Interpreting colluvial deposits: Archaeopedological reconstruction of land use dynamics in southwestern Germany

Dissertation

der Mathematisch-Naturwissenschaftlichen Fakultät
der Eberhard Karls Universität Tübingen
zur Erlangung des Grades eines
Doktors der Naturwissenschaften
(Dr. rer. nat.)

vorgelegt von
Jessica Henkner
aus Leipzig

Tübingen
2017

Gedruckt mit Genehmigung der Mathematisch-Naturwissenschaftlichen Fakultät der Eberhard Karls Universität Tübingen.

Tag der mündlichen Qualifikation:	20.12.2017
Dekan:	Prof. Dr. Wolfgang Rosenstiel
1. Berichterstatter:	Dr. Peter Kühn
2. Berichterstatter:	Prof. Dr. Thomas Scholten

Table of contents

List of figures

List of tables

Abbreviations

^{14}C-SPD	SPD based on radiocarbon datings of charcoal found in colluvial deposits
AMS	Accelerator mass spectrometry
As	Arsenic
b2k	Age referring to before 2000
Bre	Site Breg valley
Bri	Site Brigach valley
Bub	Site Bubenbach
C	Carbon
cal BCE/CE	Calibrated age before / in current era
cal BP	Calibrated age before present, referring to 1950
Cr	Chrome
Cu	Copper
Fue	Site Fuerstenberg
Gei	Site Geisingen
Goe	Site Boettingen
Gru	Site Grueningen
Koe	Site Koenigsheim
Leh	Site Oberer Lehmgrubenhof
Lin	Site Lindenberg
Mag	Site Magdalenenberg
MPI	Max Plank Institute
N	Nitrogen
NAP	Non-arboreal pollen
Ni	Nickel
OSL	Optically stimulated luminescence dating
OSL-SPD	SPD based on OSL datings from colluvial deposits
Pb	Lead
RADON	Radiocarbon dates online 2014: Central European and Scandinavian database of ^{14}C dates for the Neolithic and Early Bronze Age (Hinz et al., 2012b)
Rus	Site Russberg
SD	Standard deviation
SFB	Sonderforschungsbereich (=collaborative research center)
SOC	Soil organic carbon
Spa	Site Spaichingen
SPD	Summed probability density curve
Zn	Zinc

Zusammenfassung

Ziel der Arbeit ist es ein Konzept zur Interpretation kolluvialer Ablagerungen zu erstellen, um diese als Archive für (prä)historische Landnutzungsdynamiken zu nutzen. Im Rahmen des Projektes „B02: Gunst-Ungunst? Erschließung von Ressourcen in Marginalräumen“ des Sonderforschungsbereichs SFB1070 RESOURCENKULTUREN werden dazu 68 Bodenprofile an 13 archäopedologischen Standorten auf der Baar, im südöstlichen Schwarzwald und auf der südwestlichen Schwäbischen Alb, sowie zwei Moore im Schwarzwald untersucht.

Nach der Ablagerung vereinzelter Kolluvien im Mesolithikum, setzt großräumige Ablagerung im gesamten Arbeitsgebiet während des Neolithikums ein. Die weiträumige und intensive anthropogene Landschaftsänderung beginnt also im Neolithikum mit der Sesshaftwerdung und dem Beginn der landwirtschaftlichen Nutzung der Gebiete. In den drei Landschaftsräumen können jeweils unterschiedliche Kolluvienstratigraphien erstellt und daraus Landnutzungsdynamiken rekonstruiert werden. Die Baar weist eine detaillierte Stratigraphie von kolluvialen Ablagerungen auf, aus welcher schon im Mesolithikum erste Phasen intensiver Landnutzung oder Landnutzungsänderung abgelesen werden können. Im Schwarzwald dagegen datieren kolluviale Ablagerungen kaum in prähistorische Zeiten, in diesen Ablagerungen gefundene Holzkohlestückchen anthropogenen Ursprungs jedoch schon. Sie zeigen lokale und wahrscheinlich saisonale anthropogene Aktivität in prähistorischen Zeiten im Schwarzwald an. Während des Mittelalters und der frühen Neuzeit nimmt die Ablagerung von Kolluvien zu, was durch eine Veränderung der Landnutzung, insbesondere der Intensivierung und Expansion der Landwirtschaft, begründet sein kann. Im Vergleich zu den höher gelegenen Gebieten der Schwäbischen Alb und des Schwarzwaldes, stellt die Baar einen günstigen Raum für die landwirtschaftliche Nutzung dar. Obwohl eine ähnliche Landnutzungsdynamik in den beiden ungünstigen Räumen erwartet werden könnte, wird auf der Schwäbischen Alb eine andere Landnutzungsdynamik rekonstruiert. Bereits während der Eisenzeit kommt es dort zu vermehrter Ablagerung von Kolluvien, während es kaum mittelalterliche Ablagerungen gibt. Die Standorte auf der Alb, nahe an der Schichtstufe zur Baar gelegen, zeigen ein ähnliches Muster wie die östliche Baar.

Datierungen von Holzkohlen aus Kolluvien und des Bodenmaterials selbst müssen unterschiedlich interpretiert werden. Radiokohlenstoff Datierungen von Holzkohle weist auf menschliche Aktivität zu dieser Zeit hin, sofern davon ausgegangen wird, dass die Holzkohle anthropogenen Ursprungs ist. Der genaue Fundort der Holzkohlen innerhalb des Bodenprofils ist vernachlässigbar, da die Holzkohlen vertikal verlagert oder erst nach Ablagerung des Kolluviums eingetragen werden können. Somit ist die Wahrscheinlichkeit hoch, dass Holzkohle Alter in andere Zeiten datieren als der Boden in dem sie gefunden werden. Im gesamten Untersuchungsgebiet zeigen gefundene Holzkohlen eine erhöhte menschliche Aktivität vom Endneolithikum bis zur Latènezeit und vom Hochmittelalter bis in die frühe Neuzeit an. OSL Alter geben den Zeitpunkt der Ablagerung des Kolluviums an und können somit direkt mit Phasen geomorphodynamischer Aktivität korreliert werden, die mit intensiver Landnutzung oder Landnutzungsänderung in Verbindung stehen. Auf Basis der OSL Datierungen des kolluvialen Bodenmaterials zeigt sich demnach auch ein anderes Muster als das der Holzkohlen. So weisen OSL Datierungen aus den Arbeitsgebieten auf intensive Landnutzung während der Eisenzeit und der Römischen Kaiserzeit und vom Hochmittelalter bis in die frühe Neuzeit hin. Beachtet werden muss jedoch immer die Möglichkeit, dass kolluviale Ablagerungen z.B. in Senken temporär zwischengespeichert werden können, wodurch eine Zeitverzögerung zwischen der initialen Bodenerosion am Oberhang und der Ablagerung am Unterhang entstehen kann. Die zeitliche Gleichsetzung der Ablagerung mit dem Zeitpunkt der Erosion bzw. der Landnutzung als Auslöser der Erosion, kann also nicht immer vorausgesetzt werden.

Der Datensatz von Datierungen, Profilbeschreibungen und Laborergebnissen macht es möglich ehemalige Landoberflächen zu rekonstruieren. In einzelnen Bodenprofilen lässt die detaillierte Stratigraphie auf Basis der Datierung jedes kolluvialen Horizontes längere Zeiträume ohne kolluviale Ablagerung erkennbar werden. Während diesen Zeiten geomorphodynamischer Stabilität fand keine Bodenerosion und Ablagerung statt. Pedogene und biologische Prozesse verändern während solchen stabilen Phasen vor allem den Ah Horizont. Es wurde vermutet, dass sich im oberen Teil der kolluvialen Horizonte eine Anreichung von organischem Material oder die Erhöhung von Schwermetallgehalten finden lässt. Solche Anreicherungen werden jedoch eher im unteren Teil der kolluvialen Horizonte erfasst. Dies könnte durch die Erosion und Verlagerung des Oberbodens mit anschließender Ablagerung auf vermutlich erodierter Oberfläche erklärt werden.

Sozial-ökologische Systeme und adaptive Zyklen dienen als theoretische Konzepte um die empirischen Ergebnisse zu landwirtschaftlicher Entwicklung und kolluvialen Ablagerungen in einem übergeordneten und abstrakten Rahmen zu interpretieren. Der adaptive Zyklus der agrarischen Bodennutzung beginnt im Neolithikum und verändert sich durch die Industrialisierung zu einem zweiten adaptiven Zyklus der landwirtschaftlichen Bodennutzung. Dies entspricht dem rekonstruierten Muster der Landnutzungsdynamik und der kolluvialen Ablagerungen, die während des Neolithikums einsetzen und im Mittelalter auf eine verstärkte Intensivierung hindeuten.

Zusammenfassend wird in dieser Arbeit ein Konzept für die Nutzung kolluvialer Ablagerungen als Proxy für Landnutzungsdynamiken in Südwestdeutschland entwickelt. Durch empirische Analysen, verschiedene Datierungsmethoden und deren statistische Auswertung lassen sich Interaktionen zwischen Mensch und Umwelt in den Arbeitsgebieten nachweisen und mithilfe theoretischer Konzepte einordnen.

Summary

The aim of this study is to establish a concept to interpret colluvial deposits as archives and to use them to reconstruct past land use dynamics. The archaeopedological study is part of the project "B02: Favor-Disfavor? Development of Resources in Marginal Areas" within the framework of the collaborative research center SFB1070 ResourceCultures.

The analysis of 68 soil profiles at 13 archaeopedological sites and two bogs in southwestern Germany includes the agriculturally favorable Baar area and the unfavorable southeastern Black Forest and western Swabian Jura. Over the whole study area, dated charcoals indicate increased human activity from the Final Neolithic to the Latène period and also from the High Middle Ages to Early Modern times. OSL dating shows a different pattern of colluviation, and therefore intensified land use, with a focus on the Iron Age to Roman Empire and the High Middle Ages to Early Modern period. Following isolated colluvial deposits, dating to the Mesolithic, there is evidence of wide-ranging colluviation during the Neolithic, which coincides with the establishment of agriculture in the area.

Focusing on differences between the landscapes shows a spatially heterogeneous colluviation and land use dynamic through time. The Baar area has a detailed and long stratigraphy of colluvial deposition beginning during the late Mesolithic, which can be linked to phases of intensive land use or land use change. In the Black Forest in contrast, few prehistoric colluvial deposits can be found. Still, charcoal ages indicate local and probably seasonal human activity. During the Middle Ages and the Early Modern period colluviation increased strongly which seems to result from land use change, specifically intensification and expansion. Even though a similar land use pattern was expected to be found in both unfavorable landscapes, the Swabian Jura shows increased colluvial deposition already during the Iron Age but only little colluviation during the Middle Ages. Sites close to the edge of the Swabian Jura have a similar land use pattern than the eastern Baar.

The empiric study is associated with theoretical concepts like social-ecological systems and adaptive cycles, which provide a helpful approach to frame and interpret the agricultural development and colluvial deposition through time. The adaptive cycle of agrarian soil use begins

in the Neolithic and transforms into a second adaptive cycle of agrarian soil use with the industrialization. This follows the reconstructed pattern of land use dynamics and colluvial deposition, which set in during the Neolithic and reach a new level during the Middle Ages.

The reassessment of AMS-^{14}C ages of anthropogenic charcoal fragments indicates that charcoals can be used to reconstruct human activities, but are not necessarily connected to the colluvial deposit, in which they were found. Thus, the sampling depth of charcoals found within colluvial deposits is negligible. The dating of soil sediment by OSL, however, reliably dates the period of time when the colluvial deposit was accumulated. Therefore, OSL ages can be used to date colluvial deposition, which is linked to intensified land use or land use change. Nevertheless, temporary storage and a possible time lag between erosion and accumulation must be considered.

The acquired data support the interpretation of certain colluvial deposits as former land surfaces. Selected soil profiles show a detailed stratigraphy of colluvial deposits, which allowed the reconstruction of phases of geomorphodynamic stability. During such phases no colluviation took place and pedogenic and biologic processes occurred. The changes in the upper part of a colluvial deposit, being the land surface, cannot be found. However, changes are rather found in the lower parts of colluvial deposits, possibly resulting from erosion and relocation of topsoil sediment with subsequent deposition on an eroded surface. Thus, material with increased soil organic matter content can be found in the lower parts of colluvial deposits, instead of in the upper parts.

In summary, this thesis provides a thorough investigation of colluvial deposits as a proxy of land use dynamics in southwestern Germany. Theoretical ideas like the adaptive cycle concept and how to interpret and statistically use different dating methods help to understand past human-environment interactions.

List of included publications

Manuscript I: **Henkner, Jessica**; Ahlrichs, Jan J.; Downey, Sean; Fuchs, Markus; James, Bruce R.; Knopf, Thomas; Scholten, Thomas; Teuber, Sandra; Kühn, Peter (2017): Archaeopedology and Chronostratigraphy of Colluvial Deposits as a Proxy for Regional Land Use History (Baar, southwest Germany). *CATENA* 155, 93-113. DOI: 10.1016/j.catena.2017.03.005.

The complete manuscript can be found on pages 93 to 148.

Manuscript II: Henkner, Jessica; Ahlrichs, Jan J.; Fischer, Elske; Knopf, Thomas; Rösch, Manfred; Scholten, Thomas; Kühn, Peter (2018): Land use dynamics derived from colluvial deposits and bogs in the Black Forest, Germany. *Journal of Plant Nutrition and Soil Science* 181/5, 240-260. DOI: 10.1002/jpln.201700249.

The manuscript was accepted on November 19, 2017 and the published manuscript can be found on pages 149 to 190.

Manuscript III: Henkner, Jessica; Ahlrichs, Jan; Downey, Sean; Fuchs, Markus; James, Bruce R.; Junge, Andrea; Knopf, Thomas; Scholten, Thomas; Kühn, Peter (2017): Archaeopedological analysis of colluvial deposits in favourable and unfavourable areas: Reconstruction of land use dynamics in SW Germany. *Royal Society Open Science* 5. DOI: 10.1098/rsos.171624.

This synthesis paper was submitted to *Royal Society Open Science* on October 12, 2017. The published version can be found on pages 191 to 234.

Manuscript IV: Teuber, Sandra; Ahlrichs, Jan; **Henkner, Jessica**; Knopf, Thomas; Kühn, Peter; Scholten, Thomas (2017): SoilCultures - the adaptive cycle of agrarian soil use in Central Europe. *Ecology and Society.*

The complete manuscript can be found on pages 235 to 282 *(accepted for publication).*

Manuscript V: Knopf, Thomas; Ahlrichs, Jan J.; **Henkner, Jessica**; Scholten, Thomas; Kühn, Peter (2015): Archäologische und bodenkundliche Untersuchungen zur Besiedlungs- und Landnutzungsgeschichte der Baar. S*chriften des Vereins für Geschichte und Naturgeschichte der Baar*, Bd. 58, p. 9-24. 2015.

The complete manuscript can be found on pages 283 to 304.

Manuscript VI: Ahlrichs, Jan; **Henkner, Jessica**; Teuber, Sandra; Schmidt, Karsten; Scholten, Thomas; Kühn, Peter; Knopf, Thomas (2016): Archaeological and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory: A Case Study from the Western Baar, SW Germany. In: Kolodziejczyk, Piotr; Kwiatkowska-Kopka, Beata 2016: Landscape as impulsion for culture: research, perception & protection. *Landscape in the past & forgotten landscapes* 2 p. 39–49.

The complete manuscript can be found on pages 305 to 320.

1 Introduction

1.1 Soil ecosystem services and soil functions

Ecosystem services are the services provided by the environment to support human well-being. Soils are an integral part of the environment and thus, provide ecosystem services, categorized in provisioning, regulating, supporting, and cultural services (Adhikari and Hartemink, 2016; Millennium Ecosystem Assessment, 2005; Widlok et al., 2012). As such they are part of several sustainable development goals; such as “life on land” to promote sustainable use of terrestrial ecosystems, halt and reverse land degradation (SDG15) and promote the “zero hunger” goal to achieve food security and promote sustainable agriculture (SDG2) (United Nations, 2016; United Nations General Assembly, 2015).

Soil functions in particular can be categorized into ecological functions, such as biomass production, the protection of humans and the environment (filter, buffer, transformation), and the function as a gene reservoir. Non-ecological functions include the soil being the physical basis of human activities, the source of raw materials, and to protect geogenic and cultural heritage (Blum, 2005; Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, 2006). Particularly the intensification of agriculture leads to a depletion of these soil functions and ecosystem services (Stavi et al., 2016; Williams and Hedlund, 2014). Despite the crucial role of soils within the ecosystem (Blum, 2005; Koch et al., 2013) and for the achievement of the sustainable development goals, soil functions and soil ecosystem services are only considered in few studies. These studies mostly focus on regulating soil services, like the regulation of gas and water, climate, floods, erosion, and biological processes such as pollination and diseases. When the focus of studies is on sustainability of ecosystems and ecosystem services in the face of human pressures there is no substitute for history and using environmental archives (Dearing et al., 2006; Deevey, 1969). Particularly the cultural heritage or archive function of soil provides insight into human-environment interactions, since soils are a key resource for food production and habitation. By using the soil humans alter the environment and inscribe their actions into the soil; thereby generating an archive for human history, which is of wide spatial and temporal distribution (Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW), 2008;

Lucke, 2017; Zolitschka et al., 2003). Still, only a small number of studies focus on cultural heritage (Adhikari and Hartemink, 2016). Koch et al. (2013) paraphrases Roosevelt (1937) saying “the Nation that destroys its soil destroys itself” and states “the world that secures its soil will sustain itself”. Thus, soils depict an important resource to learn about from the past and a fundamental resource to sustain life.

1.2 Soils in history

Soils have been a research focus since the late 19th century (Henkner et al., 2017) when researchers suggested that soils result from interactions among parent material, climate, topography, biota and time (Glinka, 1927; Hilgard, 1914; Kraft et al., 1880; Liebig, 1840). The theories and concepts of soil formation include the shape of the soil surface as an essential variable, at least since Milne (1935) published the concept of a *catena*. A catena or toposequence describes soils along a landscape sequence, where soil properties change depending on geologic, geomorphic, atmospheric, or biologic processes (Schaetzl, 2013; Wysocki and Zanner, 2006). However, none of these concepts explicitly include the effect of human activities on soil formation and erosion processes. Richter et al. (2015) describe how humans have altered soils chemically, physically, and biologically, transforming them into a human-natural system. This process started with the transition of society from hunting and gathering to sedentism and the use of agricultural production. These changes in human settlement patterns, techniques for subsistence, and social organization subsequently triggered the Neolithic Transition, which saw higher carrying capacities and increased demographic growth rates (Bocquet-Appel, 2011; Downey et al., 2014). During this period, permanent land uses like farming, which involves digging, plowing, and harvesting, ultimately led to deforestation (Fyfe et al., 2015) resulting in bare soils along slopes, which are prone to soil erosion (Montgomery, 2007). These human activities created a cultural landscape during the Holocene. The eroded soil is deposited in depressions and along slopes, and is called *colluvial deposit*. These deposits are central archives of human-environment interactions in a region (Dreibrodt et al., 2010; Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW), 2008; Miehlich, 2009). Moreover, these soils allow the reconstruction of past land use, landscape and climate change, or pollution (James et al., 2014; Lazar et al., 2011; Nicolay et al., 2014; Pietsch and Kühn, 2017).

1.3 Understanding colluvial deposition

In German the term *Kolluvium* is used when describing slope deposits formed by human induced or intensified soil erosion by water due to their land use (Ad-hoc-AG Boden, 2005; Kalis et al., 2003; Kleber, 2006; Leopold and Völkel, 2007a). The characteristic corresponding land use is agriculture (Blume et al., 2010; Bork, 1989, 2006), but it could also be deforestation, mining, village establishment or infrastructure building. Hunter and gatherer populations also used the land and depended on the soil, but these non-sedentary societies had smaller impacts on soil erosion and colluvial deposition than agricultural societies (Miller, 2006). Thus, farming marks the beginning of a more intense and permanent anthropogenic land use that led to the formation of colluvial deposits. Generally, human activities lead to a wide-spread deforestation in order to obtain (agricultural) land and use timber resources (Mäckel et al., 2002). Here, the terms *colluvium* and *colluvial deposit* are used to describe soil landscape features formed by human induced processes, including induced or intensified soil erosion by water and down slope deposition of eroded material. Because of the formation process, colluvial deposits are always directly connected to the slope area above and thus can be considered an important resources or proxy to understand land use and settlement history (Emadodin et al., 2011; Leopold and Völkel, 2007a; Pietsch and Kühn, 2017) on a local, high-resolution scale. The situation on nearby slopes can be different. These archives represent the duration and intensity of local human impact on their environment during the Holocene (Helbig et al., 2002; Leopold and Völkel, 2007b; Schroedter et al., 2013; Verstraeten et al., 2009).

Lang and Hönscheidt (1999) formulated the cascade-model to explain the development of multi-layered colluvium in southern Germany. It explains the sequence of colluvial layers over time and along a slope using multiple temporary sinks to store soil material before it is released and transported further downslope. This cascading effect causes a time lag between the initial soil erosion and the deposition of the now observable colluvial/alluvial deposit and depends on precipitation events, land management, land use structures, and topography (Lang et al., 2003; Lang and Hönscheidt, 1999). The temporal offset can be sufficiently large to shift the colluviation signal into a phase of low land use intensity (Dotterweich, 2013), thereby giving a false impression about the time of initial soil erosion (Verstraeten et al., 2017). The nonlinear correlation of soil erosion and colluvial deposition or alluviation (cascading effect) must be considered when inferring a chronostratigraphy based on dated colluvial layers. The cascading effect produces different signals over time making a standardized analysis and interpretation of these complex phases of geomorphodynamic stability or activity problematic (Dotterweich, 2013). Today, these temporary sinks might be difficult to detect because the accumulation of eroded soil in depressions has a leveling effect on the relief and can lead to a change of landscape properties. However, studying soil properties along a catena can provide the possibility to infer possible recent or former sediment sinks. The term “geomorphodynamic activity” was coined by Rohdenburg (1970) to describe phases of increased slope erosion triggered by an accentuated precipitation regime and thereby changed vegetation cover during the Pleistocene. In this study, the terms geomorphodynamic activity or stability are used to describe whether slope deposits are being eroded or stable. Thus, they are broken down to a local or site-specific scale to describe phases of soil erosion and colluvial deposition, which are not necessarily connected to climate but rather to land use changes triggering soil erosion. Due to slope stability and the supporting influence of vegetation, pedogenic processes take place mainly during stable phases whereas geomorphodynamic activity leads to redeposition and soil loss (Emadodin et al., 2011; Jenny, 1994).

The redeposition of soil material leads to a change of soil properties along a slope, e.g. the accumulation of soil material rich in organic matter in a wet downslope position increases soil quality making it drier, more fertile, loosely aggregated and more favorable for agricultural use. Soil quality of the eroded areas, in contrast, declines and can hinder the recovery of shrub or wood vegetation leading to a permanent geomorphodynamic activity and new equilibrium (Dotterweich, 2013). Spatially or temporally different soil erosion and accumulation rates can result from different starting points (relief, precipitation, vegetation, land use) and from different triggers of soil erosion. The behavior of this complex system is nonlinear and cannot simply be broken down to cause-effect relationships (Dearing et al., 2006; Dearing et al., 2015). In a dynamic system external forces and an internal organization occur and may exert their influence through exceeding thresholds, a time lag between driver and responses and entanglement of past and present processes (Dearing et al., 2006) impeding simple explanations.

Colluvial deposition can also be understood as a process of niche construction (Laland et al., 2016; Odling-Smee et al., 2003; Odling-Smee et al., 2013). Humans alter their environment in different ways, one of it being unintentional soil erosion and accumulation (colluvial deposition), through which environmental properties are changed. The altered anthropogenic landscape might be more or less suitable for anthropogenic uses. Considering colluvial deposition and agricultural land use, environmental and, especially, soil properties are enhanced in lower slope positions, because organic- and nutrient-rich topsoil material is accumulated and possibly elevates land surfaces above groundwater level. These changes have a positive effect on ongoing agricultural land use, since they can result in higher yield and an easier processing of agricultural fields, which again might influence human population. Resource use in general is a foundational driver of niche construction by which humans constantly modify their environment to come closer to a preferred niche ecosystem.

Colluvial deposits usually cover natural sediment or soil creating a boundary between the natural land surface and the human-modified material and processes. Edgeworth et al. (2015) call this boundary the lower boundary of anthropogenic deposits or "*boundary A*". It gives an impression of the paleorelief and illustrates the formative effect of humans (Ellis et al., 2013a; Ellis et al., 2013b), since everything overlying the boundary A is anthropogenic it can be called the "*archaeosphere*" (Edgeworth, 2014; Edgeworth et al., 2015).

As described, colluvial deposits are excellent archives of past human-environment interactions, because they store information about land use dynamics. Land use is simply defined as the use of open land, without further specification of the type of land use. Intensified land use, is defined as having triggered soil erosion and colluvial deposition, which makes it possible to reconstruct phases of intensified land use, by analysing colluvial deposits. Agriculture is one form of intensified land use, typically leading to colluvial deposition. The term land use dynamics refers to a sequence of land use changes, either in form of intensity or type, which are traceable in colluvial deposits. The reconstruction of land use dynamics can be done through the interpretation of "site-biographies", which are primarily based on the dating of colluvial deposits and charcoal fragments. Charcoal fragments itself are interpreted to indicate human activity. A site-biography can be understood as the chronostratigraphy of colluvial deposition and, thus, as a local reconstruction of deposition and land use phases, including environmental properties, especially soil properties like soil organic carbon content, particle sizes, or heavy metal content, and topography. The understanding of site specific soil mosaics during space and time (=site-biographies) can help to understand the dynamic human-environment relation (Henkner et al., 2018a).

1.4 Concept of favorable and unfavorable landscapes

Landscapes are understood as geographic areas with spatially varying variables of interest. A landscape can be separated from other landscapes by geographic, ecological, or administrative units, which are relevant to a research question (Pearson, 2013; Wu, 2013). In this study landscapes are defined mainly by their environmental conditions like topography, climate, soils, wetlands, native plant communities, or other environmental factors. In central Europe, the concept of favorable and unfavorable regions refers to the environmental conditions and the time a region has been settled (Gebhardt, 2007; Seidl, 2006). Favorable landscapes (German: *Gunstraum* or *Altsiedelland*) are often loess covered, having fertile soils, low relief intensity, and a sufficient climate to practice agriculture and were therefore, supposedly settled earlier (Henkner et al., 2017; Kühn et al., 2017; Seidl, 2006). Bourke (1984) states that a minimum mean temperature of 6°C for six consecutive months is needed to grow and harvest certain crops, which could be used as a criterion to differentiate between agriculturally favorable and unfavorable landscapes. Unfavorable landscapes are usually characterized as being less productive for agriculture, and therefore, were supposedly settled later. The history of human activities in such unfavorable landscapes lack scientific research (Gassmann et al., 2006; Schreg, 2008; Valde-Nowak, 2002). The low mountain range of the Black Forest is a well-known example of an unfavorable landscape. It is commonly assumed that it was not continuously settled before the High Middle Ages (Schaab, 2003), thus, it has been the last marginal landscape in southwestern Germany to have been settled (Ahlrichs et al., 2016). The term marginal land focuses more on the economic value of land and can be defined as land on which cost effective food and feed production is not possible due to environmental conditions (Dauber et al., 2012). Other terms might be degraded land, waste land, upland, hinterland, or outland. All these terms do not describe intrinsic properties of the physical environment but an idea in relation to particular economic and social systems (Brown et al., 1998; Coombes and Barber, 2005).

The interpretation of landscapes as favorable and unfavorable is a relative and dynamic concept to evaluate the quality of an environment to serve a certain purpose. A favourable landscape for practicing agriculture can turn into an unfavourable landscape by soil degradation or climate change. Another scenario could be that agriculture might lose its importance because other economically more valuable raw materials like silver or gold were found. In the latter scenario the landscape would be seen as favourable because of the mining and exploitation of raw materials, instead of agriculture, which means a shift of perspective and context. Thus, landscapes can be unfavorable to grow crops, but at the same time, very favorable in order to use geological resources, the forest, or water. Consequently, the application of the concept of favorable and unfavorable landscapes to a research question needs to be explained in specific geographic and archaeological contexts. The agriculturally favourable Baar area, can also be seen as being rather unfavourable because of a large number of freezing days, high fog and less fertile soils (Siegmund, 2006), as compared to other more favourable, loess covered areas nearby. Unquestionable unfavourable landscapes to practice agriculture, however, are the Black Forest and the plateau of the Swabian Jura.

1.5 Theoretical understanding of resources and social-ecological systems

In general, resources are understood to include raw materials of economic importance, such as wood, iron ore, water, etc. (cf. Millennium Ecosystem Assessment, 2005). But this restricted understanding of resources cannot explain certain archaeological finds and human actions, such as the decision to settle unusual and unfavorable places. Hence, this study understands the term "resources" as an analytical concept with a constructivist perspective: as a base to create, maintain or alter social relations, units, and identities within the framework of culturally shaped beliefs and practices (Bartelheim et al., 2015; Hardenberg et al., 2017). It thereby, includes a wide variety of tangible and intangible means and social contexts. This understanding of resources asks about the cultural pre-conditions and dynamics to turn something into a resource of social relevance. It is thought that raw materials are turned into a resource by society's (physical, social, cultural) needs. This process adds value to the formerly not important and invaluable raw material. One can also say that "resources are made by people, when they valuate tangible or intangible means within their specific way of life" (Bartelheim et al., 2015). This illustrates that raw materials or resources and ways to use a resource need a specific, cultural context from which they achieve their relevance. Raw materials do not have a “natural” or intrinsic potential for use (Bartelheim et al., 2015). The determining cultural dimension results in an unpredictable use of resources, how they are developed and who is allowed to use them (Bartelheim et al., 2015; Hardenberg et al., 2017). By using the resources people influence them and these resources influence the organization of cultures. Resources also store information about people, thus, they contain traces of past actions and can be seen as assemblages of human and non-human (Latour, 1993, 1999; Hodder, 2012 in Hardenberg, 2017). Resources do not exist or are used as isolates but in combination with other resources. This combination of resources, objects, persons, knowledge, and practices is called a “resource complex”. Resource complexes have a specific history and are dynamic systems (Hardenberg et al., 2017). Taken together, resources, resource complexes, social practices, relations and identities make up the resource culture. Resource cultures are open multidimensional models comprising the dynamic development and mutual influence of resources, resource complexes, and cultures (Hardenberg et al., 2017).

Soils as a basis for life have always been an essential resource, but only with the Neolithic Transition to sedentism and practicing agriculture their importance and value became distinct and directly connected to the wellbeing of humans, because they produced food. The value of the resource soil depended on the quality of soil, other environmental qualities, society’s knowledge, and the used techniques. Due to the slow soil formation (Jenny, 1994; Stockmann et al., 2014) and the much faster, counteracting process of soil erosion, soils must be considered a non-renewable resource.

Soil is the key resource of the resource complex agricultural land use, since agriculture is based on soil. The resource complex also includes other environmental variables like climate and topography, the grown plants, the available knowledge, the techniques, all of which can be considered important resources in themselves. The history of agrarian land use (Lal et al., 2007; Teuber et al., 2017) makes clear that resources and resource complexes are not stable but dynamic systems, changing with society’s needs, beliefs, and possibilities.

From the perspective of this study, focusing on the archive function of soils; soils are additionally a resource to learn from the past.

The development of the agricultural system can be analyzed by using the concepts of the adaptive cycle and the dynamic social-ecological system (Teuber et al., 2017). A social-ecological system (SES) is characterized by the integration of natural and social components (Berkes et al., 2003; Berkes, 2004; Berkes and Folke, 1998; Widlok et al., 2012). SESs shape the world, and to understand them, it is necessary to split the bigger systems into smaller parts. However, the smaller systems are also part of other SESs. The present analysis focuses on the SES agrarian soil use, which is part of a bigger SES and in turn can be broken up in smaller SES on any temporal or spatial scale. The main variable of the SES agrarian soil use is soil, which has been used agriculturally since the Neolithic Transition. Other variables of the SES agrarian soil use are climate and crops. Crop refers to cereals, i.e. barley, wheat, rye, etc. and is observable via archaeobotanical analyses (Rösch, 1996). Climate change can be traced in ice cores, speleothems, lake and ocean sediments, corals, tree rings, fossil leaves and changes in the pollen communities (Aranbarri et al., 2014; Caseldine and Turney, 2010). The effect of climate on the settlement pattern of a region is discussed by experts (Berglund, 2003; Zolitschka et al., 2003). The observable variable concerning society is knowledge and technological development of tools (Teuber et al., 2017).

The concept of adaptive cycles was developed for ecosystem dynamics. It is composed of four phases, the r-phase of exploitation, the K-phase of conservation, the Ω-phase of release or creative destruction, and the α-phase of reorganization (Holling et al., 2002a; Holling and Gunderson, 2002). This cycle is shaped by three properties: the potential of a system to change, the degree of connectedness between internal variables and processes, and the adaptive capacity of a system, its resilience as a measure of its vulnerability to unexpected shocks (Holling, 2001). The adaptive cycle metaphor (Gunderson and Holling, 2002) is used as a theoretical framework for the narrative of agricultural history in Central Europe (Teuber et al., 2017).

2 Objectives

The change of the relationship between humans and ecological systems can be traced with archaeopedological methods, including soil description, chemical and physical soil analyses, and dating of colluvial deposits and charcoals (Pietsch and Kühn, 2017). Thus, soils are records of the past (Fuchs and Lang, 2009; Kühn et al., 2017) and archives to learn about past human-environment interactions and reasons to settle and use unfavourable landscapes continuously.

Archaeopedology is defined as the study of site formation history, cultural chronology, land use (change), environmental change and to answer archaeological questions with pedological methods (Fritzsch, 2011; Nikiforoff, 1943; Pietsch and Kühn, 2017). Using a socio-cultural understanding of resources might help to evaluate the dynamic and interdependent assessment of resources, human activities and the effect on the environment from the Mesolithic to Modern Era. Which socio-economical, socio-cultural or environmental factors played a role in the use and population of unfavorable landscapes will need to be addressed. The importance of climate fluctuations and environmental determinism for the accumulation of colluvial deposits and population or depopulation processes is discussed (Coombes and Barber, 2005; Haupt, 2012; Knopf et al., 2015; Löhr et al., 2002). The goal is to present a colluvial based land use history and tie human activities to environmental conditions and resources.

In detail, the objectives of this study are:

Archaeopedological site characteristics

(i) Establish a pedological description of colluvial deposits at the sites

Reconstruction of land use dynamics

(ii) Analysis of a local chronostratigraphy and archaeopedology of colluvial deposits across the favorable Baar region and the interpretation of possible causes related to human land use history, paleoclimate, and socioeconomic factors (Manuscript 1, 5, 6)

(iii) Investigation of colluvial deposits, heavy metal contents, and pollen profiles in the unfavorable Black Forest in relation to land use and vegetation history (Manuscript 2)

(iv) Investigation of colluvial deposits on the plateau of the Swabian Jura against the background of past human-environment interactions (Manuscript 3)

(v) Synthesis of the dynamic development of colluvial deposits and land use in favorable and unfavorable landscapes (Manuscript 1, 2, 3, 4)

Use of colluvial deposits as archives

(vi) Establish a concept to interpret colluvial deposits as archives and to use them to reconstruct past land use and human settlements

(vii) Reassessment and interpretation of AMS-^{14}C and OSL ages from colluvial deposits as proxies to reconstruct human activities and colluvial deposition

(viii) Interpretation of the gaps between colluvial deposition events

This thesis is part of the collaborative research center "SFB1070 ResourceCultures", in particular in the project "B02 Favour - Disfavour? Development of Resources in Marginal Areas". The SFB1070 is investigating the socio-cultural dynamics deriving from the use of resources, focusing on developments, movements and valuations.

3 Regional setting

3.1 Study area

The study area in southwest Germany (Fig. 1) comprises the granitic basement of the Black Forest to the west (Henkner et al., 2018b) and the limestone escarpment of the Swabian Jura to the east (Henkner et al., 2018a). In between is the Baar (Henkner et al., 2017), a depression of older escarpments that includes the Danube River and its headwater streams, the Brigach and Breg, originating in the southeastern Black Forest. The entire study area is an unfavorable region, but compared to the Black Forest and Swabian Jura the Baar can be considered a favorable region for agriculture because it has fertile soils, often influenced by Loess

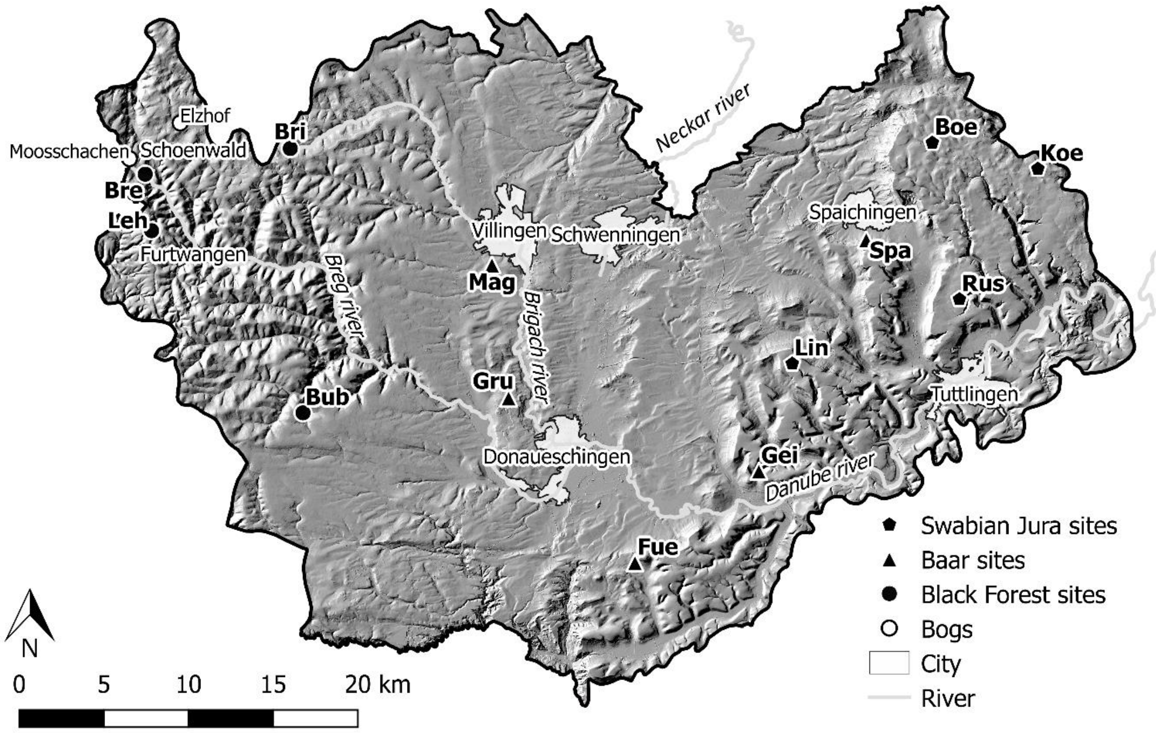

Fig. 1: Study area in southwestern Germany with all archaeopedological and palynological study sites, major rivers and cities. The Baar is considered as the agriculturally favorable landscape and the Black Forest and Swabian Jura are understood as unfavorable landscapes. The site names are abbreviations usually from the nearest villages: Boe=Boettingen, Bre=Breg valley, Bri=Brigach, Bub=Bubenbach, Fue= Fuerstenberg, Gei=Geisingen, Gru=Grueningen, Koe=Koenigsheim, Leh=Lehmgrubenhof, Lin=Lindenberg, Mag=Magdalenenberg, Rus=Russberg, Spa=Spaichingen. The background map depicts the topography (Jarvis et al., 2008).

deposits (Kösel and Rilling, 2002; Lazar, 2005), higher mean annual temperature (7-8°C) and lower mean annual precipitation (850 mm) (Siegmund, 2006). Swabian Jura and Black Forest have lower average temperatures and higher annual precipitation; they are considered unfavorable for agricultural land use. In the low mountain range of Black Forest, soils tend to be more acidic, and the relief is higher, having peaks of up to 1000 m height. On the 750-900 m high plateau of the western Swabian Jura, the supply of fresh water is limited because of low water storage capacity in the limestone bedrock, and depends mostly on precipitation.

