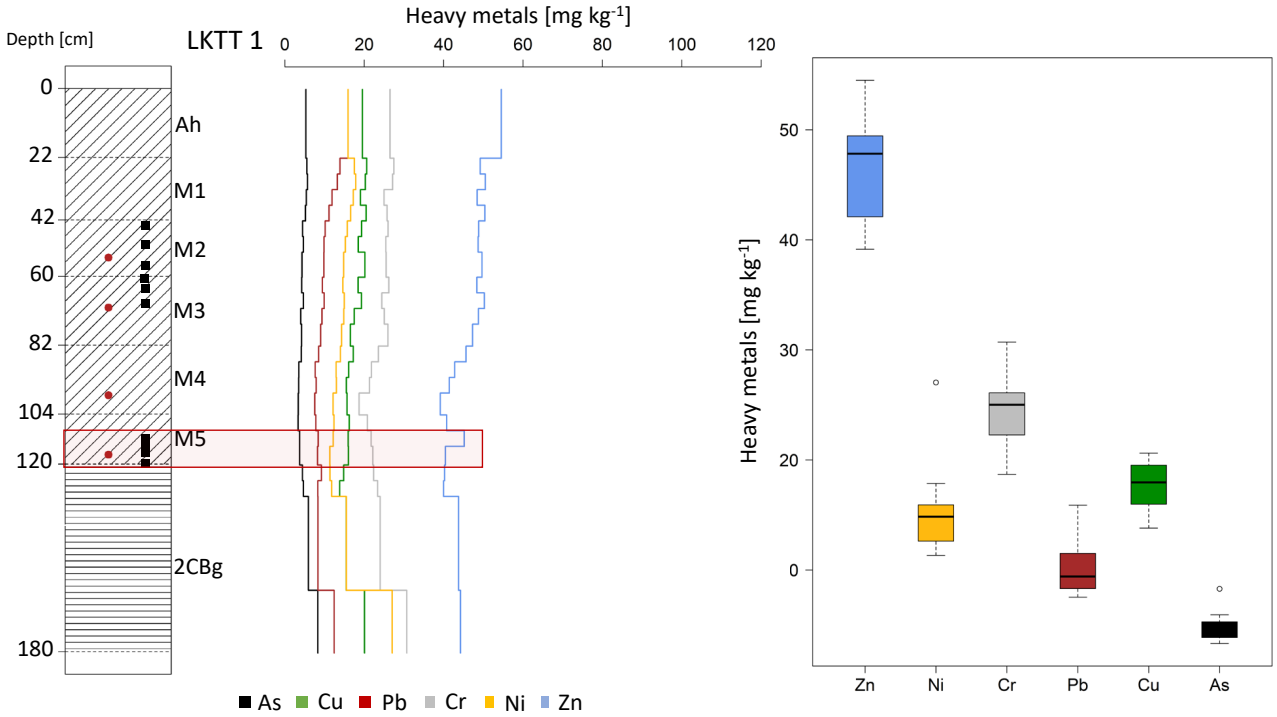

Figure 4.12: Heavy metal (given as mg kg^{-1}) depth function of the LKTT 1 profile (left panel) and heavy metals of the LKTT 1 profile summarized in boxplots (n for all analyzed elements: 23, right panel); boxplots show the median, 25th and 75th percentile (box range), and the 5th and 95th percentile (boxplots whiskers); Zn: zinc, Ni: Nickel, Cr: chrome, Pb: lead, Cu: copper, As: arsenic; Red bar: Time range of the Middle Bronze Age, (Scherer et al., in prep.).

throughout the formation of the LKTT 1 profile. This was different from the LKNT 2 profile, where pronounced differences, especially in silt content, indicated different intensities of flood activity and associated sorting of grain sizes (Paola, 1988). The heavy metal contents showed no past and present anthropogenic contamination (Fig. 4.12). This was especially observable in the lack of positive outliers in the uppermost soil horizons. At this point, the difference in heavy metal input between colluvial and alluvial deposits is obvious. For the colluvial deposit the main heavy metal input occurs through anthropogenic activity at the land surface, while the alluvial deposits are influenced by contamination distributed by river systems. This contamination is most pronounced in the first few decimetres of soil profiles since artificial fertilizers have been intensively applied since the early 20th century (Swennen and Van der Sluys, 2002).

Colluvial deposits in the surrounding area of the Middle Bronze Age settlement near Winterstetten (WUT site)

The MBA settlement complex 'Winterstetten Urlauer Tann' (WUT site) is about nine kilometres southeast of the LUA site. The WUT site comprised a fortified hilltop settlement (including a rampart/ditch) and at least two burial mounds which could be attributed to the MBA (Höpfer et al., 2020). In the surrounding area of this settlement complex, two colluvial profiles were established, one of which was selected for numerical dating and for biogeochemical

analyses (Fig. 4.13. This MBA settlement is located on a spur of the so called 'Wuchzenhofener Platte', which mainly consists of gravel deposits of the Riss glaciation.
Based on the archaeological record, this MBA settlement complex could be dated to the older part of the Middle Bronze Age (1500-1600 BCE). A chronology based on ^{14}C ages, from the rampard, the ditch and the burial mounds, matched the temporal classification based on shards; however a significant amount of charcoal dated to the Early Bronze Age. Nonetheless, EBA archaeological remains were absent in the area surrounding the WUT site, and we therefore interpret the accumulation of EBA charcoal as the result of the 'old wood effect'. Assuming a natural forest mainly consisting of conifers before the arrival of the MBA settlers, the degree of succession and related older trees could bridge the gap of 100-300 years between the ^{14}C ages (data will be published in a dissertation by B. Höpfer as a part of the B02 project). The profile WUT GS 1 was composed of six colluvial horizons (200cm) which buried a fully preserved Cambisol (Fig. 4.8). The buried topsoil (2Ahb) was characterized by an accumulation of charcoal and well-preserved MBA shards. The low level of fragmentation of the shards suggested that they were deposited *in-situ* rather than transported along the slope (Höpfer et al., 2020). An OSL age from the 2Ahb horizon dated to the transition of the Final Neolithic to the Early Bronze Age, whereas the occurrence of MBA shards also indicated the use of the land surface during the MBA. The first phase of colluviation was dated to the Middle Bronze Age (median of the three OSL ages: 1500 ± 300 BCE) and was responsible for the formation of M6, M5 and M4 (up to 90 cm of colluvial deposit). Phases of colluvial deposition were further observed for the Hallstatt period (M3, 600 ± 300 BCE), the pre-Roman Iron Age (100 ± 200 BCE), the Migration period (400 ± 100 CE) and pre-modern times (1550 ± 40 BCE). Charcoal samples were collected from the horizons 2Bwg, 2Ahb, M6 and M5 and dated unexceptionally into the Bronze Age. Comparable to the settlement complex on the spur, the ^{14}C ages from WUT GS 1 dated to the last phase of the Early Bronze Age. However, deforestation of a matured forest, which could have led to the intensive colluvial deposition during the Middle Bronze Age, could have also resulted in the radiocarbon dating of dead wood material and thus it could still be related to the settlement complex of the WUT site.

Whether the sedimentation of M6, M5 and M4 occurred simultaneously, as a single event, or continuously, as the result of several erosion processes, cannot be reconstructed from the OSL ages. However, the grain size distribution gave weak indications that the erosion of the MBA colluvial horizons did not occur all at once (Fig. 4.14). For example, the M6 horizon had higher proportions of silt and clay compared to sand, while the sand proportions were tendentially increasing from the M6 to M4 horizons. Once soil erosion takes over, the smaller grain sizes are mobilized first, while the erosion of sand and gravels require a higher erosional effort to be transported downslope (Shi et al., 2012; Vogt, 2016). The SOC and C/N depth trends showed a distinct peak in the 2Ahb horizon, which was the result of both the accumulation of soil organic matter during pedogenesis and the accumulation of charcoal as the result of

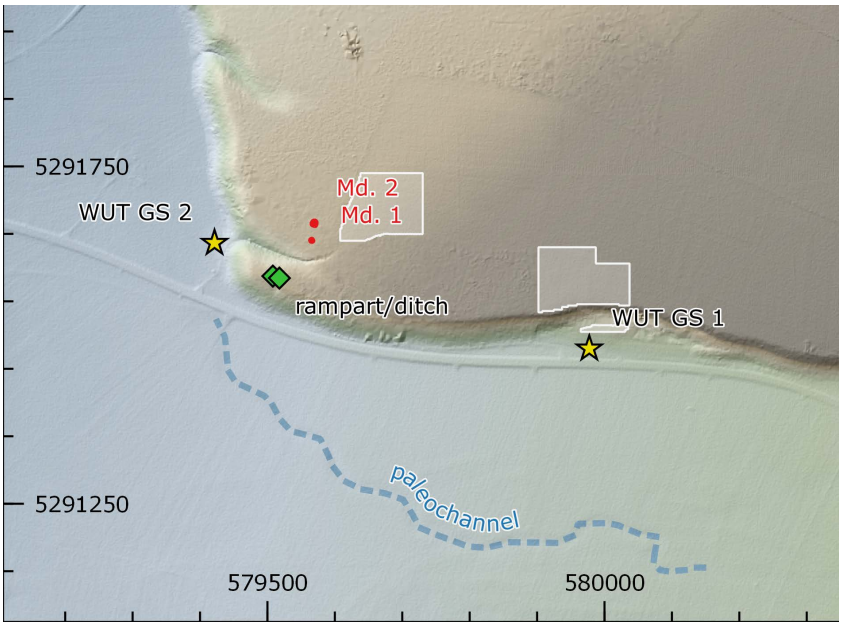

Figure 4.13: Location of the investigated colluvial profiles (yellow stars) in the surrounding area of the Middle Bronze Age settlement of the WUT site. The WUT site comprised a rampart, a ditch and several burial mounds, which two of them were excavated (Md.1, Md.2); the white areas are plots of applied geomagnetical measurements; LIDAR credits: Geobasisdaten ©LGL Baden-Württemberg, www.lgl-bw.de, Az.: 2851.9-1/19; (Scherer et al., in prep.).

fire activities during the Bronze Age. The influence of charcoal is especially observable with a higher C/N in the 2Ahb compared to current land surface.

Despite urease/C_{mic} ratios around zero for the MBA colluvial horizons, the steroid assemblage for the M6 horizon indicated an occurrence of 5ß-stanols (coprostanol, epicoprostanol). This input of omnivorous faeces could be attributed to the MBA settlement complex on the spur, possibly as the result of livestock husbandry; however, related land use activities at the foot of the slope could not be ruled out. This is further supported by the depth profiles of copper and zinc (Fig. 4.15). When the boxplots, including the 5th and 95th percentiles of the data, represent the geogenic background of heavy metals for the whole profile, the positive outliers may give hints of additional anthropogenic input. In many cases – e.g. for the LKNT 2 profile – the positive outliers are found in the current topsoil or upper subsoil horizons, and can be attributed to modern accumulation of heavy metals. In the 2Ahb horizon (200-220 cm), the zinc content increased by 30 % compared to the 95th percentile of the data.

Since zinc is mostly mobile at pH < 4.5, and the pH values at the WUT GS 1 profile did not drop below 5.2 (n: 48, mean: 5.7, sd: 0.2), a distribution along the soil column could be ruled out (Wilke, 1997). Therefore, anthropogenic contamination by zinc seems likely during the MBA. A similar depth trend was observed for copper, although not as clear and statistically proven.

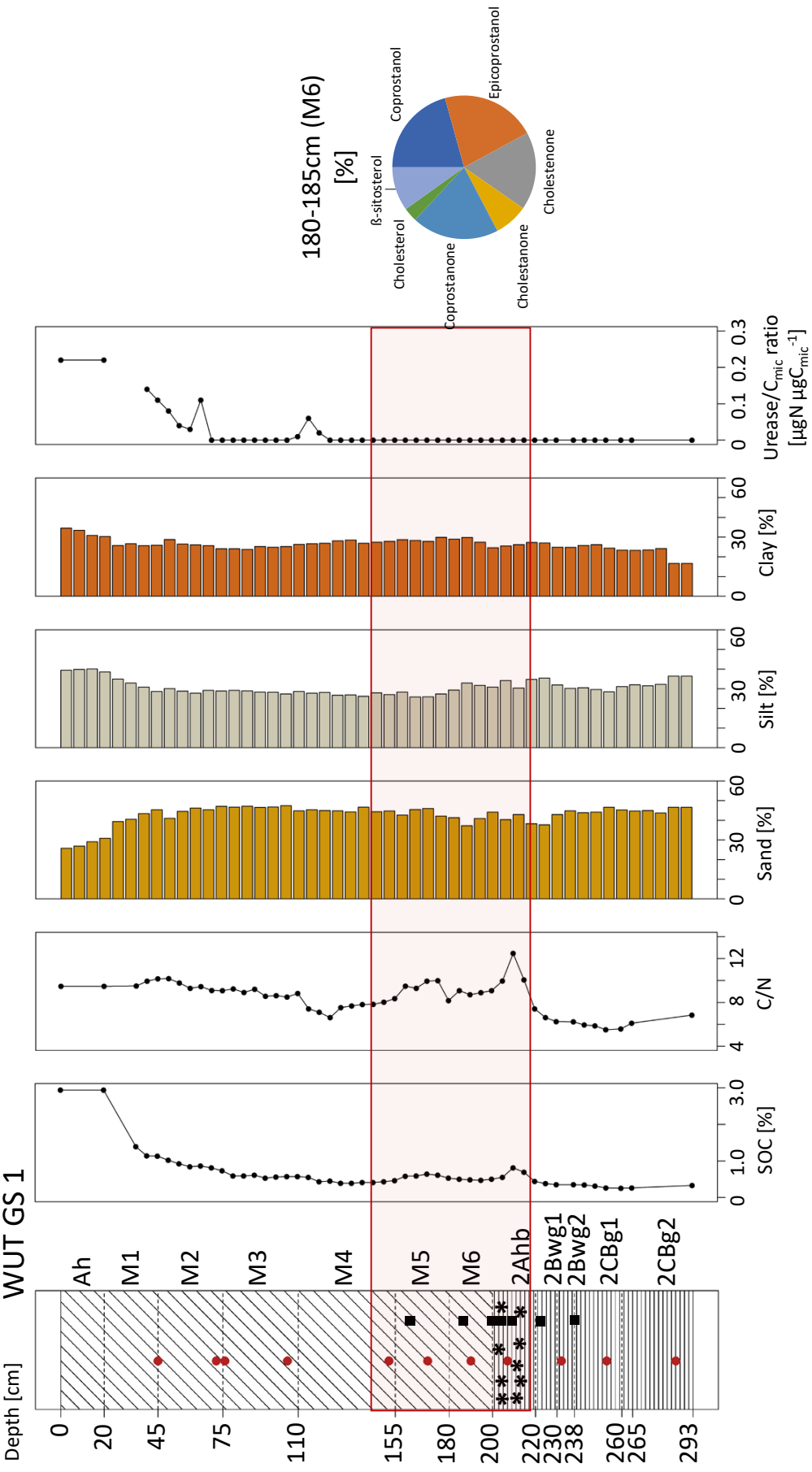

Figure 4.14: Depth functions of soil organic carbon (SOC, in mass-%), carbon to nitrogen ratio (C/N), sand, silt, clay (in mass-%) and urease to microbial biomass ratio (urease/C_{mic}, in μgN μgC_{mic}^{-1}) of the WUT GS 1 profile; the pie chart shows the steroid assemblage of a sample from M6 (180-185cm); Red bar: Time range of the Middle Bronze Age, (Scherer et al., in prep.).

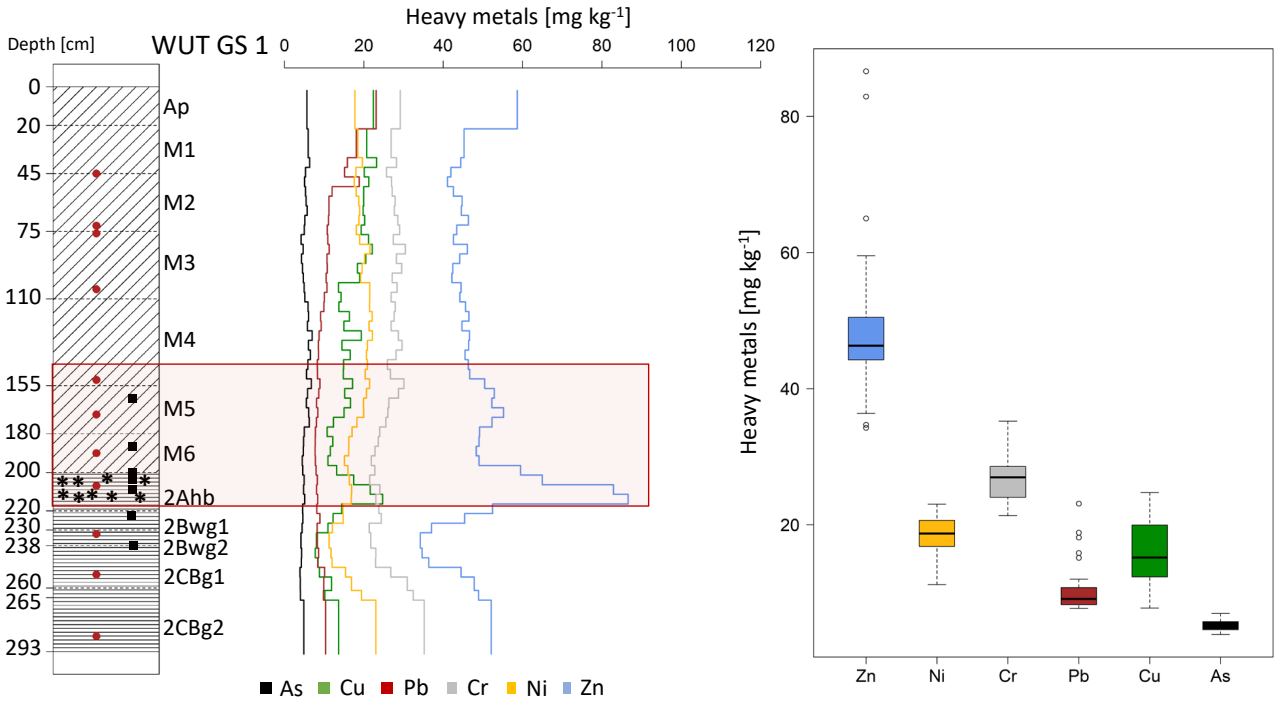

Figure 4.15: Heavy metal (given as mg kg^{-1}) depth function of the WUT GS 1 profile (left panel) and heavy metals of the WUT GS 1 profile summarized in boxplots (n for all analyzed elements: 48, right panel); boxplots show the median, 25th and 75th percentile (box range), and the 5th and 95th percentile (boxplots whiskers); Zn: zinc, Ni: Nickel, Cr: chrome, Pb: lead, Cu: copper, As: arsenic; Red bar: Time range of the Middle Bronze Age, (Scherer et al., in prep.).

Summarizing discussion: Land use in the area surrounding the MBA settlements of the LUA site and the WUT site (Westallgäu) could be demonstrated. For both case studies, several phases of colluvial deposition and peaks in ^{14}C ages could be chronologically synchronized with the local archaeological record. At the LUA site, land use areas were likely in the floodplain area of the Eschach River, underneath the lower terrace edge to the west (LKNT 2) and on the lower terrace to the north (LKTT 1). Land use areas might have also been distributed across the entire area surrounding the MBA settlement; however, the investigation of further cardinal points was mostly limited by modern urban development and industrial facilities.
At the WUT site, the first MBA settlement complex in the Westallgäu, comprising a fortified hilltop settlement and a ritual place, could be verified (Höpfer et al., 2020). During the MBA, massive soil erosion could be documented, with about 90 cm of soil column being moved within a few hundred years. Land use practices such as metal processing (zinc peak in the 2Ahb) and keeping livestock (occurrence of 5ß-stanols in the M6), were indicated in the area surrounding the settlement. Further research and data analysis (manuscript in prep.) will focus on these aspects to allow for detailed insights into the MBA occupation of the WUT site, and to serve as a first example of MBA land use in the Westallgäu.

4.3.4 Synthesis

The three case studies clearly demonstrated that the multi proxy study of multi-layered colluvial deposits and local archaeological records provides information on the intensity and nature of past land use in the areas surrounding prehistoric settlements. In most cases, the phases of colluvial deposition at the Baar (FUE site), in the Hegau (ABR site) and in the Westallgäu (LUA and WUT site) could be synchronized with the local archaeological record and seemed to have caused each other. This underlines the definition by Kadereit et al. (2010) who described colluvial deposits as "correlate sediments of [human-induced] soil erosion" (p. 97).
To fill the mere assumption that human land use, in general, was responsible for the formation of colluvial deposits (e.g. Schulte and Stumböck, 2000; Henkner et al., 2017; Feeser et al., 2019; Van der Meij et al., 2019), the analysis of land use proxies from colluvial deposits was applied. Even though the databases of the three case studies were not exactly equal, at all investigated sites, land use areas and practices were demonstrated to have existed in the areas surrounding the prehistoric settlements. For example at the FUE site, a combination of wood procurement and livestock husbandry, as evidenced by an overall open landscape with a high abundance of *Juniperus* and the analytical detection of past urea (urease/SOC ratio) and faeces (steroid assemblage) input, was indicated during the transition of the Bronze to Iron Age. At the ABR site, elaborated land use practices could be reconstructed from colluvial deposits and archaeological features for the Middle Bronze Age. These land use practices comprised arable farming (including ploughing, crop growth, varying sowing and harvesting times and post-processing techniques such as drying, roasting and storing of cereals), livestock husbandry (including forest pasture for pig farming and pasture on fallow land), the use of fire (onsite domestic fire vs. near-site biomass burning) and wood procurement (collecting wood following the 'principle of least effort'). The occurrence of these land use practices were supported by offsite pollen profiles which showed a peak of microcharcoal (landscape opening, use of fire), non-arboreal pollen (arable farming) and *Quercus* (forest pasture) during the Middle Bronze Age. At the LUA and at the WUT site, Middle Bronze Age land use was indicated by corresponding colluvial horizons in the areas surrounding the MBA settlements. Based on our data, livestock husbandry and metal processing seemed to be part of the investigated settlements in the Westallgäu. In the Westallgäu, the mere occurrence of MBA settlements and (intensive) colluvial deposition provide essential information that suggests that these presumably unfavourable landscapes were populated and used during the Middle Bronze Age.
With respect to the case studies presented, the question of what additional information could be gained to better understand the Middle Bronze Age 'Tumulus Culture' in southwestern Germany arises?
From the perspective of the 'pile dwelling' settlements, there is a gap in population dynamics in the Middle Bronze Age at the lakes of the Circum-Alpine region (Menotti, 2001, 2009). Climate deterioration during the Subboreal, as a consequence of the 'Löbben' variation, caused rising

lake levels and glacial advances and could explain the abandonment of lakeshore settlement at the transition of the Early to the Middle Bronze Age (Magny, 2004; Nicolussi and Kerschner, 2014; Zolitschka et al., 2003) as well as the drastic increase in MBA settlements further inland (Menotti, 2003; Höpfer, 2014). Based on the case studies presented, this settlement shift is demonstrated by the fact that a widespread colluviation did not occur prior to the Middle Bronze Age in the inland areas of the Hegau, and that, although Neolithic and Early Bronze Age land use has been demonstrated in these areas (Hald and Wahl, 2009; Hald et al., 2015; Hald, 2020b).

This settlement shift must have implied significant changes in the subsistence economy during the Middle Bronze Age, since the different resources of areas that existed further inland would have moved into the foreground, and different cultural techniques may have been required. These new cultural techniques, such as the use of the bronze sickle, the beginning cultivation of spelt and the widespread occurrence of stilted pantries (particularly typical for the northwestern Alpine foreland) (Gnepf-Horisberger and Hämmerle, 2001; Rösch et al., 2014; Falkenstein, 2009) could have improved the subsistence economy during the Middle Bronze Age and could have enabled the occupation of sites further inland in the Hegau and the Westallgäu. These areas are commonly considered more unfavourable compared to the sites at the lakeshores. However, the pollen data from the Hartsee and Grassee profiles as well as the charcoal spectra from colluvial deposits at the ABR site, suggested no abrupt shift in land use from the Early to Middle Bronze Age (Scherer et al., submitted). This was especially reflected in the observation of a forest management that promoted the occurrence of *Quercus* at the expense of *Fagus* and oak-mixed forests. These *Quercus* dominated forest ecosystems appeared to be a central element of the Early Bronze Age land use in the area surrounding Lake Constance (Rösch et al., 2014; Rösch, 1987) but also of the Middle Bronze Age land use beyond the lakeshores.

With regards to the Favor-Disfavor dichotomy, human occupation of 'unfavourable' landscapes, such as the Westallgäu, might have also taken place due to a change in the perception of resources inherent to the landscape. In the Westallgäu, the landscape infrastructure with its river network that link the Rhine and the Danubian system might have played a decisive role in giving value to a landscape, which from a present day vantage point, is considered 'unfavourable' (Mainberger et al., 2019). Trading networks were already important in the Bronze Age economy, with glass and amber being distributed from southern Scandinavian to the Mediterranean region (Kaul, 2018; Varberg et al., 2020). Additionally, the use and processing of metals, which probably originated from the Eastern Alps, gained importance (Lutz and Pernicka, 2013), and was probably responsible for the development of cultural techniques during the Bronze Age (Knopf, 2017). Hence, permanent habitation of such 'unfavourable' landscapes was likely, even though climatic conditions would rationally exclude them for efficient agricultural practices (Primas, 2002).

4.4 Resources in prehistory (Manuscript II, III, IV)

Based on the archaeological, archaeobotanical, archaezoological and archaeopedological data from the settlement site in Anselfingen (Hegau, southwest Germany) and its surrounding area, an exemplary ResourceComplex (RC) and ResourceAssemblage (RA) according to the concept of ResourceCultures can be constructed. In the following, both the RC and RA are discussed in terms of the CRC 1070 terminology.

4.4.1 The ResourceComplex 'Middle Bronze Age settlement'

The ResourceComplex 'Middle Bronze Age settlement' can be described as a network of categories and associated resources, both tangible and intangible, which were important for the economic and cultural subsistence of Middle Bronze Age (MBA) settlers in Anselfingen (ABR). Hereinafter, the example of cereal crop growth within the RC 'Middle Bronze Age settlement' is discussed.

The domestication of certain cereal crops has probably marked the transition between hunter and gatherer and sedentary societies on a global scale (McNeill et al., 2010; Bogaard, 2004). However, the cultivation of cereal crops requires a spectrum of tangible and intangible resources in order to guarantee a successful endeavour. On the side of tangible resources, the cereal plants (or grains), soils, climate, tools for soil tillage, fire pits with heat stones, organic manure and stilted pantries were identified to be important for MBA settlers at the ABR site. These tangible resources can be interpreted as the framework necessary for MBA crop growth in the study area. Before sowing the cereal grains, the soils were prepared by using the available tools for tillage. The climatic conditions (amount of precipitation, temperature) predetermined the vegetation period in which crop growth is most promising. Fire pits and stilted pantries were used for post-processing of the harvested crops, namely for curing (drying) and storing. Even though this tangible framework of resources provides already a picture of a sophisticated agricultural system during the MBA, it is far from a holistic understanding of past human-land interaction in terms of crop growth (Fig. 4.16).

Intangible categories such as knowledge and tradition are useful to shed light on the behaviour of prehistoric farmers, their perceptions of the environment and their decision-making. Knowledge must have been essential since the emergence of the species *Homo sapiens* in East-Africa and as time proceeded knowledge systems developed and adapted to changing environments (Harari, 2014). Hence, knowledge is a resource that evolves from the past, i.e. from coping with different situations, keeping them as memory, and transmitting them between individuals and generations. The accumulation and usage of memorized knowledge and the derivation of behaviour patterns might lead to traditions, which are representative of certain communities in a defined geographical space and time (Champion et al., 2016). For the MBA settlers at the ABR site, knowledge for crop growth was necessary on different scales. The tillage of soil is the

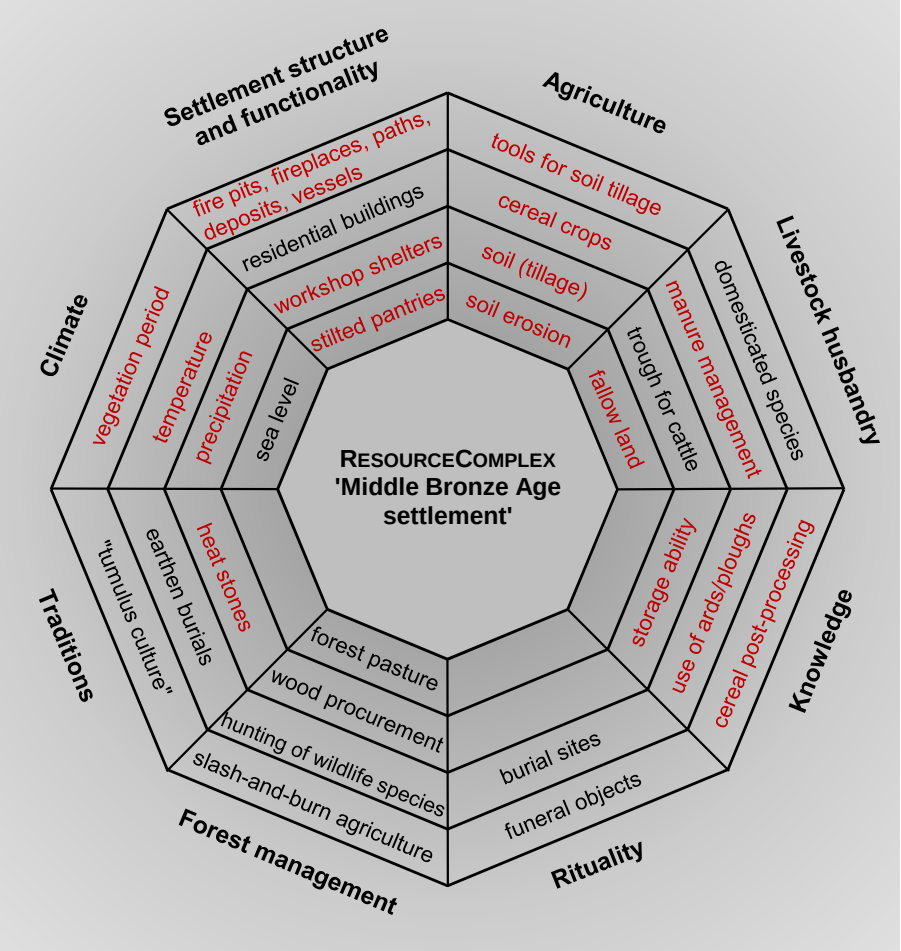

Figure 4.16: The RESOURCECOMPLEX 'Middle Bronze Age settlement' based on the available data from case study II (see section 4.3.2). The red marked rescources/categories build a RESOURCECOMPLEX, which includes the necessary resources required for the Middle Bronze Age crop production.

most basic requirement for growing cereal crops. The processing of tools to improve soil tillage promotes more efficient crop production, with the expansion of arable fields, while maintaining the same level of energy input. At the transition between the Neolithic and Bronze Age periods, the emergence of the traction-plough might have been responsible for an increased agricultural efficiency in Central Europe and the departure from small-scale systems such as hoe-farming and house gardening (Bishop, 1936; Tegtmeier, 1987). At the ABR site, evidence of ploughing was observed with the occurrence of a buried MBA plough horizon and MBA colluvial horizons (Scherer et al., submitted). Furthermore, the cultivation of various cereal crops is related to the availability of knowledge. Besides the botanical abilities needed for crop domestication, the occurrence of several crops also requires a sophisticated agricultural system with different sowing times, harvesting times and distribution of labour throughout the year (Banks et al., 2013). At the ABR site, cereal crops of emmer, einkorn, free threshing wheat, barley and spelt were identified, all crops which are commonly discovered by archaeobotanical research from MBA structures (Rösch et al., 2014). In the study area, emmer is nowadays grown preferentially during the summer terms, while spelt, which is resistant to low temperatures, is typically sown in winter. Einkorn and barley are known to be viable as both summer and winter crops. The expansion of the variety of cereal crops might have enabled food security as the failures of certain crops could not affect the overall food supply. However, the growing of different cereals also required knowledge about post-harvesting processes such as husking, curing and storing (Banks et al., 2013). At the ABR site, the husking of crops can be assumed from the presence of several crop species, such as emmer and spelt, that must be processed before consumption. The storage of cereals is indicated by small archaeological structures consisting of four post-holes with a squared or short-rectangular shape. There is a broad consensus that such constructions represent stilted pantries for the storage of food, especially of cereals (Gnepf-Horisberger and Hämmerle, 2001). In addition, stones that have been heated in fire pits, could have been used for the curing or roasting of cereal crops (Lindemann, 2008). At the ABR site, several soil pits have been documented without evidence of fire, but containing heat stones. These heat stones are discussed as a traditional element of the MBA period in the northwestern Alpine foreland, where they are found much more frequently compared to neighbouring regions such as Bavaria and France (Gnepf-Horisberger and Hämmerle, 2001).

In summary, both tangible and intangible resources are important to better understand past human-land interactions. The ResourceComplex 'Middle Bronze Age settlement' shows that resources are interacting within a network from which the key needs of a society can be derived. However, it must be considered that a ResourceComplex provides a snapshot of societal needs for a defined period, while the reassessment of resources has always been dynamic and still takes place when internal or external societal requirements change.



Figure 4.17: Aerial photo of the Welschingen site and Anselfingen site (Hegau, southwestern Germany) with the Hohenhewen volcano hill in the background. Photo credits: Archaeological Service of the District of Constance, photo taken by Björn Schleicher.

4.4.2 The ResourceAssemblage 'Diachronic land use patterns'

In contrast to the RC 'Middle Bronze Age settlement', the ResourceAssemblage 'Diachronic land use patterns' includes archaeological remains from two sites from the Early Neolithic to the Roman period. Besides the ABR site, the Welschingen site lies on lowland position beside the modern floodplain area of the Hepbach river (Hegau, southwest Germany). Both sites are located at a distance of < 3 km and both should be considered when discussing land use patterns and related changes in the resource perception of the area (Ehrle et al., 2018; Gutekunst and Hald, 2015; Hald and Wahl, 2009; Hald et al., 2015; Ehrle et al., 2015; Rösch, 1996; Hald, 2020a,b) (Fig.4.17). However, it must be noted that the database of archaeological remains beyond the MBA, at the Anselfingen site (main focus of the project B02 of the CRC 1070), is fairly weak, and references regarding the interpretation of other archaeological periods in Anselfingen and its surrounding, are scarce. To take this into account, a simplified differentiation is made between settlement and ritual sites. Settlement sites include archaeological remains such as postholes, fireplaces, fire pits and shards, which indicate a permanent occupation of the area, while ritual places are characterized by burial finds without settlement traces.

The first phase of human occupation is documented for the Early Neolithic (5500-5000 BCE, Linear Pottery Culture) as indicated by settlement finds at the Welschingen site (Hald et al., 2015). Corresponding ^{14}C ages of charcoals from colluvial deposits at the Anselfingen site (see

section 4.3.2, Fig. 4.5) suggest human presence also on the gravel terrace, which could be interpreted as the related land use area of the Welschingen settlement. For the Middle Neolithic (5000-4300 BCE), neither settlement and ritual sites in Anselfingen and Welschingen, nor ^{14}C ages of charcoals from colluvial deposits at the Anselfingen site have been documented. If we consider the possibility that Middle Neolithic remains and land use areas exist in close proximity, but are not congruent with the excavation areas of the Anselfingen and Welschingen site, we can at least assume that the land use varied spatially. Since archaeological and archaeopedological finds are missing, an interpretation regarding a changed perception of available resources compared to the Early Neolithic is not possible. A group of burial finds containing human remains and funeral objects, which have been dated to the Younger Neolithic (4100-3500 BCE), suggest that the area around Welschingen was mainly perceived as a ritual site (Hald and Wahl, 2009). Corresponding ^{14}C ages of charcoals from colluvial deposits at least indicate human influence at the gravel terrace in Anselfingen, while evidence of settlement and ritual sites have not been documented. Hence, human occupation during the Younger Neolithic was restricted to the lowland area in Welschingen and mainly focused on the interpretation of the landscape as a ritual site. With the transition to the Late Neolithic (Horgener Culture, 3400-2800 BCE), the gravel terrace in Anselfingen was perceived differentially compared to the previous periods. Both settlement and ritual finds have been excavated (Ehrle et al., 2018, 2015; Hald and Wahl, 2009) that are consistent with ^{14}C ages of charcoals from colluvial deposits. Corresponding burial finds at the Welschingen site support the significance of the area as a ritual space during the Late Neolithic (Gutekunst and Hald, 2015). Final Neolithic (2800-2200 BCE) settlement remains, such as shards and waste pits, indicate a shift of the settlement activity from the gravel terrace to the lowland area around Welschingen. Simultaneously, burial finds with human remains and funeral objects indicate that the Anselfingen site was also utilized as a ritual place during the Final Neolithic (Ehrle et al., 2018; Rösch, 1996). With the transition from the Neolithic period to the Bronze Age (Early Bronze Age, 2200-1600 BCE), the landscape perception and spatial distribution of settlement and ritual sites was reversed as evidenced by the occurrence of architectural remains on the gravel terrace (Hald, 2020b) and of funeral objects in the lowland area around Welschingen (Hald, 2020a). During the Middle Bronze Age (1600-1250 BCE), human occupation increased as shown by the remains of the MBA settlement at the Anselfingen site, which is considered as one of the most detailed MBA settlement sites in the northwest Alpine foreland (Ehrle et al., 2018), and the first phase of colluvial deposition indicated by OSL ages. The significance of the MBA settlement in Anselfingen is further supported by burial mounds, which are interpreted as an integral part of the human reach on the gravel terrace, and corresponding settlement remains in Welschingen (Hald et al., 2015). In the Late Bronze Age (1250-800 BCE), the human occupation of the gravel terrace was continuous, while the archaeological evidence at the Welschingen site suggests a reversed perception of the area with the occurrence of burial finds and the absence of settlement remains (Gutekunst and

Hald, 2015). During the Iron Age (Hallstatt period, 800-450 BCE; Latàne period, 450-15 BCE), a continuous perception of the area as settlement site is indicated by archaeological remains in Anselfingen (Ehrle et al., 2018) and Welschingen (Gutekunst and Hald, 2015), while the occurrence of burial finds were alternating. Based on the current archaeological data, the burial finds can be interpreted in a way that indicates that ritual sites were still important, but had reduced distribution compared to settlement areas. The influence of farming is further supported by colluvial horizons that are dated to the Iron Age (see section 4.3.2, Fig. 4.5). With the transition to the Roman period, ritual sites further lost significance at both sites, while the architectonical remains in Anselfingen supports the assumption that the gravel terrace was still perceived as a favourable settlement site (Ehrle et al., 2018).
In summary, the alternating human occupation of the Anselfingen and Welschingen site, either as settlement or as ritual site, show the diachronic change in demands on humans and the associated perception of the landscape and its inherit resources. Even if the current state of knowledge is the result of missing archaeological finds, spatial shifts within and between the individual sites can already be interpreted as a continuous reassessment of landscape and its inherit resources over time.

4.4.3 Synthesis

The application of the CRC 1070 terminology, especially the frameworks of ResourceComplex and ResourceAssemblage, allows for coherent insights into the possible landscape perception and evaluation of Bronze Age settlers in southwestern Germany. Regarding the RC 'Middle Bronze Age settlement', interdisciplinary research enables landscapes to be understood beyond their tangible resources, which were important to maintain the economic subsistence. Intangible resources take the motives and effects of human behaviour patterns into account and enable phenomena like the emergence and distribution of knowledge, the trade and communication of tangible and intangible resources, the spread of traditions, and the occurrence of social/political factors that have a decisive role in prehistoric human-decision making to be understood.
Based on the current state of archaeological knowledge at the two study sites, the RA "Diachronic land use patterns" indicates a dynamic landscape evaluation by distinguishing settlement and ritual sites. In particular, the spatial shift of settlement or ritual sites over time could be the result of a re-evaluation of local resources, according to the specific needs at a given time. However, when interdisciplinary research and an advanced archaeological and archaeopedological analysis of certain periods are lacking, only a superficial interpretation of landscape perception and reassessment over time is possible. The identification of motives responsible for a reassessment of resources/landscapes is closely related to the quality of the archaeological record and natural-scientific data and is most fruitful when interdisciplinary research is conducted.

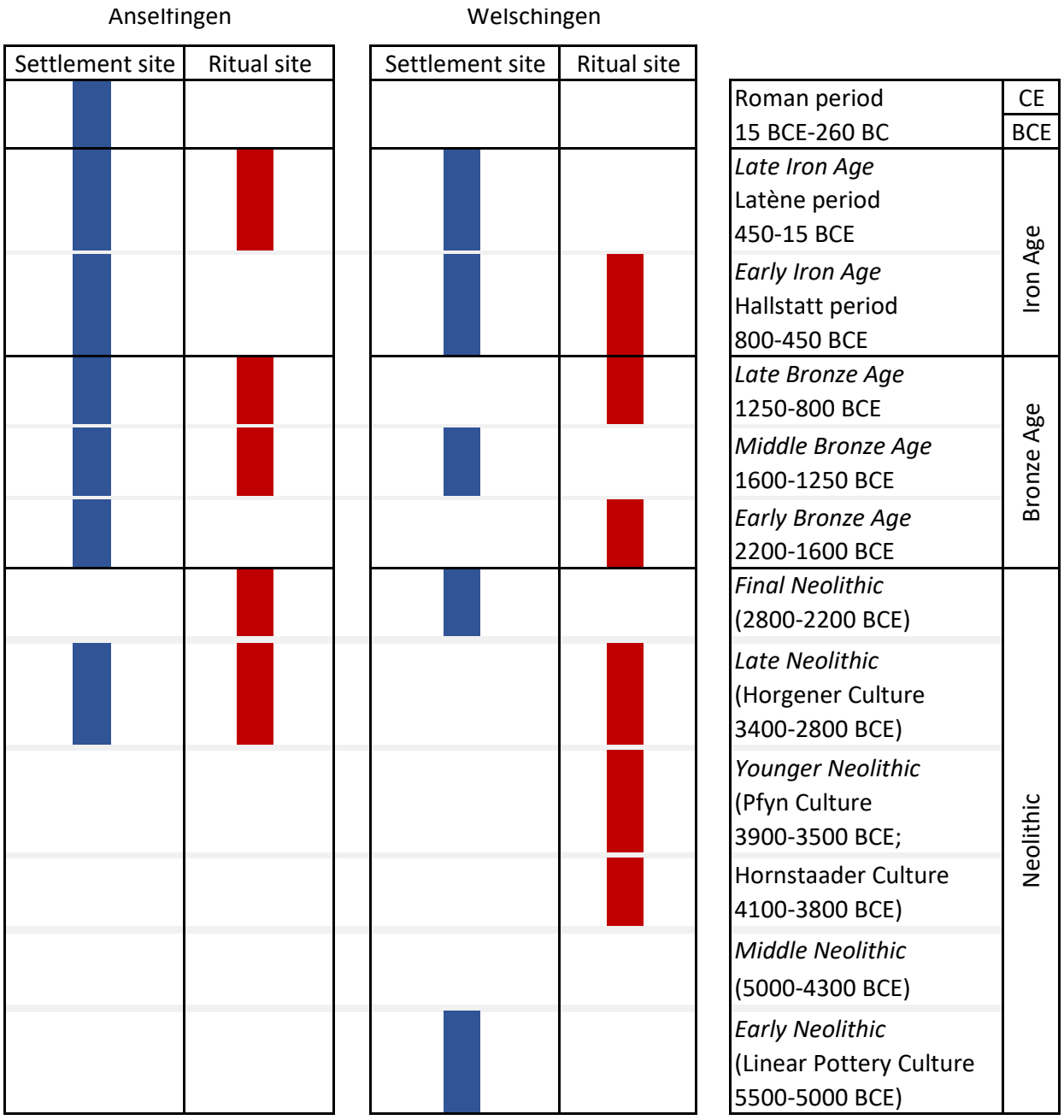

Figure 4.18: Phases of human occupation differentiated by archaeological remains of settlement and ritual sites from Anselfingen and Welschingen (according to Ehrle et al., 2018; Gutekunst and Hald, 2015; Hald and Wahl, 2009; Hald et al., 2015; Ehrle et al., 2015; Rösch, 1996; Hald, 2020a,b).

The application of the ResourceCultures concept provides additional approaches for the interpretation of prehistoric data derived from archaeological and archaeopedological research. Similar conclusion were drawn by James et al. (accepted) (see manuscript IV), where the framework of Complex Adaptive Systems was applied to investigate the nature of past and present human-land interactions. Both the ResourceCultures concept and the Complex Adaptive System framework seems to extend the Favor-Disfavor dichotomy in a way that no static con-

ditions, but complex and dynamic developments of natural and cultural systems should be adduced for the decipherment of past and present human decision-making. Above all, the comprehension that prehistoric human decision-making is not subject to modern thought patterns, but includes aspects which can also be contradictory to modern values, helps to implement a preferably holistic approach for the interpretation of past human-land interaction.

5 Conclusion

In this thesis the multi-proxy analysis of multi-layered colluvial deposits is applied to contribute to the decipherment of human-land interaction within and in the area surrounding prehistoric settlements. This multi-proxy approach enables an interdisciplinary research including methods from soil sciences, archaeology, archaeobotany and archaeozoology. In particular at study sites with limited preservation of organic and biogeochemical proxies as well as archaeological material due to aerobic soil conditions, the analysis of colluvial deposits provides the opportunity to gain insights into the site formation history, the paleoenvironment and phases of land use and related practices.

(i) It could be demonstrated that through a multi proxy analysis of colluvial deposits the reconstruction of soil erosion and sedimentation history, paleoenvironment and land use dynamics is possible. Nonetheless, the human contribution to the formation of colluvial deposits is often assumed from the local chronostratigraphy and archaeological record without explicitly addressing the nature of land use. (ii) One part of this thesis was to further refine the analytical potential of colluvial deposits and to reveal biogeochemical and archaeobotanical methods that contribute to the decipherment of colluvial deposits as archives for past land use practices. All of the applied methods are established in the field of natural scientific research, but some of them have scarcely been used, or not used at all, in the context of colluvial deposits. The analysis and archaeopedological interpretation of steroid biomarker (e.g., sterols, stanols and stanones) and urease enzyme activities from colluvial samples is presented for the first time in this thesis. From the three case studies, it can be concluded that the analysis of biogeochemical and archaeobotanical proxies from colluvial deposits is recommended for the reconstruction of (human-induced) vegetation change and land use practices on a local scale; however, the archaeopedological interpretation of land use proxies from colluvial deposits should always be synchronized with the local archaeological record and offsite pollen archives in order to provide detailed information on the local and regional scale.

With regard to the Favor-Disfavor dichotomy, a clear demarcation between the Hegau and the Baar as favourable landscapes and the Westallgäu as an unfavourable landscape was not observed. If we ignore the slightly different datasets for the three case studies, and the fact that only one (or two) site(s) have been investigated in the different regions, some general observations appear that may reject the classification of this region into favourable and unfavourable landscapes. In the area surrounding every prehistoric settlement site, a formation of colluvial deposits was documented and could be associated with the archaeological remains. (iii) At the Baar, colluvial deposits were analysed close to the prehistoric site of Fürstenberg and indicated that wood procurement and livestock husbandry were likely at the transition between the Late Bronze Age and Early Iron Age, while land use activities were weak or absent

before and after this period. In particular, a several thousand year phase of geomorphodynamic stability was associated with soil formation processes and the lack of archaeological remains, which supports the correlation of the colluvial deposition and anthropogenic influence. (iv) From a multi-proxy analysis of colluvial deposits and archaeological features at the MBA settlement in Anselfingen (Hegau), elaborated land use practices during the Middle Bronze Age were deduced. These land use practices comprised arable farming (e.g., ploughing, possible manuring, cultivation and post-processing of cereals), forest management (wood procurement and forest pasture), livestock husbandry (on fallow land and in the forest) and settlement activities (domestic fires). From the comparison of onsite and near-site vegetation and land use proxies with offsite pollen data, a regional pattern of vegetation and land use was indicated during the Middle Bronze Age in the north-western Alpine foreland. (v) Even though the Westallgäu was considered unfavourable for prehistoric human occupation, the colluvial profiles at the MBA settlement sites of Leutkirch and Winterstetten could be synchronized with the local archaeological remains. Furthermore, the strongest colluviation (up to 90 cm of soil column within several hundred years) was observed in the Westallgäu.
(vi) Possible reasons for the Middle Bronze Age settlement shift, from the shores of Circum-Alpine to the areas further inland, were discussed. Climate deterioration most likely triggered the settlement shift from the lakes to the areas further inland; however, new cultural techniques (e.g., the use of bronze sickle and the cultivation of spelt) may have enabled a successful subsistence economy in areas that are nowadays considered unfavourable. Furthermore, the existence of trading routes along the river systems of the Alpine foreland could also be responsible for a change in the perception of these 'unfavourable' landscapes; though landscapes may have been agriculturally less favourable, they may have been 'favourable' in the context of the distribution of tangible (e.g., raw material) and intangible resources (e.g., knowledge).
(vii) From the integration of different concepts for the interpretation of past human-land interactions (e.g., ResourceCultures and Complex Adaptive Systems), the importance of different resources for a defined period, as well as the changed perception of resources over time, could be deduced. In this thesis the concept of ResourceCultures has mainly been applied to describe prehistoric behaviour in the light of different resources. These concepts can be recommended because they break with common thought patterns of Favor and Disfavor and offer a multidimensional perspective of prehistoric farmers and the way they used and valued the landscape around them.
Future research must focus on the 'fixed' integration of colluvial deposits in the study of archaeological remains. Most often, colluvial deposits are considered as sediments that bury the 'archaeological treasure'; thus, colluvial deposits must be removed. However, past research has already demonstrated that these sedimentary archives may provide information complementary to the archaeological record. This thesis further intents to demonstrate a strong connection between archaeological settlements (onsite) and their surrounding areas (near-site), which can

be interpreted as associated areas of land use.

From a methodological point of view, the interpretation of colluvial deposits regarding the distinction of *in-situ* soil formation processes that can be attributed to the original (buried) soil surface and to 'inherited' pedogenic properties, which developed from parent material at upslope position, still remains a major challenge in colluvial research. One milestone in this matter is a highly resolved sampling strategy, which allows for insights into small-scale changes in single colluvial horizons. The application of multi-proxy approaches on an interdisciplinary level can further contribute to unravelling the formation of colluvial deposits in detail. Thus, former land surfaces beyond the *in-situ* buried soil could be identified to provide information on the playground of past human societies. If we refer again to the conclusive question of manuscript I "What's in a colluvial deposit?", we can conclude on the one hand that colluvial deposits contain much more information than we thought, but on the other hand, we see that challenges remain for future methodological research.

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Appendix

Manuscript I

What's in a colluvial deposit? Perspectives from archaeopedology.

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Abstract.

Colluvial deposits are considered as sedimentary archives for the reconstruction of the sedimentation and climate history, past pedogenesis and phases of land use. However, the human contribution to the formation of colluvial deposits is mainly based on assumptions derived from the local chronostratigraphy and archaeology. For this reason, there is often a substantial gap in the identification of specific land use practices that promoted prehistoric soil erosion and sedimentation processes.

We use an archaeopedological multi-proxy approach on a multi-layered colluvial deposit (six colluvial horizons) at the prehistoric site of Fürstenberg (Southwest Germany) to gain detailed insights into the sedimentation history, past pedogenesis and land use practices since the Neolithic. Soil and geochemical analyses such as X-ray fluorescence (XRF), X-ray diffraction (XRD), pedogenic oxides, pH-value and calcium carbonate content support the chronostratigraphy based on ages from optically stimulated luminescence (OSL) and AMS ^{14}C dating. Further, biogeochemical analyses of phytoliths, charcoal spectra, black carbon (BC), soil organic matter (SOM) composition by using pyrolysis-field ionization mass spectroscopy (Py-FIMS), urease activity, steroid biomarker and heavy metals (HM) are used as land use proxies.

The OSL and ^{14}C ages and the local archaeological record indicate six phases of colluvial deposition that occurred through five phases of land use comprising the Early to Younger Neolithic, the Urnfield to Hallstatt period, the Iron to Roman Age, the High Middle Ages, and the pre-modern period. The soil and geochemical proxies correlate with a phase of geomorphodynamic stability between the Early to Younger Neolithic and the Urnfield to Hallstatt period. The high abundance of grass morphotypes since the Neolithic and the increase of *Juniperus* since the Urnfield to Hallstatt period indicate a persistent anthropogenic impact on the vegetation. Considerable amounts of burned OM (up to 676 g BC kg^{-1} SOC, also identified as thermally stabilized SOM compounds by Py-FIMS) in colluvial horizons provide information that fire clearing (e.g. slash-and-burn) was especially used to open and maintain the landscape until the Roman Age. The absence of phytolith species originating from cereals, the occurrence of *Juniperus* and the evidence from the analysis of urease activity and faecal biomarkers indicate that the slopes of the Fürstenberg were mainly used for livestock farming and wood procurement.

Thus, the application of specific soil-biogeochemical proxies to colluvial deposits provide new information on the nature of past land use practices that caused the formation of colluvial

deposits at that time. In general, archaeopedological multi-proxy analyses of colluvial deposits, integrating the local archaeological record, contributes to a refined understanding of how humans have shaped the landscape since the Neolithic.

Keywords: Archaeopedology, colluvial deposits, multi-proxy approach, local archaeology, sedimentation history, past pedogenesis, past land use practices

1. Introduction

Colluvial deposits are important archives for the decipherment of the sedimentation and climate history, past pedogenesis and phases of land use (Dreibrodt et al., 2010a; Pietsch and Kühn, 2017). These archives are ubiquitously distributed in the landscape as they are the result of numerous slight and moderate soil erosion processes (Dreibrodt et al., 2010b). Considering the variety of definitions of colluvium (Mücher et al., 2018; Zádorová et al., 2018), we refer to colluvial deposits as sedimentary archives derived from human-induced soil erosion. In Central Europe, they began to form as an effect of land use practices such as forest clearings, tillage, creation of paths and house constructions at the beginning of sedentism in the Neolithic around 5500 BCE (Dotterweich, 2008). Colluvial deposits are therefore the indirect response to phases of past human activity and can be associated with land use practices in the catchment of bygone prehistoric settlements (Miera et al., 2019; Vogt, 2014).

So far, colluvial deposits have been object to multi-proxy approaches including methods from soil sciences (Kühn et al., 2017), geomorphology (Fuchs and Lang, 2009), geoarchaeology (Cremeens et al., 2003) and archaeobotany (Dreibrodt et al., 2009). However, the human contribution to the formation of colluvial deposits is mainly based on assumptions derived from the chronostratigraphy and local archaeology, while evidence of specific land use practices that triggered soil erosion is often missing. For example, Schulte and Stumböck (2002) were able to establish a local record of land use history from colluvial deposits in the vicinity of a Neolithic settlement in the Hegau region (Southwest Germany), while specific proxies that focus on the nature of this land use were not applied. Henkner et al. (2017) used colluvial deposits as a proxy for regional land use history at the Baar (Southwest Germany), and derived information on land use from the temporal correlation of colluvial deposits and archaeological finds only.

In this paper we argue that an archaeopedological multi-proxy approach comprising the stratigraphic resolution of colluvial deposits by including numerical dating and pedogenetic analyses as well as specific soil-biogeochemical proxies and local archaeology could overcome these limitations and additionally increase the significance of colluvial deposits as archives for the reconstruction of past land use practices. Numerical dating on colluvial deposits such as optically stimulated luminescence (OSL) of sediments and AMS radiocarbon (^{14}C) measurements of charcoals were successfully reported in recent studies (Fuchs et al., 2010; van der Meijs et al., 2019). This temporal framework of sedimentation can be correlated with archaeological periods to obtain regional information on human impact (Miera et al., 2019).

Phases of soil formation are associated with the lower intensity or complete absence of sedimentation and are therefore an indicator of reduced or changed land use. Soil and geochemical analyses such as X-ray diffraction (XRD) (Dietel et al., 2017), X-ray fluorescence (XRF) (Kronberg and Nesbitt, 1981), the analysis of pedogenic oxides and soil organic matter (SOM) (Lin, 2011) on different colluvial horizons show the intensity of mineral weathering and SOM accumulation, which are linked to the time and intensity of past pedogenetic processes. Heavy metal analyses on colluvial deposits are frequently used to differentiate between the geogenic background and the additional atmospheric or direct input by anthropogenic contamination (Henkner et al., 2018a).

Yet, rather few studies have combined soil-biogeochemical proxies on colluvial deposits to date. Dreibrodt et al. (2009) analysed charcoal spectra from colluvial deposits in Northern Germany and provided evidence on local vegetation change. Whether these changes were mainly natural (e.g. climate) or human-induced (e.g. deforestation) could not be conclusively assessed. In a study by Kühn et al. (2017) on a colluvial sequence in Central Germany, BC analysis showed anthropogenic fire activities at least since the Iron Age. So far, tillage could not be reconstructed from colluvial deposits, although the analysis of phytoliths may provide the necessary information (Pietsch and Machado, 2014). The progress in lipid biomarker research opened new possibilities to decipher land use practices such as livestock farming and manuring from sedimentary archives. Higher amounts of urease activity in sediments serve as indicator of the input of animal faeces (Chernysheva et al., 2015). The subsequent analysis of faecal biomarkers such as sterols, stanols and stanones allow the identification and differentiation of herbivorous and omnivorous digestion residues (Birk et al., 2011; Prost et al., 2017). To our knowledge, urease activity and faecal biomarkers have not been investigated in the context of colluvial deposits yet, although these proxies are reported to be stable and immobile in the soil environment (Bull et al., 2002; Zantua and Bremner, 1976).

The aim of the current study is to combine the local archaeology with an archaeopedological multi-proxy approach to one multi-layered colluvial deposit. We aim to extend the analytical potential of colluvial deposits and to gain insights into past pedogenesis and land use practices that triggered soil erosion and sedimentation processes at the prehistoric site of Fürstenberg (Southwest Germany). Our hypothesis is that colluvial deposits are archives for the reconstruction of past land use practices in the vicinity of archaeological sites.