3.2 Environmental and human history

3.2.1 Climate and vegetation

The Holocene vegetation history shows in its first half a reforestation of the steppe vegetation, first by shrubs and dwarf shrubs as *Salix*, *Betula nana*, *Juniperus* and *Hippophae*, then by rather open forest with *Pinus sylvestis* and *Betula alba*, then by the immigration and expansion of *Corylus* and later Mixed Oak Forest (Lang, 2005).

Palynological studies show, that the dominating forest vegetation might have been manipulated by hunter-gatherer societies during the Mesolithic (9600-5500 BCE) by their use or creation of clearings (Divišová and Šída, 2015). Especially during the late Mesolithic patterns of plant use support the thesis of controlled, regular and intensive plant use which influenced landscapes and is considered to be not only incidental (Divišová and Šída, 2015). But the discussion whether or not the occurrence of cereal-type pollen or charcoal point to Mesolithic agriculture is wide (Behre, 2006; Lüning, 2000; Tinner et al., 2007). Unarguably is the transition of a rather meat based diet of hunter-gatherer societies to the intensified use of plants of rather agrarian subsistence economies during the Neolithic (Doll, 2017; Holst, 2010; Sørensen and Karg, 2014). With the establishment of agricultural practices during the Neolithic the landscape opened up close to settlements, and man-made or man-enlarged clearings were used for crop cultivation or grazing (Bakels, 2014).

During the Boreal, preceded by the Younger Dryas, climate transformed from colder conditions to the thermal climatic optimum of the Holocene during the following Atlantic period (Anderson et al., 2007). This is interrupted by abrupt cooling events like the so called 8.2 ka event (Magny et al., 2003; Matero et al., 2017).

The Neolithic (5500-2150 BCE) is characterized by the warm and moist Atlantic chronozone (Anderson et al., 2007; Litt et al., 2009), leading to the immigration and expansion of shade trees during the Neolithic. The Black Forest acquired distinct vegetation patterns, different from surrounding landscapes. The immigration sequence is *Picea*, *Abies*, *Fagus* genera, but with the expansion, *Abies* dominance is enhanced in time, which leads to a phase called the "Tannenzeit" (*Abies*-period). The *Abies* expansion coincides approximately with the *Ulmus* decline and dates to about 4000-4500 BCE (Henkner et al., 2018b).

The Subboreal chronozone sets in during the Final Neolithic and covers the entire Bronze Age (800-0 BCE), it held warmer and dryer conditions compared to the recent climate (Anderson et al., 2007), with a dominance of *Abies, Alnus*, *Fagus,* and in some areas also *Picea* (Henkner et al., 2018b; Litt et al., 2009). Vegetation composition changed only slightly from then on. The climate of the Iron Age (800-0 BCE) is warm and dry within the Subboreal period which turns into the cooler and wetter Subatlantic period (Anderson et al., 2007). During the Roman Empire (0-450 CE) the Subatlantic opened with a warm period followed by a temperature decline during the Migration period (Broecker, 2001; Büntgen et al., 2011). The cool period during the Migration period followed a climate amelioration during the Middle Ages (450-1500 CE), almost to the levels of the Roman Empire, which reached the maximum during the High Middle Ages (Anderson et al., 2007; Büntgen et al., 2011). The Medieval Optimum was followed by the Little Ice Age around the 1300-1400 CE, characterized by low temperatures and glacier advances, but also by a wide variety of climate fluctuations (Anderson et al., 2007).

3.2.2 Past soil erosion and colluviation

The nature and intensity of past and present soil erosion by water and corresponding soil accumulation depends on climate, relief, soil type, but also land cover and land management practices like field sizes, crop rotations and tillage (Bork, 1989). Mostly discussed are precipitation and human influence as factors controlling soil erosion and colluviation (Bork, 1989; Dotterweich and Dreibrodt, 2011; Notebaert and Verstraeten, 2010). Slowly changing environmental conditions can be excluded as potential reasons for short term changes in soil erosion rates and minor long term erosion, because they are largely constant (Bork, 1989). Especially on agricultural land, local management practices i.e. tillage, change the microrelief, loosen soil and destroy the vegetation cover thereby controlling sediment fluxes. The intensity of land use (change) and hence the intensity of its influence on the environment, is mainly influenced by population density, which can be illustrated by the pronounced increase of soil erosion during the Neolithic and the distinctive decrease during the Migration period and Early Medieval times (Dotterweich, 2008; Zimmermann, 1996, 2012).

Different phases of increased geomorphodynamic activity occurred in central Europe and can be connected to agricultural extension and deforestation. Phases of stability are connected with phases of vegetation recovery (Kaplan et al., 2009; Williams, 2006). The phases geomorphodynamic activity, thus, intensified agricultural land use can be reconstructed by using archives of soil erosion and colluvial deposition. The oldest phase of increased soil erosion dates to the early Neolithic (Dotterweich, 2008) and can be correlated to increased population density (Shennan et al., 2013; Shennan and Edinborough, 2007; Zimmermann, 1996) and the onset of agricultural land use (Bork, 1989; Lang, 2003; Mäckel et al., 2002; Mäckel et al., 2003). Colluvial deposition increases during the Early Bronze Age until the Roman Empire (Mäckel et al., 2002) but covers small areas due to little agriculturally used land (Bork, 1989). Further phases of increased soil erosion and colluvial deposition occur during the Urnfield period (~1000 BCE), the Latène period to the end of the Roman Empire (~500 BCE-250 CE), and to the High Middle Ages and Modern times (Dotterweich, 2008; Hoffmann et al., 2009; Lang, 2003). Phases of little soil erosion in contrast were detected for the Early Bronze Age, the Migration period and the Early Middle Ages (Dotterweich, 2008). Based on OSL ages from Germany several peaks of increased fluvial and colluvial geomorphodynamic activity can be determined (at 7050 BCE, 6250 BCE, 5525 BCE, 3690 BCE, 2250 BCE, 1350 BCE, 820 BCE, 325 BCE and since 875 CE (Hoffmann et al., 2008)). Hoffmann et al. (2008) states that until 2250 BCE these phases are triggered by wetter and/or cooler climatic phases. The coupling of geomorphodynamic activity to climate decreases until 875 CE due to the increasing influence of a growing population and intensification of agricultural activities. From then onwards the growing population and the associated changes in land use can be considered the major external forcing increasing the sensitivity of landscapes to erosion and thus the geomorphodynamic activity (Hoffmann et al., 2009; Houben, 2008). Extreme precipitation events like in early summer 1342 CE and around 1800 CE (Glaser, 2013) contributed to extreme soil erosion in agriculturally used areas of central Europe (Bork, 1989, 1998).

3.2.3 Settlement and land use history

Epochs and periods as used in southwestern Germany are given in Tab. 1. Sedentary settlement and land (Henkner et al., 2018c) use in southwestern Germany begun with the Linear Pottery Culture during the Early Neolithic (Nübling, 2005; Schmid, 1991, 1992).

Tab. 1: Epochs and periods in southwestern Germany.

Epoch	Period	Start (cal BCE/CE)	End (cal BCE/CE)	Reference
Mesolithic				
	Mesolithic	9600	5500	
Neolithic				
	Early Neolithic	5500	5000	Lüning (1996)
	Middle Neolithic	5000	4400	Lüning (1996)
	Younger Neolithic	4400	3500	Lüning (1996)
	Late Neolithic	3500	2800	Lüning (1996)
	Final Neolithic	2800	2150	Lüning (1996); Stockhammer et al. (2015)
Bronze Age				
	Early Bronze Age	2150	1550	Stockhammer et al. (2015)
	Middle Bronze Age	1550	1300	Müller and Lohrke (2011); Della Casa (2013)
	Late Bronze Age	1300	1200	Mäder and Sormaz (2000); Müller and Lohrke (2011); Della Casa (2013)
	Urnfield period	1200	800	Della Casa (2013)
Iron Age				
	Hallstatt period	800	450	Maise (2001); Guggisberg (2008)
	Latène period	450	±0	Poppi (1991); Kaenel and Müller (1999)
Roman Empire (Antiquity)				
	Roman Empire	±0	375	Eggert and Samida (2013)
	Migration period	375	450	Eggert and Samida (2013)
Middle Ages				
	Merovingian period	450	750	Ament (1977)
	High Middles Ages	750	1250	Sangmeister (1993)
	Late Middle Ages	1250	1500	
Modern Times				
	Early modern period	1500	1789	
	Modern era	1789	today	

Stone tools from the Magdalenenberg and other sites indicate Early Neolithic activity on the eastern and western Baar (Schmid, 1991, 1992). The earliest archaeological evidence of settlements on the southwestern Swabian Jura date to the Final Neolithic (Biel, 1987; Müller and

Nübling, 2010), in the southeastern Black Forest Neolithic findings are scarce and Bronze and Iron Age sites are mostly unknown (Henkner et al., 2018b). The dynamic development of the settlement and land use history of the Baar can be found in Manuscript 1 (Henkner et al., 2017), for the Swabian Jura see Manuscript 3 (Henkner et al., 2018a) and for the southeastern Black Forest see Manuscript 2 (Henkner et al., 2018b). A comprehensive description of settlement dynamics can also be found in Ahlrichs (2017).

4 Methods

4.1 Field methods

Field work for this study was carried out from 2013 to 2016. It included the description of 68 soil profiles, following the German soil classification system (Ad-hoc-AG Boden, 2005), the FAO (2006), and the WRB 2015 (IUSS Working Group WRB, 2015). The German classification system includes the horizon designation *M* (M = Lat. *Migrare*, to migrate) for anthropogenic colluvial horizons lacking other pedogenic properties. Since it is important to differentiate colluvial horizons from others with different pedogenic development, the M horizon was used together with the FAO nomenclature.

The soil profiles are located along catenas reaching from the upper slope to foot slope positions. Catenas represent a sequence of soil profiles along a slope having different characteristics due differences in topography, elevation, drainage, erosion or deposition (Schaetzl, 2013). The locations of catenas and soil profiles were chosen to represent a stratigraphy of colluvial deposits in close proximity to known prehistoric activities, documented by prehistoric settlements or findings. Age determination was done on colluvial deposits showing the most detailed pedostratigraphy and being characteristic for the site. In order to prevent sampling bias for a specific time soil samples for dating were collected consistently from all soil horizons, where sampling was possible.

A total of 728 bulk samples and 688 volumetric samples (each consisting of 3 x 100 cm^3 subsamples) were taken from all horizons. From each colluvial horizon, the upper 5 cm were sampled separately, and colluvial horizons thicker than 20 cm were split into thinner sampling units. Pottery fragments were collected and interpreted as indicators of a nearby settlement (Niller, 2001; Wunderlich, 2000). A lack of pottery fragments might indicate agricultural land use or deforestation (Mäckel et al., 2003).

Results for vegetation history are based on two profiles from Elzhof and Moosschachen/Martinskapelle. Both are small raised bogs with an area of approximately 4 ha, situated in or near the European main watershed of the rivers Rhine and Danube, near the village of Schoenwald in the Black Forest. In the centers of these two raised bogs, cores were taken with a Russian sampler, containing 4.0 m bog peat at Elzhof, and 3.3 m bog peat at Moosschachen.

The profiles were sampled in intervals of 1 and 12 cm, resulting in a total of 248 samples at Elzhof and 72 samples at Moosschachen

4.2 Lab methods and data analysis

Soil-pH was determined using a soil-to-solution ($CaCl_2$) ratio of 1:2.5 (Blume et al., 2010). Carbonate content was determined volumetrically by CO_2 evolution using a Calcimeter. Bulk density [g cm^{-3}] of the fine soil (<2 mm) was gravimetrically determined on volumetric samples, using a general density of 2.65 g cm^{-3} to account for rock fragments (cf. Don et al., 2007). Total C and N contents [mass %] were analyzed using oxidative heat combustion at 1150 °C in a He atmosphere. Soil organic C content (SOC) was determined using: SOC = C_{total}-$CaCO_3$x0.1200428, soil organic matter was calculated by multiplying SOC*1.72 (Eberhardt et al., 2013). SOC stocks were calculated using: SOC_i [kg m^{-2}]=SOC_i [%]*$depth_i$ [cm]*$BD_{finesoil}$[g cm^{-3}]*(1-(S*100^{-1}))*0.1, where S is the rock fragment fraction [vol%] (Don et al., 2007; Dörfer et al., 2013; Poeplau et al., 2017). Texture was determined by X-ray granulometry using SediGraph 5120 for grain sizes < 20 µm and combined sieving for grain sizes from 2000 µm to 20 µm. For the analysis of total heavy metal contents, a reverse *aqua regia* digestion was done (DIN ISO 11466: 1997-06) using a HNO_3 and HCl solution in a ratio of 1:3. Samples were digested. Solutions were analyzed for Cd, Cu, Cr, Ni, Pb, Zn, Hg, and As with the ICP-OES. Used wavelength were 228.802 nm for Cd, 327.393 nm for Cu, 267.716 nm for Cr, 231.604 nm for Ni, 220.353 nm for Pb, 206.2 nm for Zn, 194.168 nm for Hg, and 188.979 nm for As (Nölte, 2003). Heavy metal contents increasing with depth are thought to result from weathering of the parent material, a decreasing heavy metal content or significant peaks in certain horizons in contrast point to an anthropogenic input of heavy metals.

Pollen samples were treated using HCl, hot HF if necessary, chloration, and acetolysis, staining in glycerol (Berglund and Ralska-Jasiewiczowa, 1986). Data compilation and evaluation was done using *Taxus* (Rösch et al. unpubl.) and *Tilia* (Grimm, 1991). The relation between organic and minerogenic matter was determined as loss-on-ignition, sampling in 1 cm intervals (Berglund and Ralska-Jasiewiczowa, 1986). After drying for 12 hours at 102°C and weighting the material was heated at 550°C for two hours and weighted again. The difference in weight is the portion of organic matter. Further heating with higher temperatures to separate and determine calcareous and minerogenic material was not necessary, because bog peat contains no lime. AMS-^{14}C dating on 27 peat bulks was carried out in the laboratories of Erlangen and Poznan. The calibration of the AMS-^{14}C ages and the construction of the Bayesian time and deposition models was done with OxCal 4.2 (Bronk Ramsey, 2009).

To estimate depositional ages of the colluvial sediments, optical stimulated luminescence (OSL) dating was applied, using opaque steel cylinders with a diameter of 4.5 cm for sampling. For equivalent dose (D_e) determinations, the coarse grain (90-200 µm) quartz fraction was prepared and measured with a single-aliquot regenerative-dose protocol after Murray and Wintle (2000). All luminescence measurements were carried out at the luminescence laboratory of the Justus-Liebig-University in Giessen, using a Freiberg Instruments Lexsyg reader (Lomax et al., 2014). For OSL data analysis, the R luminescence package (Kreutzer et al., 2016) was used. OSL ages are listed with the 1σ standard error, which combines all random and quantifiable systematic errors (Lang et al., 1999).

To avoid modern bleaching by bioturbation, the upper 30 cm of the profiles were not sampled for OSL dating. In consequence, colluvial deposition of the modern era might be underrepresented. This might also apply to older colluvial deposits, because of the generally better preservation of younger deposits. However, the general suitability of OSL dating on colluvial deposits, is shown in numerous studies, despite issues of partial bleaching (e.g. Fuchs et al., 2011; Fuchs and Lang, 2009; Kadereit et al., 2010). Most samples have good properties for luminescence dating, showing a bright luminescence signal. Therefore, small aliquots with a diameter of 1-2 mm were measured. In the case of skewness of the equivalent dose distribution a minimum age model was used to calculate correct ages. Skewness can result from partial bleaching and would result in an over- or underestimation of ages.

AMS-^{14}C dating of charcoal fragments found within the colluvial sediments was carried out at the laboratories of Erlangen, Jena, Mannheim, and Poznan. The pretreatment was done using the ABA (acid-base-acid) or, in case of samples measured in Jena, by an ABOx (acid-base-oxidation) procedure (Steinhof et al., 2017). The conversion of the ^{14}C isotope ratios in calendar and calibrated ages was done with OxCal 4.2 (Bronk Ramsey, 2015) using the IntCal13 calibration curve (Bronk Ramsey, 2009; Reimer, 2013). Confidence levels or error margins of radiocarbon dating include the statistical errors (Lang et al., 1999), this study lists the 1σ level.

The basic assumption for the interpretation of charcoal ages is that no relocation within the soil profile occurred. Occasionally, sample ages were encountered which appear to be out of sequence in relationship to other dated samples within a soil profile. In those cases, where the majority of ages formed a clear stratigraphic sequence, and certain charcoal samples date to much older or younger times than would have been expected due to their sampling location within the sequence, a relocation of those samples by natural processes of bioturbation or redeposition was assumed. Age inconsistencies may also be due to the use or re-use of old timber because the samples date to the time when the organism stopped to metabolize atmospheric carbon and the relation between the stable ^{12}C and the decaying ^{14}C started changing, rather than the time when the wood was processed and used. These confounding effects can also explain charcoal ages which appear older than OSL ages. Another assumption is that the charcoal fragments are the result of consecutive inputs, most probably of anthropogenic origin, because single charcoal pieces are distributed throughout the soil profiles and not layered. If the pretreatment omitted all contaminations, the age of the charcoal represents the age of the layer plus the time span from the growth year (after which the tree stopped integrating atmospheric carbon) to deposition, i.e. the charcoal age is an upper limit for the age of the colluvial horizon. The true age of the formation of colluvial deposits is not necessarily dated with the radiocarbon or luminescence method.

The radiocarbon calibration process can also introduce additional errors if particular ages are associated with problematic parts of the calibration curve ("wiggles" or non-linearities of the calibration curve), which result in extremely large and non-normal standard error estimates, even for very precisely dated samples. Finally, younger charcoal samples might be overrepresented because of better preservation and an increasing probability of destructive processes like erosion and weathering (Eckmeier et al., 2011; Lang, 2003; Surovell et al., 2009), which limits the explanatory power especially for older periods. Thus, radiocarbon ages from charcoal could be older, younger, or of the same age than OSL samples, depending on site taphonomy and age calibration dynamics. Ten additional radiocarbon ages were omitted from the analysis because they dated soil organic matter, which usually gives older ages, since it originates from the older soil formation phase and was relocated with the colluvial material.

Only the available radiocarbon and OSL ages from colluvial layers with a high reliability, based on the comparison of luminescence and ^{14}C ages and the stratigraphic context, were used for the calculation of the summed probability density (SPD) plots (Downey et al., 2014; Parnell et al., 2008). To meet the critique on SPDs (Bleicher, 2013) sampling should be representative in a way that the probability of having a sample dating to a certain period, should have the same relation to the number of sites for all periods (Shennan and Edinborough, 2007). Soil pit locations were purposefully sampled from archaeological contexts; however, within each soil pit, soil material for dating was sampled from the top to the bottom of the vertical pit wall, and from within each identifiable and dateable layer. Because of this, the distribution of the age samples represents an unbiased, temporal sample and therefore, the SPD curves from the ^{14}C and OSL ages and error distributions are valid profiles of the colluviation intensity of these sites through time. To calculate SPDs, uncalibrated radiocarbon ages and errors were used and calibrated using the statistical software package Bchron (Parnell, 2016) and the calibration curve IntCal13 (Reimer, 2013). The SPD for the OSL ages was generated by sampling from a Gaussian distribution for each age where the mean was estimated as the date and the standard error was estimated as the OSL error distribution. The different age probability curves are summed and plotted.

In order to contextualize our study area in the larger region we extracted 737 Neolithic and Early Bronze Age radiocarbon ages from the RADON database (Hinz et al., 2012b) and calculated a regional SPD. To get a representative dataset we included ages from following areas: southwest Germany (Baden-Württemberg n=556), the Swiss lowlands (Schaffhausen n=18, Zuerich n=100, Basel-Stadt n=0, Basel-Land n=14, Thurgau n=14, Aargau n=8, Solothurn n=3, Jura n=10) and eastern France (Elsass n=0, Franche Comte n=13, Lothringen n=0, Haut Rhin n=0).

Correlations of lab results were calculated with normally distributed data. For every statistical analysis the programs R (R Development Core Team, 2016) with RStudio (RStudio Inc., 2016) or Microsoft Excel (Microsoft Corporation, 2017) were used.

The catena and soil profile graphs were drafted freehand and partially in Adobe Illustrator and adapted in Adobe Illustrator (Adobe Systems Software Ireland Ltd., 2017) by R. Szydlak.

5 Results

5.1 Archaeopedological site characteristics (Manuscript 1, 2, 3)

In this study a total of 58 individual soil profiles were described (Henkner et al., 2018c) with an average of 3 colluvial horizons per soil profile (Tab. 2, Tab. 3). Additionally, 10 soil profiles could be used in the Baar area, which initially were analyzed for a different purpose. Most of the soils were classified as Kolluvisols (49 out of 58), the others as (Para)Rendzinas (n=4), Parabraunerde (n=1) or Braunerde (n=4) within the German classification system (Ad-hoc-AG Boden, 2005). Following the IUSS Working Group WRB (2015) 32 of the soil profiles were classified as Cambisols (colluvic), as Colluvic Regosols (n=17) and a few as Luvisols and Umbrisols. Results of radiocarbon dating on charcoal fragments and pollen and OSL dating of colluvial deposits can be found in Henkner et al. (2018c).

Tab. 2: Numbers of described soil profiles, augers, and taken samples. ()= sample not dated.

Area	Baar	Swabian Jura	Black Forest	Total
Catenas	7+1	4	4	16
Soil profiles	26 +10	15	17	68
Augers	177	107	133	417
Bulk samples	402	166	160	728
Volumetric samples	420	128	140	688
OSL ages (samples)	28 (50)	10 (15)	9	47 (65)
AMS-^{14}C ages of charcoal	58	29	25	112
AMS-^{14}C ages of peat bulks	-	-	27	27
Pollen profiles	-	-	2	2

The field analyses of colluvial deposits usually lead to a site-biographical interpretation of soil development, colluvial deposition, and a wider interpretation about environmental change and land use. This process to assess the geomorphodynamic situation leads to the interpretation of geomorphodynamically stable and instable phases. Geomorphodynamically stable phases are usually characterized by thin or no colluvial layer, whereas thick and multi-layered colluvial deposits containing many artefacts indicate geomorphodynamic instability, most likely caused by land use (Fig. 8). Multi-layered colluvial deposits can be covered by deposits having a fully developed topsoil horizon indicating a phase of environmental stability, thus surface horizon development. The site-biography of colluvial deposits can be interpreted using datings, archaeological knowledge, soil chemical and physical results, and further (paleo)environmental data to reconstruct local site-specific land use dynamics. The summary of several sites within a region leads to a regional land use history.

Tab. 3: Characteristics of colluvial deposits in the study area.

	mean ± SD	min	max
Thickness of colluvium [cm]	111 ± 65	25	231
Thickness of colluvial horizons [cm]	36 ± 30	2	167
Colluvial horizons per profile [number]	3 ± 2	1	9
Slope inclination [%]	6.4 ± 4.3	0.8	18.9
Bulk density of fine soil (<2 mm, [g cm^{-3}])	1.1 ± 0.2	0.2	1.6
SOC [%]	2.4 ± 1.4	0.3	9.2
N [%]	0.14 ± 0.13	0.04	0.81
Carbonate [%]	11.3 ± 20	0	67.8
Coarse fragments >2 mm (determined from volumetric samples, [Mass%])	10 ± 13	0	64
pH CaCl2	6.2 ± 1.1	3.9	7.7
Sand (0.063 to <2 mm, [%])	18.5 ± 20.9	0.8	78.1
Silt (0.002 to < 0.063 mm, [%])	38.8 ± 11.9	13.3	67.9
Clay (<0.002 mm, [%])	42.5 ± 15.2	8.2	69.1
As (detection limit >1.66, [mg kg^{-1}])	32.3 ± 25.4	3.5	112.2
Cd (detection limit >0.2, [mg kg^{-1}])	0.4 ± 0.3	0	1.2
Cr (detection limit >0.08, [mg kg^{-1}])	59.3 ± 30.7	6.4	164
Cu (detection limit >0.18, [mg kg^{-1}])	15.4 ± 7.8	3	41.6
Ni (detection limit >0.26, [mg kg^{-1}])	36.0 ± 18.4	1.6	75.8
Pb (detection limit >0.42, [mg kg^{-1}])	36.0 ± 39.4	2.2	220
Zn (detection limit >0.1, [mg kg^{-1}])	91.8 ± 50.7	6.6	273.8

Colluvial deposits cover almost the entire area of the studied slopes, even upper backslopes (footslope n=12, backslope n=15, shoulder n=6), in contrast to published soil maps (Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg, 2013) after which they are expected to be thicker in and limited to foot slope positions. Soil properties of colluvial deposits (Tab. 3) show a wide variety (Henkner et al., 2018c).

Particle size as an example of varying soil properties (Fig. 2), is controlled by the weathered parent material. Therefore, sites in the Black Forest developed from sandy rock mostly have a sand content of >40%. Soils on the Baar and the Swabian Jura show range of silt and clay contents and usually <20% sand content.

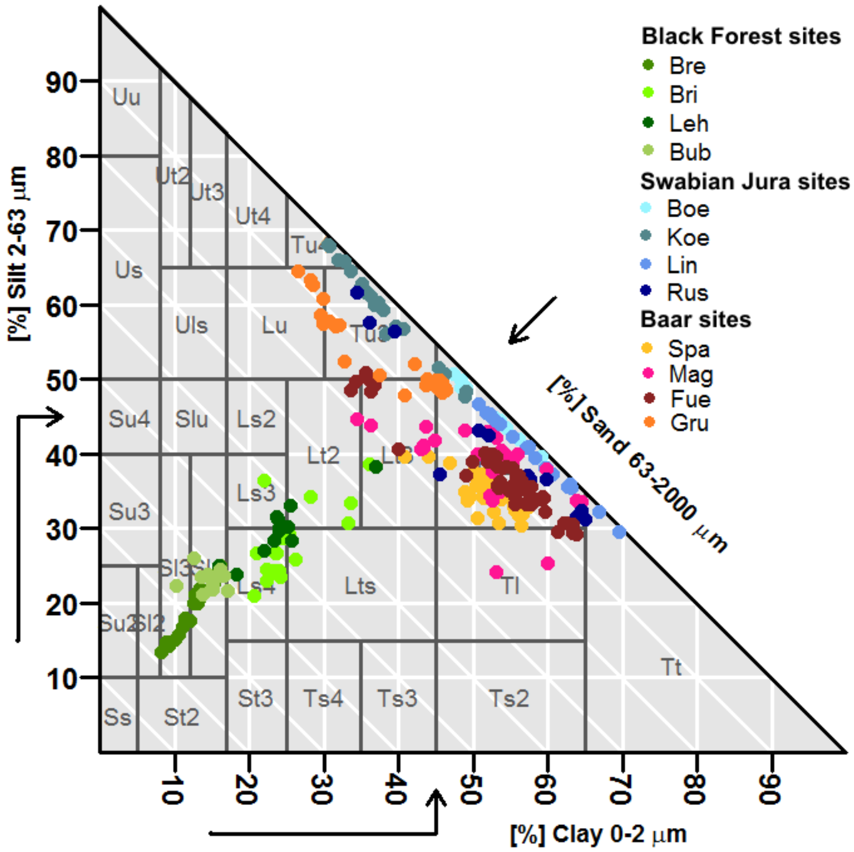

Fig. 2: Particle size [in µm] distribution of colluvial deposits plotted in a particle size triangle after Ad-hoc-AG Boden (2005). One dot represents one sample. Red-orange colors= Baar sites, Blue =Swabian Jura sites, Green colors = Black Forest sites.

Particle size is an important factor influencing soil erosivity and might control whether or not a soil erodes facing certain land use conditions. Because of its importance to soil erosion particle size is included in erosion equations, as are structure, organic matter content, and permeability. Slope morphology, precipitation regime, and vegetation also influence soil erosivity (Nearing et al., 2017). Clay soils are typically more coherent and consequently protected against erosion compared to loose sandy soils, having more macro-pores. Soils with a larger particle size are therefore, more prone to soil erosion than finer soils, because water can more easily detach particles from each other. On the other hand, soils with a high content of macro-pores might promote infiltration and thereby delay or prevent run off. The hypothesis that sandy soils are more easily eroded and should, therefore, have thicker colluvial deposits cannot be accepted, considering the factors thickness of colluvial deposits and particle size. Colluvial deposits in the Black Forest mostly have a sandy soil texture and additionally higher relief energy and higher mean annual precipitation. Still, the thickness of the colluvial deposits is smaller than in the Baar area. This can be explained by lower land use intensities or different types of land use.

The presence of charcoal, an often cited condition needed to determine a colluvial deposit, appears only in 76% of the soil profiles and burned clay artefacts only in about 48% of soil profiles (anthropogenic artefacts in general like broken glass, iron, burned clay, etc. occurred in 60% of the soil profiles). Overall the variety of soil properties within the colluvial deposits/horizons varies strongly.

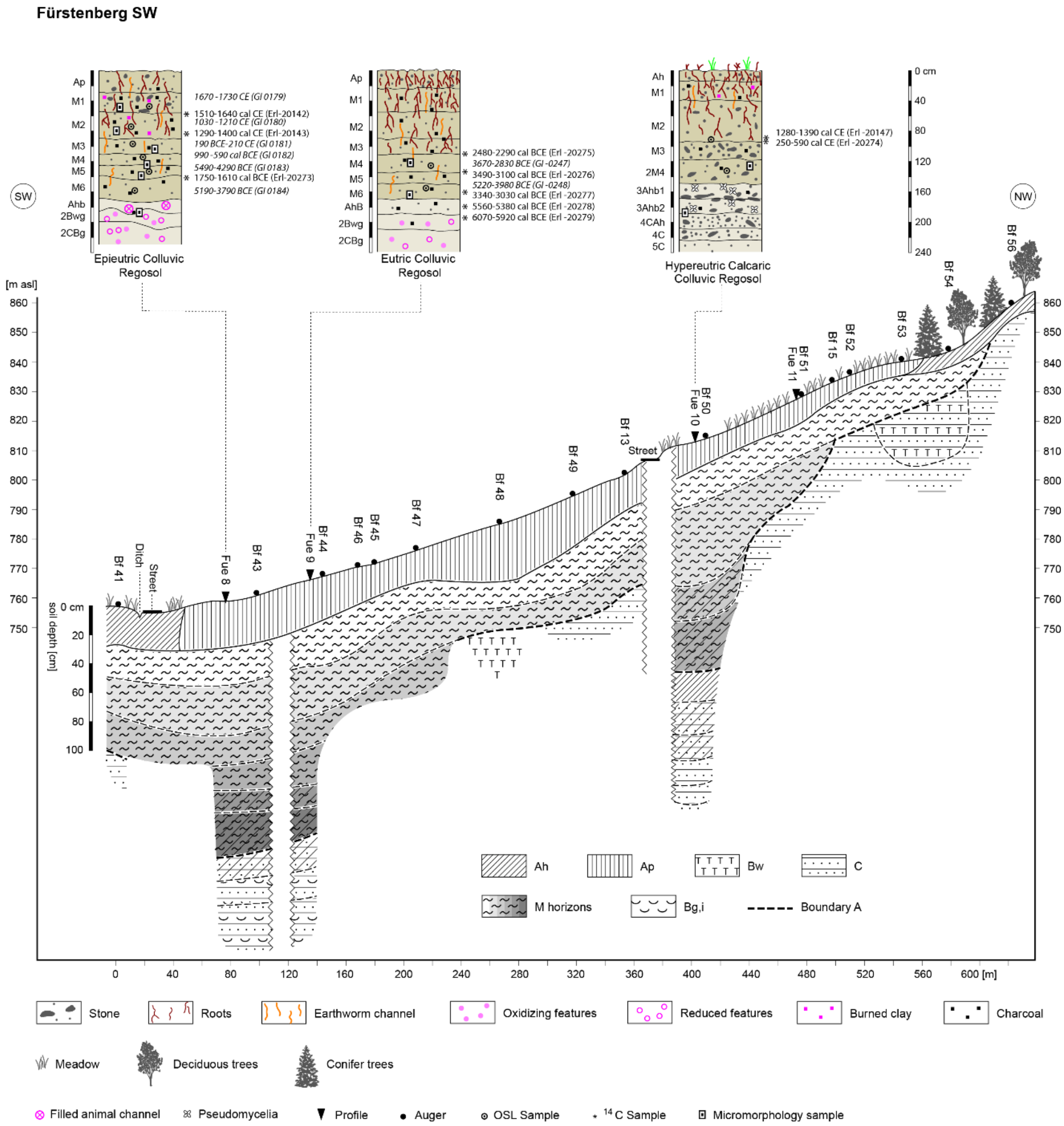

Fig. 3: Catena and soils on the southwestern slope near Fuerstenberg (updated Fig. 3 of Henkner et al., 2017).

Colluvial deposits usually show a downslope continuum of soil properties (e.g. Fig. 3). However, they are not necessarily parallel to the surface, but show a highly variable paleorelief with depressions, indicated by the boundary A. Especially streets crossing a slope (between Bf13 and Fue10) can function as boundaries and sediment traps, collecting most of the eroded material and lead to a change of colluvial deposits characteristics. But also apparently connected soil horizons like the colluvial deposits of Fue8 and Fue9 or Bre1 and Bre2, may have to be separated because of different deposition times.

Generally, all sites are still used today, either for farming or grazing, thus the land is drained if necessary and the surface modified. The colluvial deposits overlie periglacial slope deposits, sometimes separated by buried topsoil horizons.

5.2 Colluvial deposits on the Baar (Manuscript 1, 5, 6)

The Baar area is in contrast to neighboring regions of the Swabian Jura and the Black Forest a favorable landscape: the soils are fertile, slope inclination is lower, and the mean annual temperature is higher than in those unfavorable landscapes (Lazar and Rilling, 2006; Siegmund, 2006). For the settlement in early history those environmental factors played a role, but systematic archaeological knowledge about the relation between environmental factors and the population of the Baar is still limited (Knopf et al., 2015).

The application of the catena concept to five sites on the Baar resulted in several representative well-stratified soil profiles. In this study, >150 colluvial deposits were described from 36 individual soil profiles (Henkner et al., 2017). These colluvial deposits present a high resolution spatial archive of land use history of the area upslope, from which the material was eroded (Bettis, 2003; Emadodin et al., 2011; Leopold and Völkel, 2007a). Archaeopedological analysis is useful, since people are expected to have relied on subsistence agriculture for living, which would have left traces in the soil (Knopf et al., 2015).

The intensive land use seems to have started in the south and northwest of the Baar area, since the oldest colluvial deposits stem from the sites at Fuerstenberg and Magdalenenberg. The earlier onset of permanent land use (most likely agriculture) might be explained by higher temperatures and fewer frost days compared to other parts of the Baar and neighboring regions (Henkner et al., 2017).

The site Fuerstenberg was chosen because of its long and well-studied settlement history starting in the Younger Neolithic and continuing during the Urnfield and Hallstatt period and later also during the Roman Empire and High Middle Ages (Knopf et al., 2015). The analysis of 11 colluvial soil profiles confirm the settlement during those phases and indicate the same periods as phases of intensive land use and colluvial deposition (Henkner et al., 2017). The archaeopedological analysis of the other sites also confirmed or extended the archaeological knowledge about past settlement and land use phases. The site Magdalenenberg for example holds 80 cm thick colluvial deposits (Mag1) in a toeslope position and is recently used as a hay meadow. Yet, the thick colluvial deposits dated to the Mesolithic, Neolithic and Middle Ages suggest a more intensive land use over the last nearly 6000 years until about 1000 years ago (Ahlrichs et al., 2016; Henkner et al., 2017). Results from an archaeological dig 2010 revealed an anthropogenic stone pavement underneath a low rampart across a slope, the function of which is not entirely clear. Radiocarbon dating of the colluvial deposits, overlying and building up the rampart indicate Neolithic settlement, support the interpretation of early settlements and land use and contradicts the notion of a late settlement during the Middle Ages (Knopf et al., 2015).

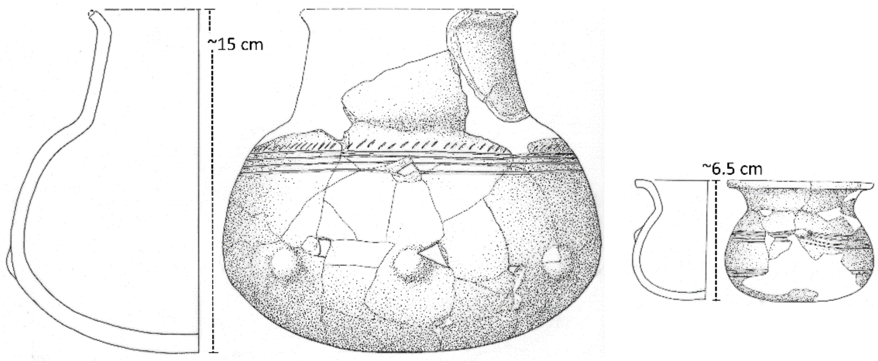

Fig. 4: Two vessels from the Urnfield period were found in the soil profile Gru8_14 in 65 cm depth at the lower boundary of the M2 horizon. The bigger vessel contained the smaller one, no contents could be determined (Henkner et al., 2017; Henkner et al., 2018a).

Only very little archeological finds were discovered during the pedological field work. The finding of two vessels dating to the Urnfield period in the soil pit Gru8_14 at the site Grueningen (Ahlrichs et al., 2016; Henkner et al., 2017) proofed to be extraordinary. The colluvial deposition points to continuous human habitation and land use since the Roman Empire and earlier temporary phases of land use during the Final Neolithic and Bronze Age. The finding of the vessel within the lower colluvial horizon clarified the stratigraphy of two divergent radiocarbon ages

(MAMS 122277, Erl-20136) and lead to the interpretation of the younger age as deriving from a relocated charcoal fragment (Henkner et al., 2017). Additionally, the vessel extends the proof of land use and habitation during the Urnfield period and is probably related to the contemporaneous settlement in the upper slope area (Ahlrichs et al., 2016).

All sites (Fue, Gei, Gru, Mag, Spa) show a long history of intensive land use, indicated by colluvial deposition, alternating with periods of extensive land use or phases of geomorphodynamic stability visible through the differentiation of colluvial deposits.

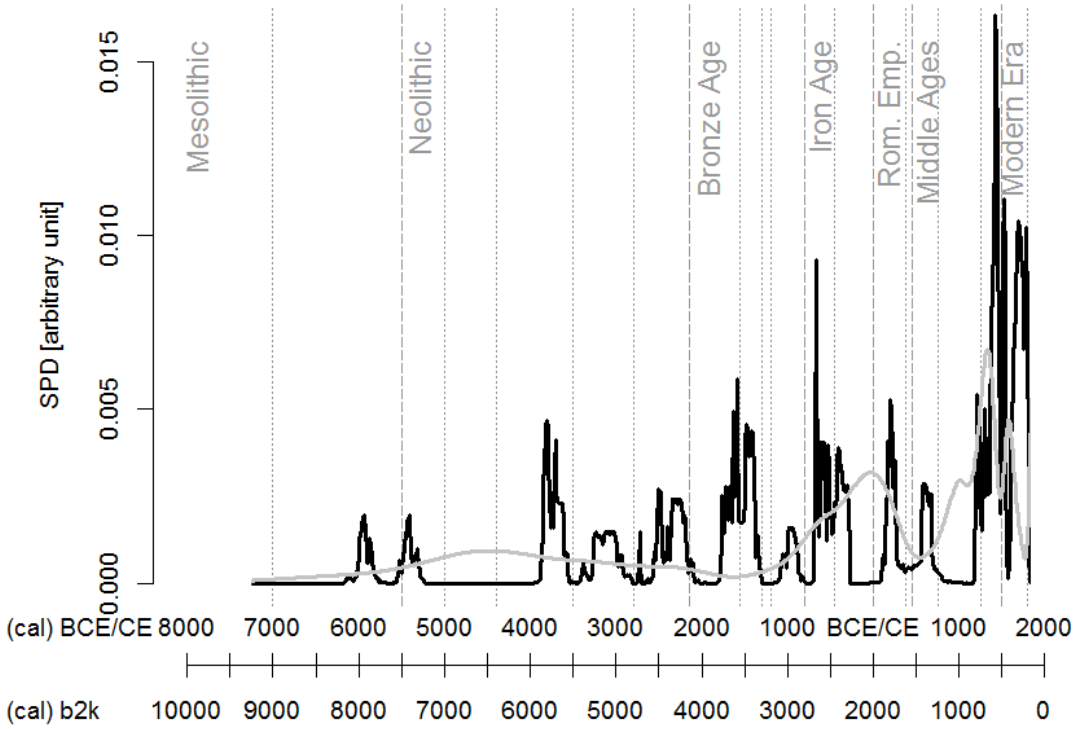

Fig. 5: Summed probability density (SPD) curve of ages from anthropogenic soil-erosion derived colluvial deposits on the Baar. Grey line: OSL data, n=28; black lines AMS-^{14}C data, n=41 (Henkner et al., 2017).

The chronostratigraphy of colluvial deposition complements and breaks down the archaeological record of settlements and land use in the Baar area and can be analyzed using the summed probability density (SPD) curves of the ages (Fig. 5). The SPDs show peaks of increased probability of ages from a specific time along the time axis. These ages are interpreted as being connected to colluviation and thus land use and settlement. Especially the OSL-SPD is interpreted to have a strong connection to intensive land use, and to be interpretable as showing phases of increased land use leading to higher soil erosion and deposition rates. The OSL-SPD shows increased colluviation during the Middle to Younger Neolithic based on samples from the

Magdalenenberg and Fuerstenberg site. The following peak around 500 CE comprises ages from Fuerstenberg and Spaichingen. This peak is higher and narrower than the preceding ones. The pronounced depression falls in the Migration and Merovingian period. Increased probability in the High and Late Middle Ages is evident at all sites, except Grueningen. Radiocarbon ages result in narrower and therefore, higher SPD peaks. Lower peaks are a result from the calibration curve and cannot be interpreted as a proxy of human activity. The oldest peak dates to the late Mesolithic at the Fuerstenberg. There are several pronounced individual peaks from the late Neolithic onwards, and they originate from the samples at Fuerstenberg, Grueningen and Spaichingen. The Magdalenenberg dates appear only in the younger Neolithic and the High to Late Middle Ages. The increased probability of ages in the Middle Ages counts for all of the sites except Spaichingen, where only older charcoal was found (Henkner et al., 2017).

Summing up the SPDs of radiocarbon and luminescence ages, seven main phases of increased probability of colluviation (Fig. 6) can be differentiated as distinct maxima from several secondary peaks with lower probability. The oldest peak dates to around 3800 cal BCE, i.e. the younger Neolithic (1), and is followed by smaller peaks of increased probability for colluvial formation during the late Neolithic to early Bronze Age. Temporary sediment sinks on slopes can accumulate colluvial deposit for a certain time before the material is eroded and transported further downslope, thereby resetting the physical signal for OSL dating which results in a younger age. This is known as the cascade model of colluvial formation, which might be an explanation for the minimal available information about Neolithic colluvial deposits (Lang and Hönscheidt, 1999). Another reason might be the pedogenic transformation of colluvial deposits into soils, which can be misinterpreted as an entirely in situ formation. Increased colluviation is calculated for the middle Bronze Age (2) and Latène period (3). The main deposition phase (4) around 100 CE is connected to the Romans and their land use. The following Migration period shows decreased colluviation. From the high Middle Ages onwards the probability of colluvial formation is doubled. Colluviation increases even more to the end of the high Middle Ages (5) and around 1300 (6) and 1600 cal CE (7) (Henkner et al. 2017). Considering confidence intervals (not shown) leaves only the peaks during the Bronze and Iron Age and the Middle Ages as statistically reliable peaks of increased colluviation.

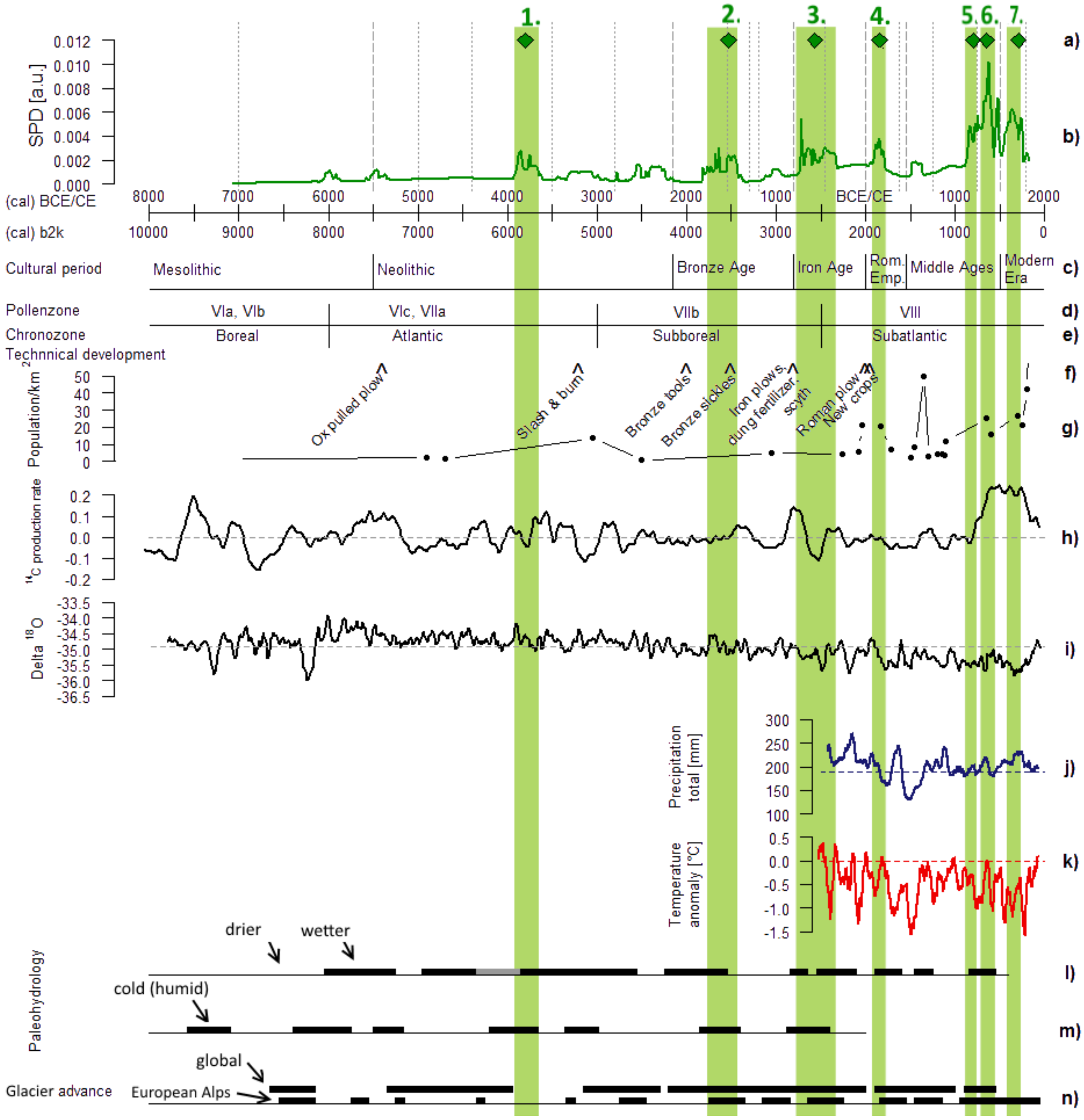

Fig. 6: Main colluviation phases of the Baar compared to paleoenvironmental data. a) Seven main colluviation phases; b) Combined SPD of radiocarbon and OSL ages from the Baar; c) Periods in South Germany; d) Jesse-Godwin pollenzones after Godwin, 1975 in Anderson et al. (2007); e) Chronozones after Mangerud et al., 1982 in Anderson et al. (2007); f) Technical innovations (Lal, 2007; Teuber et al., 2017; Tinner et al., 2003); g) Population density in central Europe (Henning, 1994; Zimmermann, 1996); h) Anomalies of atmospheric ^{14}C production rates compared to the mean (Kromer and Friedrich, 2007); i) $\delta^{18}O$ [‰] record from NGRIP1, 100 year means compared to the mean of all δ 18 O values (NGRIP Members, 2004; Vinther et al., 2006); j) Tree ring based reconstruction of precipitation from April to June in central Europe with respect to the 1901-2001 period (dashed line), 50 year means of yearly data (Büntgen et al., 2011); k) Tree ring based reconstruction of summer (June-August) temperature anomalies in central Europe with respect to 1990-2000, 50 year means of yearly data (Büntgen et al., 2011); l) Wet phases in central Europe (Jäger, 2002); m) Cold and humid phases in central Europe until 2000 BP (Haas et al., 1998); n) Glacial fluctuations during the Holocene (Koch and Clague, 2006). Figure from Henkner et al., 2017.

5.3 Colluvial deposits, heavy metals, and pollen records in the Black Forest (Manuscript 2)

Colluvial deposits cover much of the studied slopes overlying periglacial layers and are linked to alluvial sediments in toeslope positions and alluvial plains. In the southeastern Black Forest 58 colluvial horizons were identified in 17 soil profiles, with an average of 3 colluvial deposits per profile (Henkner et al., 2018b).

The dating of colluvial deposits allows the differentiation of five phases of colluvial deposition. The oldest phase (1) dates from the Younger to the Final Neolithic, the second (2) from the Early Bronze Age to the Roman Empire, (3) the third from the Migration period to the Late Middle ages, the fourth (4) dates to the Early Modern period and the fifth (5) covers the recent Modern Era. The older phases are generally characterized by minor intensity of colluviation and include only a few ages, whereas the younger phases during the Middle Ages and the Modern times are interpreted as main colluviation phases. The main phases of formation of colluvial deposits are the Middle Ages for the Brigach and Breg sites and the Early Modern period for the Bubenbach and Lehmgrubenhof sites. There are, however, ages indicating land use around Lehmgrubenhof and Brigach spring as early as the Neolithic (Henkner et al., 2018b).

While there are mining settlements known in the northern Black Forest no such sites are identified in the southeastern Black Forest, maybe because of the lower quality of iron ore in this area (Knopf, 2017). The analysis of heavy metal contents in soils can indicate the land use type and possible smelting of iron ore, even though no slags might have been found. The contents of As, Cr, Cu, Ni, Pb, Zn, Cd, and Hg were analyzed, but Cd and Hg contents were mostly below the detection limit, so they were excluded from further interpretation (Henkner et al., 2018b). The depth function of As, Cr, Cu, Ni, Pb, and Zn is different in all eight investigated soil profiles. The sites Brigach spring and Lehmgrubenhof have similarly high Cr, Ni, and Zn contents and both overlie periglacial slope deposits and paragneiss in contrast to periglacial slope deposits and granite as in Bubenbach and Breg valley. No general trend of the depth functions is visible, except of Pb, which is decreasing with depth in all soil profiles. Thus, Pb can be interpreted as resulting from anthropogenic activities.

Heavy metal contents were bulked in time slices, i.e. each colluvial horizon was assigned to one of five time slices according to the ages of the horizon or the surrounding horizons (Fig.

7). Most heavy metal contents are within the median range of geologic background and thus not reliably to be interpreted as a result of human actions. There are however, some local maxima connected to weathering of genuine rocks, texture differences, redoximorphic features, or anthropogenic input. Local minima, even below the level of geologic background contents, might be related to low soil pH and subsequent relocation of heavy metals. Soil pH and particle size are strongly correlated to the contents of Cr, Zn, and Ni, while Cr, Zn, and Ni are also strongly correlated to each other. Pb correlates positively with SOC and Cu correlates with sand content (Henkner et al., 2018b).

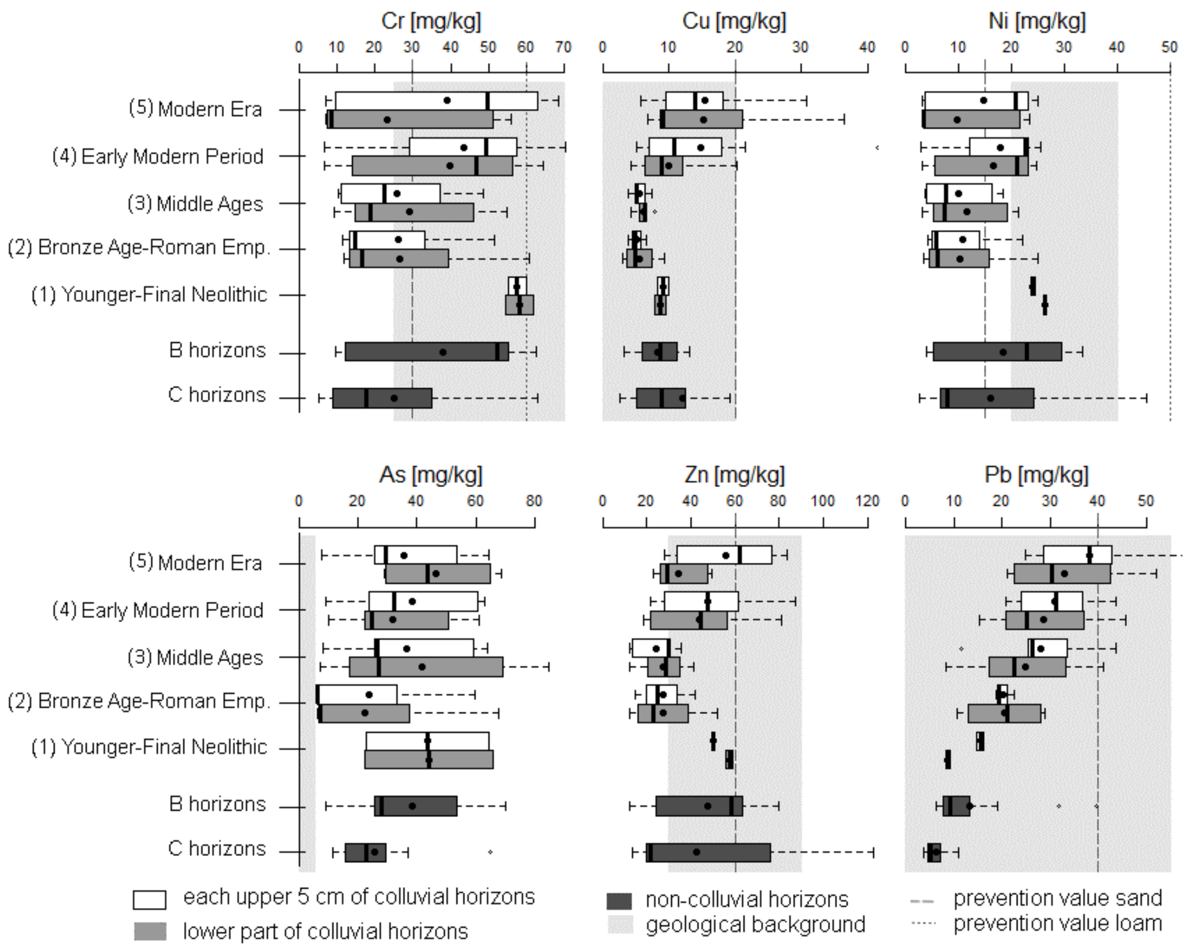

Fig. 7: Heavy metal contents according to the approximate age and soil horizon type (colluvial deposits, B or C horizons). Note different scales for each metal. The grey background displays the median range of the geological background content (Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg, 2016). Prevention values according to Bundesministerium der Justiz und für Verbraucherschutz (1998); no prevention value exists for As. Figure from Henkner et al., 2018b.

The two pollen profiles from Elzhof and Moosschachen (Henkner et al., 2018b) show a record of forest-dominated vegetation history of the last 8000 years. The radiocarbon ages from the Elzhof bog provide a consistent time-depth model but with a slowing rate of peat growth in the upper 35 cm, most probably caused by artificial drainage. The Elzhof profile shows the typical central European succession (after Firbas, 1949) with *Corylus*, *Quercus*, *Tilia*, *Betula*, *Ulmus*, and *Fraxinus*. Around 4000 cal BCE pollen from the shade trees *Abies* and *Fagus* set in and are accompanied by peaks of *Tilia*, *Vaccinium* type, *Calluna*, *Sphagnum*, and first traces of human indicators such as cereals and *Plantago lanceolata*. The pollen record from then onwards is dominated by *Abies* and *Fagus*, only around 1000 cal BCE a slight increase of non-arboreal pollen (NAP) suggests increased human impact on vegetation. During the Roman Empire deforestation and thus human impact is distinct but coupled to population levels, and decreases during the Migration period. During the Middle Ages the share of *Abies* and later also *Fagus* pollen decreases and from around 1400 cal CE the pollen record is dominated by *Pinus*, *Picea*, and NAP (Henkner et al., 2018b).

5.4 Colluvial deposits on the Swabian Jura (Manuscript 3)

The four sites on the plateau of the southwestern Swabian Jura (Henkner et al., 2018a) are situated in similar topographical positions in depressions or the beginning of a valley incision with underlying late Jurassic limestone. The environmental conditions result in similar pedologic characteristics of the soil profiles (e.g. SOC, silt, clay content, and pH). The chronostratigraphy of colluvial deposits inferred from dated charcoals indicates a Mesolithic beginning of intensified land use or land use change in the Mesolithic at the sites Koenigsheim, Russberg and Lindenberg. The onset of continuous land use seems to have started during the Neolithic. Neolithic charcoals were found in colluvial deposits at Lindenberg, Koenigsheim and Boettingen. The oldest OSL ages of colluvial deposits, however, date to the Late Bronze Age and Urnfield period. The onset of luminescence ages indicates an intensification of agricultural land use or land use change from the Late Bronze Age to the Hallstatt period. Already during the Roman Empire land use is not detectable at the sites Boettingen and Koenigsheim using colluvial deposits as a proxy, which indicates the absence of or human activities with a very low impact on the environment. Charcoals date to the Iron Age in colluvial deposits at the Russberg site. At Lindenberg and Russberg colluvial deposits and charcoals were found dating to the Roman Empire. Despite the well documented archaeological knowledge of the Middle Ages, medieval colluvial deposits were only found at Russberg and Koenigsheim. Even though the environmental conditions on the southwestern Swabian Jura are very similar, differences in land use dynamics between the investigated sites can be inferred from colluvial deposits and dated charcoals (Henkner et al., 2018a).

5.5 Social-ecological system and adaptive cycle agrarian soil use (Manuscript 4)

The SES agrarian soil use underwent one adaptive cycle from the Neolithic Transition to the Industrial Revolution (Teuber et al., 2017). The Neolithic Transition enabled people to settle down, producing higher food quantities (Childe, 1936; Holling et al., 2002b), new crops, and agrarian tools were introduced. The Industrial Revolution marks the beginning of a second adaptive cycle with the industrialization of agriculture and food production. In between those two r-phases, the majority of society practiced agriculture (Evans, 2012). The main crops of Central Europe remained similar to the ones introduced during the Neolithic, with the exception of potato or maize, introduced after the “discovery” of the American continent during the K-phase (Hawkes and Francisco-Ortega, 1993; Rebourg et al., 2003; Rösch, 1998). The soil cultivation depended on man and animal labor. The technology improved from the spade to the ard to the plow during the r-phase (Teuber et al., 2017).

During the Mesolithic, hunting and gathering was the subsistence form of life (Bailey and Spikins, 2008; Prummel and Niekus, 2011; Tolksdorf et al., 2009; Uerpmann, 2007), the impact on the soil remained small. When humans settled down and developed agriculture, they gained impact on the environment and the SES agrarian soil use began. The Neolithic transition marks the onset of the reorganization (α-phase) and the start of the r-phase of the SES agrarian soil use in Central Europe. The variable soil became important to the sedentary people. They cleared forests for timber, fuel and fields, changing the water and nutrient cycles, and influencing soil formation processes (Bork et al., 2006; Ellis et al., 2013b; Gerlach and Eckmeier, 2012; Kaplan et al., 2009). Deforestation led to the formation of anthropogenic colluvium in valleys and on slopes (Henkner et al., 2017; Teuber et al., 2017). Soil quality and the proximity to fresh water seem to have been relevant for the settlement of a region (Banks et al., 2013; Brozio et al., 2014;

Davison et al., 2006; Fries, 2005; Lüning, 2000; Rösch et al., 2002; Zolitschka et al., 2003). During the Neolithic, the SES agrarian soil use was in the r-phase of exploitation by transforming the landscape to adjust it to new human needs connected to sedentariness. The arrival of the crop plants, the development of tools and the onset of erosion show the emergence of the SES agrarian soil use. After the Neolithic Transition, the SES agrarian soil use remained in the r-phase through Bronze and Iron Age (Teuber et al., 2017).

Writings on agriculture by Greek and Roman authors show that the SES agrarian soil use moved toward the K- or conservation phase. The traditions and land management practices were written down and the importance of “good” practices was stressed (Teuber et al., 2017). However, it is important to note, that the knowledge documented in the literary works of the agrarian writers might not have been applied to agriculture north of the Alps (Deschler-Erb and Akeret, 2011). Agricultural technology was also developed during Roman times leading e.g. to the use of iron in spades (Lal, 2007). The further development of existing tools and the existence of written sources concerning agricultural practices indicate the K-phase where connectedness increases, including knowledge and technology needed for a successful agriculture. The variable soil shows erosion and colluviation processes. However, agrarian soil use is still connected to animal and men power with similar tools. These tools have been improved but no invention happened that altered the actual practice of agrarian soil use (Teuber et al., 2017). The K-phase continued during Medieval times, an epoch that comprises many different dynasties, societal and regional developments (Fried, 2009).

The soil was slowly treated differently, because fertilization became increasingly part of agriculture during Medieval times (Behre, 2000). Furthermore, the variables soil and knowledge/technology became interconnected. Erosion and colluviation increased during medieval times (Dreibrodt et al., 2010; Zolitschka et al., 2003). Mining activities led to a rapid deforestation but also to new regulations prohibiting forest clearing in certain areas (Steuer, 1993). Deforestation for agricultural purposes continued, leading to erosion and the formation of anthropogenic colluvial deposits (Henkner et al., 2017; Henkner et al., 2018a; Teuber et al., 2017). However, humans still practiced agriculture with the help of tools and animals used for traction, the SES agrarian soil use was not restructured as such but remained in the K-phase.

With industrialization, the SES agrarian soil use moved through the Ω-phase of creative destruction and the α-phase of reorganization. The different variables changed considerably. During the 19th century, the scientific analysis of soil increased. Albrecht Daniel Thaer, Justus von Liebig, Charles Darwin and Vasilii V. Dokuchaev wrote their important works on soils (Darwin, 1890; Liebig, 1841; Thaer, 1880). A change of the knowledge/technology variable is observable in new machines, but also resulted in global societal changes. Technological advances, such as the invention of the steam engine led to motorization and mechanization of agricultural practices (Bergmann, 1970; Gessner, 1976; Hahn, 2011). The use of new technologies changed the strong link between agriculture and animal husbandry, because animals were no longer needed for traction and manure (Lambin et al., 2001). Traditional crop rotation practices and fallow were also abandoned due to cheap nitrogen availability (Montgomery, 2007). This development marks the r-phase of exploitation where growth is accomplished with new efficient technologies. It also starts the process towards a knowledge-based society, which influences the agricultural sector (Uekötter, 2012), and raised the work force in the secondary and tertiary sector (Hahn, 2011), leading additionally to urbanization (Antrop, 2004) and globalization (Levitt, 1999; Robertson, 1992). The dependence on fossil fuels indicates a growing rigidity of the SES, which would point towards the end of the K-phase of the adaptive cycle (Teuber et al., 2017).

6 Discussion

6.1 Using colluvial deposits as archives

6.1.1 Concept to interpret colluvial deposits (Manuscript 3)

Studying complex nonlinear colluvial deposits as archives and thus as a resource to learn about past human-environment interactions demands guidelines of interpretation (Fig. 8). Here, the presence of colluvial deposits including artefacts and/or charcoal fragments is interpreted as a local proxy of former land use (change) on the corresponding hillside. More intensive (unsustainable) land use might have led to thicker colluvial deposits. However, the link between colluvial deposition and land use or the specific site of a settlement is not always reliable. The concurrence of colluvial deposits and known archaeological sites in the area could be shown, but a direct relation to a certain archaeologically known settlements in the vicinity could not be established. When the colluvium is made up by multi-layered deposits, it is assumed that the sites have undergone alternating phases of geomorphodynamic instability and stability, in other words alternating phases of intensified land use including colluvial deposition and phases of no land use with predominantly natural vegetation cover or phases where sustainable land use techniques were used. Phases of geomorphodynamic stability can also be interpreted as phases of sustainable land use, preventing soil erosion and accumulation. These phases are the deposition gaps between colluvial layers. The duration of these stable periods is the difference between the ages of the colluvial layers. The underlying older horizon would have served as a land surface during that time and might show different pedogenic properties (like an enrichment in SOC or heavy metals) as a result of pedogenic processes, vegetation growth and increased activity of organisms. Later soil erosion of colluvial deposits also presents itself as a deposition gap and can be misinterpreted as a phase of geomorphodynamic stability. Anthropogenic colluvial deposits have to be distinguished from natural slope deposits, formed by periglacial processes, bioturbation or soil creep (Hughes et al., 2009; Kleber et al., 2013; Larsen et al., 2016). Multiple local archaeopedological chronostratigraphies of colluvial deposition and land use phases or site-biographies can be summarized and taken as a proxy for regional colluvial deposition and land use history.

The occurrence of soil erosion and deposition depends on environmental conditions (e.g. topography, soil, climate), population density, technological knowledge and practices (e.g. trade, rituals, valuations), and other factors. The trigger of intensified land use can be hypothesized using archaeological knowledge about peoples' activities or by reading environmental properties interpretable in favor of a certain activity or environmental characteristic. An uncomprehensive list of possible reasons is: (1) A higher population density in the studied area or in neighboring regions. (2) The discovery, development, or exploitation of resources. (3) Agricultural techniques may have been improved making overproduction and trade possible. Or (4) climatic changes or variabilities made more intensive land use possible.

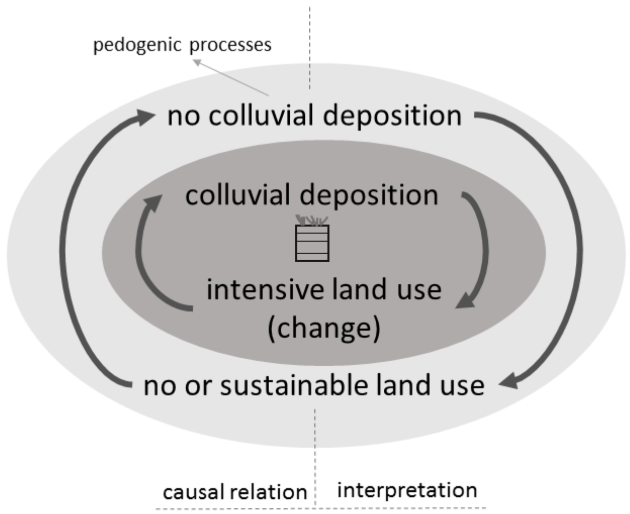

Fig. 8: Interpretation scheme of colluvial deposits as a nonlinear human-natural system linked by land use and archiving site-biographies. Dark grey= geomorphodynamic activity, light grey= geomorphodynamic stability. Figure from Henkner et al. (2018a)

Dating colluvial deposits is a crucial point for the interpretation and linkage of deposition events to land use or other triggering events and circumstances. Based on this study, dating is done best by OSL dating, resulting in the most reliable age of the deposition event (see chapter 6.1.2).

The outlined guidelines require an anthropogenic influence on soil erosion and accumulation processes. Natural events, like frequent wild fires followed by erosion or landslides, must be eliminated as causes for the deposition response.

6.1.2 Interpretation of OSL and AMS-^{14}C ages

Regarding the pre- and early historic land use, radiocarbon dating of charcoals found in colluvial deposits and OSL dating of colluvial deposits provide numerous new insights, since they add knowledge, which does not rely on archaeological finds. Radiocarbon dating of charcoals is precise but difficult to interpret in relation to the timing of the formation of colluvial deposits. This has several reasons: charcoal fragments (1) are prone to relocation by bioturbation within the soil, the extent of which cannot be measured (Klooß et al., 2012), (2) can be incorporated into the soil during a later time period, (3) can result from burning old wood, (4) can be fragmented within the soil, and (5) can be polluted by younger humic substances. Additionally, one must decide about the natural or anthropogenic origin of the charcoal. Thus, the dating of charcoals must be interpreted carefully with consideration of the (paleo)environmental circumstances.

In this study, charcoal ages are interpreted as a proxy of human presence or activity and rather sustainable land use in terms of soil conservation, otherwise there would also be OSL ages dating to the same period. OSL ages refer to the period of time when the deposit was formed and are thereby closely linked to soil erosion, which can be triggered by unsustainable (intensive) land use like agriculture. Unknown is also the timely correlation of charcoal fragments to their incorporation into the colluvial deposit and possible further lateral or vertical relocation within the soil. Therefore, the sampling depth of the charcoal fragment found in a colluvial deposit is insignificant. The interpretation as a proxy for human presence is similar to many archaeological studies, specifically using charcoal dating to reconstruct population intensities (cf. Downey et al., 2014; Gamble et al., 2005; Hinz et al., 2012a; Nikulka, 2016; Shennan et al., 2013). High human activity can also be interpreted as high human impact on the environment. The common use of radiocarbon dating of charcoal fragments found in colluvial deposits to date the deposition event (cf. Dotterweich et al., 2013; Emadodin et al., 2011; Lang and Hönscheidt, 1999; Wilkinson, 2003) is mostly based on the argument, that the charcoal was incorporated into the colluvial deposit at the time of deposition, with little time between burning and incorporation. Thus, the age of the charcoal can be interpreted as a maximum age of the colluvial deposit. If the assumption is correct, radiocarbon dating of charcoal fragments to date colluvial deposits would be a fast and comparatively cheap method to establish a chronostratigraphy. Yet, the comparison of AMS-^{14}C and OSL ages shows that this line of arguments must be rejected as being unreliable.

Radiocarbon dating of soil organic matter is also used to date colluvial deposits, but it is not clear if soil organic matter was accumulated *in situ* or inherited and deposited with the colluvial soil. Results show a divers relationship of the ages of soil organic matter to OSL and charcoal ages (dates not shown).

Dating archaeological artefacts found within a colluvial deposit bears some of the limitations described for dating charcoal fragments. The difference is that artefacts are usually younger than the colluvial deposit and are, depending on their size, not relocated. Therefore, artefacts cannot be used to date colluvial deposits. However, artefacts clearly are to be interpreted as indicating human presence and are not to be mistaken as a natural phenomenon.

OSL ages can be interpreted as the age when the colluvial deposit was formed. Attention must be paid to the nonlinear time lag between the response deposition event and the triggered soil erosion event (see above). Still, it is assumed that the deposition happens with little delay to the erosion event and that the material was eroded and deposited only once. Advantageous for the archaeopedological interpretation is the small source area of colluvial deposits and, thus, the limited transportation distance. But for OSL dating the short distance might result in partial bleaching of minerals because of insufficient energy input (Fuchs and Wagner, 2005). Under optimal conditions however, signals can be fully bleached within seconds (Fuchs and Wagner, 2005; Godfrey-Smith et al., 1988). When dating colluvial deposits, samples might have to be corrected for partial bleaching to prevent an age overestimation. Another problem is bioturbation and mechanical processes within the soil, which lead to material relocation and possibly to signal bleaching. This can result in the over- or underestimation of a colluvial age (Berger and Mahaney, 1990; Fuchs and Lang, 2009). Despite challenging conditions, many studies showed that dating of colluvial deposits is possible (Fuchs and Lang, 2009).

AMS-^{14}C dating of charcoal and OSL dating of soil minerals resulted in a wide and unpredictable range of age differences between the dating methods, even though samples have been taken from the same depth (Fig. 9). Charcoal ages are up to 3000 years older than the corresponding OSL ages taken from the same horizon in a similar sampling depth. In few cases, the results of both dating methods yield similar or even the same results, which give a robust chronostratigraphy of colluvial deposits (age pairs on the left of Fig. 9). There is no obvious trend of a larger age difference between the methods in older ages. Lang and Hönscheidt (1999) also encountered that charcoals and other artifacts resulted in a random stratigraphy whereas OSL ages align chronologically. Given that both dating techniques provide physically correct ages and the dynamics of colluvial deposition processes, OSL ages seem to be – in most instances – more reliable in giving a model age of the period of time during which the dated colluvial layer was formed (Fuchs and Lang, 2009; Kadereit et al., 2002; Lomax et al., 2011). The downside of OSL dating is the wide error range on a 1σ level. Additionally, there might be a time lag between the time when soil erosion was triggered (the period when the slope was actually used) and the time when it was deposited, which is interpreted as the time when the slope was used. However, it is assumed that trigger and response date to the same time. This time lag depends on the occurrence of temporary sediment sinks along the slope and the velocity of soil relocation.

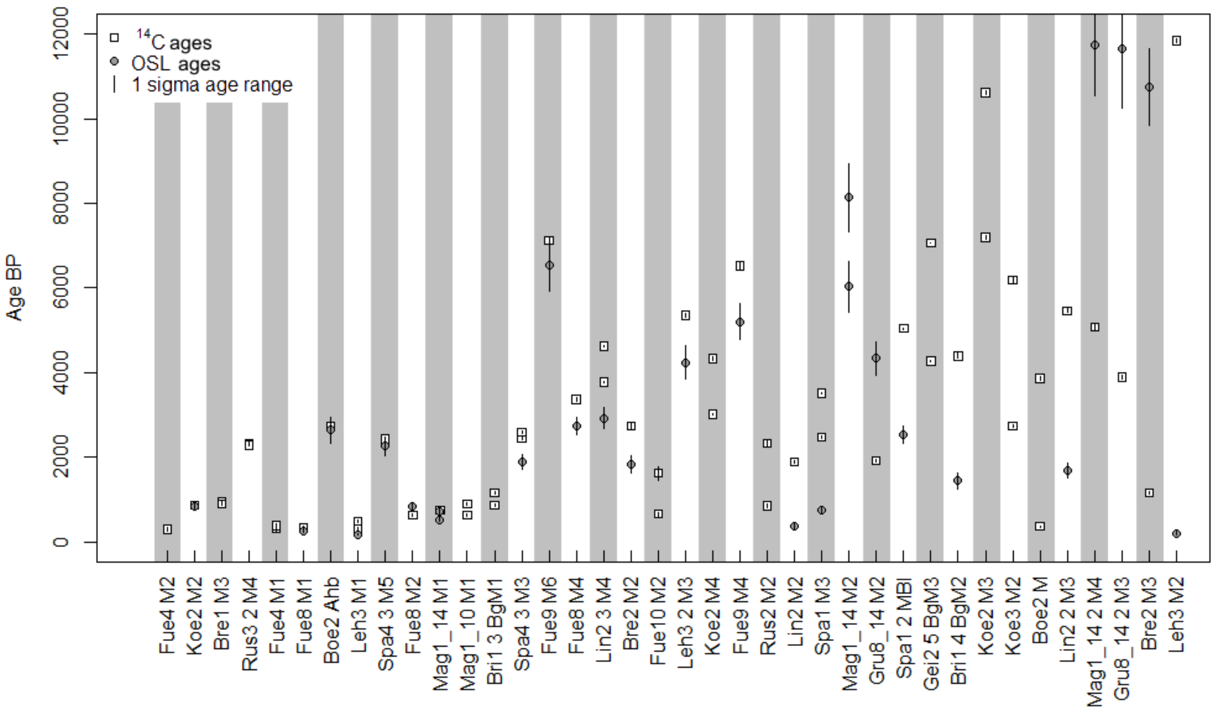

Fig. 9: Differences between OSL and AMS-^{14}C ages sampled from the same horizons. Sampled soil profile and horizon designation is given on the x-axis and sorted following the age differences.