2. Study area.

2.1 Physical geographical setting

The study site is located in SW-Germany at the Fürstenberg (Fig. 1), a Zeugenberg of the Swabian Jura. The Fürstenberg (Fue) is part of the Baaralb, which marks the transition between the Baar (part of the German Trias) region in the west and the Swabian Jura in the east. The Fürstenberg is 918 m a.s.l. and thus 200 m higher than its surroundings and is characterized by gentle slopes, which mainly consist of limestones from the late Jurassic and clay-rich sediments from the early Jurassic. Loess sediments, which were relocated by periglacial processes, are covering the slopes (Kösel and Rilling, 2002). Cambisols, Stagnosols and Regosols were the dominant Reference Soil Groups according to WRB 2015 (IUSS Working Group WRB, 2015) and mainly developed from periglacial layers with varying amounts of local rocks. The mean annual temperature is 7-8 °C and the mean annual precipitation is ca. 850 mm.

2.2 Archaeological setting

Field surveys and excavations at the Fürstenberg were carried out by several (geo)archaeologists since 1932 (for a compilation see Miera, 2020). Most recently, land use activities since the Neolithic have been studied using numerical dating and local archaeology (Henkner et al., 2017; Miera et al., 2019).

Pottery fragments and stone artefacts indicate a Neolithic settlement on the plateau of the Fürstenberg (Schmid, 1991; 1992). However, given the state of fragmentation of the pottery and the atypical character of the stone artefacts, these finds can only be described as Neolithic (5500–2150 BCE) in general without further temporal resolution (Wagner, 2014).

Pottery fragments discovered during field surveys in 2011 and 2012 point to a potential settlement only in the last phase of the Bronze Age, the late Urnfield period (1200–800 BCE) (Wagner, 2014; 2015). The establishment of hilltop settlements is typical for this period and in the immediate vicinity of the Fürstenberg, several hilltop settlements were dated accordingly (Ahlrichs et al., 2018).

Wagner (2014; 2015) was also able to recover pottery fragments from the early pre-Roman Iron Age, indicating a hilltop settlement dating to the Hallstatt period (800–450 BCE). According to the available archaeological evidence, this settlement was abandoned with the transition to the subsequent La Tène period (Knopf and Ahlrichs, 2017).

Based on the discovery of *Terra sigillata* at the Fürstenberg from the production facility La Graufesenque in France (Revellio, 1932; 1933), Roman land use on Fürstenberg can be dated to the middle or to the end of the first century CE (Wagner, 2015).

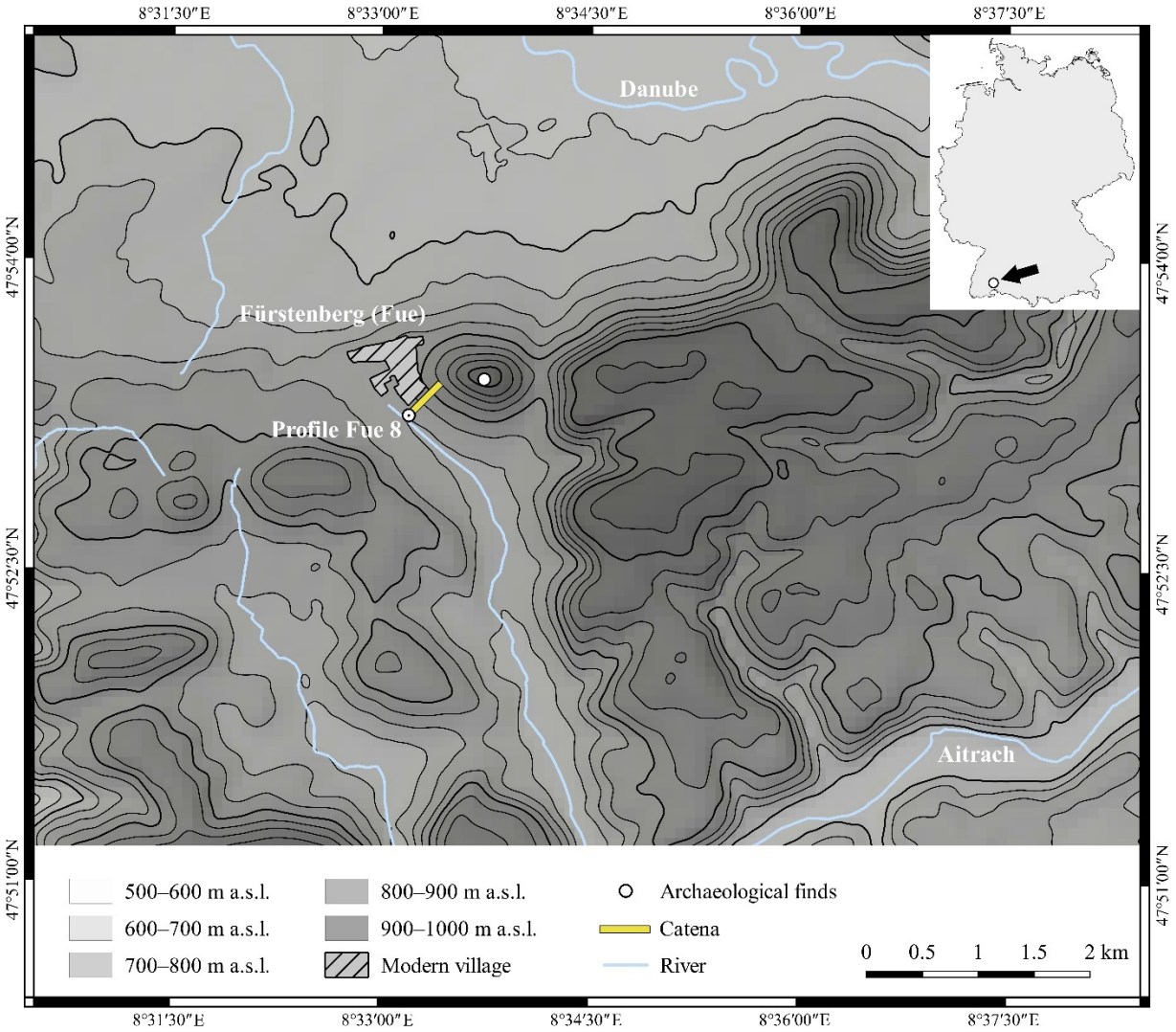

Fig. 1: Study site of Fürstenberg (SW-Germany).

However, due to its height, the topographic location would be unusual for a Roman farm since the plateau is exposed to weather peaks and water supply is limited due to the local geology. A large Roman fort about ten kilometers northwest (ca. 670 m a.s.l.) near Hüfingen (Revellio, 1937; Mayer-Reppert, 1995) could at least explain a small Roman military post on the Fürstenberg (Wagner, 2015).

A small settlement was founded on the Fürstenberg in the High Middle Age (late 12th century CE) that could be further confirmed during a field survey in 2018 conducted by members of the Collaborative Research Centre (SFB). This settlement was destroyed by fire in 1841. Pieces of pottery found in some of the parcels around the Fue 8 profile site relate to this medieval land use, whereas material from earlier epochs seemed not to be present on the steep slopes. Since then, the village of Fürstenberg is no longer on top, but next to the mountain (Wagner, 2014).

3. Material and methods.

3.1 Field work

Field work was conducted in 2014. The soils were described by Henkner et al. (2017) following the German soil classification system (Ad-hoc-AG Boden, 2005) and translated to the WRB 2015 (IUSS Working Group WRB, 2015) according to Eberhardt et al. (2014). Soil horizons that appear brownish, enriched in organic matter and charcoals and without other characteristics of soil formation are designated as colluvial horizons (M horizon, *lat. migrare*, to migrate). The profile Fürstenberg 8 (Fue 8) is embedded into a well-resolved catena containing three different soil profiles and 16 augers (Fig. 2) and is in the immediate vicinity of the prehistoric hilltop site of Fürstenberg (Fig. 1). Due to its detailed and pronounced pedostratigraphy, Fue 8 was selected for the multi-proxy analysis on a single colluvial deposit. Along the profile, the upper 5 cm of each colluvial horizon were sampled separately and colluvial horizons thicker than 20 cm were further divided into sub-samples.

3.2 Physical, chemical and biological soil analyses

For optically stimulated luminescence dating (OSL), sediment samples were taken using opaque steel cylinders (4.5 cm in diameter) and the equivalent dose (D_e) was measured following a single-aliquot regenerative (SAR) dose protocol suggested by Murray and Wintle (2000). The samples GI-181, GI-182 and GI-183 were analysed using the coarse fraction (90-200 µm) mounted on 2 mm aliquots, while for the samples GI-179, GI-180 and GI-184 the fine grain (4-11 µm) quartz was used for D_e determination. All OSL measurements were carried out on a Freiberg Instrument Lexsyg reader (Lomax et al., 2014) and the data analysis was performed using the R luminescence package (Kreutzer et al., 2012). Modern bleaching by ploughing activity or bioturbation was considered by neglecting the upper first 50 cm of the profile. Most of the samples collected at Fürstenberg had good OSL characteristics, while the samples GI-181 and GI-183 showed indication for incomplete bleaching as evidenced by D_e distributions with a skew towards high D_e values (Fig. S3). For these samples, a bootstrap minimum age model (sigma b value of 10 %) was applied (Galbraith et al., 1999; Cunningham and Wallinga, 2012). The D_e of the remaining samples was calculated using the central age model (Galbraith et al., 1999). As fine grain data does not allow analyses on the degree of bleaching using D_e distributions, it cannot be ruled out that these samples are also affected by incomplete bleaching.

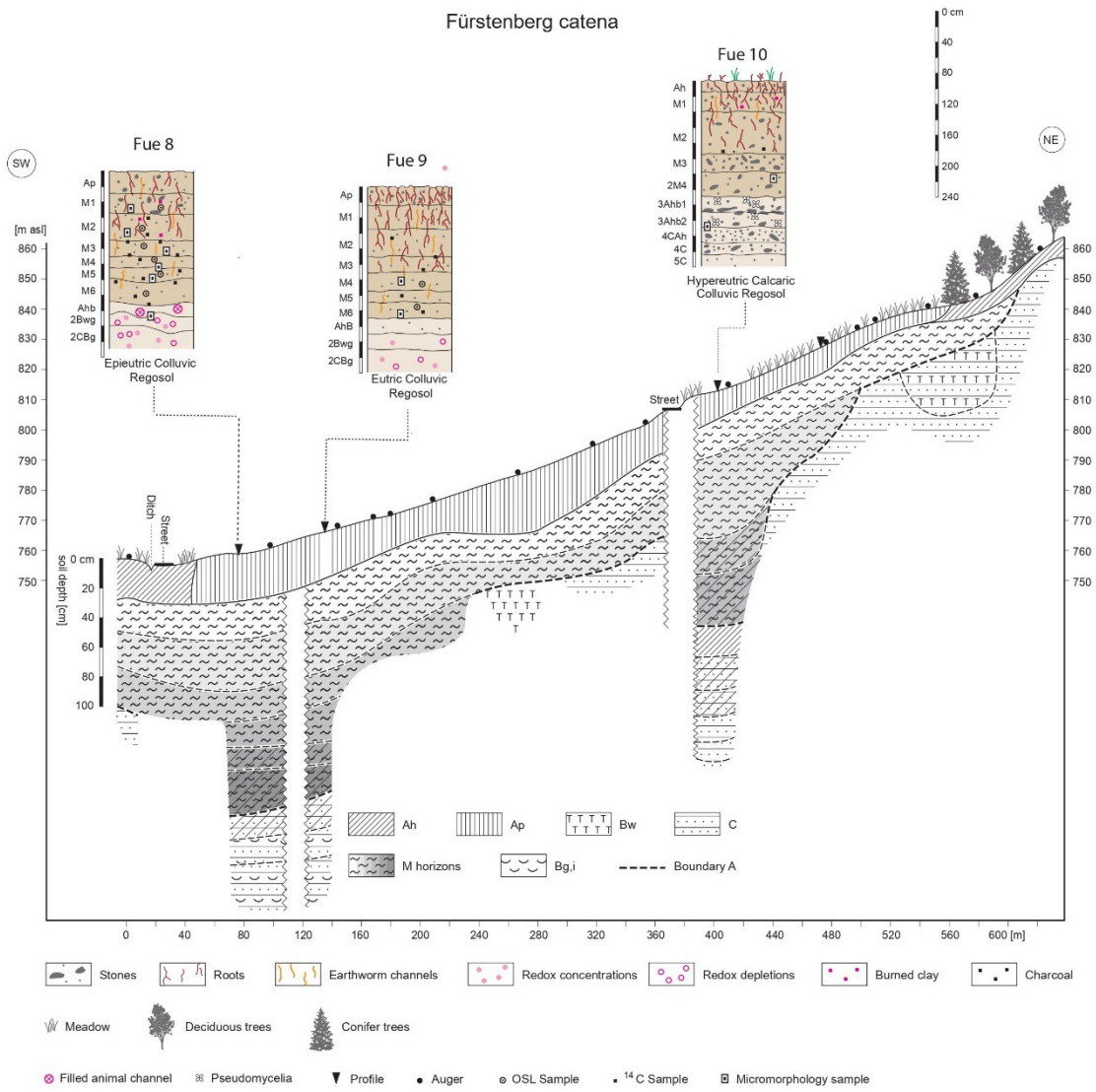

Fig. 2 Catena and pedostratigraphy of the southwestern slope of Fürstenberg. Adapted from Henkner et al. (2017).

Charcoal fragments collected along the colluvial profiles were dated with AMS-^{14}C dating at the laboratory of MPI for biogeochemistry in Jena and at the Klaus-Tschira Centre of Archaeometry in Mannheim. Acid-base-acid (ABA) pretreatment was performed for sample cleaning (Steinhof et al., 2017). The ^{14}C ages were corrected for fractionation based on the δ^{13}. The conversion of the ^{14}C ages into calibrated calendar years were performed with R bacon package (Blaauw and Christen, 2011) using the IntCal13 calibration curve (Ramsey, 2009; Reimer et al., 2013).

The grain size distribution was measured using X-ray granulometry with SediGraph 5120 (Micromeritics GmbH, Germany) for grain sizes < 20 µm; grain sizes between 20 and 2000 µm were determined by sieving. Soil pH ($CaCl_2$, H_2O) value was measured with a soil:solution

ratio of 1:2.5 (Sentix 81, WTW, pH 340). A Calcimeter (Eijkelkamp, Giesbeek) was used for the volumetric measurement of carbonate content. Total carbon (TC) and nitrogen (TN) content were analysed in helium (He) atmosphere using oxidative heat combustion at 1150 °C (element analyzer "vario EL III", Elementar Analysesysteme GmbH, Germany, in CNS mode). The content of soil organic C (SOC) was calculated by the difference between total inorganic (TC) and carbonate carbon ($CaCO_3$ x 0.12) (Don et al., 2009).

Major elements were analysed with a wavelength dispersive XRF (AXS S4 (Rh-tube at 4kW) Pioneer, Bruker, USA). Prior to preparation, the samples (ratio Li-metaborate to soil 1:5) were ground with an agate mill for 10 minutes. Major elements were used for the calculation of the CIA (chemical index of alteration) $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)]*100$ (Nesbitt and Young, 1981), where CaO* is the amount of silicate-bound CaO. The CIA indicates the state of weathering as a result of feldspar breakdown, which is related to the formation of secondary minerals (Kronberg and Nesbitt, 1981). Higher CIA values are interpreted as increasing weathering intensity and/or duration.

For XRD analyses, samples were milled with a Retsch/McCrone micronizing mill. Samples were prepared both as random powders using the back-loading technique and as preferred oriented specimens by transferring suspended clay fractions to ceramic tiles using a vacuum filter. These oriented mounts were used to identify clay mineral species and measured in an air-dried and in ethylene glycol saturated state after storing at 60 °C overnight in a desiccator. The random powder measurements were used to quantify the mineral phases present by applying the Rietveld program BGMN (Bergmann et al., 1998) and the structural models for interstratified illite-smectite (Ufer et al., 2012a; b). The sum of crystalline phases is normalized to 100 % w/w. The goodness of fit was evaluated by Rexp (theoretically best possible fit) and Rwp (achieved fit) values. XRD patterns were recorded using a PANalytical X'Pert PRO MPD Θ-Θ diffractometer operating with Co-Kα radiation at 40 kV and 40 mA. For detailed information about the equipment, step size and angular range, see Dietel et al. (2018).

Pedogenic oxides of iron (Fe) were extracted with the ammonium-oxalate (Fe_o) method after Schwertmann (1964) and with the dithionite-citrate (Fe_d) method after Mehra and Jackson (2013). Fe was determined with an ICP OES (DV 5300, Perkin Elmer) at a wavelength of 238.204 nm. The higher the Fe_o/Fe_d ratio the higher is the activity of weathering of primary silicates (Schwertmann, 1964). A low ratio indicates a higher proportion of well-crystallized iron (hydr)oxides. The Fe_d/Fe_t (Fe_t: total iron) ratio gives information on the iron release from primary mineral weathering and formation of Fe (hydr)oxides and oxyhydroxides: A higher ratio indicates longer or more intensive chemical weathering processes (Baumann et al., 2014).

Phytoliths were extracted and counted following the rapid extraction method by Katz et al. 2010. The identification of different morphotypes was done by following the standard literature (ICPT, 2019; Twiss et al., 1969) and the PhytCore online database (Albert et al., 2016). Phytoliths were studied using a Zeiss Axioscope AX10 petrographic microscope at 200x and 400x magnifications.

Charcoals for anthracological identification were retrieved by flotation and the identification was done by the detection of diagnostic features on transversal, tangential and radial sections, using magnifications between 60x and 500x. Identification literature (Schweingruber, 1990) was consulted as well as the reference collection at the University of Tübingen.

For pyrolysis-field ionization mass spectroscopy (Py-FIMS), an aliquot (2 to 5 mg) of finely ground sample was pyrolyzed in the ion source (emitter: 4.7 kV, counter electrode -5.5 kV) of a double-focusing Finnigan MAT 95 mass spectrometer. The samples were heated in high vacuum of 10^{-4} Pa from 50 °C to 650 °C, in 10 K temperature steps. Between magnetic scans the emitter was flash heated to avoid residues of pyrolysis products. About 60 spectra were recorded for the mass range 15 to 900 (three replicates). Ion intensities were referred to 1 mg of the sample. The Py-FIMS method, including assignment of specific marker signals (*m/z*) to relevant compound classes, was described in detail by Schulten and Leinweber (1999) and Leinweber et al. (2009). Furthermore, close relationships between microbial decomposition and thermal stability in Py-FIMS were reflected by separation of Py-FIMS thermograms into thermally labile (faster degradable) and stable (slower degradable and/or modified by fire) proportions (Leinweber et al., 2008). The thermostability was calculated as follows: thermostability = stabile proportions/(stabile + labile proportions), whereas < 420 °C is labile ≥ 420 °C is stable.

For the oxidation of the molecular residues of incomplete combustion BC to benzene polycarboxylic acids (BPCAs), a revised protocol of Brodowski et al. (2005) and Kappenberg et al. (2016) was applied. A gas chromatograph (GC) Hewlett Packard 6890 (Hewlett Packard GmbH, Germany) equipped with an HP-5 capillary column (30 m 0.32 mm i.e., 0.25 mm film thickness, Macherey-Nagel, Germany) and a flame ionisation detector was used for sample analysis. A GC program according to Brodowski et al. (2005) was applied. The determination of duplicates showed deviations of < 5 %. The internal standard (citric acid) recovery was > 75 % in all cases. The conversion factor of 2.27, proposed by Glaser et al. (1998), was used to calculate BC from BPCAs.

The activity of extracellular urease derived from soil organisms was colorimetrically determined according to a modified protocol of Kandeler and Gerber (1988). 5 g of air-dried

soil samples were moistened with 3.5 ml 0.08 M aqueous urea solution and incubated for 2 h at 37 °C. Subsequently, 45.5 ml 1 M KCl/0.01 M HCl solution were added and mechanically shaken for 30 min. After filtration, 0.5 ml of the filtrate were mixed successively with 4.5 ml of distilled H_2O, 2.5 ml of mixture solution (in equal parts: 0.3 M NaOH, nitroprussid-salicylate, H_2O) and 1 ml of 0.1 % dichlorisocyanurate acid. Colorimetric measurements were conducted at 690 nm with Synergy HTX multi-mode reader (BioTek).

Faecal biomarkers were analysed using modified methods according to Prost et al. (2017) and Birk et al. (2012). Soil samples were extracted via an accelerated solvent extractor (Speedextractor E-916, Büchi Labortechnik GmbH, Germany) using DCM (dichlormethane) and MeOH (methanol) (2:1, 1:3, v/v). 10 g of soil sample was filled into the 40 ml extraction cells together with quartz sand. After extraction, the samples were spiked with 100 µl of internal standard (IS1) d7-cholest-5-en-3ß-ol (5ng μl^{-1} in MeOH, Avanti Polar Lipids inc.). Silylation of the total lipid extract (TLE) was performed for 1 h at 80 °C by using 50 µl BSTFA (*N*,*O*-bis(trimethylsilyl)trifluoroacetamide, Sigma Aldrich) and 10 µl DCM:Pyridine (1:1, v/v, Sigma Aldrich). 100 µl of d6-campesterol (10ng μl^{-1} in MeOH) was used as second internal standard (IS2). All samples were analysed using gas chromatography-mass spectrometry (GC-MS/MS, Agilent 5977B EVO3, Chromtech, Germany) equipped with a fused silica capillary column (Optima 5MS-0.25µm, 30 m x 0.25 mm ID) and high purity (99.999 %) helium (He) was used as carrier gas. Measurements were performed using scan mode to identify peak identity and retention times. Selected ion monitoring (SIM) with specific masses (*m/z*) was applied for the quantification of sterols, stanols and stanones.

The heavy metal contents (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) were analysed with a reverse *aqua regia* solution (HNO_3 to HCl ratio 1:3, DIN ISO 11466: 1997-06) in a microwave (MLS GmbH, Germany). The solution was measured with an ICP-OES (Optima 5300DV, Perkin Elmer Inc.) with a Miramist nebulizer using the element-specific wavelengths (As: 188.979; Cd: 228.802; Cr: 267.716; Cu: 327.393; Hg: 194.168; Ni: 231.604; Pb: 220.353; Zn: 206.200) according to Nölte (2002).

4. Results.

4.1 Pedostratigraphy and field properties

Six colluvial horizons (M1-M6) were described at the Fue 8 profile (Fig. 2 and 3, Tab. 1), which reached a depth of up to 170 cm. A modern ploughing horizon (Ap) was observed within the first 30 cm from the soil surface. The lowest colluvial horizon (M6) buried an *in-situ* developed soil profile that comprised a preserved topsoil (2Ahb) and two subsoil horizons with stagnic and vertic conditions (2Bwg, 2CBg). The buried soil was 45 cm in depth (185-230 cm). The Fue 8 profile was classified as Epieutric Colluvic Regosol (Aric, Pantoclayic, Humic, Bathyruptic, Bathythaptomollic) (Henkner et al., 2017).

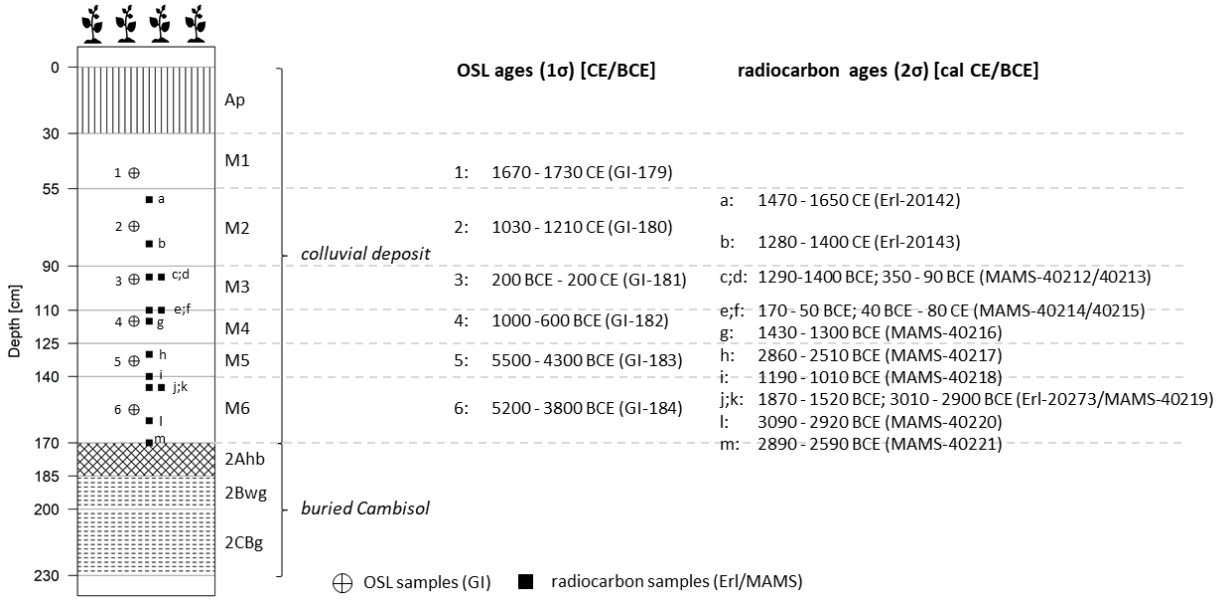

Fig. 3: Pedostratigraphy, OSL and AMS-^{14}C ages of the Fue 8 profile. The ^{14}C ages were calibrated with OxCal v4.3.2 after Bronk and Ramsey (2017) using the IntCal13 atmospheric curve according to Reimer et al. (2013). OSL (analysed in Giessen (GI)) and ^{14}C ages are adapted from Henkner et al. (2018c); ^{14}C samples are analysed in Erlangen (Erl), except of ^{14}C ages denominated with MAMS (analysed in Mannheim).

Tab. 1: Selected soil properties of the Fue 8 profile (total nitrogen: TN; soil organic carbon to nitrogen: C/N; soil organic carbon: SOC; CIA: chemical index of alteration; Fe_o: ammonium-oxalate iron; Fe_d: dithionite-citrate iron; Fe_t: total iron; units in mass-%; n.a.: not analysed). Adapted from Henkner et al. (2018c).

Horizon	Lower boundary depth increments [cm]	Substrate genesis	TN [%]	C/N	SOC [%]	$CaCO_3$ [%]	pH	Sand [%]	Silt [%]	Clay [%]	CIA	Fe_o/Fe_d	Fe_d/Fe_t
Ap	30	colluvial	0.34	8.9	3.0	3.3	7.3	7	34	59	59.2	0.05	0.36
M1	35	colluvial	0.28	8.6	2.5	4.5	7.3	9	29	61	57.6	0.05	0.36
M1	55	colluvial	0.19	8.8	1.7	3.1	7.4	7	30	62	59.6	0.04	0.40
M2	60	colluvial	0.18	9.1	1.6	0.2	7.2	6	30	63	74.2	0.04	0.34
M2	75	colluvial	0.18	9.2	1.7	0.2	7.3	7	29	64	74.9	0.05	0.33
M2	90	colluvial	0.18	9.9	1.8	0.1	7.1	6	30	63	75.1	0.05	0.35
M3	95	colluvial	0.18	10.1	1.8	0.1	7.1	7	31	62	75.1	0.05	0.36
M3	110	colluvial	0.16	10.4	1.7	0.0	7.1	6	34	59	75.0	0.06	0.39
M4	115	colluvial	0.15	10.4	1.6	0.0	7.1	8	35	57	75.1	0.06	0.35
M4	125	colluvial	0.15	10.8	1.7	0.0	7.1	8	36	56	75.3	0.05	0.39
M5	130	colluvial	0.15	11.7	1.8	0.1	7.0	9	38	53	75.9	0.05	0.57
M5	140	colluvial	0.16	12.1	1.9	0.1	7.0	8	40	52	73.1	0.08	0.42
M6	145	colluvial	0.17	12.8	2.2	0.1	6.9	7	40	52	72.5	0.08	0.42
M6	160	colluvial	0.18	12.9	2.3	0.1	6.9	7	38	54	72.3	0.09	0.41
M6	170	colluvial	0.16	12.9	2.1	0.1	6.9	8	38	53	72.3	0.08	0.40
2Ahb	185	weathered	0.12	11.1	1.3	n.a.	6.8	11	39	50	74.4	0.08	0.34
2Bwg	200	weathered	0.08	7.9	0.6	n.a.	6.9	14	30	56	75.7	0.07	0.34
2CBg	230	weathered	0.06	5.6	0.3	n.a.	6.9	11	30	59	72.4	0.03	0.30

4.2 Grain size distribution, pH, $CaCO_3$

The grain size distribution was dominated by the clay (< 2µm) and the silt fraction (2-63 µm) with amounts of > 85 % as the sum of both fractions for all colluvial and *in-situ* developed horizons. The sand fraction (63-2000 µm) showed slightly higher values at the lower part of the profile. Most of the colluvial sequence (M2-M6) is non-calcareous; only the Ap and M1 horizons contained about 2-4 % $CaCO_3$ indicating a recalcification of the upper part of Fue 8 because of the transport of the limestone from the upper slope. The pH-values were around 7 with a slightly decreasing tendency with depth (Tab. 1).

4.3 Dating

The OSL ages of Fue 8 (Fig. 3, data published in Scherer et al., 2020) showed a clear trend with a positive correlation between depth and age. For the AMS-^{14}C ages (Fig. 3, data published in Scherer et al., 2020), a comparable trend with only slight temporal reversals could be observed. Based on the OSL age from the M6 horizon, the first phase of sedimentation was dated to the Early to Younger Neolithic (GI-184, 5200-3800 BCE), while ^{14}C dating shows considerably younger ages at the same depth. Between the horizons M5 and M4, the OSL ages GI-183 (5500-4300 BCE) and GI-182 (1000-600 BCE) showed a temporal gap of 3300-4900 years, respectively from the Early/Middle Neolithic to the Urnfield to Hallstatt period. The ^{14}C ages in M5 and M4 (MAMS-40217, 2860-2510 BCE; MAMS-40216, 1430-1300 BCE) corresponded to the periods of Final Neolithic and Mid Bronze Age. Further, three phases of sedimentation were detected with depositional ages between the Iron and the Roman Age (M3, GI-181, 200 BCE-200 CE), in the High Middle Ages (M2, GI-180, 1030-1210 CE) and in the pre-modern period (M1, GI-179, 1670-1730 CE). The ^{14}C ages in the M3 to M1 horizon correspond to the OSL ages and show phases of land use in the Late Iron Age and the Roman period (M3/M4, MAMS 40213-40215, 40 BCE – 80 CE, 170-50 BCE, 350-90 BCE), in the High to Late Middle Ages (M2, Erl-20143, 1280-1400 CE) and in the pre-modern times (M1, Erl-20142, 1470-1650 CE).

4.4 Chemical index of alteration (CIA), pedogenic oxide ratios (POR), XRD

The CIA varied from 57.6 to 75.9 and a distinct increase was detected between the horizons M1 and M2 (Tab. 1, data published in Scherer et al., 2020). Minor differences were observed between the M2 to 2CBg horizon (72.3–75.9). The maximum ratio was measured at the upper 5 cm of the horizon M5. The Fe_d/Fe_t ratios varied from 0.30 to 0.57 (Tab. 1) with the highest ratios of the whole sequence (0.57) occurring in the upper 5 cm of the M5 horizon. For the buried *in-situ* developed soil horizons, lower Fe_d/Fe_t ratios were determined (0.34, 0.30). The

Fe_o/Fe_d ratios were generally low with a profile mean of 0.06. We observed a slightly increasing trend by depth and age of colluvial horizons. Only for the 2CBg horizon, the ratio dropped to its minimum of 0.03 indicating a very low activity.

Based on the XRD analysis, the main phases were identified in order of their relative abundance as illite-smectite (I-Sm) (29-43 % w/w), quartz (28.5-40.4 % w/w), goethite (2.4-13.5 % w/w), muscovite (3.4-6.5 % w/w), kaolinite (3.7-5.4 % w/w), feldspars (Na-rich plagioclase 2.1-3.2 % w/w, K-feldspar 3.7-5.4 % w/w), and tri-trioctahedral chlorite (<0.5-2.8 % w/w) (Tab. 2). Other phases present as traces were rutile, anatase, apatite, calcite, and lepidocrocite (all < 2 % w/w). Calcite occurred only in the upper horizons (M1, M2) supporting the calcimetry results. Lepidocrocite was detected in the horizons M6, 2Ahb, 2Bwg, increasing with depth to a maximum of 1.9 % w/w. Clay mineralogy was dominated by interstratified illite-smectite (I-Sm) (29-43 % w/w), which was composed of mainly non-expandable (micaceous/illitic) layers (62-76 % mol/mol). The main Fe containing minerals present were goethite, lepidocrocite, chlorite, and I-Sm. Ferrihydrite and X-ray amorphous Fe-phases were not found in significant amounts.

Tab. 2: Mineral contents determined by X-ray diffraction of the Fue 8 profile using the rietveld refinement technique. Interstratified illite-smectite was dominated by non-expandable/illitic layers (62-76 % mol/mol) and abbreviated with I-Sm. [% w/w]: SI unit mass-% given as g mineral/g sample. R_{wp} and R_{exp} denote values to evaluate the goodness of the fit. Lower R_{wp} values indicate better fits and R_{exp} is the lowest achievable R_{wp} value (perfect fit, see Dietel et al. 2018).

Horizon	Lower boundary depth increments [cm]	Quartz	K-feldspars	Plagioclase	Muscovite	Rutile	Anatase	Apatite	Calcite	Goethite	Lepidocrocite	I-Sm	Kaolinite	Chlorite	R_{wp}	R_{exp}
		[/% w/w]													[/%]	
M1	35	28.5	5.0	2.7	4.2	0.6	0.7	0.2	4.2	10.7	<0.1	36.0	7.5	<0.5	8.3	6.8
M2	75	28.9	4.2	2.8	5.0	0.9	0.8	0.1	0.1	12.3	<0.1	38.0	7.2	<0.5	8.1	6.6
M4	115	33.0	3.7	2.5	5.2	0.9	0.5	0.2	<0.1	13.1	<0.1	33.0	6.3	2.0	8.1	6.6
M4	125	32.6	4.2	2.1	4.3	0.8	0.7	0.1	<0.1	13.5	<0.1	35.0	5.1	2.2	7.8	6.6
M5	130	34.3	5.4	2.8	5.7	1.3	0.6	0.6	<0.1	10.5	<0.1	31.0	5.4	2.6	8.2	6.6
M5	140	38.5	4.1	3.1	5.7	1.0	0.4	0.1	<0.1	8.4	<0.1	30.0	6.2	2.5	8.4	6.8
M6	145	40.4	4.8	2.8	6.5	0.8	0.5	0.1	<0.1	6.2	<0.1	30.0	5.9	2.7	8.4	7.0
M6	160	38.7	4.1	3.0	5.5	1.0	0.5	0.1	<0.1	7.0	0.1	31.0	6.3	2.5	8.6	6.9
M6	170	38.1	4.1	3.2	5.1	0.9	0.6	0.1	<0.1	7.6	0.2	32.0	6.0	2.2	8.2	6.9
2Ahb	185	36.6	4.9	2.9	3.9	0.9	0.4	0.1	<0.1	11.2	0.5	29.0	6.5	2.8	8.2	6.6
2Bwg	200	27.1	4.0	2.3	4.5	0.7	0.3	0.1	<0.1	14.1	1.9	35.0	6.7	2.7	7.9	6.3
2CBg	230	36.2	4.6	2.7	3.4	0.7	0.4	0.1	<0.1	2.4	<0.1	43.0	4.4	2.0	9.3	7.0

4.5 Phytoliths

Most of the phytolith samples showed concentrations slightly higher compared to the control (Tab. 3). Therefore, assemblages were characterized only for samples that yielded more than 300,000 phytoliths per gram of sediment in order to reach well-grounded interpretations. All samples exhibited large amounts of rugose and weathered morphotypes, and most samples exhibited low concentrations or complete lack of phytoliths in anatomical connection (multicells). These features are indicative of poor preservation due to chemical dissolution and/or mechanical transport (Cabanes et al., 2011; Cabanes and Shahack-Gross, 2015). Grasses dominated the assemblages except for the samples of the lower part of M2 and M3 horizon, which were heavily degraded. Dicots in the form of herbaceous and woody plants were present in relatively substantial amounts in the Ap and M1 and the lower part of the M3 horizon. This became especially apparent when considering that in general trees produce less phytoliths per unit weight of starting material than grasses (Albert and Weiner, 2001; Tsartsidou et al., 2007). Most of the grasses were C_3 plants that grow under moist and temperate conditions, as indicated by the high percentage of RONDEL cells from the Pooideae subfamily. These grasses did not seem to derive from domesticated cereals, considering that the percentage of ELONGATE DENDRITIC morphotypes was well below 7 in all samples (Albert et al., 2008). Samples from the M4 to the M6 horizon exhibited considerable amounts of phytoliths of C_4 grasses, especially from the Panicoideae subfamily (BILOBATE morphotype). The plant part most represented is the leaf/stem, but this might also be affected by the partial or total dissolution of the most delicate morphotypes. Nevertheless, given the high percentage of leaf/stem phytoliths, it seems that inflorescence was a minor component of the assemblages, regardless of preservation.

Tab. 3: Phytolith concentrations and percentages of different morphotypes of the Fue 8 profile. Percentages are calculated over the total number of morphotypes identified in each soil sample; at least 200 morphotypes were identified in each sample (n.a. = not applicable due to low concentration). 2Bwg and 2CBg serve as control samples. Pooideae, Panicoideae and Chloridoideae are given as percentage over all the grass short cell morphotypes within each soil sample. Lower boundary = lower boundary depth increments.

Horizon	Lower boundary [cm]	Concentration [millions/g of sed.]	Monocots [%]	Dicots	Weathered	Monocot	Monocot leaf and stem	Dendritic morphotype	Pooideae	Panicoideae	Chloridoideae	Multicells
Ap	30	0.60	63	17	20	2	39	1.8	100	0	0	11
M1	35	0.42	51	19	30	3	36	2.8	100	0	0	6
M1	55	0.10	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
M2	60	0.09	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
M2	75	0.35	51	6	43	1	39	0.9	100	0	0	7
M2	90	0.50	44	2	54	1	34	1.4	100	0	0	0
M3	95	0.11	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
M3	110	0.45	44	10	46	0	32	0	100	0	0	0
M4	115	0.51	55	7	38	0	42	0	82	18	0	5
M4	125	0.84	60	1	39	0	44	0	73	17	10	0
M5	130	0.61	61	3	36	0	45	0	75	18	7	0
M5	140	1.17	64	4	32	0	46	0.4	61	34	5	0
M6	145	1.00	82	3	15	0	57	0	63	31	6	5
M6	160	0.69	76	2	22	0	54	0	43	46	11	0
M6	170	0.94	68	5	27	0	48	0	33	51	16	4
2Ahb	185	0.13	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
2Bwg	200	0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
2CBg	230	0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

4.6 Anthracology

In total, 527 charcoal fragments were analysed from the Fue 8 profile and minimally seven charcoal taxa were identified, including the species of *Quercus* sp., *Fagus* sp., *Juniperus* sp., *Fraxinus* sp., *Alnus* sp., *Corylus* sp. and *Populus* or *Salix* sp. (Fig. 3). Dicotyledonous taxa were dominating within the profile. Moreover, all horizons, except the Ap, contained more Dicotyledonous than coniferous charcoal. The lower levels differed from the upper levels in their charcoal content: *Quercus* sp. overall appeared to be hardly present in the upper layers (especially in most layers of M2 and M1), whereas it was present in all levels below. *Juniperus* sp. and conifers only appeared in the upper levels (from M4 onwards), just as *Fagus* sp. was present only in most of the upper layers (from M3 onwards). However, many fragments were too small (from 0,63 mm onwards) to have a precise determination, whereas a distinction was possible only between dicotyledonous and coniferous wood, causing the rather high number of unspecified Dicotyledons and conifers.

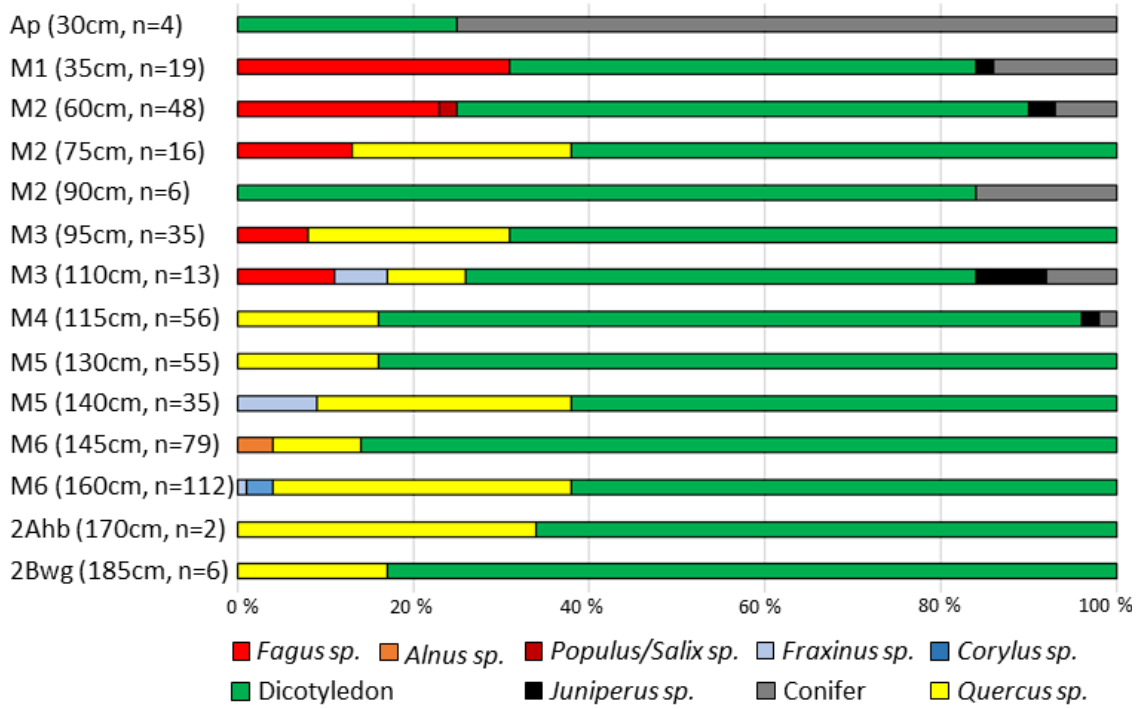

Fig. 4: Percentage distribution of charcoal taxa for different sampling depths at the Fue 8 profile (n=number of identified charcoal fragments).

4.7 Soil organic matter composition (SOC, Py-FIMS, BC, urease, faecal biomarker)

The SOC contents ranged from 0.3 to 3.0 % and showed an average of 1.8 % (Tab. 1). Excluding the modern topsoil horizon (Ap), the highest SOC contents were measured at the upper part of M1 (2.5 %) and at the lower part of M6 (2.1-2.3 %). The SOC values of the buried

topsoil (2Ahb, 1.3 %) and the subsoil horizons (2Bwg, 2CBg, 0.3-0.6 %) showed pronounced differences.

The thermograms for the volatilization of organic molecules (Fig. S1) showed almost Gaussian-like curves with maximum volatilization at slightly above 400 °C. Overall there was a clear trend of intensity reductions with profile depth visualized by the gradual decrease in ion intensities at volatilization maximum from about 3×10^6 counts at 30 to 35 cm over 0.4 to 0.6 $\times 10^6$ counts at 75 to 90 cm to about 0.2×10^6 counts at 125 to 170 cm and $< 0.2 \times 10^6$ counts at 185 cm profile depth. This decrease in total ion intensities is also shown in Fig. S1 (numbers printed into the upper right inserts of the thermograms). At the deepest parts of Fue 8, the pyrolyzed soil samples exhibit thermograms that increasingly differ from the rather ideal Gaussian curve shapes as seen in the upper profile parts. Correspondingly, the mass spectra for the upper horizons showed more m/z signals over a wider mass range compared to the spectra of samples from greater soil depth. Spectra from the upper soil profile showed distinct signals of carbohydrates (e.g. *m/z* 82, 96, 110), phenols and lignin monomers (e.g. *m/z* 94, 108) in the lower mass range (Tab. 4). The most pronounced trends with soil depth were distinct increases in the proportions of mostly heterocyclic N containing compounds (NCOMP) and peptides (PEPTI) at the expense of especially lignin dimers (LDIM), both correlated to TN (Fig. S2, c, d). The thermal stability of bulk SOM also increased slightly with soil depth. Furthermore, spectra from a soil depth of 55 cm showed intensive peaks of wood burning markers as indicated by pyrene (m/z 202), hydroxypyrene (*m/z* 218), benzonitrile (*m/z* 103), naphthalene (*m/z* 128), and acetate (*m/z* 58).

Relative changes in BC input are indicated by BC to SOC normalization (Fig. 5). A moderate increase of BC with depth was observed for all colluvial horizons. The values varied between ca. 100 and 700 g BC kg^{-1} SOC. Within this range, the maximum BC contents were determined in the M5 horizon (676 g BC kg^{-1} SOC). BC contents of up to 1000 g BC kg^{-1} SOC were measured in the 2CBg horizon; as the SOC content is very low at 0.3 %, this corresponds to 3.6-12.9 g BC kg^{-1} soil in the 2CBg horizon. The BPCA composition (e.g. B5CA/B6CA) can be used as proxy for fire temperature, with ratios < 1.0 indicating hot (likely anthropogenic) fires and ratios > 1.0 pointing to cold (natural) fires (Wolf et al., 2013). The ratio showed a slight decrease with depth for the colluvial horizons, whereas the lowest ratio was determined in the M4 horizon (0.83). In the 2CBg horizon, the amount of mellitic acid compared to pentacarboxylic acid increased sharply and the ratio dropped to 0.6. The B5CA/B6CA and the BC/SOC ratio were negatively correlated (R^2: 0.70) (Fig. S2, a). There was also a very good

agreement between the BC concentrations and the TII-proportions of marker signals for BC (R^2: 0.91, *m/z* 103, benzonitrile and *m/z* 128 naphthalene, released at > 450°C) (Fig. S2, b).

The ratio of extracellular urease activity and soil organic carbon (urease/SOC) served as indicator for the past and present occurrence of urea degrading microorganisms in colluvial horizons differentiating between the modern application of manure and possibly prehistoric addition of urea to the soil. The urease/SOC ratio varied between 0 and 65 and showed a decreasing trend until 100 cm below surface. In deeper colluvial horizons, we found very low urease/SOC ratios with two exceptions: The horizons M4 and 2Bwg showed urease/SOC ratios in the range of 12 to 15 (Fig. 5).

Based on the compound-specific decay pattern of steroids during GC-MS/MS measurement, nine different steroid compounds were detected (data published in Scherer et al., 2020). The steroid compounds can be assigned to the groups of Δ^5-sterols (cholesterol, β-sitosterol), 5α-stanols (5α-cholestanol), 5β-stanols (coprostanol, 5β-stigmastanol), epi-5β-stanols (epicoprostanol) and stanones (cholestanone, coprostanone, 4-cholesten-3-one). Since steroid compounds derive from different transformation and digestion processes of plants, mammals (omnivore, herbivore lifestyle), birds and edaphon (Prost et al., 2017), we summarized the relative amounts of β-sitosterol and 5β-stigmastanol as well as of coprostanol, epicoprostanol and coprostanone to provide information on herbivore and omnivore lifestyles, respectively. However, the highest relative amounts of steroid compounds (52-73 %) are determined for cholesterol and its derivates, which are ubiquitously distributed in the ecosystem (Mouritsen and Zuckermann, 2004) and can originate from plant and animal tissues (Hartmann, 1998), soil fauna (Albro and Schroeder, 1992), root exudates (Thompson, 1983), and fungi species (Weete et al., 2010). Considering only steroid compounds of specific herbivorous and omnivorous digestion processes (Fig. 5), we found clear indications of faecal inputs in the analysed horizons M2, M3, M5 and M6. In all cases we observed a dominance of steroids from plants (83-100 %) over steroids from omnivorous (0-17 %) and herbivorous faeces (0-39 %).

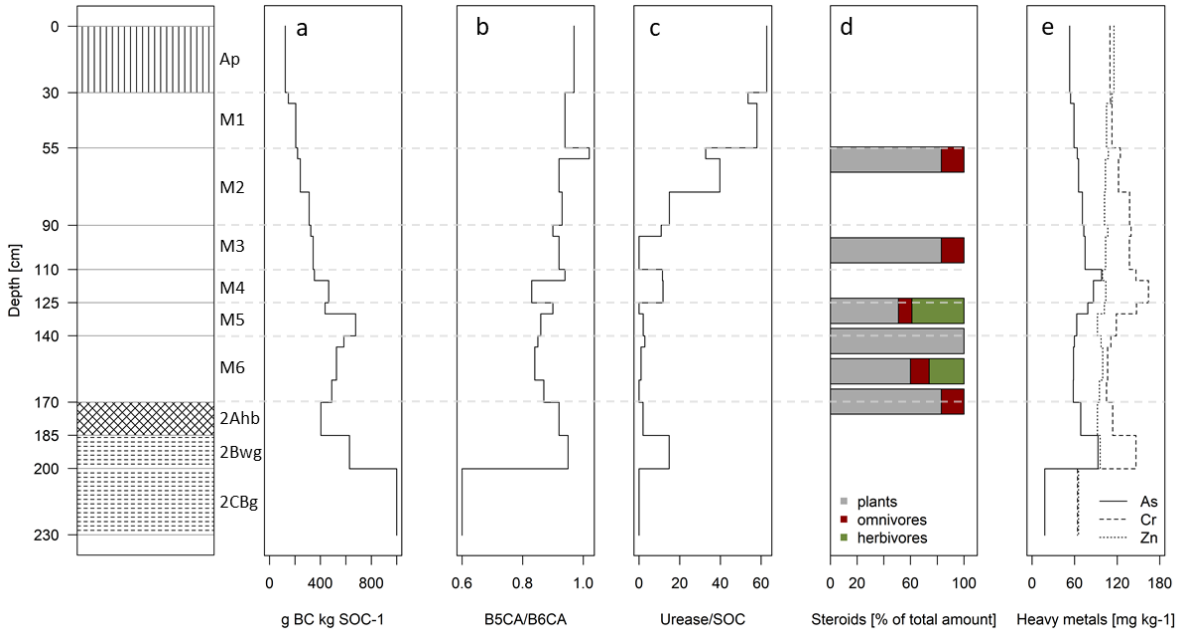

Fig. 5: Depth functions of black carbon/soil organic carbon ratio (BC/SOC, a), pentacarboxylic acid/mellitic acid ratio (B5CA/B6CA, b), urease/soil organic carbon ratio (Urease/SOC, c), relative amounts of steroid compounds (as % of total amount, d) and heavy metals contents (As=arsenic, Cr=chrome, Ni=nickel, e). All detected steroid compounds are summarized in the compound classes *plants* (ß-sitosterol), *herbivores* (5ß-stigmastanol) and *omnivores* (coprostanol, epicoprostanol, coprostanone) based on their probable input pathway into the soil.

4.8 Heavy metals

The contents for mercury (Hg) were mostly below the detection limit (< 0.43) and were excluded from further interpretation (Fig. 5, data published in Scherer et al., 2020). For Cd, Cu, Pb and Zn a decreasing trend from the present surface to the buried soil profile was observed without distinct enrichments in single colluvial horizons. In contrast, As, Cr and Ni peaked in the M4 and 2Bwg horizon, whereas maximum values were detected in the colluvial horizon M4 (98.0, 146.5, 64.4 mg kg^{-1} for As, Cr, Ni respectively). As had higher values in the upper 5 cm of the M4 horizon, whereas maximum values for Cr and Ni were observed below 5 cm.

[Table 4]: Amount of volatile matter (VM) and relative abundance of 10 important compound classes of soil organic matter of the Fue 8 profile derived from Pyrolysis-Field Ionization Mass Spectrometry (% of total ion intensity, TII); carbohydrates (CHYD), phenols + lignin-monomers (PHLM), lignin dimers (LDIM), lipids (LIPID), alkylaromatics (ALKYL), heterocyclic N containing compounds and nitriles (NCOMP), peptides (PEPTI), suberin (SUBER), free fatty acids (FATTY).

Horizon	Lower boundary depth increments [cm]	VM [%]	Abundance of compound classes in % TII								
			CHYDR	PHLM	LDIM	LIPID	ALKYL	NCOMP	PEPTI	SUBER	FATTY
Ap	30	21.5	7.5	13.3	4.1	8.4	15.7	4.8	6.7	0.1	0.5
M1	35	19.8	8.2	17.1	2.8	8.4	19.1	6.2	7.5	0.0	0.1
M1	55	19.0	9.7	18.2	1.6	6.9	19.6	9.7	10.8	0.0	0.1
M2	60	22.0	9.8	17.8	1.3	6.5	19.7	10.8	12.4	0.0	0.1
M2	75	20.2	10.0	17.8	0.9	6.8	19.0	11.9	13.3	0.0	0.0
M2	90	26.7	10.7	17.8	0.7	6.0	17.5	12.8	13.9	0.0	0.0
M3	95	26.3	11.0	18.0	0.9	6.4	17.7	13.2	14.0	0.0	0.1
M3	110	23.5	10.6	18.0	0.5	6.1	18.0	14.3	14.9	0.0	0.1
M4	125	15.7	10.0	16.9	0.5	6.0	16.6	14.7	16.2	0.0	0.1
M5	130	20.3	9.5	17.5	0.4	6.7	16.5	14.8	16.0	0.0	0.1
M5	140	17.1	10.2	17.5	0.4	7.4	17.3	14.4	14.7	0.0	0.1
M6	170	20.6	10.0	16.9	0.5	7.4	16.4	13.7	14.1	0.0	0.3
2Ahb	185	16.4	6.7	18.2	0.3	7.4	15.5	14.5	16.2	0.0	0.1

5. Discussion.

The colluvial profile of Fue 8 shows six phases of colluvial deposition (M6-M1) that occurred through five phases of land use from the Early to Younger Neolithic to the pre-modern period. Based on the archaeopedological multi-proxy approach and the local archaeology, we were able to identify five time-specific depositional events, which we relate to five phases of land use (1-5) at the prehistoric site of Fürstenberg. One pronounced phase without colluvial deposition but soil formation occurred after sedimentation processes in the Neolithic.

Before Early to Younger Neolithic period (2CBg, 2Bwg, 2Ahb)

The colluvial horizons of Fue 8 bury a stagnic Cambisol (2Ahb, 2Bwg, 2CBg) with vertic features formed from the clay-rich weathering products of the early Jurassic (Henkner et al., 2017). *In-situ* pedogenesis is indicated by a decreasing trend of SOC, C/N and Fe_d/Fe_t from 2Ahb to 2CBg. The lepidocrocite content of 1.9 % w/w in the 2Bwg horizon and relatively low Fe_d/Fe_t values in the buried soil indicate the influence of stagnant water (Schwertmann, 1988; Różański et al., 2013). Lepidocrocite is often closely associated with goethite in these soils (Fitzpatrick et al., 1985) as shown by the high goethite contents of > 11 % w/w in 2Ahb and 2CBw.

Based on the applied land use proxies, evidence of human impact before the Neolithic is missing. The charcoal record confirms the occurrence of oak-dominated woodlands in Southwest Germany during the Atlantic period (Rösch, 1987), whereas the overall number of fragments is low and a determination further than Dicotyledonous was difficult. Phytoliths are less abundant or absent in the buried soil, suggesting that grass species were minor in the vegetation composition. Remarkable were the higher contents of BC/SOC in the 2CBg (all SOC detected as BC) and of urease/SOC in the 2Bwg horizon since we would expect higher ratios at the buried surface (2Ahb). Since pre-Neolithic occupation has not been documented at the Fürstenberg and also the vegetation proxies support no human influence, natural processes such as wildfires, SOM mineralization and the overall low SOC values tend to explain the accumulation of BC and urease relative to SOC (Wang et al., 2014). However, stable compounds such as BC are also subject to degradation processes in the soil reaching mean residence times of some centuries in active soil horizon (Lehndorff et al., 2014; Singh et al., 2012). This might also explain the sharp decrease of the B5CA/B6CA ratio, as the number of benzene rings indicates not only the afforded burning temperature (Wolf et al., 2013), but might also be affected by decomposition processes (Braun et al., 2020). An overall negative relationship between B5CA/B6CA and BC/SOC (R^2: 0.70, Fig S2, a), as observed for Fue 8,

was also reported for two maar lakes in the West German Eifel region by Lehndorff et al. (2015). In such lake sediments degradation can be neglected, suggesting that also in colluvial deposits lower B5CA/B6CA ratios indicate anthropogenic fire activity, which may also have occurred at least since the Neolithic period.

(1) 5500-3800 BCE: Early to Younger Neolithic period (M6, M5)

The first sedimentation events as indicated by OSL ages occurred at the Fürstenberg between the Early and Younger Neolithic (Fig. 3) which formed the colluvial horizons M6 and M5 (GI-184; GI-183). The overlapping of the OSL ages within 1σ errors indicate a short period between the two depositional phases. However, because the D_e distribution of GI-183 shows evidence of insufficient bleaching (Fig. S3), M5 might be younger than the calculated OSL age of 6.9 ± 0.6 ka. Insufficient bleaching mainly occurs when sediment is transported over short distances, resulting in a short pre-depositional light exposure of the sediment grains (Fuchs and Lang, 2009). The ^{14}C ages in the M6 and M5 horizons (i-m, Fig. 3) are younger, ranging from the Late Neolithic to the Late Bronze Age. The temporal discrepancy can be explained by different causes: (i) insufficient bleaching of mineral grains during the erosion processes can lead to older OSL ages. GI-184 was measured using fine grain; thus, the D_e distribution does not provide information on the degree of bleaching, but incomplete bleaching and age overestimation appear at least as likely as for coarse grain samples (GI-183) (e.g. Fuchs and Lomax, 2019); (ii) the *in-situ* relocation of charcoals along soil cracks, root channels and animal burrows as result of increased soil formation and pedo-/bioturbation processes and human land use can lead to younger ^{14}C ages in older dated colluvial horizons. Similar observations were reported by Vogt (2014) for a colluvial sequence near Lake Constance (Southwest Germany). Phases of slope stability may promote the accumulation of charcoal fragments of different ages on the soil surface (Leue et al., 2017), which could have been the case for M5 considering the time of surface exposure. Similar observations have been made for another profile at the Fürstenberg catena (Fue 9), which is located upslope. Here, one OSL age indicates Early to Younger Neolithic colluvial deposition, while the charcoals in comparable depth were dated much younger to the Younger and Final Neolithic (Henkner et al., 2017). Despite the time discrepancies between ^{14}C and OSL ages, but in consideration of the local archaeology that indicates a Neolithic hilltop settlement at the Fürstenberg (Wagner, 2014; 2015), we propose the first phases of colluvial deposition and land use in the Early to Younger Neolithic. Other studies on the sedimentation history in Southwest Germany support this finding (Dreibrodt et al., 2010b; Henkner et al., 2017).