In any case, more samples and a variety of dating methods would increase the reliability of a chronostratigraphy, and all dating results must be discussed and evaluated in their geomorphological and pedological context (cf. Fuchs and Lang, 2009; Lang et al., 1999). The compilation and comparison with other data from the same region can also help to identify a robust regional chronostratigraphy of colluvial deposits. Yet, a fully independent age control is not possible.

Calculated ^{14}C-SPDs succumb to the same interpretation difficulties, which is why they are interpreted as an indirect proxy of periods with increased human activity in the area (cf. Downey et al., 2014) as compared to OSL-SPDs which are interpreted as depicting colluvial deposition and thereby intensity of land use.

6.1.3 Dating the gaps of colluvial deposition: Geomorphodynamically stable times (Manuscript 3)

The reconstruction of phases of colluvial deposition allows in return to infer phases of relative geomorphodynamic stability without soil erosion and formation of colluvial deposits. These phases are the deposition gaps between colluvial deposits. The duration of the stable periods is the difference between the ages of the colluvial horizons. The underlying older horizon would have been the land surface during that time and therefore, might show different pedogenic properties like an enrichment of SOC, Ni, Cr, Cu, and Pb content in the upper part of the colluvial horizon (Henkner et al., 2018a).

In the present study, 10 possible former land surfaces were determined in different depth based on the dating of colluvial deposits. The hypothesis of increased SOC contents in the upper part of a potential former land surface as a result of elevated input by plants can be tested by measuring SOC contents. The comparison shows that the SOC content of the upper 5 cm of the lower colluvial horizon in average is slightly lower (-0.09%) than that of the above lying colluvial horizon. Considering the complete colluvial horizon the difference is more pronounced (-0.39%). There are no correlations to the period or the length of the time gap, which is the duration of the potential land use. It can be concluded that, if a lower colluvial horizon was a former land surface the upper part with the Ah horizon (enriched in SOC) must have been reworked into the above lying colluvial horizon and/or transported downslope by erosion. This might also explain the tendency of higher SOC contents in the lower part of the colluvial horizons. The overall tendency of declining SOC contents with increasing depth has to be kept in mind (Henkner et al., 2018a).

6.1.4 Connecting adaptive cycle theory with land use dynamics (Manuscript 4)

The adaptive cycle narrative is useful to examine the changes occurring in a SES, such as the changes of the agrarian soil use over the last millennia. The narrative helps understanding changes of and within the SES over time while focusing on important variables, in the presented case soil, crops, knowledge/technology. The approach can also be important for archaeological and soil scientific research in general, as the concept of SESs and the adaptive cycles can be applied to individual case studies or broader developments within SES, as shown in this study (Teuber et al., 2017).

The adaptive cycle of the SES agrarian soil use started with the Neolithic Transition and sedentariness. During the Neolithic, the Bronze and Iron Age the adaptive cycle was in the r-phase. Innovative tools and ideas developed which enabled the societies to successfully practice agriculture. With Antiquity, the SES moves into the K-phase, where the knowledge concerning agricultural practices is documented by written sources and best practice methods are determined. During the Medieval and Modern times, the general knowledge and agricultural knowledge in particular increases. Furthermore, agricultural tools are improved by e.g. using iron in plow shares, thus incorporating the adaptive cycle of the SES metallurgy. With industrialization, the SES moves through the Ω-phase of release or creative destruction and the α-phase of reorganization. The SES changed considerably with the α-phase, leading to a separation of animal husbandry and arable farming and a new r-phase after the mechanization of agriculture. This is comparable to the establishment of agriculture in the Neolithic due to the big innovations that changed the SES. The Neolithic transition led to sedentariness, so that first settlements and probably new societal structures developed. The Industrial Revolution enabled a diversified society with more people working outside the agrarian business due to the innovations of the r-phase. The knowledge and technology variable are interconnected in both r-phases, e.g. in the development of the plow. After industrialization and mechanization, agrarian soil use no longer means work of animals and men, but work of machines. This has new consequences for the variable soil, comparable to the consequences of deforestation, which subjected the soil to erosion after the establishment of fields since the Neolithic. The new impact on soil includes compaction, nutrient depletion, and other forms of soil degradation. The crops used in agriculture were first introduced in the Neolithic. They were used in different proportions during the last millennia. With industrialization, new genetically modified organisms were developed, connecting the variables crop and knowledge/technology. The crop variable underwent another change, as we depend on very few crop plants for nutrition today (Teuber et al., 2017).

A difference between the two adaptive cycles is the speed of the transition from r- to K-phase, which lasted several millennia in the first cycle but happened in the course of decades in the second. The increasing knowledge of the first K-phase, which started with the Greek and

Roman agricultural writers and culminated among others with Thaer, Liebig and Darwin, eventually had a vast effect on surplus production and technological development that resulted in a reorganization of the SES and the second adaptive cycle. The knowledge is still increasing steadily and technological development has led to a high-tech agribusiness, depending on computers, GIS, fertilizers and more. These new developments also affect the soil and crops used. To investigate these effects interdisciplinary work is needed, to ensure the resilience of the SES agrarian soil use without detrimental effects on soil, crops, knowledge/technology, and climate (Teuber et al., 2017).

6.2 Reconstruction of land use dynamics (Manuscript 1, 2, 3, 4)

6.2.1 SPDs of land use dynamics

The AMS-^{14}C ages are interpreted as indices of human activity and OSL ages as indices of intensified land use. With optimal sample conditions, OSL ages have a high accuracy but a low precision for dating sedimentation processes, therefore, OSL-SPD peaks of increased probability are wider than peaks of the ^{14}C-SPD based on charcoal ages, which have a high precision and a high accuracy. But charcoal ages date “the time when plant stopped integrating carbon into that part of the organism” and are thus only an indirect and uncertain measure of sedimentation processes (see 6.1.2). The ^{14}C-SPD (Fig. 10a) shows narrower and higher peaks, mirroring the nature of the ages. The ^{14}C-SPD can be interpreted as showing the phases of increased human activity in the whole study area. Human activity can include all kinds of land use from foraging to high intensity agricultural land use. The graph has many peaks within the confidence intervals, which may result from the calibration error. It is shown that the probability of charcoal occurrence increases during the Neolithic, indicating increasing human activity in the study area. Cluster of peaks above the confidence intervals (0.05 and 0.10), like during the Bronze and Iron Age and from the High Middle Ages to Early Modern period, reliably indicate phases of high human activity. A higher number of sites contributing dated samples during phases of increased human activity indicate a wider areal distribution, than during other times, where an increased SPD is based on samples from few sites. Latter peaks indicate a local increase of human activity. This means, based on the data presented here, that human activity and, thus, influence on the landscape was highest and most wide-spread during the High and Late Middle Ages and Early Modern period.

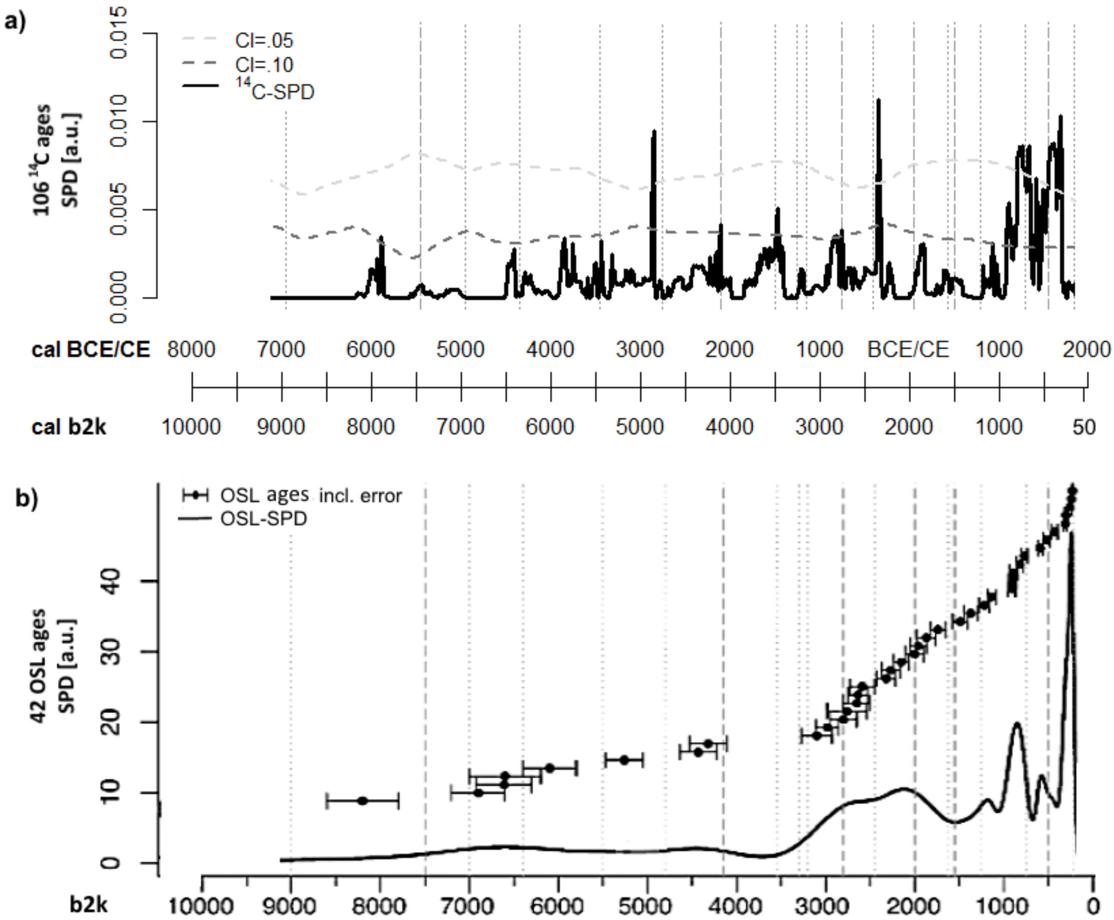

Fig. 10: SPDs calculated for the whole study area with the indication of the periods and main colluviation phases with inclined lines. The number of investigated sites per sub-period is also given, to indicate the locality or rationality of a potential peak. a) using 94 ^{14}C ages, b) using 39 OSL ages, c) combination of the OSL and ^{14}C ages. Figure from Henkner et al. (2018a).

The OSL-SPD (Fig. 10b) is interpreted as showing phases of increased colluvial deposition, which is linked to increased erosion and intensified agricultural land use. The probability is very low during the Neolithic, but shows a strong increase from the Late Bronze to the Iron Age. However, the signal has to be interpreted on a local basis, since a maximum of four sites contribute to the result. As indicated by OSL-SPD peaks, colluvial deposition increases further during the High Middle Ages and the Early Modern period. Even though the first 30 cm of the soils were not sampled for OSL age determination the SPD curve indicates a much higher probability for the recent era compared to all other periods. Still, only four sites contribute dates from the Early Modern period, indicating locally variable land use.

The overall precision of phases of increased human activity and/or colluvial deposition, based on the interpretation of SPDs, seems to be higher than the archaeological reconstruction of human presence, since the inferred phases of intensified land use are not bound to periods.

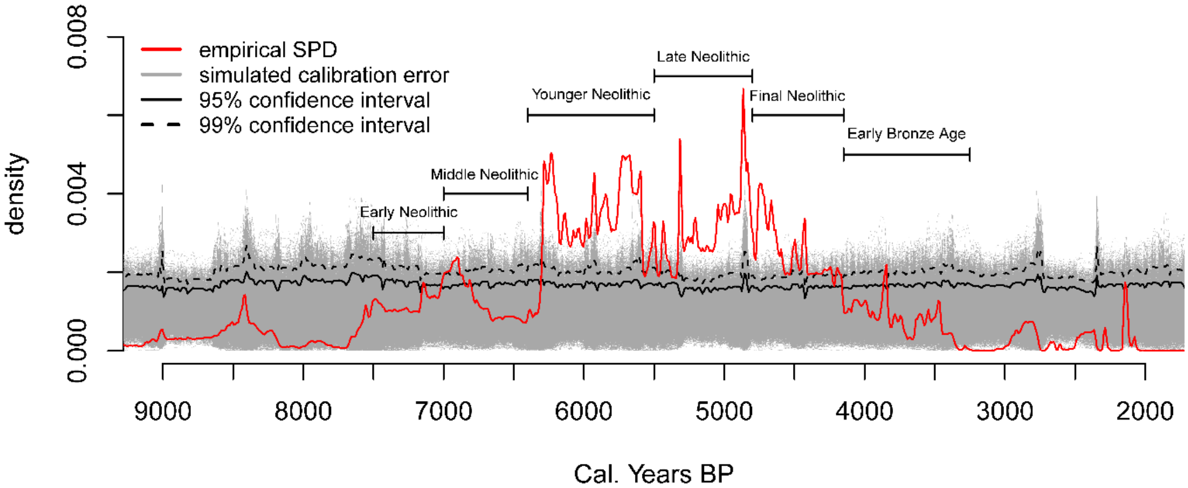

Fig. 11: SPD of radiocarbon ages from the RADON database (Hinz et al. 2012), showing the confidence intervals and periods. The RADON database focuses on ages from the Neolithic and Early Bronze Age. Figure from Henkner et al. (2018a).

To set the datings of colluvial deposits and charcoals into a larger context the SPD of radiocarbon ages from southwestern Germany, eastern France and the Swiss lowlands (from the RADON database, Hinz et al., 2012b) was calculated (Fig. 11). The database and, thus, the SPD is focused on the Neolithic and Early Bronze Age and shows a clear increase of human impact at the transition from the Early to the Middle Neolithic (around 7000 cal BP), followed by a rapid decline during the Middle Neolithic. A strong signal dates to the Younger and Late Neolithic, which can be separated into two phases because the SPD drops below the confidence interval and into the error margin. The Final Neolithic and Early Bronze Age show a general decline in radiocarbon ages and thereby human activity. However, it should be noted that the RADON database focuses on the Neolithic, and the decline apparent in this figure is in part due to edge effects.

6.2.2 Land use dynamics based on colluvial ^{14}C and OSL ages

The overall wide distribution of colluvial deposits highlights the human impact on the environment and formative strength since the beginning of agrarian land use in southwestern Germany. The variety of colluvial deposit properties points to a local influence of parent material and land use history. It is important to keep in mind that even though almost all soil profiles

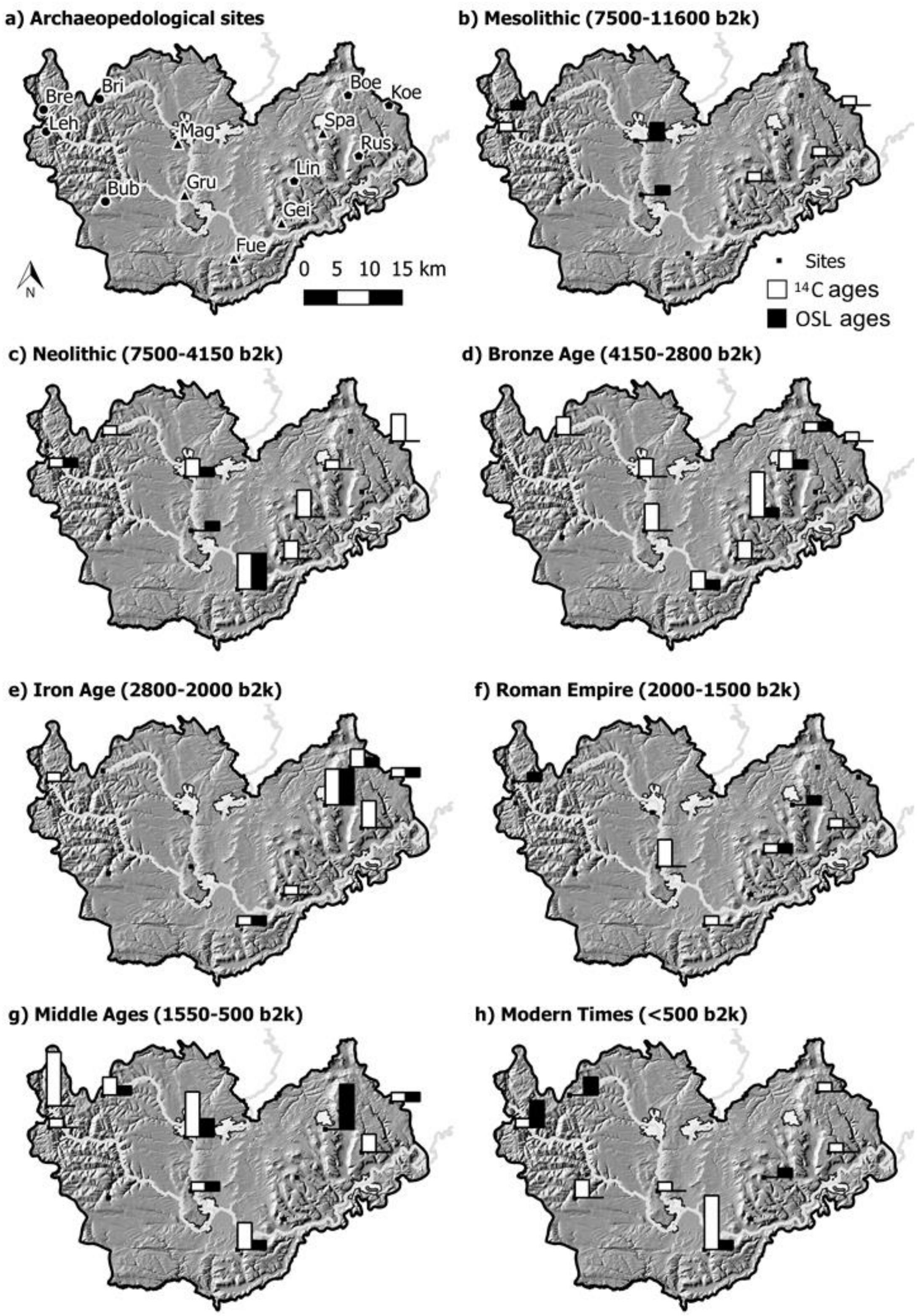

Fig. 12a-h): ^{14}C AMS- and OSL ages sampled in colluvial deposits across the study area. The height of the black bars indicates the number of OSL ages at the respective site. The range is from 1 to 5. The height of the white bars indicates the number of ^{14}C ages at the site. The range is 1 to 6. The Swabian Jura sites (*pentagon*) and the Black Forest sites (*circle*) are situated in unfavourable areas, whereas the Baar sites (*triangle*) are characterized as favourable. The background map depicts the topography after (Jarvis et al., 2008) (Jarvis et al., 2008). Figure from Henkner et al. (2018a).

were classified as Kolluvisols or soils covered by colluvial deposits, their properties cannot be inferred from this classification. The IUSS Working Group WRB (2015) translates the Kolluvisols to other RSGs laying a focus on other soil properties than the German classification focusing on the sedimentation processes instead of pedological processes.

The interpretation of soil properties like heavy metal contents did not proof to be conclusive since the contents are within the range of the geological background and pH is low. Still several examples could be identified, where heavy metal contents stand out and indicate an external, most likely human, influence on the input of such heavy metals.

The comparison of ^{14}C and OSL ages of the Swabian Jura and the Black Forest with ages from the Baar (Fig. 12) shows that the two unfavorable landscapes were settled and used differently. The southeastern Black Forest shows only local land use prior to the Middle Ages, whereas the Swabian Jura seems to have had similar land use dynamics as the western Baar. Already Mesolithic land use activities were detected at the central Baar area, but no colluvial deposits were found during the Iron Age. It is obvious that land use was not continuously practiced at all sites and through all periods.

Mesolithic land use

Charcoals from Russberg, Koenigsheim and Lindenberg indicate land use during the Mesolithic on the Swabian Jura. The lack of archaeologic Mesolithic sites on the Swabian Jura is most likely a result of the nomadic way of life during this epoch (Kind, 2006). Forager societies usually had smaller settlements and thus less influence on the environment making it much more difficult to detect their former presence in an area (Downey et al., 2014). In this way Mesolithic charcoals can be an indication of human presence or they can be interpreted as being caused by natural processes like wildfires.

The Mesolithic overview (Fig. 12b) shows that there are two sites on the Baar and one in the Black Forest having Mesolithic OSL ages. The OSL age from the Black Forest is likely to result from a contamination of the colluvial sample with underlying periglacial sediment. The Mesolithic samples of the Baar, show no indication of contamination and might be interpreted as the beginning of colluvial deposition and, thus, long term and intensive land use during the

Mesolithic in the area. Traditionally, Mesolithic communities are not expected to practice agriculture or clear forests, but the disturbance of the natural forest vegetation is visible in many pollen diagrams through the presence of micro-charcoals and were connected with burning and clearance (Bos and Urz, 2003; Pokorný et al., 2010; Vera, 2000). Divišová and Šída (2015) offer the explanation of forest clearings as social phenomena out of fear and anxiety about the environmental surroundings. Mesolithic societies have also used, and possibly created and managed, forest clearings to improve their hunting success (Brown, 1997; Davies et al., 2005). The increased use of wild plants during the Mesolithic (Divišová and Šída, 2015; Holst, 2010) might have led to local agriculture and the transition to the Neolithic culture (Bocquet-Appel, 2011; Downey et al., 2014; Isern and Fort, 2012). There is a long time discussion about the interpretation of proxies for Mesolithic agriculture: the practice of agriculture during the Mesolithic is inferred from cereal pollen found in bogs in central Europe, especially in Switzerland (Tinner et al., 2007; Tinner, 2008). Behre (2006) contrasted that the interpretation of Mesolithic agriculture is often based on single pollen finds described as cereal pollen, where it could also be pollen from wild forms of cereal-type plants and is therefore, not reliable as a proxy for agriculture.

These archaeopedological results add another proxy to the discussion. As the finding of many charcoals in soils is interpreted as an indirect proxy for human presence and land use, some forms of land use can undoubtedly be shown for the Mesolithic. The Mesolithic OSL ages can be interpreted as a reference of open landscapes and probably former agriculture, thus, as an early development or adaptation to a new lifestyle (cf. Isern and Fort, 2012). The beginning of colluvial deposition and the increased number of charcoals with the transition from the Mesolithic to the Neolithic clearly points at intensive and continuous land use and consequently at sedentary and agricultural life styles

Neolithic land use

The onset of an area-wide sedentary and agricultural society can be dated to the Neolithic. The number of Neolithic charcoals on the Swabian Jura and the western Baar is higher than in the eastern study area (Fig. 12c). The Neolithic charcoals of Lindenberg, Koenigsheim, and Boettingen can be interpreted as proxies of temporary land use on the Swabian Jura, possibly within the framework of a seasonal pasture economy. On the Swabian Jura, land use was only known from the Heuberg area, which is the first known indication of land use at these sites during the Neolithic period. Pollen records from the southeastern Black Forest (Henkner et al., 2018b) date the first occurrence of human indicator pollen to the Younger Neolithic. The oldest phase of colluvial deposition on the Baar also dates to the Younger Neolithic (~3700 BCE, Henkner et al., 2017) and correlates with a wetter and colder period (Negendank, 2004). Additionally, decreasing atmospheric ^{14}C production rates (Kromer and Friedrich, 2007) and increased ice rafted debris in the northern hemisphere (Engels and van Geel, 2012) indicate these conditions. Temperature reconstructions using lake levels (Magny, 2004) and pollen data (Davis et al., 2003), in contrast, indicate dryer and warmer conditions. Despite these contrasting climate reconstruction, colluviation seems to be triggered by the onset of agricultural land use. The increased signal of human activities during the Neolithic (charcoals, pollen, colluvial deposits, and archaeological finds) found across the study area point to an increased regional human impact on the landscape from the Neolithic onwards, which is in agreement with the SPD calculated from the RADON database (Hinz et al., 2012b) covering an over regional area (Fig. 11).

Shennan et al. (2013) date the earliest farming in southern Germany to around 7450 cal b2k and reconstruct the first significant agriculture-driven boom of population density from 7200 to 6950 cal b2k followed by a rapid decline, the bust-phase during the Middle Neolithic. The Younger and Late Neolithic are characterized by several minor boom-bust phases and led to a steady decline during the Final Neolithic and Early Bronze Age, which is mirrored by the trend of the RADON based SPD. The first increase of population levels during the Early Neolithic is shown by Shennan and Edinborough (2007) for all of Germany. This study shows a different trend during the Younger Neolithic, where only low population levels were reconstructed. Compared to these SPDs the archaeopedological ages seem to have a delayed trend picturing the peaks in the Late Neolithic. This difference likely results from the smaller dataset of the study area, excluding some favorable landscapes and well-studied archaeological locations, thus, maybe truly depicting later and less intense development. Pollen records from the southeastern Black Forest (Henkner et al., 2018b), in contrast, mirror the increase of population with the onset of human indicator pollen.

The onset of increased colluvial deposition interpreted as a proxy for intensified land use (based on OSL of colluvial deposits and ^{14}C ages of charcoals) supports the interpretation of the

Neolithic transition as the decisive establishment of the SES agrarian soil use and the adaptive cycle agrarian soil use (Teuber et al., 2017). It marks the reorganization of the ecosystem by humans and the beginning of the exploitation phase. Certain crops (especially *Triticum monococcum*, *Triticum dococcum*) were used from the Neolithic to the Iron Age (Teuber et al., 2017).

Land use during Bronze Age

OSL ages provide the earliest evidence for land use on the southwestern Swabian Jura during the Early Bronze (Fig. 12d). Archeological finds point to land use during the Middle Bronze Age and Urnfield period on the Heuberg (Ahlrichs et al., 2017 submitted), but the OSL and ^{14}C ages of Boe3 and Koe2 indicate land use during the Late Bronze Age. For the Urnfield period the archaeological record and archaeopedological data correlate well indicating land use. Further, intensive land use is indicated on the Baar marking a main colluviation phase (~1400 cal BCE, Henkner et al., 2017) and also at one site in the southeastern Black Forest. The increased colluvial deposition coincides with a cold and humid climate (Negendank, 2004) with especially cold summers as reconstructed by pollen data (Davis et al., 2003), but again low lake levels (Magny, 2004), an indifferent, global trend of ^{14}C production (Kromer and Friedrich, 2007), and the occurrence of ice rafted debris (Engels and van Geel, 2012). It is the transition to a dry period (Jäger, 2002; Schönwiese, 1995).

The improved agricultural technology (Lal, 2007; Teuber et al., 2017) or the favorable climate (Anderson et al., 2007) lead to slightly increased colluviation. The similar colluviation and land use pattern compared to the Neolithic period leads to the conclusion that the SES of agrarian soil use remains in the exploitation phase (Teuber et al., 2017).

Land use during Iron Age

The overall impression is a decline of used land during the Iron Age based on archaeopedological dating and site description in the southeastern Black Forest and the Baar area (Fig. 12e). Neither the warm and dry climate at the beginning of the Iron Age (Anderson et al., 2007), nor the increased population density (Zimmermann, 1996) during the end of the Iron Age with cooler and wetter climate (Anderson et al., 2007) seem to increase colluvial deposition in general. Exceptions are the sites Fuerstenberg and Spaichingen on the Baar. Spaichingen, located at the lower slope of Swabian Jura cuesta, even shows four ^{14}C and four OSL ages indicating a major phase of land use at this site, which correlates to archaeological findings (Schmid, 1991). This local phase of increased colluviation on the Baar and the Swabian Jura (~500 BCE, Henkner et al., 2017) falls in a cold period (Büntgen et al., 2011; Davis et al., 2003; Kromer and Friedrich, 2007). The rather unfavorable climate in addition to low land use intensity (Dotterweich, 2008) and population density (Zimmermann, 1996) have resulted in the formation of spatially different intensities of colluvial deposition.

However, on the southwestern Swabian Jura the archaeological records and archaeopedological data correlate well during the Hallstatt period and the Latène period and indicate decreasing settlement and land use intensity. Deforestation in order to mine and smelt bean ore or for other purposes might have triggered colluvial deposition on the Swabian Jura (Henkner et al., 2018a).

With consideration of the SES agrarian soil use changes occur during Iron Age. Roman and Greek writers like Hesiod begin to transform (practical) knowledge into literature about agriculture, thereby tracing the changing attitude towards agricultural practices. This is the beginning of the conservation phase of the SES agrarian land use (Teuber et al., 2017).

Land use during Roman Empire

In contrast to the expected intensification of land use (Dreibrodt et al., 2010; Mäckel et al., 2003) under a warm climate (Broecker, 2001), land use and the corresponding soil erosion seem to have declined during the Roman Empire (Fig. 12f). Only few Roman charcoals and OSL samples date to this period, indicating a generally low land use intensity. Even though Roman settlements are known on the Baar, the assumed high land use intensity is not visible in the studied colluvial deposits. The exception is increased deposition of charcoals in Grueningen (Henkner et al., 2017), which is the only colluviation phase falling into a dry and warm period (Büntgen et al., 2011; Davis et al., 2003). Charcoal deposition might have been triggered by practicing agriculture to support a Roman castrum a few kilometres south near Huefingen, which supposedly accommodated about 1000 soldiers (Ahlrichs et al., 2016; Eckerle, 2005).

The generally low colluviation and land use intensity is contrasting to the assessment of the Roman Empire having the strongest anthropogenic influence on landscapes because of intensive farming methods, new agricultural techniques and crops, settlement expansion, and mining (Mäckel et al., 2002; Teuber et al., 2017). The site Spaichingen is located near a formerly productive spring and next to a Roman road connecting Tuttlingen and Rottweil north of Spaichingen (Paulus, 1876), but only one age falls into the period of the Roman Empire. Equally little colluvial deposition is found at the Black Forest sites, although the wood might have been a valuable resource at specific logging sites. It can be concluded that the selected sites were not intensively used by the Romans or that their activities did not lead to colluvial deposition.

The following Migration period is characterized by low population densities (Zimmermann, 1996), a temperature decline (Büntgen et al., 2011) and only very little indication of land use based on the occurrence of colluvial deposits and charcoals found therein.

Medieval land use

Medieval land use and settlements are archaeologically well documented on the Swabian Jura, the Baar and the Black Forest. The climate of the High to Late Middle Ages was warm until the Little Ice Age and the transition to the Early Modern period (Büntgen et al., 2011; Davis et al., 2003; Dergachev et al., 2007). Especially the forests were cut to use the wood or to clear areas for farming or animal husbandry leaving less than 20% of the forest cover (Blümel, 2006; Dotterweich, 2008; Kaplan et al., 2009). Overall, the archaeopedological evidence (Fig. 12g) supports the finding of intensified and wide spread land use during the Middle Ages. Striking is the limited archaeopedological record on the Swabian Jura with only two sites dating to the late High Middle Ages. One explanation for the low record on the Swabian Jura could be that these sites were not agriculturally used. Another point could be the potential incorporation of Medieval colluvial deposits into the recent Ap horizon, which might be likely given the shallow development of soils (Henkner et al., 2018a).

The Black Forest shows strong evidence of intensified land use, which can be explained by the expansion of agriculture into formerly not or less intensely used (farm)land due to a higher population density (Knopf et al., 2012; Zimmermann, 1996). People used the natural resources of the Black Forest for various economic purposes: wood was used for building infrastructure, as an energy source and for charcoal production; sand was used to produce glass. Iron ore, silver, and lead could have been mined and the granite was used as building material. Pastures and small fields followed on the already deforested land (Häbich, 2009). Until the 1990s archaeologists argued that the medieval settlement of the Black Forest was the first population of the impenetrable primeval forest, which people formerly avoided whenever possible (Brückner, 1981; Schaab, 2003). Field work proved, that settlement activities indeed increased during the Middle Ages, but the southeastern Black Forest was already used during the Neolithic. The main triggers for the medieval settlement might have been demographic pressures or enforced movements into the Black Forest (Kullen, 1989; Schmid, 1991).

Despite the intensified and changed land use reconstructed from colluvial deposition, the SES agrarian soil use remained in the conservation phase (Teuber et al., 2017), since it still relied on traditional agricultural practices based on man and animal labor. Nevertheless, the attitude and treatment of soil changed. Soil fertilization became an increasing part of medieval agriculture (Behre, 2000) and the ridge and furrow system developed, resulting in a leveling of yield despite variable precipitation (Andersen et al., 2016). But only with the onset of industrialization and mechanization of agriculture and the increasing knowledge and development of new tools, the creative destruction and reorganization of the SES agrarian soil use happened, thereby starting a new adaptive cycle in the Early Modern period (Teuber et al., 2017).

7 Conclusion

In this archaeopedological study multi-layered colluvial deposits are used as archives to reconstruct land use dynamics in southwestern Germany. Colluvial deposits are understood as the correlate soil sediments of erosion triggered by intensive land use or land use change. Thus, colluvial deposits can be interpreted as a proxy for land use phases. Pedological field work, soil sample analysis, AMS-^{14}C dating of charcoal and pollen, OSL dating of soil sediment, pollen analysis and archaeological evaluation contributed to the presented interdisciplinary study. The pedological description of the archaeopedological sites showed a spatially wide distribution of colluvial deposits, controlled by (paleo)topography and former or recent land use. Thus, colluvial deposits present an archive with a high spatial and temporal resolution. Soil characteristic of colluvial deposits also show a wide variety, depending on characteristics of the source material and post-depositional in situ pedogenesis. On most sites it is possible to determine multiple deposition events and thereby reconstruct different phases of land use, which could be dated by OSL. OSL ages date the point in time when the colluvial deposit formed, which can be interpreted as a period of intensified land use, whereas ^{14}C ages of anthropogenic charcoals are interpreted as proxies of human presence, not connected to the deposit where it was found.

The assumption that colluvial deposits are useful archives to reconstruct land use dynamics proved to be true. Each colluvial deposit is the result of a deposition event with unknown duration. However, few colluvial deposits could not be distinguished from each other based on age because of wide and overlapping OSL error margins. Especially difficult is the dating, the interpretation of former land surfaces, and the differentiation between inherited and post-depositional soil properties. The comparison of AMS-^{14}C ages of charcoal fragments found within colluvial deposits with OSL ages from the same colluvial deposit (soil horizon) showed that charcoal ages cannot be used to date the colluvial deposit. Even though charcoal dating is commonly used as an indirect dating method of colluvial deposits. Nevertheless, dating of charcoal fragments can be used to reconstruct the intensity of human activity, if the charcoal is most likely of anthropogenic origin. The reconstruction of phases of geomorphodynamic stability, thus, land surfaces needs a detailed sampling strategy based on multiple subsamples per soil horizon. Depending on the depth function of soil properties it is possible to reconstruct a former land surface. The working hypothesis was that SOC or heavy metal content would be elevated in former land surfaces, which were expected to be found in the upper 5 cm of a colluvial deposit. The analysis of well dated colluvial deposits from different deposition events showed that, against expectation, the depth function of SOC content increases slightly in the lower part of the colluvial deposit instead of the upper part. However, the result is not significant and can only be interpreted as a first indication of SOC and heavy metal changes within colluvial deposits and former land surfaces. The age differentiation of deposits based on OSL dating is possible. Direct differentiation of inherited soil properties from *in situ* post-depositional properties, however, is not possible using the described methods.

The establishment of a detailed chronostratigraphy across the Baar, the southwestern Swabian Jura, and the southeastern Black Forest based on OSL ages lead to a regional reconstruction of phases with increased colluvial deposition and thus land use, based on site-biographies of soil development. The trichotomy of the study area allowed a comparison of land use dynamics between rather favorable and unfavorable landscapes. The evaluation of landscapes was done concerning its agricultural potential, which means it concentrates on climate, relief, and soils and how well these environmental conditions favor agricultural land use. The favorable Baar area shows a detailed chrono-pedostratigraphy of colluvial deposits, retracing multiple phases of colluvial deposition most likely triggered by intensive, unsustainable land use. Sites on the rather unfavorable Swabian Jura indicate human activities from the Neolithic to the Iron Age, but less evidence of medieval land use. The Black forest in contrast, indicates land use during the Middle Ages and the Early Modern period and only scattered evidence is found for earlier intensive land use and colluvial deposition. Nevertheless, Neolithic and Bronze Age human activities could be reconstructed in the Black Forest area.

The first evidence of open landscapes, most likely due to agricultural land use, are colluvial deposits dating to the Mesolithic, which were found on the Baar. But only during the Younger Neolithic land use leads to intensive colluvial deposition, especially in the Baar and the Swabian Jura. This supports the archaeological narrative of the beginning of sedentary and agricultural life styles in central Europe during the Neolithic. Colluvial deposition is increasing during the Bronze Age and spatially concentrated on the eastern Baar and the southwestern Swabian Jura. Contrary to the archaeological interpretation of an increased population during

Iron Age and Roman Empire colluvial deposits indicate only local, intensive land use. Intensive land use during the Middle Ages leaves thick and multi-layered colluvial deposits, which can be separated into different phases of increased colluvial deposition.

Climate change is commonly used to explain different patterns of land use and population levels, but climate determinism does not explain all phases of intensified land use. It can be concluded that from the Neolithic to the Bronze Age climate and the environmental conditions in general seem to be the determining factors controlling population dynamics and land use and thereby colluvial deposition. But during the Iron Age population dynamics and technological advances seem to grow more important to determine land use and, thus, colluvial deposition. The warm and dry climate and high population density of the Roman Empire did not result in increased colluvial deposition, which might be due to other forms of land use. Increasing population density and land use intensity during the Middle Ages can be seen as the cause of the increased number of colluvial deposits.

The trigger of colluvial deposition certainly is intensive land use or land use change on slopes. However, the question remains, what drives people to settle certain areas at a certain time? Raw materials (such as ore, wood, rock, salt) have always been available in the Black Forest and Swabian Jura but were not used all the time, which indicates that cultural conditions might have played a crucial role in defining resources. Such cultural conditions might have been the rise of the population density, which led to an intensification of land use like it is shown for the beginning of the Neolithic, following the increase of population density. Another explanation is the state of the technological development, which allowed people to use raw materials and to turn them into resources. Religious practices, trade or communication might also influence the use of raw materials as resources. The economic, cultural, political or social need for resources in favorable landscapes might have been reasons to use neighboring unfavorable landscapes, like low mountain ranges of the Black Forest and the Swabian Jura. Other explanations might be to evade state interference by inhabiting marginal areas (Scott, 2009) or the retreat to secluded landscapes because of religious reasons. Once these unfavorable landscapes were used, changing environmental conditions do not necessarily lead to the abandonment of areas. Diversification of land use for example might have made it possible to use continuously unfavorable landscapes, sustained by the buffering capacity and resilience of societies (Gronenborn et al., 2017; Redman, 2005). The use of resources most likely varied with time and space, depending on the societies' needs and possibilities. The present study could not answer the question of archaeopedological intangible reasons to settle and use landscapes. This would need further interdisciplinary studies including soil science, archaeology, archaeobotany, zooarchaeology, dating experts and cultural anthropologist.

The general importance to analyze colluvial deposits is based on a growing societal and political awareness to track environmental changes. It is also an opportunity to assess human niche construction and the overall anthropogenic influence on the environment. The analysis of colluvial deposits also contributes to national and international efforts to protect soils as a natural non-renewable resource. Some soil types are additionally protected as essential archives of the past which can provide insights into societal and environmental sustainability. It is also necessary to know about the past to assess and think about recent activities and possible (un)intended outcomes in the future. Colluvial deposits combine all three topics and are, thus, ideal research objects to reconstruct past land use dynamics and human-environment interactions.

References

Adhikari, K., Hartemink, A.E., 2016. Linking soils to ecosystem services — A global review. Geoderma 262, 101–111. doi:10.1016/j.geoderma.2015.08.009.

Ad-hoc-AG Boden (Ed.), 2005. Bodenkundliche Kartieranleitung. KA5, 5., verb. und erw. Aufl. ed. Schweizerbart, Stuttgart, 438 S.

Adobe Systems Software Ireland Ltd., 2017. Adobe Illustrator.

Ahlrichs, J., 2017. Ur- und frühgeschichtliche Siedlungsdynamiken zwischen Gunst- und Ungunsträumen in Südwestdeutschland: eine Fallstudie zur Baar und den angrenzenden Naturräumen des Schwarzwaldes und der Schwäbischen Alb. Dissertation, Tübingen.

Ahlrichs, J., Henkner, J., Schmidt, K., Scholten, T., Kühn, P., Knopf, T., 2017 submitted. Bronzezeitliche Siedlungsdynamiken zwischen der Baar und angrenzenden Naturräumen, in: Transporte, Transportwege und Transportstrukturen. Jahressitzung der Arbeitsgemeinschaft Bronzezeit, Tübingen. 30.-31. Oktober 2015, Tübingen.

Ahlrichs, J., Henkner, J., Teuber, S., Schmidt, K., Scholten, T., Kühn, P., Knopf, T., 2016. Archaeological and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory: A Case Study from the Western Baar, SW Germany, in: Kolodziejczyk, P., Kwiatkowska-Kopka, B. (Eds.), Landscape as impulsion for culture: research, perception & protection. Landscape in the past & forgotten landscapes, vol. 2. Institute of Archeology Kraków, Institute of Landscape Architecture Kraków, Cracow, pp. 39–49.

Ament, H., 1977. Zur archäologischen Periodisierung der Merowingerzeit. Germania 55, 133–140.

Andersen, T.B., Jensen, P.S., Skovsgaard, C.V., 2016. The heavy plow and the agricultural revolution in Medieval Europe. Journal of Development Economics 118, 133–149. doi:10.1016/j.jdeveco.2015.08.006.

Anderson, D.G., Goudie, A.S., Parker, A.G., 2007. Global environments through the quaternary: Exploring environmental change. Oxford University Press, Oxford.

Antrop, M., 2004. Landscape change and the urbanization process in Europe. Landscape and Urban Planning 67 (1-4), 9–26. doi:10.1016/S0169-2046(03)00026-4.

Aranbarri, J., González-Sampériz, P., Valero-Garcés, B., Moreno, A., Gil-Romera, G., Sevilla-Callejo, M., García-Prieto, E., Di Rita, F., Mata, M.P., Morellón, M., Magri, D., Rodríguez-

Lázaro, J., Carrión, J.S., 2014. Rapid climatic changes and resilient vegetation during the Lateglacial and Holocene in a continental region of south-western Europe. Global and Planetary Change 114, 50–65. doi:10.1016/j.gloplacha.2014.01.003.

Bailey, G., Spikins, P. (Eds.), 2008. Mesolithic Europe. Cambridge University Press, New York.

Bakels, C., 2014. The first farmers of the Northwest European Plain: Some remarks on their crops, crop cultivation and impact on the environment. Journal of Archaeological Science 51, 94–97. doi:10.1016/j.jas.2012.08.046.

Banks, W.E., Antunes, N., Rigaud, S., d'Errico, F., 2013. Ecological constraints on the first prehistoric farmers in Europe. Journal of Archaeological Science 40 (6), 2746–2753. doi:10.1016/j.jas.2013.02.013.

Bartelheim, M., Hardenberg, R., Knopf, T., Scholz, A., Staecker, J., 2015. 'ResourceCultures' - A Concept for Investigatin the Use of Resources in Different Societies, in: Danielisová, A., Fernández-Götz, M. (Eds.), Persistent Economic Ways of Living. Production, Distribution, and Consumption in Late Prehistory and Early History, vol. 35. Archaeolingua, Budapest, pp. 39–49.

Behre, K.-E., 2000. Frühe Ackersysteme, Düngemethoden und die Entstehung der Nordwestdeutschen Heiden. Archäologisches Korrespondenzblatt 30, 135–151.

Behre, K.-E., 2006. Evidence for Mesolithic agriculture in and around central Europe? Veget Hist Archaeobot 16 (2-3), 203–219. doi:10.1007/s00334-006-0081-7.

Berger, G.W., Mahaney, W.C., 1990. Test of thermoluminescence dating of buried soils from Mt. Kenya, Kenya. Sedimentary Geology 66 (1-2), 45–56. doi:10.1016/0037-0738(90)90005-E.

Berglund, B.E., 2003. Human impact and climate changes—synchronous events and a causal link? Quaternary International 105 (1), 7–12. doi:10.1016/S1040-6182(02)00144-1.

Berglund, B.E., Ralska-Jasiewiczowa, M. (Eds.), 1986. Handbook of the Holocene palaeoecology and palaeohydrology. Blackburn Press, Caldwell, N.J.

Bergmann, K., 1970. Agrarromantik und Großstadtfeindschaft. Verlag Anton Hain, Meisenheim am Glan.

Berkes, F., 2004. Rethinking Community-Based Conservation. Conservation Biology 18 (3), 621–630. doi:10.1111/j.1523-1739.2004.00077.x.

Berkes, F., Colding, J., Folke, C. (Eds.), 2003. Navigating Social-Ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge, UK.

Berkes, F., Folke, C. (Eds.), 1998. Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge University Press, Cambridge, UK.

Bettis, E.A., 2003. Patterns in Holocene colluvium and alluvial fans across the prairie-forest transition in the midcontinent USA. Geoarchaeology 18 (7), 779–797. doi:10.1002/gea.10087.

Biel, J., 1987. Vorgeschichtliche Höhensiedlungen in Südwürttemberg-Hohenzollern. Landesamt für Denkmalpflege Regierungspräsidium Stuttgart, Stuttgart.

Bleicher, N., 2013. Summed radiocarbon probability density functions cannot prove solar forcing of Central European lake-level changes. The Holocene 23 (5), 755–765. doi:10.1177/0959683612467478.

Blum, W.E.H., 2005. Functions of Soil for Society and the Environment. Rev Environ Sci Biotechnol 4 (3), 75–79. doi:10.1007/s11157-005-2236-x.

Blume, H.-P., Brümmer, G.W., Horn, R., Kandeler, E., Kögel-Knabner, I., Kretzschmar, R., Stahr, K., Wilke, B.-M., 2010. Scheffer/Schachtschabel. Lehrbuch der Bodenkunde, 16. Aufl ed. Spektrum, Akad. Verl., Heidelberg, Berlin, XIV, 569 S.

Blümel, W.D., 2006. Klimafluktuationen – Determinanten für Kultur- und Siedlungsgeschichte. Nova Acta Leopoldina NF 94 (346), 13–36.

Bocquet-Appel, J.-P., 2011. When the world's population took off: the springboard of the Neolithic Demographic Transition. Science (New York, N.Y.) 333 (6042), 560–561. doi:10.1126/science.1208880.

Bork, H.-R., 1989. Soil erosion during the past millennium in Central Europe and its significance within the geomorphodynamics of the Holocene, in: Ahnert, F. (Ed.), Landforms and Landform Evolution in West Germany, Frankfurt a. M., pp. 121–131.

Bork, H.-R., 1998. Landschaftsentwicklung in Mitteleuropa: Wirkungen des Menschen auf Landschaften, 1. Aufl. ed. Klett-Perthes, Gotha [u.a.], 328 S.

Bork, H.-R., 2006. Landschaften der Erde unter dem Einfluss des Menschen. Wissenschaftliche Buchgesellschaft, Darmstadt, 207 S.

Bork, H.-R., Dreibrodt, S., Mieth, A., 2006. Die langfristigen Wirkungen von Witterungsextremen auf Umwelt und Gesellschaft, in: Klimawandel - Klimafolgen - Naturkatastrophen und deren Auswirkungen auf Umwelt und Gesellschaft, Rostock. 20.10.2006, Rostock, pp. 11–22.

Bos, J.A.A., Urz, R., 2003. Late Glacial and early Holocene environment in the middle Lahn river valley (Hessen, central-west Germany) and the local impact of early Mesolithic people?: Pollen and macrofossil evidence. Veget Hist Archaebot 12 (1), 19–36. doi:10.1007/s00334-003-0006-7.

Bourke, A., 1984. Impact of climatic fluctuations in Euroean agriculture: Central Europe, in: Flohn, H., Fantechi, R. (Eds.), The climate of Europe. Past, present and future ; natural and man-induced climatic changes; a European perspective. Kluwer, Dordrecht u.a., pp. 269–296.

Broecker, W.S., 2001. Was the Medieval Warm Period Global? Science 291 (5508), 1497–1499. doi:10.1126/science.291.5508.1497.

Bronk Ramsey, C., 2009. Bayesian Analysis of Radiocarbon Dates. Radiocarbon 51 (01), 337–360. doi:10.1017/S0033822200033865.

Bronk Ramsey, C., 2015. OxCal 4.2.

Brown, T., 1997. Clearances and Clearing: Deforestation in Mesolithic/Neolithic Britain. Oxford Journal of Archaeology 16 (2), 133–146.

Brown, T., Crane, S., O'Sullivan, D., Walsh, K., Young, R., 1998. Marginality, multiple estates and environmental change: The case of Lindisfarne, in: Coles, G., Mills, C.M. (Eds.), Life on the edge. Human settlement and marginality ; [papers presented from the annual conference of the Association for Environmental Archaeology held in Edinburgh in 1992]. Oxbow Books, Oxford, pp. 139–148.

Brozio, J.P., Dörfler, W., Feeser, I., Kirleis, W., Klooß, S., Müller, J., 2014. A Middle Neolithic well from Northern Germany: a precise source to reconstruct water supply management, subsistence economy, and deposition practices. Journal of Archaeological Science 51, 135–153. doi:10.1016/j.jas.2013.03.029.

Brückner, H., 1981. Die Entwicklung der Wälder des Schwarzwaldes durch die Nutzung vergangener Jahrhunderte und ihre heutige Bedeutung, in: Liehl, E. (Ed.), Der Schwarzwald. Beiträge zur Landeskunde, Bühl/Baden, pp. 155–180.

Bundesministerium der Justiz und für Verbraucherschutz, 1998. Gesetz zum Schutz vor schädlichen Bodenveränderungen und zur Sanierung von Altlasten (Bundes-Bodenschutzgesetz - BBodSchG): BBodSchG.

Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D.C., Trouet, V., Kaplan, J.O., Herzig, F., Heussner, K.-U., Wanner, H., Luterbacher, J., Esper, J., 2011. 2500 years of European climate variability and human susceptibility. Science 331 (6017), 578–582.

Caseldine, C.J., Turney, C., 2010. The bigger picture: towards integrating palaeoclimate and environmental data with a history of societal change. J. Quaternary Sci. 25 (1), 88–93. doi:10.1002/jqs.1337.

Childe, V.G., 1936. Man makes himself. Watts, London.

Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions, 2006. Thematic Strategy for Soil Protection: [SEC(2006)620] [SEC(2006)1165] / *COM(2006)231 final*. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52006DC0231.

Coombes, P., Barber, K., 2005. Environmental determinism in Holocene research: causality or coincidence? Area 37 (3), 303–311. doi:10.1111/j.1475-4762.2005.00634.x.

Darwin, C., 1890. The Formation of Vegetable Mould through the Action of Worms with Observation on their habits. D. Appleton & Company, New York.

Dauber, J., Brown, C., Fernando, A.L., Finnan, J., Krasuska, E., Ponitka, J., Styles, D., Thrän, D., van Groenigen, K.J., Weih, M., Zah, R., 2012. Bioenergy from “surplus” land: Environmental and socio-economic implications. BR 7, 5–50. doi:10.3897/biorisk.7.3036.

Davies, P., Robb, J.G., Ladbrook, D., 2005. Woodland clearance in the Mesolithic: The social aspects. Antiquity 79 (304), 280–288. doi:10.1017/S0003598X00114085.

Davis, B.A.S., Brewer, S., Stevenson, A.C., Guiot, J., 2003. The temperature of Europe during the Holocene reconstructed from pollen data. Quaternary Science Reviews 22 (15-17), 1701–1716. doi:10.1016/S0277-3791(03)00173-2.

Davison, K., Dolukhanov, P., Sarson, G.R., Shukurov, A., 2006. The role of waterways in the spread of the Neolithic. Journal of Archaeological Science 33, 641–652.

Dearing, J.A., Acma, B., Bub, S., Chambers, F.M., Chen, X., Cooper, J., Crook, D.S., Dong, X., Dotterweich, M., Edwards, M.E., Foster, T., Gaillard, M.-J., Galop, D., Gell, P., Gil, A., Jeffers, E.S., Jones, R.T., Anupama, K., Langdon, P., Marchant, R., Mazier, F., McLean, C., Nunes, L., Sukumar, R., Suryaprakash, I., Umer, M., Yang, X., Wang, R., Zhang, K., 2015. Social-ecological systems in the Anthropocene: The need for integrating social and biophysical records at regional scales. The Anthropocene Review 2 (3), 220–246. doi:10.1177/2053019615579128.

Dearing, J.A., Battarbee, R.W., Dikau, R., Larocque, I., Oldfield, F., 2006. Human–environment interactions: Learning from the past. Reg Environ Change 6 (1-2), 1–16. doi:10.1007/s10113-005-0011-8.

Deevey, E.S., 1969. Coaxing History to Conduct Experiments. BioScience 19 (1), 40–43. doi:10.2307/1294629.

Della Casa, P., 2013. Switzerland and the Central Alps, in: Fokkens, H., Harding, A. (Eds.), The Oxford handbook of the European Bronze Age, 1. ed. ed. Oxford Univ. Press, Oxford, pp. 706–722.

Department of Economic and Social Affairs, 2016. Global Sustainable Development Report 2016, New York.

Dergachev, V.A., Raspopov, O.M., Damblon, F., Jungner, H., Zaitseva, G.I., 2007. Natural Climate Variability During the Holocene. Radiocarbon 49 (02), 837–854. doi:10.1017/S0033822200042715.

Deschler-Erb, S., Akeret, Ö., 2011. Archäobiologische Forschungen zum römischen Legionslager von Vindonissa und seinem Umland: Status quo und Potenzial. Jahresbericht Gesellschaft Pro Vindonissa, 13–36.

Divišová, M., Šída, P., 2015. Plant Use in the Mesolithic Period. Archaeobotanical Data from the Czech Republic in a European Context – a Review. Interdisciplinaria Archaeologica 6 (1), 95–106.

Doll, M., 2017. Archäozoologie und Umweltverhalten: Forschungsgeschichte, Methoden, Quellenkritik, in: Knopf, T. (Ed.), Ressourcennutzung und Umweltverhalten prähistorischer Bauern. Universität Tübingen, Tübingen, pp. 289–332.

Don, A., Schumacher, J., Scherer-Lorenzen, M., Scholten, T., Schulze, E.-D., 2007. Spatial and vertical variation of soil carbon at two grassland sites — Implications for measuring soil carbon stocks. Geoderma 141 (3-4), 272–282. doi:10.1016/j.geoderma.2007.06.003.

Dörfer, C., Kühn, P., Baumann, F., He, J.-S., Scholten, T., 2013. Soil organic carbon pools and stocks in permafrost-affected soils on the tibetan plateau. PloS one 8 (2), e57024. doi:10.1371/journal.pone.0057024.

Dotterweich, M., 2008. The history of soil erosion and fluvial deposits in small catchments of central Europe: Deciphering the long-term interaction between humans and the environment — A review. Geomorphology 101 (1-2), 192–208. doi:10.1016/j.geomorph.2008.05.023.

Dotterweich, M., 2013. The history of human-induced soil erosion: Geomorphic legacies, early descriptions and research, and the development of soil conservation—A global synopsis. Geomorphology 201, 1–34. doi:10.1016/j.geomorph.2013.07.021.

Dotterweich, M., Dreibrodt, S., 2011. Past land use and soil erosion processes in central Europe. PAGES news 19 (2), 49–51.

Dotterweich, M., Kühn, P., Tolksdorf, J.F., Müller, S., Nelle, O., 2013. Late Pleistocene to Early Holocene natural and human influenced sediment dynamics and soil formation in a 0-order catchment in SW-Germany (Palatinate Forest). Quaternary International 306, 42–59. doi:10.1016/j.quaint.2013.04.001.

Downey, S.S., Bocaege, E., Kerig, T., Edinborough, K., Shennan, S.J., 2014. The neolithic demographic transition in Europe: correlation with juvenility index supports interpretation of the summed calibrated radiocarbon date probability distribution (SCDPD) as a valid demographic proxy. PloS one 9 (8), e105730. doi:10.1371/journal.pone.0105730.

Dreibrodt, S., Lubos, Carolin Clara Marie, Terhorst, B., Damm, B., Bork, H.-R., 2010. Historical soil erosion by water in Germany: Scales and archives, chronology, research perspectives. Quaternary International 222 (1-2), 80–95. doi:10.1016/j.quaint.2009.06.014.

Eberhardt, E., Schad, P., Berner, T., Lehmann, C., Walthert, L., Pietsch, D., 2013. Ableitungsschlüssel zur Klassifizierung von Böden nach WRB 2007: aus Daten der KA 5-Nomenklatur. Handbuch, Hannover, Berlin.

Eckerle, K., 2005. Hüfingen (VS): Kastell, Bad und Gutshof, in: Planck, D. (Ed.), Die Römer in Baden-Württemberg. Römerstätten und Museen von Aalen bis Zwiefalten. Theiss, Stuttgart, pp. 127–132.

Eckmeier, E., Pätzold, S., Lehndorff, E., Gerlach, R., 2011. Geochemische Untersuchungen von Böden zur Rekonstruktion der prähistorischen Landnutzungsgeschichte, in: Bork, H.-R., Meller, H., Gerlach, R. (Eds.), Umweltarchäologie - Naturkatastrophen und Umweltwandel im archäologischen Befund. 3. Mitteldeutscher Archäologentag vom 7. bis 9. Oktober 2010 in Halle (Saale), pp. 37–45.

Edgeworth, M., 2014. The relationship between archaeological stratigraphy and artificial ground and its significance in the Anthropocene, in: Waters, C.N., Zalasiewicz, J., Williams, M., Ellis, M.A., Snelling, A.M. (Eds.), A Stratigraphical Basis for the Anthropocene, vol. 395. Geological Society Publishing House, pp. 91–108.

Edgeworth, M., Richter, D.d., Waters, C.N., Haff, P.K., Neal, C., Price, S.J., 2015. Diachronous beginnings of the Anthropocene: The lower bounding surface of anthropogenic deposits. The Anthropocene Review 2 (1), 33–58. doi:10.1177/2053019614565394.

Eggert, M.K.H., Samida, S., 2013. Ur- und Frühgeschichtliche Archäologie, 2., überarb. und aktualis. Aufl ed. Francke, Tübingen, Basel, XI, 334 S.

Ellis, E.C., Fuller, D.Q., Kaplan, J.O., Lutters, W.G., 2013a. Dating the Anthropocene: Towards an empirical global history of human transformation of the terrestrial biosphere. Elem. Sci. Anth. 1, 000018: 1-6. doi:10.12952/journal.elementa.000018.

Ellis, E.C., Kaplan, J.O., Fuller, D.Q., Vavrus, S., Klein Goldewijk, K., Verburg, P.H., 2013b. Used planet: a global history. Proc. Natl. Acad. Sci. U.S.A. 110 (20), 7978–7985. doi:10.1073/pnas.1217241110. 23630271.

Emadodin, I., Reiß, S., Bork, H.-R., 2011. Colluviation and soil formation as geoindicators to study long-term environmental changes. Environ Earth Sci 62 (8), 1695–1706. doi:10.1007/s12665-010-0665-5.

Engels, S., van Geel, B., 2012. The effects of changing solar activity on climate: Contributions from palaeoclimatological studies. J. Space Weather Space Clim. 2, A09. doi:10.1051/swsc/2012009.

Evans, S., 2012. Agricultural Production and Environmental History, in: Pilcher, J.M. (Ed.), The Oxford Handbook of Food History. Oxford University Press, Oxford.

FAO, 2006. Guidelines for soil description, 4th ed. Food and Agriculture Organization of the United Nations, Rome.

Firbas, F., 1949. Spät- und nacheiszeitliche Waldgeschichte Mitteleuropas nördlich der Alpen: Band 1: Allgemeine Waldgeschichte. Gustav Fischer, Jena.

Fried, J., 2009. Das Mittelalter: Geschichte und Kultur, 3. Auflage ed. C.H. Beck, München.

Fries, J.E., 2005. Methodische Überlegungen zur Ressource Boden. Archäologische Informationen 28 (1&2), 139–147.

Fritzsch, D., 2011. Mikromorphologische und archäopedologische Untersuchung von Böden und Sedimenten der bronzezeitlichen Siedlung Tell Chuera, Nord-Syrien. Dissertation, Frankfurt.

Fuchs, M., Lang, A., 2009. Luminescence dating of hillslope deposits—A review. Geomorphology 109 (1-2), 17–26. doi:10.1016/j.geomorph.2008.08.025.

Fuchs, M., Wagner, G.A., 2005. The chronostratigraphy and geoarchaeological significance of an alluvial geoarchive: comparative OSL and AMS 14C dating from Greece. Archaeometry 47 (4), 849–860.

Fuchs, M., Will, M., Kunert, E., Kreutzer, S., Fischer, M., Reverman, R., 2011. The temporal and spatial quantification of Holocene sediment dynamics in a meso-scale catchment in northern Bavaria, Germany. The Holocene 21 (7), 1093–1104. doi:10.1177/0959683611400459.

Fyfe, R.M., Woodbridge, J., Roberts, N., 2015. From forest to farmland: pollen-inferred land cover change across Europe using the pseudobiomization approach. Global change biology 21 (3), 1197–1212. doi:10.1111/gcb.12776.

Gamble, C., Davies, W., Pettitt, P., Hazelwood, L., Richards, M., 2005. The Archaeological and Genetic Foundations of the European Population during the Late Glacial: Implications for. Cam. Arch. Jnl 15 (02), 193. doi:10.1017/S0959774305000107.

Gassmann, G., Rösch, M., Wieland, G., 2006. Das Neuenbürger Erzrevier im Nordschwarzwald als Wirtschaftsraum während der Späthallstatt- und Frühlatènezeit. Germania 84, 273–306.

Gebhardt, H. (Ed.), 2007. Geographie Baden-Württembergs: Raum, Entwicklung, Regionen. Kohlhammer, Stuttgart, 376 S.

Gerlach, R., Eckmeier, E., 2012. Prehistoric Land Use and Its Impact on Soil Formation since Early Neolithic. Examples from the Lower Rhine Area, in: Landscape Archaeology. Proceedings of the International Conference. Landscape Archaeology Conference, Berlin. 6.-8.6.2012, pp. 11–16.

Gessner, D., 1976. Agrarverbände in der Weimarer Republik: Wirtschaftliche und soziale Voraussetzungen agrarkonservativer Politik vor 1933. Dissertation, Köln.

Glaser, R., 2013. Klimageschichte Mitteleuropas: 1200 Jahre Wetter Klima Katastrophen. Mit Prognosen für das 21. Jahrhundert, 3rd ed. Primus, Darmstadt.

Glinka, K.D., 1927. Dokuchaiev's ideas in the development of pedology and cognate sciences. The Academy, Leningrad.

Godfrey-Smith, D.I., Huntley, D.J., Chen, W.-H., 1988. Optical dating studies of quartz and feldspar sediment extracts. Quaternary Science Reviews 7 (3-4), 373–380. doi:10.1016/0277-3791(88)90032-7.

Godwin, H., 1975. The history of the British flora: A factual basis for phytogeography, 2. ed. ed. Cambridge Univ. Press, Cambridge u.a., IX, 541 S.

Grimm, E., 1991. Tilia 1.2: Tilia Graph 1.18. Illinois State Museum, Research and collection center, Springfield, Illinois.

Gronenborn, D., Strien, H.-C., Lemmen, C., 2017. Population dynamics, social resilience strategies, and Adaptive Cycles in early farming societies of SW Central Europe. Quaternary International 446, 54–65. doi:10.1016/j.quaint.2017.01.018.

Guggisberg, M.A., 2008. Chronologische Fixpunkte der späten Hallstatt- und frühen Latènezeit: Der Beitrag der klassischen Archäologie., in: Hessisches Landesmuseum Darmstadt, Landesamt für Denkmalpflege Hessen, Archäologie und Paläontologie (Eds.), Der Glauberg in keltischer Zeit. Zum neuesten Stand der Forschung ; öffentliches Symposium 14. - 16. September 2006 Darmstadt. Habelt, Wiesbaden, pp. 159–170.

Gunderson, L.H., Holling, C.S. (Eds.), 2002. Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, D.C.

Haas, J.N., Richoz, I., Tinner, W., Wick, L., 1998. Synchronous Holocene climatic oscillations recorded on the Swiss Plateau and at timberline in the Alps. The Holocene 8 (3), 301–309. doi:10.1191/095968398675491173.

Häbich, S., 2009. Umweltbedingte und anthropogene Geomorphodynamik im europäischen Hauptwasserscheidengebiet des Mittleren Schwarzwald. Dissertation. Institut für Physische Geographie und Institut für Kulturgeographie der Universität Freiburg, Freiburg i. Br.

Hahn, H.-W., 2011. Die industrielle Revolution in Deutschland. Oldenbourg Wissenschaftsverlag GmbH, München.

Hardenberg, R., 2017. Dynamic Correspondences. RESOURCECULTURES, in: Scholz, A., Bartelheim, M., Hardenberg, R., Staecker, J. (Eds.), ResourceCultures. Sociocultural Dynamics and the Use of Resources - Theories, Methods, Perspectives. Universität Tübingen, Tübingen, pp. 25–34.

Hardenberg, R., Bartelheim, M., Staecker, J., 2017. The ‘Resource Turn’. A Sociocultural Perspective on Resources, in: Scholz, A., Bartelheim, M., Hardenberg, R., Staecker, J. (Eds.), ResourceCultures. Sociocultural Dynamics and the Use of Resources - Theories, Methods, Perspectives. Universität Tübingen, Tübingen, pp. 13–24.

Haupt, P., 2012. Landschaftsarchäologie: Eine Einführung. Theiss, Stuttgart, 222 pp.

Hawkes, J.G., Francisco-Ortega, J., 1993. The early history of the potato in Europe. Euphytica 70, 1–7.

Helbig, H., Klerk, P.d., Kühn, P., Kwasniowski, J., 2002. Colluvial sequences on till plains in Vorpommern (NE Germany). Zeit fur Geo Supp 128, 81–100.

Henkner, J., Ahlrichs, J., Downey, S.S., Fuchs, M., James, B.R., Knopf, T., Scholten, T., Kühn, P., 2018a. Archaeopedological analysis of colluvial deposits in favourable and unfavourable areas: Reconstruction of land use dynamics in SW Germany. Royal Society Open Science 5. doi:10.1098/rsos.171624.

Henkner, J., Ahlrichs, J., Downey, S.S., Fuchs, M., James, B.R., Knopf, T., Scholten, T., Teuber, S., Kühn, P., 2017. Archaeopedological analyses of colluvium: A proxy for regional land use history in southwest Germany. CATENA 155, 93–113. doi:10.1016/j.catena.2017.03.005.

Henkner, J., Ahlrichs, J., Fischer, E., Fuchs, M., Knopf, T., Rösch, M., Scholten, T., Kühn, P., 2018b. Land use dynamics derived from colluvial deposits and bogs in the Black Forest, Germany. J. Plant Nutr. Soil Sci. 181 (2), 240–260. doi:10.1002/jpln.201700249.

Henkner, J., Scholten, T., Kühn, P., 2018c. Data from: Archaeopedological analysis of colluvial deposits in favourable and unfavourable areas: reconstruction of land use dynamics in SW Germany. Soil description, soil properties and ages of colluvial deposits in SW Germany. A SFB1070-B02 data table. Dryad Digital Repository. doi:10.5061/dryad.rh67h. https://doi.org/10.5061/dryad.rh67h.

Henning, F.-W., 1994. Das vorindustrielle Deutschland 800 bis 1800, 5., durchges. und erg. Aufl. ed. Schöningh, Paderborn, 323 pp.

Hilgard, E.W., 1914. Soils. Macmillan, New York.

Hinz, M., Feeser, I., Sjögren, K.-G., Müller, J., 2012a. Demography and the intensity of cultural activities: An evaluation of Funnel Beaker Societies (4200–2800 cal BC). Journal of Archaeological Science 39 (10), 3331–3340. doi:10.1016/j.jas.2012.05.028.

Hinz, M., Furholt, M., Müller, J., Raetzel-Fabian, D., Rinne, C., Sjögren, K.-G., Wotzka, H.-P., 2012b. RADON - Radiocarbon dates online 2012: Central European database for the Neolithic and Early Bronze Age, 1–4. www.jungsteinsite.de. Accessed status of April 2017.

Hodder, I., 2012. Entangled: An archaeology of the relationships between humans and things. Wiley-Blackwell, Malden Ma. u.a.

Hoffmann, T., Erkens, G., Gerlach, R., Klostermann, J., Lang, A., 2009. Trends and controls of Holocene floodplain sedimentation in the Rhine catchment. CATENA 77 (2), 96–106. doi:10.1016/j.catena.2008.09.002.

Hoffmann, T., Lang, A., Dikau, R., 2008. Holocene river activity: analysing 14C-dated fluvial and colluvial sediments from Germany. Quaternary Science Reviews 27 (21-22), 2031–2040. doi:10.1016/j.quascirev.2008.06.014.

Holling, C.S., 2001. Understanding the Complexity of Economic, Ecological, and Social Systems. Ecosystems 4 (5), 390–405. doi:10.1007/s10021-001-0101-5.

Holling, C.S., Gunderson, L.H., 2002. Resilience and Adaptive Cycles, in: Gunderson, L.H., Holling, C.S. (Eds.), Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, D.C., pp. 25–62.

Holling, C.S., Gunderson, L.H., Ludwig, D., 2002a. In Quest of a theory of Adaptive Change, in: Gunderson, L.H., Holling, C.S. (Eds.), Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, D.C., pp. 3–22.

Holling, C.S., Gunderson, L.H., Peterson, G.D., 2002b. Sustainability and, in: Gunderson, L.H., Holling, C.S. (Eds.), Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, D.C., pp. 63–103.

Holst, D., 2010. Hazelnut economy of early Holocene hunter–gatherers: A case study from Mesolithic Duvensee, northern Germany. Journal of Archaeological Science 37 (11), 2871–2880. doi:10.1016/j.jas.2010.06.028.

Houben, P., 2008. Scale linkage and contingency effects of field-scale and hillslope-scale controls of long-term soil erosion: Anthropogeomorphic sediment flux in agricultural loess watersheds of Southern Germany. Geomorphology 101 (1-2), 172–191. doi:10.1016/j.geomorph.2008.06.007.

Hughes, M.W., Almond, P.C., Roering, J.J., 2009. Increased sediment transport via bioturbation at the last glacial-interglacial transition. Geology 37 (10), 919–922. doi:10.1130/G30159A.1.

Isern, N., Fort, J., 2012. Modelling the effect of Mesolithic populations on the slowdown of the Neolithic transition. Journal of Archaeological Science 39 (12), 3671–3676. doi:10.1016/j.jas.2012.06.027.

IUSS Working Group WRB, 2015. World reference base for soil resources 2014, Update 2015: International soil classification system for naming soils and creating legends for soil maps. FAO, Rome.

Jäger, K.-D., 2002. Oscillations of the water balance during the Holocene in interior Central Europe—features, dating and consequences. Quaternary International 91 (1), 33–37. doi:10.1016/S1040-6182(01)00100-8.

James, B.R., Blum, W.E.H., Dazzi, C., 2014. Bread and Soil in Ancient Rome: A Vision of Abundance and an Ideal of Order Based on Wheat, Grapes, and Olives, in: Churchman, G.J., Landa, E. (Eds.), The soil underfoot. Infinite possibilities for a finite resource. CRC Press/Taylor and Francis, Boca Raton, pp. 153–174.

Jarvis, A., Reuter, H.I., Nelson, A., Guevara, E., 2008. Hole-filled SRTM for the globe Version 4: CGIAR-CSI SRTM 90m Database.

Jenny, H., 1994. Factors of soil formation: A system of quantitative pedology, Unabridged, unaltered republ., new foreword ed. Dover Publ, New York, 281 pp.

Kadereit, A., Kühn, P., Wagner, G.A., 2010. Holocene relief and soil changes in loess-covered areas of south-western Germany: The pedosedimentary archives of Bretten-Bauerbach (Kraichgau). Quaternary International 222 (1-2), 96–119. doi:10.1016/j.quaint.2009.06.025.

Kadereit, A., Lang, A., Hönscheidt, S., Müth, J., Wagner, G.A., 2002. IR-OSL-dated colluvial archives as evidence for the Holocene landscape history. Case studies from SW-Germany. Zeit fur Geo Supp 128, 191–207.

Kaenel, G., Müller, F., 1999. Einleitung, in: Müller, F. (Ed.), Die Schweiz vom Paläolithikum bis zum frühen Mittelalter. vom Neandertaler zu Karl dem Grossen. Band 4, pp. 13–27.

Kalis, A.J., Merkt, J., Wunderlich, J., 2003. Environmental changes during the Holocene climatic optimum in central Europe - human impact and natural causes. Quaternary Science Reviews 22 (1), 33–79. doi:10.1016/S0277-3791(02)00181-6.

Kaplan, J.O., Krumhardt, K.M., Zimmermann, N.E., 2009. The prehistoric and preindustrial deforestation of Europe. Quaternary Science Reviews 28 (27-28), 3016–3034. doi:10.1016/j.quascirev.2009.09.028.

Kind, C.-J., 2006. Die letzten Jäger und Sammler: Das Mesolithikum in Baden-Württemberg. Denkmalpflege in Baden-Württemberg 35 (1), 10–17.

Kleber, A., 2006. "Kolluvium" does not equal "colluvium". Zeit fur Geo Supp 50 (4), 541–542.

Kleber, A., Terhorst, B., Bullmann, H., Hülle, D., Leopold, M., Müller, S., Raab, T., Sauer, D., Scholten, T., Dietze, M., Felix-Henningsen, P., Heinrich, J., Spies, E.-D., Thiemeyer, H., 2013. Subdued Mountains of Central Europe, in: Kleber, A., Terhorst, B. (Eds.), Mid-latitude slope deposits (cover beds). Elsevier Science, Amsterdam, London, pp. 9–93.

Klooß, S., Sass, O., Geitner, C., Prietzel, J., 2012. Soil properties and charcoal dynamics of burnt soils in the Tyrolean Limestone Alps. CATENA 99, 75–82. doi:10.1016/j.catena.2012.07.011.

Knopf, T., 2017. Ressourcennutzung und Umweltverhalten prähistorischer Bauern: Eine Analyse archäologischer und ethnographischer Untersuchungen, in: Knopf, T. (Ed.), Ressourcennutzung und Umweltverhalten prähistorischer Bauern. Universität Tübingen, Tübingen, pp. 1–277.

Knopf, T., Ahlrichs, J., Henkner, J., Scholten, T., Kühn, P., 2015. Archäologische und bodenkundliche Untersuchungen zur Besiedlungs- und Landnutzungsgeschichte der Baar. Schriften des Vereins für Geschichte und Naturgeschichte der Baar 58, 9–24.

Knopf, T., Baum, T., Scholten, T., Kühn, P., 2012. Landnutzung im frühen Mittelalter?: Eine archöäopedologische Prospektion im mittleren Schwarzwald. Archäologisches Korrespondenzblatt 42 (1), 123–133.

Koch, A., McBratney, A.B., Adams, M.A., Field, D.J., Hill, R., Crawford, J.W., Minasny, B., Lal, R., Abbott, L., O'Donnell, A., Angers, D.A., Baldock, J., Barbier, E., Binkley, D., Parton, W.J., Wall, D.H., Bird, M., Bouma, J., Chenu, C., Flora, C.B., Goulding, K., Grunwald, S., Hempel, J., Jastrow, J.D., Lehmann, J., Lorenz, K., Morgan, C.L., Rice, C.W., Whitehead, D., Young, I.M., Zimmermann, M., 2013. Soil Security: Solving the Global Soil Crisis. Glob Policy 4 (4), 434–441. doi:10.1111/1758-5899.12096.

Koch, J., Clague, J.J., 2006. Are insolation and sunspot activity the primary drivers of Holocene glacier fluctuations? PAGES news 14 (3), 20–21.

Kösel, M., Rilling, K., 2002. Die Böden der Baar - ein Beitrag zur regionalen Bodenkunde Südwestdeutschlands. Schriften des Vereins für Geschichte und Naturgeschichte der Baar 45, 99–128.

Kraft, G., Lehmann, G., Thaer, A.D., Thiel, H. (Eds.), 1880. Albrecht Thaer's Grundsätze der rationellen Landwirthschaft, Berlin.

Kreutzer, S., Dietze, M., Burow, C., Fuchs, M.C., Schmidt, C., Fischer, M., Firedrich, J., Mercier, N., Smedley, R.K., Durcan, J., King, G., 2016. Comprehensive Luminescence Dating Data Analysis. R package.