The phytolith data show an openness of the landscape since the Early to Younger Neolithic as grass morphotypes are dominating the plant assemblages at M6 and M5 horizons. For the same period, the charcoal spectra indicate a natural forest vegetation mainly consisting of *Quercus* species, which suggests a patchy landscape with natural forest and open areas as result of human impact (Rösch, 1987). Fire practises, e.g. slash-and-burn agriculture, may have played a major role in opening the forested landscape in the Neolithic as shown by the results of Py-FIMS and BC analysis in M6 and M5 (Fig. 5, Fig. S1, Tab. 4). The Py-FIMS data show the relative enrichment of thermally stabilized SOM compounds which may result from the ancient inputs of thermally affected biomass. Still, the smaller input of fresh thermally labile biomass-derived organic matter and slow stabilization processes such as organic-mineral bindings may have also contributed to this trend. In a study including the analysis of SOM in colluvial horizons by Py-FIMS (Jandl et al., 2019), lipids and plant-derived lignin were found in greater profile depth. Here, however, we found that nitrogen bearing compounds were enriched in the lower part of the profile indicating that SOM composition rather depends on different input quality and environmental conditions than on depth-dependent stabilization or translocation processes. A higher portion of stable N components in SOM typically results from reduced microbial decomposition (Jandl et al., 2019). The BC/SOC values in M6 and M5 are higher than in the overlying horizons, while the B5CA/B6CA ratio is < 1, indicating an increased fire activity and a predominance of high-temperature fires. This is further supported by the correlation between the BC concentrations and the TII-proportions of marker signals for BC (R^2: 0.91) that were derived from laboratory heating studies (*m/z* 103, benzonitrile and *m/z* 128 naphthalene, released at > 450°C) (Fig S2, b).

Keeping of livestock and organic manuring might have occurred since the Neolithic (Giguet-Covex et al., 2014) and geochemical studies also determined faeces-derived steroids from anthropogenic soils (Prost et al., 2017). However, the urease/SOC ratios close to zero and the predominance of steroids deriving from diverse sources (cholesterol, cholestanol, cholestanone, cholestenone) and from plants (ß-sitosterol), provide no clear evidence of Neolithic livestock farming at the Fürstenberg. A relative enrichment of cholesterol and ß-sitosterol compared to specifically animal-derived steroids has also been documented in Prost et al. (2017). The detection of 5β-stigmastanol as a marker for herbivore digestion products in M6 and M5 (up to 26 %) and coprostanol and epicoprostanol for omnivorous faeces (14-16 %) could at least be interpreted as an indicator of herbivorous and omnivorous lifestyles at the Fürstenberg. However, the degree of domestication, the possible presence of wildlife and intentional or unintentional manuring cannot be deduced from the data.

Between the Early to Younger Neolithic (M5) and the Urnfield to Hallstatt period (M4)

The OSL ages (GI-183 and GI-182) date a hiatus of about 3300 (min) to 4900 (max) years and thus a geomorphodynamically stable phase without intensive sedimentation from the Early to Younger Neolithic (M5) to the Urnfield to Hallstatt Period (M4). Such hiatus in depositional ages were not reported in other studies in Southwest Germany, which showed formation of colluvial deposits also during the Early and Middle Bronze Age (Henkner et al., 2018b; Vogt, 2014). The ^{14}C ages at comparable depths (g and h, Fig. 2) range from the Final Neolithic to the Mid Bronze Age and correspond to this phase of slope stability, whereas a natural and/or human-induced accumulation of charcoals cannot be differentiated. The absence of archaeological evidence for an Early and Middle Bronze Age occupation of the Fürstenberg plateau supports a reduced human influence and a correlation between colluvial deposition and human presence (Henkner et al., 2017).

The slope stability for more than 3300 years is also reflected by the pedogenetic properties. *In situ*-silicate weathering and formation of pedogenic oxides within the first 5 cm of M5 is shown by the maximum CIA and Fe_d/Fe_t values. Here, sufficient time was given for soil formation processes after the deposition of M5 (Chadwick and Chorover, 2011). This contrasts with the other colluvial horizons (M6, M4-M1) that had only slight differences in the SOC, CIA and Fe_d/Fe_t values between the upper 5 cm and the lower part of the respective horizons. Different causes could be conceivable such as shorter periods between depositional events (Field and Banning, 1998), the homogenization processes during soil erosion (Mücher et al, 2018) and the overall low degree of acidic weathering (pH value not < 6.9, low Fe_o/Fe_d ratios) of Fue 8.

(2) 1000-600 BCE: Urnfield to Hallstatt period (M4)

The deposition of the M4 horizon at 1000-600 BCE (GI-182) corresponds to the occupation of the hilltop during the Urnfield and the Hallstatt periods (Wagner 2014; 2015). The phytolith data show a dominance of monocotyledonous morphotypes, which indicate a possible human-induced openness of the landscape. In addition, there is a striking change in the abundance of phytoliths originating from C_4 (M6-M4 horizon) to phytoliths originating from C_3 plants (M3-Ap horizon). This may indicate an adaption of grasses to local climatic changes, with C_4 grasses indicating drier climatic conditions between the Early to Younger Neolithic and the Urnfield to Hallstatt period (5490-590 BCE) and C_3 grasses showing an increase in humidity after then. Indeed, extended periods of varying moistness seem to have occurred much more frequently since the beginning of the first Millennium BCE (Jäger, 2002). Another explanation could be a human-driven change in land management, e.g. that grassland consisting of wild grasses (C_4)

was converted into arable land (C_3). Although the grasses from the Pooideae subfamily did not seem to derive from domesticated cereals, we should however note that the almost complete absence of these morphotypes might be a result of diagenesis (Cabanes et al., 2011). The change in the phytolith distribution in the M4 horizon corresponds to two changes in the charcoal spectra: (i) the increase of *Fagus* sp. at the expense of *Quercus* sp. and (ii) the increase of conifer species, especially *Juniperus*. Once forestation has proceeded, *Fagus* species can also rejuvenate in a growing forest, whereas *Quercus* is more light demanding (Mosandl and Abt, 2016). The occurrence of *Juniperus* indicates the presence of open areas since it thrives best without competition from other trees. In addition, the practice of grazing favours the expansion of *Juniperus* at the expense of broadleaved trees (Domdey-Kunz, 1986). These results correspond to vegetation changes from Lake Herrenwiese (Black Forest, Southwest Germany) located 100 km to the north, which have been interpreted as a result of ongoing anthropogenic impact (Rösch, 2012). There, *Juniperus* also appears in the upper part of the profile comprising the last 1000 years. Additionally, before 3600 BCE *Fagus* was hardly detected, while *Quercus* was proportionally more present before 3800 BCE than afterwards (Rösch, 2012). Hence, the observed increase in the proportion of *Fagus* to *Quercus* may indicate that the opening of the forest took place in a previously densely forested area, which is additionally supported by the local archaeological record with no settlement documentation between the Neolithic and Urnfield to Hallstatt period. The results of Py-FIMS show an enrichment of stable organic matter such as mostly heterocyclic N containing compounds (NCOMP) and peptides (PEPTI) in M4, while for TN the lowest values of all colluvial horizons were determined. This is accompanied by the positive correlation between BC/SOC and the TII-proportions of marker signals for BC as well as the highest BC/SOC values (676 g C kg^{-1} SOC) for all colluvial horizons in the upper part of M5 and indicate a higher fire intensity during this period. Also, the lowest B5CA/B6CA ratio (0.83) is observed in the M4 horizon, which can be interpreted as anthropogenic fire activities during the Urnfield to Hallstatt period. In addition to the expansion of *Juniperus* species, livestock farming in the Urnfield to Hallstatt period is also indicated by a peak of the urease/SOC ratio in the M4 horizon. However, the overall amount of urease in the colluvial horizons was relatively low, so other processes may have also been responsible for the fluctuation of the urease/SOC ratio. Contrary to the findings of Corstanje et al. (2007), the highest activity of urease at the Fue 8 profile is not associated with increased values of SOC. In fact, the urease activity is almost zero for the highest SOC values in the M6 horizon. Additionally, varying clay contents may influence the behaviour of the urease activity in soils (Dharmakeerthi and Thenabadu, 2013). Although there is no

correlation between the clay content and the urease/SOC ratio, a relation cannot be completely excluded since the whole Fue 8 is rich in clay (> 50 %, Tab. 1). The steroid composition in the upper part of M5 mainly consists of β-sitosterol, cholesterol and cholestenone indicating a steroidal input from plants and undefined sources. However, 16 % of the source-specific steroid composition can be attributed to 5β-stigmastanol, which originates predominately from herbivorous digestion processes, which may support livestock farming during the Urnfield to Hallstatt period.

The highest contents of As, Cr and Zn were observed in M4 for all colluvial horizons. A modern input of heavy metals and their percolation through the Fue 8 profile can be neglected as the pH-values are around 7. Ni is mostly mobile at pH-value < 5.5 and As and Zn at pH-value < 4.5 (Schimming, 2011). Based on their prehistoric use, Cr and Ni are typical secondary components of bronze (Völkel, 2003). Even though, metal finds are missing at the Fürstenberg site (Wagner, 2014; 2015), the enrichment in As, Cr and Zn in the M4 at least indicate the presence and the processing of metals tools during the Urnfield to Hallstatt period.

(3) 200 BCE – 200 CE: Iron Age (Laténe period) to Roman Age (M3)

Archaeological findings date the Roman land use on the Fürstenberg from the middle to the end of the first century CE (Wagner, 2015). This land use can be associated with the depositional phase of the M3 horizon having an OSL age of 200 BCE – 200 CE (GI-181). Three out of four ^{14}C ages from the M3 horizon also suggest Roman land use (d-f, Fig. 2,), while the ^{14}C age of sample c can be assessed as an outlier (1290-1400 BCE).

The phytolith data show a still high abundance of monocotyledonous with a relative increase also in dicotyledonous morphotypes, which indicate slight succession with simultaneously continuous anthropogenic impact. The charcoal spectra show a further increase in the abundance of *Fagus* and conifer (especially *Juniperus*) species, which confirms the human-driven vegetation change (Domdey-Kunz, 1986). A decreasing trend of BC/SOC and TII-proportions of marker signals for BC from the M4 horizon onwards indicates a lower intensity of burning activities. These trends also correspond to the overall and slight decrease of maximum volatilization temperature towards the soil surface (Fig S1, upper right inserts). Possibly, wood as fuel source was less abundant because deforestation progressed, or settlers used other techniques such as livestock farming to maintain the landscape open (Rösch, 2013). This is accompanied by the determination of omnivorous steroids (up to 17 %), whereas plant-derived steroid (up to 83 %) are dominating the overall composition. The absence of herbivorous-derived faecal biomarkers and urease/SOC ratios close to zero exclude the keeping

of livestock during the Roman period. The records of vegetation and land use proxies support the suggestion by Wagner (2015) who assumed no intensive Roman land use at the Fürstenberg because of the exposure to extreme weather events and the limited water supply, whereas the periodic and extensive use, e.g. as military post, might have been possible.

(4;5) 1030 –1210 CE: High Middle Ages (M2); 1670 –1730 CE: Pre-modern period (M1)

The depositional ages of M2 (GI-180) and M1 (GI-179) and the related ^{14}C ages (a-c, Fig. 2,) correspond to a small settlement founded at the Fürstenberg in the High Middle Ages (Wagner, 2014) and an ongoing human presence until today. This is also supported by the phytolith data and the charcoal spectra with a predominance of grass morphotypes and the continuous increase in the abundance of *Fagus* and conifer species. The importance of fire to maintain the landscape seemed further reduced since BC/SOC contents continuously decrease and the B5CA/B6CA ratios in M2 and M1 are close to one. Additionally, in the uppermost horizons, the highest variety in SOM compounds with distinct signals of carbohydrates, phenols and lignin monomers in the lower mass range are observed, which is interpreted as ongoing microbial decomposition of fresh organic matter (Jandl et al., 2019). The positive correlation of TN and lignin dimers (LDIM, R^2: 0.86, Fig. S2, d) could be the result of modern tillage practices as we would expect a higher abundance of lignin dimers at greater soil depth (Fig S2, d), because of their relative stability compared to labile compounds such as carbohydrates and lignin monomers. Phases of clay mineral and Fe-oxide transformation could not be detected in the upper 100 cm since the phases without or reduced colluvial deposition were shorter and human influence was probably omnipresent. Further, the reconstruction of land use practices was not possible due to the lacking distinctness of specific proxies in the upper 100 cm of Fue 8 and missing archaeological finds. Whether the modern ploughing horizon (Ap) is a result of tillage activities of the M1 horizon cannot be conclusively assessed because ongoing sedimentation cannot be ruled out. However, sediment properties as for example sand and silt content of Ap and M1 are similar.

6. Conclusions.

Based on the archaeopedological multi-proxy approach on a multi-layered colluvial deposit, we were able to identify land use practices such as deforestation, wood procurement, the use of fire and livestock farming that convergently shaped the landscape and triggered colluvial deposition at the Fürstenberg since the Neolithic. Especially the integration of local archaeology provided a framework of land use phases, which was confirmed by numerical dating and human-driven vegetation change. We could also show that fire as means of changing the landscape was mainly important until the Hallstatt period. Land use practices such as agriculture and metal processing at the Fürstenberg appear unlikely, as the analysis of phytoliths and heavy metals provided no clear evidence. Conversely, the novel application of the analysis of urease activity and faecal biomarkers to colluvial deposits revealed evidence of livestock at the Early to Younger Neolithic and especially during the Urnfield to Hallstatt period.

A simple answer to our guiding question "What is in a colluvial deposit?" could now be “Much more than we previously thought”. However, colluvial deposits can still be considered, at least partially, as a buried treasure that needs to be raised to shed more light on the prehistory of land use related to phases of sedimentation. Progress in archaeopedological research will help us to understand what other proxies are archived in colluvial deposits and refine our comprehension of how people in the past used and shaped the land to maintain their subsistence.

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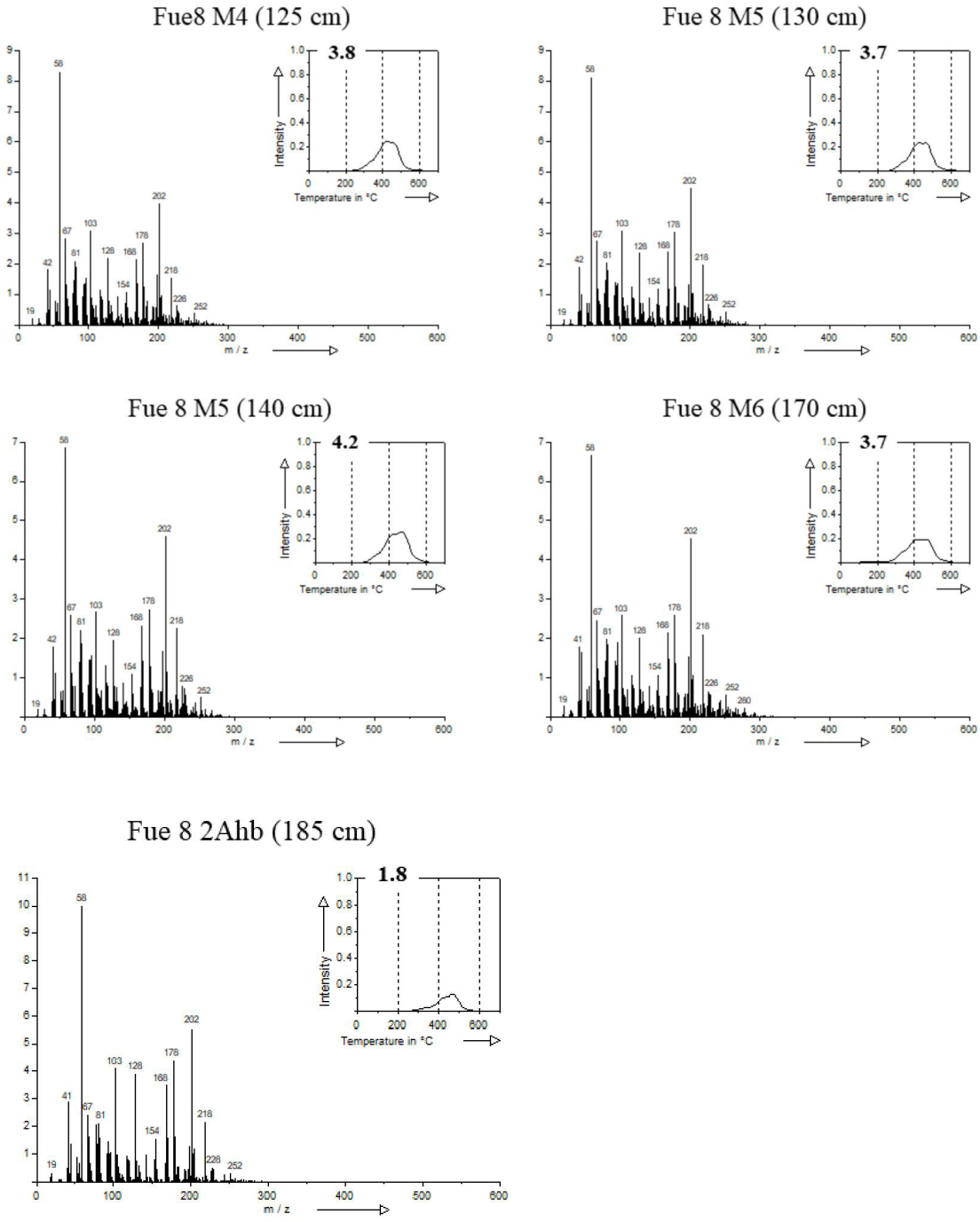
Supplements

Fig. S1: Thermograms of total ion intensity (TII) and TII data (in 106 counts mg-1, inserts upper right) and summed and averaged Py-FI Mass spectra of the Fue 8 profile from 30 to 185 cm profile depth.



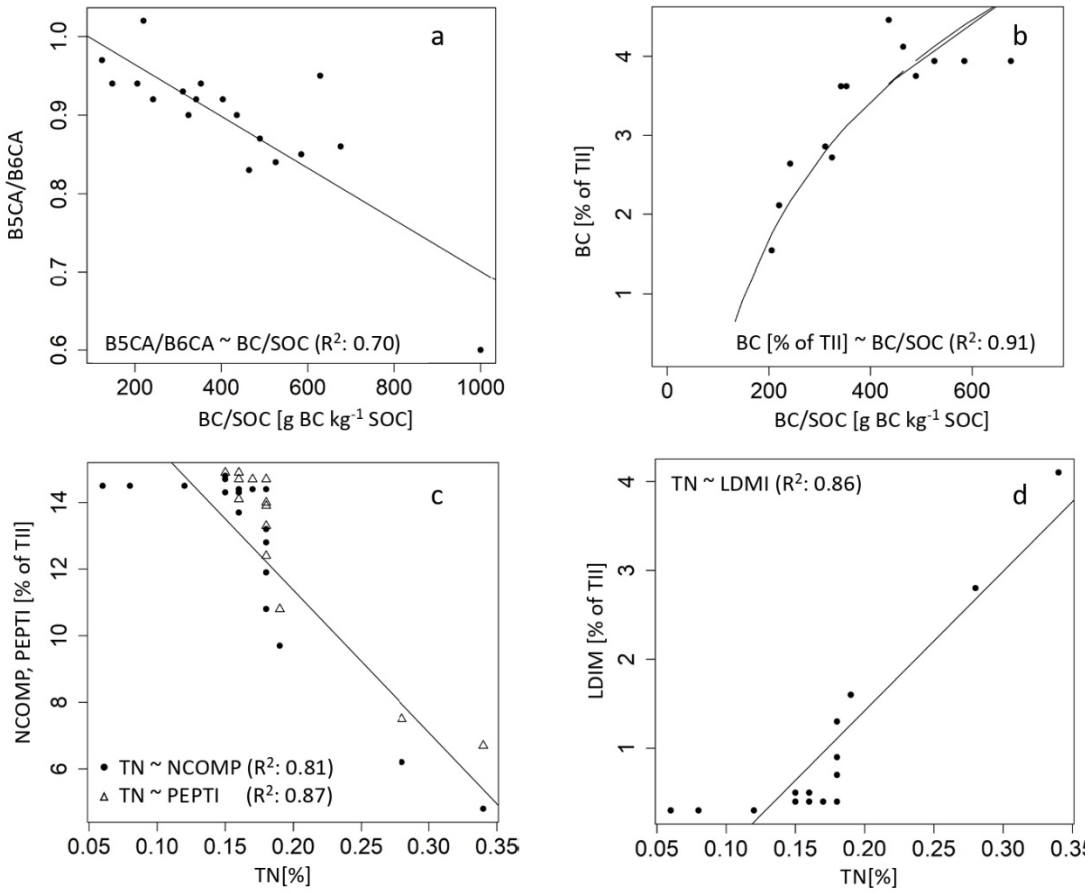


Fig. S2: Linear regression of soil organic matter (SOM) components at the Fue 8 profile. B5CA/B6CA: pentacarboxylic acid/mellitic acid ratio; BC/SOC: black carbon/soil organic carbon ratio; BC [of % TII]: marker signals for black carbon as % of total ion intensity; NCOMP: heterocyclic N containing compounds; PEPTI: peptides; LDIM: lignin

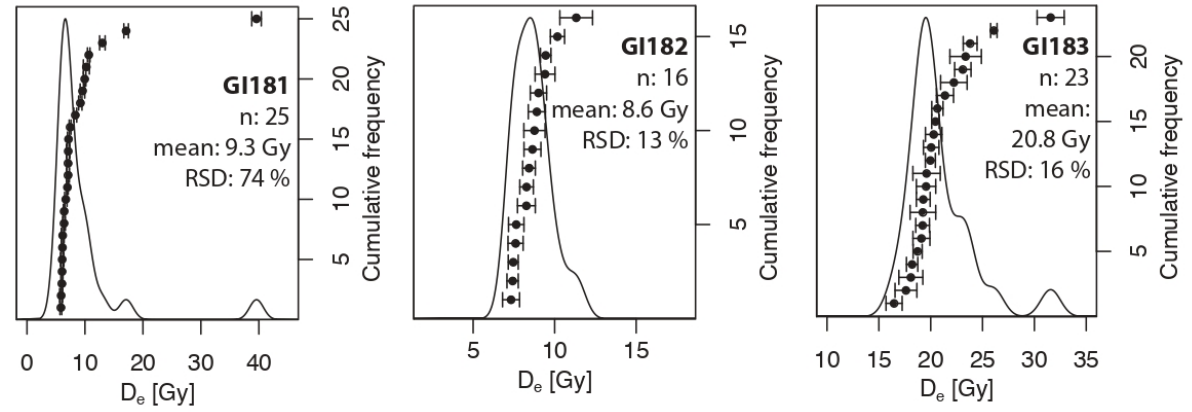


Fig. S3: Kernel density estimation plot for the coarse grain OSL samples GI181-183. The accepted aliquots are shown in ascending order, with information about the grain size, n (number of aliquots) mean De and RSD (relative standard deviation). The graphs are created with the function plot_KDE() in R using the luminescence package (Kreutzer et al., 2017).

Manuscript II

Middle Bronze Age land use practices in the north-western Alpine foreland – A multi-proxy study of colluvial deposits, archaeological features and peat bogs

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https://datadryad.org/stash/share/hVuLgYtHXROjtUDhBg9BRgVQ3H4pfL1INAXwzjTnT5E

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Abstract

This paper aims to reconstruct Middle Bronze Age (MBA) land use practices in the north-western Alpine foreland (SW Germany, Hegau). We used a multi-proxy approach including the biogeochemical proxies from colluvial deposits in the surrounding of the well-documented settlement site of Anselfingen and offsite pollen data from two peat bogs. This approach allowed in-depth insights into the MBA subsistence economy and shows that the MBA in the north-western Alpine foreland was a period of establishing settlements with sophisticated land management and land use practices. The reconstruction of phases of colluvial deposition was based on ages from optically luminescence (OSL) and radiocarbon (AMS ^{14}C) dating from multi-layered colluvial deposits and supports the local archaeological record with the first phase of major colluvial deposition occurring during the MBA followed by phases of colluvial deposition during the Iron Age, the Medieval period, and modern times. The onsite deposition of charred archaeobotanical remains and animal bones from archaeological features, as well as polycyclic aromatic hydrocarbons (PAHs), charcoal spectra, phytoliths, soil microstructure, urease enzymatic activity, microbial biomass carbon (C_{mic}) and heavy metal contents, were used as proxies for onsite and near-site land use practices. The charcoal spectra indicate MBA forest management which favoured the dominance of *Quercus* in the woodland vegetation in the surrounding area north of the settlement site. Increased levels of 5ß stanols (up to 40 %) and the occurrence of pig bones (up to 14 %) support the presence of a forest pasture mainly used for pig farming. In the surrounding area south of the settlement, an arable field with a buried MBA plough horizon (2Apb) could be verified by soil micromorphological investigations and high concentrations of grass phytoliths from leaves and stems. Agricultural practices (e.g. ploughing) focussed on five stable cereal crops (*Hordeum distichon/vulgare*, *Triticum dicoccum*, *Triticum monococcum, Triticum spelta*, *Triticum aestivum/turgidum*), while the presence of stilted pantries as storage facilities and of heat stones indicate post-harvest processing of cereal crops and other agrarian products within the settlement. In the area surrounding the settlement, increased levels of urease activity, compared to microbial biomass carbon (up to 2.1 µg N µg C_{mic}^{-1}), and input of herbivorous and omnivorous animal faeces indicate livestock husbandry on fallow land. The PAH suites and their spatial distribution support the use of fire for various purposes, e.g. for opening and maintaining the landscape, for domestic burning and for technical applications. The offsite palynological data support the observed change in onsite and near-site vegetation as well as the occurrence of related land use practices. During the Early and Middle Bronze Age fire played a major role in shaping the

landscape (peak of micro-charcoal during the MBA) and anthropogenic activities promoted oak dominated forest ecosystems at the expense of natural beech forests. This indicates a broader regional human influence in the north-western Alpine foreland at low and mid altitude inland sites during the Middle Bronze Age.

1 Introduction

Human use of land has profoundly altered terrestrial ecosystems since the Late Pleistocene and Early Holocene (Ellis et al., 2011; Redman, 1999). The emergence of sedentism and agricultural practices has intensified this trend, at least since population sizes and technological capabilities increased (Ellis et al., 2013). In the north-western Alpine foreland, most Middle Bronze Age (MBA, 1600 – 1250 BCE) settlements are known from sites with aerobic soil conditions further inland, while the lakeshores and bogs were widely depopulated during this period (Menotti, 2001; Köninger, 2015). However, weathering processes and aerobic soil conditions limit the preservation of archaeological finds, organic remains and biogeochemical proxies (Jansen and Wiesenberg, 2017). Therefore, rather few onsite and near-site (distance < 5 km to the site) archaeopedological and archaeobotanical evidence is available so far for MBA settlements in the north-western Alpine foreland. Additionally, the information from offsite (distance > 5 km to the site) proxies is more closely related to the vicinity of lakes and bogs than to settlements further inland (Rösch, 2013; Tinner et al., 2003).

One approach to overcome these drawbacks is the analysis of colluvial deposits as archives for the reconstruction of past land use practices, close to documented settlement sites (Kittel, 2015, Ponomarenko et al., 2020). We refer to the German term 'Kolluvium', which defines a colluvial deposit as the correlate sediment of human-induced soil erosion (Kadereit et al., 2010). Natural and anthropogenic drivers for the formation of colluvial deposits have been controversially discussed in the recent literature (Crombé et al., 2019; Kołodyńska-Gawrysiak et al., 2018). In Central Europe, the human impact on the terrestrial ecosystem has distinctly increased since the Late Holocene, and land use practices such as deforestation and soil tillage are the dominant drivers for phases of colluvial deposition (Dreibrodt et al., 2020; Poręba et al., 2019). Colluvial deposits impede the degradation of biogeochemical proxies by continuous sedimentation and provide additional information on their temporal input. Therefore, colluvial deposits can be considered one of the key archives for human-land interactions (Pietsch and Kühn, 2017; Zádorová, and Penížek, 2018) as they store not only the history of climate and sedimentation, but also proxies for past land use change and associated practices (Dreibrodt et al., 2010a;b; Scherer et al., accepted). These land use proxies can be spatially and temporally related to nearby settlement sites, which allows for a more detailed understanding of local phases of land use. For example, the determination of charcoal assemblages from different colluvial horizons can help to identify changes in woody vegetation that could be the result of anthropogenic efforts to promote a certain type of land use (Dreibrodt et al., 2009; Schroedter et al., 2013).

The vegetation changes could be accompanied by the use of fire, which is reflected in the accumulation of polycyclic aromatic hydrocarbons (PAHs) (Tan et al., 2020). An increased occurrence of open landscapes, as indicated by a higher abundance of grass phytoliths and the determination of charred archaeobotanical remains, provides information on past arable farming and on the nutritional basis of past societies (Ball et al., 1999; Rösch, 2013; Weißkopf et al., 2014). The application of manure and/or the keeping of livestock can be considered an integral part of prehistoric land use practices (Bogaard, 2004). The analysis of extracellular urease and faecal biomarker in colluvial horizons helps to identify these land use practices (Borisov and Peters, 2017; Lauer et al., 2014). The distinction between the geogenic background and the additional atmospheric or direct input by anthropogenic contamination in colluvial horizons can be investigated by heavy metal analyses of all horizons, including part of the buried soil profiles, which have no or minor anthropogenic influences (Dreibrodt et al., 2009; Henkner et al., 2018b).

Within the north-western Alpine foreland, the Hegau (south-west Germany) is a suitable study area for the investigation of MBA land use due to the widely distributed occurrence of colluvial deposits and the density of known archaeological sites (Dieckmann, 1998; Höpfer, 2014). Studies on colluvial deposits in the Hegau have shown that local land use activities can be dated back to the Neolithic and still occur in the modern period (Höpfer et al., 2016; Schulte and Stumböck, 2000; Vogt, 2014). Regarding the Bronze Age, Vogt (2014) has documented a regional deposition phase close to Lake Constance, that occurred mainly in the Early Bronze Age (EBA, 2200 – 1600 BCE). Further inland, Schulte and Stumböck (2000) found only Late Bronze Age (LBA, 1050 – 800 BCE) to Early Iron Age (EIA, 800 – 450 BCE) colluvial deposits. However, archaeological remains from the inner Hegau reflect phases of human occupation during the MBA, but corresponding phases of colluvial deposition are far less frequent. Hence, biogeochemical proxies of MBA colluvial deposits for the reconstruction of related land use practices have not been analysed in this region so far.

To address the question of which land use practices were typical for the MBA in the north-western Alpine foreland, we applied a multi-proxy approach to colluvial deposits and archaeological features at the well-documented settlement site of Anselfingen, ca. 20 km west of Lake Constance. Colluvial deposits and archaeological features were associated by deciphering the local stratigraphy. Numerical dating, such as the optically stimulated luminescence (OSL) dating of single colluvial horizons and the AMS radiocarbon (^{14}C) measurements of charcoal fragments, were applied to establish a temporal framework that could be related to local archaeological records. The analysis of the soil micromorphology,

phytoliths, charred archaeobotanical remains, urease activity, faecal biomarker, animal bones, PAHs, charcoal assemblages, and heavy metals were used to reconstruct past land use practices. The sum of all proxies, which were applied within the settlement (onsite) and at the presumable land use areas (near-site), is used for a better understanding of land use practices related to the human occupation at the Anselfingen site. The investigation of two offsite pollen profiles in this study allowed for a comparison between the local information of land use and vegetation change with vegetation and land use pattern visible on a regional scale.

Our study focuses on the:

(i) archaeopedological reconstruction of phases of colluvial depositions and onsite and near-site land use practices (e.g. crop cultivation, livestock husbandry, and manuring as well as the use of fire, wood and metal) at the settlement site of Anselfingen through combining the biogeochemical analyses of colluvial deposits with the analysis of archaeological features,

(ii) identification of spatial patterns of on- and near-site land use practices within the Anselfingen settlement and its surrounding area,

(iii) characterization of differences and similarities between the onsite and near-site vegetation patterns resulting from land use practices in Anselfingen and the offsite vegetation signals derived from two pollen profiles.

2 Material and methods

2.1 Physical geographical setting

The study area is in the north-west of the Hegau (south-west Germany), which is part of the north-western Alpine foreland (Fig. 1). In the north, the study area borders the southern decline of the Swabian Jura, from where the tertiary sediments of the younger Juranagelfluh were transported into the Hegau. The Hegau is characterized by filled volcanic vents (with phonolite, basalt, and porphyry) as remains of the tertiary volcanism and is mainly covered by tertiary porphyry (Deckentuff), Würmian glacial and glacio-fluvial deposits such as (terminal) moraines and gravel (Schreiner, 2008; Geyer et al., 2011).

Soil substrates in and around the excavation near Anselfingen (ABR) are redeposited sediments and weathered bedrock from the Younger Juranagelfluh and the Würmian glaciofluvial deposits (mainly gravel, sand and silt). Volcanic material comes from the Hohenhewen (mainly basalt) in the west of the excavation area. The ABR site lies on glaciofluvial deposits next to

the outer young terminal moraine of the Würmian (Äußere Jungendmoräne). Cambisols, Luvisols, Phaeozems and Calcaric Regosols, which developed on different substrates and with different stagnic and vertic features, dominate the Reference Soil Groups according to WRB (IUSS Working Group WRB, 2015). The climate is moderately warm with annual average air temperatures between 7.5 and 8.5 °C, whereas the hilltops are between 6 and 7 °C. The annual precipitation is between 700 and 825 mm. The potentially natural vegetation is dominated by Central European thermophilous calciphilous beech forests (*Fagus sylvatica*) with white wood-rush (*Luzula luzuloides*) and by Central European sessile oak (*Quercus petraea*)-beech forests; both are characterized by a rich and diverse shrub and herb layer (Bohn et al, 2003). The modern vegetation is strongly shaped by agricultural and forestry activities.

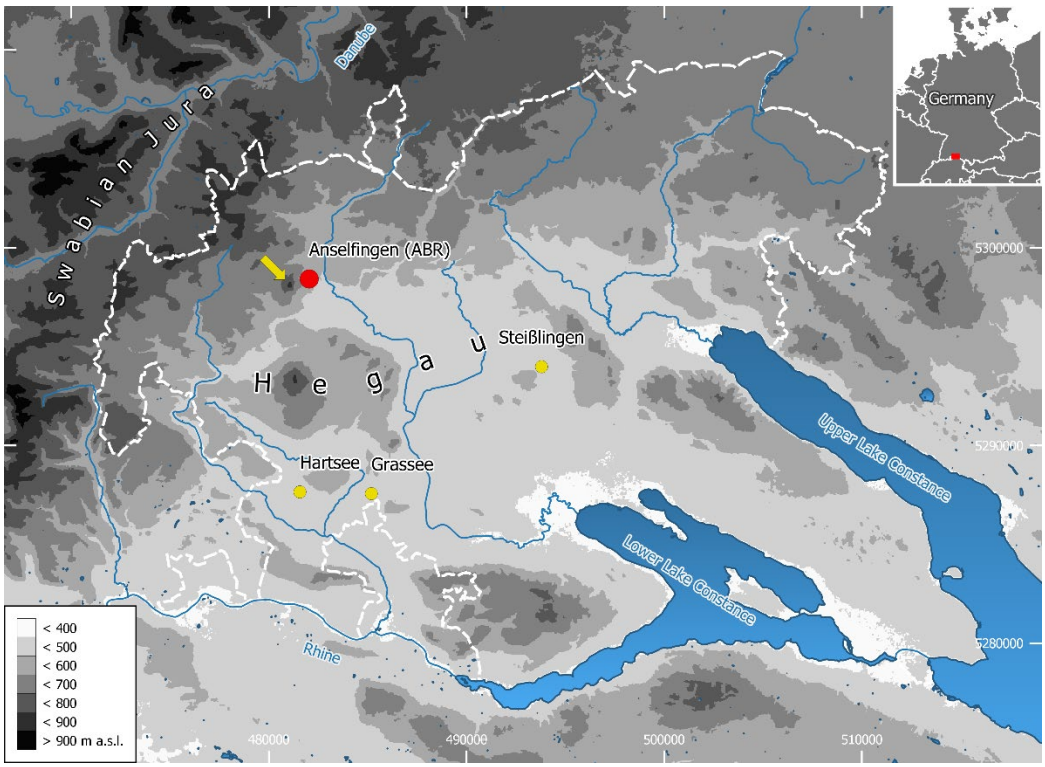

Figure 1: Study area (Hegau, Southwest Germany) with the Middle Bronze Age settlement site of Anselfingen (ABR, red dot), the pollen profiles (yellow dots) and Hohenhewen (yellow arrow). Coordinates are shown in UTM 32N reference system; EPSG 25832.

2.2 Archaeological setting

The Hegau is rich in archaeological sites and is particularly important for the Bronze Age research in the north-western Alpine foreland (Hald and Kramer, 2011). Among the most prominent sites are the large Early Bronze Age (EBA) cemetery of Singen (Krause et al., 1988) and several well-preserved lakeside settlements such as Bodman "Schachen" (Köninger, 2006). However, EBA sites are comparatively scarce further inland, whereas, during the Middle

Bronze Age (MBA), there was an increase in settlement activity concentrated mainly on the areas further inland, while the lakeshore sites were almost completely excluded (Höpfer, 2014; Menotti, 2003). From the Late Bronze Age (LBA) numerous burial sites are known, such as the necropolis in Singen (Brestrich, 1988). Additionally, numerous LBA settlements have been documented in the inland, on the lakesides and on the hilltops (Schöbel, 1996; Hopert et al., 1998).

The Anselfingen (Anselfingen-Breite, ABR) settlement (Fig. 2) lies further inland of the Hegau and had occupation phases in the Younger and Final Neolithic, the EBA, MBA and LBA, the Hallstatt and Latène period of the Celtic Iron Age, and the Roman period (Ehrle et al., 2018). The adjacent area was densely settled during the MBA, with up to three additional villages, Mühlhausen-Ehingen (Dieckmann, 1998; Hald, 2015), Engen-Welschingen (Hald et al., 2015) and Hilzingen-Binningen (Wissert, 1985), within a distance of 5 km in. Since the beginning of the 20th century, the gravel pit has been active and many archaeological finds have been reported. Until recently, these finds mainly included the remains of a Celtic settlement (Kellner-Depner, 2016). Along with a scattering of Final Neolithic finds, there were also stray finds, which indicated the existence of an MBA burial site (Kraft, 1928; Garscha, 1936). The actual MBA settlement was discovered during rescue excavations, which have been performed by the Cultural Heritage Authorities of Baden-Württemberg and the Archaeological Service of the District of Constance since 2008 and continue with the expansion of the gravel pit. To date, almost nine hectares have been excavated and another four hectares to the north have been explored by trench-prospection.

2.3 Vegetation history

Compared to the Lake Constance area, with its lake, mire and wetland depositional environments, the inner Hegau was hardly investigated palynologically until the end of the 20th century (Eusterhues et al., 2002; Hölzer and Hölzer, 1990). Lake Steißlingen remained the most north-western pollen archive investigated so far, which left the interpretation of vegetation history vague further inland. Despite the scarceness of potential archives in the inner Hegau, the profiles of Grassee and Hartsee presented here (Fig. 1) are two recently studied pollen profiles that provided nearly complete Late Würmian and Holocene sequences with sufficient pollen preservation.

Around Lake Steißlingen the vegetation was dominated by mixed birch and pine forests in the early Holocene (Preboreal, 9600-8700 BCE) before the spread of hazel in the Boreal (8700-

7200 BCE). During the Atlanticum (7200-3700 BCE) the land was mainly covered by thermophilus deciduous vegetation, with mixed oak forests restricted to drier soil conditions (Lechterbeck, 2001; Rösch, 1987). Before the arrival of the settlers of the Linear Pottery Culture (5500- 5000 BCE), those forests, consisting of *Quercus, Alnus, Fraxinus, Ulmus* and *Corylus*, were probably dense. Evidence for agricultural activity at Lake Steißlingen cannot be traced back earlier than 4200 BCE (Lechterbeck, 2001) and is in line with the analysed pollen profiles from the shores of Lake Constance (Rösch, 1987). From the EBA to the beginning of the MBA, indicators for open landscapes, such as herbs and sweet grasses, are more abundant in the pollen spectra of Lake Steißlingen and lakes in the area surrounding Lake Constance. A lower density of mixed oak forests, an increase in micro-charcoal (as proxy for paleo-fire) and non-arboreal pollen (as proxy for open vegetation) seem to further underline human influence on the landscape. During the MBA and LBA, natural succession indicates a weakening of anthropogenic disturbance (Lechterbeck, 2001; Rösch, 1987). Thereafter, phases of natural succession alternate with phases of human-land interaction during the early Latène period (ca. 450 BCE), the Roman period (ca. 50 BCE – 260 CE) and since 550 CE (Lechterbeck, 2001).

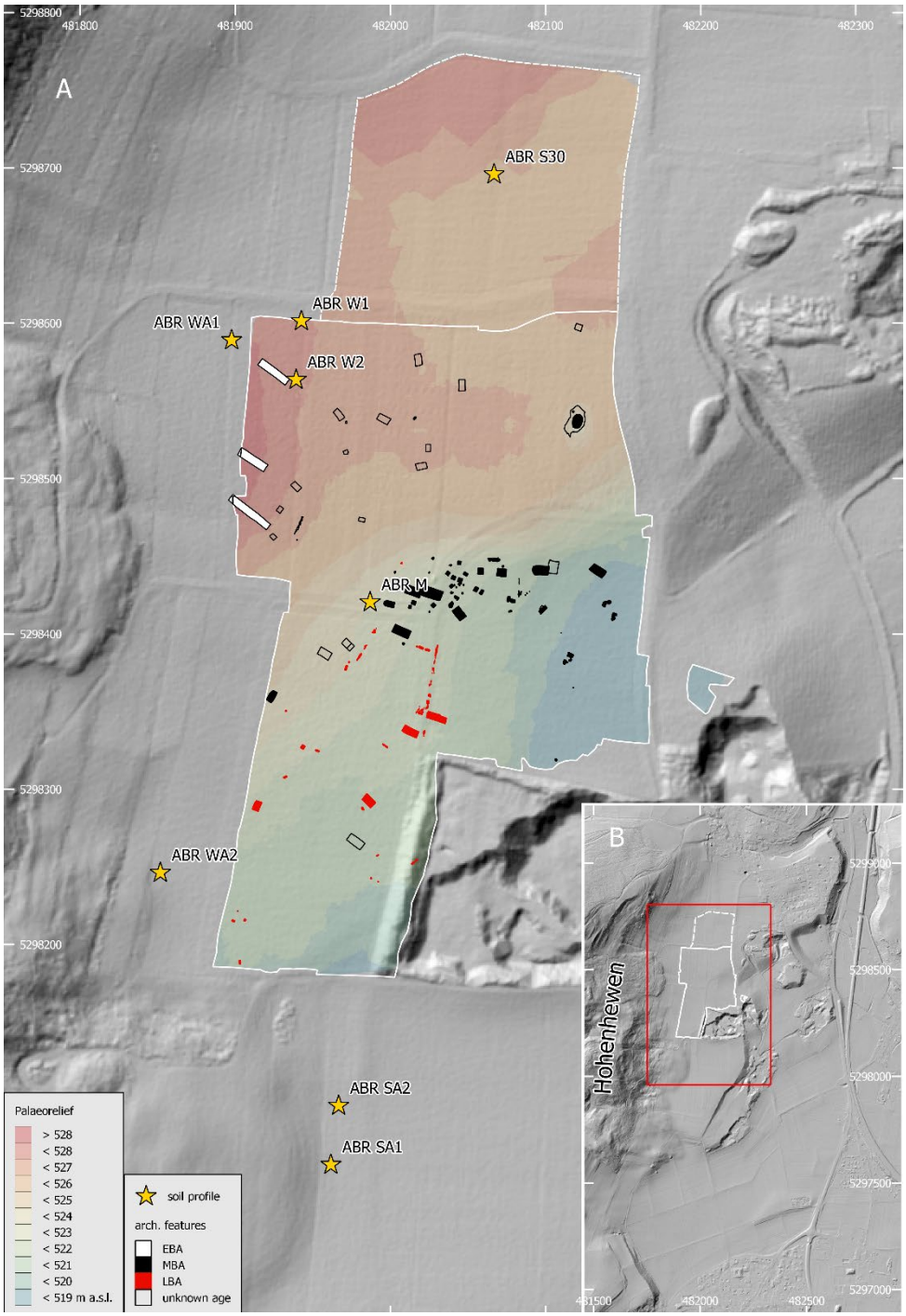

Figure 2: (A) Location of the investigated colluvial deposits and the Bronze Age structures (EBA: Early Bronze Age; MBA: Middle Bronze Age; LBA: Late Bronze Age) and their topographic situation in Anselfingen "Breite" (ABR). Coloured area shows the boundary A after Edgeworth et al. (2015), i.e. the paleosurface on which the colluvial deposits accumulated. (B) The excavation area (red frame) and the anscent to the Hohenhewen to the west. Coordinates are shown in UTM 32N reference system; EPSG 25832.

2.4 Field work

Soil samples were collected in 2017 and 2018. Soil description followed the German guidelines for soil description (Ad-hoc-AG Boden, 2005) and were classified according to the World Reference Base for Soil Resources (IUSS Working Group WRB, 2015) by using the translation software of Eberhardt et al. (2014). Soil horizons that appeared blackish-brown, were homogeneous and mostly rich in organic matter and charcoal fragments and were without other characteristics of soil formation, were designated as colluvial horizons (M horizon, *lat. migrare*, to migrate). In the area surrounding the ABR settlement, colluvial deposits are widely distributed due to the slopes of the Hohenhewen and the heterogeneous paleo-relief which remained after glacier retreat. After a soil survey, eight locations were chosen for colluvial profiles. Along the profiles, every colluvial horizons was sampled in a continuous column with 5 cm depth increments. Different samples were collected for the analysis of faecal biomarkers as well as for the investigation of charcoal, microbiological proxies, soil micromorphological features and further pedogenic and soil-biogeochemical proxies. The microbiological samples were cooled during field work and stored at –18 °C.

Two samples for micromorphology were taken in Profile ABR SA2 from 187-197 cm and 190-200 cm, which refers to the buried plough horizon 2Apb. Samples for luminescence dating were taken from newly cleaned profile walls with light-proof steel cylinders that were hammered horizontally into the profiles. Bulk samples for dose-rate determination and water content measurements were taken in plastic bags around the sample holes of the cylinders.

During the rescue excavation, the colluvial deposits were removed mechanically until the *in-situ* soil was exposed (Fig. 3). Subsequently, a main planum was made and documented. Archaeological features observed in colluvial horizons were documented in additional plana. All features were further examined in at least one cross section. Documentation comprised analogue and digital photography, standardized text descriptions and digital mapping via theodolite and/or photogrammetry. Spatial data were processed using ArchaeoCAD (ArcTron GmbH) during the excavation and transferred to Quantum GIS (long term release 3.10.8 “A Coruña”) for analysis. From a series of documented finds, charcoal samples for further AMS-^{14}C measurements were collected, in addition to those already published (Höpfer et al., accepted).

The two cores for the pollen analysis were taken with a modified Livingstone sampler (Merkt and Streif, 1970) from the almost dry surface of Grassee and from a raft at Hartsee. The Grassee mire is divided into two sections by a forest and two forest tracks. The eastern section is

dominated by an alder carr and the western section, from which the core was taken, represents an open fen. The Hartsee mire consists of several small and shallow lakes which are surrounded by wetland. The core was taken from the eastern part. Both profiles were subsampled in close distances; samples for pollen analysis were taken at 2 cm intervals. The Grassee and Hartsee profile had a length of 700 and 635 cm, respectively.

2.5 Laboratory analyses

X-ray granulometry (SediGraph 5120, Micromeritics GmbH, Germany) was used for the determination of grain sizes < 20 µm, while grain sizes between 20 µm and 2 mm were measured by weighing the sieved soil material. Soil pH ($CaCl_2$) value was analysed by using a soil:solution ratio of 1:2.5 (Sentix 81, WTW, pH 340). Carbonate content ($CaCO_3$) was volumetrically determined using a calcimeter (Eijkelkamp, Giesbeek). An element analyzer ("vario EL III", Elementar Analysesysteme GmbH, Germany, in CNS mode) with helium atmosphere and oxidative heat combustion at 1150 °C was used for the measurement of total carbon (TC) and nitrogen (TN). The difference of total inorganic carbon (TIC) and TC was used for the calculation of the soil organic carbon (SOC) content (Don et al., 2009).

After air-drying, the oriented samples for soil micromorphology were impregnated with Viscovoss N50S resin and MEKP505F hardener. After the resin had cured, the blocks were first formatted into 60 × 90 mm blocks and then cut in half with a saw (Woco Top 250 A1, Uniprec). One half was ground with an encapsulated precision grinding machine (LDQ 6100, Huayid) and mounted on a glass. After three days the mounted samples were cut into about 100 µm thick slices and then ground to 30 µm. Thin sections were described under a polarizing microscope (Zeiss Axio Imager.A2m; Software AxioVision 4.7.2) mainly using the terminology of Stoops (2003).

All samples for OSL dating were analysed using the coarse grain quartz fraction with a grain size range of 90-200 µm. The paleodose (D_e) determination was conducted using a standard SAR protocol following Murray and Wintle (2000; 2003). Radionuclide concentrations were determined either via a combination of thick source alpha-counting (for U and Th) and ICP-OES (for K), or via a combination of alpha- and beta-counting in a µdose system (Tudyka et al., 2020).

Charcoal fragments from the colluvial profiles and archaeological features were dated with AMS-^{14}C dating at the Klaus-Tschira-Lab at the Curt-Engelhorn-Centre of Archaeometry in Mannheim. The Acid-Base-Acid method was conducted for sample pre-treatment (Steinhof et

al., 2017). The ^{14}C ages were normed to δ^{13} C = -25 ‰ (Stuiver and Polach, 1977). The calibration of ^{14}C ages to calendar years was performed with SwissCal 1.0 using the IntCal13 calibration curve (Ramsey, 2009; Reimer et al., 2013).

For the determination of charcoals, 529 fragments from three colluvial profiles (ABR W2: 267, ABR SA1: 120, ABR SA2: 162) were retrieved by flotation. The transversal, tangential and radial sections of charcoal were investigated for diagnostic features, using magnifications between 60x and 500x. Identification literature (Schweingruber, 1990a; b) was consulted as well as the charcoal reference collection of the Archaeobotany Laboratory at University of Tübingen.

The extraction of phytoliths was conducted at the Universities of Würzburg and Tübingen and followed the procedures outlined by Albert et al. (1999) and Katz et al. (2010), respectively. Morphological identification of the phytoliths followed the standard literature (Brown, 1984; Parr and Carter, 2003; Piperno, 2006; Twiss et al., 1969) and modern plant reference collections (Albert, 1999; Meister et al., 2017; Portillo et al., 2014; Tsartsidou et al., 2007). The International Code for Phytolith Nomenclature was followed where possible (Madella et al., 2005). Phytolith morphologies are grouped into three main categories: herbaceous dicotyledonous plants, woody dicotyledonous plants and monocotyledonous plants (Piperno, 2006). For detailed information about sample preparation, equipment and data presentation, see Scherer et al. (2020).

For the archaeobotanical investigation, a total of 20 samples from MBA structures (e.g. firepits with heat stones, fireplaces, deposited vessels, and post-holes from architectural remains) were analyzed. The sediment samples were washed over a multi-part sieve set. The smaller fractions were floated to separate the organic components from the mineral ones. The 0.3 mm fractions of three charcoal-rich samples could only be examined for 10 to 30 %. All other samples and fractions were screened completely under the binocular and botanical macro remains, excluding charcoal, were taken out. The determination was carried out following the current literature (Jacomet, 1987; Jacomet et al., 1989; Bekker and Cappers, 2006) and the reference collection of the Laboratory for Archaeobotany in Hemmenhofen.

For the analysis of polycyclic aromatic hydrocarbons (PAHs), a modified protocol of Bläsing et al. (2016) was followed. A Speed Extractor (E-916, Büchi Labortechnik GmbH, Germany) was used for sample extraction; samples were concentrated using Rotavapor (Büchi, Switzerland). Solid Phase Extraction (SPE) was used for sample purification according to Lehndorff and Schwark (2009). The quantification of PAHs was performed using gas chromatography (GC, Agilent Technologies 7890B, Germany) coupled with mass

spectrometry (MS/MS, EVO 3, Chromtech, Germany). For detailed information about sample preparation, equipment, hardware settings and data analysis, see Scherer et al. (2020).

The extracellular enzyme urease is responsible for the cleavage of urea to ammonia and CO_2 and its microbial production is stimulated by the presence of eutrophic soil conditions (e.g. faeces of animals) (Kandeler and Gerber 1988). Its specific feature is that urease-organo-mineral complexes are stable for long time periods (Skujiņs and McLaren, 1968). Extracellular urease activity derived from soil organisms was determined colorimetrically according to Kandeler and Gerber (1988). Synergy HTX multi-mode reader (BioTek) was used for colorimetric measurements at 690 nm. For a detailed description of the laboratory procedure, see Scherer et al. (2020).

Microbial biomass carbon (C_{mic}) was determined by the substrate-induced respiration method (SIR) (Anderson and Domsch, 1978). Measurements were taken using an automated respirometer system based on electrolytic O_2 microcompensation (Scheu, 1992). A detailed description of sample preparation and data analysis is given in see Scherer et al. (2020). In this study, the urease activity was related to the microbial biomass carbon to differentiate between past and present input of urea, since extracellular urease is considered to be very stable and C_{mic} as proxy for current microbial activity. Increased urease activities to microbial biomass ratios are therefore an indicator for ancient soil eutrophication by animal faeces.

Faecal biomarkers (sterols, stanols, stanones) were analysed using a modified protocol according to Prost et al. (2017) and Birk et al. (2012). A Speed Extractor (E-916, Büchi Labortechnik GmbH, Germany) was used for accelerated sample extraction. For the analysis of sterols, stanols and stanones, the total lipid extracts (TLE) were analysed by using gas chromatography (GC, Agilent Technologies 7890B, Germany) coupled with mass spectrometry (MS/MS, EVO 3, Chromtech, Germany). For detailed information about sample preparation, equipment and hardware settings, see Scherer et al. (2020).

A reverse *aqua regia* solution (HNO_3 to HCl ratio 1:3, DIN ISO 11466: 1997-06) in a microwave (MLS GmbH, Germany) was used for the dissolutions of the heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn). ICP-OES (Optima 5300DV, Perkin Elmer Inc.) equipped with a Miramist nebulizer using the element-specific wavelengths according to Nölte (2002), was used for the measurements of heavy metal contents.

The taxonomic and taphonomic analysis of bone material was carried out in the zooarchaeological comparative collection of the University of Tübingen. The faunal age was assessed and classified according to Lyman (1994). The taphonomic analysis comprised natural and anthropogenic impacts on the bones such as burning, animal bites, human cutmarks and

traces of natural environmental influences as root etching, changes due to sunlight or weathering. Burned bones were categorized in six categories following Stiner (1995). A detailed description of the methodological approach is given in see Scherer et al. (2020).
The investigation of the pollen profiles was focused on the Bronze Age period (2200 – 800 BCE), and was composed of 17 pollen samples at the Grassee and 59 pollen samples from the Hartsee mire. The time resolution was 70 years for the Grassee and 20 years for the Hartsee mire. The chemical preparation for pollen analyses was carried out using hot HCl, HF, Chloration, and Acetolysis (Berglund, 1986). The material was stored in Glycerol. For the analysis, permanent unstained Glycerol-slides were used.

3 Results

3.1 Stratigraphy and related pedofeatures

Eight multi-layered colluvial profiles were documented with a thickness of at least 200 cm (Tab. 1). The colluvial horizons of ABR S30, ABR W1, ABR W2, ABR WA1 and ABR M developed mostly from the sediments of the Younger Juranagelfluh and buried fully preserved or truncated (Vertic) Cambisols, which developed in loamy glacio-fluvial sediments with different proportions of gravels. In profiles ABR W1, ABR W2 and ABR WA1, paleo-land surfaces were characterized by blackish horizons with a well-developed prismatic and angular blocky structure with slickensides. An excavation boundary of about 150 m stratigraphically connects profiles ABR W1, ABR W2, ABR WA1 and the paleo-surface, which contained the archaeological finds. The thickness of colluvial deposits along the excavation wall decreased from north to south (Fig. 3). For ABR M and ABR S30, a higher percentage of calcareous gravel was observed. The soil substrate of profiles ABR WA2, ABR SA1 and ABR SA2 were mostly derived from basaltic material from the Hohenhewen volcano. For profile ABR SA2, a buried plough horizon (2Apb) with a sharp transition to the underlying subsoil horizon (2CBw) was observed. For all profiles, the transition between colluvial deposit and paleo-surface (boundary A after Edgeworth et al., 2015), i.e. the prehistoric surface, was documented.

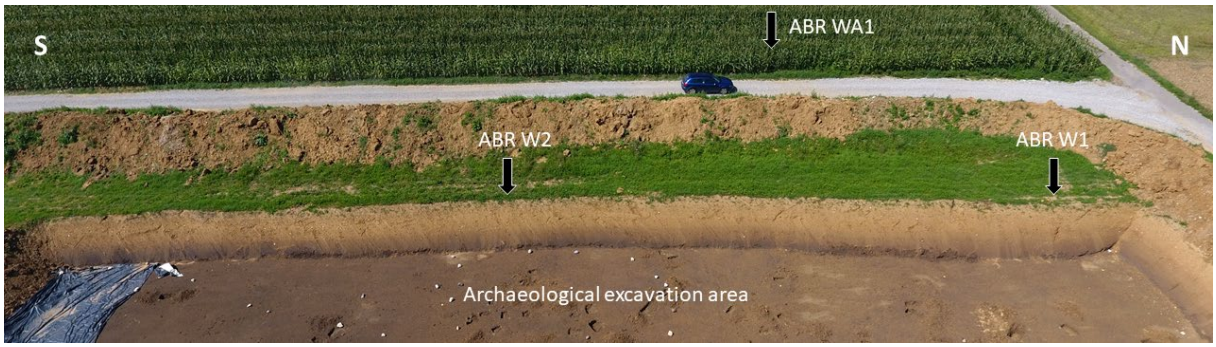

Figure 3: Overview of the western excavation boundary at the ABR site with the colluvial profiles ABR W1, ABR W2, ABR WA1 and related colluvial horizons (M). Photo:Höpfer, 2017. The distance between ABR W1 and ABR W2 is about 38 m.

For all colluvial profiles, a high clay content between 32 and 65 %, with a sharp (ABR W1, ABR W2) to moderate (ABR SA2) increasing trend with depth, was determined. The maximum clay contents (> 60 %) were measured in the buried subsoil horizons (2Bwig) of ABR W1 and ABR W2. The sand fraction decreased with depth (up to 17 % difference) for profiles ABR W1 and ABR W2, whereas for ABR SA2 differences of only 7 % were determined. The silt proportions were the highest at the present topsoil horizons and ranged between 25 and 48 %. The soil pH of all soil profiles showed a neutral soil milieu and no tendency in depth, with values between 7.1 and 7.8 (mean: 7.4, sd: 0.1, n: 75). The content of $CaCO_3$ ranged between 1 and 32 % (mean: 11.1, sd: 9.6, n: 75) for all profiles, with decreasing values in greater soil depth. The less weathered or unweathered glacial and glacio-fluvial sediments (all 2C horizons) showed less evidence of decalcification. The SOC contents were between 0.1 and 3.1 % (mean: 0.9, sd: 0.5, n: 75) and for all profiles the maximum values were found in the present and buried topsoil and in the deepest colluvial horizons. The carbon to nitrogen ratio (C/N) mimicked the depth gradients of SOC, showing narrower ratios at lower carbon states. In total the ratio varied between 5 and 12 (mean: 7.8, sd: 3.0, n: 75) (Tab. 1).

3.2 Dating

All measurements revealed bright and fast decaying luminescence signals indicative of quartz with a dominant fast component. At least 19 aliquots were measured per sample, and the resulting D_e distributions were analysed with respect to their overdispersion, kurtosis and skewness (Bailey and Arnold, 2006). The samples GI520-GI531 (ABR W1 and ABR W2), GI743 (ABR SA2), GI 786 and GI788 (both ABR M) showed narrow and symmetric D_e distributions, typical for complete bleaching, whereas all other samples (mainly from ABR SA1 and ABR M) displayed strong indications for incomplete bleaching through positively

skewed and overdispersed D_e distributions. (Galbraith et al., 1999; Cunningham and Wallinga, 2012) was applied. A sigma b-value of 0.12-0.15 was used in this model, according to the lowest overdispersion of a well bleached sample from the same profile. Resulting ages are in correct chronostratigraphic order and are summarised in Fig. 4 (see also see Scherer et al., 2020), along with D_e values and the underlying age model.

Table 1: Pedological data of selected profiles (units are given as mass-%), n.a.: not analyzed, LoD: Limit of detecion.

Horizon	Depth [cm]	$CaCO_3$ [%]	pH [$CaCl_2$]	Clay, silt, sand [%]	SOC [%]	C/N
ABR W1, *Calcaric Cambisol (Endoclayic, Pantocolluvic, Epiloamic, Ochric, Epiraptic)*						
Ap	0-10	28	7.6	32, 47, 21	0.5	6
M1	10-50	26	7.6	36, 45, 19	0.4	5
M2	50-105	20	7.6	40, 43, 17	0.3	5
M3	105-153	10	7.6	48, 40, 12	0.5	6
M4	153-180	2	7.6	53, 37, 10	0.9	9
M5	180-206	1	7.4	52, 38, 10	1.0	10
M6	206-215	1	7.4	50, 39, 11	1.2	11
2Bwig/2Ahb	215-235	1	7.3	50, 40, 10	1.4	12
2Bwig	235-282+	1	7.3	65, 31, 4	0.5	7
ABR W2, *Calcaric Pantocolluvic Regosol (Aric, Pantoclayic, Ochric, Endoraptic)*						
Ap	0-30	27	7.4	34, 48, 18	1.1	7
M1	30-82	29	7.5	34, 44, 22	0.2	< LoD
M2	82-98	28	7.5	35, 44, 21	0.1	< LoD
M3	98-155	15	7.5	46, 39, 15	0.5	6
M4	155-170	4	7.6	54, 36, 10	1.0	8
M5	170-185	2	7.5	54, 34, 12	1.1	9
M6	185-215	1	7.4	57, 35, 8	1.6	11
2Bwig/2Ahb	215-230	1	7.4	59, 35, 7	1.7	11
2Bwig	230-262	1	7.3	62, 33, 6	0.9	8
2CBg	262-290+	17	7.6	45, 38, 16	0.3	< LoD
ABR WA1, *Calcaric Pantocolluvic Regosol (Aric, Anoloamic, Ochric, Amphiraptic, Bathyclayic)*						
Ap	0-25	31	7.1	n.a.	0.9	6
M1	25-52	30	7.4	n.a.	0.3	< LoD
M2	52-94	27	7.4	n.a.	0.2	< LoD
M3	94-130	23	7.5	n.a.	0.2	< LoD
M4	130-163	20	7.5	n.a.	0.5	6
M5	163-200	10	7.4	n.a.	0.8	7

M6	200-220	6	7.4	n.a.	1.0	9
2Bwig/2Ahb	220-260	2	7.3	n.a.	1.3	10
2Bwig	260-275	8	7.4	n.a.	0.7	5
2CBg	275-290+	21	7.4	n.a.	0.1	< LoD
ABR WA2, *Calcaric Cambisol (Pantocolluvic, Humic, Anoloamic, Bathyclayic)*						
Ah	0-20	11	7.3	n.a.	2.4	8
M1	20-64	14	7.3	n.a.	0.9	6
M2	64-95	11	7.4	n.a.	0.8	8
M3	95-124	7	7.4	n.a.	0.9	7
M4	124-150	11	7.4	n.a.	0.7	7
M5	150-190	6	7.5	n.a.	0.9	8
M6	190-205	6	7.5	n.a.	1.0	9
M7	205-225	2	7.5	n.a.	1.3	10
2Bwg	225-250+	1	7.4	n.a.	1.1	9
ABR SA1, *Calcaric Cambic Phaeozem (Aric, Anoclayic, Pantocolluvic, Bathyloamic)*						
Ah	0-20	14	7.2	n.a.	2.2	9
M1	20-33	15	7.3	n.a.	1.6	8
M2	33-50	15	7.4	n.a.	0.9	8
M3	50-63	16	7.4	n.a.	0.7	8
M4	63-75	13	7.4	n.a.	0.7	7
M5	75-88	6	7.5	n.a.	0.9	8
M6	88-100	2	7.5	n.a.	1.1	9
M7	100-128	1	7.3	n.a.	1.2	9
2Bw	128-145	1	7.3	n.a.	0.9	8
2CBw	145-200+	17	7.4	n.a.	0.6	6
ABR SA2, *Calcaric Pantocolluvic Regosol (Aric, Anoclayic, Humic, Endoraptic, Bathyloamic)*						
Ah	0-27	11	7.3	47, 31, 22	2.1	8
M1	27-40	10	7.3	52, 32, 26	1.2	7
M2	40-66	10	7.4	51, 31, 26	0.8	7
M3	66-80	9	7.4	45, 28, 27	0.8	7
M4	80-95	11	7.4	43, 29, 28	0.8	7
M5	95-123	8	7.4	45, 28, 27	0.9	8
M6	123-150	8	7.4	43, 27, 28	0.8	8

M7	150-172	6	7.4	42, 29, 29	0.8	8
2Apb	172-190	2	7.2	42, 31, 27	0.6	7
2Bw	190-215+	1	7.2	51, 25, 24	0.5	6
ABR S30, *Hypereutric Epicalcaric Cambisol (Pantocolluvic, Pantoloamic, Ochric)*						
Ap	0-13	11	7.6	n.a.	1.5	8
M1	13-45	11	7.6	n.a.	0.6	7
M2	45-72	3	7.6	n.a.	0.7	8
M3	72-90	1	7.5	n.a.	0.8	8
M4	90-140	1	7.5	n.a.	0.8	8
M5	140-150	1	7.4	n.a.	0.7	8
2Bwg	150-212	3	7.3	n.a.	0.4	5
2CBg	212-240+	25	7.8	n.a.	0.2	< LoD
ABR M, *Hypereutric Epicalcaric Endoskeletic Cambisol (Pantocolluvic, Humic, Anoloamic, Amphiraptic, Bathyclayic)*						
Ap	0-10	22	7.3	n.a.	3.1	9
Ap2	10-20	23	7.5	n.a.	1.5	7
M1	20-50	28	7.6	n.a.	0.9	7
M2	50-90	22	7.7	n.a.	0.4	4
M3	90-110	1	7.5	n.a.	0.9	8
2Bwg/2Ahb	110-140	1	7.4	n.a.	0.8	10
2Bwig	140-160	1	7.4	n.a.	0.5	7
2CBg	160-212	10	7.6	n.a.	0.2	6
2Cg	212-244+	32	7.8	n.a.	0.1	< LoD

For well bleached samples, the mean D_e was calculated using the Central Age Model (Galbraith et al., 1999) and for incompletely bleached samples, a bootstrap Minimum Age Model
The AMS ^{14}C ages showed a correct chronological trend, and only a few minor age reversals occurred on a 2-sigma significance level (Fig. 4; see also see Scherer et al., 2020). The comparison of OSL and ^{14}C ages at the same sampling depth mostly showed older radiocarbon ages in younger dated sediments (especially ABR W1 and ABR W2). The overall range of ^{14}C and OSL ages was narrower at the profile ABR SA2.

3.3 Archaeology

The majority of MBA finds was observed in the central part of the excavation (Fig. 2, Höpfer et al., accepted). Most MBA features were from wooden architecture, especially in the form of several hundred post-holes. At least 20 buildings, of mostly rectangular shapes but varying sizes and layouts, could be reconstructed (Fig. 5). Ten buildings were reconstructed with smaller areas (ca. 3-7 m^2) and square or short-rectangular shapes (Fig. 5, J-T). These were grouped around the presumed MBA settlement centre. A small kiln was observed, while a small pit to the north contained a 2 kg fragment of a copper ingot. Several shallow pits and stone clusters filled with heat stones were grouped around the presumed settlement centre. Up to ca. 50 m southeast of these domestic structures, several ceramic pots and larger firepits with heat stones were found. The ceramic pots were apparently set into the ground and sometimes contained heat stones. Several wagon tracks and linear discolorations or stone clusters were documented, albeit of mostly uncertain age. North of the settlement, a small kettle hole with a stone plaster was described. The pottery from these features has its biggest similarities with inventories from the later MBA (ca. 1450-1300 BCE). Among the characteristic elements are thick flattened rims on short and steep vessel mouths, raw slurried surfaces, lobes on the body and rim of larger pots and the occasional notched decoration on finer pottery (Krumland, 1998; Rigert et al., 2001; Honig, 2008).

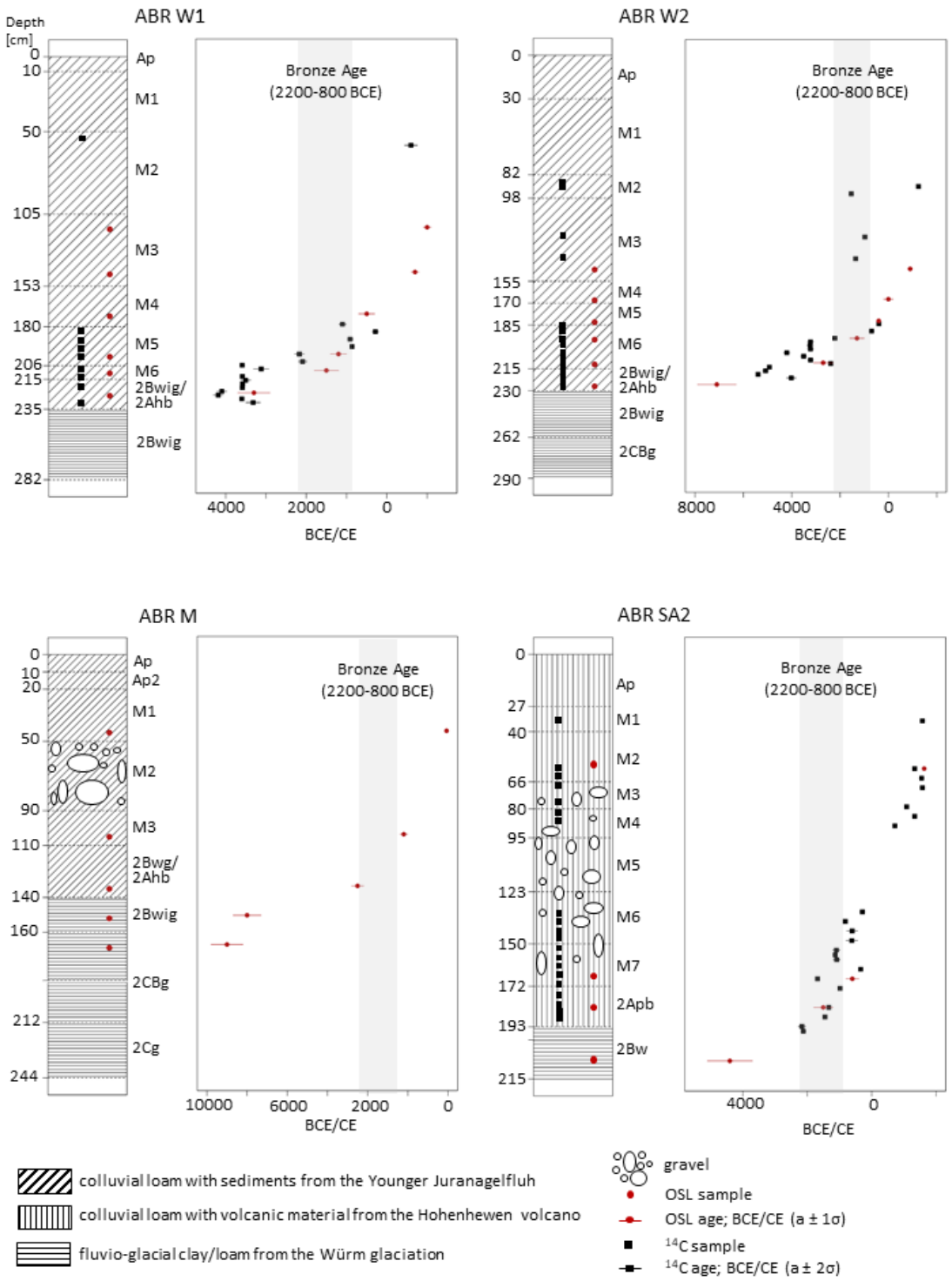

Figure 4: Colluvial profiles used for OSL and ^{14}C dating. Profile designations are given in bold, colluvial horizons are designated as M.

3.4 Archaeobotanical proxies

In total 555 charcoal fragments were collected from the colluvial profiles ABR W2, ABR SA1and ABR SA2. Although ca. 1.5 m of ABR W2 were not sampled for charcoal determination, the more than 1 mm charcoal output was the highest compared to the other two

profiles (50 %). Of the charcoal fragments, 29 % were collected from the ABR SA2 profile, and 21 % from ABR SA1. Amongst the charcoal proportions from ABR W2, between a depth of 141 and 262 cm was only dicotyledonous woods. *Quercus* sp. were strongly represented throughout this depth. *Fagus* sp. could be identified in the horizons M4 to M6 (165-200 cm). Additionally, a few *Fraxinus* sp. fragments were found in the horizon M6 (200-215 cm) (Fig. 6, a). The charcoal spectra of ABR SA1 showed the following trend: From horizon M7 onwards (110 cm), only dicotyledons were present, amongst which *Quercus* sp. were strongly represented. Charcoal fragments of *Quercus* sp. were not found in a soil depth lower than 73 cm, whereas *Fagus* sp. occurred in the horizons Ap to M4 (0-73 cm) only. From the modern surface to 85 cm (Ap-M5) conifers appear, some of which could be identified as *Pinus* sp. (Fig. 6, b). A considerable number of charcoal fragments from ABR SA2 could not be determined in detail, because they were too small, but are attributed as dicotyledonous. In horizon M6 (133-138 cm), *Quercus* and *Fagus* sp. dominated the charcoal spectra. In horizons M3 to M5 single fragments were allocated to *Pinus* sp., *Quercus* sp., *Prunus* sp. and conifer wood in general, whereas the majority were determined as dicotyledonous only. In horizons Ap, M1 and M2 similar amounts of conifer (*Pinus* sp., *Abies* sp.) and deciduous species (*Quercus* sp., *Fagus* sp., *Populus/Salix* sp.) were identified (Fig. 6, c).

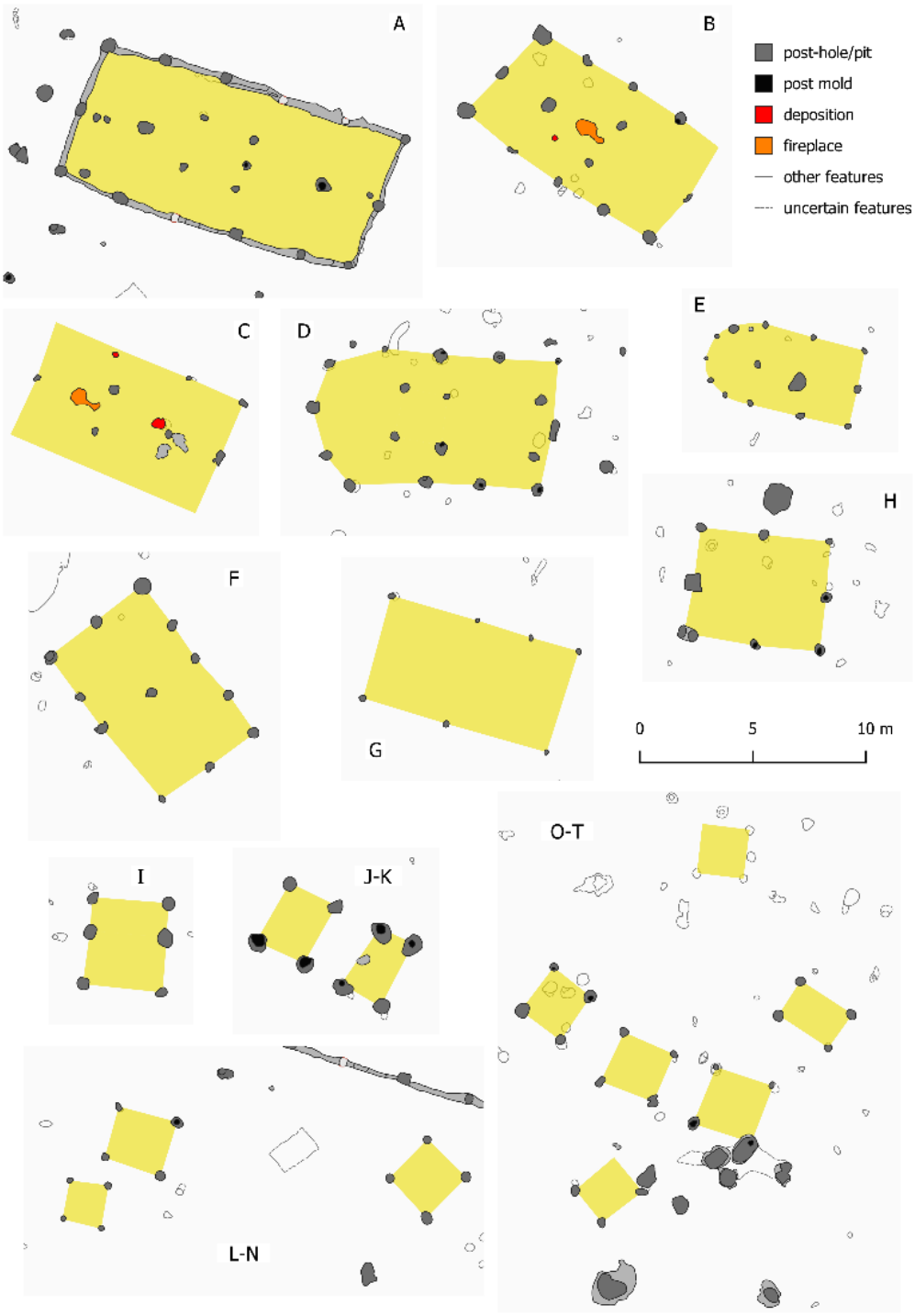

Figure 5: House floor plans of the Middle Bronze Age (MBA) at the Anselfingen excavation.

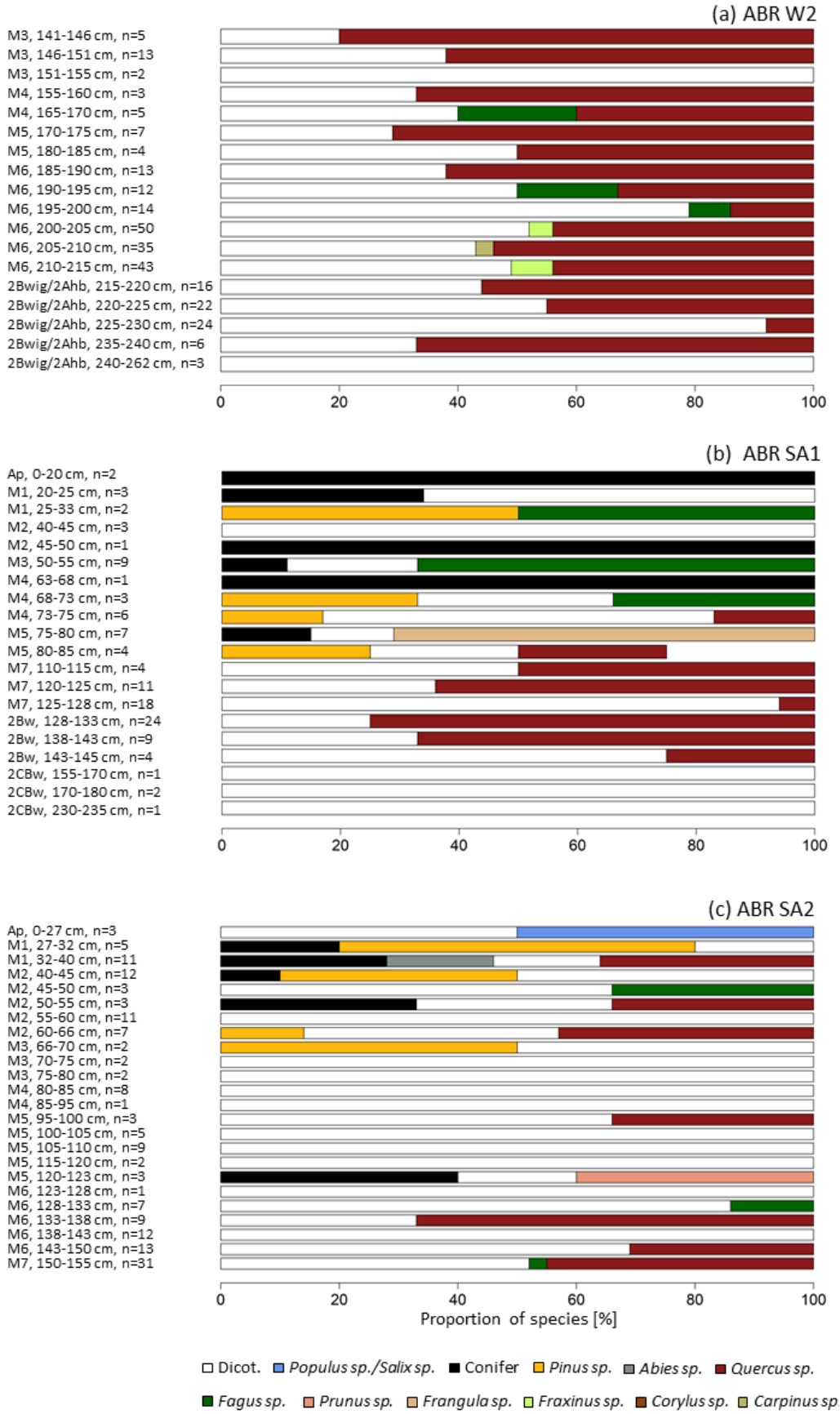

Figure 6: Percentage distribution of charcoal taxa for different sampling depths at the profiles ABR W1 (a), ABR SA1 (b), ABR SA2 (c) (n=number of identified charcoal fragments). Particle size ranges: 1-2 mm, > 2mm.

Phytoliths were found in all investigated samples of profiles ABR W1, ABR W2 and ABR SA2 (Tab. 2). The absolute phytolith concentrations of profile ABR W1 were not comparable with those of ABR W2 and ABR SA2 due to different analytical approaches. However, a relative comparison of the phytolith concentrations and different morphotypes and their anatomical origin was possible.

The phytolith concentrations showed an increasing trend with depth for all investigated profiles. The highest values were found in the buried topsoil horizons (2Bwig/2Ahb; 2Apb) and the lowest values in the present topsoil and buried subsoil horizons. The morphological analysis revealed that all profiles were similar in their morphotype assemblages. Monocotyledonous morphotypes were the most common group identified. At all profiles 68 % (sd: 14.0 %, n: 24) of the phytoliths were assigned to grasses, whereas 16 % (sd: 10.0 %, n: 24) were determined as dicotyledonous morphotypes. On average, 15 % (sd: 10.8, n: 24) of the phytoliths appeared to be weathered, so that a morphological or anatomical identification was not possible. Moreover, grass phytoliths were divided into the different anatomical plant parts in which they were formed. At all profiles, short cell morphotypes, commonly produced in leaves and stems, occurred at difference rates, ranging from 9 % to 50 % (mean: 30 %, sd: 9.3 %, n: 24). The majority of short cells recovered from these samples were those associated with the C_3 Pooideae subfamily, to which cereals also belong (e.g. rondels). Grass phytoliths derived from their floral parts ranged between 0 and 26 % (mean: 6 %, sd: 6.5, n: 24), while higher proportions were identified in the samples of ABR W1 (mean: 13 %, sd: 6.0, n: 9). Phytoliths stemming from the inflorescence plant parts were minor in the samples of ABR W2 (mean: 2 %, sd: 1.6, n: 8) and ABR SA2 (mean: 3 %, sd: 1,9, n: 6). Epidermal cells from grass leaves and stems were observed with an average amount of 63 % (sd: 12.8 %, n: 24).

In total, 163 charred archaeobotanical remains were found in different archaeological features of the ABR site (Fig. 7). They were recovered through wash-over flotation from ca. 150 liters of sediment and reached a concentration of ca. one plant macro remain per liter. The majority of these finds comprises chaff and grains of cereals like barley (*Hordeum distichon/vulgare*), emmer (*Triticum dicoccum*), einkorn (*Triticum monococcum)*, spelt (*Triticum spelta*) and free threshing wheat (*Triticum aestivum/turgidum*) and occur mostly in fire pits and architectural remains. The chaff originates exclusively from hulled wheats, namely einkorn, emmer and spelt. Figure 7 (b) shows the grain equivalents for the chaff, i.e. how many grains were developed in the glumes and spikelets of the respective species. A fragment of hazelnut (*Corylus avellana*) shell and a nutlet that probably derived from a raspberry, blackberry or dewberry (cf. *Rubus*) indicate the use of nuts and fruits from the surrounding vegetation. The

number of wild plant finds was also low since only a few seed remains from weeds and footpath vegetation occur in the studied material (Fig. 7, a).

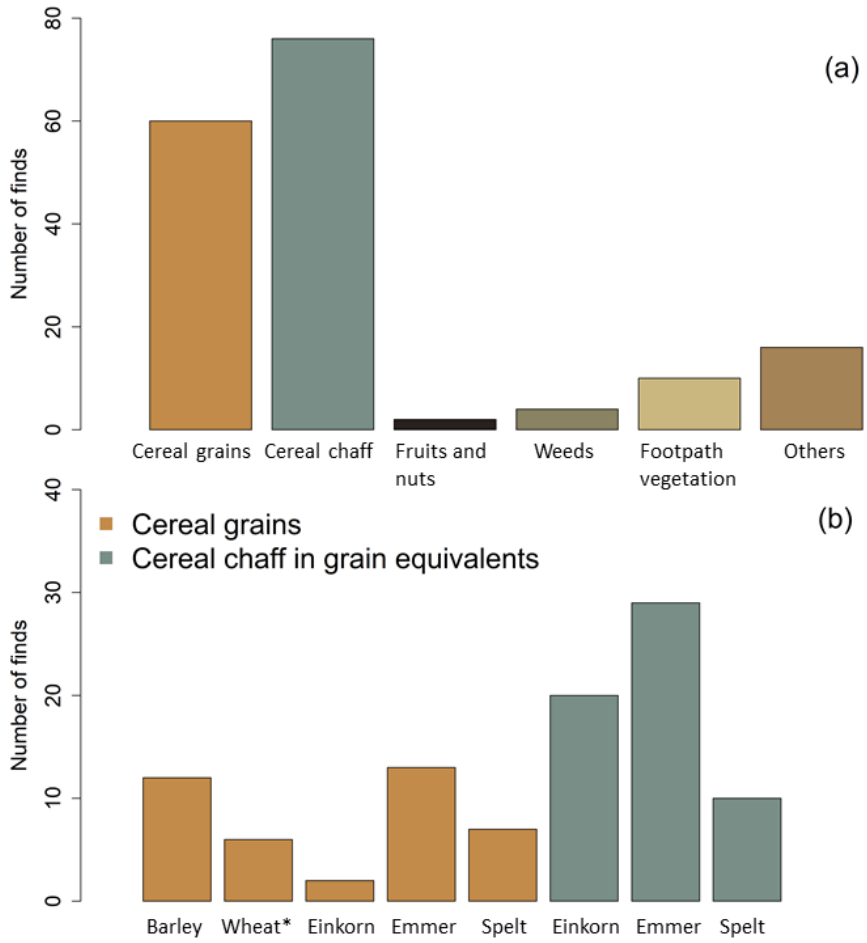

Figure 7: Charred plant macro-remains identified in the archaeological features of Anselfingen Amount of plant macrofossils from the main economic and ecological groups (a) and amount of the main archaeological finds of cereal crops (b). Wheat*: Fresh threshing wheat.

Table 2: Phytolith concentrations, percentages of different morphotypes (monocotyledonous, dicotyledonous) and of single morphotype plant compounds of selected profiles. Percentages are calculated over the total number of morphotypes identified in each soil sample; at least 200 morphotypes were identified in each sample (n.i. = not identified).

Profile	**Horizon**	**Sampling depth**	**Phytolith conc.**	**Morphotypes**			**Monocot.**			**Dicot.**	
				Monocot.	Dicot.	Weathered	Leaves and stems	Infloresence	Short cells	Leaves (and stems)	Wood and bark
		[cm]	[number per gram sediment]	[%]							
ABR W1	Ap	0-10	3,428	43	21	36	40	10	50	2*	19
ABR W1	M5	180-185	5,174	59	16	25	52	8	40	4*	12
ABR W1	M5	190-195	15,948	60	20	20	43	26	31	3*	17
ABR W1	M5	200-206	17,111	52	18	30	56	15	29	5*	13
ABR W1	M6	206-211	26,501	62	15	23	52	15	33	4*	11
ABR W1	M6	211-216	10,459	57	19	24	51	8	41	3*	16
ABR W1	IIP-fAh	216-221	36,401	60	19	21	55	16	29	4*	14
ABR W1	IIP-fAh	226-231	42,185	61	17	22	56	7	37	4*	13
ABR W1	IISdw-P	240-282	7,041	51	9	40	55	10	35	2*	6
ABR W2	M6	190-195	735,215	81	8	11	77	0	23	100	0
ABR W2	M6	195-200	523,841	79	11	10	82	0	18	100	0
ABR W2	M6	200-205	908,928	85	8	7	88	3	9	100	0
ABR W2	M6	205-210	753,596	93	5	2	76	0	24	100	0
ABR W2	M6	210-215	670,884	87	10	3	78	3	19	100	0
ABR W2	IIP-fAh	215-220	1,481,459	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.

ABR W2	IIP-fAh	220-225	1,366,765	78	12	10	71	2	27	95	5
ABR W2	IIP-fAh	225-230	590,335	73	20	7	58	3	39	67	33
ABR W2	IISdw-P	230-235	318,593	75	14	11	77	4	19	100	0
ABR SA2	Ap	0-27	356,075	43	57	0	67	0	33	100	0
ABR SA2	M7	170-172	1,246,262	75	12	13	56	5	39	100	0
ABR SA2	IIfAp	172-177	2,646,775	66	20	14	65	4	31	85	15
ABR SA2	IIfAp	177-182	3,242,155	83	14	3	68	1	31	97	3
ABR SA2	IIfAp	182-187	2,288,357	72	20	8	59	4	37	98	2
ABR SA2	IIfAp	187-190	2,380,259	76	13	11	72	3	25	94	6

3.5 Micromorphology

The thin section from the upper part of the 2Apb horizon (ABR SA2, 183-193 cm) had a channel to a weakly developed angular blocky microstructure with few partially accommodating planes. A dark brown limpidity, with an undifferentiated b-fabric, was pronounced for most parts of the micromass, with the exception of rounded peds within the groundmass, which showed a light brown limpidity and stipple speckled to mosaic-speckled b-fabric. Despite the non-calcareous micromass, fragments of limestone and oval pellets of micritic calcium carbonate occurred. Throughout the thin section there were small fragments of charcoal and fragments of basaltic, metamorphic and magmatic rocks (Fig. 8, a) Partially laminated very dusty thick (up to 1600 µm) dark brown clay coatings with embedded coarse material (quartz and feldspars) with a size of up to 700 µm were particularly common in the macrochannels (Fig. 8, b).

The thin section from the lower part of the 2Apb horizon (ABR SA2, 190-200 cm) had a well-developed subangular to angular blocky microstructure with well to partially accommodating planes (Fig. 8, c). A dark brown limpidity of the micromass with a predominantly undifferentiated b-fabric, was pronounced for about two thirds of the thin section, with the exception of rounded and angular peds within the groundmass, which showed a light brown limpidity and stipple speckled to mosaic-speckled b-fabric. The last third is covered by an almost rectangular area with sharp boundaries and a light brown limpidity of the micromass (Fig. 8, d), which had a stipple-speckled, mosaic speckled and striated b-fabric. In many parts, granostriated b-fabric was present. Within this area, bands, inclined at about 45°, alternate with coarse material "floating" in fine material with bands consisting mainly of clay and silt - micromass with mosaic to striated b-fabric (Fig. 8, e). Additionally, large (up to 2000 µm) rounded to subrounded peds were frequently occurring (Fig. 8, f). The coarse material consisted mainly of basaltic fragments and weathered volcanic shards, limestone fragments, micritic pellets and, to a lesser extent, magmatic and metamorphic fragments and fragments of charcoal. Many small coprolites (50-100 µm) could be detected under fluorescent light. Some of the micritic carbonate pellets showed green autofluorescence at 470 nm. Similar to the upper thin section, very dusty thick (however only up to 800 µm) dark brown clay coatings, together with coarse material (metamorphic and magmatic rock fragments) with a size of up to 2000 µm, were particularly common in the macrochannels.

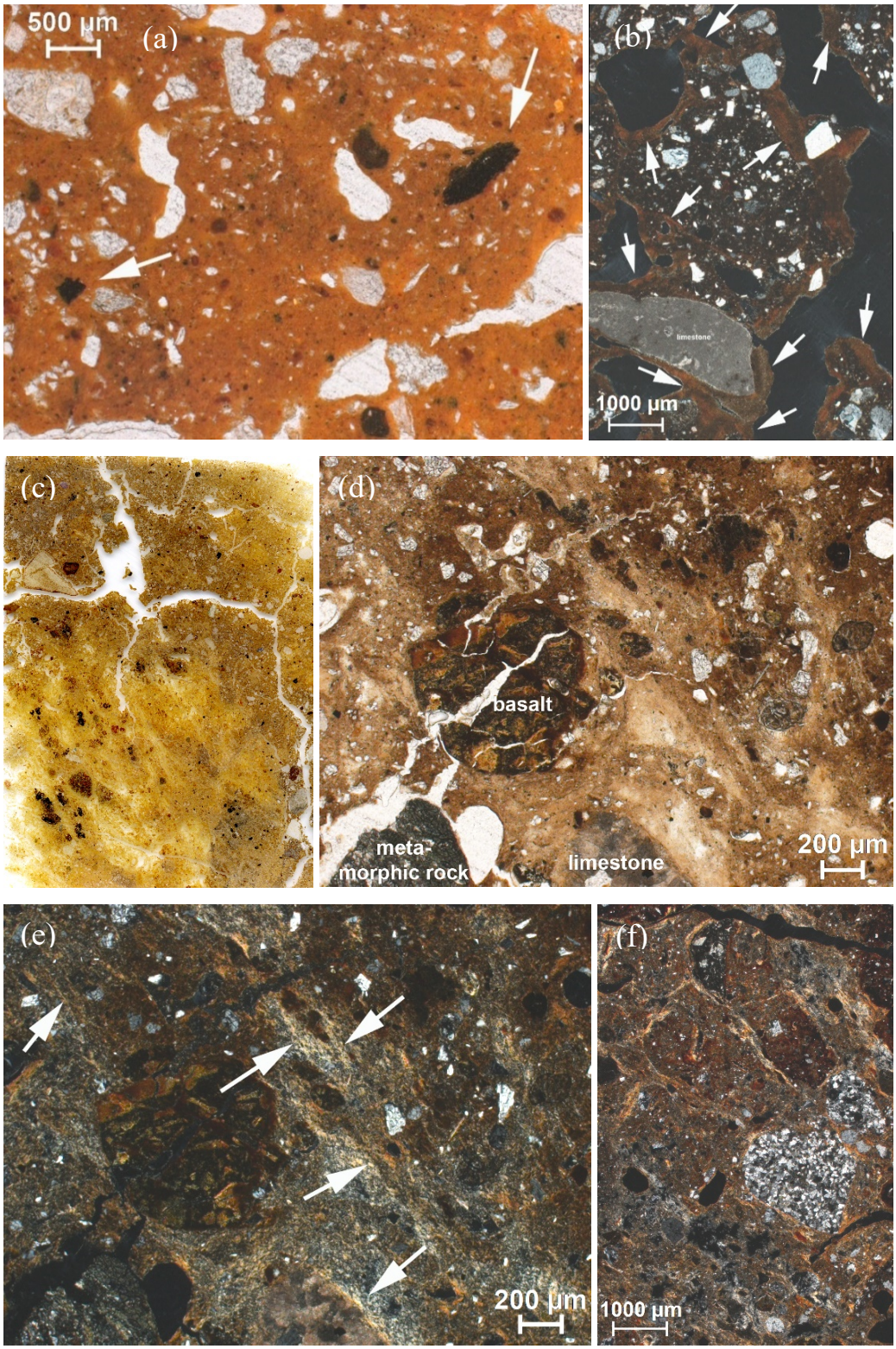

Figure 8: Micromorphological analysis of the buried plough horizon (2Apb). (a) white arrows point at fragments of charcoals (< 500µm) – ABR SA2 183-193 cm: OIL, ppl; (b) very dusty clay coating (white arrows) with incorporated coarse material – ABR SA2 183-193 cm: xpl; (c) scan of the thin section 6 x 9 xm – ABR SA2 180-190 cm; (d) compacted (low porosity) rounded to subrounded peds and rock fragments; some channels and one partially accommodating plane are present. Some peds are surrounded by a granostriated b-fabric – ABR SA2

180-190 cm; xpl; (e, f) about 45° inclined bands with alternating coarse and fine material; mosaic to striated b-fabric (white arrows) – ABR SA2 180-190 cm; (e) - ppl; (f) – xpl.

3.6 Biogeochemical proxies

Relative changes in polycyclic aromatic hydrocarbon (PAH) input were indicated by PAH to SOC normalization. The suite of individual PAHs was dominated by phenanthrene, fluoranthene and pyrene for all horizons of the analysed profiles ABR M, ABR W1 and ABR SA2 (Fig. 9, a-c). The amounts of anthracene, methylated phenanthrenes, benz[a]anthracene and chrysene were low for all samples. The suite of PAHs was most complete in ABR M, as well as in the upper horizons of ABR W1 and ABR SA2. The maximum concentration of phenanthrene were observed in the buried topsoil and subsoil horizons of ABR M (2Bwg, 110-115; 2CBg, 160-165 cm). In the M5 horizon of ABR SA2, no PAHs were detected. The sum of three-ring PAHs (phenanthrene, anthracene, methylated phenanthrenes) dominated the lower horizons, while four-ring PAHs (fluoranthene, pyrene, chrysene, benz[a]anthracene) revealed considerable amounts in the upper first horizons of ABR M (M1, 20-25 cm; M2, 50-55 cm) and ABR SA2 (Ap, 0-27 cm; M1, 27-32 cm).

The ratio of fluoranthene to fluoranthene plus pyrene (Flu/Flu+Py) was higher than 0.5 in 77 % of the values. The ratio was lower in ABR W1 (M6, 206-211 cm: 0.41) and in ABR SA2 (Ap, 0-27 cm: 0.46; M7, 150-155 cm: 0.24). The phenanthrene to phenanthrene plus the sum of methylated phenanthrenes ranged between 0.76 and 1 (Fig. 9, d). The pattern for both ratios was similar and with a distribution of the ratios independent of the sum of PAH concentrations.

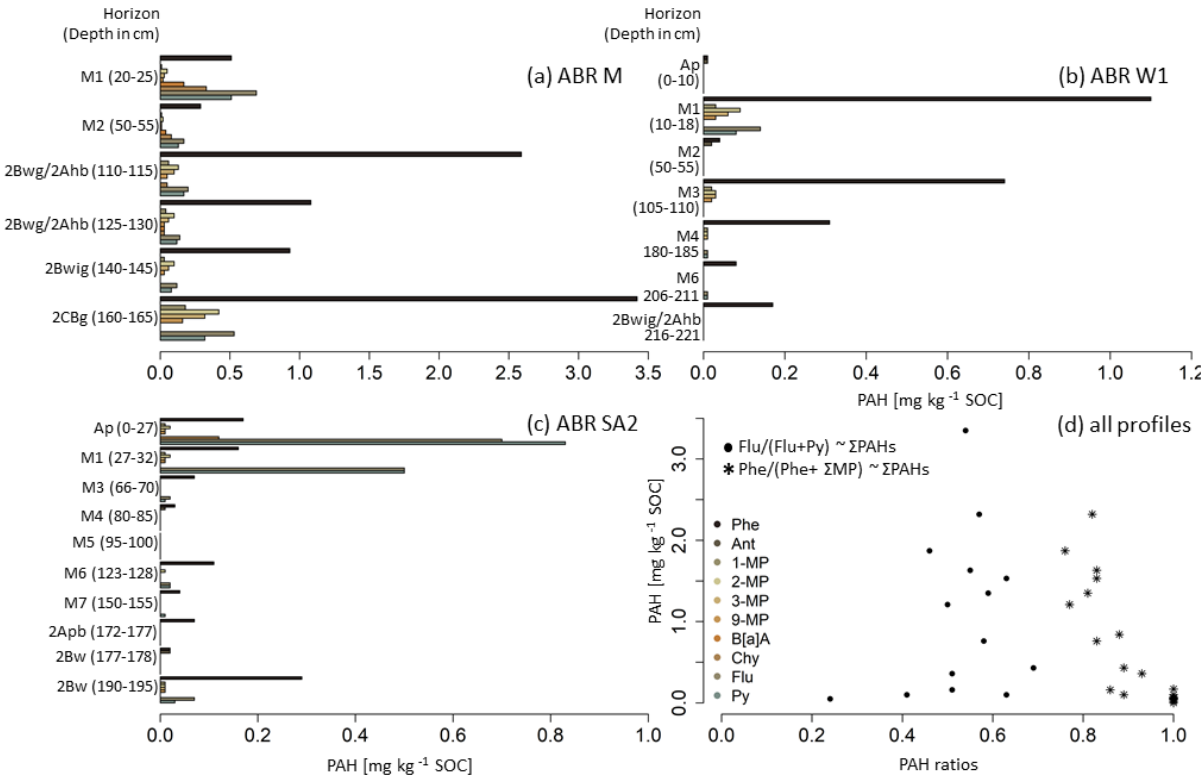

Figure 9: Polycyclic aromatic hydrocarbons (PAHs) with SOC normalization (a-c) of selected colluvial profiles and sampling depths (cm); PAH ratios vs. sum of PAHs (d). Phe: Phenanthrene, Ant: Anthracene, 1-MP: 1-Methyl-Phenanthrene, 2-MP: 2-Methyl-Phenanthrene, 3-MP: 3-Methyl-Phenanthrene, 9-MP: 9-Methyl-Phenanthrene, B*[a]*A: Benz*[a]*anthracene, Chy: Chrysene, Fl: Fluoranthene, Py: Pyrene.

The urease activity to microbial biomass (C_{mic}) ratio was determined for colluvial profiles ABR W1, ABR W2, ABR WA1, ABR WA2, ABR SA1 and ABR SA2 and varied between 0 and 2.1 µgN µgCmic^{-1} (Fig. 10). All profiles showed a comparable trend with increasing values with greater soil depth. A peak in the urease activity/C_{mic} ratio was either reached in the buried topsoil horizon (ABR W1, 2Bwig/Ahb, 216-235 cm; ABR WA1, 2Bwig/Ahb, 220-260 cm; ABR SA1, 2Bw, 128-145 cm) or in the deepest colluvial horizon (ABR W2, M6, 185-215 cm; ABR WA2, M7, 205-225 cm) and was in all cases considerably higher than the ratios of the modern topsoil horizon. Only for ABR SA2, the peak in urease activity/C_{mic} ratio occurred in the upper part of the profile (M6, 123-150 cm). Besides the maximum ratios, smaller peaks in several profiles were also observed. The peak value at ABR SA1 was remarkable that it far exceeded other values from the same profile. A positive correlation of urease [µgN gTS^{-1}*2h] and SOC was observed within 0 and 130 ± 20 cm for most of the analysed profiles (R^2: 0.82). Below this depth, the correlation of urease and SOC was weaker (R^2: 0.44). Clay and urease activity were not (ABR W1, ABR W2) or only weakly positively correlated (R^2: 0.37, ABR SA2) (Tab. S3).

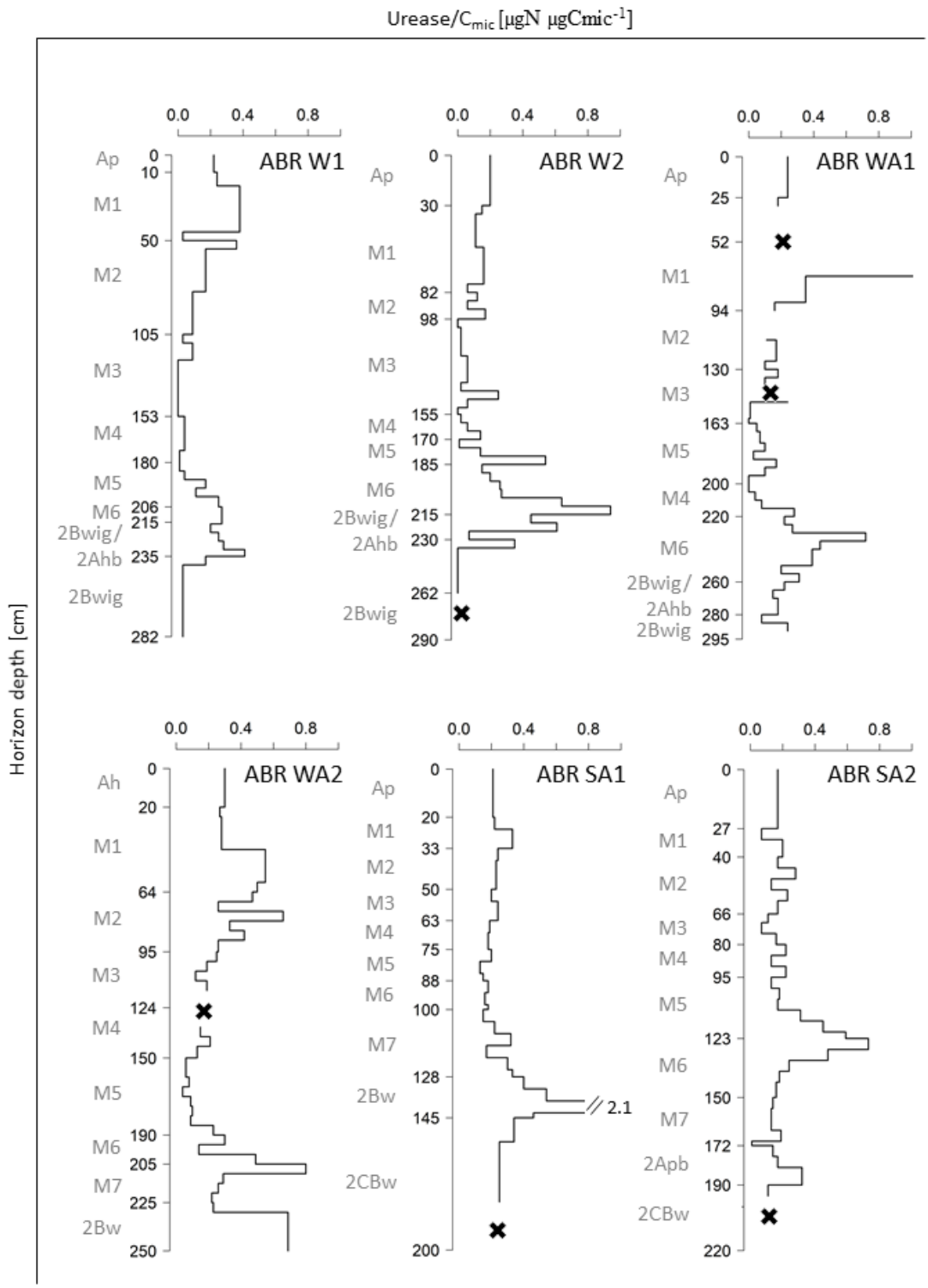

Figure 10: Depth profiles of Urease/C_{mic} ratio of selected colluvial profiles. "x" = not analysed.

Steroid compositions were analysed for selected horizons of profiles ABR W1 and ABR SA1 (Fig. 11, a-b). In total, eleven different compounds were identified comprising the molecular groups of stanols (coprostanol, epicoprostanol, 5ß-stigmastanol, epi-5ß-stigmastanol), stanones (cholestanone, coprostanone, cholestenone) and Δ^5-sterols (cholesterol, ß-sitosterol,

ergosterol, ß-stigmasterol). At ABR W1 coprostanol, epicoprostanol, cholestanone and cholesterol were dominating the molecular assemblages, whereas the relative amount of coprostanol and epicoprostanol was decreasing from horizon M6 (206-211 cm) to 2Bwig (235-240 cm) and an opposite trend was observed for cholestanone and cholesterol. At ABR SA1, cholestanone also increased with depth, while the relative proportions of coprostanol and epicoprostanol were less distinct compared to ABR W1. Further, at ABR SA1 considerable proportions of ß-sitosterol and 5ß-stigmastanol and epi-5ß-stigmastanol were observed.

At ABR W1, the ratio of coprostanol/(coprostanol+epi-5ß-stigmastanol)*100 was mainly greater than 73 % for the colluvial horizon M6 (206-211 cm) and the buried topsoil 2Bwig/Ahb (216-221 cm, 226-231 cm). In the buried subsoil horizon 2Bwig (235-240 cm), a single value below 38 % was calculated. The profile ABR SA1 showed ratios below 38 % which mainly occurred in the buried subsoil horizon 2Bw (133-138 cm, 138-145 cm) and above 73 % in the colluvial horizon M7 (110-115 cm) and buried subsoil horizon 2Bw (133-138 cm) (Fig. 11, c).

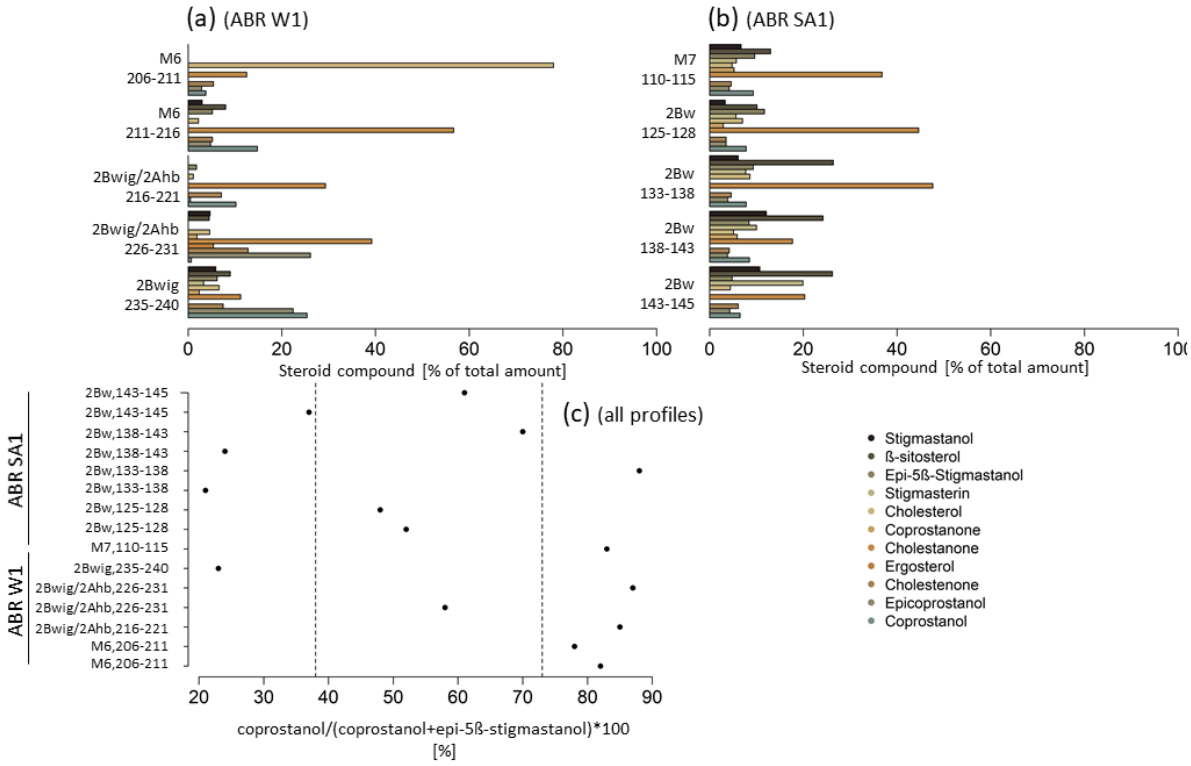

Figure 11: Steroid compounds as percent of total amount (a-b) of selected colluvial profiles and sampling depths (cm); Steroid ratio according to Leeming et al. (1997) (c). Values < 38 % indicate herbivorous faeces, values > 73 % indicate omnivorous faeces.

The heavy metal contents showed two main patterns (Fig. 12). First, the Pb, Cu and As contents were significantly lower than the Zn, Ni and Cr contents for all colluvial profiles. Secondly, different values were observed for the different soil substrates, with the highest heavy metal

contents in the (b) basaltic sediments of the Hohenhewen volcano and the lowest in the (a) sediments of the Younger Juranagelfluh. In most cases, the 25th and 75th quartile ± 1.5 Interquartile range mimicked the natural variation of the heavy metal contents, depending on the substrate, according to the data of the geological state office of Baden-Württemberg (LGRB, 2020). Positive outliers, which indicate human influence, were detected at the colluvial profiles ABR S30 (Cu, M4 horizon, 110-115 cm, sediments of the Younger Jurannagelfluh), ABR WA2 (As, M7, 220-225 cm; Pb, Ap, 0-20 cm, sediments of the Hohenhewen volcano) and ABR SA1 (Zn, M6-M7, 100-128 cm, sediments of the Hohenhewen volcano). Heavy metals analysed from sediment samples from the Younger Juranagefluh and the glacial and fluvio-glacial sediments of the Würm glaciation correlated mostly with $CaCO_3$. No correlation was observed between heavy metals and SOC, pH-value as well as heavy metals from samples of the sediments of the Hohenhewen volcano with $CaCO_3$, SOC and pH-value (Tab. S4).

3.7 Animal bones

In total 415 animal bones from different MBA features (onsite) with a total weight of 1076 g were investigated at the ABR site (Tab. 3). In total, 21 % of the animal bones could be assigned to their species while 79 % had to stay unidentified due to their high level of fragmentation. Considering only those bones that were assigned to species, most of them belonged to sheep/goat (30 %; 95 g), cattle (30 %; 290 g) and pig (14 %; 47 g). Wild animal species (e.g. roe deer, deer, boar, wolf, wild cattle) made up 17 % (187 g) of the elements identified to species.

The taphonomic analysis revealed natural and human modifications of animal bones. Most of the assemblages were affected by insect damage or by root damage in different stages. The burning of bones could be identified with a low rate of 0.7 %, and occurred mainly in the fillings of pits and deposited vessels. Anthropogenic traces such as cutmarks were documented on only 0.3% of the animal bones. Another human modification was observed in a piece of antler (most likely red deer) from an MBA house, which had been worked into a point (tool or hunting object). Another specimen from an MBA fire pit showed slight polishing of one of the edges. Carnivore marks could only be identified on one specimen from the MBA sample.

Table 3: Absolute (n) and relative number (n-%) of animal bones, absolute (g) and relative weight (mass-%) of species-specific animal bones, which were assigned to their species.