Kromer, B., Friedrich, M., 2007. Jahrringchronologien und Radiokohlenstoff: Ein ideales Gespann in der Paläoklimaforschung. Geographische Rundschau 59 (4), 50–55.

Kühn, P., Lehndorff, E., Fuchs, M., 2017. Late Pleniglacial to Holocene Pedogenesis and Formation of Colluvial Deposits in Central Europe (Gambach, Germany). CATENA 154, 118–135. doi:10.1016/j.catena.2017.02.015.

Kullen, S., 1989. Baden-Württemberg, Stuttgart.

Lal, R., 2007. Anthropogenic Influences on World Soils and Implications to Global Food Security. Advances in Agronomy 93, 69–93. doi:10.1016/S0065-2113(06)93002-8.

Lal, R., Reicosky, D.C., Hanson, J.D., 2007. Evolution of the plow over 10,000 years and the rationale for no-till farming. Soil & Tillage Research 93 (1), 1–12. doi:10.1016/j.still.2006.11.004.

Laland, K.N., Matthews, B., Feldman, M.W., 2016. An introduction to niche construction theory. Evolutionary ecology 30, 191–202. doi:10.1007/s10682-016-9821-z.

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skånes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel, C., Xu, J., 2001. The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change 11 (4), 261–269. doi:10.1016/S0959-3780(01)00007-3.

Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW) (Ed.), 2008. Böden als Archive der Natur- und Kulturgeschichte: Grundlagen und beispielhafte Auswertung, Dez. 2008, 1. Aufl. ed. LUBW, Karlsruhe, 19 S.

Lang, A., 2003. Phases of soil erosion-derived colluviation in the loess hills of South Germany. CATENA 51, 209–221.

Lang, A., Bork, H.-R., Mäckel, R., Preston, N., Wunderlich, J., Dikau, R., 2003. Changes in sediment flux and storage within a fluvial system: Some examples from the Rhine catchment. Hydrol. Process. 17 (16), 3321–3334. doi:10.1002/hyp.1389.

Lang, A., Hönscheidt, S., 1999. Age and source of colluvial sediments at Vaihingen–Enz, Germany. CATENA 38 (2), 89–107. doi:10.1016/S0341-8162(99)00068-5.

Lang, A., Moya, J., Corominas, J., Schrott, L., Dikau, R., 1999. Classic and new dating methods for assessing the temporal occurrence of mass movements. Geomorphology 30 (1-2), 33–52. doi:10.1016/S0169-555X(99)00043-4.

Lang, G., 2005. Seen und Moore des Schwarzwaldes als Zeugen spätglazialen und holozänen Vegetationswandels : stratigraphische, pollenanalytische und großrestanalytische Untersuchungen. dem Andenken an Erich O. Oberdorfer (1905 - 2002) gewidmet, Karlsruhe.

Larsen, A., Robin, V., Heckmann, T., Fülling, A., Larsen, J.R., Bork, H.-R., 2016. The influence of historic land-use changes on hillslope erosion and sediment redistribution. The Holocene 26 (8), 1248–1261. doi:10.1177/0959683616638420.

Latour, B., 1993. We have never been modern. Harvard Univ. Press, Cambridge Mass., IX, 157 S.

Latour, B., 1999. Pandora's hope: Essays on the reality of science studies. Harvard Univ. Press, Cambridge, Mass., 324 pp.

Lazar, S., 2005. Bodenzustandsbericht Baar, 1st ed. Landesamt für Umweltschutz Baden-Württemberg, Karlsruhe, 195 pp.

Lazar, S., Rilling, K., 2006. Die Böden der Baar, in: Siegmund, A. (Ed.), Faszination Baar. Porträts aus Natur und Landschaft, 2 ed. Mory, Donaueschingen, pp. 17–57.

Lazar, S., Schippers, B., Kaufman-Boll, C., 2011. Archivböden: Empfehlungen zur Bewertung und zum Schutz von Böden mit besonderer Funktion als Archiv der Natur- und Kulturgechichte.

Leopold, M., Völkel, J., 2007a. Colluvium: Definition, differentiation, and possible suitability for reconstructing Holocene climate data. Quaternary International 162-163, 133–140. doi:10.1016/j.quaint.2006.10.030.

Leopold, M., Völkel, J., 2007b. Quantifying prehistoric soil erosion—A review of soil loss methods and their application to a Celtic square enclosure (Viereckschanze) in Southern Germany. Geoarchaeology 22 (8), 873–889. doi:10.1002/gea.20199.

Levitt, T., 1999. The Globalization of Markets, in: Aliber, R.Z., Click, R.W. (Eds.), Readings in International Business: A Decision Approach, Third printing ed. MIT Press, Cambridge, Massachusetts, London, England, pp. 249–266.

Liebig, J., 1840. Die organische Chemie in ihrer Anwendung auf Agricultur und Physiologie, Braunschweig.

Liebig, J., 1841. Die organische Chemie in ihrer Anwendung auf Agricultur und Physiologie. Verlag von Friedrich Vieweg und Sohn, Braunschweig.

Litt, T., Schölzel, C., Kühl, N., Brauer, A., 2009. Vegetation and climate history in the Westeifel Volcanic Field (Germany) during the past 11 000 years based on annually laminated lacustrine maar sediments. Boreas 38 (4), 679–690. doi:10.1111/j.1502-3885.2009.00096.x.

Löhr, H., Schütt, B., Baumhaur, R., 2002. A data bank of archaeological sites for the Trier region (Rhineland-Palatine, Germany) to reconstruct location factors of pre-historcal sites. Zeit fur Geo Supp 128, 17–29.

Lomax, J., Hilgers, A., Radtke, U., 2011. Palaeoenvironmental change recorded in the palaeodunefields of the western Murray Basin, South Australia – New data from single grain OSL-dating. Quaternary Science Reviews 30 (5-6), 723–736. doi:10.1016/j.quascirev.2010.12.015.

Lomax, J., Kreutzer, S., Fuchs, M., 2014. Performance tests using the Lexsyg luminescence reader. Geochronometria 41 (4), 327–333. doi:10.2478/s13386-013-0174-x. http://dx.doi.org/10.2478/s13386-013-0174-x.

Lucke, B., 2017. Landscape tranformations in the context of soil development, land use, and climate: A comparison of marginal areas in Jordan, Mexico, and Germany : with 70 figures and 14 tables. Borntraeger Science Publishers, Stuttgart, 199 pp.

Lüning, J., 1996. Erneute Gedanken zur Benennung der neolithischen Perioden. Germania 74 (1), 233–237.

Lüning, J., 2000. Steinzeitliche Bauern in Deutschland - die Landwirtschaft im Neolithikum. Habelt, Bonn, 285 pp.

Mäckel, R., Schneider, R., Friedmann, A., Seidel, J., 2002. Environmental changes and human impact on the relief development in the Upper Rhine valley and Black Forest (South-West Germany) during the Holocene. Zeit fur Geo Supp 128, 31–45.

Mäckel, R., Schneider, R., Seidel, J., 2003. Anthropogenic impact on the landscape of southern Badenia (Germany) during the Holocene - Documented by colluvial and alluvial sediments. Archaeometry 45 (3), 487–501. doi:10.1111/1475-4754.00123.

Mäder, A., Sormaz, T., 2000. Die Dendrodaten der beginnenden Spätbronzezeit (Bz D) von Elgg ZH-Breiti. Jahrbuch der Schweizerischen Gesellschaft für Ur- und Frühgeschichte 83, 65–78. doi:10.5169/seals-117627.

Magny, M.J., 2004. Holocene climate variability as reflected by mid-European lake-level fluctuations and its probable impact on prehistoric human settlements. Quaternary International 113 (1), 65–79. doi:10.1016/S1040-6182(03)00080-6.

Magny, M.J., Bégeot, C., Guiot, J., Peyron, O., 2003. Contrasting patterns of hydrological changes in Europe in response to Holocene climate cooling phases. Quaternary Science Reviews 22 (15-17), 1589–1596. doi:10.1016/S0277-3791(03)00131-8.

Maise, C., 2001. Zur Untergliederung der Stufe Ha C/D1 im Breisgau. Fundberichte aus Baden-Württemberg 25, 389–461.

Mangerud, J., Birks, H.J.B., Jäger, K.-D., 1982. Chronostratigraphical Subdivisions of the Holocene: A review. Striae 16, 1–6.

Matero, I.S.O., Gregoire, L.J., Ivanovic, R.F., Tindall, J.C., Haywood, A.M., 2017. The 8.2 ka cooling event caused by Laurentide ice saddle collapse. Earth and Planetary Science Letters 473, 205–214. doi:10.1016/j.epsl.2017.06.011.

Microsoft Corporation, 2017. Microsoft Office 2016 Excel.

Miehlich, G., 2009. Böden als Archive der Natur- und Kulturgeschichte. MNA Berichte 1, 76–85.

Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being: Synthesis. Island Press, Washington, DC, 137 pp.

Miller, F.P., 2006. Planet and Human Society, Soil as a Heritage of. Encyclopedia of Soil Science, 1288–1293. doi:10.1081/E-ESS-120042729.

Milne, G., 1935. Some suggested units of classification and mapping particularly for East African Soils. Soil Research 4, 183–198.

Montgomery, D.R., 2007. Soil erosion and agricultural sustainability. Proceedings of the National Academy of Sciences of the United States of America 104 (33), 13268–13272. doi:10.1073/pnas.0611508104.

Müller, D., Nübling, V., 2010. Die Befestigungen auf dem Dreifaltigkeitsberg bei Spaichingen: Vor- und frühgeschichtliche Befestigungen 21, Stuttgart.

Müller, J., Lohrke, B., 2011. Neue absolutchronologische Daten für die süddeutsche Hügelgräber-bronzezeit. Germania 87, 25–38.

Murray, A.S., Wintle, A.G., 2000. Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. Radiation Measurements 32 (1), 57–73. doi:10.1016/S1350-4487(99)00253-X.

Nearing, M.A., Yin, S.-q., Borrelli, P., Polyakov, V.O., 2017. Rainfall erosivity: An historical review. CATENA 157, 357–362. doi:10.1016/j.catena.2017.06.004.

Negendank, J.F.W., 2004. The Holocene: considerations with regard to its climate and climate archives, in: Fischer, H. (Ed.), The climate in historical times. Towards a synthesis of holocene proxy data and climate models. Springer, Berlin, London, pp. 1–12.

NGRIP Members, 2004. High-resolution record of Northern Hemisphere climate extending into the last interglacial period. Nature 431 (7005), 147–151. doi:10.1038/nature02805.

Nicolay, A., Raab, A., Raab, T., Rösler, H., Bönisch, E., Murray, A.S., 2014. Evidence of (pre)historic to modern landscape and land use history near Jänschwalde (Brandenburg, Germany), in: Engel, M., Brückner, H. (Eds.), Geoarchaeology. Exploring terrestrial archives for evidence of human interaction with the envionment, vol. 2. Borntraeger, pp. 7–31.

Nikiforoff, C.C., 1943. Introduction to paleopedology. American Journal of Science 241 (3), 194–200. doi:10.2475/ajs.241.3.194.

Nikulka, F., 2016. Archäologische Demographie: Methoden, Daten und Bevölkerung der europäischen Bronze- und Eisenzeiten. SIdestone Press, Leiden, 1436 pp.

Niller, H.-P., 2001. Wandel prähistorischer Landschaften: Kolluvien, Auenlehme und Böden: Archive zu Rekonstruktion vorgeschichtlicher anthropogener Landschaftsveränderungen im Lößgebiet bei Regensburg. erd 55 (1), 32–48.

Nölte, J., 2003. ICP-Emissionsspektrometrie für Praktiker: Grundlagen, Methodenentwicklung, Anwendungsbeispiele. Wiley-VCH, Weinheim.

Notebaert, B., Verstraeten, G., 2010. Sensitivity of West and Central European river systems to environmental changes during the Holocene: A review. Earth-Science Reviews 103 (3-4), 163–182. doi:10.1016/j.earscirev.2010.09.009.

Nübling, V., 2005. Donaueschingen. Fundberichte aus Baden-Württemberg 28 (2), 122–124.

Odling-Smee, J., Erwin, D.H., Palkovacs, E.P., Feldman, M.W., Laland, K.N., 2013. Niche Construction Theory: A Practical Guide for Ecologists. The Quarterly Review of Biology 88 (1), 3–28. doi:10.1086/669266.

Odling-Smee, J., Laland, K.N., Feldman, M.W., 2003. Niche construction: The neglected process in evolution. Princeton University Press, Princeton N.J. u.a., XII, 472 S.

Parnell, A.C., 2016. Bchron: Radiocarbon Dating, Age-Depth Modelling, Relative Sea Level Rate Estimation, and Non-Parametric Phase Modelling.

Parnell, A.C., Haslett, J., Allen, J.R.M., Buck, C.E., Huntley, B., 2008. A flexible approach to assessing synchroneity of past events using Bayesian reconstructions of sedimentation history. Quaternary Science Reviews 27 (19-20), 1872–1885. doi:10.1016/j.quascirev.2008.07.009.

Paulus, K.E., 1876. Beschreibung des Oberamts Spaichingen. Digitale Volltext-Ausgabe bei Wikisource URL: https://de.wikisource.org/w/index.php?title=Seite:OASpaichingen0116.jpg&oldid=2073814, 28.9.2013rd ed. H. Lindemann, Stuttgart.

Pearson, S.M., 2013. Landscape Ecology and Population Dynamics, in: Levin, S.A. (Ed.), Encyclopedia of biodiversity, 2nd ed. ed. Academic Press, Amsterdam, pp. 488–502.

Pietsch, D., Kühn, P., 2017. Buried soils in the context of geoarchaeological research—two examples from Germany and Ethiopia. Archaeol Anthropol Sci 9, 1571–1583. doi:10.1007/s12520-014-0180-9.

Poeplau, C., Vos, C., Don, A., 2017. Soil organic carbon stocks are systematically overestimated by misuse of the parameters bulk density and rock fragment content. SOIL 3 (1), 61–66. doi:10.5194/soil-3-61-2017.

Pokorný, P., Šída, P., Chvojka, O., Žáčková, P., Kuneš, P., Světlík, I., Veselý, J., 2010. Palaeoenvironmental research of the Schwarzenberg Lake, southern Bohemia, and exploratory excavations of this key Mesolithic archaeological area. PAMÁTKY ARCHEOLOGICKÉ 101, 5–38.

Poppi, L.K., 1991. The Archaeological Sources, in: Moscati, S., Arslan, E.A., Vitali, D. (Eds.), The Celts. Rizzoli, New York, pp. 42–50.

Prummel, W., Niekus, M.J.L.T., 2011. Late Mesolithic hunting of a small female aurochs in the valley of the River Tjonger (the Netherlands) in the light of Mesolithic aurochs hunting in NW Europe. Journal of Archaeological Science 38 (7), 1456–1467. doi:10.1016/j.jas.2011.02.009.

R Development Core Team, 2016. R: A language and Environment for Statistical Computing.

Rebourg, C., Chastanet, M., Gouesnard, B., Welcker, C., Dubreuil, P., Charcosset, A., 2003. Maize introduction into Europe: the history reviewed in the light of molecular data. TAG. Theoretical and applied genetics. Theoretische und angewandte Genetik 106 (5), 895–903. doi:10.1007/s00122-002-1140-9.

Redman, C.L., 2005. Resilience Theory in Archaeology. American Anthropologist 107 (1), 70–77.

Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg, 2013. Bodenkundliche Grundflächen. - Bodenkarte von Baden-Württemberg 1 : 50 000: blattschnittsfreie Geodaten der Integrierten geowissenschaftlichen Landesaufnahme (GeoLa).

Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg, 2016. WMS LGRB-BW HW_GEO: Geogene Grundgehalte (Hintergrundwerte) in den petrogeochemischen Einheiten von Baden-Württemberg 1 :300 000. http://maps.lgrb-bw.de/.

Reimer, P., 2013. IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. Radiocarbon 55 (4), 1869–1887. doi:10.2458/azu_js_rc.55.16947.

Richter, D.d., Bacon, A.R., Brecheisen, Z., Mobley, M.L., 2015. Soil in the Anthropocene. IOP Conf. Ser.: Earth Environ. Sci. 25, 12010. doi:10.1088/1755-1315/25/1/012010.

Robertson, R., 1992. Globalization: Social Theory and Global Culture. SAGE Publications, London, Thousand Oaks, New Delhi.

Rohdenburg, H., 1970. Morphodynamische Aktivitäts- und Stabilitätszeiten statt Pluvial- und Interpluvialzeiten. Eiszeitalter und Gegenwart 21, 81–96.

Roosevelt, F.D., 1937. Letter to all State Governors on a Uniform Soil Conservation Law. The American Presidency Project http://www.presidency.ucsb.edu/ws/?pid=15373.

Rösch, M., 1996. New approaches to prehistoric land-use reconstruction in south-western Germany. Vegetation History and Archaeobotany 5, 65–79.

Rösch, M., 1998. The history of crops and crop weeds in south-western Germany from the Neolithic period to modern times, as shown by archaeobotanical evidence. Vegetation History and Archaeobotany 7, 109–125.

Rösch, M., Ehrmann, O., Herrmann, L., Schulz, E., Bogenrieder, A., Goldammer, J.P., Hall, M., Page, H., Schier, W., 2002. An experimental approach to Neolithic shifting cultivation. Vegetation History and Archaeobotany 11, 143–154.

RStudio Inc., 2016. RStudio, Boston.

Sangmeister, E. (Ed.), 1993. Zeitspuren: Archäologisches aus Baden, 1. Aufl. ed. Kehrer, Freiburg i. Br., 240 pp.

Schaab, M., 2003. Beiträge zur Siedlungs- und Wirtschaftsgeschichte des Schwarzwaldes. W. Kohlhammer, Stuttgart.

Schaetzl, R.J., 2013. Catenas and Soils, in: Shroder, J.F. (Ed.), Treatise on geomorphology. Elsevier/Acad. Press, Amsterdam, pp. 145–158.

Schmid, B., 1991. Die urgeschichtlichen Funde und Fundstellen der Baar: Eine Auswertung des Bestandes. Band 1: Text und Tafeln. Schäuble Verlag, Rheinfelden.

Schmid, B., 1992. Die urgeschichtlichen Funde und Fundstellen der Baar: Eine Auswertung des Bestandes. Band 2: Katalog. Schäuble Verlag, Rheinfelden.

Schönwiese, C., 1995. Klimaänderungen: Daten, analysen, prognosen. Springer-Verlag, Berlin, xiii, 224.

Schreg, R., 2008. Before Colonization: Early Medieval Land-Use of Mountainous Regions in Southern and Western Germany, in: Cultural heritage and landscapes in Europe. Proceedings of the International Conference, Bochum, June 8-10, 2007 = Landschaften : kulturelles Erbe in Europa. Deutsches Bergbau-Museum, Bochum, pp. 293–312.

Schroedter, T.M., Dreibrodt, S., Hofmann, R., Lomax, J., Müller, J., Nelle, O., 2013. Interdisciplinary interpretation of challenging archives: Charcoal assemblages in Drina Valley alluvial and colluvial sediments (Jagnilo, Bosnia and Herzegovina). Quaternary International 289, 36–45. doi:10.1016/j.quaint.2012.02.030.

Scott, J.C., 2009. The art of not being governed: An anarchist history of upland Southeast Asia. Yale Univ. Press, New Haven, 442 pp.

Seidl, A., 2006. Deutsche Agrargeschichte. DLG-Verl., Frankfurt, M., 376 S.

Shennan, S.J., Downey, S.S., Timpson, A., Edinborough, K., Colledge, S., Kerig, T., Manning, K., Thomas, M.G., 2013. Regional population collapse followed initial agriculture booms in mid-Holocene Europe. Nature Communications 4, 2486. doi:10.1038/ncomms3486.

Shennan, S.J., Edinborough, K., 2007. Prehistoric population history: From the Late Glacial to the Late Neolithic in Central and Northern Europe. Journal of Archaeological Science 34 (8), 1339–1345. doi:10.1016/j.jas.2006.10.031.

Siegmund, A., 2006. Der Klimacharackter der Baar - ein regionales Querprofil, in: Siegmund, A. (Ed.), Faszination Baar. Porträts aus Natur und Landschaft, 2 ed. Mory, Donaueschingen, pp. 115–132.

Sørensen, L., Karg, S., 2014. The expansion of agrarian societies towards the north – new evidence for agriculture during the Mesolithic/Neolithic transition in Southern Scandinavia. Journal of Archaeological Science 51, 98–114. doi:10.1016/j.jas.2012.08.042.

Stavi, I., Bel, G., Zaady, E., 2016. Soil functions and ecosystem services in conventional, conservation, and integrated agricultural systems. A review. Agron. Sustain. Dev. 36 (2). doi:10.1007/s13593-016-0368-8.

Steinhof, A., Altenburg, M., Göbel, M., Machts, H., 2017. Sample preparation at the Jena 14C laboratory. Radiocarbon 59 (3), 815–830. 10.1017/RDC.2017.50.

Steuer, H., 1993. Von der Steinzeit bis zum Mittelalter - Erzgewinnung als Spiegel der Epochen, in: Steuer, H., Zimmermann, U. (Eds.), Alter Bergbau in Deutschland. Konrad Theiss Verlag, Stuttgart, pp. 7–15.

Stockhammer, P.W., Massy, K., Knipper, C., Friedrich, R., Kromer, B., Lindauer, S., Radosavljevic, J., Wittenborn, F., Krause, J., 2015. Rewriting the Central European Early Bronze Age Chronology: Evidence from Large-Scale Radiocarbon Dating. PloS one 10 (10), e0139705. doi:10.1371/journal.pone.0139705.

Stockmann, U., Minasny, B., McBratney, A.B., 2014. How fast does soil grow? Geoderma 216, 48–61. doi:10.1016/j.geoderma.2013.10.007.

Surovell, T.A., Byrd Finley, J., Smith, G.M., Brantingham, P.J., Kelly, R., 2009. Correcting temporal frequency distributions for taphonomic bias. Journal of Archaeological Science 36 (8), 1715–1724. doi:10.1016/j.jas.2009.03.029.

Teuber, S., Ahlrichs, J., Henkner, J., Knopf, T., Kühn, P., Scholten, T., Ahlrichs, J.J., 2017. SoilCultures – the adaptive cycle of agrarian soil use in Central Europe: An interdisciplinary study using soil scientific and archaeological research. Ecology and Society 22 (4), 13. doi:10.5751/ES-09729-220413.

Thaer, A.D., 1880. Albrecht Thaer's Grundsätze der rationellen Landwirthschaft. Wiegandt, Hempel & Parey, Berlin, -XLIII, 1100.

Tinner, W., 2008. Reply: Evidence for Late-Mesolithic agriculture? A reply to Karl-Ernst Behre. Quaternary Science Reviews 27 (13-14), 1468–1470. doi:10.1016/j.quascirev.2008.03.001.

Tinner, W., Lotter, A.F., Ammann, B., Conedera, M., Hubschmid, P., van Leeuwen, J.F.N., Wehrli, M., 2003. Climatic change and contemporaneous land-use phases north and south of the Alps 2300 BC to 800 AD. Quaternary Science Reviews 22 (14), 1447–1460. doi:10.1016/S0277-3791(03)00083-0.

Tinner, W., Nielsen, E.H., Lotter, A.F., 2007. Mesolithic agriculture in Switzerland?: A critical review of the evidence. Quaternary Science Reviews 26 (9-10), 1416–1431. doi:10.1016/j.quascirev.2007.02.012.

Tolksdorf, J.F., Kaiser, K., Veil, S., Klasen, N., Brückner, H., 2009. The Early Mesolithic Haverbeck site, Northwest Germany: evidence for Preboreal settlement in the Western and Central European Plain. Journal of Archaeological Science 36 (7), 1466–1476. doi:10.1016/j.jas.2009.03.002.

Uekötter, F., 2012. Die Wahrheit ist auf dem Feld: Eine Wissensgeschichte der deutschen Landwirtschaft. Vandenhoeck & Ruprecht GmbH, Göttingen.

Uerpmann, H.-P., 2007. Von Wildbeutern zu Ackerbauern: Die Neolithische Revolution der menschlichen Subsistenz. Mitteilungen der Gesellschaft für Urgeschichte 16, 55–74.

United Nations General Assembly, 2015. Resolution adopted by the General Assembly on 25 September 2015: Transforming our world: the 2030 Agenda for Sustainable Development. United Nations.

Valde-Nowak, P., 2002. Siedlungsarchäologische Untersuchungen zur neolithischen Nutzung der mitteleuropäischen Gebirgslandschaften, Rahden/Westfalen.

Vera, F.W.M., 2000. Grazing Ecology and Forest History. CABI.

Verstraeten, G., Broothaerts, N., van Loo, M., Notebaert, B., D'Haen, K., Dusar, B., Brue, H. de, 2017. Variability in fluvial geomorphic response to anthropogenic disturbance. Geomorphology. doi:10.1016/j.geomorph.2017.03.027.

Verstraeten, G., Lang, A., Houben, P., 2009. Human impact on sediment dynamics — quantification and timing. CATENA 77 (2), 77–80. doi:10.1016/j.catena.2009.01.005.

Vinther, B.M., Clausen, H.B., Johnsen, S.J., Rasmussen, S.O., Andersen, K.K., Buchardt, S.L., Dahl-Jensen, D., Seierstad, I.K., Siggard-Andersen, M.-L., Steffensen, J.P., Svensson, A.M., Olsen, J., Heinemeier, J., 2006. A synchronized dating of three Greenland ice cores throughout the Holocene. J. Geophys. Res. 111 (D13). doi:10.1029/2005JD006921.

Widlok, T., Aufgebauer, A., Bradtmöller, M., Dikau, R., Hoffmann, T., Kretschmer, I., Panagiotopoulos, K., Pastoors, A., Peters, R., Schäbitz, F., Schlummer, M., Solich, M., Wagner, B., Weniger, G.-C., Zimmermann, A., 2012. Towards a theoretical framework for analyzing integrated socio-environmental systems. Quaternary International 274, 259–272. doi:10.1016/j.quaint.2012.01.020.

Wilkinson, K.N., 2003. Colluvial deposits in dry valleys of southern England as proxy indicators of paleoenvironmental and land-use change. Geoarchaeology 18 (7), 725–755. doi:10.1002/gea.10090.

Williams, A., Hedlund, K., 2014. Indicators and trade-offs of ecosystem services in agricultural soils along a landscape heterogeneity gradient. Applied Soil Ecology 77, 1–8. doi:10.1016/j.apsoil.2014.01.001.

Williams, M., 2006. Deforesting the earth: From prehistory to global crisis. An Abridgement.

Wu, J., 2013. Landscape Ecology, in: Leemans, R. (Ed.), Ecological systems. Selected entries from the Encyclopedia of Sustainability Science and Technology. Springer, New York, NY, pp. 179–200.

Wunderlich, J., 2000. Prähistorische und historische Bodenerosion im Amöneburger Becken - Abgeleitet aus einer Sequenz datierter Kolluvien. Berichte der Kommission für Archäologische Landesforschung in Hessen 5, 9–16.

Wysocki, D.A., Zanner, C.W., 2006. Landscape Elements, in: Lal, R. (Ed.), Encyclopedia of soil science. Volume 2, 2nd ed. ed. Taylor & Francis, New York, Abingdon, Oxon, pp. 1008–1012.

Zimmermann, A., 1996. Zur Bevölkerungsdichte in der Urgeschichte Mitteleuropas, in: Campen, I., Hahn, J., Uerpmann, M. (Eds.), Spuren der Jagd - die Jagd nach Spuren. Festschrift für Hansjürgen Müller-Beck. Mo Vince, Tübingen, pp. 49–61.

Zimmermann, A., 2012. Cultural cycles in Central Europe during the Holocene. Quaternary International 274, 251–258. doi:10.1016/j.quaint.2012.05.014.

Zolitschka, B., Behre, K.-E., Schneider, J., 2003. Human and climatic impact on the environment as derived from colluvial, fluvial and lacustrine archives—examples from the Bronze Age to the Migration period, Germany. Quaternary Science Reviews 22 (1), 81–100. doi:10.1016/S0277-3791(02)00182-8.

Appendix

Included publications

Manuscript I

Archaeopedology and Chronostratigraphy of Colluvial Deposits as a Proxy for Regional Land Use History (Baar, southwest Germany)

Henkner, Jessica[1,2]; Ahlrichs, Jan J.[1,3]; Downey, Sean[4]; Fuchs, Markus[5]; James, Bruce R.[6]; Knopf, Thomas[1,3]; Scholten, Thomas[1,2]; Teuber, Sandra[1,2]; Kühn, Peter [1,2]

Catena 155 (2017) 93–113, DOI: http://dx.doi.org/10.1016/j.catena.2017.03.005

[1] SFB1070 ResourceCultures, Gartenstr. 29, 72074 Tübingen, Germany

[2] Department of Geosciences, Soil Science and Geomorphology, Eberhard Karls University Tübingen, Rümelinstrasse 19-23, 72070 Tübingen, Germany

[3] Institute for Pre- and Protohistory and Medieval Archaeology, Eberhard Karls University Tübingen, Burgsteige 11, Schloss Hohentübingen, 72070 Tübingen, Germany

[4] Department of Anthropology, University of Maryland, 1106 Woods Hall, College Park, MD 20742 USA

[5] Department of Geography, Justus-Liebig-University Gießen, Senckenberstrasse 1, 35390 Gießen, Germany

[6] Department of Environmental Science and Technology, University of Maryland, 0220 Symons Hall, College Park, MD 20742 USA

Abstract

Soils are the basis of our food production, supplying plants with nutrients and water. Farming leaves traces in the soil because cultivation can cause soil erosion. One result is the formation of colluvial deposits, which can be used as geoarchives of past human impacts on their terrestrial environment. The present study combines pedological and archaeological knowledge with chronostratigraphic analyses to infer deposition phases of colluvial material, thereby allowing the reconstruction of past land use and settlement activities in the Baar region, SW Germany. Local colluvial signals are interpreted as a regional proxy for increased soil erosion and colluviation. On the Baar, seven main deposition phases of colluvial material can be detected by 28 luminescence dates and 41 radiocarbon ages distributed through 26 soil profiles. Our results indicate increased colluviation in the younger Neolithic (~3800 BCE), the early to middle Bronze Age (~1550 BCE), the Iron Age (~500 BCE), the Roman Empire (~100 CE) and from the high Middle Ages onwards (>1200 CE, 1300 CE, 1600 CE). These dates and record of colluviation complement archaeological knowledge of the fundamental impact of human activities on the landscape due to sedentism and agriculture (early anthropogenic hypothesis). Our study shows that most periods of intensified colluvial deposition often, but not always, date to times with colder, more humid climatic periods. The spatial and temporal correlation of main depositional phases with archaeological finds points to land use as the determining factor of colluvial deposition, at least since Roman times.

1 Introduction

Today many landscapes and geographic regions are considered unfavorable for settlement or permanent use due to climate, soils, topography, and native plant communities, while others are classified as favorable. In central Europe, the concept of favorable and unfavorable regions refers to the environmental conditions and the time a region has been settled (Gebhardt, 2007). A favorable area (German: *Gunstraum* or *Altsiedelland*) is assumed to have been settled earlier than an unfavorable area. Reasons for an early settlement could include a more accessible landscape, fertile soils, warmer climate and sufficient rainfall for agriculture. Unfavorable areas are usually characterized as being less productive for agriculture, and therefore were supposedly settled later. However, the application of this definition to a research question needs to be explained in specific geographic and archaeological contexts. An interdisciplinary prehistoric archaeology and soil science project at the University of Tübingen is examining land use and settlement history in unfavorable areas in southwestern Germany. The focus is on soils that are a key resource for food production and human habitation. The technological capacity of human societies to use and modify soils has changed dramatically through time, as have the reasons for carrying out these activities. Soils itself preserve the signature of past human activities, as well as, paleoenvironmental conditions (James et al., 2014; Nicolay et al., 2014; Pietsch and Kühn, 2014).

Soils have been a research focus since the times of Thaer (in Kraft et al., 1880) and Liebig (1840), who studied agricultural land use. The first scientist to describe soils and their properties were Dokuchaev in Russia (Glinka, 1927) and Hilgard (1914) in North America. They suggested that soils result from interactions among parent material, climate, topography, biota and time. In 1941, Jenny (1994) explained soil formation in his quantitative pedology, which is based on these five functionally related soil forming factors. The theories and concepts of soil formation include the shape of the soil surface as an essential variable, at least since Milne (1935) published the concept of a *catena*. A catena or toposequence describes soils along a landscape sequence, where soil properties change gradually depending on geologic, geomorphic, atmospheric, or biologic processes (Wysocki and Zanner, 2006). However, none of these concepts explicitly include the effect of human activities on soil formation and erosion processes. This is changing; the term *Anthropocene* highlights a new geological epoch characterized by a significant transformation of the natural environment by humans (Crutzen and Stoermer, 2000; Lewis and Maslin, 2015; Ruddiman, 2013). Richter et al. (2015) describe how humans have altered soils chemically, physically, and biologically, transforming them into a human-natural system. This process started with the so called *Neolithic Revolution* – the transition from a hunting and gathering society to sedentism and the use of agricultural production. These changes in human settlement patterns, techniques for subsistence, and social organization subsequently triggered the Neolithic Revolution or Neolithic Demographic Transition, which saw higher carrying capacities and increased demographic growth rates (Bocquet-Appel, 2011; Downey et al., 2014). During this period, permanent land uses like farming, which involves digging, plowing, and harvesting, ultimately led to deforestation

(Fyfe et al., 2015) and bare soils along slopes are prone to soil erosion. The eroded soil is deposited in depressions and along slopes, and called *colluvial deposit.* These deposits are important archives of the physical and cultural heritage of the region (Dreibrodt et al., 2010b; Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW), 2008; Miehlich, 2009).

The German term *Kolluvium* is used when describing slope deposits formed by human induced or intensified soil erosion due to their land use (Ad-hoc-AG Boden, 2005; Kleber, 2006; Leopold and Völkel, 2007a). The characteristic corresponding land use is agriculture (Blume et al., 2010; Bork, 2006), but it could also be deforestation, mining, village establishment or infrastructure building. Hunter and gatherer populations also used the land and depended on the soil, but non-sedentary societies had smaller impacts on soil erosion and colluvial deposition than did agricultural societies (Miller, 2006). Thus, farming marks the beginning of a more intense and permanent anthropogenic land use that led to the formation of colluvial deposits. In this paper, the terms *colluvium* and *colluvial deposit* are used to describe soil landscape features formed by anthropogenic processes, including induced or intensified soil erosion by water and down slope deposition of eroded material. The term *colluvial soil horizon* describes a soil horizon out of colluvial material. These colluvial deposits are important resources to understand land use and settlement history (Emadodin et al., 2011; Leopold and Völkel, 2007a; Pietsch and Kühn, 2014). Further relocation of colluvial material, as well as absent, sustainable, or soil conserving land use lead to missing colluvial deposits. Soil formation, per the concept of Jenny (1994), takes place in periods of physical geomorphodynamic stability. If this stability is disturbed soil relocation occurs and pedogenesis slows dramatically. Environmental influences, especially precipitation variation and thunderstorm events associated with climate change, should be considered when interpreting and quantifying colluvial deposits as anthropogenic geoarchives (Dreibrodt et al., 2010a).

A colluvial deposit is always directly related to adjacent upward slope areas and thus it can be considered a local, high-resolution spatial phenomenon. The situation on nearby slopes can be different. If colluvial deposits are archives representing the impact of humans on their environment (Verstraeten et al., 2009), they can be used as a local proxy for the intensity and duration of human settlement, land uses, and migration during the Holocene (Dotterweich and Dreibrodt, 2011; Helbig et al., 2002; Leopold and Völkel, 2007b; Schroedter et al., 2013). Thus, we hypothesize that a geomorphological and spatially controlled sample of colluvial deposits can be taken as a regional proxy for land use history. Consequently, the research presented in this paper focusses on the following objectives:

(i) Analyzing the local chronostratigraphy and archaeopedology of colluvial deposits in different areas of the Baar region
(ii) Identifying main periods of colluvial deposit formation across the Baar region
(iii) Inferring possible causes of the formation of colluvial deposits as related to human land use history and climate

1.1 Regional setting of the Baar

The study area in southwest Germany comprises the granitic basement of the Black Forest to the west and the limestone escarpment of the Swabian Jura to the east (Fig. 1). In between is the Baar, a depression of older escarpments that includes the Danube River and its headwater streams, the Brigach and Breg. The entire study area is an unfavorable region, but compared to the Black Forest and Swabian Jura the Baar can be considered a favorable region for agriculture because it has fertile soils, often influenced by loess deposits (Kösel and Rilling, 2002; Lazar, 2005). The area was known as the breadbasket of the Baden region (Reich, 1859; Schröder, 2001). The Baar has an average elevation of about 700-800 m, and it has a lower relief intensity than the Black Forest and Swabian Jura. Mean annual temperature is 7-8 °C and mean annual precipitation is approximately 850 mm (Siegmund, 2006). Swabian Jura and Black Forest have lower average temperatures and higher annual precipitation; they are considered unfavorable for agricultural land use. In the low mountain range of Black Forest, soils tend to be more acidic, and the relief is higher, having peaks of up to 1000 m height. On the 750-900 m high plateau of the Swabian Jura, the supply of fresh water is limited because of low water storage capacity in the bedrock, and depends mostly on precipitation. Thus, this paper focuses on the Baar region, representing a rather favorable area for agricultural land use.

During the winter, stable atmospheric inversions occur in the Baar that can create heavy fog and many freezing days (122 ±10 days from 1994-1996); along with short periods of frost-free days (approximately 140 days) (Siegmund, 2006). The Baar region is therefore more unfavorable than regions to the south and north, such as the Upper Rhine lowlands or the Hegau region.