Species	**n**	**n%**	**weight (g)**	**weight%**
Cattle (*Bos primigenius*)	30	34	290	27
Horse (*Equus caballus*)	1	1	33	3
Pig (*Sus scrofa domesticus*)	14	16	47	4
Goat/sheep (*Capra/Ovis*)	27	30	95	9
Boar (*Sus scrofa*)	5	6	50	5
Wolf (*Canis lupus*)	3	3	4	0
Deer (*Capreolus capreolus*)	1	1	0.8	0
Roe deer (*Cervus elaphus*)	5	6	12	1
Wild cattle (*Bison bison*)	3	3	120	11
Total	**89**	**100**	**1076**	**100**

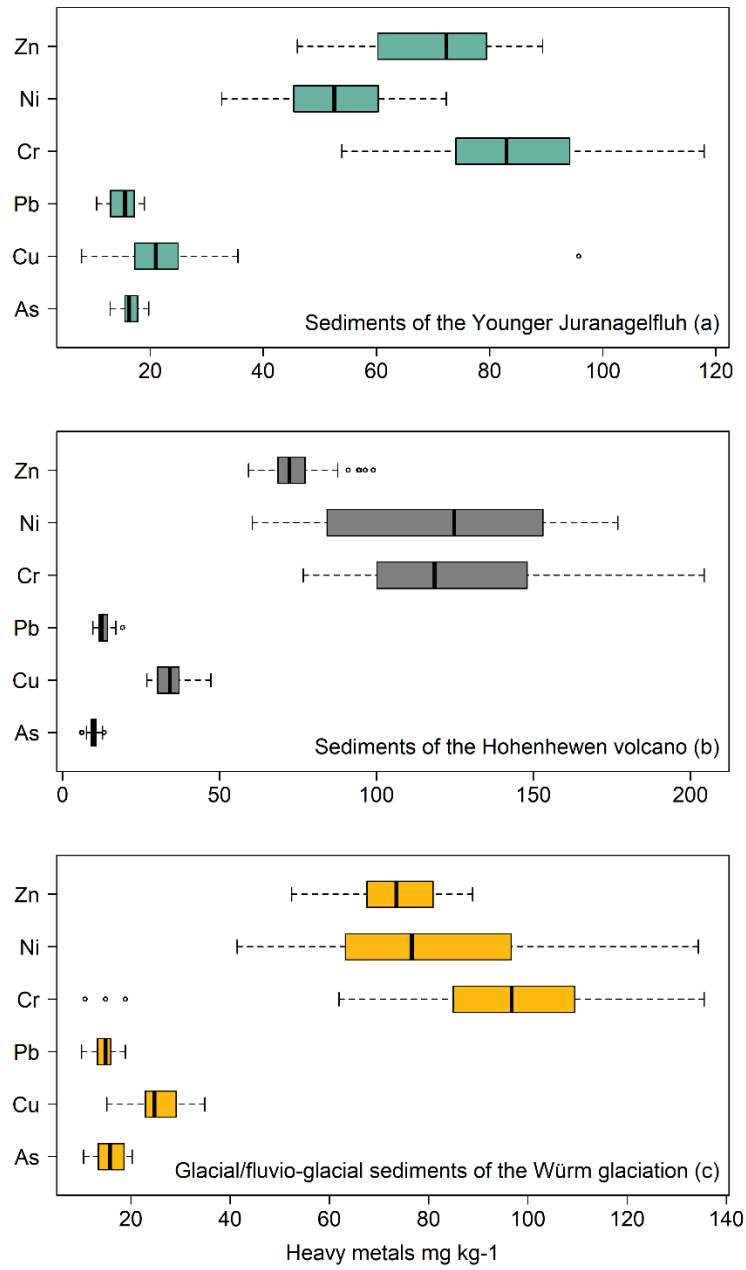

Figure 12: Heavy metal contents of the soil profiles ABR W1, ABR W2, ABR M, ABR S30, ABR SA1, ABR SA2 according to their soil substrates: (a) sediments of the Younger Juranagelfluh (n: 113), (b) sediments of Hohenhewen volcano (n: 93), (c) glacial/fluvio-glacial sediments of the Würm glaciation (n: 38). The boxplots show median, 25th (Q_1) to 75th (Q_3) percentile (=Interquartile range, IQR), data minimum (Q_1-1.5*IQR), data maximum (Q_3+1.5 IQR) and outliers.

3.8 Offsite pollen profiles

For the Grassee profile (Fig. 13), which consisted mainly of fen peat, six local pollen assemblages' zones (LPAZ) could be distinguished (according to Bastin 1979):

1. (2600-2500 BCE): NAP (non-arboreal pollen) low; *Fagus* and *Corylus* codominant, *Betula* subdominant; *Corylus* increasing, *Fagus* decreasing;
2. (2500-2200 BCE): NAP increasing to >5%; *Corylus* predominant, slowly decreasing; *Fagus* subdominant, later codominant, increasing, micro-charcoal peak in the beginning of the zone;
3. (2200-2000 BCE): NAP low; a sequence of *Fagus*, *Betula*, and finally *Corylus* peak;
4. (2000-1600 BCE): NAP peak, *Fagus* predominant, *Corylus* and *Quercus* subdominant;
5. (1600-850 BCE): NAP initially reduced, then with a maximum; *Fagus* predominant, *Corylus* and *Quercus* subdominant; *Quercus* decreases slightly from 1100 BCE onwards, a weak micro-charcoal peak;
6. (850-700 BCE): NAP decreasing, *Fagus* increasing;

Between 2000 and 800 BCE, the pollen curves of major anthropogenic indicators like *Artemisia* and *Plantago lanceolata* were continuous, with the highest values in the zone 5 (1600-850 BCE) exactly like the non-arboreal-pollen (NAP) sum. The curves of cereals (Cerealia-type, *Triticum*-type and *Hordeum*-type) were however discontinuous. Changes in the arboreal pollen (AP) composition are moderate. After 2000 BCE, *Betula* decreased slightly. *Quercus* reached its highest values in the LPAZ 4 and 5. The dominating tree during the whole period was *Fagus*, while coniferous trees like *Abies* and *Picea*, both minor components, increased in the10th century BCE.

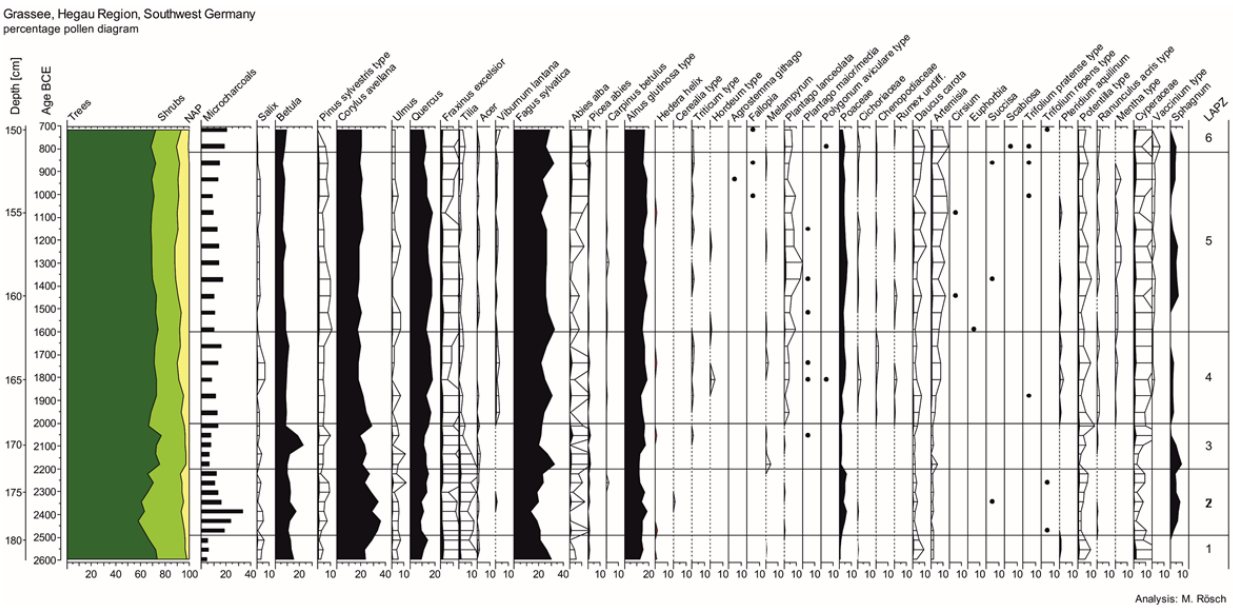

Figure 13: Pollen profile of Grassee mire. NAP: non-airborne pollen, the samples were investigated in increments of one cm.

For the Hartsee mire (Fig. 14), where peat and lake sediments alternate, seven LPAZ could be distinguished during the Bronze Age:

1. (2700-2600 BCE): NAP low; predominance of *Fagus*
2. (2600-2500 BCE): NAP still low; *Corylus* predominant, *Fagus* and *Quercus* subdominant; *Betula* has a weak maximum;
3. (2500-1900 BCE): Slight increase of the NAP sum; predominance of *Fagus;* subdominance of *Corylus* (decreasing) and *Quercus,* a pronounced microcharcoal peak;
4. (1900- 1750 BCE): NAP decrease, towards the upper limit increase; predominance of *Fagus,* subdominance of *Corylus* (prevailing) and *Quercus; Corylus* increasing*, Betula* decreasing;
5. (1750-1550 BCE): NAP increase to 10%, parallel to a micro-charcoal peak; *Fagus* dominates, but decreases; towards the upper limit codominance of *Quercus* and *Fagus*;
6. (1550-1050 BCE): NAP increasing to 15-20 % in line with high micro-charcoal increase and peak, codominance of *Fagus*, *Quercus*, and *Corylus; Carpinus* curve ± continuous;
7. (1050-700 BCE*):* NAP slightly decreasing; *Quercus* slightly predominant*, Fagus, Corylus* and *Betula* subdominant;

During the Bronze Age, the anthropogenic indicators *Plantago lanceolata* and *Artemisia* were continuously present. The cereal pollen (especially *Triticum*-type and *Hordeum*-type) showed almost continuous occurrence with their curves following the same trend as that of the NAP sum. After a minimum during the 18th/17th century BCE, *Betula* was increasing, with some fluctuations, and gained a maximum of 15.5 % in the 12th century BCE. Another peak (20.4%) occurred in the late 11th century BCE. From 930 BCE onwards, the overall occurrence of *Betula* was continuous (11–15 %). After a maximum in the 18th century BCE, *Corylus* decreased continuously, apart from minor peaks. *Quercus* showed a peak in the 17th/16th century BCE and retained a strong significance afterwards. A more distinct increase was not observed as earlier as the pre-Roman Iron Age. *Fagus*, the dominating tree at the beginning of the Bronze Age, decreased from the 17th century BCE onwards. After a recovery phase in the 13th/11th century BCE, it decreased again. The micro-charcoal record shows a first peak at ca. 2250 BCE and two more pronounced at ca. 1650-1600 BCE and 1150-1100 BCE.

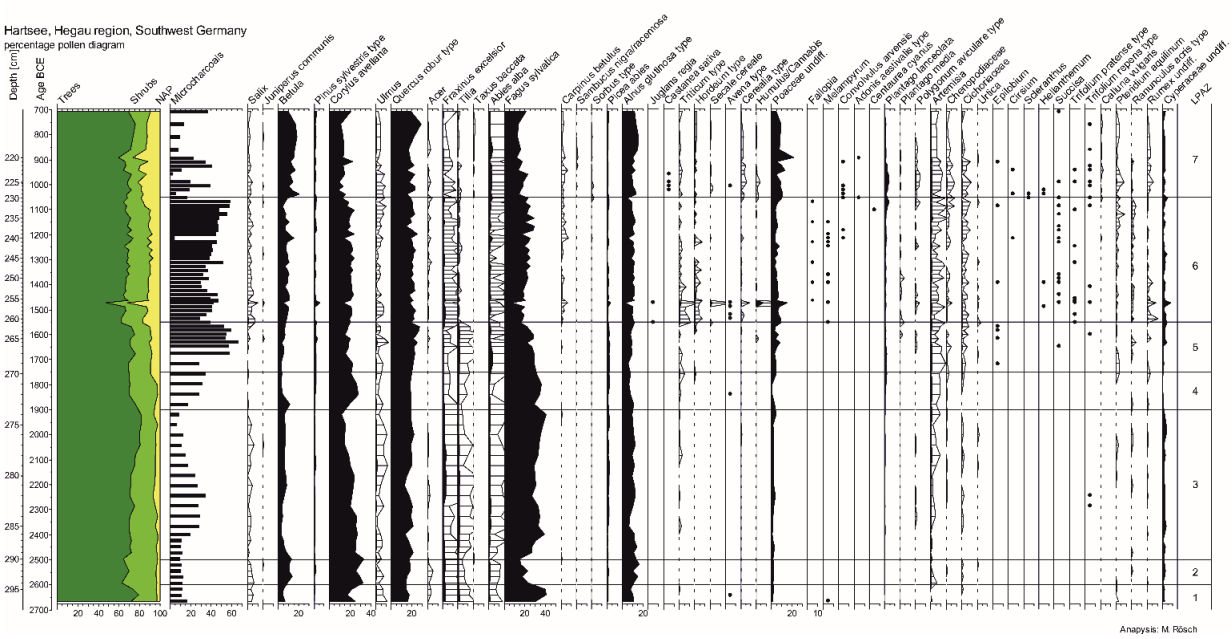

Figure 14: Pollen profile of Hartsee mire. NAP: non-airborne pollen, the samples were investigated in increments of one cm.

4 Discussion

4.1 Phases of colluvial deposition and land use

The stratigraphic and chronostratigraphic deciphering of colluvial deposits based on ^{14}C and OSL dating is fundamental for the reconstruction of land use phases of nearby settlements (Kittel, 2015; Scherer et al., accepted). In the north-western Alpine foreland, phases of colluvial deposition during the MBA have been reported much less frequently (Schulte and Stumböck, 2000; Vogt, 2014), while related archaeological remains provide evidence of simultaneous human occupation (Dieckmann, 1998; Ehrle et al., 2018; Wissert, 1985).

The summed probability density (SPD) of OSL ages (Fig. 15, a) indicate main phases of colluvial deposition during the Middle Bronze Age (MBA), the Iron Age, the Medieval period and modern times. During the Late Neolithic, weak colluviation is observed (M6 in ABR W2, 2700 ± 400 BCE; cf. Tab. S1), while soil tillage (e.g. hoe-farming) of the paleo-surface may have also been responsible for Younger Neolithic OSL signals (2Bwig/Ahb in ABR W1, 3300 ± 400 BCE; 2Bw in ABR SA2, 4400 ± 700 BCE; 2Bwg/Ahb in ABR M, 2500 ± 300 BCE). Neolithic soil deposition was also reported by Poręba et al. (2019) and Zádorová et al. (2013) in loess-covered upland sites in Poland and the Czech Republic, where the sedimentation rates were higher, which could be the result of a high erodibility of loess. At the ABR site, the main colluvial deposition began during the MBA, as indicated by the OSL ages from ABR W1 (M6,

1500 ± 300 BCE; M5, 1200 ± 200 BCE) and ABR W2 (GI529, M6, 1300 ± 300 BCE) and the formation of about 30 cm of colluvial deposit. These phases of colluvial deposition are in line with MBA settlement remains but are restricted to the northern surrounding areas of the ABR site (ABR W1, ABR W2), while during the MBA no colluvial deposition occurred within the settlement area (ABR M) or south of it (ABR SA1, ABR SA2). However, the OSL signal from the 2Apb in profile ABR SA2 (1500 ± 300 BCE) indicates MBA soil tillage of the paleo-surface and the presence of an agricultural field associated with the MBA settlement. Pedofeatures indicating prehistoric ploughing are scarce (Twardy, 2011), while to our knowledge an MBA ploughing horizon is not yet documented (see sect. 5.2.2). Regarding the profile ABR M, colluvial deposition was not expected during the MBA due to its location within the settlement area. Since the Iron Age, colluvial deposition occurred across the ABR site as reflected in the higher sedimentation rate compared to the MBA (Fig. 15, b). This is in line with the sedimentation history from other study sites, and is mostly interpreted as the consequence of increased human impact (e.g. Dotterweich, 2008; Dreibrodt et al., 2010b; Henkner et al., 2017; Lang, 2003). However, the low sedimentation rate during the Roman period is remarkable and contradicts the archaeological finds at the ABR site (Ehrle et al., 2018). Possible explanations are that Roman land use did not contribute to higher soil erosion rates, or Roman land use areas were located elsewhere at the ABR site. It should be noted that the SPDs could also be biased in this respect, as no charcoal was found and no OSL samples could be taken from the M5 horizon in ABR SA2, which according to the ages of the over- and underlying horizons M4 and M6, could be dated to the Roman period (Fig. 4).

Higher SPDs of ^{14}C ages often precedes phases of colluvial deposition, indicating that landscape opening by local deforestation was responsible for colluvial deposition at the ABR site. During the Neolithic at least three phases of land use are reflected in the ^{14}C ages (Fig. 15, a). They can be related to the Early (Linear Pottery Culture, 5500-5000 BCE), Younger (Hornstaader Culture, 4100-3800 BCE) and Late Neolithic (Horgener Culture, 3700-2800 BCE), all of which are documented through burials or architectural remains from the ABR site or its close proximity (Ehrle et al., 2018; Hald, 2020, Fig. 14, c). During the Bronze Age, the ^{14}C peaks of the SPDs complement the local archaeological record and the MBA depositional phase, indicating human occupation during the Early, Middle and Late Bronze Age (Ehrle et al., 2018; Hald, 2020). The succeeding ^{14}C peaks of the SPD curve correspond to the main phases of colluvial deposition during the Iron Age, Medieval Ages and modern times.

Based on the phases of colluvial deposition and land use, human occupation during the MBA is reflected in the sedimentary archives at the ABR site. Considering the scarcity of MBA

colluvial horizons in the north-western Alpine foreland, the well-dated colluvial horizons, the buried paleosurfaces and the archaeological features from the MBA provide promising archives for the archaeopedological, archaeobotanical and archaeological reconstruction of on- and near-site land use practices at the ABR site.

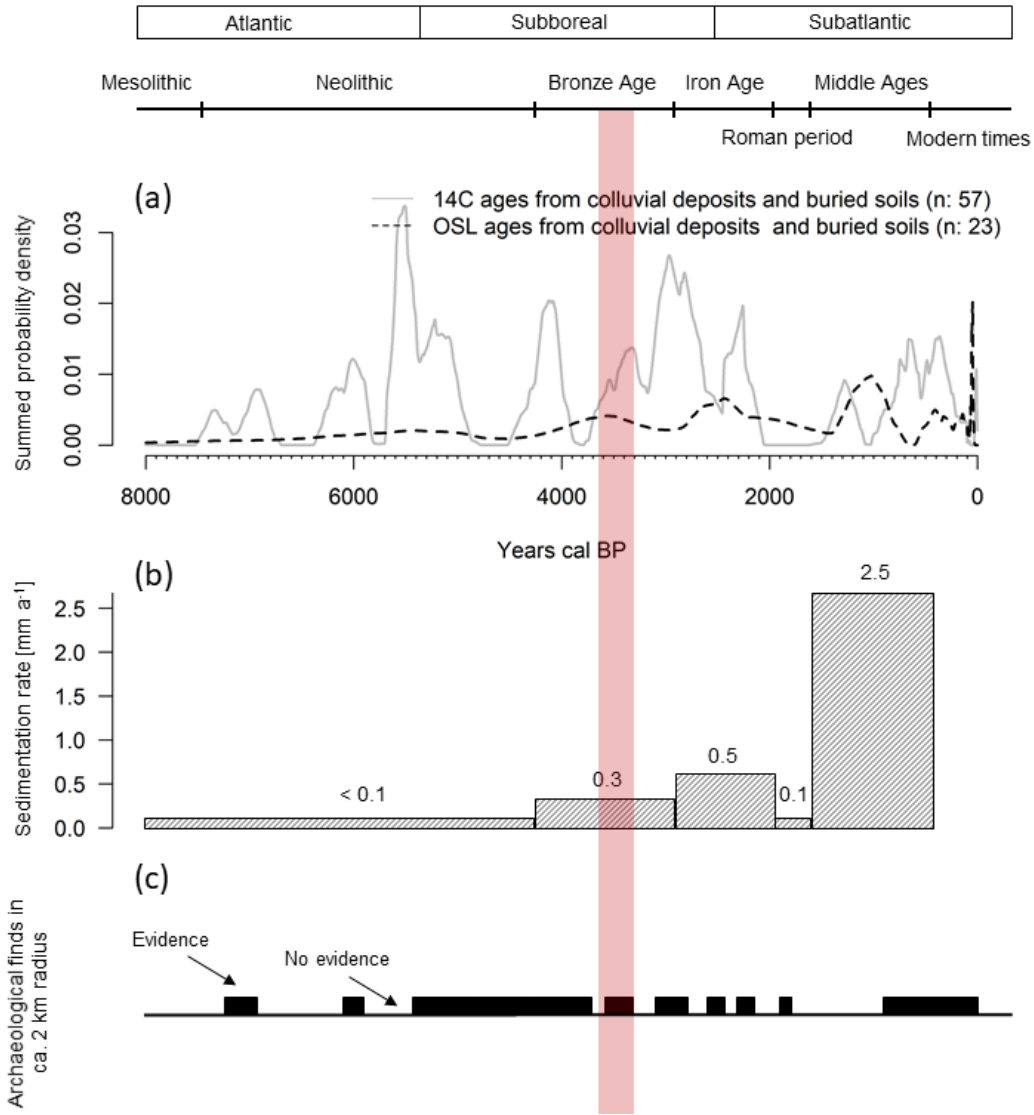

Figure 15: Summed probability density (SPD) curves from AMS-^{14}C and OSL ages (a); sedimentation rate by depositional ages (OSL) and related to archaeological periods (b); Evidence of archaeological finds within a radius of 2 km from the Anselfingen settlement site (c).

4.2 Onsite- and near-site Middle Bronze Age land use practices at the Anselfingen site

4.2.1 Use of fire, deforestation, and forest management

Prehistoric deforestation and landscape maintenance could have been accompanied by fire practices (Rösch, 2013), which led to the accumulation of charcoal and PAHs in respective colluvial horizons (Tan et al., 2020). The PAH sum of the examined profiles was slightly related to SOC (R^2: 0.30), indicating that SOM partially explains the PAH abundances, but other processes might have also contributed to their accumulation. In the north-western Alpine foreland, thermophilus deciduous vegetation comprising the species *Quercus, Alnus, Fraxinus, Ulmus* and *Corylus* were naturally growing before the beginning of anthropogenic disturbances. Since the forests were assumed to be rather dense before human arrival, large-scale deforestation with the help of fire was likely afterwards (Lechterbeck, 2001). In the 2Bwg/2Ahb and 2CBg horizons (ABR M) PAH distribution points to natural vegetation fires during the early Holocene with *Pinus*, *Betula* and *Poaceae* as the natural vegetation and possible fuel source. The higher concentrations of phenanthrene, compared to all other PAHs, in greater soil depths indicates contribution not only of *in-situ* combustion residue inputs but also of atmospherically transported fire condensates (Lehndorff and Schwark, 2004; Kappenberg et al., 2019). This is also indicated by the phenanthrene to phenanthrene plus the sum of methylated phenanthrenes ratio (Phe/Phe+ΣMP), which suggests a predominance of complete combustion processes with lower concentrations of methylated phenanthrenes and an excess of fire condensates. In the horizons related to the MBA (2Bwg/Ahb in ABR M; M6 in 2Bwig/Ahb in ABR W1; 2Apb in ABR SA2) we found indications for relatively low combustion temperatures as might have been the case for controlled burning of biomass to maintain land use areas. This is supported by the fluoranthene to fluoranthene plus pyrene ratio (Fl/Fl+Py) with values mostly > 0.5, indicating that the combustion of grass, wood and charcoal (Budzinski et al., 1997; Yunker et al., 2002) was predominant at the ABR site. Moreover, we would expect different combustion processes within the settlement area compared to its surroundings as indicated by several MBA fire places, fire pits and the secondary deposition of heat stones. Indeed, the suites of PAHs were more complete at the ABR M profile (onsite), which is located within the MBA settlement area, compared to the profiles ABR W1 and ABR SA2 (near-site). There, various combustion processes, such as cooking practices, heating of houses, and technical application (e.g. metal processing and burning of ceramics), and different fire temperatures may have contributed to the PAH pattern.

In relation to MBA fire-use practices, the determination of onsite and near-site charcoal assemblages provide information on natural and human-modified vegetation patterns and thus, on past land use practices such as deforestation, wood procurement, promotion of individual tree species and forest ecosystems (Jansen and Nelle, 2014; Schroedter et al., 2013). Moreover, different fuel sources can be estimated from the investigation of charcoal assemblages from fireplaces and fire pits (Höpfer et al., accepted). The generally very small size of charcoal fragments in the M horizons may be the consequence of erosional transport, while longer-distance aerial transport can be neglected due to fragment sizes > 1 mm (Whitlock and Larsen, 2002). Hence, an anthracological determination further than dicotyledons was not always achievable. However, the higher abundance of *Quercus* compared to *Fagus* in the buried soils and colluvial horizons related to the MBA (2Bwig/Ahb, M6 in ABR W2; 2Bw, M7 in ABR SA1) indicates a shift from thermophilous calciphilous forests consisting of sessile oak and beech, to a forest ecosystem dominated by oak. These findings are supported by charcoal assemblages from MBA fire pits at the settlement site of Anselfingen (Höpfer et al., accepted). The MBA fire pits contained about 85 % *Quercus* charcoal, while 98 % of the total charcoal spectra consisted of *Quercus* and *Fagus* (Rösch, 1996). Whether *Quercus* and *Fagus* were collected intentionally or unintentionally during the MBA cannot be conclusively assessed. However, the very good fuel quality of both taxa along with the occasionally observed insect holes within the charcoal fragments and the smaller branch diameters, strongly indicate an opportunistic collection of deadwoods following the "principle of least effort" (Höpfer et al., accepted). Naturally, oak mixed forests develop into beech forests, since oak is more light demanding, and therefore restricted to drier or alluvial sites and beeches are faster growing, even in shady areas (Mosandl and Abt, 2016). The potential occurrence of *Quercus* was probably limited to alluvial areas or drier sites close to the ABR site. Therefore, a human-induced promotion, for different purposes, of *Quercus* appears likely during the MBA, which is also suggested by the off-site palynological record from the pollen archives of Hartsee and Grassee (see sect. 4.3), where more or less pronounced microcharcoal peaks occur from ca. 1750-1600 BCE onwards. At Hartsee, the increase of *Quercus* and decrease of *Fagus* are accompanied by relative high values of micro-charcoal and several palynological indicators for human impact on the vegetation in the time span between ca. 1650 – 1150 BCE. The fern *Pteridium aquilinum*, typical in pasture and marginal areas, which is favoured by fire activities also shows a continuous curve for the same period. In Grassee those tendencies are less pronounced, therefore the two charcoal peaks at 1650 BCE and 1400 BCE are more difficult to interpret, but also seem related to subsequent increases in oak and anthropogenic indicators.

Particularly since the Final Neolithic, forest pastures in anthropogenically modified forest ecosystems were likely; these pastures likely resulted from the combined effects of wood procurement (construction, burning) and maintenance of areas for livestock husbandry (Rösch, 2013). Considering the weaker evidence for Neolithic settlements at the ABR site, such land use practices seem to have commenced at the beginning of the Bronze Age, especially considering the archaeological record of the MBA. Similar observations were made for pollen profiles from Lake Biber (close to an MBA settlement in Switzerland), where increased abundances of *Quercus* pollen were interpreted as the result of human promotion of oak species to maintain areas for livestock husbandry (e.g. acorn for pigs) as well as for timber and firewood procurement (Achour-Uster et al., 2001; Knaap and Leeuwen, 2001). The higher diversity of taxa in the upper part of ABR SA1 and ABR SA2 with increasing amounts of conifers and *Fagus,* indicates human impact until the modern period (Vrška et al., 2009).

During the MBA, the use of fire at the ABR site for landscape opening, maintenance and domestic purposes, associated with the combustion of grass as well as wood and charcoals is indicated by the PAH patterns in the corresponding colluvial horizons and by the local archaeological record. The forest ecosystems were anthropogenically modified and *Quercus* was promoted, which can be linked to land use practices, such as forest pastures (see sect. 4.2.3) and wood procurement. The offsite pollen data support the occurrence of oak dominated forest ecosystems on a regional scale (see sect. 4.3).

4.2.2 Arable farming

Past land use practices in the context of arable farming can be interpreted from different proxies preserved in archaeological remains and colluvial deposits. These proxies provide information on the presence and spatial distribution of potential arable land (open landscapes), the occurrence of different crop species and related archaeological and pedological structures such as storage facilities and plough marks (e.g. Gnepf-Horisberger and Hämmerle, 2001; Pietsch and Machado, 2014; Rösch et al., 2014a).

With this, phytoliths from buried soils and colluvial deposits are frequently used to decipher past arable farming (e.g. Meister et al., 2017; Weisskopf et al., 2014). At the ABR site, the high proportion of weathered phytoliths together with the absence of multicellular phytoliths are an indication of the poor preservation of the assemblages, likely due to a variety of depositional and post-depositional processes (Cabanes et al., 2009; Madella and Lancelotti, 2012). However, some general trends can be noted in the phytolith assemblages: Monocotyledonous

plants produce more phytoliths than dicotyledons in most cases (Piperno 2006), but the relatively higher abundance of monocotyledonous morphotypes in combination with the other proxies is likely the result of an open landscape in the area immediately surrounding of the ABR site. It is interesting to note that the lowest phytolith concentrations were found in the modern topsoils (Ap) and the highest concentrations in the buried horizons, as the phytolith concentrations usually decrease with soil depth (Meister et al. 2017). The phytolith assemblages from all samples were predominantly composed of phytoliths originating in the leaves and stems of monocotyledonous plants, which includes many of the regionally important crop species. As the result of harvesting activities, the inflorescences of these plants were likely removed from the agricultural field leading to a lower abundance of inflorescence phytoliths in these samples (Dietrich et al. 2019). Particularly in the buried plough horizons (2Apb) of the ABR SA2 profile, a relatively high concentrations of phytoliths with a simultaneous low abundances of inflorescence compartments indicate an arable field south of the MBA settlement that may have been quickly buried, thus leading to better phytolith preservation and higher concentrations in these horizons (Cabanes et al., 2009). Micromorphology also confirmed a buried plough horizon (2Apb) in profile ABR SA2. Very dusty clay coatings with embedded coarse material (clay-silt-sand coatings) can be related to soil cultivation (Macphail et al., 1990, Usai, 2001), while the occurrence of compacted large (sub)rounded peds may indicate ploughing with an ard (cf., Fig. 6 in Gebhardt 1999). The occurrence of a nearly rectangular area with inclined bands of alternating coarse and fine material can be caused by the disturbance of ards or ploughs as described by Lewis (2012); with this, the material is relocated in clods and inclined around 45° to one side. All found relocation features such as inclined bands, large partially rounded peds and the very dusty clay-sand coatings indicate mixing and slaking and can be interpreted as a result of cultivation (Macphail 1990). In addition, the frequently occurring charcoal fragments, coprolites and phytoliths can be related to cultivation. Based on the phytolith and micromorphological data, the agricultural activity at the ABR site is verified; however, the question of which staple crops were used by MBA farmers in the Hegau remains open.

This gap can be filled by the onsite archaeobotanical remains at the ABR site. These remains hold special value, as on- and near-site evidence on MBA crop production in the north-western Alpine foreland is still scarce (Rösch et al., 2014a,b; Rösch et al., 2015). The cereals typical for the Early and Middle Bronze Age like *Hordeum distichon/vulgare*, *Triticum dicoccum*, *Triticum monococcum*, *Triticum aestivum/turgidum*, *Triticum spelta* also occur at the ABR site. A similar spectrum of cereals was found in fire pits at the MBA settlement in Cham-Oberwil

(Switzerland) (Gnepf-Horisberger and Hämmerle, 2001), however these fire pits also contained pulses (e.g. broad bean), which were missing at the ABR site. From the observed cereal crop diversity, a sophisticated cropping system, with utilized different soil types, different sowing and harvesting times and a variety of food processing techniques can be assumed. In the study area, emmer is grown in modern times preferentially during the summer periods, while spelt, which is resistant to low temperatures, is typically sown in winter. Einkorn and barley are known to be viable as both summer and winter crops. Einkorn, emmer and spelt can easily be stored, all of them require further time-consuming processing (e.g. husking) before consumption in contrast to free-threshing wheat, which however is more vulnerable to storage infestation. The MBA crop diversity allows a distribution of the agricultural activities throughout the year, leads to a potentially larger territory being available for crop growing and improves food security. However, the cultivation of various cereals crops requires knowledge and capacities for post-harvest processing of the cereal crops (e.g. drying, roasting, husking) and storing, which are both indicated by the archaeological record. The secondary deposition of heat stones at the ABR site can also be related to MBA food processing. Even though the function of the heat stones is widely discussed, with interpretations including technical applications such as stone breweries and metal processing (Beigel, 2019; Honeck, 2009), they are most commonly considered to be cooking pits for the roasting of cereals and other agrarian products (Lindemann, 2008). Furthermore, post-holes from ten very small constructions with square or short-rectangular shapes at the ABR site are most likely remnants from storage buildings. There is a broad consensus that such constructions are related to arable farming and represent stilted pantries for the storage of food, especially of cereals (Gnepf-Horisberger and Hämmerle, 2001). In general, stilted pantries are frequently observed from MBA sites in the north-western Alpine foreland, whereas similar structures are significantly in excavations from neighboring regions, such as Bavaria (Höpfer et al., accepted). Statements on the importance of individual cereal species cannot yet be made, since the number of records is still too low and the hulled wheat species with their very robust glumes are often overrepresented in archaeobotanical records. Leguminous (lens, broad bean and pea) as well as oil and fiber (flax and poppy) crops were also important elements of the Early and Middle Bronze Age agricultural economy of the Alpine foreland (Stika and Heiss 2013), but they are rarely preserved in charred form and are therefore mostly underrepresented at sites with aerobic soil conditions (Rösch et al., 2014a; Rösch et al., 2015). During the Middle Bronze Age sporadic finds of millet are also known from the study area but did not occur in the record of botanical macro remains of the ABR site. However, the fact that all those crops are missing from the

archaeobotanical assemblages of the ABR site cannot be interpreted as their definitive absence in the region's MBA economy. Nevertheless, the occurrence of open landscapes and an MBA arable field, which was cultivated for cereal crop production, are verified, and are also supported by the identification of the common MBA crop species. Furthermore, post-harvest processing and storage facilities for cereal crops appeared to be an integral part of the MBA agriculture.

4.2.3 Livestock husbandry

The reconstruction of livestock husbandry from sedimentary archives is commonly achieved through the analysis of urease activity or faecal biomarker resulting from past exposure to urea or animal faeces (e.g. Chernysheva et al., 2015; Prost et al., 2017). Both proxies are a suitable marker for the past as they are resistant against weathering (urease-organo-mineral complexes and aromatic molecule structure) and rather immobile in the soil environment and therefore persist in soils over millennia (Bull et al., 1999; Burns et al., 2013; Skujiņs and McLaren, 1968). The comparison of these proxies with the zooarchaeological record of animal bones derived from archaeological features could provide detailed information about past livestock farming practices.

Eutrophication always leads to an input of urea into the soil, and urea may originate from past and recent animal faeces or from the degradation of nucleic acids as part of the soil necromass. However, in greater soil depths, lower levels of currently active microorganisms and urease enzyme activity are expected. Therefore, a higher urease to microbial biomass C quotient in greater soil depths indicates formerly eutrophicated areas that could be associated with areas of livestock husbandry, such as pastures or livestock shelters. In contrast to other studies, increased levels of urease enzyme activities in soils of the ABR site cannot be solely explained by a relationship to SOC or clay (Roscoe et al., 2000; Taylor et al., 2002). Particularly below 130 ± 20 cm, other factors must have been responsible for increased urease activities. The past anthropogenic input of urea in relation to livestock husbandry or manuring has been shown in several archaeological studies (e.g. Borisov and Peters, 2017; Chernysheva et al., 2015). Hence, elevated urease/C_{mic} ratios in soil horizons, associated with the MBA land surface or concurrent colluvial horizons, can be interpreted as an anthropogenic input of urea due to land use activities at the ABR site. However, no spatial differences in urease/C_{mic} ratios could be observed that would indicate a separation of different land use practices and intensities. Only the lower part of the 2Bw horizon in profile ABR SA1 had considerably higher values of

urease/$C_{mic,}$ ratio, suggesting formerly eutrophicated areas and high urease levels in the past. Although the OSL age from the 2Bw horizon showed a last bleaching of mineral grains during the Roman period (300 ± 200 CE), soil tillage prior to the Roman period is likely for two reasons: First at ABR SA1, the first phase of sedimentation is dated to the Early Medieval period (800 ± 100 CE, M7), which means the *in-situ* land surface could have been used during the MBA. Second, ABR SA1 is located less than 40 m north of ABR SA2, which has a buried plough horizon (2Apb) that is dated to the MBA and indicates related land use activities. At the ABR site, the increased urease/C_{mic} ratios in MBA soil horizons indicate past input of urea into the soils, which could be associated with land use practices such as livestock husbandry (on fallow land and in forests) and the application of manure to arable fields. However, there is weak evidence of intentional manure application during MBA, and agricultural practices such as livestock farming on long-standing fallow land have more likely contributed to increased urea concentrations (Tserendorj et al., accepted). Whether urea originated from omnivorous or herbivorous livestock cannot be assessed by the analysis of urease enzyme activity.

The analysis of faecal biomarker enables a differentiation between herbivorous and omnivorous animal faeces, which enter the soil via the faeces of past livestock. In previous studies steroid analyses helped to identify organic manuring in Neolithic soil relicts (Lauer et al., 2014) and in soils surrounding a Roman settlement (Simpson et al., 1999). Hence, the steroid composition of human-influenced soil horizons (buried topsoils, colluvial horizons) should be different from the adjacent subsoils, if such land use was practiced. In the northern surrounding area of the ABR site (ABR W1), 5ß-stanols (e.g. coprostanol, epicoprostanol) were enriched in the M6 horizon and support the interpretation of the MBA deposition of faeces, as indicated by higher levels of past urease enzyme activities. These 5ß-stanols originate mainly from the microbial reduction of Δ^5-sterols during omnivorous digestion processes and are related to pig or human faeces in the context of past land use (Birk et al., 2011). The higher levels of 5ß-stanols are further supported by the coprostanol/(coprostanol+epi-5ß-stigmastanol)*100 ratio, which was introduced by Leeming et al. (1997) to differentiate between herbivorous and omnivorous faeces. In profile ABR W1, the ratio clearly indicates an input of steroids from omnivorous digestion processes (> 73 %). With increasing soil depth, cholestanone and cholesterol were most abundant at both profiles. Cholesterol is the dominating Δ^5-sterol occurring in nearly all eukaryotic cells (Mouritsen and Zuckermann, 2004), while cholestanone is produced by microbial transformation from its sterol precursors. We interpret the higher abundance of source-unspecific sterols and lipids formed during

microbial metabolization as the given background composition of steroids of the soil environment with low human influence. In profile ABR SA1, 5ß-stanols were not as dominant as in profile ABR W1, indicating a reduced input of omnivorous faeces. Nevertheless, faecal input by wildlife species, organic manuring and/or occasional pasture on fallow land could have contributed to the occurrence of 5ß-stanols. The latter may have also contributed to increased levels of epi-5ß-stigmastanol, which mainly originates from herbivorous digestion processes (Derrien et al., 2011). This is in line with the coprostanol/(coprostanol+epi-5ß-stigmastanol)*100 ratio, pointing to mainly faecal input by herbivores (< 38 %) at the ABR SA1 profile. There, phytosterols, such as ß-sitosterol and stigmastanol, were also more abundant. In the buried subsoil of ABR SA1 (2Bw), source-unspecific steroids, e.g. cholestanone, were dominating the steroidal assemblage, indicating lower anthropogenic influence. The faecal biomarkers show past input of animal faeces in the area surrounding the MBA settlement, which can be associated with the occurrence of omnivorous and herbivorous livestock. North of the settlement site, we identified a dominance of 5ß-stanols, which, together with the results from the charcoal determination, suggests a forest ecosystem dominated by oaks, where mainly pig farming was practiced (see sect. 4.2.1). Higher levels of plant lipids and herbivorous biomarker in the area south of the settlement site supports the presence of arable fields, which could have also been subject to an input of animal faeces during fallow practices or intentional manuring.

Information on different animal species, which were part of the farming practices at the ABR site, can be provided by the determination of animal bones, which were deposited at the MBA settlement. With 79 % of the unidentified animal bones from various archaeological pit fillings, the degree of fragmentation is high, which is further indicated by post-depositional bone damage from insects and roots. Acidic weathering of animal bones can be mostly ruled out at the ABR site since the soil milieu is neutral. Hochuli et al. (2001) reported a similar degree of fragmentation of animal bones at an MBA settlement in Switzerland. The taxonomic determination of animal bones, with four to five domestic and five wild species at the ABR site, supports the results of the urease enzymatic activity and faecal biomarker investigations insofar as domestication and livestock husbandry were important at the ABR site during the MBA. The dominance of sheep/goat, pig and cattle species are also observed at MBA settlements sites in southwest Germany (Kokabi, 1990; Köninger, 2006; Stephan, 2016). Nevertheless, the wide range of wildlife species and their share in the total number and weight illustrate that hunting was still important during the MBA. The high percentage of sheep/goat and cattle bones partially contradicts the low evidence of herbivorous faeces by steroid

analysis. However, it is likely that the colluvial profiles were not always congruent with MBA grazing areas. Areas within the MBA settlement and in the east, where the Hepbach river might have formed floodplain forests, could have been suitable for grazing. However, the abundance of pig bone is consistent with higher concentrations of 5ß-stanols especially in the north of the ABR site (ABR W1). Combining the results from the charcoal and animal bone determination, urease enzyme activity and faecal biomarker, a spatial distribution of livestock practices can be observed. North of the MBA settlement, the occurrence of oak dominated forest ecosystems and the high concentrations of 5ß-stanols are in line with a considerable amount of pig bone from MBA pit fillings and indicate a forest pasture mainly for pig farming and wood procurement. In the south of the ABR site, the higher concentrations of phytoliths with minor amounts of grass phytoliths derived from the floral parts, as well as the occurrence of an MBA plough horizon and the increased input of herbivorous faeces indicate an open landscape for crop cultivation (arable fields) and livestock husbandry on fallow land and/or manuring with animal faeces.

4.2.4 Metal processing

The distribution of heavy metals in soils is influenced by the substrate, pH-value, content of lime and SOC, sedimentation processes and past and modern anthropogenic impact (Young, 2013). These factors must be considered when assessing the natural and anthropogenic accumulations of heavy metals (Henkner et al., 2018b). Cu and Zn are major elements of bronze that gained importance during the Metal Ages but had to be traded over long distances due to their limited natural occurrences in the area (Jennings, 2017; Knopf, 2017). Cr and Ni, as secondary components, can also be associated with the production of bronze. Pb has been used metallurgically since the Roman period, while Cd and As are tracers for more recent land use (around 1900 CE) (Smolders and Mertens, 2013; Völkel, 2003).

The percolation of heavy metals through the soil can be neglected in all profiles of the ABR site since the pH is always > 7. The variations in $CaCO_3$ mostly explain the heavy metals patterns for the sediments of the Younger Juranagelfuh and Würm glaciation, but not for the basaltic sediments of the Hohenhewen volcano. The natural variation of heavy metals, as indicated by the range between the 25th and 75th quartile ± 1.5 Interquartile range, is supported by the analysis of geological background values by the geological state office of Baden-Württemberg (LGRB, 2020). However, a few positive outliers were identified for the different soil substrates. At ABR WA2 and ABR S30, the outliers cannot be further assessed for

prehistoric human-land interactions due to lacking age determinations, while the maximum tin values at ABR SA1 are detected at the colluvial horizon M7, dated to the Roman period. Based on heavy metal contents, which are mostly in the range of natural variation, and their correlation with CaCO3, an intensive MBA metal processing, which also affects the adjacent sediments, cannot be deduced at the ABR site. The deposited copper ingot, most likely from the Eastern Alps (Lutz and Pernicka, 2013), however, indicates that metals were traded over long distances and that the processing and maintaining of tools may have been carried out at the ABR site, but with no detectable effect of heavy metals in the investigated buried and colluvial horizons.

4.3 Offsite vegetation signals in relation to land use practices at the ABR site

The two new pollen profiles (Fig. 13 and 14) show close similarities regarding the Bronze Age (2200-800 BCE) human-land interactions in the Hegau. At Grassee and Hartsee, human impact is very weak between 2000 and 1800 BCE. At Grassee, a short period of human impact on the vegetation can be noticed in the 18th century BCE, which subsequently decreases between 1600-1500 BCE. At Hartsee, human influence was high between the 17th and 15th century BCE without any intermediate decrease. Both profiles show a very strong human influence between 1500-1400 BCE, which after that slightly decreases. At Hartsee, human influence is clearly pronounced between 1000 and 800 BCE, whereas this influence is absent in the Grassee pollen profile.

The NAP percentages at Grassee and Hartsee, which are a robust indication of human-land interaction, are analogous to other profiles near Lake Constance (Rösch et al., accepted). Especially during the MBA, anthropogenic deforestation appears to be rather similar in the Hegau. In Oberschwaben, the Allgäu (southern Germany) and in the Black Forest (south-west Germany) deforestation is generally weaker, while at Lake Aalkisten in the Kraichgau (south-west Germany) a pronounced deforestation is observed in the EBA and LBA (Rösch et al., accepted).

The comparison of the pollen archives of Grassee and Hartsee with the local records of the ABR site helps to assess the supraregional character of onsite and near-site land use and vegetation changes at MBA settlements in the north-western Alpine foreland. In both profiles, the percentage of NAP increases from the EBA to the MBA with a distinct peak between 1500 and 1400 BCE. This peak is accompanied by low percentages of *Betula*, *Corylus* and *Fagus*, suggesting that human-land interactions gradually shifted from the lakeshores of Lake

Constance (EBA) to areas further inland (MBA). This cannot be interpreted as an abrupt shift in the land use pattern, but rather a refined form of agropastoralism, which had its roots in the EBA and continued throughout the MBA in the Hegau. This is also supported by the offsite pollen record with several micro-charcoal peaks, which indicate palaeo-fire activities shaping the land cover since 2450 BCE, as well as the high concentrations of phytoliths in MBA soil horizons as the result of advanced landscape opening related to local agricultural practices. The pollen curves of *Quercus* and *Fagus* clearly alternate corresponding to increasing and decreasing human occupation. Considering the different input data between pollen and charcoal records, with respect to their catchment area, the pollen spectrum comprises the regional vegetation record of human occupation and adjacent successional phases, while the anthracological data indicate local vegetation patterns (colluvial deposits) and human decision-making (fuel procurement). The human impact on vegetation, as recorded in those palaeoecological archives, seems to clearly promote the increase of *Quercus* in the MBA landscape of Hegau. This is in line with the charcoal record of MBA colluvial deposits and fireplaces at the ABR site, which exhibited a strong dominances of *Quercus*. In the pollen diagram of Hartsee the *Fagus* usually decreases after the occurrence of microcharcoal peaks and is then followed by an increase in *Quercus* and pollen indicators of agriculture (*Triticum*-type) and pasture (*Plantago lanceolata*). Forest pastures for pig farming are indicated at the ABR site, when considering the high occurrence of *Quercus* in the colluvial deposits and MBA fireplaces as well as the identification of 5ß-stanols and pig bone (see sect.s 4.2.1, 4.2.3). Agricultural indicators are present in both the onsite and near-site colluvial and archaeological archives at the ABR site and in the offsite pollen records. These indicators, as well as indicators from another MBA settlement close to the Hartsee profile (Hald, 2016), clearly underline the regional character of the identified land use practices during the MBA.

5 Conclusion

The multi-proxy analysis of archaeological features (onsite), colluvial deposits (near-site), and peat bogs (offsite) of the Middle Bronze Age in the Hegau (south-west Germany) shows how helpful such multi-proxy approaches can be for a refined understanding of past human-land interactions. (i) From the archaeopedological reconstruction of phases of colluvial deposition and onsite and near-site land use practices, we can infer sophisticated land use practices at the Middle Bronze Age settlement site in Anselfingen, which undoubtedly marked the beginning of major colluvial deposition. The land use practices promoted *Quercus* at the expense of

Fagus, the arable farming relied on cultivation of five cereal crops and involved ploughing and the livestock husbandry utilized pasture on fallow land and for pig farming forest pasture and also hunting was part of the MBA economy. (ii) The spatial patterns of the onsite and near-site land use practices revealed that a forest management (incl. pig farming) mostly occurred in the surrounding area north of the ABR settlement site, while arable farming was practiced in the south of the MBA settlement. Based on the differentiation of combustion processes between the settlement and the close by land use areas, we conclude a wide range of fire application such as domestic fires for cooking, technical applications and ritual practices as well as fires to open and maintain the land use areas, that differed on the spatial scale. (iii) From the comparison of onsite and near-site vegetation patterns from colluvial deposits and archaeological remains and the offsite vegetation signals from two pollen profiles, we conclude similar patterns of human-induced vegetation change, which characterized the anthropogenic impact in the Hegau on a local and regional scale. The pollen records show that during the Early and Middle Bronze Age fire played a role in shaping the landscape and that also on regional scale anthropogenic activities favoured *Quercus* dominated forest ecosystems.

In summary, the interdisciplinary approach between soil science, archaeology, archaeobotany and archaeozoology allowed in-depth insights into the Middle Bronze Age subsistence economy in the Hegau. From the similar patterns of human-induced vegetation change and land use on a local and regional scale, one can infer a characteristic appearance of landscapes in the north-western Alpine foreland during the Middle Bronze Age. The study also supports the assumption that the Middle Bronze Age in the north-western Alpine foreland was a period of mainly spatial changes at a regional scale with a shift of settlements from the lakeshore to sites further inland, which was accompanied by corresponding landscape transformations.

Authors Contribution

PK, TK and TS acquired the funding to carry out the study. SaS, BH, TK, TS and PK conceptualized the research experiment and the hypothesis. SaS carried out the soil scientific field work and sampling, and most of the data collection, including the analysis of urease activity, microbial biomass carbon and faecal biomarker. JL and MF performed the OSL dating, BH contributed with data of the local archaeological record, JM and KW analyzed the phytolith assemblages, KD performed the anthracological determination of charcoals, EF investigated the charred archaeobotanical remains, HR analyzed the polycyclic aromatic hydrocarbons, JZ performed the zooarchaeological investigations, MR and EM contributed

with the pollen analysis. SaS and PK prepared the manuscript and all authors contributed to the interpretation of the results, to the discussion and the manuscript in general.

Competing interests

The authors declare that they have no conflict of interest.

Data availability

All data used in the analysis of colluvial deposits and the tables and figures are available at https://datadryad.org/stash/share/hVuLgYtHXROjtUDhBg9BRgVQ3H4pfL1INAXwzjTnT5E

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Manuscript III

Mittelbronzezeitliche Siedlungsfunde aus Engen-Anselfingen (Lkr. Konstanz, Baden-Württemberg): erste Einblicke in Struktur und Organisation der Siedlung

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Zusammenfassung

Die laufende Auswertung einer der in Baden-Württemberg am großflächigsten untersuchten mittelbronzezeitlichen Siedlungen eröffnet Einblicke in das Siedlungswesen dieser Zeit. Erst seit den letzten zwei bis drei Jahrzehnten wurden auch in Baden-Württemberg und in der Schweiz vermehrt Siedlungen aus der Mitte des 2. Jahrtausends v. u. Z. entdeckt. Zuvor hatten die in größerer Anzahl bekannten Bestattungsplätze der Hügelgräberkultur weitgehend isoliert gestanden. Anhand einer kursorischen Vorstellung der wichtigsten Anselfinger Befunde werden hier ausgewählte, sich abzeichnende Verbindungen wie auch Gegensätze zu umliegenden Regionen und vorausgehenden bzw. nachfolgenden Zeitabschnitten angesprochen, während die Ergebnisse einer anthrakologisch-botanischen Untersuchung von Holzkohlen aus mehreren Brand- bzw. Gargruben in Bezug zu bisherigen Proxydaten zur bronzezeitlichen Landnutzung gesetzt werden.

Schlüsselwörter: *Südwestdeutschland, Hegau, Mittelbronzezeit, Siedlung, Handwerk und soziale Aktivitäten, Brandgruben mit Hitzesteinen, Landnutzung und Vegetationsgeschichte*

Abstract

The ongoing evaluation of one of the most extensively investigated settlements of the Middle Bronze Age in Baden-Württemberg provides insights into the settlement system of this period. It is only since the last two or three decades that settlements from the middle of the second millennium BCE have been found more frequently in Baden-Württemberg and in Switzerland. Previously, the more numerous burial sites of the Tumulus Culture had seemed mostly isolated. On the basis of a cursory presentation of the most important structures from Anselfingen, some emerging connections as well as contrasts to surrounding regions and preceding or following periods are pointed out, while the results of an anthracological-botanical investigation of charcoals from several fire pits are put in context with existing proxy data on Bronze Age land use.

Keywords: *Southwest Germany, Hegau, Middle Bronze Age, settlement, craftmanship and social activities, fire pits with heated stones, land use and vegetation history*

1 Einleitung

Die Untersuchung der mittelbronzezeitlichen Siedlung von Engen-Anselfingen im Landkreis Konstanz erbrachte zahlreiche architektonische Befunde und umfangreiches Fundmaterial, die den Kenntnisstand für jenen in Baden-Württemberg vor allem durch Grabfunde geprägten Zeitabschnitt wesentlich bereichern. Seit 2008 fanden dort Rettungsgrabungen durch das Landesamt für Denkmalpflege Baden-Württemberg und die Kreisarchäologie Konstanz statt, seit 2017 werden die freigelegten bronzezeitlichen Strukturen im Rahmen eines Dissertationsvorhabens an der Universität Tübingen ausgewertet. Gefäßdeponierungen, verschiedene Ofen-, Herd- und Feuerstellen sowie weitere Strukturen lassen neben den Baubefunden und dem Fundmaterial ein vielfältiges Siedlungsgeschehen erkennen. Im vorliegenden Beitrag werden die bisherigen Grabungsergebnisse zusammengefasst und erste, auf der laufenden Auswertung der zahlreichen Funde und Befunde beruhende Einblicke in die Organisation der Siedlung gegeben. Darüber hinaus wird eine umfangreiche anthrakologische Untersuchung von Brennhölzern aus mittelbronze- und urnenfelderzeitlichen Brandgruben mit Hitzesteinen vorgestellt. Die Diskussion der vertretenen Baumarten erlaubt es, die Siedlung nicht zuletzt auch in Bezug zu ihrer Umwelt zu sehen.

1.1 Naturraum und Forschungsregion Hegau

Der Hegau ist ein westlich an den Bodensee angrenzender Teil des voralpinen Hügel- und Moorlandes (Abb. 1). Er umfasst Teile der Juraschichtstufe des Südwestdeutschen Schichtstufenlandes. Daran schließt sich die Jungmoränenlandschaft des zentralen Hegaus an, die heute intensiv ackerbaulich genutzt wird. Deren Ränder prägen häufig verfüllte Vulkanschlote des tertiären Vulkanismus, die kegelförmige Vollformen ausbilden (Seifriz 1968, 152–155). Im Osten gliedern langgestreckte Molassehöhenzüge die Landschaft, zwischen denen sich die Täler zum Bodensee hin in ausgedehnte Uferniederungen verbreitern

(Meynen/Schmithüsen 1953–1962. Schreiner 1968, 5–39; 2008). In diesem Teil des Hegaus überwiegt heute Wald- und Grünlandnutzung (Kuner 1968, 178–181).

Seit Langem ist der Hegau als eine der fundreichsten Altsiedellandschaften Baden-Württembergs bekannt, was nicht zuletzt auch für die Bronzezeit gilt (Hald/Kramer 2011, 78–109). Aus der Frühbronzezeit stammen einige überregional bekannte Funde, darunter die älter-frühbronzezeitlichen Grabfunde von der Singener Nordstadtterrasse (Krause 1988), denen seit neuestem eine zweite, wenn auch kleinere Nekropole in Singen-Bohlingen an die Seite zu stellen ist (Hald/Kitzberger 2018a), verschiedene Randleistenbeil-Horte (Kienlin 2006) und natürlich einige hervorragend erhaltene Seeufersiedlungen wie Bodman „Schachen“ (Köninger 2006). Landeinwärts sind neben den genannten Grab-, Hort- und Einzelfunden bis heute jedoch kaum frühbronzezeitliche Siedlungsplätze nachgewiesen (Höpfer 2014). An den Übergang von später Früh- zu früher Mittelbronzezeit wird vor allem eine Reihe von Höhenfundstellen – mutmaßlich Höhensiedlungen – datiert (Köninger/Schöbel 2010). Eine massive Fundstellenverdichtung lässt sich im Westhegau erst für die mittlere Bronzezeit feststellen. Sie ist mittlerweile mit mehreren Dutzend Mineralbodensiedlungen belegt, die vor allem in den letzten drei Jahrzehnten im Zuge intensiver Bautätigkeit entdeckt wurden (Dieckmann 1997. Hald/Kramer 2011 bes. 78–109. Höpfer u.a. 2017b). Besonders deren jüngeren Abschnitt – d.h. der Stufe Reinecke C nach etwa 1500 v. u. Z. – lassen sich auch regelmäßig Bestattungsplätze zuordnen, unter anderem in Singen (Brestrich 1998), Radolfzell-Güttingen (Hald 2010) oder Hilzingen (Hald 2003b). Aus der spätbronzezeitlichen Urnenfelderkultur sind neben etlichen Bestattungsplätzen – am bekanntesten wieder die große Nekropole in der Singener Nordstadt (Brestrich 1998) – zahlreiche Land- und Ufer-, aber auch weiterhin Höhensiedlungen wie der „Hals“ bei Bodman (Hopert u.a. 1998) bezeugt.