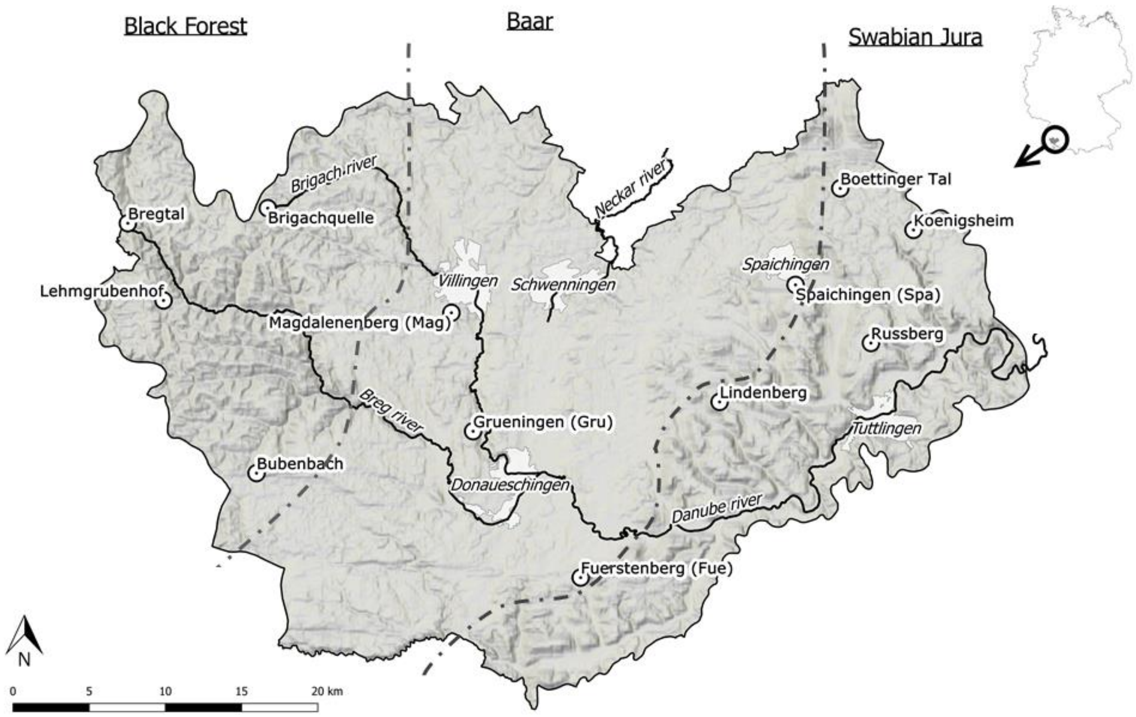

Fig. 1. SRTM image (Jarvis et al., 2008) of the study area in SW Germany, covering the eastern Black Forest in the west, the Baar in the center and the western Swabian Jura to the east (all separated by dash-dot lines). The study sites (marked with circles) Magdalenenberg (Mag), Grueningen (Gru), Fuerstenberg (Fue) and Spaichingen (Spa) are situated on the Baar; the others sites are located in neighboring regions. Modern settlements are given in italics.

Four sites on the Baar were chosen for archaeopedological and chronostratigraphic analyses because they provided the oldest archaeological findings in the Baar region, as known from literature. Since the locations were chosen in accordance with archaeological evidence (Tab. 1), we hypothesize that the phases of colluvial deposition can be linked to the local and regional settlement history. We, thus, use the colluvial deposits as a proxy for land use history. The four sites are: (1) The Magdalenenberg (Mag) site in the northwestern Baar close to Villingen, with its famous burial mound built of wood and earthen material dating to 616 BCE (Knopf, 2012). The location of the corresponding ancient settlement(s) is unknown. Archaeological findings indicate land use here since the Neolithic (Schmid, 1991; 1992). The bedrock is middle Triassic limestone, partially covered by loess containing Holocene slope deposits (Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg, 2013). (2) The Grueningen (Gru) site is located above the Brigach River near Donaueschingen. The dominant bedrock in the area is limestone covered by Pleistocene-to-Holocene deposits, containing admixtures of loess. (3) The Fuerstenberg (Fue) site is in the southern Baar and close to the transition to the Swabian Jura. It comprises slope deposits from late Jurassic limestone to early Jurassic clay-rich sediments covered by relocated loess. (4) At the site close to the town Spaichingen (Spa) the upper and middle slope is built up by limestone (middle Jurassic); the lower part consists of early Jurassic claystone and is covered by Holocene sediments.

Slopes and depressions at all four sites are covered by slope deposits, of periglacial or anthropogenic origin during the Quaternary, which are the parent material for soil formation (Kösel and Rilling, 2002). Regosols and Cambisols (according to the World Reference Base of Soil Resources, IUSS Working Group WRB, 2015) are the most common soil types on these sites. As a result of different pedogenic processes, Luvisols, Vertisols, and Gleysols occur as well.

1.2 Settlement and land use history of the Baar region

The cultural periods of SW Germany are given in Table 1 starting with the Neolithic Period at the beginning of agricultural activities within the study area. Each period is documented by artifacts found in a 2 km radius around the pedological study sites. Additionally, many finds are known from other sites in the Baar region (Schmid, 1991, 1992). On the western and southern Baar, two settlements from the first sedentary settlers and farmers of the Early Neolithic period, known as the Linear Pottery Culture, are identified (Nübling, 2005; Schmid, 1991; 1992). Stone tools from the Magdalenenberg and other sites indicate Early Neolithic activity on the western and eastern Baar (Schmid, 1991; 1992). Findings from the middle Bronze Age cluster around Donaueschingen and Villingen-Schwenningen, other finds from the Bronze Age are scattered across the Baar. During the Urnfield Period, the settlements were concentrated on the western Baar, and two settlement sites are known near Spaichingen (Hanöffner, 2005; Schmid, 1991, 1992). With the transition to the Iron Age, the number of known archaeological sites increases. During the Roman occupation settlements are known around Huefingen and Villingen-Schwenningen, while only a few farmsteads are found in the vicinity of Spaichingen (Paret, 1932; Schmid, 1992). In the eastern Baar, few settlements date to ±10 to 300 CE (Christ, 1960; Hübener, 1972; Spindler, 1977). In the Middle Ages, the number of archaeological sites markedly increases and the overall settlement pattern changes (Buchta-Hohm, 1996; Fischer, 1936; Revellio, 1935). Most archaeological sites are found in the valleys of the Brigach and Breg Rivers. In the east, south, and center of the Baar, settlements were rather loosely scattered. The distribution of the medieval sites is comparable to today's settlement pattern of the Baar.

2 Methods

2.1 Field

Field work for this study was carried out from 2013 to 2015. It included the description of 26 soil profiles, following the German soil classification system (Ad-hoc-AG Boden, 2005), the Food and Agriculture Organization of the United Nations (FAO) (2006), and the WRB 2015 (IUSS Working Group WRB, 2015). The German classification system includes the horizon designation *M* (M = Lat. *Migrare*, to migrate) for anthropogenic colluvial horizons lacking other pedogenic properties. Since it is important to differentiate colluvial horizons from others with different pedogenic development, we use the M horizon together with the FAO nomenclature. German soil types were translated into WRB using translation software (Eberhardt et al., 2013a, 2014). Soil properties like type and abundance of coarse fragments (e.g. limestone), redoximorphic features, root abundance and special features in the soil (pieces of charcoal or burned clay) were described according to Ad-hoc-AG Boden (2005).

The soil profiles are located along catenas reaching from the upper slope to foot slope positions. Catenas represent a sequence of soil profiles along a slope having different characteristics due differences in topography, elevation, drainage, erosion or deposition (Schaetzl, 2013). The locations of catenas and soil profiles were chosen to represent a stratigraphy of colluvial deposits in close proximity to known prehistoric activities, documented by prehistoric settlements or findings (Tab. 1). Dating was done on colluvial deposits showing the most detailed pedostratigraphy and being characteristic for the site. In order to prevent sampling bias for a specific time soil samples for dating were collected consistently from all soil horizons, where sampling was possible.

Tab. 1: Summary of archaeological finds sorted by cultural periods in SW Germany in a 2 km radius around each of the four study sites on the Baar. Questionable interpretation of the material is marked with a "?". Not listed are many known undated stone and earth mounds.

Period (duration; references)	Site	Finds and records	Interpretation	References
Neolithic				
Early Neolithic (5500-5000 BCE; Lüning, 1996)	Mag	Flint tools	Single finds	(Schmid, 1991, 1992)
Middle Neolithic (5000-4400 BCE; Lüning, 1996)				
Younger Neolithic (4400-3500 BCE; Lüning, 1996)				
Late Neolithic (3500-2800 BCE; Lüning, 1996)				
Final Neolithic (2800-2150 BCE; Lüning, 1996; Stockhammer et al., 2015)				
Neolithic in general	Mag	Stone axe	Single find	(Hettich, 1984/85)
	Fue	Sherds, flint artifacts	Settlement?	(Revellio, 1933; Schmid, 1992)
	Spa	Scraper	Single find	(Nübling, 1990)
Bronze Age				
Early Bronze Age (2150-1550 BCE; Stockhammer et al., 2015)				
Middle Bronze Age (1550-1300 BCE; Della Casa, 2013; Müller and Lohrke, 2011)	Gru	Human remains, metal artifacts	Burial site	(Schauer, 1971; Wagner and Haug, 1908)
	Spa	Human remains, metal artifacts	Burial site	(Schmid, 1992)
Late Bronze Age (1300-1200 BCE; Della Casa, 2013; Mäder and Sormaz, 2000; Müller and Lohrke, 2011)				
Urnfield period (1200-800 BCE; Della Casa, 2013)	Gru	Sherds, bronze needle	Settlement?	(Knopf et al., 2015; Knopf and Seidensticker, 2013)
	Gru	2 vessels	Deposition	(Ahlrichs et al., 2017 submitted)
	Fue	Sherds	Settlement?	(Wagner, 2014)
	Spa	Many sherds on several sites	Settlement?	(Schmid, 1991, 1992)

Iron Age				
Hallstatt Period (800-450 BCE; Guggisberg, 2008; Maise, 2001)	Mag	Burial mounds	Burial sites	(Spindler, 1977, 1996, 2004)
	Gru	Human remains, sherds, metal artifacts, etc.	Burial site	(Schmid, 1991, 1992)
	Fue	Sherds	Settlement?	(Wagner, 2014)
Latène Period (450 BCE- ±1; Kaenel and Müller, 1999; Poppi, 1991)	Mag	Sherds in a pit	Settlement	(Weber-Jenisch, 1994)
	Mag	Sherds, coins, glass jewelry	Settlement?	(Weber, 1991/1992)
	Spa	Coin	Single find	(Fischer, 1936)
Roman Empire				
Roman Empire (±1 -375 CE; Eggert and Samida, 2013)	Mag	Coins	Single finds	(Christ, 1960)
	Mag	Terra-Sigillata fragments	Burial?	(Hettich, 1984/85)
	Fue	Sherds	Settlement?	(Revellio, 1933)
	Fue	Remnants of a building	Farmstead	(Fischer, 1936)
	Fue	Coins	Single finds	(Fischer, 1936; Wagner and Haug, 1908)
	Spa	Remnants of a building	Farmstead	(Paret, 1932)
	Spa	Sherds	Settlement?	(Schmid, 1992)
Migration Period (375-450 CE, Eggert and Samida, 2013)				
Middle Ages				
Merovingian Period (450-750 CE; Ament, 1977)	Mag	Bronze needle	Single find	(Hettich, 1984/85; Spindler, 1979)
	Gru	Several burials	Cemetery	(Buchta-Hohm, 1996; Wagner and Haug, 1908; local archaeological records (Ortsakten))
	Spa	Several burials	Cemetery	(Buchta-Hohm, 1996; Stoll and Gehring, 1938)
	Spa	Remnants of buildings	Village	(Paret, 1932)
	Spa	Human remains	Cemetery?	(Buchta-Hohm, 1996)
High Middles Ages (750-1250 CE; Sangmeister, 1993)	Mag	2 historical records	Fortification	(Buchta-Hohm, 1996)
	Mag	Historical record	Settlement	(Badische Historische Kommission, 1904b; Spindler, 1979)

	Gru	Historical records	Settlement	(Buchta-Hohm, 1996)
	Fue	Historical records	Settlement	(Badische Historische Kommission, 1904a; Wagner, 2014)
	Spa	4 historical records	Deserted village	(Buchta-Hohm, 1996; Heizmann, 1968; Paret, 1932)
Late Middle Ages (1250-1500 CE)				
Middle Ages in general	Gru	Aerial photo	Cemetery?	local archaeological records (Ortsakten)
	Gru	Aerial photo; Remnants of a building	Village	local archaeological records (Ortsakten)
	Gru	2 historical records	Farmstead?	(Badische Historische Kommission, 1904a)
	Gru	Earth walls	Fortification	local archaeological records (Ortsakten)
	Spa	Aerial photo	Settlement?	local archaeological records (Ortsakten)
	Spa	Sherds	Single finds	local archaeological records (Ortsakten)

A total of 339 bulk samples and 318 volumetric samples (each consisting of 3 x 100 cm^3 subsamples) were taken from all horizons. From each colluvial horizon, the upper 5 cm were sampled separately, and colluvial horizons thicker than 20 cm were split into thinner sampling units. If we found pottery fragments in the soil, we collected and took them as indicators of a nearby settlement (Niller, 2001; Wunderlich, 2000). A lack of pottery fragments might indicate agricultural land use or deforestation (Mäckel et al., 2003).

2.2 Laboratory

Soil-pH was determined using a soil-to-solution ($CaCl_2$, H_2O, with Sentix 81, WTW, pH 340) ratio of 1:2.5 (Blume et al., 2010). Carbonate content was determined volumetrically by CO_2 evolution using a Calcimeter ("Calcimeter", Eijkelkamp, Giesbeek). Total C and N contents [mass %] were analyzed using oxidative heat combustion at 1150 °C in a He atmosphere (element analyzer "vario EL III", Elementar Analysesysteme GmbH, Germany, in CNS mode). Soil organic C content (SOC) was determined using: SOC = C_{total}-$CaCO_3$x0.1200428, soil organic matter (SOM) was calculated using the factor 1.72 (Eberhardt et al., 2013b). Bulk density [g cm^{-3}] was gravimetrically determined (cf. Don et al., 2007). Texture was determined by X-ray granulometry using SediGraph 5120 (Micromeritics GmbH, Mönchengladbach) for grain sizes < 20 µm and combined sieving for grain sizes from 2000 µm to 20 µm.

To estimate depositional ages of the colluvial sediments, optical stimulated luminescence (OSL) dating was applied, using opaque steel cylinders with a diameter of 4.5 cm for sampling. For equivalent dose (D_e) determinations, the coarse grain (90-200 µm) quartz fraction was prepared and measured with a single-aliquot regenerative-dose (SAR) protocol after Murray and Wintle (2000). All luminescence measurements were carried out at the luminescence laboratory of the Justus-Liebig-University in Giessen, using a Freiberg Instruments Lexsyg reader (Lomax et al., 2014). For data analysis, the R luminescence package (Kreutzer et al., 2016) was used.

To avoid modern bleaching by bioturbation, the upper 30 cm of the profiles were not sampled for OSL dating. In consequence, colluvial deposition of the modern era might be underrepresented. This might also apply to older colluvial deposits, because of the generally better preservation of younger deposits. However, the general suitability of OSL dating on colluvial deposits, is shown in numerous studies, despite issues of partial bleaching (e.g. Fuchs et al., 2011; Fuchs and Lang, 2009; Kadereit et al., 2010). Most samples have good properties for luminescence dating, showing a bright luminescence signal. Therefore, small aliquots with a diameter of 1-2 mm were measured. In the case of skewness of the equivalent dose distribution a minimum age model was used. Skewness can result from partial bleaching or *in situ* redeposition.

AMS ^{14}C radiocarbon dating of charcoal fragments found within the colluvial sediments was carried out at the laboratories of Erlangen, Jena, Mannheim, and Poznan. The pretreatment was done using the ABA (acid-base-acid) or, in case of samples measured in Jena, by an ABOx (acid-base-oxidation) procedure (Steinhof et al., 2017). The conversion of the ^{14}C isotope ratios in calendar and calibrated dates was done with OxCal 4.2 using the IntCal13 calibration curve (Bronk Ramsey, 2009; Reimer, 2013).

The basic assumption for the interpretation of charcoal ages is that no relocation within the soil profile occurred. Occasionally, we encountered sample dates which appear to be out of sequence in relationship to other dated samples within a soil profile. In those cases, where the majority of dates formed a clear stratigraphic sequence, and certain charcoal samples date to much older or younger times than would have been expected due to their sampling location within the sequence, we assumed relocation of those sample by natural processes of bioturbation or redeposition. Age inconsistencies may also be due to the use or re-use of old timber because the samples date to the time when the tree grew, rather than the time when the wood was processed and used. These confounding effects can also explain charcoal ages which appear older than OSL ages. Another assumption is that the charcoal fragments are the result of consecutive inputs, most probably of anthropogenic origin, because single charcoal pieces are distributed throughout the soil profiles and not layered. If the pretreatment omitted all contaminations, the age of the charcoal represents the age of the layer plus the time span from growing to deposition, i.e. the charcoal age is an upper limit for the age of the colluvial horizon. The true age of the formation of colluvial deposits is not necessarily dated with the radiocarbon or luminescence method.

The radiocarbon calibration process can also introduce additional errors if particular dates are associated with problematic parts of the calibration curve ("wiggles" or non-linearities of the calibration curve), which result in extremely large and non-normal standard error estimates, even for very accurately dated samples. Finally, younger charcoal samples might be overrepresented because of better preservation and an increasing probability of destructive processes like erosion and weathering (Eckmeier et al., 2011; Lang, 2003; Surovell et al., 2009), which limits the explanatory power especially for older periods. Thus, radiocarbon ages from charcoal could be older, younger, or of the same age than OSL samples, depending on site taphonomy and date calibration dynamics. In addition, ten radiocarbon ages were omitted from the analysis because they dated soil organic matter, which gives older ages, since it originates from the older soil formation phase and was relocated with the colluvial material.

Only the available radiocarbon and OSL ages from colluvial layers with a high reliability, based on the comparison with luminescence ages and the stratigraphic context, were used for the calculation of the summed probability density (SPD) plots (Downey et al., 2014; Parnell et al., 2008). Soil pit locations were purposefully sampled from archaeological contexts; however, within each soil pit, soil material for dating was sampled from the top to the bottom of the vertical pit wall, and from within each identifiable and dateable layer. Because of this, the distribution of the date samples represents an unbiased, temporal sample and therefore the SPD curves from the ^{14}C and OSL dates and error distributions are valid profiles of the colluviation intensity of these sites through time. To calculate SPDs, uncalibrated radiocarbon ages and errors were used and calibrated using the statistical software package Bchron (Parnell, 2016) and the calibration curve IntCal13 (Reimer, 2013). The SPD for the OSL dates was generated by sampling from a Gaussian distribution for each date where the mean was estimated as the date and the standard deviation was estimated as the OSL error distribution. The different age probability curves are summed and plotted.

3 Results

3.1 Stratigraphy and properties of colluvial deposits on the Baar

Colluvial deposits cover almost the entire area of the studied slopes, although they are expected to be limited to and thicker in foot slope positions (Ad-hoc-AG Boden, 2005). In this study, more than 130 colluvial soil horizons were described from 26 individual soil profiles, with an average of 5 colluvial horizons per soil profile. Most of the soils (#23 out of 26) were classified as Kolluvisols, the others as Rendzinas or Parabraunerde within the German Classification System (Ad-hoc-AG Boden, 2005). Following the IUSS Working Group WRB (2015), 14 of the soils were classified as Cambisols, 6 as Regosols, and a few as Luvisols and Umbrisols.

Magdalenenberg

The catena at Magdalenenberg (Fig. 2) shows a characteristic distribution of colluvial deposits with an onset in the middle slope (between Mag4 and Mag3) and an increase in thickness and numbers of separate colluvial layers at lower slope positions (Mag1 and Mag2). Soil horizon boundaries are roughly parallel to the slope surface. Signs of former agricultural use (relic Ap horizon) are found on the plateau under forest (Mag6) and on the smoother middle and lower slope (from B1 downwards). Soil profile Mag1 was opened in 2010 (=Mag1_10) and again 2014 (=Mag1_14). The lowest colluvial horizons of Mag1 and Mag2 are underlain by *in situ* weathered material from limestone showing signs of water logging and clay relocation or periglacial slope deposits. The SOC content of the Mag1_14 soil profile decreases with depth from 4 % in the Ap to an average 1.15 % in colluvial horizons, and to 0.2 % in *in situ* horizons (Tab. 2). The Mesolithic OSL age (GI-0133) from the lowest colluvial horizon (2 M4) indicates pre agricultural soil erosion. The overlying M3 and M2 horizons formed in the late Mesolithic and younger Neolithic

(GI-0132, GI-0131). Until the high Middle Ages, no colluvial horizons were formed, but archaeological evidence such as the Magdalenenberg burial mound point to human presence during this time (Tab.1). The upper 47 cm of the soil were accumulated from the high Middle Ages (750-1250 CE, GI-0130) onwards.

Tab. 2: Selected soil properties of Mag1_14: Haplic Umbrisol (Anthric, Aric, Clayic, Colluvic, Raptic)

Horizon	Lower boundary [cm]	Substrate genesis	SOC [%]	Further soil properties
Ap	25	colluvial	4.03	
M1	40	colluvial	2.20	
M2	60	colluvial	1.32	
M3	70	colluvial	0.64	10% limestones, redoximorphic features
2 M4	80	colluvial	0.45	10% limestones, redoximorphic features
3 CBsg	95+	weathered	0.20	

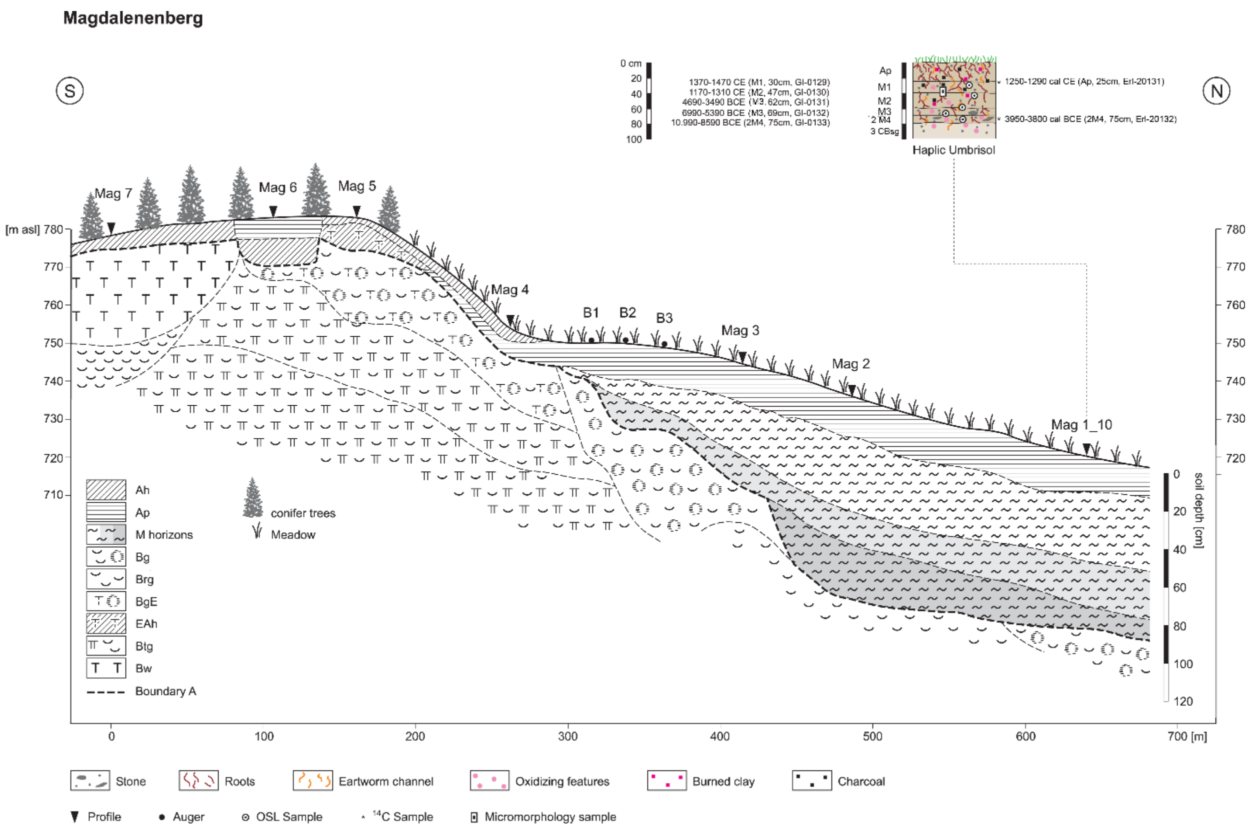

Fig. 2: Catena Magdalenenberg. The drawing of the catena is based on work from 2010; the profile Mag 1 displays the soil description of 2014.

Fuerstenberg

The catena on the southwestern slope of Fuerstenberg (Fig. 3) also shows a downslope continuum of the colluvial horizons. However, they are not necessarily parallel to the surface, but show a paleorelief with depressions, indicated by the boundary A. The colluvial cover at mid and lower slope positions (from auger Bf13 downwards) is built up by organic matter-rich material containing limestones, and can be differentiated in up to 6 colluvial horizons. Today the slope is drained and used for growing crops (wheat: *Triticum aestivum*, rapeseed: *Brassica napus*). The bedrock is covered by periglacial slope deposits from the late Jurassic limestone and overlying nearly 2 m thick colluvial deposits, indicating long anthropogenic land use. On the middle slope (between Bf47 and Bf13) there are two colluvial horizons, but then they increase again to four (Fue10, Bf50). A change of substrate and probably paleorelief occur between Bf13 and the soil profile Fue10. The upper slope soils are siltier, lighter brown, contain less SOC content, and are rich in limestone and $CaCO_3$ content. The soil pH is about 0.5 units higher than on the lower slope. The profile Fue10 can be differentiated in four colluvial horizons, of which the deeper two horizons show a remarkable dark brown color and high SOC content. Further upslope (from Fue11 upslope) the thickness of the colluvial horizons declines rapidly and Regosols dominate the soilscape covered by grass. The late Jurassic escarpment above is covered by mixed hardwood and coniferous forest vegetation.

Fue8 and Fue9 (Tab. 3), situated on the south facing footslope, are characteristic soil profiles of lower slope positions in the transition area to the Swabian Jura. Six colluvial soil horizons have formed from the Neolithic to modern times, having an average SOC content of approximately 2.3 %. On average, the colluvial horizons of Fue8 contain 1.9 % SOC. At the depth of 125-170 cm, a former relocated Ah surface horizon (M5 and M6, containing 2.04 % SOC) is buried and contains a charcoal piece dating to 1750-1610 cal BCE (130-140 cm, Erl-20273). The corresponding OSL age dates to 5490-4290 BCE (135 cm, GI 0183). Below approximately 190 cm non-colluvial horizons are developed in weathering products of the middle Jurassic. These horizons show vertic features. The profile Fue9 has a similar pedostratigraphy (Tab. 3), but dates to older time periods (Fig. 3, Tab. 7, Tab. 8) and contains more SOC in colluvial horizons (2.6 % SOC).

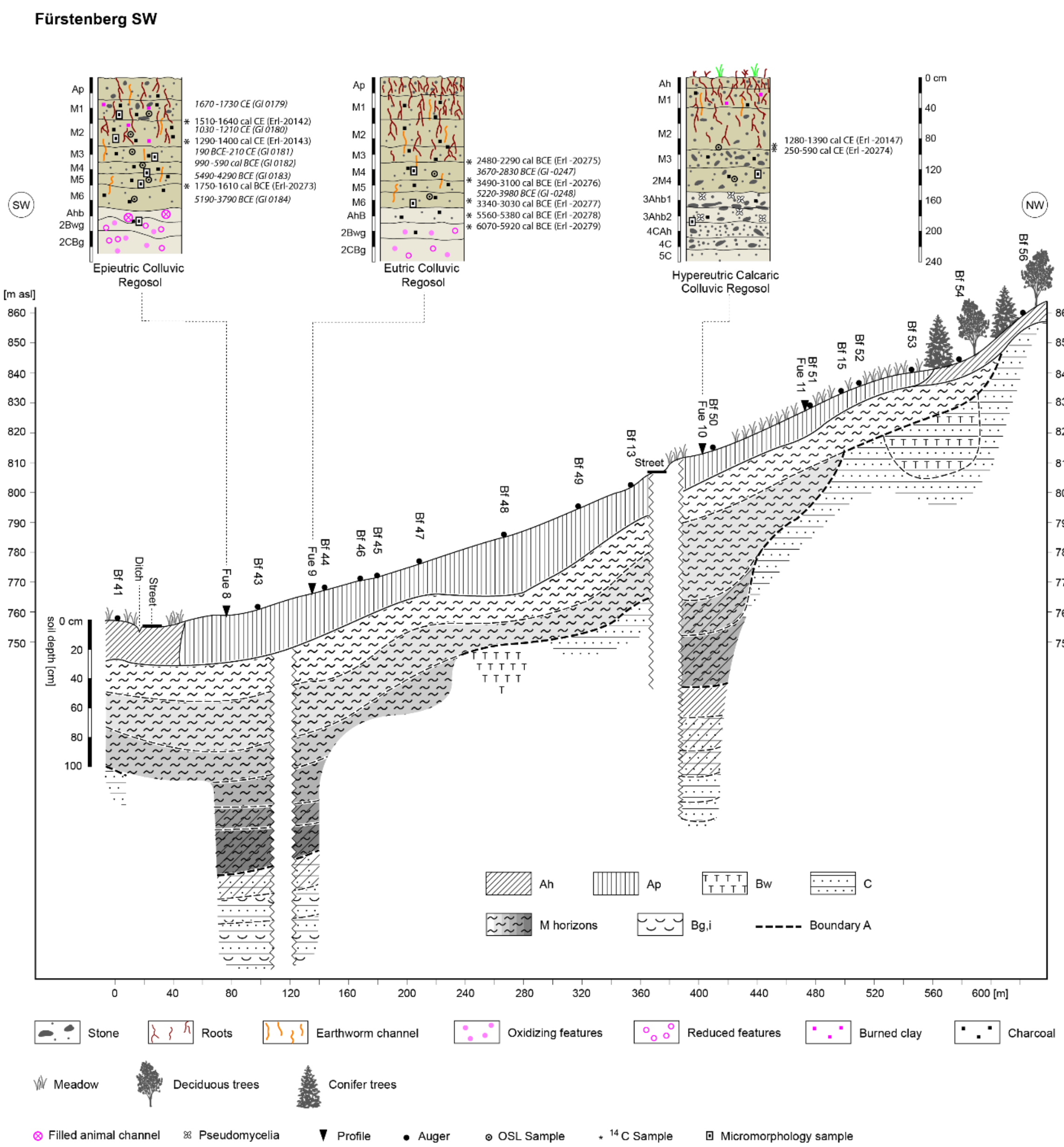

Fig. 3: Catena and soils at the south western slope of the Fuerstenberg.

The Fuerstenberg NW catena (Fig. 4) is more complex and is influenced by a fluctuating water table (from Bf57 to Bf 64). The lower slope is used for agricultural crops (wheat and corn: *Zea mays*). The middle slope is used as a pasture for sheep and as a mixed fruit orchard. The relief shows signs of a series of small, independent landslides. The upper mid-slope between Bf70 and Fue7 is terraced with signs of former plowing. Colluvial deposits are thicker and more differentiated just above the terrace step. Thickness and number of colluvial horizons decrease upslope to the next terrace. The colluvial horizons have high SOC contents and merge to a hortic horizon in the gentler upper mid-slope (Fue7). The steep upper slope from Bf73 upwards is covered by mixed hardwood forest and is dominated by Regosols.

Tab. 3: Selected soil properties of profile Fue8: Epieutric Colluvic Regosol (Aric, Pantoclayic, Humic, Raptic, Bathythaptomollic) on the left and Fue9: Eutric Colluvic Regosol (Aric, Humic, Raptic, Anosiltic, Bathyclayic) on the right.

Hori-zon	Lower boundary [cm]	Sub-strate genesis	SOC [%]	further proper-ties	Hori-zon	Lower boundary [cm]	Sub-strate genesis	SOC [%]	further proper-ties
Ap	30	colluvial	3.02	10% limes-tones	Ap	25	colluvial	2.82	10% limes-tones
M1	55	colluvial	2.07	20% limes-tones	M1	55	colluvial	2.07	
M2	90	colluvial	1.68		M2	90	colluvial	2.01	
M3	110	colluvial	1.74		M3	110	colluvial	2.62	
M4	125	colluvial	1.62		M4	135	colluvial	3.12	
M5	140	colluvial	1.86		M5	150	colluvial	3.32	
M6	170	colluvial	2.22		M6	170	colluvial	2.96	
Ahb	185	weat-hered	1.33		Ahb	190	weat-hered	1.71	vertic
2 Bwg	200	weat-hered	0.60	Redoxi-morphic p.; vertic	2 Bwg	210	weat-hered	0.73	Redoxi-morphic p.; vertic
3 CBg	230+	weat-hered	0.31	Redoxi-morphic p.	2 Cbg	230+	weat-hered	0.35	Redoxi-morphic p.; vertic

The paleorelief is highly variable along the slope. It is formed by land use and small scale landslides. The four colluvial horizons of soil profile Fue4 (Tab. 4) show only small differences in color, coarse fragment content and soil structure. The SOC content averages 2.7 %. The dating of charcoal pieces (Erl-20271- 20272, Erl-20139-20140; Tab. 8, Fig. 4) indicate a rapid formation of colluvial deposits in the late Middle Ages to the early Modern Period. Profile Fue3 (Tab. 4) is typical for poorly drained downslope positions, having a thick colluvial cover with about 1.9 % SOC and a strong groundwater influence resulting in gleyic properties below 60 cm. Dating of one charcoal piece from the lowest horizon (2 MBrl2, 110 cm) indicates colluvial formation around 560 cal BCE (Erl-20138).

Tab. 4: Selected soil properties of Fue3 (left): Eutric Endogleyic Cambisol (Pantoclayic, Colluvic, Humic, Raptic) and Fue4 (right): Eutric Protic Colluvic Regosol (Pantoclayic, Humic, Raptic).

Horizon	**lower boundary [cm]**	**Substrate genesis**	**SOC [%]**	**further properties**	**Horizon**	**lower boundary [cm]**	**Substrate genesis**	**SOC [%]**	**further properties**
Ah	10	colluvial	4.00		Ah	10	colluvial/landslide	4.88	
M1	25	colluvial	2.75		Ap	25	colluvial/landslide	3.49	
M2	60	colluvial	2.30		M1	70	colluvial/landslide	2.54	
2 MBrl1	100	colluvial	1.54	15% pelites, redoximorphic features; gleyic	M2	100	colluvial/landslide	2.53	
2 MBrl2	170+	colluvial	1.06	Reductimorphic colors; gleyic	2 M3	115	colluvial/landslide	2.49	
					2 M4	140	colluvial/landslide	2.14	
					3 C	170+	weathered	1.23	

Spaichingen

Colluvial deposits near Spaichingen (Fig. 5) show a complex relief development with up to seven colluvial horizons (Spa2), which are not parallel to the present surface and do not show a continuous development along the slope. The boundary A indicates a changing paleorelief and intense land use or anthropogenic shaping from the younger Neolithic onwards (

Tab. 8). The catena shows that the thickness and number of colluvial horizons in the lower positions (auger Bs19-Bs12) are smaller compared to the soil profile Spa1. These sites are closer to the main drainage and next to a formerly open running drainage. In Spa1, an underground small creek was discovered at 2.2 m depth, which was buried by colluvial deposits already during the younger Neolithic (3950-3780 cal BCE, P 12878,
Tab. 8).

Recent land use is similar to Fuerstenberg, with crop cultivation (wheat) on the lower slope and pasture on the middle slope. The upslope is covered by mixed hardwood and coniferous forest. The soils are artificially drained, and the current influence of groundwater and interflow is limited to below 160 cm.

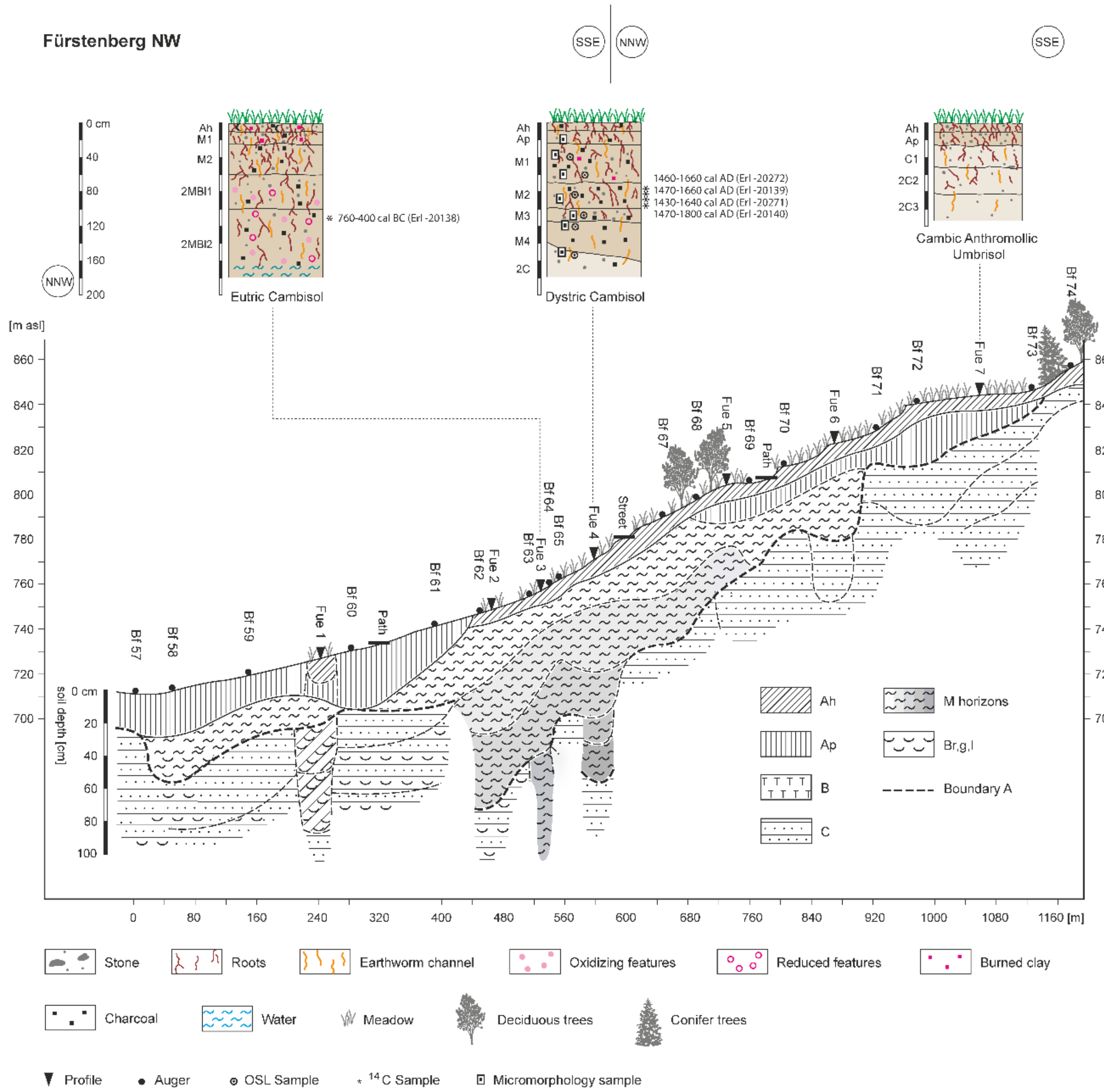

Fig. 4: Catena and soils on the NW slope of Fuerstenberg.