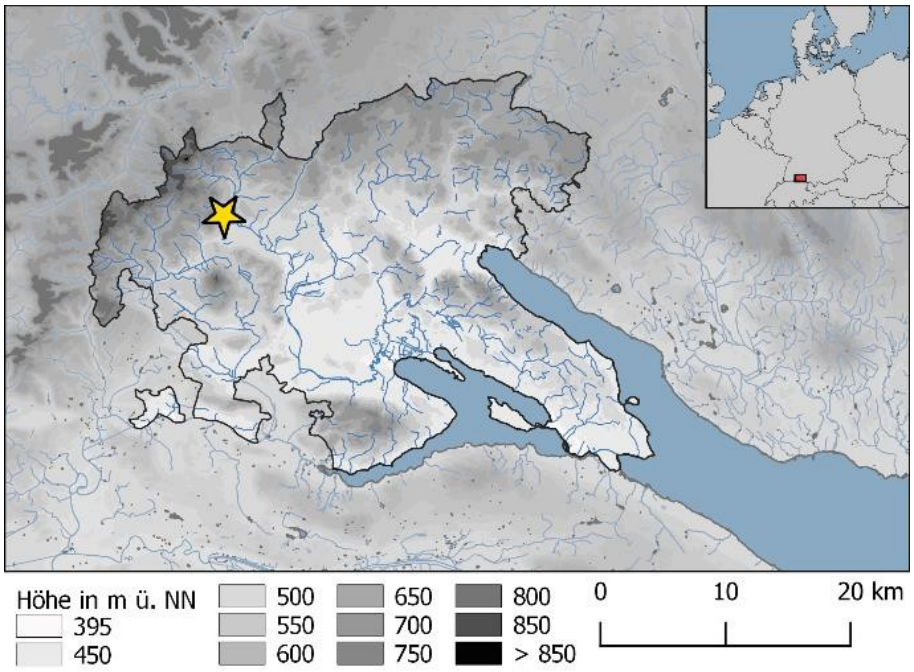

Abb. 1: Lage der Fundstelle Engen-Anselfingen „Breite“ im westlichen Hegau. Hervorgehoben der Lkr. Konstanz.

1.2 Lage und Forschungsgeschichte der Fundstelle

Die hier besprochene Fundstelle liegt am Osthang des Hohenhewen, dem nordwestlichsten Basalt-Schlot des tertiären Hegauvulkanismus. Er stellt den Westrand der Großen Hegauniederung (Singener Niederung) dar, einer alten Schmelzwasserrinne, die heute in den Bodensee entwässert (Schreiner 1997; 2008). Seit Beginn des 20. Jahrhunderts wird dort auf einer bis zu 25m über der Talaue gelegenen Schotterterrasse würmeiszeitliches Material abgebaut (Abb. 2). Wiederholt wurden dabei Funde aus verschiedenen vor- und frühgeschichtlichen Epochen bekannt, die vor allem auf eine bedeutende Siedlung der jüngeren Latènezeit hinwiesen (Kellner-Depner 2017). Seit 2008 wurden großflächige Erweiterungen der Abbaufläche in jährlichen Rettungsgrabungen durch das Landesamt für Denkmalpflege Baden-Württemberg und die Kreisarchäologie Konstanz begleitet. Auf einer Fläche von gut 8 Hektar konnten Spuren einer regelmäßigen und vielseitigen Geländenutzung seit dem Jungneolithikum bis zur römischen Kaiserzeit dokumentiert werden (Ehrle/Hald/Höpfer 2018). Unerwartet wurden hierbei auch die Überreste einer mittelbronzezeitlichen Siedlung

aufgedeckt, bei denen es sich neben der nahegelegenen Fundstelle „Bei der Mauer“ in Mühlhausen-Ehingen (Dieckmann 1997, 67–71; 1998. Zuletzt Hald 2015) inzwischen um die Fundstellen mit der größten Ausdehnung dieser Zeit in Baden-Württemberg handelt.



Abb. 2: Luftbild der Grabungsfläche 2016 im Vorfeld des Kiesabbaus, Blick nach Südost. Die früheren Grabungsflächen sind bereits weitgehend abgebaut

2 Gesamtstruktur und zeitliche Tiefe der bronzezeitlichen Besiedlung

Überwiegend traten diese Befunde am Nordrand einer mit glazifluvialem Lehm gefüllten Senke zutage, die sich zwischen zwei vom Hohenhewen aus jeweils ungefähr nach Nordost verlaufenden Schotterwällen erstreckte (Abb. 3). Auf dem nördlich angrenzenden, rund 2–3 m höheren Schotterwall, bei dem der moderne Pflughorizont bereits in den anstehenden Schotter eingriff, konnten zwar vereinzelt bronzezeitliche Funde nachgewiesen werden, Baubefunde scheinen aber weitgehend zu fehlen. Aber auch weiter im Norden, wo wiederum eine Lehmdecke über dem Schotterrelief und teils mehrere Meter mächtige Kolluvien über dem Befundniveau liegen, traten nur sehr vereinzelt Strukturen dieser Zeitstellung auf, sodass die Ausdehnung der hier besprochenen Nutzungsphase nach Norden hin vermutlich trotz der schlechten Erhaltung in den Schotterflächen insgesamt recht gut erfasst wurde. Nach Süden ist

sie hingegen erst vage abzuschätzen, da sie dort zunehmend von jüngeren Besiedlungs- und Nutzungsphasen überlagert wird, was bei der Einordnung einzelner Strukturen zur Vorsicht mahnt. Südöstlich der mittelbronzezeitlichen Befundkonzentration wurde in der Lehmsenke eine rund acht Meter breite und 40 Meter lange Steinpackung freigelegt. Ihre Aufschüttung datiert zwar wahrscheinlich in die vorrömische Eisenzeit, Grau-Bleichung und Ausfällungen von Mangen- und Eisenoxiden im tonigen Untergrund in diesem Bereich ließen aber annehmen, dass mit den Steinen vermutlich eine Wegführung durch das zumindest periodisch durchfeuchtete Gelände gangbar gemacht bzw. gehalten wurde (Bräuning u.a. 2014). Es ist also davon auszugehen, dass sich diese etwas tiefer gelegenen Teile der Lehmsenke auch in der Mittelbronzezeit als Baugrund weniger eigneten, weil sich Niederschläge und Hangwasser rasch an der Oberfläche sammelten. So lässt sich vorläufig eine bebaute Siedlungsfläche von rund einem Hektar rekonstruieren, wobei aus oben genannten Gründen eine größere Ausdehnung nicht ausgeschlossen werden kann und auch eine Zeitgleichheit aller darin gefassten Strukturen nicht zwingend vorauszusetzen ist. Im Gegensatz zur Mittelbronzezeit konnte für die Urnenfelderzeit in Anselfingen bisher keinerlei Bebauung nachgewiesen werden. Es liegen aus dieser Zeit lediglich einige Sonderbefunde wie Brandgruben mit Hitzesteinen, Brandgräber und Gruben mit vereinzelten menschlichen Skelettresten sowie Keramik- und Tierknochendeponierungen vor, die sich mehrheitlich im Süden der Grabungsfläche verstreut befanden (Ehrle/Hald/Höpfer 2018).

Insgesamt können die mittelbronzezeitlichen Funde gut dem Spektrum der Siedlungskeramik dieses Zeitabschnitts (z.B. Bauer u.a. 1992. Hochuli 1994. Fischer 1997. Krumland 1998. Rigert u. a. 2001, 81–86. Honig 2008) zugeordnet werden, auch wenn die Fundbearbeitung zum gegenwärtigen Zeitpunkt noch nicht abgeschlossen ist. Merkmale, die zwingend der ausgehenden Frühbronzezeit (Bz A2 nach Reinecke 1924) oder dem zur Mittelbronzezeit überleitenden Übergangshorizont Bz A2/B1 (Hundt 1957. Krumland 1998, 12–15)

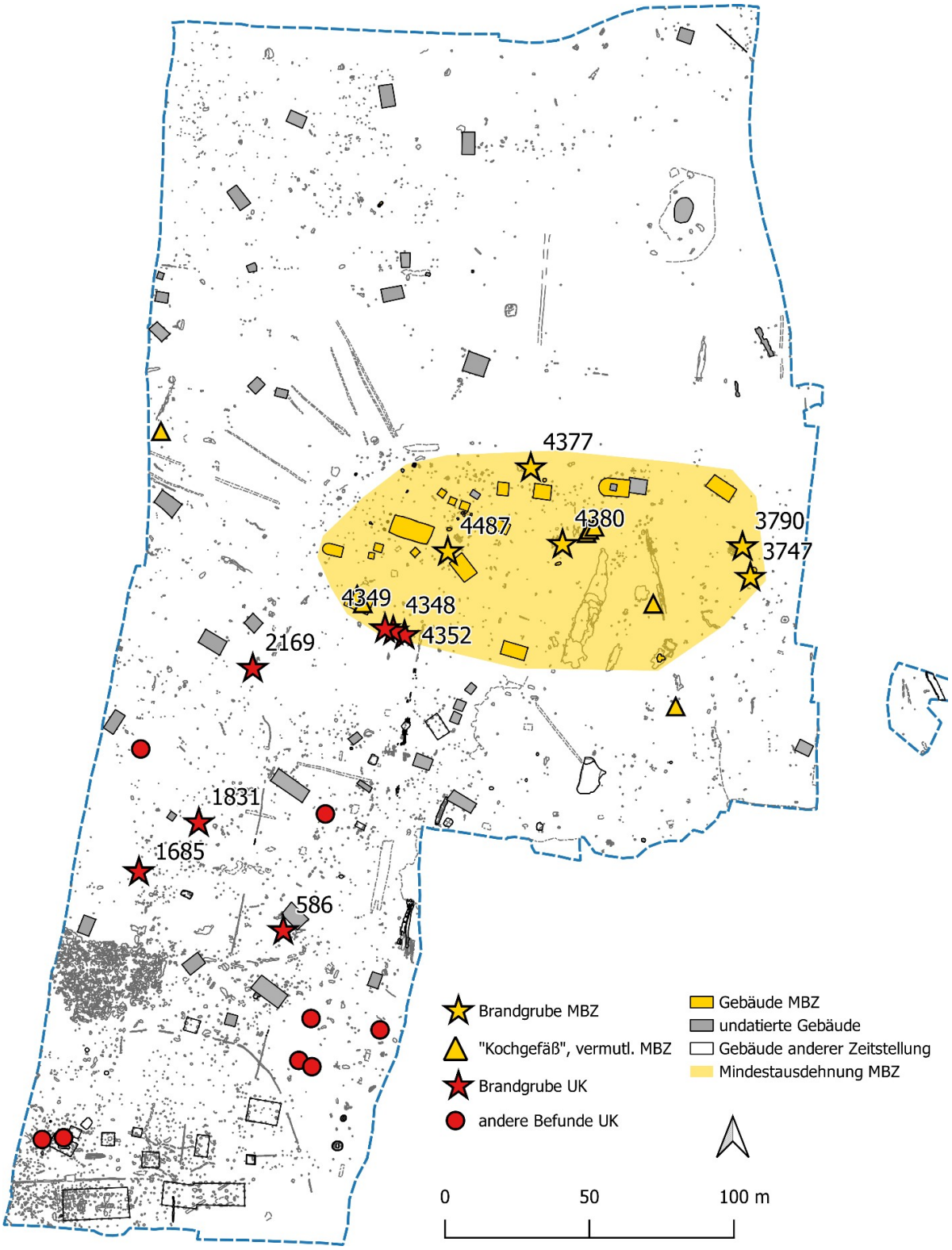

Abb. 3: Engen-Anselfingen „Breite“, vorläufiger Gesamtplan mit Hervorhebung der nach bisherigem Auswertungsstand in die Mittelbronzezeit datierbaren (Gebäude-) Strukturen und Nummerierung der im Text näher angesprochenen Einzelbefunde

zuzuschreiben wären, begegnen nicht. Ein Beginn der Besiedlung noch vor dem 16. Jahrhundert v. u. Z. gibt sich demnach nicht zu erkennen. Vielmehr liegen Merkmale vor, die eher der jüngeren Mittelbronzezeit (Reinecke Bz C) etwa ab dem 15. Jahrhundert v. u. Z. zugeschrieben werden, insbesondere eine große Anzahl verdickter und flach abgestrichener Randlippen an kurzen, steil stehenden Gefäßmündungen, einige Griff- und Randlappen (Rigert u.a. 2001, 83–86 m. Abb. 95) sowie gelegentlich Scherben mit Kerbschnittverzierung (Krumland 1998, 58–59). Kaum vertreten sind Trichterhälse, die im Siedlungsmaterial dieses Zeitabschnitts eigentlich ebenfalls geläufig sind (Krumland 1998, 71). Dies könnte aber der überwiegend sehr starken Fragmentierung des Anselfinger Materials geschuldet sein, denn gerade ausbiegende Randscherben und scharfe Schulter-Hals-Umbrüche sind regelmäßig vorhanden und könnten von genau solchen Trichterhalsgefäßen stammen. Sehr vereinzelt sind schließlich Merkmale wie umriefte Buckel oder zur Mündung hin schräg abgestrichene Ränder vertreten, die bereits den Beginn der Stufe D andeuten und vielleicht eine entsprechende Laufzeit bis ins 13. Jahrhundert v. u. Z. hinein anzeigen könnten.

Fünf bisher durchgeführte ^{14}C-Datierungen bestätigen vorläufig diese Ansätze (Abb. 4; Tab. 1). Zwei Daten von verkohlten Hölzern aus mittelbronzezeitlichen Brandgruben scheinen zunächst recht weit auseinander zu liegen, nämlich schwerpunktmäßig jeweils im 17. und 15. Jahrhundert v. u. Z. Während jedoch die jüngere Probe von einem Kernobstbaum und somit vermutlich nicht von altem Holz stammt, kann es sich bei der älteren Eichenprobe durchaus um sehr altes Kernholz handeln. Ebenfalls ins 17. Jahrhundert v. u. Z. datiert ein Buchenfragment aus einer zu einem Gebäude gehörenden Feuerstelle. Auch hier ist aufgrund des vergesellschafteten Fundmaterials ein Altholzeffekt zu vermuten. Ins 15. Jahrhundert v. u. Z. datiert wiederum ein Eichenfragment, vermutlich von einem Zweig oder Ast, aus der Verfüllung einer zum Wandgräbchengebäude (s.u.) gehörenden Pfostengrube. Vorbehaltlich weiterer, besonders auch an kurzlebigeren Pflanzenresten und Tierknochen geplanter

Datierungen bestätigt ein Teil der bisherigen Daten den Ansatz einer Besiedlung ab dem 15. Jahrhundert. Ältere Daten sind vorläufig am ehesten auf die Verwendung von massiverem, vielleicht um die 200 Jahre altem Eichen- und Buchenbrennholz zurückzuführen. Eine weitere Eichenholzkohle aus einer urnenfelderzeitlichen Brandgrube hat ihren Datierungsschwerpunkt im 11. Jahrhundert v. u. Z., kann zuzüglich eines möglichen Altholzeffekts also der jüngeren Urnenfelderkultur (Ha B) zugewiesen werden.

Tab. 1: Messergebnisse von AMS-^{14}C-Datierungen an Holzkohlen aus verschiedenen Brandgruben (1-3), aus der Feuerstelle des nordöstlichen Rechteckgebäudes mit Y-Pfostenstellung (4) und aus einer zum Wandgräbchengebäude gehörenden Pfostengrube (5). Alter kalibriert nach Intcal13 (Reimer u.a. 2013) in OxCal 4.3.2 (Bronk Ramsey 2009), gerundet auf zehn Jahre.

	Labornr.	Material	AMS-^{14}C-Alter	Δ^{13}C AMS [‰]	calBCE (1σ)	calBCE (2σ)
1)	Poz-105760	Holzkohle (*Quercus* sp. laubabwerfend)	3356 ± 29	-26,2	1690-1620	1740-1530
2)	Poz-105761	Holzkohle (Maloideae)	3163 ± 32	-25,8	1500-1410	1510-1320
3)	Poz-105782	Holzkohle (*Quercus* sp. laubabwerfend)	2878 ± 32	-22,5	1120-1000	1200-930
4)	MAMS-37961	Holzkohle (*Fagus* sp.)	3357 ± 25	-25,3	1690-1620	1740-1560
5)	MAMS-37960	Holzkohle (*Quercus* sp. laubabwerfend)	3201 ± 20	-26,4	1500-1440	1510-1430

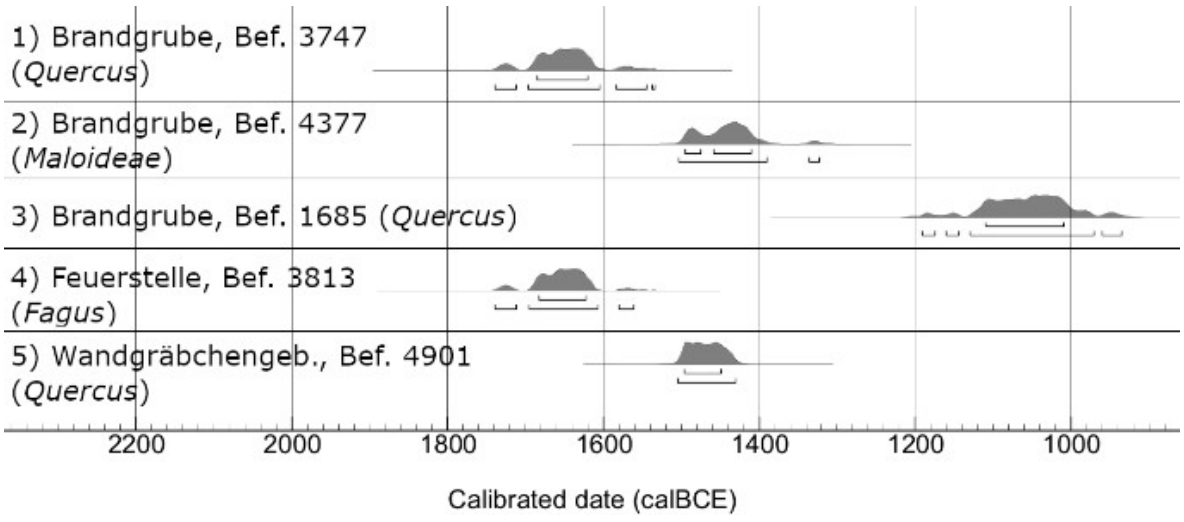

Abb. 4: Wahrscheinlichkeitskurven für Radiokarbondatierungen von Holzkohlen aus verschiedenen Brandgruben (1-3), aus der Feuerstelle des nordöstlichen Rechteckgebäudes mit Y-Pfostenstellung (4) und aus einer zum Wandgräbchengebäude gehörenden Pfostengrube (5). Alter kalibriert nach Intcal13 (Reimer u.a. 2013).

3 Architektonische Vielfalt

Wie bereits in Mühlhausen-Ehingen „Bei der Mauer“ und anderen benachbarten Mittelbronzezeit-Siedlungen (Dieckmann 1998) gibt sich auch in Anselfingen eine erstaunlich vielfältige Architektur zu erkennen. Dabei scheint die Orientierung an einer ungefähr zwischen Nordwest–Südost und Westnordwest–Ostsüdost rangierenden Bauflucht ein wiederkehrendes Merkmal zu sein.

Am auffälligsten ist ein gut 6 m breites und mindestens 14 m langes Gebäude mit umlaufenden Wandgräbchen (Abb. 5, A). In seinem Zentrum ist möglicherweise eine Art Rauchfang zu rekonstruieren, wenngleich sich keine konkreten Hinweise auf eine Herdstelle fanden. Parallelen zu solchen Konstruktionen finden sich etwa in Mühlhausen-Ehingen bei einem größeren Pfostengebäude mit Überresten einer vermutlich ebenerdigen Feuerstelle innerhalb eines solchen Pfostengevierts (Aufdermauer/Dieckmann 1995. Dieckmann 1998). Aber auch im westschweizerischen Kehrsatz (Kt. Bern) enthielt ein Rechteckbau vielleicht einen ähnlichen Innenausbau (Mamim/Gubler 2017, 72). Hinsichtlich des Aufgehenden deuten massivere, etwas von den Stirnseiten nach innen versetzte Firstpfosten auf eine Walmdachkonstruktion. Sowohl innerhalb der Wandgräbchenverfüllung als auch in dessen westnordwestlicher Verlängerung zeichneten sich weitere Pfostenstellungen ab, weshalb eine Mehrphasigkeit des Gebäudestandortes gut möglich ist (vgl. Dieckmann 1998). Es hätte dann ein bis zu 16 m langer Pfostenbau eine knapp 14 m lange Schwellbalkenkonstruktion abgelöst. Tatsächlich enthielten die Pfostengrubenverfüllungen im Vergleich zum gesamten Wandgräbchen deutlich mehr Fundmaterial, was dafür spricht, dass sie erst nach einer gewissen Stand- und Nutzungszeit angelegt wurden, als sich an Ort und Stelle bereits ein gewisser Fundniederschlag angesammelt hatte. Allerdings schien die Sohle des Wandgräbchens nicht durchgehend zu verlaufen, sondern in unterschiedlich tiefen Segmenten zwischen den Pfostenstellungen. Dies könnte wiederum auf einen konstruktiven

Zusammenhang zwischen Schwellbalken- und Ständerkonstruktion hindeuten. Insgesamt ist die Gebäudestruktur wohl sehr gut erhalten. Von einem nennenswerten Substanzverlust infolge von Bodenerosion ist in diesem Bereich der Grabungsfläche nicht auszugehen, will man nicht gerade annehmen, dass die noch bis zu 0,3 m tief erhaltenen Wandgräbchensegmente ursprünglich als schmale Schlitzgräbchen angelegt waren. Gebäude mit umlaufendem Wandgräbchen stellen einen Gebäudetyp dar, der im Hegau bereits in Mühlhausen-Ehingen (Dieckmann 1998) und in Orsingen-Nenzingen (Hald/Kitzberger 2018b; freundl. Mitt. J. Hald) belegt ist. Mitunter sind vergleichbare mittelbronzezeitliche Gebäude auch aus Oberbayern bekannt. Sie lassen sich dort nicht nur anhand der Wandgräbchen, sondern auch anhand leicht bauchig ausschwingender Wandseiten, wie es zumindest an der Südsüdwestwand des Anselfinger Baus noch zu erahnen ist, auf frühbronzezeitliche Traditionen zurückführen (Bankus 1995. Schefzik 2010).

Auffällig sind auch zwei Pfostengebäude mit halbrundem bzw. trapezoidem, apsidenartigem Abschluss ihrer jeweils nach Westnordwest weisenden Schmalseite (Abb. 5, B, C). Eines davon befand sich im Osten des während der Mittelbronzezeit bebauten Areals. In seinem Innern fand sich statt einer Firstpfostenreihe wiederum eine kleine, quadratische Pfostenstellung. Am ehesten ist auch hier an eine Art Rauchfang zu denken, der angesichts der fehlenden Firstkonstruktion aber auch dachtragende Funktion gehabt haben könnte. In vielen der mit bis zu 0,45 m vergleichsweise tief erhaltenen Pfostengruben zeichneten sich Standspuren der einstigen Pfosten durch dunklere und kiesärmere Verfüllung sowie leicht vermehrten Holzkohleeintrag ab. Die Pfosten müssen also nach einer gewissen Standzeit gezogen worden sein. Ein zweiter Apsidenbau im Westen der Siedlungskonzentration war deutlich kleiner und anstatt eines Pfostengevierts befand sich in seinem Zentrum lediglich eine größere, nicht näher einzuordnende Grube. Zudem waren die Apsis-Pfostengruben im Vergleich zu den übrigen Wandpfosten deutlich kleiner dimensioniert, bildeten offenbar also

eher einen nicht tragenden Anbau. Der gerundete Hausabschluss scheint demnach in Anselfingen nicht zwingend mit einer bestimmten Gebäudefunktion einherzugehen. Apsidengebäude sind ebenso aus Ostfrankreich wie aus Bayern bekannt und datieren mitunter noch frühbronzezeitlich (Schefzik 2010, 336).

Auf eine Reihe verschiedenster, meist einschiffiger Pfostenbauten mit Innenflächen von weniger als 30 Quadratmetern sei hier nur kursorisch hingewiesen. Aufgrund ihrer Größe und Variabilität wird man in ihnen vorläufig verschiedenerlei Zweckbauten vermuten dürfen – Lager- und Vorratsräume, Werkstätten, vielleicht auch Ställe oder Unterstände. Eine wiederkehrende Grundform stellen hingegen etwas größere Gebäude von knapp 10 m Länge und 5–6 m Breite dar, deren Seitenwände von je fünf Pfostengruben gebildet werden (Abb. 5, G–J). Drei von vier solcher Bauten wiesen Giebel- und Innenpfosten auf. Einmal ist dabei ein einzelner Firstpfosten belegt (Abb. 5, H), zweimal ein Wechsel von zwei- zu dreischiffigem Teil in Form einer Y-Pfostenstellung (Abb. 5, I, J). Die beiden letzteren Bauten lagen jeweils am nordöstlichen und südwestlichen Rand der mittelbronzezeitlichen Siedlungskonzentration. Neben ihrer auffallend ähnlichen Konstruktion enthielten sie gleichermaßen Keramik- bzw. Gefäßdeponierungen sowie je eine Feuerstelle. Ob es sich um Wohnbauten handelt, wie es das Vorhandensein von Feuerstellen vermuten lässt, und ob sie gleichzeitig bestanden, bleibt zunächst offen.

Schließlich können mindestens sechs kleine Vierpfostenbauten aufgeführt werden, die als gestelzte, also vom Boden abgesetzte Vorratsspeicher anzusprechen sind (Abb. 5, K–P; Gnepf-Horisberger/Hämmerle 2001, 58–60). Andernorts wurden aus Pfostengruben solcher Gebäude teils größere Mengen verkohlter Pflanzenreste geborgen, die darauf hinweisen, dass sie tatsächlich vor allem der Getreidelagerung dienten, z. B. in Payerne „En Planeise“ (Kt. Waadt) (Jacquat 2012). Sie gruppieren sich in Anselfingen nordöstlich und südwestlich des großen Wandgräbchengebäudes, teilweise aneinandergereiht. Eine ähnliche Gruppierung

derartiger Kleinstbauten ist auch in anderen mittelbronzezeitlichen Siedlungen nachgewiesen, etwa in Cham-Oberwil (Gnepf-Horisberger/Hämmerle 2001, Beilage 1), in Hilzingen „Unter Schoren“ (Dieckmann 1989) und vermutlich auch in Kehrsatz „Breitenäcker“ (Mamim/Gubler 2017, Abb. 2). Ob die einzelnen Speicher solcher Baugruppen gleichzeitig bestanden oder sich zeitlich ablösten, kann derzeit nicht näher beurteilt werden. In einem Fall (Abb. 5, L) schneidet eine der vier Pfostengruben die mit (Hitze-)Steinen durchsetzte Verfüllung einer ebenfalls mittelbronzezeitlichen Grube, sodass der Speicherbau einer jüngeren Siedlungsphase angehören muss.

Wie in vielen vor- und frühgeschichtlichen Siedlungsarealen lassen sich allerdings auch in Anselfingen viele als Pfostengruben angesprochene Befunde nicht eindeutig einzelnen Gebäudegrundrissen zuordnen, obwohl sie durchaus zum Teil noch regelhafte Anordnungen erahnen lassen. Angesichts der guten Erhaltung anderer bronzezeitlicher Strukturen wird dieser Umstand nicht allein auf eine fragmentarische Erhaltung der Bausubstanz zurückzuführen sein. Vielmehr dürfte ein Teil dieser „freien“ Pfostengruben von weniger symmetrischen bzw. unauffälligeren Strukturen wie Umzäunungen, Viehpferchen oder dergleichen stammen (vgl. Gnepf-Horisberger/Hämmerle 2001, 38). Besonders nordwestlich des Wandgräbchengebäudes zeichnet eine Vielzahl meist kleinerer Gruben ein System von Pfostenreihen nach, die ihrerseits teilweise auf dieses Gebäude Bezug zu nehmen scheinen (Abb. 3). Welchem Zweck solche Abgrenzungen im Einzelnen wohl dienten, sei dahingestellt, doch sind in Siedlungen, deren Subsistenz nicht zuletzt auch auf der Haltung und Zucht von Schafen, Ziegen und Schweinen beruhte (Benecke 1994. Falkenstein 2009, 153–157), Einhegungen verschiedener Art zu erwarten.

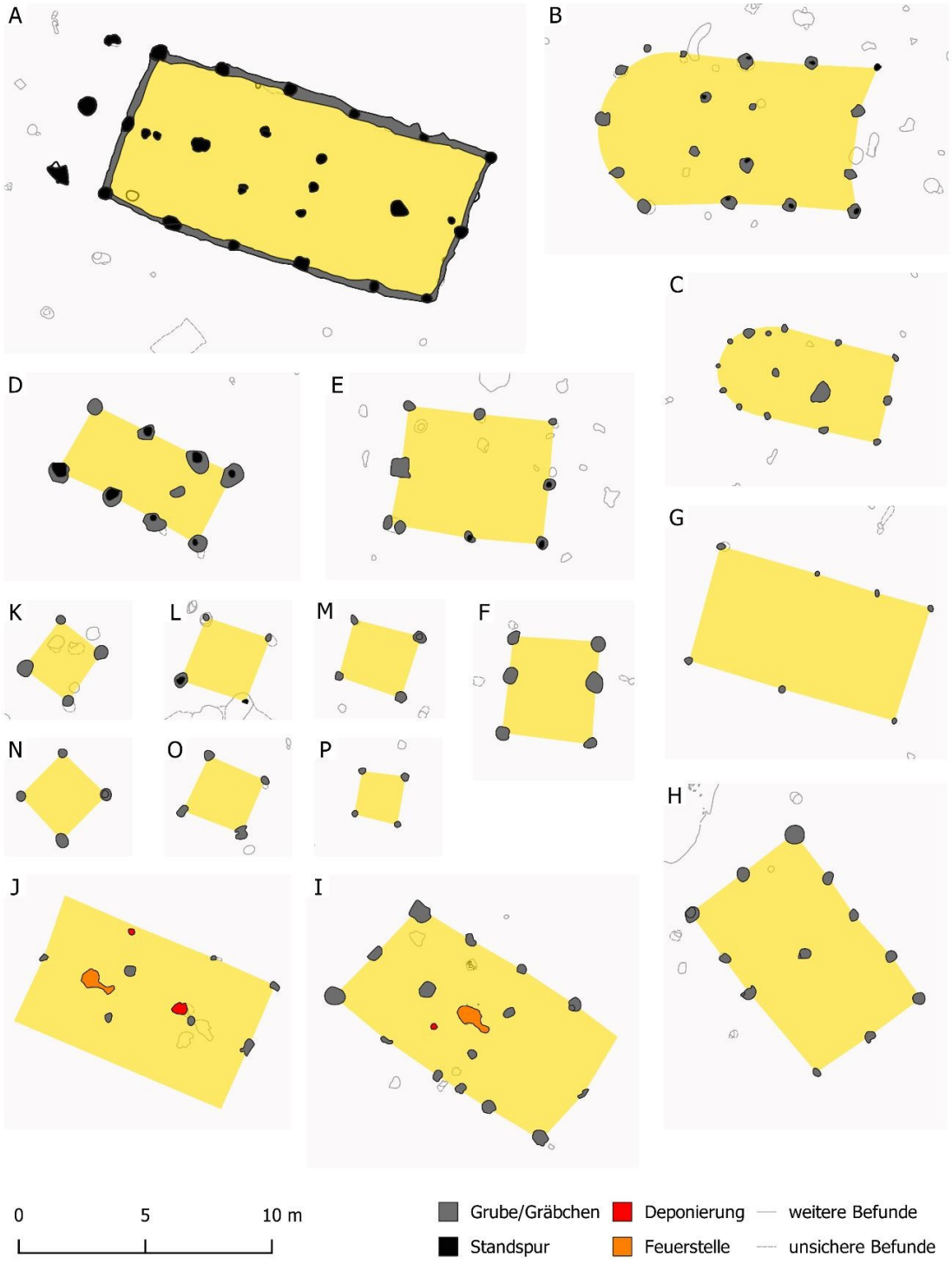

Abb. 5: Zusammenstellung der nach bisherigem Auswertungsstand in die Mittelbronzezeit datierbaren Gebäudegrundrisse.

4 Infrastruktur und funktionale Einrichtungen

Über die hier angerissene Vielfalt architektonischer Strukturen hinaus wurde in Anselfingen eine Reihe von Befunden dokumentiert, die auf ebenso mannigfaltige handwerkliche und häusliche Aktivitäten schließen lassen. Da bislang jedoch im südwestdeutschen Raum kaum vergleichbare Siedlungskomplexe untersucht wurden, ist deren Einordnung schwierig. Der Wasserversorgung, z. B. als Viehtränke, könnte unter anderem eine kleine Geländemulde auf dem Schotterwall nördlich der Siedlungskonzentration gedient haben. Es handelt sich um ein etwa 20 x 10 m großes, ursprünglich mindestens rund 3,5 m tiefes Toteisloch. Wasserstauende, glazifluviale Tone bilden die Basis dessen Verfüllung, darüber befanden sich Schwemmschichten, die aufgrund vereinzelter Holzkohleflitter vorgeschichtlichen Alters sein müssen. Zu einem Zeitpunkt, als die Senke nur noch rund 2 m tief war, wurden in ihrem Zentrum auf einer Fläche von rund 6,5 x 8 m mehrere Lagen Steine eingebracht, möglicherweise um die Nutzung als natürliche Zisterne, Viehtränke o.ä. zu erleichtern. Teils handelte es sich dabei um gerötete oder gesprungene Hitzesteine, die vermutlich als Kochsteine ausrangiert worden waren. Anhand kleinteiliger Keramikfragmente konnte diese Nutzung zunächst zwar nur allgemein in die vorrömische Eisenzeit datiert werden (Ehrle u.a. 2015, 112), vergleichbare mittelbronzezeitliche Strukturen sind aber z.B. aus den benachbarten Siedlungsarealen von Mühlhausen-Ehingen „Im Kai“ (Hald 2003a) und Mühlhausen-Ehingen „Bei der Mauer“ (Hald 2004) bekannt. Auf die massive, bis zu 8 m breite Wegbefestigung südöstlich der bronzezeitlichen Bebauung wurde oben bereits hingewiesen. Während diese vermutlich in die vorrömische Eisenzeit datiert (Bräuning u.a. 2014), könnten mehrere kleinere Wegführungen, die mit variierender Ausrichtung auf verschiedenen Trassen ungefähr von Süden her zur bronzezeitlichen Bebauung herführen, durchaus zum Teil bronzezeitlich sein. Es handelt sich um diffus-längliche Verfärbungen und Verdichtungen des Untergrunds, um flache Steinrollierungen oder um Bündel paralleler Wagenspuren. In letzteren Fällen rangiert

die Spurbreite häufig um 1,2 m. Gerade in Form von Rollierungen oder Pflasterungen sind Wegführungen in verschiedenen mittelbronzezeitlichen Siedlungen belegt, besonders eindrücklich zum Beispiel in Cham-Oberwil (Gnepf-Horisberger/Hämmerle 2001, 61).

Eine technisch-funktionale Einrichtung wurde wenige Meter westlich des Wandgräbchengebäudes freigelegt. In einer kreisrunden, gut 0,7 m durchmessenden Grube zeichneten sich Verfüllungen aus leuchtend gelbem und rotbraunem Sediment ab, die von intensiver Hitzeeinwirkung zeugen. In mehreren sich abwechselnden Lagen verfüllten diese eine noch rund 0,2 m tiefe Mulde, die wiederum in eine insgesamt gut 0,4 m tiefe, kesselförmige und zunächst mit homogenem, dunkelgraubraunem Lehm verfüllten Grube einschnitt. Die regelmäßige Schichtung der gebrannten Sedimente im oberen Grubenteil deutet auf wiederholte Befeuerung hin. Holzkohlen fanden sich darin allerdings nur vereinzelt, sodass anzunehmen ist, dass Brandreste ggf. aus dem Grubenofen geräumt wurden. Angesichts der deutlichen Hitzeeinwirkung ist der Befund in einem pyrotechnologischen Zusammenhang zu sehen. Ob dabei an einen Grubenbrand zur Keramikproduktion oder vielleicht auch an Metallverarbeitung – wenngleich die Dimensionierung der Brennkammer für das bloße Aufschmelzen von Buntmetallen äußerst großzügig erscheint – zu denken ist, ist vorläufig kaum zu entscheiden. Dass letzteres in Anselfingen durchaus anzunehmen ist, bezeugt ein annähernd 2 kg schweres, fast exakt auf ein Kreisdrittel portioniertes Gusskuchenfragment, das sich rund 10 m nördlich des Wandgräbchengebäudes und gut 15 m nordöstlich Grubenofens auf der Sohle einer zunächst völlig unscheinbaren Grube befand (Höpfer u.a. 2017a). Schwermetallanalysen an Sedimentproben aus dem Grubenofen sollen nähere Hinweise zu dessen Funktion liefern.

Auf die Feuerstellen in den zwei Rechteckbauten mit Y-Pfostenstellung wurde oben bereits hingewiesen. Es handelte sich um flache Mulden, die mit Steinen und mitunter großen Kalksteinplatten ausgelegt waren (Abb. 6). Brandrückstände in Form von Holzkohlen und

gerötetem Lehm fanden sich vor allem in flachen, länglichen Ausbuchtungen außerhalb der Steinauskleidungen, möglicherweise Bedien- bzw. Ausräumschächte. Gerötete oder zersprungene Hitzesteine befanden sich teils in diesen Ausbuchtungen, teils auf den Kalksteinplatten und dürften als Kochsteine anzusprechen sein. Hitzesteine stellen in den mittelbronzezeitlichen Siedlungen der Region ein so markantes Element dar, dass sie zuweilen als „Leitfossil“ oder „Kulturzeiger“ bezeichnet wurden (Dieckmann 1997, 67. Gnepf-Horisberger/Hämmerle 2001, 66). Auch wenn die Verwendung heißer Steine keineswegs auf die Nahrungszubereitung beschränkt sein muss und die aufwendige Konstruktion beider Feuerstellen zunächst vielleicht weniger an Herdstellen denken lässt, lässt die Auskleidung mit flachen Kalksteinen, deren Beständigkeit und Betriebssicherheit im Zusammenhang mit Hochtemperaturhandwerk sicher zu wünschen gelassen hätten, eher auf geringere Zieltemperaturen und ein Bedürfnis nach ebenen Standflächen etwa für Kochgefäße schließen Tatsächlich fand sich innerhalb des südwestlichen Gebäudes und kaum drei Meter von der dortigen Feuerstelle entfernt das in eine flache, passgenaue Mulde eingelassene Unterteil eines grobkeramischen Topfes, in dem noch mehrere, teils kantig zerbrochene Steine lagen. Vier sehr ähnliche Befunde, also in passgenaue Gruben eingelassene Grobgefäße, in denen teilweise in situ noch Hitzesteine lagen, wurden außerhalb von Gebäuden entdeckt und dürften der mittelbronzezeitlichen Siedlungsphase angehören. Auch in anderen mittelbronzezeitlichen Siedlungen des Hegaus sind derartige Kochgefäße nachgewiesen, etwa in Orsingen-Nenzingen (Hald/Kitzberger 2018b). Angesichts der tendenziell guten Befunderhaltung im Bereich der Anselfinger Lehmsenke lässt das regelhafte Fehlen der oberen Gefäßpartien vermuten, dass diese Töpfe nie vollständig eingegraben, sondern lediglich ihre Unterteile in passgenaue Mulden eingelassen waren. Möglicherweise sollte auf diese Weise ihr sicherer Stand auch bei der Verwendung im Freien gewährleistet werden. Auf einer abstrakt-symbolischen Ebene spricht auch dies gegen eine Entledigung im Sinne „sakralen Abfalls“, der aufgrund seiner

Verwendung in kultisch-rituellem Zusammenhang mit einem Wiederverwendungstabu behaftet war (hierzu Stapel 1999, bes. 139–141; 264). Derlei Hintergründe werden besonders bei deponiertem Trinkgeschirr vermutet, wie es in bronzezeitlichen Siedlungen Süddeutschlands nicht selten beobachtet wird (Berthold 1998. Stapel 1999) und gelegentlich Bezüge zur Errichtung von Gebäuden erkennen lässt (Trebsche 2005). Während also bei den mutmaßlichen Kochgefäßen mehr ihr funktionaler Aspekt hervorsticht – womit wohlgemerkt über den weiteren Charakter und Hintergrund ihrer Verwendung noch nichts ausgesagt ist – fanden sich in Anselfingen durchaus mehrere Keramikdeponierungen, die im engeren Sinne den Charakter einer Entledigung oder einer Art Opfer aufweisen. Gemeint sind weitgehend vollständige Becher und Schälchen – feinkeramische Trink- und Schöpfgefäße – oder größere Partien von grober Gebrauchskeramik, die aufrecht stehend in Gruben, auf der Sohle von Pfostengruben liegend oder in Standspuren gezogener Pfosten vorgefunden wurden. Ihre Anzahl und Verbreitung ist allerdings wegen der oft unklaren Abgrenzung gegenüber unbewusst eingelagerten Gefäßbruchstücken nicht exakt zu beziffern.



Abb. 6: Teilfreigelegte Feuerstelle des nordöstlichen Gebäudes mit Y-Pfostenstellung mit (Kalk-) Steinauskleidung, brandgerötetem Lehm, Hitzesteinen und holzkohlehaltigem „Bedienschacht“.

5.1 Brandgruben im nordwestlichen Alpenvorland

Das nordwestliche Alpenvorland hat innerhalb dieser Gesamtverbreitung eine gewisse Sonderrolle inne, stammen doch von hier die ältesten diesem Typus zugerechneten Befunde, was möglicherweise auf ein entsprechendes Ursprungsgebiet hindeutet (Honeck 2009, 19). Bislang sind hier, wie insgesamt im süddeutschen Raum und damit im Gegensatz zur nordeuropäischen Verbreitung, keine größeren Grubengruppen oder -reihen bekannt (Beigel 2019, 122–125). Vor allem aber machten einige in den letzten Jahren hinzugekommene Ausgrabungen inzwischen deutlich, dass Brandgruben mit Hitzesteinen hier keineswegs als isolierte, durch die Landschaft streuende Befundgattung, sondern als regelhafter Bestandteil (mittel-)bronzezeitlicher Siedlungen anzusehen sind. Dazu gehören neben der hier vorgestellten Fundstelle in Anselfingen einige weitere Siedlungen aus dem westlichen Bodenseeraum, vor allem dem Hegau. In Hilzingen „Unter Schoren“ (Lkr. Konstanz) konnten unter bzw. in einem stellenweise in situ erhaltenen Laufhorizont neben Gebäuderesten mindestens zwei Brandgruben mit Hitzesteinen dokumentiert werden (Dieckmann 1989 m. Abb. 35; 1991; 1998; 2011. Aufdermauer 1998). Sie lagen dort wenige Meter südlich der nächstgelegenen Einzelpfosten und knapp 20 m südwestlich der nächsten identifizierten Gebäude – vorrangig kleine Vierpfostenspeicher – am Rande der untersuchten Fläche. Für die bereits mehrfach erwähnte Siedlung von Mühlhausen-Ehingen „Bei der Mauer“ sind ebenfalls zwei Brandgruben mit Hitzesteinen belegt (Aufdermauer/Dieckmann 1995. Dieckmann 1996; 1998). In Orsingen-Nenzingen „Unteres Geländ“ (Lkr. Konstanz) lagen etliche Brandgruben mit Hitzesteinen über ein größeres Areal verstreut und waren dabei von zahlreichen, bislang aber noch nicht weiter zu Strukturen rekonstruierbaren Pfostengruben umgeben. Ein mittelbronzezeitliches Gebäude mit umlaufendem Wandgräbchen war bei vorherigen Prospektionsmaßnahmen einige Dutzend Meter östlich davon entdeckt worden (Hald/Kitzberger 2018b; 2019; freundl. Mitt. J. Hald). In Gottmadingen-Bietingen „Hinter den

Gärten“ (Lkr. Konstanz) schließlich wurde in einer schmalen Erschließungstrasse eine Brandgrube sowie eine eher als Hitzesteinkonzentration anzusprechende Struktur freigelegt (Hald 2016). In der untersuchten Erschließungstrasse lagen sie rund 10 m nördlich der nächsten als bronzezeitlich identifizierbaren Bebauung, zu der kleine Speicherbauten, aber auch größere Pfostenrechteckgebäude gehörten. Regelmäßig begegnen Brandgruben mit Hitzesteinen auch in den mittelbronzezeitlichen Siedlungen des nordöstlichen und zentralen Schweizer Mittellandes. In Birmensdorf „Stoffel“ (Kt. Zürich) fanden sich derer sechs bis sieben, von denen vier eine Gruppe bildeten, um die herum mehrere Gebäude unterschiedlicher Größe angeordnet waren (Achour-Uster/Kunz 2001, 22–29; 70–72 m. Abb. 127). Eine größere Anzahl von Brandgruben mit Hitzesteinen ist inzwischen aus Cham-Oberwil „Hof“ (Kt. Zug) bezeugt, von denen fünf vermutlich mit der mittelbronzezeitlichen Besiedlung, weitere fünf hingegen möglicherweise mit der spätbronzezeitlichen Geländenutzung in Verbindung zu bringen sind (Gnepf Horisberger/Hämmerle 2001, 70–71. Jecker u. a. 2014. Jecker/Schaeren 2015; 2016; 2017; freundl. Mitt. D. Jecker, Kantonsarchäologie Zug). Im unmittelbaren Zusammenhang mit mittelbronzezeitlicher Bebauung fanden sich schließlich drei Brandgruben mit Hitzesteinen in Zug „Rothuswiese“ (Kt. Zug; freundl. Mitt. D. Jecker). Aber auch noch in der Westschweiz scheinen entsprechende Situationen vorzukommen. Bei einer großflächigen Untersuchung in Kehrsatz „Breitenacker“ (Kt. Bern) wurden neben zahlreichen Gebäuden – darunter etliche kleine Vierpfostenbauten, aber auch größere Rechteckgebäude – bislang acht Gruben mit Hitzesteinpackungen entdeckt, bei denen es sich vermutlich um Brandgruben handelt (Mamim/Gubler 2017). Sie konzentrierten sich auf ein Areal im Südwesten der Grabungsfläche, in dem zwar auch Pfostengruben streuten, sich aber nicht eindeutig zu Grundrissen rekonstruieren ließen. Erwähnt seien schließlich Brandgruben mit Hitzesteinen aus Leutkirch im Allgäu „Untere Auen“ (Lkr. Ravensburg), die allerdings neben einer

mittelbronzezeitlichen Besiedlung vielleicht auch mit hallstattzeitlicher Geländenutzung in Verbindung stehen könnten (Morrissey/Langer/Höpfer in Vorb.).

5.2 Lage innerhalb der Siedlung Anselfingen

Auch wenn bei den oben genannten Beispielen häufig nur kleine Ausschnitte untersucht wurden und sich Mehrphasigkeiten in der Regel nicht näher aufschlüsseln ließen, belegen sie doch den engen Zusammenhang von Brandgruben und mittelbronzezeitlichem Siedlungsgeschehen. Dort, wo auch größere Flächen freigelegt werden konnten, zeichnet sich zum Teil eine lockere Gruppierung der Brandgruben in bestimmten Siedlungsbereichen ab, die wiederum unbebaut scheinen. In Anselfingen trifft dies für drei von fünf mittelbronzezeitlichen Brandgruben zu, die sich mindestens 15 m von den nächsten Gebäuden entfernt befanden. Die anderen beiden wurden in unmittelbarer Nähe von Baubefunden entdeckt, nehmen mit ihrer Lage und Ausrichtung allerdings keinen weiteren Bezug auf diese, sodass offen bleiben muss, inwieweit einzelne Brandgruben und Gebäude tatsächlich zeitgleich bestanden oder unterschiedlichen mittelbronzezeitlichen Nutzungsphasen angehörten. Insgesamt ähnelt die Lage der Anselfinger Brandgruben der der passgenau in den Untergrund eingelassenen Kochgefäße (s.o.), die ebenfalls zu einem größeren Teil abseits der nachgewiesenen Bebauung in der Lehmsenke beobachtet wurden (Abb. 3).

5.3 Charakterisierung der Anselfinger Brandgruben

Soweit es Befundsituation und Grabungsmethodik beurteilen lassen, handelte es sich mehrheitlich um flache Gruben (vgl. auch Dieckmann 1991, 57–58). Beim maschinellen Abtrag der Deckschichten begegneten in der Regel zuerst die kompakten Hitzesteinpackungen, und zwar teilweise noch innerhalb eines dunkel-humosen Horizonts zwischen hangenden Kolluvien und liegendem Gewachsenem, bei dem es sich möglicherweise um Reste der damaligen Geländeoberfläche handelt, die sich in der Lehmsenke stellenweise hatten erhalten können. Die meisten anderen Grubenverfüllungen

zeichneten sich hingegen erst einige Zentimeter tiefer im gelbbraunen Lehm ab, was vermutlich ihrer schlechten Erkennbarkeit in dem dunkleren Horizont geschuldet sein dürfte. Im Profil zeigten sich die Brandgruben wannen- oder flach muldenförmig mit weitgehend ebener Sohle, bei selten mehr als 0,2 m Tiefe, gemessen vom höchsten Stein bis zur Grubensohle (Abb. 7, oben). Deutliche Unterschiede zwischen urnenfelder- und mittelbronzezeitlichen Brandgruben geben sich in der Form und Größe zu erkennen (Abb. 7, unten): erstere waren recht einheitlich proportioniert und fast durchweg gerundet langrechteckig, letztere hingegen größer und in der Form etwas variabler.

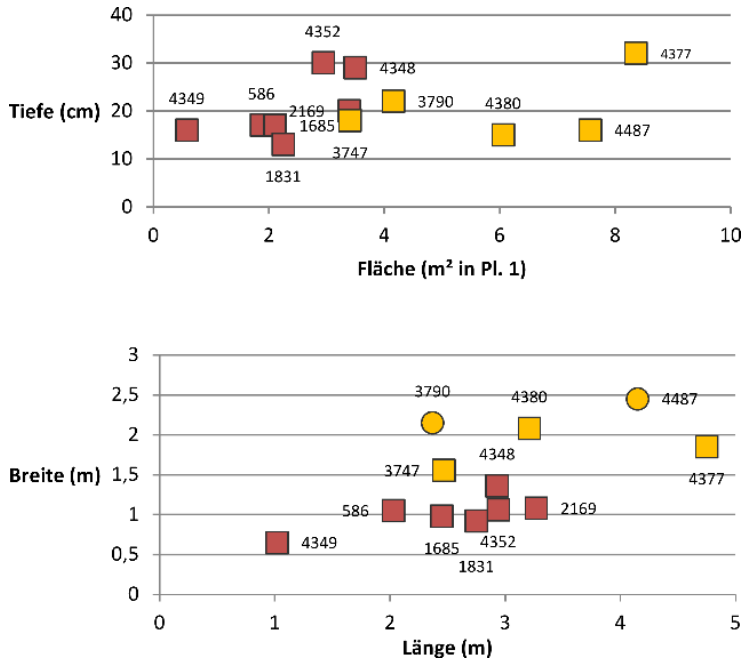

Abb. 7: Größen- und Formverhältnisse der mittelbronze- (gelb) und urnenfelderzeitlichen (rot) Brandgruben mit Hitzesteinen. Im unteren Diagramm markieren Quadrate die tendenziell rechteckigen, Kreise die rundlichen oder ovalen Gruben

Kennzeichnendes Merkmal für die Ansprache als Brandgruben ist – in Abgrenzung zu anderen Gruben mit Hitzesteinpackungen, aber ohne nennenswerten Holzkohleanteil, die es in Anselfingen wie auch in anderen Fundstellen durchaus gibt – das Vorhandensein von Brandresten auf der Grubensohle. In der Regel sind diese als kleinteilige Holzkohlestücke und Aschereste mehr oder weniger flächig über die Grubensohle verstreut. Darüber hinaus

enthielten jedoch drei urnenfelder- (Bef. 1685. 1831. 4352) und vier mittelbronzezeitliche (Bef. 3747. 4377. 4380. 4487) Gruben auch größere, im Wuchsverbund verkohlte Stücke (Abb. 8). Diese wenige Zentimeter starken Holzreste waren mitunter noch über einen Meter lang und fanden sich oft im Zentrum der Grubensohle. Ihre Erhaltung macht ein längeres Offenstehen der Grube nach dem Brand unwahrscheinlich, da sie unter Witterungseinfluss rasch hätten zerfallen müssen. Dabei gilt es zu beachten, dass größere, im Wuchsverbund verkohlte Hölzer neben den meist viel zahlreicheren kleinen Holzkohlen und Ascheresten keineswegs als isolierte Brandnester verstanden werden müssen. Vielmehr dürften diese Hölzer zuletzt aufgelegt bzw. vor ihrer vollständigen Verbrennung überdeckt worden sein.

Neben den verkohlten Holzresten zeigten einige Gruben auch Brandrötungen und Verziegelungen des umliegenden Sediments als Spuren der Hitzeeinwirkung. Dies gilt für fünf der urnenfelderzeitlichen (Bef. 586. 1685. 4348. 4349. 4352), jedoch nur für zwei der mittelbronzezeitlichen Befunde (Bef. 3747. 3790). Da die Befunde überwiegend in vergleichbares Sediment eingegraben waren, könnte dies auf entsprechend höhere Brenntemperaturen bzw. auf eine stärkere Konzentration der Hitze auf die Wände und Sohlen der schmaleren Gruben zurückzuführen sein. Wenn, dann waren vor allem die Randbereiche der Grubensohle und die Grubenwände betroffen. In mehreren Fällen korrelierten derartige Rötungen der Grubensohlen mit der Lage von Holzkohlen (Bef. 586. 1685. 4348. 3747. 3790). Dies macht eine wiederholte Nutzung mit längeren Ruhephasen unwahrscheinlich, da zumindest unter ähnlich starker Befeuerung dann weitere Teile der Grubensohle hätten entsprechend überprägt werden müssen.

An den über die Brandreste eingebrachten Hitzesteinpackungen gibt sich die Hitzeeinwirkung durch Rotfärbung und durch das Zerplatzen der Steine zu erkennen. In allen Brandgruben sind sowohl unterschiedliche Gerölle – jedoch fast nie Kalksteine – aus dem lokal anstehenden Geschiebe als auch Basalte, die am nahegelegenen Hang des Hohenhewen aufgeschlossen sind,

vertreten. In der Regel wurden dabei etwa 10–15 cm große Steine verwendet. Wiederum lässt sich eine Veränderung zugunsten von Basalten in den urnenfelderzeitlichen Befunden erkennen. Dies könnte einer höheren beabsichtigten Brenntemperatur geschuldet sein, zeigt aber auch, dass man während der jüngeren Spätbronzezeit bereit war, etwas größeren Aufwand für das Sammeln des Steinmaterials zu betreiben. Meist bildeten die Steine eine rund 0,1–0,2 m mächtige Packung aus ein bis drei Lagen, die in ihrer Form ungefähr der ausgehobenen Grube folgte. Mit wenigen Ausnahmen (Bef. 586. 4348. 4380) waren sie dabei aber zum Grubenzentrum hin etwas dichter bzw. mächtiger aufgeschichtet. Dies deckt sich mit der tendenziell zum Grubenzentrum hin abnehmenden Brandrötung bzw. Verziegelung und der zunehmenden Holzkohleerhaltung: nachdem der Brand vor allem zentral mit der Hitzesteinpackung abgedeckt wurde, verkohlten die Hölzer dort, während das Feuer am Rande weiterbrennen konnte oder möglicherweise sogar weiter geschürt wurde.



Abb. 8: Mittelbronzezeitliche Brandgrube Bef. 4380 mit Hitzesteinpackung und teilfreigelegten Brandresten auf der Grubensohle. Gut zu erkennen die länglichen, im Wuchsverbund erhaltenen Holzkohlen im Grubenzentrum.

Bemerkenswerterweise enthielten die Anselfinger Brandgruben im Gegensatz zu vielen spätbronze- und eisenzeitlichen Befunden durchweg reichlich Fundmaterial (Abb. 9). Der größte Teil davon entstammt der jeweiligen Hitzesteinpackung. Nähere Angaben zu

Macharten und Erhaltung können hier für die mittelbronzezeitlichen Befunde gemacht werden: Bei der Gefäßkeramik handelt es sich um meist stark fragmentiertes Material aller Macharten, von hochwertiger Feinkeramik bis zu grob gearbeiteten Koch- und Vorratsgefäßen. Größere Gefäßpartien ließen sich nur sehr vereinzelt aus Passscherben zusammensetzen und auch Verteilungsschwerpunkte bestimmter Keramikmacharten, die auf ein gezieltes Ablegen und späteres Zerbrechen von Gefäßen hinweisen könnten, zeichneten sich nicht ab. Vielmehr fanden sich zahlreiche Anpassungen längs und quer durch die Steinpackungen. Es kann also davon ausgegangen werden, dass lediglich Bruchstücke von bereits zuvor zerbrochenen Gefäßen in die Gruben gelangten. Insgesamt entspricht die Keramik somit in ihrer Erhaltung und ihren Gefäßformen eher dem allgemein in der Siedlung vertretenen Fundniederschlag, als dass sie mit einer bestimmten Funktion oder gar einem einzelnen Ereignis in Verbindung zu bringen wäre. Darüber hinaus sind einige weitere Materialien vertreten, die am ehesten in das Spektrum regulären Siedlungsabfalls passen. Dazu gehören vor allem zahlreiche unverbrannte Tierknochen, darunter nicht selten Zahnfragmente, die sich in allen mittelbronze- wie urnenfelderzeitlichen Gruben fanden. Aber auch Silices waren in drei der mittelbronzezeitlichen Steinpackungen (Bef. 4377. 4380. 4487) enthalten, darunter ein stark abgebauter Klingenkern aus grauem Jurahornstein (Abb. 10, D). Mit Gewissheit im häuslichen Kontext zu verorten sind verziegelte Lehmstücke (Bef. 3790), sofern diese anhand von Flachseiten oder Flechtwerkabdrücken als Bestandteile von Ofen- oder Wandkonstruktionen erkennbar sind (Abb. 10, C). Ein Zeugnis der Getreideeinlagerung in der Siedlung lieferte die bisher einzige Schlämmprobe aus einer der Brandgruben mit Hitzesteinen (Bef. 3790). Von gut 40 verkohlten Samenresten ließen sich 30 Stück als Getreidekörner identifizieren, wobei mit Weich- oder Hartweizen, Einkorn, Emmer, Dinkel und Gerste sämtliche bronzezeitlichen Hauptgetreide vertreten sind (RÖSCH u.a. 2014a). Die Getreidereste müssen zusammen mit den verwendeten Hitzesteinen und weiterem

Fundmaterial in diese Brandgrube gelangt und angesichts ihrer verschiedenen Erntezeiträume zumindest teilweise zuvor eingelagert gewesen sein. Makrorestanalysen an weiteren Schlämmproben sind in Kooperation mit dem Landesamt für Denkmalpflege Baden-Württemberg vorgesehen.

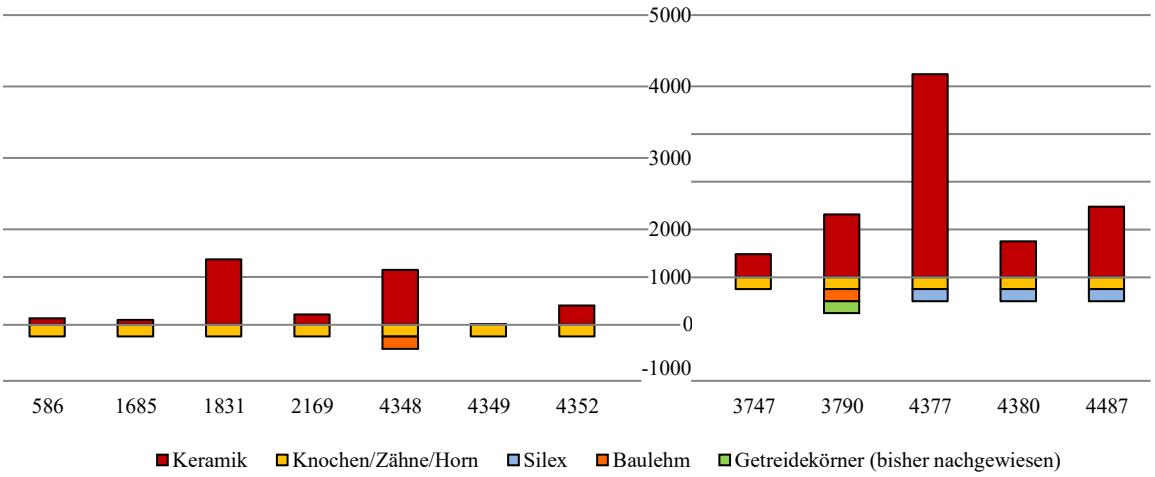

Abb. 9: Menge (positive Werte, Masse in Gramm) und Vorkommen (negative Werte, noch nicht genauer ausgewertet) verschiedener Fundgattungen in den mittelbronze- (rechts) und urnenfelderzeitlichen (links) Brandgruben mit Hitzesteinen.

Insgesamt lassen Art und Erhaltung der Funde kaum einen anderen Schluss zu, als dass offenbar zusammen mit den Hitzesteinen teils erhebliche Mengen alltäglich in der mittelbronzezeitlichen Siedlung anfallenden Abfalls in die Brandgruben gelangten. Die beiden östlichsten Brandgruben (Bef. 3747. 3790) enthielten u. a. mehrere Scherben mit einer Verzierung aus an einen Schnurdekor erinnernden Horizontalreihen von Schrägeindrücken. Diese Verzierung wirkt für sich betrachtet zwar der bronzezeitlichen Siedlungskeramik Südwestdeutschlands fremd, lässt sich aufgrund technischer Unterschiede aber ebensowenig mit der der in Anselfingen durchaus belegten Schnurkeramikkultur in Verbindung bringen. In ihrer Machart identische, wenn auch nicht konkret anpassende Scherben fanden sich in einer der Pfostengrubenverfüllungen des nordöstlichen Gebäudes mit Y-Stellung, sodass die Vermutung naheliegt, dass der in diesen Brandgruben sekundär verwendete Abfall ursprünglich aus diesem Haushalt stammte (Abb. 10,A). Inwieweit derartige Zusammenhänge auch für die urnenfelderzeitlichen Befunde gilt, muss allerdings offenbleiben, konnte doch für

diese Zeit bislang weder eine Bebauung noch ein ansatzweise darauf hindeutender Fundniederschlag nachgewiesen werden.

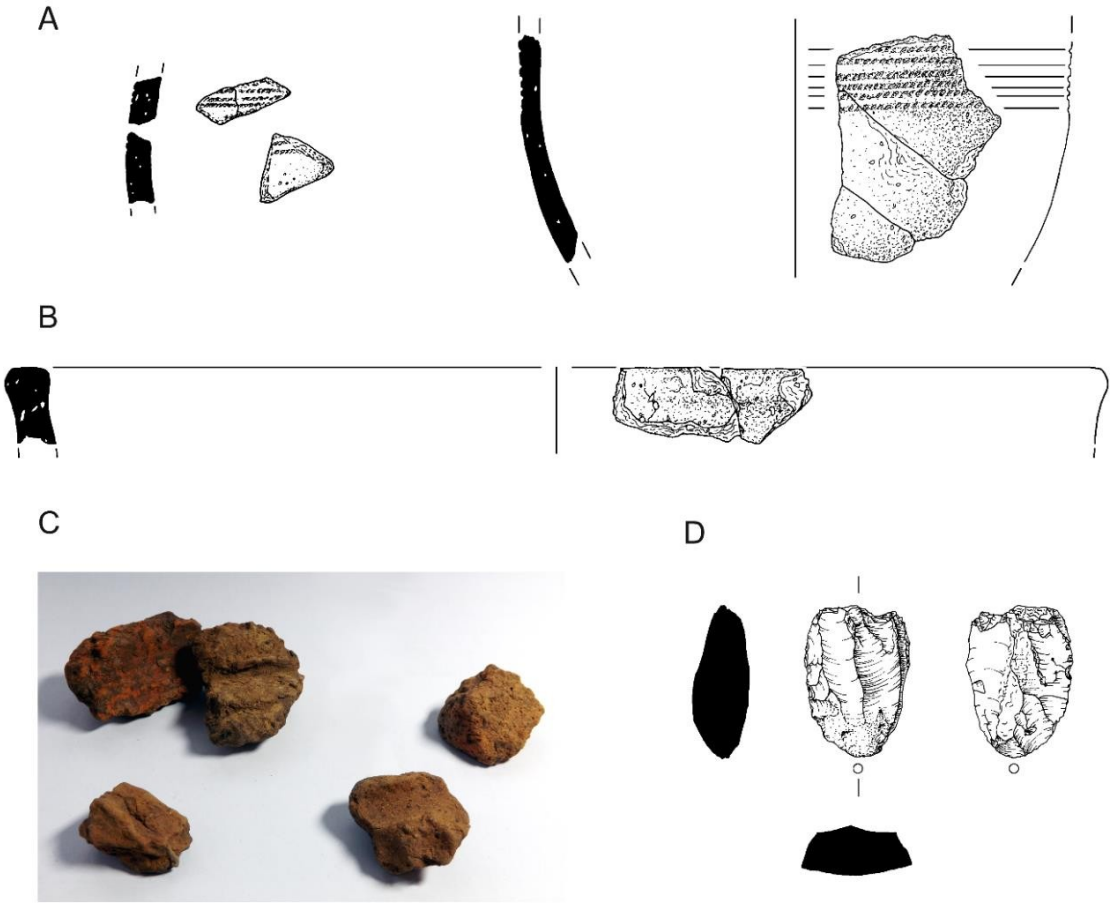

Abb. 10: Ausgewählte, im Text angesprochene Einzelfunde aus mittel- und spätbronzezeitlichen Brandgruben. A: vermutlich zusammengehörende schnurverzierte Keramik aus einer zum nordöstlichen Gebäude mit Y-Pfostenstellung gehörenden Pfostengrube (links) und aus Brandgrube Bef. 3790 (rechts), M. 1:2. B: anpassende Randscherben aus Brandgrube Bef. 4747 und angrenzender (Pfosten-) Grube Bef. 3749, M. 1:2. C: Brandlehmfragmente („Hüttenlehm“) mit Flachseiten und Flechtwerkabdrücken aus mittelbronze- (Bef. 3790, unten und rechts) und urnenfelderzeitlichen (Bef. 4348, oben rechts) Brandgruben. D: abgearbeiteter Silex-Klingenkern aus Brandgrube Bef. 3790, M. 1:2.

Während die urnenfelderzeitlichen Brandgruben offenbar isoliert oder allenfalls miteinander vergesellschaftet scheinen, zeigten sich bei den mittelbronzezeitlichen Befunden einige auffällige Gemeinsamkeiten. Stets befanden sich in unmittelbarer Nähe der Brandgruben, teils sogar angrenzend, eine oder zwei kleine Gruben (Abb. 11). Am ehesten sind diese als Pfostengruben anzusprechen, auch wenn ihre flachen und oft unregelmäßigen Profilkonturen

diese Einordnung nicht konkret zu stützen vermögen. In jedem Fall enthielten auch sie regelmäßig kleinere Holzkohlen, verziegelte oder brandgerötete Lehmstückchen, kantig zerbrochene oder gerötete Hitzesteine sowie gelegentlich Keramik. In einem Fall spricht die Anpassung zweier Randscherben eines größeren, grobkeramischen Gefäßes mit typisch mittelbronzezeitlich verdicktem und horizontal abgestrichenem Rand für die enge zeitliche Zusammengehörigkeit (Bef. 3747. 3749; Abb. 10, B).

Von besonderem Interesse für die Rekonstruktion der Nutzungsvorgänge ist die Tatsache, dass sich im Umfeld aller mittelbronzezeitlichen Brandgruben eine Steinpackung ohne nennenswerte Brandreste oder eine diffuse, oberflächliche Verfärbung fand. Was erstere anbelangt ist hervorzuheben, dass sich um die Steine herum keinerlei Grubenverfüllung beobachten ließ, sondern diese offenbar direkt auf dem gewachsenen Boden ruhten. In einem Fall (Bef. 3748. 3750 bei 3747; Abb. 11) handelte es sich um eine mehrlagige Packung aus teils zersprungenen Geröllen und zahlreichen Basalten. Anders als in den Brandgruben schienen die in dieser Steinkonzentration enthaltenen Gefäßscherben weniger gleichmäßig verstreut zu sein. Fein- und Grobkeramik weisen darin zumindest tendenziell verschiedene Verteilungsschwerpunkte auf. Dies deutet auf ein in mehreren Zügen erfolgtes Anschütten – zusammen jeweils mit den (Hitze-)Steinen – hin. An eine andere Brandgrube (Bef. 4377) grenzte eine längliche Steinkonzentration an, die im Gegensatz zur Brandgrube aber kein Fundmaterial enthielt und vorwiegend aus Geröllen bestand, die zudem keine deutlichen Spuren von Hitzeeinwirkung aufwiesen. Drei Brandgruben lagen hingegen in Nachbarschaft größerer diffuser und oberflächlicher Verfärbungen, deren Längsachsen ungefähr orthogonal zur jeweiligen Brandgrube verliefen. Während eine der Verfärbungen keinerlei Fundmaterial und kaum Steine enthielt, fanden sich in den beiden anderen vereinzelt kleine Keramikscherben und Tierknochen sowie Steine, einmal mit und einmal ohne erkennbare Spuren von Hitzeeinwirkung. Auch wenn sich alle Befundkomplexe in Einzelheiten

unterscheiden, bleibt die regelmäßige Kombination von Brandgrube mit Steinkonzentration oder Verfärbung auffallend. Möglicherweise sind hier unterschiedliche Stadien einer sekundären Nutzung von Hitzesteinen zu erkennen, die nach vorherigen Anwendungen ausrangiert und zusammen mit weiteren alltäglichen Überresten – aus heutiger Sicht Abfällen –zuerst am Platz der jeweiligen Brandgrube gesammelt und schließlich ein letztes Mal verwendet wurden.



Abb. 11: Mittelbronzezeitliche Brandgrube 3747 mit angrenzender (Pfosten-) Grube Bef. 3749 und benachbarten Steinkonzentrationen Bef. 3748 und 3750 im Hauptdokumentationsplanum 1 nach Abnahme der kolluvialen Deckschichten und des möglichen fossilen Oberbodens. Bef. 3749 grenzt an die nordöstliche Schmalseite der gerundet rechteckigen Brandgrube.

6 Anthrakologische Auswertung der Brandgruben

Um die mittelbronze- und urnenfelderzeitlichen Brandgruben mit Hitzesteinen auf einer weiteren Ebene vergleichen zu können und möglicherweise Erkenntnisse über die Vegetation im Siedlungsumfeld zu gewinnen, wurden 4.601 Holzkohlenfragmente aus den fünf mittelbronze- und aus vier urnenfelderzeitlichen Befunden anthrakologisch untersucht. Es

handelt sich überwiegend um Holzkohlen, die in Sedimentproben aus dem Sohlbereich der Gruben entnommen wurden. Daneben lagen meist auch größere, im Wuchsverbund von der Grubensohle geborgene Hölzer sowie selten kleine Sammelproben aus den Hitzesteinpackungen vor.

6.1 Exkurs zur Vegetationsgeschichte des Hegaus

Über die Vegetations- und Landnutzungsgeschichte des Hegaus gibt eine Reihe von Pollenprofilen näheren Aufschluss. Spätestens aus dem jungneolithischen 4. Jahrtausend v. u. Z. verdichten sich die Hinweise auf Rodungen, mit denen geeignete Wuchsbedingungen für die Kulturpflanzen geschaffen wurden. Besonders das vermehrte Vorkommen von Getreidepollen und Pflanzentaxa, die auf eine Öffnung der Vegetation hindeuten, etwa *Corylus* und *Betula*, bei gleichzeitigem Rückgang von *Fagus*, sind deutliche Anhaltspunkte hierfür. Basierend auf den „Off-Site"-Pollen- und Mikroholzkohlenergebnissen wird für diesen Zeitraum häufig auf eine Form der Wald-Feldbau-Brandkultur („Slash and Burn" oder „Swidden Agriculture") geschlossen. Im Gegensatz dazu sprechen archäobotanische „On-Site"-Ergebnisse eher für eine intensive Gartenwirtschaft (Jacomet u. a. 2016. Rösch u. a. 2014a). Natürlich spielen bei der Interpretation der beobachteten Veränderungen auch regionale Unterschiede eine Rolle, die mit lokalen Besiedlungsmustern zusammenhängen (Lechterbeck u.a. 2014). So gibt es zum Beispiel im Profil „Steißlinger See" – ca. 12 km östlich von Anselfingen im Hegau gelegen – kaum Hinweise auf Getreideanbau vor der Frühbronzezeit, was sich in diesem Fall mit dem archäologischen Quellenstand in der näheren Umgebung zu decken scheint (Lechterbeck/Kerig 2004). Ferner lassen die Pollendiagramme keine kontinuierliche Entwaldungsgeschichte erkennen, sondern offenbar auch immer wieder regional zwischengeschaltete Phasen der Wiederbewaldung, beispielsweise kurz vor dem Einsetzen der Glockenbecherkultur um die Mitte des 3. Jahrtausends v. u. Z. (Lechterbeck u.a. 2014). Erst nach dieser Phase verdichten sich die Hinweise auf umfangreiche Landöffnungen

und große Anbauflächen, die im Laufe der Bronzezeit zudem für immer längere Zeiträume offengehalten wurden (Rösch u.a. 2014a; Rösch u.a. 2014b; Rösch/Lechterbeck 2016). Eine besonders stark durch Offenlandanzeiger geprägte Phase während der ausgehenden Frühbronzezeit scheint in Deckung mit den bisherigen Erkenntnissen zur Erosionsgeschichte des westlichen Bodenseegebiets zu stehen. Besonders mächtige Kolluvien dort und zum Teil auch in angrenzenden Gebieten wurden ebenfalls in diesen Zeitraum datiert, was auf erhebliche Bodenerosion infolge großflächiger Landöffnung und intensiver Bodenbearbeitung hinweist (Maier/Vogt 2007. Vogt 2014. Henkner u.a. 2017. Höpfer u.a. 2017b). Dies wird vor allem mit technologischen Änderungen wie dem rindergezogenen Hakenpflug oder der bronzenen Erntesichel in Verbindung gebracht, die im Laufe der Bronzezeit eine immer tiefere Bodenbearbeitung auf immer größeren Anbauflächen ermöglichten (Behre 1998. Falkenstein 2009). Dass ausgeprägte Offenlandphasen häufig mit hohen Anteilen von Eichenpollen und erhöhten Werten für *Plantago lanceolata* (Spitzwegerich) einhergingen, ließ darüber hinaus auf eine verbreitete Mittelwaldwirtschaft schließen (Rösch u.a. 2014a, 16. Rösch u.a. 2014b). Dabei dienten die Wälder neben der Produktion von Brenn- und Bauholz explizit auch als Weideflächen sowie möglicherweise zur Gewinnung von Laubfutter für größere Viehbestände (Penack 2011). Zu betonen ist allerdings, dass repräsentative Untersuchungen von botanischer wie von pedologischer Seite bislang fast nur aus dem östlichen, bodenseenahen Teil des Hegaus stammen. Rückschlüsse auf Art und Umfang der Landnutzung in seinem westlichen Teil – jenen aufgeschotterten Talwannen und Niederungen also, für die ab der Mittelbronzezeit eine deutliche Zunahme der Besiedlung festgestellt werden kann (Höpfer 2014 Abb. 3) – bleiben vorerst nur eingeschränkt möglich. Zu erwarten wäre dort bei gleichbleibender Wirtschaftsweise aufgrund der starken Siedlungsverdichtung eine markante Zunahme der oben genannten Anzeiger für ackerbaulich genutztes Offenland und eichendominierte Nutzwälder im Laufe des 16., spätestens ab dem 15. Jahrhundert v. u. Z.

6.2 Ergebnisse zur Anthrakologie

Unter insgesamt 4601 bestimmten, unterschiedlich großen Holzkohlefragmenten konnten acht Taxa bestimmt werden (Tab. 2). Insgesamt sticht mit knapp 85 % aller bestimmten Fragmente die Eiche (*Quercus* sp.) deutlich hervor, während die Buche (*Fagus* sp.) mit gut 12 % vertreten ist. Ahorn (*Acer*), Birke (*Betula*), Haselstrauch (*Corylus*), Hartriegel (*Cornus*), Kernobst (Maloideae) und Liguster (*Ligustrum*) waren zwar vorhanden, jedoch nur in einzelnen Proben und in sehr geringen Anteilen (Abb. 13). Für die Mittelbronze- und Urnenfelderzeit zusammen dominieren mit über 98 % somit die Taxa der Querco-Fagetea-Waldgesellschaft, also *Quercus* sp., *Fagus* sp. und *Acer* sp., während Taxa wie *Betula* sp., *Cornus* sp., *Corylus* sp. und *Ligustrum* sp., die typischerweise mit Waldlichtungen einhergehen (Rösch 1996), mit nur 1,33 % vertreten sind. Mögliche Veränderungen scheinen sich allerdings in den Anteilen der Lichtungsanzeiger anzudeuten, die von den mittelbronze- zu den urnenfelderzeitlichen Befunden insgesamt um mehr als drei Viertel abnehmen (von 1,82 % auf 0,43 %). Anstelle von *Cornus* sp. sind in den bis zu 500 Jahre jüngeren Gruben vereinzelt *Corylus* sp. und *Ligustrum* sp. nachgewiesen, während *Acer* sp. nicht einmal mehr vereinzelt in den Querco-Fagetea-Taxa identifiziert werden konnte.

Gliedert man die Daten noch weiter auf, so zeigen die einzelnen Brandgruben eine zum Teil erhebliche Variationsbreite, die angesichts der Stichprobengrößen zumindest für die dominierenden Taxa weitgehend signifikant sein sollte (Abb. 12). So wird erkennbar, dass sich *Acer* sp. wie auch *Fagus* sp. in beiden Perioden hauptsächlich in einer bzw. zwei Gruben konzentrieren, wodurch die Dominanz von *Quercus* sp. in den übrigen Befunden noch deutlicher wird. Die geringe Repräsentanz der untergeordneten Lichtungs-Taxa mahnt indes bei der Interpretation ihrer Anteile zur Vorsicht. Es fällt aber zumindest auf, dass sie einerseits in großen Stichproben ausbleiben können (Bef. 4487) und andererseits durchaus in kleineren schon vorkommen können (Bef. 4377). Insgesamt könnte die Varianz bei Befunden derselben

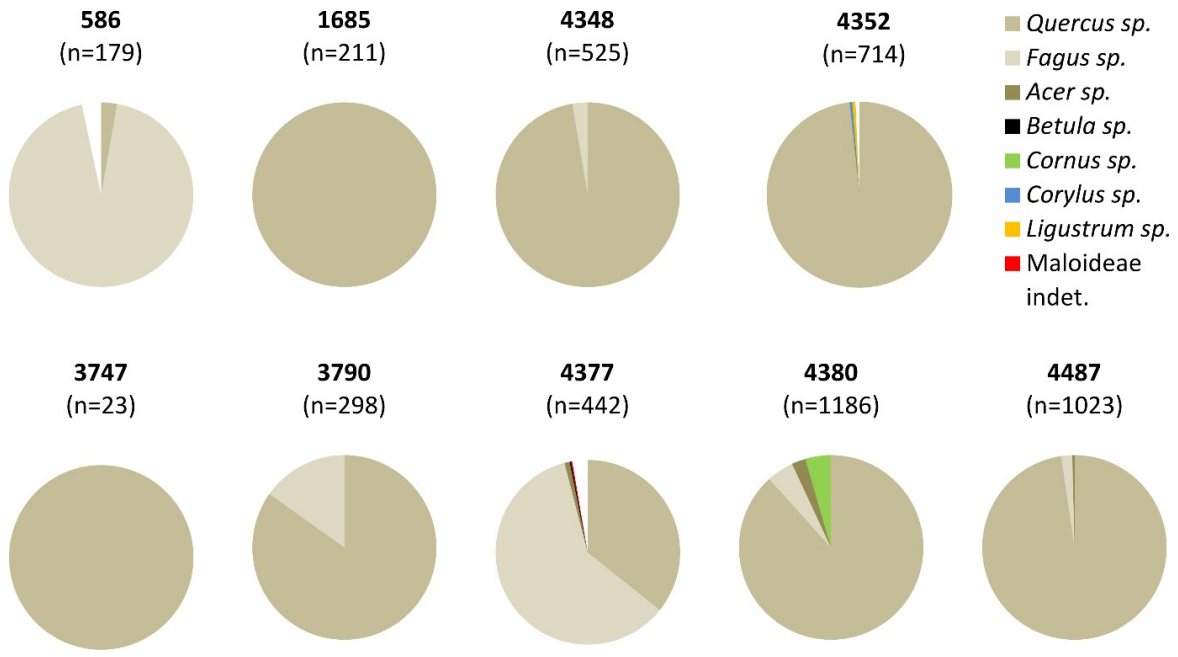

Abb. 12: Prozentuale Anteile der Taxa in den Stichproben der einzelnen, untersuchten mittelbronze- (unten) und urnenfelderzeitlichen (oben) Brandgruben.

Periode möglicherweise darauf hindeuten, dass das Brennholz an verschiedenen Standorten oder zu verschiedenen Zeitpunkten beschafft wurde. In diesem Zusammenhang ist darauf hinzuweisen, dass viele Fagus-Fragmente aus verschiedenen Proben und in einem Befund einige Male *Cornus* sp. (Bef. 4380, Fundbuchnr. 2663) Insektengänge aufwiesen. Dies deutet darauf hin, dass totes, bereits am Boden liegendes Holz gesammelt wurde. Soweit es die Fragmente erkennen ließen, wurden dabei regelmäßig dünnere Zweige sowohl von *Quercus* als auch von *Fagus* (z. B. Bef. 4380, Fundbuchnr. 2227 und 2663) verwendet. Dass mitunter aber auch dickere und ältere Stücke genutzt wurden, ist aufgrund der teils recht alten AMS-^{14}C-Daten anzunehmen (s.o.).

6.3 Interpretation „on-site“ und „off-site“

Die meisten in Anselfingen nachgewiesenen Holztaxa sind als gutes bis sehr gutes Brennmaterial bekannt. Überhaupt nicht vertreten sind Nadelhölzer, was allerdings der Situation in anderen anthrakologisch untersuchten Brandgruben-Fundstellen entspricht und

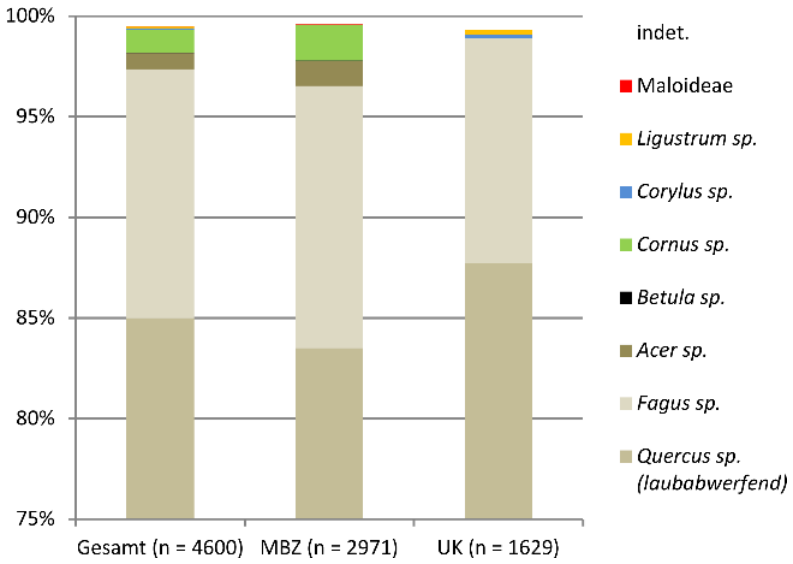

Abb. 13: Prozentuale Anteile pro Taxon für alle untersuchten Holzkohle-Stichproben aus den mittelbronze- und urnenfelderzeitlichen Brandgruben.

einerseits mit deren geringeren Brennwerten, andererseits mit einem negativen Einfluss der harzigen Hölzer auf den Geschmack etwaigen Garguts erklärt wurde (s. Beitrag Honeck in diesem Band). Unter den Laubhölzern werden generell *Quercus* und *Corylus* als sehr gutes, *Fagus*, *Betula* und Maloideae als gutes Brennmaterial angesehen (Stovesonline.co.uk). Die Verteilung der Holzkohlen spiegelt also nicht unmittelbar die Qualität des Brennmaterials wider. Davon ausgehend, dass innerhalb eines möglichst geringen Radius alles verfügbare und nicht gänzlich ungeeignete Material, d. h. außer dem wegen seiner ungünstigen Brenneigenschaften unerwünschten Nadelholz, gesammelt wurde („principle of least effort"), weist die starke Eichendominanz insofern auf anthropogene Eingriffe in die umliegenden Wälder hin. Ungestörte Querco-Fagetea-Waldgesellschaften würden sich üblicherweise zu reinem Buchenwald entwickeln, weil Buche schneller wächst und Schatten eher toleriert als Eiche, sich also unter sich selbst verjüngen kann. Das bedeutet, dass Querco-Fagetea-Waldgesellschaften nur durch menschliche Einflussnahme erhalten werden können, indem Eiche gezielt gefördert wird, z.B. für die Ernährung der Tiere (Waldweide/Hudewald), für Feuerholz (z.B. Mittelwald) oder Wertholz (Hochholz) (Mosandl/Abt 2016). In das Bild eines solchen „Mittelwald"-Managements würde sich das gleichzeitige Vorhandensein kleiner

Zweige oder Äste und einzelner älterer Hölzer (s.o.) in den Brandgruben sehr gut einfügen, auch wenn dieser Beobachtung hier keine systematische Diametermessung zugrunde liegt. In einer großflächig von offenen Anbauflächen durchzogenen Landschaft, wie sie für die Bronzezeit anzunehmen ist (s.o.), wären unter anderem *Betula* sp. und gerade auch *Corylus* sp. als Pionier- bzw. Ruderalhölzer zu erwarten. Dass sie trotz ihrer guten bis sehr guten Brenneigenschaften kaum bis gar nicht in den Brandgruben erscheinen, könnte dafür sprechen, dass weniger gezielt nach den hochwertigsten Brennmaterialien gesucht wurde, sondern das Sammeln, möglicherweise sogar eher beiläufig, während des Aufenthalts im Wald erfolgte, etwa während des Viehumtriebs. Das hier beschriebene Holzartenspektrum fügt sich darüber hinaus auch sehr gut in das Bild ein, das bisherige Untersuchungen an bronze- und eisenzeitlichen Brandgruben mit Hitzesteinen vermittelten (s. Beitrag Honeck in diesem Band). Im mittelfränkischen Burgbernheim (Lkr. Neustadt a. d. Aisch-Bad Windsheim) konnten jüngst mehrere urnenfelder- bis hallstattzeitliche Brandgruben freigelegt und botanisch untersucht werden (Beigel 2019. Herbig 2019). Auch dort konnte eine ganz deutliche Dominanz von *Quercus* sp. unter den Brennhölzern bestätigt werden, die regelmäßig als Zweigholz vorlagen. Daneben enthielten die untersuchten Brandgruben gelegentlich eher kleinteilige Keramikfragmente, überwiegend unverbrannte Tierknochen und kleine Silexfragmente. Insbesondere aufgrund der botanischen Makroreste, darunter u. a. Druschreste verschiedener Getreidearten, können die Verfüllungen „allenfalls als alltäglicher Abfall klassifiziert werden, der zufällig in den Befunden zur Ablagerung kam und dort verkohlte“ (Herbig 2019, 135).

Fundbuch-Nr.	Bef. Nr.	Abtrag/Planum	Datierung	Zuordnung	Vol	Querco-Fagatea			Waldlichtungen				Maloideae	indet.	Anmerkungen
						Quercus sp. (laubwerfend)	*Fagu* s sp.	*Acer sp.*	*Betula* sp.	*Cornus* sp.	*Corylus* sp.	*Ligustrum* sp.			
2738	3747	1-S	MBZ	unklar	no flotation	19									
1777	3747	4	MBZ	Grubenbrand	no flotation	3									
1777-1	3747	4	MBZ	Grubenbrand	no flotation	1									
1780	3790	2-3	MBZ	Grubenbrand	12 l	252	45								
1780-1	3790	2-3	MBZ	Grubenbrand	no flotation	1									
2190	4377	2	MBZ	Grubenbrand?	no flotation	17	2							5	
2799	4377	2-3	MBZ	Grubenbrand	no flotation		2							1	
2809	4377	2-3	MBZ	Grubenbrand	no flotation	22	29							1	
2181	4377	3 Ost	MBZ	Grubenbrand	no flotation		2	4	1					1	
2668	4377	3 Ost	MBZ	Grubenbrand	2,4 l	82	231								*viele Fagus*- Fragm. m. Tiergängen
2662	4377	3 West	MBZ	Grubenbrand	no flotation	1									
2662	4377	3 West	MBZ	Grubenbrand	no flotation	36								4	
2662-1	4377	3 West	MBZ	Grubenbrand	no flotation								1		
2227	4380	1-2	MBZ	Steinpackung	no flotation		6								*Fagus*- Zweige
2227-1	4380	1-2	MBZ	Steinpackung	no flotation		1								*Fagus*- Zweig mit Rinde
2663	4380	3	MBZ	Grubenbrand	8l	1048	48	29		53					*Quercus*- Zweige
2663-1	4380	3	MBZ	Grubenbrand	no flotation		1								
2667	4487	2	MBZ	Grubenbrand	10,5l	998	20	4							einige Fagus-Fragm. m. Tiergängen
2667-1	4487	2	MBZ	Grubenbrand	no flotation	1									
					Total n:	**2481**	**387**	**37**	**1**	**53**	**0**	**0**	**1**	**12**	**2972**
					Fragment %:	**83,48**	**13,02**	**1,24**	**0,03**	**1,78**	**0,00**	**0,00**	**0,03**	**0,40**	**100,00**
					Total %:	**97,75**			**1,82**						
438	586	1-S	UK	Grubenbrand	9 l	5	168							6	
757	1685	2-3	UK	Grubenbrand	6,2 l	210									
757-1	1685	2-3	UK	Grubenbrand	no flotation	1									
2800	4348	1-2	UK	Steinpackung	no flotation	4									
2808	4348	3	UK	Grubenbrand	no flotation	24									
2665	4348	3 West	UK	Grubenbrand	2,8 l	483	14								*viele Fagus*- Fragm. m. Tiergängen
2755	4352	2-3	UK	Grubenbrand	no flotation	6									
2669	4352	3 Ost	UK	Grubenbrand	8,6 l	696					3	4		5	
					Total n:	**1429**	**182**	**0**	**0**	**0**	**3**	**4**	**0**	**11**	**1629**
					Fragment %:	**87,72**	**11,17**	**0,00**	**0,00**	**0,00**	**0,18**	**0,25**	**0,00**	**0,68**	**100,00**
					Total %:	**98,90**			**0,43**						

Tab. 2: Ergebnisse der Holzkohlenbestimmung und prozentuale Verteilung der Fragmente pro Taxon in den untersuchten Stichproben.

					Total n:	3910	569	37	1	53	3	4	1	23	4601
					Fragment %	84,98	12,37	0,80	0,02	1,15	0,07	0,09	0,02	0,50	100,00
					Total %:	98,15			1,33						

7 Schlussfolgerung

Wie gezeigt werden konnte, liefert die Auswertung der mittelbronzezeitlichen Siedlung von Anselfingen bereits beim jetzigen Auswertungsstand verschiedenste Einblicke in ein vielseitiges Siedlungsgeschehen. Schon die variantenreiche Architektur lässt eine komplexe Dorfstruktur erahnen, die für verschiedene Aktivitäten und Bedürfnisse ein ideales Umfeld schuf. In Baden-Württemberg lassen sich jedoch in den wenigen bislang publizierten Mittelbronzezeit-Siedlungen nur bedingt Traditionen aus früheren Zeitabschnitten beobachten. Zwischen diesen nach bisherigem Forschungsstand mehrheitlich erst in die jüngere Mittelbronzezeit zu datierenden Wohnplätzen und den wenigen frühbronzezeitlichen Landsiedlungen wie Ulm-Bopfingen (Krause 1997) oder Hohenstadt (Thoma 2013. König u. a. 2014) klafft weiterhin eine Lücke; die Quellen dieses auf das 17. und 16. Jh. v. u. Z. fallenden Zeitabschnitts umfassen vor allem die spätfrühbronzezeitliche Pfahlbautradition der Arboner Kultur sowie eine Vielzahl mehrheitlich kaum erforschter Höhensiedlungen (Köninger 2015; Köninger/Schöbel 2010; Biel 1987).

Wegen ihrer Vergleichbarkeit mit anderen, vor allem bayerischen Fundstellen kommt den Gebäuden mit umlaufendem Wandgräbchen aus Anselfingen und anderen Fundstellen im Hegau besondere Bedeutung zu. Sie weisen auf Verbindungen in die östlicheren Gebiete der Hügelgräberkultur hin, wo sich derartige Bauten auf frühbronzezeitliche Traditionen zurückführen lassen (Bankus 1995. Schefzik 2010). Ähnliches gilt für die Gebäude mit apsidenartigen Schmalseiten, wobei derartige Bauten nicht nur aus Bayern, sondern auch aus Ostfrankreich bekannt sind (Schefzik 2010, 336 m. Abb. 3). Schwierig einzuordnen bleiben hingegen mangels nahegelegener Vergleiche diverse Bauten unterschiedlicher Rechteckform und Größe, die hier vorläufig als „Nebengebäude“ subsummiert seien. Zumindest bei den regelmäßigeren, mittelgroßen Rechteckbauten, die teilweise mit Feuerstellen ausgestattet waren, deren Auskleidungen mit Kalksteinplatten pyrotechnisches Handwerk

unwahrscheinlich erscheinen lassen, ist jedoch an die Nutzung als Wohngebäude zu denken. Bei allen Anselfinger Gebäuden sind die jeweils gegenüberliegenden Wandpfosten paarig angeordnet, waren vermutlich also durch Querlieger verbunden. Sofern vorhanden scheinen größere Firstpfosten mehrheitlich in diese Jochbildung einbezogen gewesen zu sein, während leichtere, wohl nicht tragende Einbauten zum Teil leicht versetzt von diesen Querliegern lagen. Insgesamt gibt die Proportion und Konstruktion der kurzrechteckigen Bauten bereits Anklänge zur Architektur der spätbronze- und eisenzeitlichen Mehrhausgehöfte Süddeutschlands zu erkennen (Schefzik 2001). Eine gewisse Sonderstellung scheint indes kleinen, vermutlich gestelzten Vierpfostenspeichern zuzukommen. Während sie in den südwestdeutsch-schweizerischen Mittelbronzezeit-Siedlungen regelmäßig vorhanden sind, spielten sie nach bisherigem Forschungsstand offenbar in den frühbronzezeitlichen Langhaussiedlungen Süddeutschlands praktisch keine und auch in den bereits zu Rechteckbauten tendierenden Mittelbronzezeit-Siedlungen Bayerns noch keine vergleichbare Rolle (Schefzik 2010, 336). Dass sie sich in Anselfingen und anderen mittel-bronzezeitlichen Siedlungen der Region häufig in bestimmten Arealen zu gruppieren scheinen mag einer Mehrphasigkeit geschuldet sein, könnte aber auch auf eine komplexe Form der gemeinschaftlichen Vorratshaltung hindeuten. Ihr regelhaftes Vorkommen im südwestdeutsch-schweizerischen Raum lässt vermuten, dass diese Form der Organisation von Vorratshaltung weniger mit den oben genannten Traditionen in den östlichen, bayerischen Regionen in Zusammenhang steht, sondern eher ein hiesiges Element darstellt. Ob es sich damit um ein innovatives Element der Mittelbronzezeit im nordwestlichen Alpenvorland handelt oder dessen Ursprünge in den spätfrühbronzezeitlichen Seeufersiedlungen zu suchen sind, sei dahingestellt, zumal die Feuchtbodenarchitektur naturgemäß kaum mit den hier besprochenen Strukturen zu vergleichen ist, auch wenn durchaus gelegentlich derartige Bezüge hergestellt wurden (Menotti 2003, bes. 390–393). So deuten sich gleichermaßen Bezüge zum östli-chen Verbreitungsgebiet der Hügelgräberkultur

wie auch regionale oder nach Westen weisende Eigenheiten in der Anselfinger Architektur an. Nach bisherigem Kenntnisstand dürften sich diese spätestens ab dem 15. Jahrhundert v. u. Z. in einer flächendeckenden und von den Seeufern weitge-hend losgelösten Besiedlung des nordwestlichen Alpenvorlands vereinigt haben.

Darüber hinaus sind in Anselfingen funktionale Einrichtungen wie Zäune, Viehpferche und dergleichen zu erahnen, bleiben aber rein archäologisch schwer zu fassen. Wasserstellen und Wegführungen – sofern datierbar – sowie Feuer- oder Herdstellen und Kochgefäße bezeugen ein Nebeneinander verschiedenster Aktivitäten innerhalb der Dorfstruktur, das es durch weitere Materialvorlagen einem breiteren Vergleich zuzuführen gilt. Dass in den Boden eingelassene Kochgefäße offenbar zusammen mit den Brandgruben mit Hitzesteinen gehäuft abseits der Bebauung erscheinen, rückt beide Befundgattungen in eine ähnliche Deutungssphäre. Zunächst handelt es sich nur um eine Korrelation und noch nicht zwingend um einen kausalen Zusammenhang. Beide Befundarten könnten beispielsweise mit verschiedenen geruchsintensiven Tätigkeiten verbunden oder auch Bestandteile von Gemeinschaftshandlungen gewesen sein, die gleichermaßen außerhalb des Haushalts stattfanden, ohne dabei unbedingt in Verbindung zu stehen. Sollte die mehrheitlich akzeptierte Annahme zutreffen, dass die Brandgruben der Garung von Speisen dienten, ist aufgrund ihrer Größe und abgesetzten Lage im Freien immerhin zu vermuten, dass dies nicht alltäglich geschah. Zudem können in Anselfingen keine Hinweise auf wiederholte Nutzung einzelner Brandgruben benannt werden, eher sprechen bestimmte Befund-merkmale für ihre einmalige Verwendung. Trotzdem ist klar, dass sie, ganz im Gegensatz zum übrigen, vor allem spätbronze- und eisenzeitlich belegten Verbreitungsgebiet, im nordwestlichen Alpenvorland regelhaft im Kontext mittelbronzezeitlicher Siedlungen erscheinen. Ihre Nutzung scheint über eine gewisse Zeit vorbereitet worden zu sein, nämlich durch das Ansammeln vermeintlicher „Abfälle“, insbesondere von ausrangierten Hitze-/Kochsteinen, die zur Abdeckung des

Grubenbrandes eben noch geeignet waren, sowie durch das Sammeln geeigneten Brennholzes in den vermutlich eichendominierten Nutzwäldern. Die abschließend vorgestellten Ergebnisse zum Holzartenspektrum aus den Brandgruben lassen sich sehr gut an die bisherigen palynologischen Daten zur Vegetationsgeschichte aus dem westlichen Bodenseegebiet anknüpfen. Auch wenn letztlich die Auswahlkriterien der prähistorischen Brennholzsammler unbekannt bleiben, fügt sich das vertretene Holzspektrum doch am zwanglosesten in das Bild einer eichenfördernden Waldwirtschaft ein, die in Ergänzung der sich ausbreitenden ackerbaulichen Offenlandnutzung erfolgte. Weitere Pollenprofile und andere Landnutzungsproxys in größerer Entfernung zum Bodensee, also im Westhegau, wo sich eine dichte Besiedlung erst im Laufe der Mittelbronzezeit abzeichnet, wären zur Überprüfung dieser Zusammenhänge von großer Bedeutung.

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Manuscript IV

Soils, Landscapes, and Cultural Concepts of Favour and Disfavour within Complex Adaptive Systems and ResourceCultures: Human-Land Interactions during the Holocene

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Abstract

In this paper we review and contrast three frameworks for analyzing human-land interactions in the Holocene: the traditional concept of *favoured and disfavoured landscapes*, the new concept of *ResourceCultures* from researchers at University of Tübingen, and *complex adaptive systems* which is a well-established contemporary approach in interdisciplinary research. Following a theoretical integration of fundamental concepts, we analyze three paired case studies involving modern agriculture in Germany and Belize, prehistorical changes in land use in southwest Germany, and aquaculture on the Pacific and Atlantic coasts of North America. We conclude that ResourceCultures and complex adaptive systems provide different but complementary strengths, but that both move beyond the favour-disfavour concept for providing a holistic, system-level approach to understanding human-land interactions. The three frameworks for understanding human responses to contemporary cultural and biophysical challenges are relevant to new thinking related to sustainability, resilience, and long-term environmental planning in the Anthropocene.

Keywords: *Human-environment interactions, complex adaptive systems, ResourceCultures, Black Forest agriculture; Bronze Age land use in Germany; Chesapeake Bay oyster culture; German allotment gardens; Pacific Northwest clam gardens; Q'eqchi' Maya swidden agriculture in Belize*

Introduction

In this paper we review and contrast three frameworks for analyzing human-land interactions in the Holocene. The first is the traditional concept of *favoured* and *disfavoured* landscapes, which has a long intellectual history. The second framework, *ResourceCultures*, attempts to supersede the binary limitations of the traditional favour-disfavour concepts by introducing a flexible definition of resources that includes both tangible elements such as raw materials and intangible ones such as power and knowledge. The third framework views human-land interactions as decomposable, and instead of providing an interpretivist framing, it views them as complex adaptive systems which have unique system-level properties which emerge out of non-deterministic, contingent low-level interactions among human and non-human agents. This study results from an interdisciplinary collaboration between archaeologists, ecological anthropologists, soil scientists, and ethnographers from Germany and the United States; and our key discovery is that both ResourceCultures and complex adaptive systems overcome many of the key limitations of the earlier favour/disfavour framework. While the ResourceCultures and complex adaptive systems frameworks derive from contrasting interpretivist and empirical intellectual histories, respectively, they have many qualitative similarities, including a shared focus on dynamic feedbacks between elements of the human-land system and a particular emphasis in explaining historical patterns and non-deterministic change, rather than simple classification. In this paper, we use this insight as a point of departure for analyzing the usefulness of each framework for explaining actual contemporary and archaeological landscapes.

Our approach involves four stages: (1) we review, compare, and contrast the key concepts and historical background associated with each of the three frameworks. (2) we identify key concepts from each framework and develop a protocol for assessing the utility of each for analyzing specific cases. (3) we then draw on the diverse expertise of the coauthors to analyze six, well-studied cases spanning contemporary and archaeological landscapes across Europe and the Americas according to these criteria. (4) We present the results of these analyses as three paired comparisons, and (5) discuss the key concept in order to highlight the strengths and weaknesses of each framework for understanding dynamic settlement patterns and resource use among particular types of human-land systems.

Three Theoretical Frameworks for analyzing Human-Land Interactions in the Holocene

Favourable and disfavourable landscapes

Landscapes can be understood as geographic areas that are divided into reasonably well-defined spatial components, distinguished by ecological and cultural attributes that are relevant to soils and human uses of the land (Potschin and Bastian, 2004; Pearson 2013, Wu, 2013). They are typically defined by their environmental attributes, such as topography, climate, soils, wetlands, native plant communities, or other environmental characteristics. They may contain culturally important places, and therefore are not only defined by environmental conditions, but are imbued with social, religious, and political attributes by the people using and perceiving the land. In this sense, landscapes are a product of past human use of and cultural connections to the land (McGlade 1995, Hambrecht et al. 2018). They may also be understood as socially constructed objects of analysis and individual interpretation (Tilley 1994, Bender et al. 2007).

The concepts of *favourable or disfavourable landscapes* does not refer to an intrinsic property of a physical landscape but rather to the suitability of a landscape to be used for a certain typically human purpose (e.g. grain crop agriculture). For example, a minimum mean temperature of 6°C for six consecutive months is needed to grow and harvest certain grain crops, and this climate-related criterion has been used to differentiate between agriculturally favoured and disfavoured landscapes (Bourke 1984). In central Europe, the concept traditionally refers to environmental conditions during the settlement period of a region (Seidl 2006, Gebhardt 2007). Favoured landscapes are often loess covered, possess fertile soils, low relief intensity, and a climate beneficial for agriculture. These landscapes were therefore supposedly settled earlier than disfavoured ones without such beneficial features (Seidl 2006, Henkner et al. 2017, Kühn et al. 2017). Other terms for disfavoured landscapes are *marginal land, degraded land*, *waste land*, *upland*, *hinterland*, or *outland*. These terms connote particular economic and social systems that were not sustainable and were viewed as static landscapes (Brown et al. 1998, Coombes and Barber 2005, Dauber et al. 2012).

Historically, the dichotomous categorizing of landscapes as favoured or disfavoured was based solely on the agricultural potential or the workability of soils, while not acknowledging important cultural aspects influencing the settlement dynamics of a region. In contemporary studies, the favour/disfavour categorization was also seen as problematic, which led to the development of the additional related concepts such as *territoriality*, *marginality* and *liminality* which broaden favourability (and disfavourability) to include culturally-determined concepts. Marginality, for example, focuses on human perceptions and valuation of space. Territoriality refers to social power and the control over space by certain groups or individuals, and liminality

refers to the transition or buffer zones, which separate better organized and controlled spaces. Any physical space can have multiple overlapping aspects of these concepts. Because it can be perceived and used differently by individuals or groups, the practical and symbolic uses of a space can intersect (Neuburger 2017), and territorialities can vary in time (Miera 2020). While these approaches show that the definition of a landscape as favoured is always dependent on the culturally defined needs and the perception of people, the dynamics behind such processes are not extensively evaluated. Thus, the simplistic and static terms, favour and disfavour remain insufficient for explaining dynamic historical and modern uses of and decision-making about landscapes.

For example, the successful introduction of hexaploid wheat (*Triticum aestivum*) and tetraploid emmer (*Triticum turgidum* subsp. *dicoccum* and conv. *durum*) into continental Europe starting in the early 5th millennium BCE may have shifted landscapes disfavoured due to lack of wild game for hunting into favoured ones that could then be exploited agriculturally for grain production. Similarly, agriculture might have lost its importance when other culturally desirable and economically profitable raw materials like silver, iron, or gold were found beneath the land surface. The landscape would then be favoured for mining and exploitation of raw materials; but not for agriculture. As a result, landscapes could have been disfavoured agronomically, but favoured as sources of geological resources, wood, or water. The favour-disfavour classification is clearly insufficient for understanding how and why humans used and changed such landscapes over millennia.

ResourceCultures

In order to develop a new paradigm of *resource*, interdisciplinary scholars from archaeology, cultural anthropology, soil science, and related disciplines formed the *Sonderforschungsbereich* 1070 *ResourceCultures* (RC) at the University of Tübingen (Bartelheim et al. 2015, Hardenberg 2017*ab*, Hardenberg et al. 2017). The SFB 1070 offers a new perspective on resources with the focus on their importance for social relations. The following characteristics are central to the paradigm:

(1) Both *tangible* (e.g., raw materials and soils) as well as *intangible* things (e.g., knowledge and social structures) can be defined as resources.

(2) All material and non-material things are resources if they are important for the formation, maintenance, and transformation of social networks, communities, and identities.

(3) Resources are defined as an analytical category with a constructivist perspective. Nothing is intrinsically a resource for the formation of identities and social relations. Instead, cultural perceptions and practices lead to the valuation of certain elements within social groups, thereby turning these into resources for this group.

(4) Culture is defined as a contingent spectrum of possibilities, a diversity of conceptions, organizational forms, and practices. As the perception and use of resources in a society is constantly changing, dynamic relationships evolve. These dynamics result in the emergence of new resources while other tangible or intangible things lose their status as a resource (Hardenberg 2017*ab*, Hardenberg et al. 2017).

An example of constantly changing and dynamic relationships between resources and other elements can be found in medieval monasteries in southwest Germany, where spirituality became an important resource for the monks and the nobility (Krätschmer et al. 2018). This is indicated through the dynamics of social relations between nobility and monks which is based on the transformation of tangible objects into important intangible resources for certain members of medieval societies, namely the conversion of donations of land by the nobility into eternal salvation for the gifting through prayers by the monks. However, in today's societies, these prayers have lost their importance and new resources came into being.

(5) Societies, of course, have multiple resources, as defined above. However, other elements are needed to enable the use of a specific resource. These combinations of objects, knowledge, practices, and individuals can be analyzed using so-called *ResourceComplexes*. This analytical device allows the identification of elements that interact to make use of a resource such as soil or that enable the settlement of a region.

An example of a ResourceComplex is the establishment of the settlements associated with the ditched enclosures of Azután in Spain during the Later Prehistory of Central Iberia, which required several different resources (Schmitt 2017). These resources (e.g. fertile soil, crop plants, and domesticated animals) interacted with other elements of the environment and the contemporary society forming a ResourceComplex that enabled the settlement of the region. As part of a ResourceCulture, the ResourceComplex approach connects resources with social, political, and religious relationships and identities in a meaningful way (Hardenberg 2017*ab*, Hardenberg et al. 2017). These new ideas aid in the study and analysis of both culture and time-specific perceptions and dynamic uses of landscapes.

Complex Adaptive Systems

Complex Adaptive Systems (CAS) is an interdisciplinary framework for studying social and natural systems that incorporates insights about the fundamental unpredictability that characterizes most systems (Castellani, 2013). The recognition that an alternative to earlier equilibrium-based approaches was needed arose in the early 1970s, when mathematical ecologists discovered that even the simplest biological models could exhibit extremely complex and chaotic behavior (May 1974*ab*, 1976). Simple explanations for more complex systems, such as empirical animal population dynamics (Odenbaugh 2011) or human demographic patterns (Liu 2001), appeared unreliable. This increased interest embraced the complexity of systems, rather than eliminating it, and it exposed the shortcomings of earlier reductionist approaches (Coffman 2011, Moreno et al. 2011). The broad concept of *complex adaptive systems* has thus emerged as a way to characterize and analyze systems that exhibit complex and unpredictable dynamics and patterns of behavior (Lansing 2003). Complex adaptive systems are characterized by non-equilibrium states and nearly constant change and reinvention over time. In anthropology, this idea led to prioritizing human agency and a constructivist view of nature (Scoones 1999), and to the recognition that most landscapes are dominated by human activity (Balée 2006). However, the impact of CAS on the development of methods and theory for understanding coupled dynamics of human-natural systems has been relatively small until recently (Liu et al. 2007, Bird 2015).

Complex adaptive systems consist of numerous parts interacting across multiple scales in space and time that comprise humans, animals, plants, soils, water, and other systems. Some of these elements accumulate experience and adapt by changing their modes of behavior, resulting in some form of success, reward, or survival (Holland 1995, 2014; Mitchell 2009). These systems have several common characteristics:

(1) *Emergent properties*. Colloquially, emergence refers to the idea that the whole is more than the sum of its parts (Fisher 2009), but in more formally terms, emergent properties include chaotic behavior, feedback dynamics, regular patterns in space and time, and self-organization of the system into hierarchies and classes in the absence of any form of centralized control (for examples see Lansing and Downey 2011, Lansing 2007, Lansing 2012).

(2) *Domination by non-equilibrium states*. Equilibrium states exist when aspects of a system balance one another, but it is now understood than most complex adaptive systems are dominated by non-equilibrium states (Lansing 2003). These can be steady

states, low entropy states, or self-organized states that are maintained by the input of energy and resources to maintain them in a certain condition for some period of time. If the input of energy is stopped, natural processes will drive the system to one with higher entropy and more possible degrees of disorganization.

(3) *Scale in space and time*. Systems may also be affected by inputs across a range of spatial (e.g. local to global relationships) and temporal scales (e.g. daily household interactions, annual rainfall variation, or decadal/centennial climate change) (Levin 1992).

(4) *Feedback relationships*. When subsystems interact and respond to each other the trajectory of the CAS evolves in unpredictable directions. Ecosystems change in response to the stress imposed by human use, and human societies adjust their behavior in response to perceived changes in these systems; in turn, this changes the stress imposed on ecosystems (Scheffer et al. 2002). The result of feedback relationship is non-linear system dynamics, which is a hallmark of most CAS.

(5) *Regime shifts.* Triggers and driving forces (e.g. key historical events) when system thresholds are exceeded. Typically, most CAS can exist in a variety of different *regimes*, where the same essential elements are rearranged in importance of position in a hierarchy. The capacity of a system to absorb disturbances without experiencing a regime shift is known as resilience (Gunderson and Holling 2002), but when thresholds are exceeded, regime shifts occur. *Regime shifts* can be defined as changes in the structure and function of ecosystems or societies between regimes, where these changes can be large, abrupt, persistent, and difficult to reverse (Biggs et al. 2012). Examples of regime shifts on regional scales are population collapses, mass migrations, and desertification processes, which can be caused by population feedbacks, dramatic environmental change, warfare, disease, or complex interactions among these phenomena (Downey et al. 2016).

The three frameworks for analyzing human-land interactions are compared and contrasted in Table 1. In general, we note several differences. First, the favour-disfavour framework is poorly suited for empirical research because of the subjectivity inherent in the dichotomous classification process. Its intellectual history suggests the concept itself developed slowly, and was mainly derived from pre-conceived notions about agricultural suitability that embodied a strong Eurocentric bias. In contrast, both RC and CAS are intentional "frameworks" that were designed to solve a suite of known intellectual and logical problems in analyzing human-land interactions. RC and CAS each strive to be comprehensive and generalizable, whereas the

historical favour-disfavour framework does not. The CAS framework is well suited for empirical research (data collection, analysis, and modeling) because it provides an approach composed of subunits and higher-order system properties that can be used for understanding the emergent properties of coupled human and natural systems. CAS has already made important contributions to the study of human cultural change and ecological dynamics (see examples above). The more recent ResourceCultures framework is a way to define and understand human activities on landscapes and also grapples with dynamic feedbacks among tangible and non-tangible aspects of the human-land system, but in a more flexible interpretivist framework. The valuation of resources by resource users is a central element of RC that allows dynamic, cultural processes in space and time (for example, power, knowledge, and religion) to be included in the analysis of human-land interactions in the Holocene.

In the next section, we use these three frameworks to interpret and analyze six case studies from Germany and the United States that describe human-landscape interactions during the Holocene. The case studies were paired, based on the similarities of the landscapes or their human uses.

Tab. 1: Three Systems for Evaluating Landscape Change and Human Impacts

	Favour/Disfavour	**ResourceCultures**	**Complex Adaptive Systems**
Attributes			
Dynamic vs. static?	Static and dichotomous	Dynamic within interpretive framework for resources	Dynamic in time and space
Quantifiable?	Difficult to quantify; relies on human interpretation	Subjective in interpretation of resource change and definition	Quantifiable using multiple attributes
Ecological vs. cultural	Principally ecological	Both	Both
Theoretical basis	Historical use by ecologists, soil scientists & anthropologists for last 200 years in Europe	Newly-proposed, interpretive basis in soil science and anthropology; redefining the concept of "resources."	Based on ecology and anthropology principles since 1970s; emerging from empirical studies of ecosystem and cultural change
Practical applications	Easily applied, based on traditional ways of interpreting landscapes	Currently being applied in interdisciplinary studies	Widespread tool in modern and historical case studies of human-land relationships

Approach

We posit that the CAS and the RC frameworks are more tenable than the favour-disfavour dichotomy for understanding dynamic human-land interactions on diverse landscapes and soils in historical contexts; however, the strengths and weaknesses of each approach, respectively, are less clear. To explore how CAS and RC frameworks provide a dynamic way of refining the concepts underlying favour and disfavour, we conducted a comparative analysis of three pairs of related case studies in the context of the key attributes of CAS, described below. The pairs were selected based on similarities of human uses of a landscape and time period in the Holocene. In each case, differences and similarities between the results using CAS vs. RC provided an effective and heuristic way to refine or replace the static dichotomy of favour-

disfavour. For each pair of case studies, each of the landscape-human systems was evaluated qualitatively for the following attributes:

1. Nature of land use investigated (contemporary or archaeological)
2. Favourability/unfavourability (has the system been previously defined exogenously, endogenously, or both)
3. Scale of the investigated system in space and time (small: local/months to years; medium: regional/years to centuries; large: geographic units/decades to millennia)
4. System boundaries (clearly or poorly defined)
5. Adaptation (individual or community level adaptation, adaptation through policy, or both)
6. Out-of-equilibrium conditions within the studied system (yes or no)
7. Social and natural feedback effects within the analyzed system (yes or no)
8. Evidence of emergence (local interactions, self-organization into hierarchies, unexpected/unexplainable system-level properties) within the investigated system (yes or no)
9. Alternative regimes possible (yes or no)
10. Are there material or symbolic triggers in the investigated system that have or could trigger regime shifts (yes or no)

Summaries of the Pairs of Case Studies

The first pair of case studies examines modern, small-scale food production in Belize and Germany. The integrated socioecological swidden agriculture system used in Q'eqchi' Maya communities in Belize is dominated by tropical swidden agriculture and open access to land by community members (Downey 2015). Modern urban gardening practiced by German people in two regions in temperate southwest Germany (Teuber et al. 2019) uses land that is leased from the municipality where one-third of the area has to be cultivated with foodstuffs (BKleingG 1983). Both systems have contrasting native vegetation, climates, soils, cultural histories, and land use.

The second pair compares historical and prehistorical agricultural practices in the Black Forest (Knopf et al. 2019), and settlement dynamics in southwest Germany (Henkner et al. 2018). The Black Forest was only used locally during prehistory, but during medieval times, it was systematically developed with the intensive use of wood and self-sufficient agriculture. In the 16th century, the massive expansion of agriculture into higher mountainous regions occurred;

then, starting in the 20th century, arable farming was almost completely abandoned (Knopf et al. 2019). The case study on Bronze Age land use in southwest Germany focuses on three regions, the Baar, the Hegau and the Allgäu, where settlements and their surrounding land are being investigated archaeologically and from the perspectives of soil science (Scherer et al., submitted). Both case studies focus on different areas in the sense of physical geography, but they have similar spatial and temporal dimensions, and similar cultural traditions, regional climates, and human histories.

The third comparison is based on landscapes in shoreline ecosystems, with a case study on clam gardens on the Pacific Northwest Coast of North America, and another on Maryland oyster management in the Chesapeake Bay. The clam gardens illustrate a type of niche construction in shallow coastal areas, where First Nations built broad, shallow, sandy areas as clam gardens for subsistence aquaculture (Deur et al. 2015). The case study in the Chesapeake Bay investigates submerged land and its use in the form of privately leased bottom through state approved oyster aquaculture. These case studies highlight the land-water interface and its importance in the history of North America and modern practices for gathering clams and oysters.

Results

The results of each pairwise comparison of case studies is summarized in Table 2, as they pertain to the specific attributes of CAS. Relationships with RC and ResourceComplexes are in the text descriptions that follow. Table A1.1 contains more detailed information about each of the criteria as it was solicited from each case study specialist.

Maya agriculture in tropical Belize and urban gardening in temperate Germany

Comparing perceptions of favoured landscapes in tropical Belize and temperate Germany highlights similarities defined by soils or climate, and shows differences in culture. In both case studies, a favoured status has been defined relatively, without exploring human capacity to adapt to the physical environment. The soils in the Toledo District were seen historically (by non-Maya outsiders) as less favoured for swidden (slash-and-burn) agriculture than the soils of Alta Verapaz, Guatemala, the Q'eqchi' homeland, where soils were ostensibly ‘richer’. In the German case study, highly favoured conditions are not related to soils but rather depend on climatic and spatial aspects. The latter are related to cultural dependencies, with the hierarchical gardening associations in Germany depending on federal and municipal decisions to assign

them gardening areas. In contrast to this allotment garden space, Belize swidden-related land-use decisions are made at the level of individual households.

The CAS framework generated several useful insights about these two case studies. World Wars I and II in 20th century Europe may have acted as a trigger for changes concerning horticultural land use in German cities and towns (Nilsen 2014), while 19th century social and political oppression by the liberal government of Guatemala may have had significant effects on the use of swidden in Belize by triggering the migration of indigenous communities fleeing such oppression. In Belize and Germany, both cultural and ecological feedbacks may have established new steady states or quasi-equilibria in response to war and political oppression that are important today for community-level political control and food production. In both cases, physical and chemical soil changes may have been less important than social and political factors.

Tab. 2: Summary of Case Study Data Evaluated Under the Rubric of Complex Adaptive Systems Criteria

Criteria (see text for detailed criteria)	Q'eqchi' Maya Swidden Agriculture (Belize)	Urban Gardening in SW-Germany	Agriculture in the Black Forest	Bronze Age land use in SW-Germany	Clam Gardens on the Pacific Northwest Coast (Canada)	Maryland Oyster Management (Chesapeake Bay, U.S.)
1. Nature of land use investigated	Contemporary	Contemporary	Archaeological	Archaeological	Archaeological	Contemporary
2. Favourability/ unfavourability	Both	Exogenous	Exogenous	Exogenous	Both	Both
3. Scale of the investigated system in space and time	Small	Small	Medium	Large	Medium:	Medium
4. System boundaries	Clearly defined	Clearly defined	Clearly defined	Poorly defined	Clearly defined	Clearly defined
5. Level of adaptation	Individual & community	Individual & community	Individual & community	Individual & community	Individual & community	Both individual and policy-level adaptation
6. Out-of-equilibrium conditions within the studied system?	Yes	Yes	Yes	Yes	Yes	Yes
7. Social and natural feedback effects within the analyzed system?	Yes	Yes	Yes	Yes	Yes	Yes
8. Evidence of emergence?	Yes	Yes	Yes	Yes	Yes	Yes
9. Alternative regimes possible?	Yes	No (and Yes)	Yes	Yes	Yes	Yes
10. Are there material or symbolic triggers?	Yes	Yes	Yes	Yes	Yes	Yes

Emergent properties and epiphenomena were also noted in both cases. In Belize, village labor exchange networks exhibit unexpected levels of hierarchy and connectivity despite the absence of top-down coordination of agricultural activities. Similarly, in Germany, emergent hierarchies appear to exist as all gardens participate in a local association that is part of the regional and the national allotment garden association. Further, as in Belize, where *alcaldes*

(village policemen) rarely intervene in day-to-day agricultural activities, the allotment spokespersons in Germany monitor the gardening practices of the individual gardeners only on a yearly basis to ensure that at least one third of the area is dedicated to food production as is required by law (BKleingG 1983). However, on a day-to-day basis, individual decisions, networks between the gardeners and exchange of plants, knowledge, and sometimes even tools shape the allotment garden system.

Comparing the Belize and German case studies is informative because both studies ended up with similar observations about the emergence of local agricultural or horticultural production, despite differences in their overt cultural and theoretical frameworks. The Belize case study began with CAS as an organizing framework, while the German case study began by using the ResourceComplex concept to identify system variables in a particular study site. This latter approach was developed to enable interdisciplinary research, and therefore does not determine which theoretical approach is used afterwards. Thus, the German case study ultimately analyzed the allotment system in the context of a coupled human and natural systems framework that incorporates many of the key insights about complexity and emergence from CAS theory (Gunderson and Holling 2002).

The appearance of the German allotment association during the inter-war period could be hypothesized as an emergent effect of a specific set of historical social and environmental circumstances related to the war. Under this scenario, the post-war need for urban subsistence would have set the 'initial conditions' by converting areas suitable for allotments into gardens so that over subsequent decades individual allotment garden areas could evolve into the nationwide network as described in the case study. The historical context, of course, changed dramatically and unpredictable from the post-war period to today when being outdoors and having healthy nutrition have become more important motivations than subsistence. Similarly, in Belize, historical political oppression in Guatemala led to Q'eqchi' migration into southern Belize. After this trigger event, the initial conditions were set and individual and household-level decisions related to subsistence and wage-labor eventually led to a complex system of village administration characterized by low levels of agricultural oversight, high levels of household independence with respect to land use, and to land use norms related to subsistence-oriented swidden that encouraged sustainability (Downey 2010).

Concepts of favour/disfavour were manifested in both studies as differences in soil fertility in Belize and different climatic conditions in Germany. However, in both cases the regions that have been perceived as disfavoured were ultimately considered favoured due to the adaptive ability of local famers or gardeners. Thus, in comparing the German and Belize case studies, it

appears that RC and CAS can be complementary approaches. The element-identification process encouraged by the RC framework was amenable to interpretation under the key concepts provided by CAS.

Black Forest agriculture and Bronze Age land use in southwest Germany

In traditional research, perspectives of the Black Forest, the Baar, the western Allgäu and the Hegau as favoured and disfavoured regions were based on parameters such as elevation, average temperature, amount of precipitation, and soil quality. As a result, a Western, nature-deterministic perspective predominates the assessment of a landscape's suitability for prehistoric and premodern land use. There is little direct evidence supporting whether prehistoric and premodern farmers used similar arguments to evaluate their daily subsistence or whether their decision-making processes regarding favoured and disfavoured land was guided by more complex parameters and changes over time.

Seen from a CAS perspective, the Black Forest region had unpredictable dynamics: the periods of stability were temporary, and people adapted their behavior in response to social and environmental changes. Although there probably was no centralized authority organizing the transition of mountain forests into fields, a kind of shared organization and agreement must have existed to manage the intensive labour needed for this task. Driving forces behind Black Forest dynamics were likely sociopolitical changes that allowed people to turn the land held as commons into arable fields and other productive agricultural land, as well as an increased population and its associated demand for food.

There must have been a kind of stability in the social and ecological dynamics of the food producing system, allowing people to live continuously in the Black Forest since the Middle Ages. This could be understood as an emergence with regular patterns of land management, self-organization, feedback relationships between farmers and their labour organization, and unstable natural conditions (e.g. with hard winters, late frosts, or heavy rains). The system involved also a certain degree of resilience to minor climatic challenges (e.g. cold and rainy summers); but constant small-scale adaptations of subsistence management were necessary, including the development of specialized handicrafts starting in the 18th century (e.g. cuckoo clock production and trade). The construction of stone mounds was an output of a specific land use which could be considered an emergent property resulting from the above-mentioned triggers (nascent commons and population increase). But it obviously worked only for a certain time before new triggers (e.g. industrialization) led to new adaptations.

The RC framework helps to expand perceptions of natural resources by highlighting the

importance of intangible resources. Within this framework, the definition of ResourceComplexes as an analytical tool of RC and interactive networks can express the complexity of interrelations between tangible and intangible needs based on time-specific human perceptions. From an RC perspective, the Black Forest offered some resources that were seen as favoured depending on time, scale, and specific culturally determined resource use. Concerning the stone mounds and the agriculture on higher ground, this went beyond creating new fields or producing more food. Sunny slopes above cold air pockets at lower elevations, better soils, and an intensive workload turned the formerly disfavoured resource of higher ground and slopes into a favoured landscape, at least for a certain time. But we can also assume that human societies assigned symbolic meaning to the clearing of forests, the building of terraces, and the constant input of labour in starting and maintaining these areas. This could be the positive effect of overcoming the limitations of natural conditions by creating new possibilities of food production.

The study of Bronze Age land use in southwest Germany shows that it was apparently not primarily dependent on physical-geographic parameters. At certain times, favoured regions like the inner Hegau were hardly used, while disfavoured ones like the Baar or western Allgäu were densely settled; therefore, the Bronze Age subsistence lifeways were characterized by great adaptability. It also seems likely that intangible motives like trade and communication or social/political factors might have played a decisive role. According to the RC framework, the accessibility of settlements could have been as much a resource as fish, firewood, or fertile soil. A shift of settlement from the lakes as topographic nodal points to connective inland-corridors like the Baar or western Allgäu means that the resource accessibility underwent a change.

In terms of CAS, the increasing orientation toward trading routes during the Bronze Age can be seen as an emergent property as well as a regular pattern or continuum. The effort put into the maintenance of stable exchange networks by adjusting to the environment of new – and maybe more demanding – areas emphasizes the non-equilibrium state of the land use system. Since there is no clear evidence for any kind of centralized decision-making affecting all of the southwestern German landscape units, the formation of various site types – fortified and unfortified lakeshore settlements, hilltop sites and inland settlements – attests to a self-organization of the settlement network at a local scale. Due to the typically vague chronology of prehistoric developments, however, it is hard to pinpoint specific feedback relationships. Dramatic climate change can be seen as the trigger for the abandonment of the immediate lake shores, but it is not an adequate explanation for inland shifts of many kilometers and an abandonment of previous nodal points. Thus, it seems likely that other impetuses were

eventually overcoming the systems' resilience at a certain threshold. Following the logic of the CAS framework, the system's dependence on interregional exchange might indicate external developments, such as a new political organization of supplies and their distribution as possible triggers or regime shifts.

Both case studies deal with past human-nature interactions while mostly or entirely lacking written records. Interpretations are generally dependent on the quality of material sources, the chronological placement, and the context. Thus, both theoretical perspectives, CAS and RC, provide a more differentiated perspective on favour/disfavour. The latter leads away from simple economic and natural resources to incorporate the importance of a complex set of tangible and intangible resources influencing human land use. The concept of CAS highlights that behind the extension of land use or the shift of settlements, dynamic adaptive systems are hidden. These organically grown, chaotic, and unruled systems are able to react to strong external stimuli and to adjust to changing sociopolitical and environmental changes. The CAS framework also reminds us to evaluate the internal potential for spontaneous changes and, if necessary, to check for external triggers or regime shifts.

CAS and RC disrupt and build on the traditional dichotomy of favour/disfavour concepts and offer other options to interpret how people were acting in and perceiving their landscapes. They also provide insight on how the inhabitants unconsciously changed their land use practices due to internal and external, tangible and intangible factors.

Kwakwaka'wakw clam gardens and Maryland oyster management

The comparison of Kwakwaka'wakw clam gardens and Maryland oyster management highlights shellfish aquaculture taking place on opposite sides of the North American continent, supporting the cultural and spiritual identity of two different cultures. Kwakwaka'wakw clam culture began over 1,000 years ago and largely ended after contact with Europeans led to epidemics that devastated extant human populations. Limited clam culture continued into the early 1900s. At that time, Maryland began a century of oyster management, but continued to vacillate with regard to oyster aquaculture. In both cases, favour/disfavour is subjective and malleable. The Kwakwaka'wakw used submerged land that they could adapt, rendering it favoured for clam gardens. Knowledge of clam gardening has been preserved in songs and other oral traditions for centuries or longer, describing not only the technology of clam culture but a cosmology that saw humans and clams as sharing a mutually beneficial relationship since the beginning of time, each in a way partially responsible for the well-being of the other and interacting with the rest of nature in similar ways. Today, efforts to revive clam gardens and

other foodways are central to historic and cultural preservation in these communities. In Maryland, bottom that may be deemed disfavoured by its barren description is contested by multiple user groups, one of which aims to convert barren bottom into productive oyster bottom via oyster aquaculture. Both cases highlight shifting notions of favour and disfavour, achieved through human practices. In the case of the Kwakwaka'wakw, members actively manipulated shallow coastal areas to create habitat suitable for clam growth. In Maryland, privately leased bay bottom is prepared with shell to grow oysters directly, or containers are used to hold and grow oysters just off the bottom. In both cases, perceived favourability is linked to the spiritual and cultural value of these shellfish resources, which continue to provide livelihoods that yield myriad cultural benefits, with significant contributions to individual and community identities through heritage, sense of place, and stewardship as well as enhanced experiences and capabilities enabled through relationships with these shellfish and landscapes (Michaelis et al., 2020; Michaelis 2020, Wessel 2020).

Considering each case study within the framework of RC, two scenarios focus on a tangible resource, the clam and the oyster, respectively, but also on intangible ones. In both cases, the bivalves provide a source of food directly or indirectly. Less tangibly, these bivalves are also spiritually significant for the Kwakwaka'wakw and historically important to the culture of Maryland. The sociopolitical importance of oysters expands their recognition as a resource. The RC framework also allows us to view the legal and regulatory systems for managing these bivalves as resources. The Kwakwaka'wakw had no legal prohibition on modifying coastal areas for clam gardens, so they likely did not view aquaculture as being in conflict with navigation. In Maryland, aquaculture activities are regulated, and it can be difficult to site an oyster plot on suitable barren bottom. Even if permission is obtained, major bottom alterations such as the Kwakwaka'wakw implemented are still legally prohibited in Maryland. While there is justification for the current legal and regulatory system in Maryland, it may not be fostering shellfish aquaculture as effectively and equitably as it could be. As individuals change the way they interact with their resources, the potential exists for shifting and dynamic identities, practices, and communities.

Applying the CAS framework reveals that each case is well-suited to using it; however, certain characteristics prevent full recognition of CAS details. Both cases are challenged by limited knowledge, but with opposite time constraints. For Kwakwaka'wakw clam gardens, detailed historic data are lacking. For Maryland oyster management, additional time is needed to observe the system-wide effects of more recent policy changes. Both cases demonstrate out-of-equilibrium conditions, feedback effects, potential emergent properties, and possible regime

shifts. Clam garden management influenced nearby habitat and maintained clam populations. Without active management, the system shifts from a productive clam bed to a muddy and sulfidic flat. Communities understood the importance of their management activities. In response to what may be an out-of-equilibrium condition marked by a reduced oyster population, Maryland oyster policy changes reorganized submerged land classifications to create larger no-harvest oyster sanctuaries, reduced bottom for public oyster fisheries, and expanded the potential development of oyster aquaculture (Michaelis et al., in press). As a result, there are more oysters in the water through both sanctuary restoration projects and active oyster aquaculture operations, increasing the ecosystem services provided by oysters. Resource managers hope that these policy changes, paired with better storm water, pollution, and nutrient management at local and watershed levels, may help facilitate an alternative regime with improved water quality, a self-sustaining oyster population, and a "healthier" Bay-system overall.

While triggers were not specifically studied in each case study, both may experience similar ones, particularly major weather events that could dramatically impact aquaculture operations (e.g. hurricanes). Major weather events can destroy or alter estuarine habitat and coastal communities through extreme freshwater input and sedimentation, even in a system adapted to extreme variability. Extended weather patterns during a single season can hinder shellfish recruitment and survival, while enhancing predation and disease-related mortality – potentially having a greater impact than harvest pressure (Mackenzie and Tarnowski, 2018).

Discussion and Synthesis

Favour vs. Disfavour

The presented case studies investigate human-land relationships by illustrating the use of three frameworks: the favour/disfavour dichotomy, RC, and CAS. The results show that the favour/disfavour concept has two dimensions: on the one hand, researchers apply the concept to distinguish between regions suitable and unsuitable for specific uses. On the other hand, the case studies and research on marginality, liminality, and territoriality in anthropology show that favour/disfavour are culturally defined, and the favourability of specific areas often relies on perceptions of individuals and does not always reflect biophysical variables such as temperature or soil quality.

By applying the favour/disfavour concept to different societies, the case studies presented a wide spectrum of human perceptions of landscapes. With respect to the unique temporal and

spatial setting, different variables were used in each case study to explain settlement patterns and specific land uses with regard to favour and disfavour. In the German allotment garden study, climate and different levels of available space were used to assign the favour/disfavour categories, though the gardeners themselves do not use these categories. Similarly in Belize, lands currently used by swidden cultivators are viewed favourably by resource users themselves, but are considered unfavorable for this use by outsiders. In another case study, the favour/disfavour concept was applied to the agricultural development in the Black Forest. The Black Forest is seen as a classic region belonging to the disfavourable category due to the low temperature, high precipitation, and poor-quality soils. However, current research indicates that the Black Forest might have been perceived favourably by the early settlers. The case study of Bronze Age land use in southwestern Germany investigated land use in three landscapes, one of which (the Hegau) is supposed to be favourable, while the other two areas are considered to be less suitable for agricultural land use. However, it was pointed out that the perception of these landscapes probably varied with changes in cultural practices and ideas. Thus, while the Hegau is suitable for agriculture and belongs to the favourable category, it might be less suitable for ritual practices than one of the other investigated areas. Both dimensions of the favour/disfavour concept can be seen in the Maryland oyster management as well. Oyster aquaculture leases in the Chesapeake Bay are limited to areas designated as ‘barren bottom’. Though the initial classification of an area as barren may suggest disfavour, continued discussion of best use indicates that these areas are both cultural and ecologically favourable, according to different contemporary perceptions. By using these case studies, the present paper demonstrates that the favour/disfavour concept needs to include cultural aspects, which can be analyzed and compared.

Scale and Boundaries

The studies of the Q'eqchi' Maya swidden agriculture and the allotment gardens in Germany focus on small spatial scales and include historic developments from 1850 onward, and the two other case studies in southwestern Germany cover a greater area, and span of several centuries or millennia. The case studies on aquaculture in the United States both cover a medium spatial scale and have varying time spans, with the clam gardens of the Pacific Northwest Coast dating back 1000–1700 years ago until the 1930s while the discussion of Maryland oyster management focuses on bottom classification and use in the past century. Despite the different temporal and spatial scales, the criteria of the CAS framework allow a comparison of the different studies.

Boundaries are related to the spatial scale of the systems studied, but include cultural and non-geographic aspects. The physical boundaries varied widely from the household to regional levels, and a community understanding of the boundaries of their system depended who made decisions on resource use and food production and consumption. Both frameworks, RC and CAS, appear adequate for such large variations in space and time and might both allow a cross-scale comparison of case studies that use different aspects and definitions of spatial entities.

Adaptation

Adaptation processes and decisions in both the Q'eqchi' Maya swidden agriculture and the German allotment garden are made at local, community levels. The users adapt individually to changing conditions, such as droughts, heavy rainfall events or erosion. The success of these adaptations to changing conditions can be measured through the amount and quality of the yield as well as health aspects. Similarly, Kwakwaka'wakw clans managed the clam gardens of the Pacific Northwest Coast by transmitting knowledge orally and via experience. The clans measured their success by health aspects and obtaining a good harvest while simultaneously maintaining the clam population. In the Maryland oyster management case study, adaptation happens on the level of the society and individually. Sociopolitical inputs like regulations lead to individual-level adaptations of fishing practices, which may in turn affect other aspects of the system such as target-catch population or other species and habitat. The two archaeological case studies in southwest German cannot reconstruct adaptation processes directly, as there are only limited artifacts and finds that could verify such a claim. However, long-lasting land use (over several decades and centuries) could point to successful management practices and, thus, indicate adaptation to changing social, cultural and environmental conditions. Further, the evidence of trade could indicate a swift distribution of ideas and technologies as means for adaptation. The two archaeological case studies benefit from the exchange with the contemporary studies as they provide valuable insights into cultural and social processes and enable new interpretations of archaeological evidence.

Out-of-equilibrium conditions and feedback mechanisms

Out-of-equilibrium conditions (Lansing, 2003) exist in all case studies, even though these conditions have different characteristics. All of the case studies illustrate how human land use can create out-of-equilibrium states in space and time. By using their own energy, humans transformed landscapes in the past and are creating enhanced carrying capacities in diverse regions, from tropical Belize to temperate Germany. This clearly demonstrates that any concept which addresses land use and settlement dynamics needs to account for human agency. The

creation of out-of-equilibrium states through human interference also creates feedback for the whole system. The CAS framework enables the comparison of the case studies and includes feedback mechanisms, which are inherent to human actions. The RC framework does not use equilibrium – non-equilibrium as such but includes contingency as a dynamic element to allow for out-of-equilibrium behavior of cultures and the description of cultural turns.

Emergence and regime change

In CAS, emergent properties such as the self-organization into hierarchies and classes exist, which are contingent and unexpected, so they cannot be explained by focusing on low-level system dynamics. While the archaeological case studies can only assume emergent properties based on the excavated sites and the artifacts, the observed hierarchies of the contemporary studies might be useful for the interpretation of archaeological finds. The aspect of emergence is especially useful for a better understanding of the favour/disfavour dichotomy. As emergent properties are not coordinated and cannot be explained by focusing on low-level systems dynamics, these properties could lead to a changed perception of the landscape. Thus, landscapes formerly classified as unfavourable could reclassified as favourable by the users. CAS also provides insight into how systems can shift into an alternate regime, which might lead to a reclassification of a system from the favourable category into the unfavorable one or vice versa; however, transitions between these states is subject to non-linear dynamics: movement is not always as easy in both directions. Thus, the CAS framework has the potential to provide new insights for the favour/disfavour concept.

Triggers

CAS also enables the identification of triggers that could lead to regime shifts. The case studies show that the CAS framework and the identification of possible triggers contribute to a better understanding of the dynamics connected to the favour/disfavour categories. As the case study authors stressed, the definition of favour/disfavour should include cultural aspects, CAS provides a framework for linking these sociocultural and environmental dynamics. As the case studies indicate, the CAS framework may have limitations concerning archaeological applications due to the availability of data from prehistory which might be better covered by the RC concept. However, considering certain aspects of CAS in archaeological studies can lead to new interpretations of the settlement patterns and the archaeological finds, or it may potentially drive new methods of data collection and analysis.

Conclusion

The results of evaluating the six case studies in light of Complex Adaptive Systems, ResourcesCultures, and the favour-disfavour framework provide new insight on human-landscape relations throughout the Holocene and the Anthropocene. We posit that insights from non-linear dynamics, new ways of viewing human and natural resources, and complex systems can provide a useful and adaptable framework for doing this in anthropology, archaeology and soil science. While the RC framework focuses attention on dynamic, culturally-defined resources and subjectivity, and the concept of favour-disfavour continues to be used, both RC and CAS both reflect insights into the temporal and spatial dynamics of human cultures on the land. We propose that the conceptual triptych of Complex Adaptive Systems, ResourcesCultures, and favour-disfavour is a novel tool to investigate and understand why and how human-land-culture relationships have changed since the end of the Pleistocene, and especially during the Anthropocene. As humans face challenges related to climate disruption, energy use, food production, and cultural change in the coming decades; having a variety of approaches to ask and answer questions is pertinent to broad issues of sustainability, resilience, and adaptability of human societies and environmental systems of which we are a part.

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Appendix 1 Case Studies

MAYA SWIDDEN AGRICULTURE AND GERMAN ALLOTMENT GARDENS

Q'eqchi' Maya Swidden Agriculture in Belize

This case study is located in the Toledo District, Belize, where there are 42 Maya villages with populations ranging from 70 to nearly 1,000 (mean = 28; Toledo Maya Cultural Council 1997). This area is a wet tropical, evergreen lowland forest (Meerman et al. 2003) with mean annual rainfall approaching ~4000 mm, mostly occurring during a distinct rainy season from June to December. The earliest contemporary Maya villages in the Toledo District date to the late 19th century (Toledo Maya Cultural Council 1997; Wilk 1997, Downey 2015). Bordering Guatemala to the south and west, and the Caribbean Sea to the east, Toledo has been referred to as "the forgotten district" because it was long neglected by the British colonial government. This contributed to the maintenance of a large proportion of the land in the district as property of the monarch of England up through Independence in 1981, when it became property of the government of Belize. The lack of significant private land may have benefited indigenous populations because it made available forested land for swidden farming with little external regulation or oversight.

Belizean Q'eqchi' cultural norms surrounding household-level land tenure dynamics have been explored ethnographically, and historical and political factors have also been studied (Thompson 1930, Wilk 1997, Downey 2010). Throughout the 20th century, Toledo experienced numerous attempts to develop an export economy, including bananas, oranges, lumber, hogs, and coffee. Over the past 20 years, fair trade cacao (McAnany and Murata 2006), ecotourism (Stinson 2013), illegal rosewood cutting for export to China (Zempel 2014); and most recently, oil exploration (Campbell and Anaya 2008) all impacted the region's economy and cultural transitions. Each phase of natural resource extraction was followed by a period of neglect, and this pattern became a cycle in which the Q'eqchi' had periodic opportunities for wage labor, followed by a return to swidden subsistence (Wilk 1997). And while there is some internal migration from Q'eqchi' villages, often seasonally, for wage labor in agriculture and tourism industries, emigration to the United States is less common from Belize than from other parts of Latin America. The study area has also been the focus of intense legal battles with the Belizean government (Medina 2016), and the villages have in recent years been successful as the courts in Belize and the Caribbean Court of Appeals have upheld petitions for community land rights. This has been a significant legal victory with direct implications on community land management and swidden agriculture.

Labor exchange networks in Toledo exhibit unexpected levels of hierarchy and connectivity without top-down coordination. The Village Chairman and a local leader known as an *alcalde* are responsible for the overall health of community lands, but they have rarely monitored day-to-day land use activities (Downey 2010). Other social norms and aspects of Q'eqchi' culture and beliefs suggest that local swidden exhibits a conservative ethos. However, the lack of quantitative data specifically supporting this, and poor models for explaining the dynamics of swidden systems generally, have inhibited the development of an understanding of this coupled human-natural system. Ongoing research by Sean Downey and colleagues (2016-2021; NSF BSC #1553875) is focusing on collecting data and analyzing the coupled dynamics of Q'eqchi' social norms regarding land use and labor reciprocity. They are also investigating tropical ecosystem dynamics to assess whether local carrying capacities related to maize production are enhanced by human land use activity.

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Urban Allotment Gardening in southwest Germany

The case study took place in Baden-Württemberg, southwestern Germany (Teuber et al. 2019), the state known for its capital, Stuttgart, with its global corporations, Mercedes Benz, Porsche, and Bosch. Besides metropolitan Stuttgart, the state has several rural districts where so-called "hidden champions" (Simon 2009) – little known companies that are world leaders in their business sector – provide employment and contribute to the development and growth of the German economy. Although Germany is a highly industrialized country that provides its inhabitants with ample food and many opportunities to spend their free time, gardening is and has been an important activity in the daily life of many Germans. In 2016, 8.4 million of the approximately 82 million inhabitants gardened several times a week, and 17.3% worked in the garden several times a month (Destatis 2017, Statista 2018). Several of those gardeners do not have access to gardens at their homes, but lease a garden plot from a municipality. Some of these allotments belong to the biggest German allotment association Bundesverband Deutscher Gartenfreunde e.V. (2019) with almost a million members. The allotments leased at rather low rates are located within an enclosed area in which the local representative of the allotment association is responsible for the enforcement of German law, which requires each gardener to grow food on at least one third of their plot (BKleingG 1983). Generally, each gardener tends to a plot of approximately 370 m², and all plots consist of a small cottage, vegetable patches, flowerbeds and lawn (Bundesverband Deutscher Gartenfreunde e.V., 2019). The overarching allotment association promotes organic gardening management practices. However, each gardener decides individually which practices are used in his/her allotment. In order to investigate these management practices and garden use in German allotment gardens, the ResourceComplex tool was used to identify variables interacting in the individual gardens. Using the variables soil, plants, tools, and knowledge as a starting point, a questionnaire was designed and applied in 6 allotment garden areas located in metropolitan Stuttgart and Villingen-Schwenningen, which is a town in a rural district (Teuber et al. 2019).

Cooperation within the German allotment areas is limited to the maintenance of pathways and the clubhouse or playground, and voluntary networks that individual gardeners establish. This differs from community gardening, as found in many American cities, where the garden is managed cooperatively (Armstrong 2000, Ghose and Pettygrove 2014). Allotment gardens similar in size, history, and management practices to the ones found in Germany exist in England and France (Nilsen 2014); and in Greece, Finland, Estonia, and Poland (Noori and Benson 2016).

Studies in recent years have shown that the gardener's motives for gardening range from food production to leisure activity. Similarly, the allotment gardeners in southwestern Germany value recreational aspects (Teuber et al. 2019). The comparison of metropolitan and rural allotment gardens showed that food production is more important for the latter (Teuber et al. 2019). The gardeners interested in food production retain the social-ecological memory of food production, as was first mentioned by Barthel et al. (2010) for the Stockholm allotment gardens. Further differences between the regions are the management practices used by the individual gardeners with new methods being more frequently used in the metropolitan gardens.

Both the urban and rural gardening systems have in common that out-of-equilibrium conditions are created by the gardeners within the boundaries of their plots. First, the management practices of adding compost or manure to the plots creates out-of-equilibrium soil conditions in the metropolitan and rural allotment gardens. Further, both systems have a higher biodiversity than the surrounding areas within the towns and cities where the gardens are located, thus creating another out-of-equilibrium space in the cityscape. As food is cheaply available in supermarkets and in farmers' markets in both German regions, even the time spent in the garden can be considered out-of-equilibrium, if one only considers economic reasoning. Triggers for the establishment of allotment gardens have been times of crisis, such as industrialization, and the post war periods after World War I and II (Nilsen 2014), which led to the formation of the first association in 1921 (Bundesverband Deutscher Gartenfreunde e.V. 2019). Regime shifts in the gardening community might occur if food production becomes less important within the allotment gardening community. If the allotment gardening law were to change in the future, a regime shift in the gardening community might be possible.

Applying the favour/disfavour dichotomy to the two, surveyed regions indicates that, climatically, Stuttgart is more favoured. The soil properties of the allotment gardens in both regions are good, so there is no favour/disfavour dichotomy connected to soils. However, the space required for allotment gardens is less contested in the rural region, as there are fewer conflicts of interest between gardens, infrastructure, industry, and housing, making it favoured.

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BLACK FOREST AGRICULTURE AND BRONZE AGE LAND USE IN SOUTHWEST GERMANY

Agriculture in the heights of the Southern Black Forest

The Black Forest is a mountainous area in southwest Germany covering an area of 6000 km^2 and reaching elevations of 1500 m.[1] Apart from the valleys, the natural conditions are nearly alpine. Compared to the Rhine River valley to the west, the mean annual temperatures are much

[1] This case study is based on fieldwork as part of the research project: Archaeological and natural-scientific investigations on the land use history of the southern Black Forest' financed by the German Research Foundation (DFG).

lower and the mean annual precipitation is significantly higher. In the southern parts, the main geological substratum comprises crystalline rocks, such as granite and gneiss. The soils are usually described as acidic, poor in nutrients, and containing many stones. Historically, the Black Forest is seen as a classic, disfavoured region for agriculture. Nevertheless, some authors point to the local existence of soils with a high suitability for agricultural uses (Hädrich and Stahr 2001).

Flint artifacts prove that there was discontinuous land use for hunting or pastoralism in the Paleo-, Meso- and Neolithic times, and pollen analyses show that people changed the forest tree communities for short periods in the Neolithic, Bronze- and Iron Ages; and in Roman times (Rösch 2000, Wagner 2016). From early medieval times onward (Haasis-Berner 2010), archaeological finds and colluvial deposits (Knopf et al. 2012) suggest that humans started to develop and settle the Black Forest systematically.

Since the 1980s, numerous 'stone mounds' of different shapes and sizes have been reported in the area of the town of Titisee-Neustadt. Several thousand of these obviously anthropogenic residues are now documented, mainly on the tops of forested hills and on slopes. Systematic field surveys using LiDAR and mapping were undertaken on two hills near Neustadt, and three mounds were excavated on a hill with an elevation of 1060 m (Knopf et al. 2016). As a result, the stone mounds can be described as resulting from agriculture. The slopes were terraced, and the excavated mounds consisting of irregular stone piles contained remarkable amounts of charcoal. The spatial distribution of the stone mounds suggests that relatively flat areas on the tops of the hills were left open to practice agriculture or grazing. The overgrown areas were cleared of vegetation (by burning the wood), and the stones were gathered. Radiocarbon dating indicates at least two phases of land use, with one possibly starting in the late 15th century CE, but most probably happening in the 16th century, with a second taking place in the 18th or 19th century. The land use can be imagined as a kind of temporary swidden agriculture with breaks in tillage every five or six years, as is known in other parts of the Black Forest (Reif and Katzmaier 1996, Reif and Katzmeir 1997, Henschel and Konold 2008). Intensive land use started with a growing population and the introduction of commons. It is interesting to note, that the land use with stone mounds largely coincides with the Little Ice Age (15th - 19th century CE), reflecting challenging climatic conditions for food production.

Classically defined, disfavoured topographical conditions were turned into more or less useful sites by investing a huge amount of labour. Social, political, and symbolic factors, however, could have contributed to the cultivation of this so called "marginal" land.

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Bronze Age Land Use And Settlement Dynamics In Southwest Germany

The northern pre-alpine foreland of southwest Germany is a diverse mosaic of geographic landscape units. In an ongoing archaeological-archaeopedological project [2], we are investigating settlement and land use dynamics in three physically distinct areas during the Bronze Age, especially the Middle Bronze Age (ca. 16th – 13th centuries BCE). Based on physical geographic parameters, e.g. shorter vegetation periods, lower average temperature, and higher precipitation associated with increasing elevation, two of them (Baar and Western Allgäu) appear to be disfavoured compared to the third (Hegau).

During the Bronze Age, new technologies, such as the pulled scratch plough and the bronze sickle emerged, along with new species of crops and cattle (Behre 1998, Falkenstein 2009). One of the effects of these developments was a general intensification of land use for food

[2] "Favour - Disfavour? Development of resources in marginal areas" under the supervision of Prof. Dr. Scholten, Prof. Dr. Knopf and Dr. P. Kuehn in the Collaborative Research Center SFB 1070 RESOURCECULTURES, financed by the German Research Foundation (DFG).

production. Larger fields were kept open for longer periods and tilled more deeply, resulting in drastic soil erosion in many places (Vogt 2014, Dreibrodt et al. 2010, Henkner et al. 2017). At the same time, the remaining forests increasingly became open, oak-dominated forests used for grazing (Rösch 2013; Rösch et al. 2014). Another major characteristic of this period was the increasing importance of interregional exchange of copper, tin, amber, salt and other resources, as demands for steady supplies grew along with technological and cultural developments (Woltermann 2014, Kristiansen and Suchowska-Ducke 2015).

The spatial distribution of archaeological sites seems to attest to the importance of such exchanges: many sites from the later Early and Middle Bronze Ages are situated on hills or outcrops, often referred to as "hilltop settlements," along larger river valleys. Their actual function as permanent settlements is often debatable, as is their exact age, but it seems clear that they were in some way involved in the structuring of exchange networks (Köninger and Schöbel 2010). During the transition towards the Middle Bronze Age, changes occurred in the distribution of settlement types. Earlier (ca. 18th and 17th centuries BCE), "pile dwellings" on the lakeshores had become the predominant settlement type. Some of these were quite heavily fortified, which seems to identify them as junctions or nodal points within the interregional exchange network (Köninger and Schöbel 2010). During the Middle Bronze Age, the lakeshores were quite suddenly and almost entirely abandoned. This was usually related to a phase of deteriorating climate and rising water levels, which lasted for several centuries and prevented resettlement of the lakeshores until the 11th century BCE (Menotti 2001; Magny 2004). At the same time, the number of inland settlements (around the hilltops) multiplied. This is most evident in the Hegau next to Lake Constance and might, therefore, be seen as a direct reaction to rising water levels. However, it can also be seen in the allegedly more disfavoured landscape units of the Baar and Western Allgäu further inland. Climate change and the resulting disappearance of the ephemeral lakes alone cannot explain why settlement of these remote regions should have intensified. Instead, other factors must have played a role in this dynamic, perhaps adding to the hardships already imposed by climate change. In a cultural system that increasingly focused on long-distance exchange networks, the connective topography of certain regions could obviously have become a key resource: in the Baar, the great Danube River springs, and it also connects to the northern part of southwest Germany, while the western Allgäu comprises the main watershed between the Danube and the Rhine River systems, connecting both.

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COASTAL AQUACULTURE

Clam Gardens on the Pacific Northwest Coast

Beyond the soils and landscapes of upland environments, human cultures have had complex relationships with aquatic resources and the boundary between land and sea throughout the

Holocene, for example through the creation of clam gardens. Over the past century or so, the development of the aquatic sciences and soil sciences as independent disciplines has largely prevented the application of soil and landscape concepts in aquatic environments. However, collaborations over the past two decades have begun to bridge these fields by adapting soil and land management practices and perspectives to subaqueous landscapes (Kristensen and Rabenhorst 2015). This may ultimately bring modern territorialities of aquatic resources more in line with those of prehistoric Holocene peoples, at least some of whom actively managed "clam gardens" as complex adaptive systems long before the advent of modern aquaculture.

On the North American Pacific Northwest Coast, tribes of the Kwakwaka'wakw Nation built clam gardens by rolling cobbles and boulders from existing clam beds, piling them in bulwarks near the low-tide line. This caused sediment to accumulate on the shoreward side of the bulwark, building a terrace that was exposed at low tide and covered by shallow water at high tide. This allowed the expansion of optimal soils for clam beds near settlements. Clam gardens were maintained by continuing to move exposed rocks and other debris to increase the available sandy habitat for clams, by practicing selective harvesting to maintain clam populations, and by regularly disturbing the soil using digging sticks to improve soil conditions.

The Kwakwaka'wakw had a basic, useful soil taxonomy, calling black and rotten-egg smelling soil *kwen'xlis*, which would produce unpalatable clams called *ya'yeks* (Deur et al. 2015). These soils have only recently been recognized as "monosulfidic materials" by modern soil taxonomists (Wessel and Rabenhorst 2017). The Kwakwaka'wakw would dig these soils to aerate them and to allow the silt and clay to be carried away by the tide, preventing the formation of *kwen'xlis* and maintaining sandy clam habitat.

Individual clans claimed clam gardens and maintained them for generations, with a belief that the clams were related to humans and would make themselves available for harvest if cared for. Some members of these tribes still harvest clams at these gardens, though no longer build or actively maintain them for artificially high carrying capacities for clam communities (Deur et al. 2015). Clam gardens originated at least as early as 1000-1700 years ago on Quadra Island in British Columbia, Canada, indicated by optical luminescence dating of core samples (Neudorf et al. 2017). Clam gardens improved food security and built more resilient coupled human-ocean systems, improving marginal environments with a territoriality that identified the value in cultivating this land (Jackley et al. 2016).

Achieving this type of territoriality, which allows the active management and improvement of marginal submerged land for aquaculture, has been a challenging task in many parts of the modern world due to the public trust doctrine, which dates to the Roman Empire and was

subsequently adopted by English common law and modern nation states. Under this doctrine, submerged lands are held by the government for public use, particularly to preserve the navigational use of the waterways. Many possible submerged land uses involving private property rights are generally prohibited by this doctrine (Rindner 2011). This may actually decrease the resilience of modern settlements by preventing the adoption of aquacultural practices that helped to maintain prehistoric peoples for centuries. Nonetheless, recent legislative changes in some parts of the world are expressing a territoriality that values private management of submerged lands, enabling their creative use as community resources (Beck et al. 2004).

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Maryland Oyster Management and Barren Bottom (Chesapeake Bay, USA)

In the Maryland portion of the Chesapeake Bay (United States), classification of what may be considered marginal or disfavoured submerged land underscores the dynamic and subjective nature of favour and disfavour. Maryland's eastern oyster (*Crassostrea virginica*) population has historically been managed utilizing the designation of 'barren bottom' (Kennedy and Breisch 1983, MD DNR, 1997). This terrain ranges from soft, easily penetrable muddy sediment, to hard scoured sand, to less commonly, but still possible, oyster shell left as remnants of an earlier, much larger oyster population. Though the content of 'barren bottom' varies, the designation is typified by a general absence of living oysters (Kennedy and Breisch 1983). Recognized as disfavoured to some, this estuarine bay bottom is highly valued by certain groups and holds higher import than what the label of 'barren bottom' suggests.

While unlikely habitat for large numbers of wild oysters, barren bottom hosts several species of clam (*Mercenaria mercenaria*, *Mya arenaria*, and *Tagelus plebius*) that, in addition to filling an ecological role, provide a source of income for commercial clammers (Baker and Mann 1991, Homer et al. 2011, MD DNR, 2018). Sand and mud sites that typify barren bottom also provide nursery habitat, foraging grounds, and overwintering locations for blue crabs (*Callinectes sapidus*), another commercially important species (Dittel et al. 1995, Seitz et al. 2001, Seitz et al. 2003). Barren bottom exclusively is the area available for private leasing for oyster aquaculture. Oyster aquaculture, the farming or cultivation of oysters, has existed in the Chesapeake for several centuries, but was a limited industry in Maryland until legislative changes in 2009-2010 (MD DNR 2010, Webster and Meritt 1988). Even so, over a century of regulatory changes center upon barren bottom, highlighting the irony that what is deemed disfavoured terrain continues to be socially, politically, and ecologically valuable and favoured. Conflicting claims to barren bottom are further complicated when considering the changes in the environmental and cultural aspects of the Chesapeake Bay as a complex adaptive system. Maryland's oyster population is a small fraction of its historic size due to a combination of inputs, including habitat loss, overharvest, oyster disease, and eutrophication; all exacerbated by warming water temperatures (Fulford et al. 2007, Kennedy and Breisch 1983, Wilberg et al. 2011, Mackenzie and Tarnowski 2018). As ecosystem engineers and providers of numerous ecosystem services, oysters play a large role in their systems, and their population decline contributed to the Bay's current regime and recurring dead zones (Dybas 2005, Coen et al. 2007, Diaz and Rosenberg 2007, Grabowski and Peterson 2007, Dumbauld et al. 2009,). Accordingly, a dramatic increase in the number of oysters – through both restoration projects and oyster aquaculture – is viewed by many as the potential key to a healthy Bay, though that remains a lofty goal (Fulford et al. 2007, Mann and Powell 2007, Beck et al. 2011, Bricker et al. 2017). Paired with other actions, oyster restoration efforts could lead to a new regime and state of the Bay, however, the socioeconomic implications of such a shift may not be welcomed by all. As rights to submerged land continue to change, questions of best use and equity are raised. Through ongoing work to understand participation in oyster aquaculture in Maryland, the impact of expanded no-harvest sanctuaries and privatized aquaculture leasing on local livelihoods is being investigated (2016-2018 Maryland Sea Grant SA75281600D; 2018-2020 NSF BCS1822266).

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Table A1.1 Summary of Case Study Data Evaluated Under the Rubric of Complex Adaptive Systems Criteria

Criteria	**Q'eqchi' Maya Swidden Agriculture (Belize)**	**Urban Gardening in SW-Germany**	**Agriculture in the Black Forest**	**Bronze Age land use in SW-Germany**	**Clam Gardens on the Pacific Northwest Coast (Canada)**	**Maryland Oyster Management (Chesapeake Bay, U.S.)**
Nature of land use investigated (contemporary or archaeological)	Contemporary	Contemporary	Archaeological	Archaeological	Archaeological	Contemporary
Favourability/ unfavourability (defined exogenously, endogenously, or both)	Defined both exogenously and endogenously: unfavourable for swidden cultivation (Atran 2002) due to high annual precipitation and soil leaching; favorability has previously been	Defined exogenously: Stuttgart has a more favourable climate than does rural Villingen-Schwenningen, (Baumüller J 2008; DWD 2018); no difference in soils (Teuber et al.	Defined exogenously: Black Forest as a classic unfavourable region (soil, temperature, precipitation); some resources (wood, metal ores, control of trade etc.) important, therefore favourable aspects; depending on time, scale, and specific	Defined exogenously: considering the relative suitability of areas for Bronze Age agriculture, emphasis on social/immaterial needs (including burial/ritual sites, trading routes etc.) in the assessment of a landscape's favourability.	Defined exogenously and endogenously: First Nations that practiced clam garden aquaculture saw these areas as favorable and able to be improved; most modern societies view these areas as unfavorable due to legal/cultural traditions	Defined exogenously and endogenously: oyster leases are limited to areas designated as 'barren bottom', a classification that originated with the Yates Survey in 1906 (Kennedy & Breisch, 1983) and typified by a

	defined historically and relatively. Q'eqchi' communities tend to view land use more favorably	2019); spatially, the rural region is favourable due to less contested spaces	culturally determined resource use		inherited from Antiquity.	lack of oysters, thus, seemingly unfavourable; today a contested space for multiple public fisheries, private aquaculture, and even nearby landowners
Scale of the investigated system in space and time (small: local/months to years; medium: regional/years to centuries; large: geographic units/decades to millennia)	Small: approximately 12 villages, 700 people, 77 km^2, and ~150 yr history.	Small: 2 towns, 6 garden associations, 167 gardeners, 2 yr investigation, history of garden associations dating back to the World Wars	Medium: Field work in ca. 100 km^2 around one town (Neustadt) and probably a dozen farms, focus in time ca. 400 yrs (1500-1900 CE), in Early Modern times, ~1000 people	Large: three levels of spatial scale: (i) individual settlements with their daily activity zones of several km^2, (ii) local networks of several (cooperating?) settlements, spread over a few dozen km^2, and (iii) regional networks of settlements in larger landscape units of several hundred km^2; temporal frame: Bronze Age (~ 2150	Medium: largely restricted to the Pacific Northwest Coast, particularly in the Broughton Archipelago and islands between Vancouver Island and the continent (Deur et al. 2015), managed by clans from 1000-1700 years ago to ~1930s	Medium: the Chesapeake Bay estuary spans 11,600 km^2; Maryland oyster management includes several centuries of public and private (aquaculture) fisheries in the northern portion of the Bay; fisheries vary in size and now include ~3,000 commercial

				- 800 BCE) with emphasis on the Middle Bronze Age (~ 1650 - 1250 BCE).		watermen and fewer than 500 individuals licensed to harvest aquaculture oysters; 69 individuals involved in Maryland fisheries were interviewed, participant observation was conducted with over 100.
System boundaries (clearly defined and understood or poorly defined)	Clearly defined: household organization and intra-village ties are very important; regional and global connections also important, particularly due to government, NGOs,	Clearly defined: Nested system of (i) the individual garden managed by a gardener(s); (ii) the gardening association each garden belongs to; (iii) the overarching German allotment	Clearly defined: household and farming organization for single farms, network with other farms and relation to town, probably clearly defined within rules and norms how to live and farm; religious boundaries	Poorly defined: system boundaries are based on modern assumptions due to the lack of specific historical data	Clearly defined: (i) individual clam gardens, defined by a bulwark at the seaward side and the shore on the landward side, and bounded by water depth (ii) organizational and archaeological, with a single clan generally	Clearly defined: the Chesapeake Bay is an extremely dynamic estuary experiencing wide-ranging salinities (0.5 ppt/freshwater in its upper tributaries to 30 ppt/saltwater near its mouth at the Atlantic Ocean) as well

	churches, and international development efforts; the region is being affected by climate change -- precipitation is becoming more difficult to predict which is impacting crops	garden association which issues rules and regulations according to German law; each garden as an intricate system of humans and nature	(Christianity); physical boundaries by topography and climate		maintaining one garden or area of gardens, (iii) contemporary, where these are maintained and well delineated as public trust resources that the public can use for recreational clamming during the correct seasons	as seasonal hypoxia and anoxia; political and management boundaries are also well defined in the sense that Maryland fisheries management oversees Maryland waters of the Chesapeake Bay.
Adaptation (individual or community level adaptation or adaptation through policy, or both)	Individual & community adaptation: Q'eqchi' households as primary unit of social and economic decision making; health and wealth as	Individual & community adaptation: individual gardeners decide management practices; local gardening association influences	Individual & community adaptation: expansion of agriculturally used areas; investment of labour; success measured in wealth (size of farm and amount of land)	Individual & community adaptation: evidence for frequent interregional trade during the Bronze Age in SW Germany points to swift distribution of ideas and technologies as means for adaptation	Individual & community adaptation: land tenure maintained by lineages from nearby settlements; management information passed orally and via experience; success measured by both	Both: Individuals within Maryland fisheries regularly adapt to dynamic system conditions and respond to sociopolitical inputs (regulatory restrictions, catch limits, etc.) by

	important measures of success.	decisions; success is measured through yield and taste of products			obtaining a good harvest and by leaving enough clams behind to maintain the population	adhering to fluctuating rules and laws; job satisfaction and the ability to feed one's family define success
Out-of-equilibrium conditions within the studied system (yes or no)	Yes: swidden systems worldwide suggest increased biodiversity (Balée 2006), and possibility of increased hunting returns in swidden fallows due to increased food sources for prey, source-sink dynamics, or sustainable off-takes (Bird 2015).	Yes: the gardeners are creating locally enhanced carrying capacities; highly diverse plant communities in the different gardens lead to a high plant biodiversity and in turn create habitats for fauna	Yes: woodland is turned into fields, meadows and bushland; forested areas massively declines; energy input by man-power for clearing forest/building terraces etc.	Yes: deforestation, ploughing, manure management, building burial mounds etc. changed the appearance of landscapes; to maintain these states or to minimize undesired effects, a constant input of energy was applied.	Yes: clam populations were maintained at higher than natural levels by creating habitat and managing populations; clam gardens require construction and maintenance; moved boulders and cobbles change the sediment regime to build the platform; regular digging prevents sulfide accumulation and washes away fine	Yes: the current reduced oyster population may be an out-of-equilibrium condition created by combined inputs of overharvest, habitat loss, and oyster disease (Wilberg et al., 2011) exacerbated by warming temperatures (Mackenzie & Tarnowski, 2018); progress in storm water and runoff

					particles, maintaining sandy habitat	management and increased inputs of oysters via restoration and aquaculture may contribute to a path toward an alternate state (Fulford et al., 2007).
Social and natural feedback effects within the analysed system (yes or no)	Yes: Swidden fields are placed intentionally with respect to historical forest use, local norms regarding nominal land 'ownership', past productivity, and expected future benefits; visible spatial mosaics	Yes: gardeners increase soil fertility, which enables them to grow a diverse set of plants, which provide habitat to fauna, which increases the biodiversity of the area; combination of up to 100 gardens with	Yes: most probably new cultivated land was used due to rights of ownership, but also commons existed which had to be dealt with by agreements (which parts of the mountains & terraces could be used when); feedback dynamics possibly caused by climatic problems/crop	Yes: Socio-cultural and technological developments (growing demand for fields, lumber and fuel) are likely reasons for intensified land use and erosion, especially during the Early Bronze Age (Henkner et al. 2017, Dreibrodt et al. 2010; Vogt 2014). Soil degradation may then have encouraged a shift towards more	Yes: larger clam populations would have positive water quality and habitat impacts for the ecosystem at large and would improve the resilience of the coupled human-ocean systems; larger clam harvests would support larger human settlements, who would be better able to	Yes: policy changes in 2010 reorganized submerged land classifications to create larger no-harvest oyster sanctuaries, reduce available bottom for public oyster fisheries, and expand the potential development of oyster aquaculture; more oysters in the

		different management practices in one association creates a mosaic of plant and animal communities	failure/erosion problems that led to adjustment in the use of the mountain fields and terraces	extensive land use and the settlement of former "marginal" areas. Consequently, expanding settlement networks would have become more complex as well, potentially promoting socio-cultural changes in turn.	maintain large clam gardens.	water, presumably increase many ecosystem services, and a much larger number of active oyster aquaculture operations, which also could enhance ecosystem services.
Evidence of emergence (local interactions, self organisation into hierarchies, unexpected/unexplainable system-level properties) within the investigated	Yes: village labor exchange networks exhibit unexpected levels of hierarchy and connectivity without top-down coordination	Yes: local networks between the gardeners within an association; regional networks between the spokespersons of each association; a (flat) hierarchy exists between the individual	Yes: system is dominated by local interaction of the farmers; differences between "richer" and poorer" farmers (amount of land use and invested labour); centralized control (or at least agreements) necessary for commons;	Yes: settlement networks may be clustered around local or even regional nodal points (e.g. within trading routes) and could comprise a differentiated set of settlement types (along with burial sites, functional places etc.) which may have organised themselves; no clear	Yes: landforms and large clam populations emerge from the clam garden management; communities located near highly productive clam gardens would have experienced greater food security and may have grown larger over time.	Yes: recent, locally increased submerged aquatic vegetation (SAV) populations may be an emergent property due to (i) better storm water, pollution, and nutrient management at local and watershed levels and (ii) potentially

system (yes or no)		gardeners, the spokespersons of the association they belong to, the regional networks and the country-wide garden association.		evidence for any kind of centralized decision making in SW-Germany during the Bronze Age. Still,		increased ecosystem services provided by oysters via restoration and aquaculture, though the relationship between oyster aquaculture and SAV is debated (Dumbauld & McCoy, 2015; Ferreira & Bricker, 2016; Orth et al., 2017).
Alternative regimes possible (yes or no)	Yes: transition to a grassland regime due to cattle ranching in combination with political and economic factors; villages exhibit varying degrees of	No (and Yes): Due to the German law, allotment gardens do not currently exhibit alternative regimes; but, food production becomes less important due to	Yes: creation of mountain fields and terraces might have been caused by a regime shift (growing population); with a change in the 20th century to less agriculture and more	Yes: marked shifts between lakeshore/ wetland and inland/ terrestrial habitats from the Early to Middle and Middle to Late Bronze Age; differences in local chronologies of cultural and land use changes may	Yes: with a lack of active management, soil conditions change, clam populations decline, and other organisms increase in abundance, leading the system to shift from productive	Yes: local water quality has improved in some places; major storm events can dramatically revert local improvements back to what may be considered a largely unfavoured state;

	socioecological resilience due to variation in environmental and geographic recourses, and historical and social factors	the availability of cheap fruit and vegetables in supermarkets & farmers markets	handicrafts, industrialisaion, & tourism, the mountain fields & terrace system was abandoned; the traditional big farms in the region have existed since the 15th century and point to the resilience of the system	indicate varying levels of resilience	clam beds to muddy and sulfidic flats	sociopolitical inputs may lead to an alternative regime in which there is no public oyster fishery
Are there triggers (material or symbolic) in the investigated system (yes or no)	Yes: material improvements in road infrastructure trigger regime shifts towards market integration (Chomitz and Gray 1995); recent legal decisions in favor of community land rights could be	Yes: World Wars as historic triggers to start urban gardens in Germany due to food shortage; provisioning of a healthy free time activity during industrialisation promoted among others by factory	Yes: population growth leads to more demand for food; more manpower enables forest clearing for fields; the Biblical duty of Christians to tame the wilderness (forests and mountains) as a symbolic trigger	Yes: material trigger "Bronze metallurgy" led to a reevaluation of areas; Middle Bronze Age abandonment of the lakeshores is usually correlated with climate deterioration and rising water levels	Yes: the European-inspired legal system made management strategies illegal; recently the National Park Service has considered allowing subsistence clam gardening in some areas, and many states and the US Army Corps	Yes: both material (climatic/weather) and symbolic (policy) triggers may affect the system. Major weather events can destroy or alter estuarine habitat and coastal communities, and extended weather patterns during a

	symbolic triggers for the development of novel forms of community land management	owners (Nilsen 2014, Keshavarz and Bell 2016); recent symbolic triggers: wish to be outdoors and experience nature			of Engineers have implemented systems of permitting and promoting bottom management for aquaculture; a material trigger is the initial moving of stones to build the bulwark	single season can hinder recruitment and survival; the system has been affected by far-reaching 2010 policy changes designed to catalyze oyster aquaculture and trigger a regime shift into a self-sustaining oyster population