The soil profile Spa2 (Tab. 5) has eight colluvial horizons with an average SOC content of 1.6 %. The lower two colluvial horizons are influenced by steady interflow and capillary fringe-induced redoximorphic features (MBl1 and MBl2). Reduced features are evident below 70 cm and increase in number with depth until the saturated zone is reached at 115 cm. The 3 Cr horizon consists of coarse periglacial slope deposit. Spa3 shows a similar pedostratigraphy but fewer horizons are present.

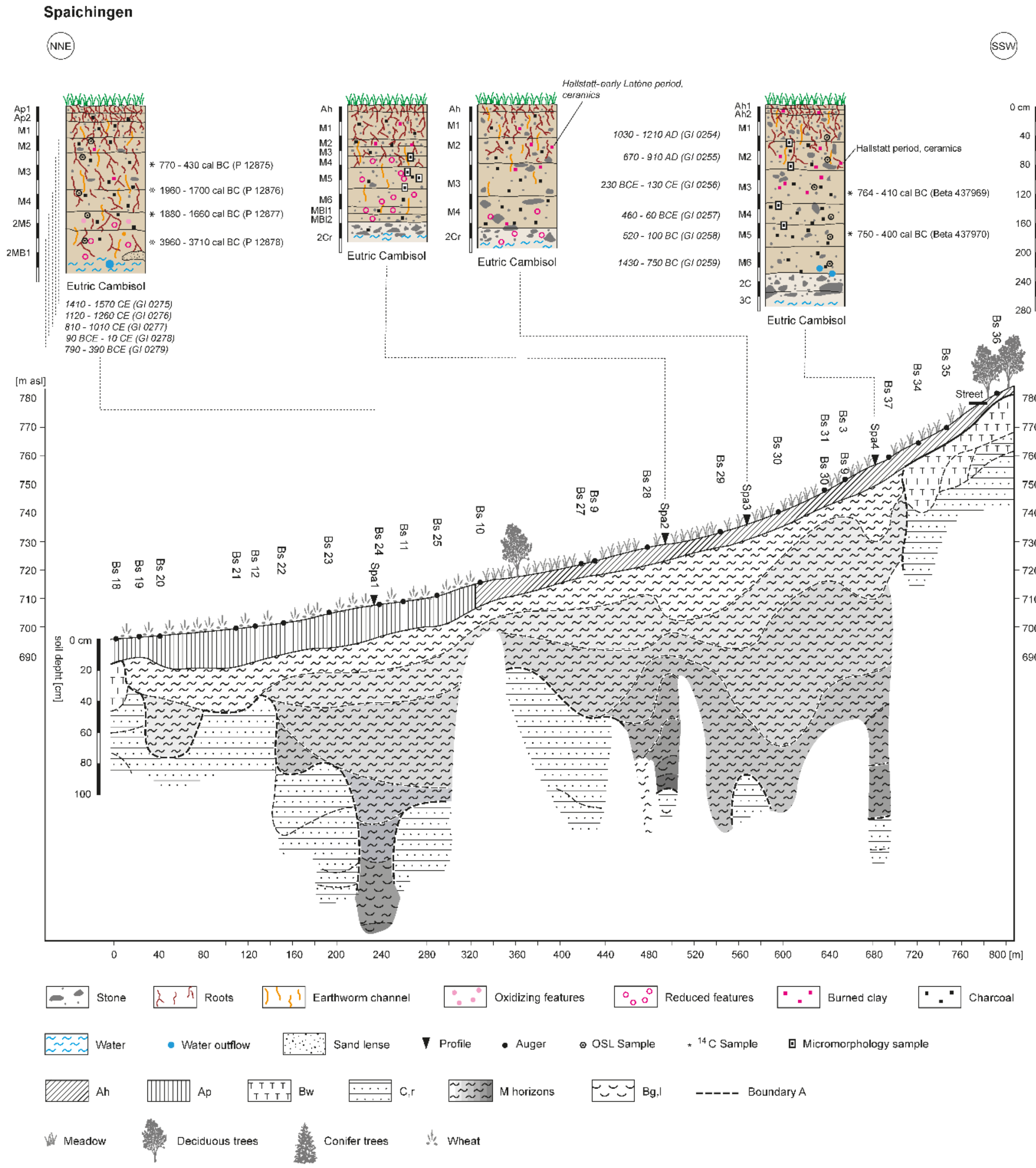

Fig. 5: Catena Spaichingen.

The finding of a sherd dating to the Hallstatt period at the base of the second colluvial horizon in Spa4 (Tab. 5) shows the relation between human activity and formation of colluvial deposits. The uppermost colluvial horizon (2 M1) of Spa4 can be dated to 1030-1210 CE (OSL dating, GI 0254), the underlying horizon also originates from the high Middle Ages (GI 0255). Both horizons contain 20-30 % limestones in contrast to the over- and underlying horizons. In addition to the sherd, two charcoal pieces were found in 120 and 176 cm depth (3 M3 and 3 M5) also dating to the Hallstatt period (Beta-437969, Beta-437970). The 3 M3 and 3 M5 horizons were dated to the Roman Empire and Iron Age (GI 0256, GI 0257). That means that an older sherd and charcoal pieces were incorporated into the colluvial deposit during Iron Age to Roman Empire. SOC content of colluvial horizons change minimally (~1.4 %), down to the 3 M6 horizon with 1.7 % SOC. This horizon can be dated to the Bronze Age (GI 0259). The slightly higher SOC content and the longer gap between the dates indicate a longer geomorphodynamic stable period. Colluvial material covers coarse periglacial slope deposits and loamy sediments without coarse fragments.

Tab. 5: Selected soil properties of Spa2 (left): Eutric Cambisol (Pantoclayic, Colluvic, Humic, Raptic, Bathyloamic) and Spa4 (right): Eutric Cambisol (Pantoclayic, Colluvic, Humic, Raptic).

Horizon	**lower boundary [cm]**	**Substrate genesis**	**SOC [%]**	**further properties**	**Horizon**	**lower boundary [cm]**	**Substrate genesis**	**SOC [%]**	**further properties**
Ah	10	colluvial	4.04		Ah1	5	colluvial	5.50	
2 M1	48	colluvial	2.31		Ah2	12	colluvial	5.12	
2 M2	58	colluvial	1.16		M1	50	colluvial	1.45	30% limestone
2 M3	70	colluvial	1.21		2 M2	88	colluvial	1.42	20% limestone
2 M4	86	colluvial	1.52	reductimorphic colors	3 M3	135	colluvial	1.46	
2 M5	115	colluvial	1.65	reductimorphic colors	3 M4	162	colluvial	1.37	
2 M6	140	colluvial	1.50	reductimorphic colors	3 M5	195	colluvial	1.46	
2 MBl1	150	colluvial	1.30	reductimorphic colors	3 M6	231	colluvial	1.69	
2 MBl2	160	colluvial	0.99		4 C	255	periglacial deposit	0.28	85% limestone
3 Cr	180+	periglacial deposit	0.39	75% limestone	5 C	265+	weathered	0.13	

Grueningen

The gently inclining south facing slope (2-5%, Fig. 6) is used for crops, the lower slope as grassland. The upper part resembles a small plateau on which Bronze Age ceramics were found (Knopf et al., 2015; Knopf and Seidensticker, 2013). Pedogenesis was dominated by weathering of limestone and loess, which were translocated by solifluidal processes under periglacial conditions during the last glacial period. The periglacial layers are covered by colluvial deposits. There are three colluvial horizons at the middle slope (auger GB3, Gru8_10) but only one on the lower slope (GB5, GB6). Colluvial accumulation differentiates again at the south facing bottom slope and in the depression (GB7, GB8). No colluvial material can be found on the north facing lower slope (GB9).

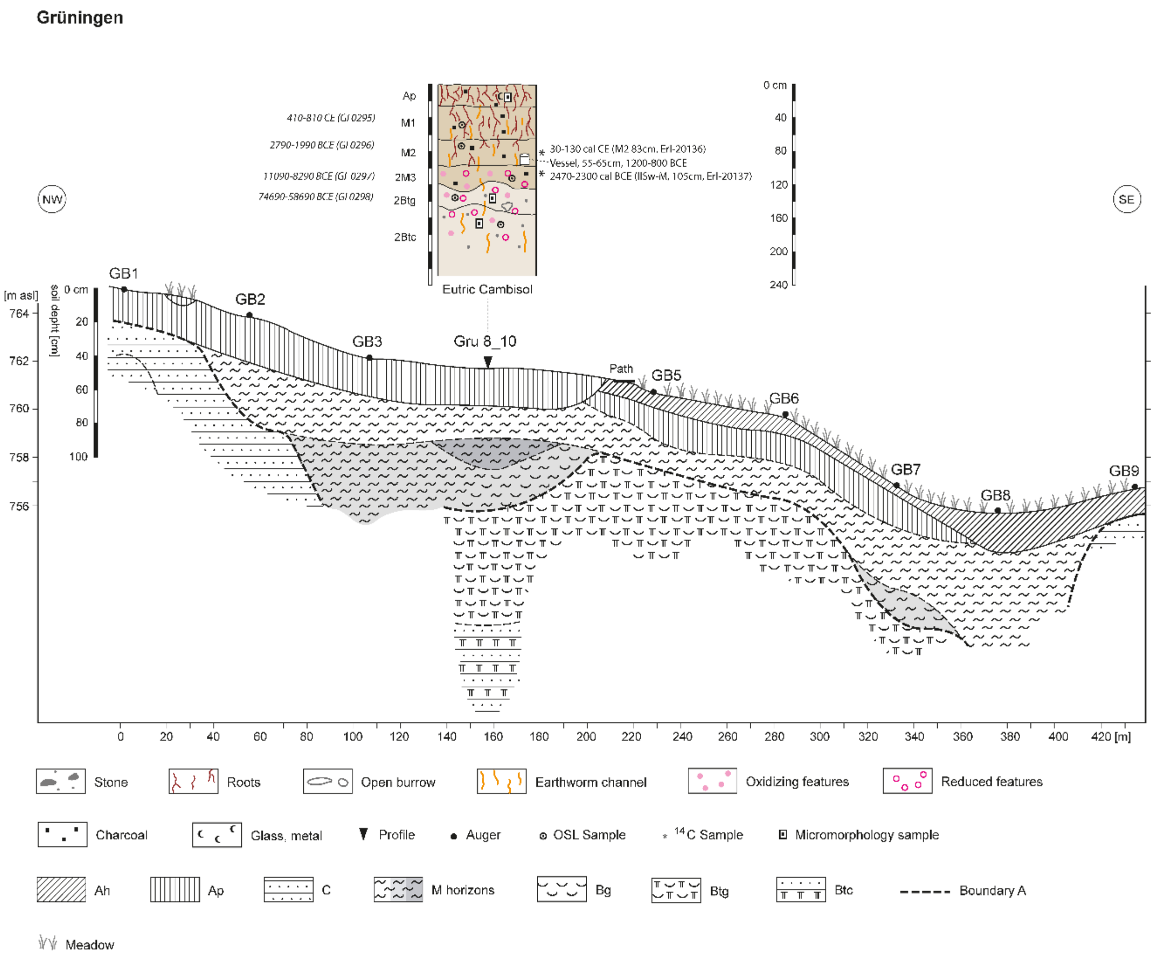

Fig. 6: Catena at Grueningen. The catena represents work done in 2010, the soil profile stems from 2014.

The soil profile Gru8 (Tab. 6) consists of three colluvial layers dating to 1040-1170 cal CE (MAMS 12275), the late Roman Empire (MAMS 12276), and the Bronze Age (MAMS 12277), pointing to continuous human habitation and land use since the Roman Empire. At the base of the second colluvial horizon (M2) two vessels were found. The smaller vessel was standing inside the bigger one. They date to the Urnfield period (Ahlrichs et al., 2017 submitted). Two divergent radiocarbon dates (MAMS 122277, Erl-20136) of the second horizon can be clarified by that age, because the horizon has to be older than the vessels. The charcoal yielding the younger age was most likely relocated by bioturbation. Therefore, this horizon is interpreted to have formed before 1620-1520 cal BCE (MAMS-12277). The complete soil profile shows redoximorphic features, and in the lower part, clay translocation. Redoximorphic features are particularly strong in the *in situ* soil horizon formed of periglacial loess-loam deposits.

Tab. 6: Selected soil properties of Gru8_14 (left): Eutric Cambisol (Geoabruptic, Aric, Colluvic, Endoloamic, Raptic, Siltic) and Gru9 (right): Endoskeletic Cambic Phaeozem (Anthric, Aric, Pantoclayic, Colluvic, Raptic).

Horizon	lower boundary [cm]	Substrate genesis	SOC [%]	further properties	Horizon	lower boundary [cm]	Substrate genesis	SOC [%]	further properties
Ap	25	colluvial	1.23		Ah	10	colluvial	3.41	
M1	65	colluvial	0.57		Ap	25	colluvial	2.83	
M2	96	colluvial	0.37		M1	50	colluvial	1.75	
2 M3	120	colluvial	0.33	redoximorphic features, Mg nodules	2 M2	85	colluvial	0.97	60% limestone
2 Btg	145	weathered	0.27	clay coatings, Mg nodules, redoximorphic features	3 M3	120	colluvial	0.84	
2 CBt	210+	weathered	0.17	clay coatings, Mg nodules, redoximorphic features	4 M4	160	colluvial	1.10	40% limestone rich
					5 M5	195	colluvial	0.63	
					6 Bw	210	weathered	0.36	20% limestones
					6 CBt	230+	weathered	0.56	60% limestone, clay coatings

Another soil profile (Gru9, Tab. 6) is located in a depression about 800 m to the east. The depression is filled with 2 m of organic matter-rich (1.3 % SOC) soil material. The profile consists of five dark brown colluvial horizons, including alternating limestone-rich layers. A radiocarbon age from 200 cm depth indicates the formation of the lowest colluvial horizon during the middle Bronze Age (Erl-20135). The limestone-rich layers are not dated, but the third colluvial horizon (3 M3) dates to the Roman Empire (Erl-20134) and the overlying first (M1) to early Modern Times (Erl-20133). Along the boundary of the depression about 2 m thick Luvisols were found. The surrounding catchment of the depression has a soil cover of about 20-30 cm thickness, with grassland used for hay.

3.2 Chronostratigraphy of colluvial deposits and archaeological finds

The AMS ^{14}C and luminescence ages (Tab. 7, Tab. 8, Fig. 7) complement the archaeological record (Tab. 1) of settlements and land use in the Baar area. Considering differences among the Baar sites, the formation of colluvial deposits at Magdalenenberg and Fuerstenberg began during the Neolithic. At Fuerstenberg, the deposition phases indicate land use in the younger to final Neolithic, middle Bronze Age, Iron Age, Roman Empire, and the transition of late Middle Ages to the early Modern Period (Fig. 7). The Magdalenenberg site has a gap in the colluvial stratigraphy from late Neolithic to high Middle Ages. In this case the excellent agreement of radiocarbon and OSL ages (GI0131, Erl-20132 and GI0130, Erl.20131, GI0129) provides a robust chronostratigraphy of the formation of colluvial deposits. The colluvial stratigraphy of Grueningen starts with the Bronze Age, with no signal in the Iron Age. The deposition of colluvial deposits at Spaichingen started in the Bronze Age and continued until the early Modern Times.

Tab. 7: OSL ages of colluvial deposits on the Baar. Age refers to the year of dating, rounded to 2010.

Lab code	Profile #	Horizon	Depth [cm]	De [Gy]	Age [ka ± 1 σ]	b2k [a ± 1 σ]	BCE/CE
GI0129	Mag 1_14	M1	30	2.33 ± 0.11	0.59 ± 0.05	580 ± 50	1370 - 1470 CE
GI0130	Mag 1_14	M1	47	2.97 ± 0.14	0.77 ± 0.07	760 ± 70	1170 - 1310 CE
GI0131	Mag 1_14	M2	62	25 ± 1.5	6.1 ± 0.6	6090 ± 600	4690 - 3490 BCE
GI0132	Mag 1_14	M2	69	30.5 ± 1.5	8.2 ± 0.8	8190 ± 800	6990 - 5390 BCE
GI0133	Mag 1_14	2 M4	75	40.6 ± 2	11.8 ± 1.2	11790 ± 1200	10990 - 8590 BCE
GI0179	Fue 8	M1	48	1.17 ± 0.08	0.31 ± 0.03	300 ± 30	1670 - 1730 CE
GI0180	Fue 8	M2	75	3.38 ± 0.1	0.89 ± 0.09	880 ± 90	1030 - 1210 CE
GI0181	Fue 8	M3	100	6.56 ± 0.22	2 ± 0.2	1990 ± 200	190 BCE - 210 CE
GI0182	Fue 8	M4	115	8.57 ± 0.35	2.8 ± 0.2	2790 ± 200	990 - 590 BCE
GI0183	Fue 8	M5	135	20.1 ± 0.9	6.9 ± 0.6	6890 ± 600	5490 - 4290 BCE
GI0184	Fue 8	M6	162	22.3 ± 0.7	6.5 ± 0.7	6490 ± 700	5190 - 3790 BCE
GI0247	Fue 9	M4	125	15.71 ± 0.54	5.26 ± 0.42	5250 ± 420	3670 - 2830 BCE
GI0248	Fue 9	M6	155	21.35 ± 0.96	6.61 ± 0.62	6600 ± 620	5220 - 3980 BCE
GI0254	Spa 4	M1	43	2.51 ± 0.19	0.89 ± 0.09	880 ± 90	1030 - 1210 CE
GI0255	Spa 4	2 M2	74	3.56 ± 0.17	1.22 ± 0.12	1210 ± 120	670 - 910 CE
GI0256	Spa 4	3 M3	112	6.09 ± 0.32	1.96 ± 0.18	1950 ± 180	130 BCE - 230 CE
GI0257	Spa 4	3 M4	154	7.28 ± 0.3	2.27 ± 0.2	2260 ± 200	460 - 60 BCE
GI0258	Spa 4	3 M5	180	7.68 ± 0.42	2.32 ± 0.21	2310 ± 210	520 - 100 BCE
GI0259	Spa 4	3 M6	218	9.95 ± 0.73	3.1 ± 0.34	3090 ± 340	1430 - 750 BCE
GI0275	Spa 1	M2	49	1.29 ± 0.17	0.52 ± 0.08	510 ± 80	1410 - 1570 CE
GI0276	Spa 1	M3	77	2.39 ± 0.09	0.82 ± 0.07	810 ± 70	1120 - 1260 CE

GI0277	Spa	1	M4	119	3.18 ± 0.13	1.1 ± 0.1	1090 ± 100	810 - 1010 CE
GI0278	Spa	1	2 M5	150	5.8 ± 0.2	2.2 ± 0.2	2190 ± 200	390 BCE - 10 CE
GI0279	Spa	1	2 MBl	183	7.62 ± 0.27	2.6 ± 0.2	2590 ± 200	790 - 390 BCE
GI0295	Gru	8_14	M1	48	4 ± 0.3	1.4 ± 0.2	1390 ± 200	410 - 810 CE
GI0296	Gru	8_14	M2	72	13.48 ± 0.66	4.4 ± 0.4	4390 ± 400	2790 - 1990 BCE
GI0297	Gru	8_14	2 M3	110	34.8 ± 3.22	11.7 ± 1.4	11690 ± 1400	11090 - 8290 BCE
GI0298	Gru	8_14	2 Btg	133	192.57 ± 16.55	68.7 ± 8	68690 ± 8000	74690 - 58690 BCE

Tab. 8: AMS ^{14}C ages of charcoal fragments from colluvial deposits on the Baar. Uncalibrated ages are given as BP [a before 1950] and ^{14}aN [‰]: Fraction of modern carbon (F14C), incl. normalization for $d^{13}C$ (Mook and van der Plicht, 1999; Reimer et al., 2004). Calibrated ages are given with 1σ (and 2σ) and rounded to 10 yr. Calibration was done with OxCal 4.2. 2016 and IntCal13.
° = excluded date, dated soil organic matter; *= excluded date.

Lab code	Profile #		Depth [cm]	Horizon	^{14}aN [‰]	$\delta^{13}C$ [‰]	BP [a ± error]	cal BCE/CE (1σ)	cal BCE/CE (2σ)	Median	cal BP (1σ)
Erl-20138	Fue	3	110	2 MBrl 2		-25.5	2443 ± 42	cal BCE 740-410	cal BCE 760-400	cal BCE 560	2690-2360
Erl-20139	Fue	4	80	M2		-26.7	310 ± 36	cal CE 1510-1650	cal CE 1470-1660	cal CE 1560	440-300
Erl-20271	Fue	4	85	M1		-24.5	384 ± 46	cal CE 1440-1620	cal CE 1430-1640	cal CE 1510	510-330
Erl-20140	Fue	4	95	M2		-24.8	293 ± 40	cal CE 1520-1650	cal CE 1470-1800	cal CE 1570	430-300
Erl-20272	Fue	4	70-80	M1		-27.5	311 ± 47	cal CE 1510-1650	cal CE 1460-1660	cal CE 1560	440-300
Erl-20144 °	Fue	8	100	M3		-25.3	2884 ± 36	cal BCE 1120-1000	cal BCE 1210-930	cal BCE 1060	3070-2950
Erl-20146 °	Fue	8	130	M5		-25.9	5105 ± 42	cal BCE 3970-3800	cal BCE 3980-3790	cal BCE 3870	5920-5750
Erl-20273	Fue	8	130-140	M4		-24.3	3369 ± 50	cal BCE 1750-1610	cal BCE 1870-1520	cal BCE 1660	3700-3560
Erl-20145 °	Fue	8	150-160	M6		-26.6	4417 ± 46	cal BCE 3270-2920	cal BCE 3340-2910	cal BCE 3060	5220-4870
Erl-20141 *	Fue	8	20-30	M1		-28.7	-562 ± 35	cal CE 1890-1910	cal CE 1890-1910	cal CE 1900	60-40
Erl-20142	Fue	8	50-60	M1-2		-23.9	325 ± 36	cal CE 1510-1640	cal CE 1470-1650	cal CE 1560	440-310
Erl-20143	Fue	8	75-80	M2		-25.2	627 ± 34	cal CE 1290-1400	cal CE 1280-1400	cal CE 1350	660-550
Erl-20276	Fue	9	90	M2		-25.6	4557 ± 67	cal BCE 3490-3100	cal BCE 3520-3020	cal BCE 3240	5440-5050

Erl-20277	Fue	9	115	M3		-25	4477 ± 58	cal BCE 3340-3030	cal BCE 3360-2930	cal BCE 3190	5290-4980
Erl-20278	Fue	9	135	M4		-27.7	6526 ± 66	cal BCE 5560-5380	cal BCE 5620-5360	cal BCE 5490	7510-7330
Erl-20280 *	Fue	9	195	2 Bwg		-25.7	10879 ± 92	cal BCE 10900-10740	cal BCE 11050-10710	cal BCE 10830	12850-12690
Erl-20279	Fue	9	150-170	M6		-25.5	7129 ± 67	cal BCE 6070-5920	cal BCE 6210-5840	cal BCE 6010	8020-7860
Erl-20275	Fue	9	60-70	M1		-25.3	3918 ± 61	cal BCE 2480-2290	cal BCE 2580-2200	cal BCE 2400	4430-4240
Erl-20147	Fue	10	85	M2		-25.3	655 ± 37	cal CE 1280-1390	cal CE 1270-1400	cal CE 1340	670-560
Erl-20274	Fue	10	87	M2		-27	1622 ± 158	cal CE 250-590	cal CE 50-690	cal CE 410	1700-1360
Erl-20149 °	Fue	10	127	Ahb2		-25	3855 ± 37	cal BCE 2460-2210	cal BCE 2470-2200	cal BCE 2330	4410-4160
Erl-20148 °	Fue	10	95-100	Ahb1		-27.9	2581 ± 36	cal BCE 810-760	cal BCE 820-550	cal BCE 780	2760-2710
Erl-20281	Fue	11	27	M1		-24.9	782 ± 61	cal 1290	cal CE 1040-1390	cal CE 1230	760-660
Erl-20282	Fue	11	65	M2		-25.5	382 ± 48	cal CE 1440-1630	cal CE 1440-1640	cal CE 1520	510-320
P 13415	Gei	2	88	2 MBg 2	0.697 ± 0.005		2899 ± 39	cal BCE 1200-1000	cal BCE 1260-920	cal BCE 1090	3150-2950
P 13418	Gei	2	144	3 MBg	0.603 ± 0.003		4070 ± 26	cal BCE 2840-2490	cal BCE 2860-2480	cal BCE 2620	4790-4440
Erl-20270 *	Gru	9	30	M1		-24.6	231 ± 45	cal CE 1630-…	cal CE 1510-…	cal CE 1730	320-…
Erl-20133	Gru	9	35	M1		-23.2	291 ± 32	cal CE 1520-1660	cal CE 1490-1670	cal CE 1570	430-290
Erl-20134	Gru	9	90	M3		-22.6	1950 ± 34	cal CE 1-90	cal BCE 40-cal CE 130	cal CE 50	1950-1860
Erl-20135	Gru	9	200	M6		-24.1	3251 ± 37	cal BCE 1610-1460	cal BCE 1620-1440	cal BCE 1530	3560-3410
MAMS 12275	Gru	8_10	40	M1		-18,7	909 ± 21	cal CE 1040-1170	cal CE 1030-1190	cal CE 1100	910-780
MAMS 12276	Gru	8_10	50	M2		-20,6	1569 ± 21	cal CE 420-540	cal CE 420-550	cal CE 480	1530-1410
MAMS 12277	Gru	8_10	72	2 M3		-23,7	3283 ± 25	cal BCE 1620-1520	CE 1190-cal BCE 1620-1500	cal BCE 1560	3560-3470

MAMS 12281 °	Gru	8_10	80-85	2 M3		-33.5	4061 ± 38	cal BCE 2840-2490	cal BCE 2860-2470	cal BCE 2600	4790-4440
Erl-20136	Gru	8_14	83	M2		-24.8	1918 ± 38	cal CE 30-130	cal CE 1-220	cal CE 90	1920-1820
Erl-20137	Gru	8_14	105	2 M3		-23.5	3889 ± 40	cal BCE 2470-2300	cal BCE 2480-2210	cal BCE 2380	4410-4250
Poz-36957	Mag	2	70	?			705 ± 30	cal CE 1260-1300	cal CE 1250-1390	cal CE 1280	690-650
Poz-36958	Mag	3	50	?			795 ± 30	cal CE 1220-1270	cal CE 1180-1280	cal CE 1240	730-680
Poz-36971 °	Mag	5	?	?			295 ± 30	cal CE 1520-1650	cal CE 1490-1660	cal CE 1570	430-300
Poz-36972 °	Mag	6	?	?			70 ± 35	cal CE 1690-1920	cal CE 1680-1930	cal CE 1850	260-30
Erl-20268 *	Mag	11	45	M1		-29.7	356 ± 975	cal CE 640-...	cal BCE 900-...	cal CE 1070	1310-...
Erl-20269 *	Mag	11	55	M2		-21.7	213 ± 53	cal CE 1640-...	cal CE 1520-...	cal CE 1760	310-...
Poz-36952	Mag	1_10	34	M1			635 ± 30	cal CE 1290-1390	cal CE 1280-1400	cal CE 1350	660-560
Poz-36953	Mag	1_10	49	M1			905 ± 30	cal CE 1040-1170	cal CE 1030-1210	cal CE 1110	910-780
Poz-36954	Mag	1_10	65	M2			4970 ± 40	cal BCE 3800-3690	cal BCE 3930-3650	cal BCE 3750	5740-5640
Poz-36955 °	Mag	1_10	?	?			1080 ± 30	cal CE 900-1000	cal CE 890-1020	cal CE 970	1050-950
Poz-36956 °	Mag	1_10	?	?			2170 ± 30	cal BCE 360-170	cal BCE 360-110	cal BCE 260	2310-2120
Erl-20131	Mag	1_14	25	M1		-25	746 ± 33	cal CE 1250-1290	cal CE 1220-1300	cal CE 1270	700-660
Erl-20132	Mag	1_14	75	2 M4		-25.2	5071 ± 51	cal BCE 3950-3800	cal BCE 3980-3710	cal BCE 3870	5900-5740
P 12875	Spa	1	80	M3	0.735 ± 0.003		2470 ± 22	cal BCE 760-530	cal BCE 770-430	cal BCE 630	2710-2480
P 12876	Spa	1	115	M3	0.646 ± 0.003		3510 ± 20	cal BCE 1890-1770	cal BCE 1930-1740	cal BCE 1830	3840-3720
P 12877	Spa	1	148	M5	0.652 ± 0.002		3437 ± 18	cal BCE 1860-1690	cal BCE 1880-1660	cal BCE 1740	3810-3630
P 12878	Spa	1	185	2 MBl	0.534 ± 0.002		5040 ± 18	cal BCE 3950-3780	cal BCE 3960-3710	cal BCE 3870	5890-5730

P 12879 *	Spa	4	112	3 M3	0.599 ± 0.002		4122 ± 19	cal BCE 2860-2620	cal BCE 2870-2570	cal BCE 2710	4810-4570
Beta-437969	Spa	4	120	3 M3	0.737 ± 0.003	-27	2450 ± 30	cal BCE 750-430	cal BCE 760-410	cal BCE 580	2700-2370
P 13413	Spa	4	120	3 M3	0.724 ± 0.004		2592 ± 31	cal BCE 820-670	cal BCE 840-540	cal BCE 780	2770-2620
P 12880 *	Spa	4	127	3 M3	0.631 ± 0.002		3696 ± 18	cal BCE 2140-2030	cal BCE 2200-1980	cal BCE 2090	4090-3980
P 12881 *	Spa	4	155	3 M4	0.585 ± 0.002		4307 ± 18	cal BCE 2930-2880	cal BCE 3020-2880	cal BCE 2910	4880-4830
Beta-437970	Spa	4	176	3 M5	0.739 ± 0.003	-23.3	2430 ± 30	cal BCE 730-410	cal BCE 750-400	cal BCE 510	2680-2360
P 12882 *	Spa	4	184	3 M5	0.551 ± 0.002		4791 ± 19	cal BCE 3640-3530	cal BCE 3650-3510	cal BCE 3570	5590-5470
P 12883 *	Spa	4	218	3 M6	0.496 ± 0.002		5631 ± 18	cal BCE 4510-4370	cal BCE 4540-4360	cal BCE 4460	6460-6320
P 12884 *	Spa	4	232	3 M6	0.535 ± 0.002		5032 ± 17	cal BCE 3940-3770	cal BCE 3950-3710	cal BCE 3860	5890-5720

The archaeological record of land use and settlements starts with Mesolithic finds at the Magdalenenberg site (Schmid, 1991, 1992). Neolithic artifacts were found at Magdalenenberg, Spaichingen and Fuerstenberg (Nübling, 1990; Schmid, 1991, 1992). Datings from these three sites yield a better chronological differentiation of time periods with intense land use than the discovered archaeological finds do. There is no archaeological evidence for human presence at the study sites during the early Bronze Age. In Grueningen, colluviation occurred earlier than known from the archaeological findings, indicating human presence as early as the middle Bronze Age. Many archaeological sites, including the Magdalenenberg, the largest burial mound in central Europe from 616 BCE (Knopf et al., 2015; Knopf and Seidensticker, 2013; Spindler, 2004), are known in the western Baar, but, no colluvial deposits date to the Hallstatt period. Colluviation dating to the Hallstatt period took place only in the eastern and southern Baar. Radiocarbon ages from Grueningen point to land use from the Roman Empire onwards. Samples dating to the Middle Ages correlate well with historical records. The town of Villingen, next to the Magdalenenberg site, was first mentioned in the written record around 800 CE (Jenisch et al., 1999).

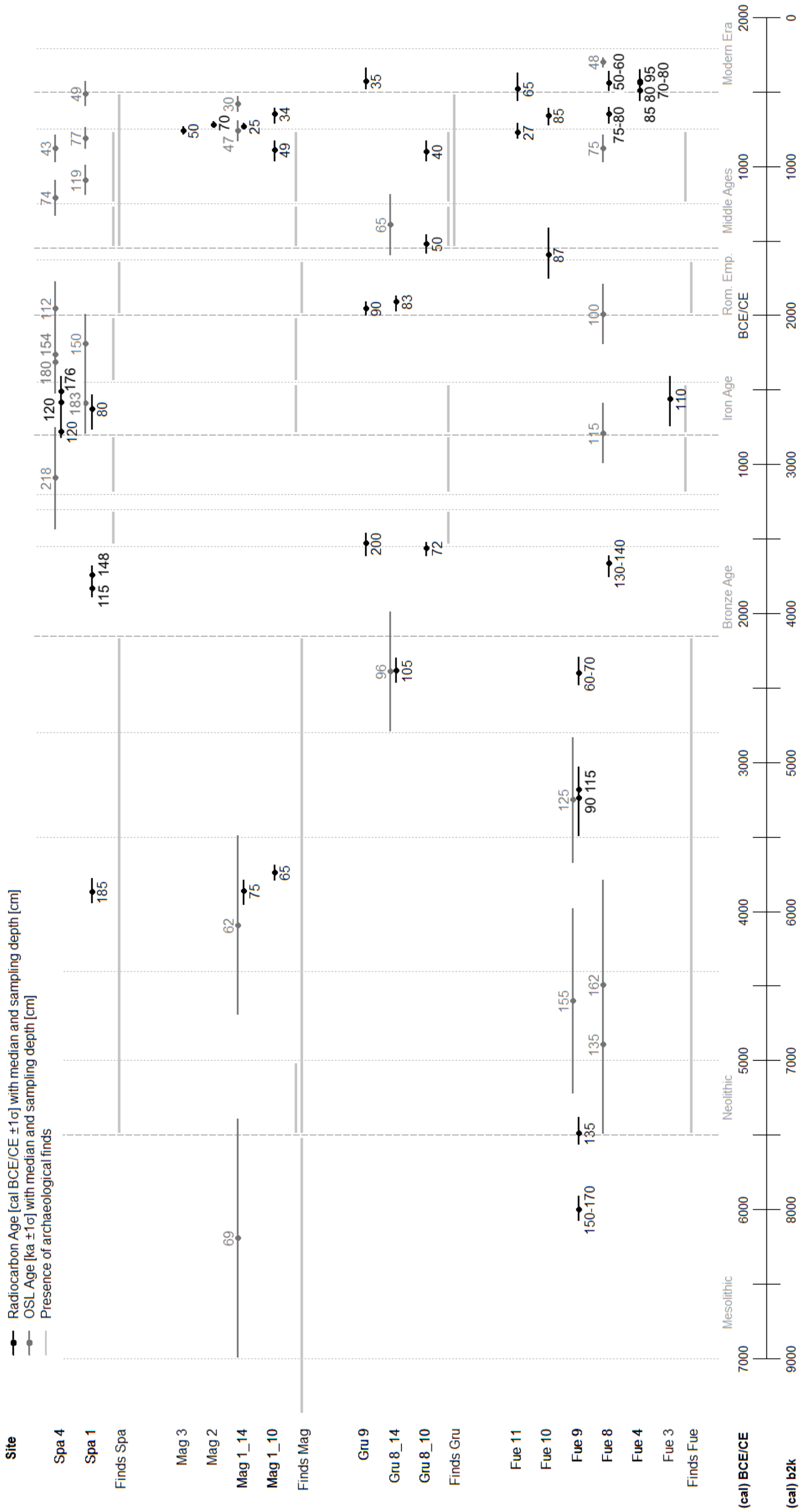

Fig. 7: AMS 14C and OSL ages of colluvial deposits across the Baar compared to known archaeological finds at each site from the Mesolithic to Middle Ages.

The town of Fuerstenberg existed on the plateau above the slopes studied here from at least 1175 until 1841 CE (Wagner, 2014). The AMS ^{14}C dates of charcoal samples from Grueningen can also be correlated with historical records of the nearby village of Grueningen, which according to historical records existed from 1139 CE onwards (Badische Historische Kommission, 1904b). Dates from Spaichingen also agree with known archaeological sites (Buchta-Hohm, 1996; Paret, 1932; Stoll and Gehring, 1938).

The summed probability density (SPD) curves show peaks along a time axis of increased probability of dates from a specific time (Fig. 8). These dates are interpreted as being connected to colluviation. The peaks of the SPD curve of OSL ages decrease and widen with older ages, because of their wider error estimates. The OSL SPD shows an increase of dates in the middle to younger Neolithic in samples from the Magdalenenberg and Fuerstenberg site. The following peak around 500 CE comprises dates from Fuerstenberg and Spaichingen. This peak is higher and narrower than the preceding ones. The pronounced depression falls in the Migration and Merovingian period. Increased probability in the high and late Middle Ages is evident at all sites except Grueningen). Radiocarbon dates result in narrower and therefore higher SPD peaks. The oldest peak dates to the late Mesolithic at the Fuerstenberg. There are several pronounced individual peaks from the late Neolithic onwards, and they originate from the samples at Fuerstenberg, Grueningen and Spaichingen. The Magdalenenberg dates appear only in the younger Neolithic and the high-to-late Middle Ages. The increased probability of dates in the Middle Ages counts for all of the sites except Spaichingen, where only older charcoal was found.

4 Discussion

4.1 Main phases of formation of colluvial deposits across the Baar

Colluvial deposits present a high resolution spatial archive of the land use history of the area upslope, from which the material was eroded (Bettis, 2003; Emadodin et al., 2011; Leopold and Völkel, 2007a). The application of the catena concept at several sites provides 13 representative, well-stratified soil profiles for dating and further analysis.

Intensive land use seems to have started in the south and northwest of the Baar, since the oldest colluvial ages stem from the sites at Fuerstenberg and Magdalenenberg (Fig. 7, Tab. 7, Tab. 8). Based on a uniformitarian perspective, assuming that general climate differences within the region did not change during the Holocene, the earlier onset of permanent land use (most likely agriculture) might be explained by higher temperatures and fewer frost days compared to other parts of the Baar.

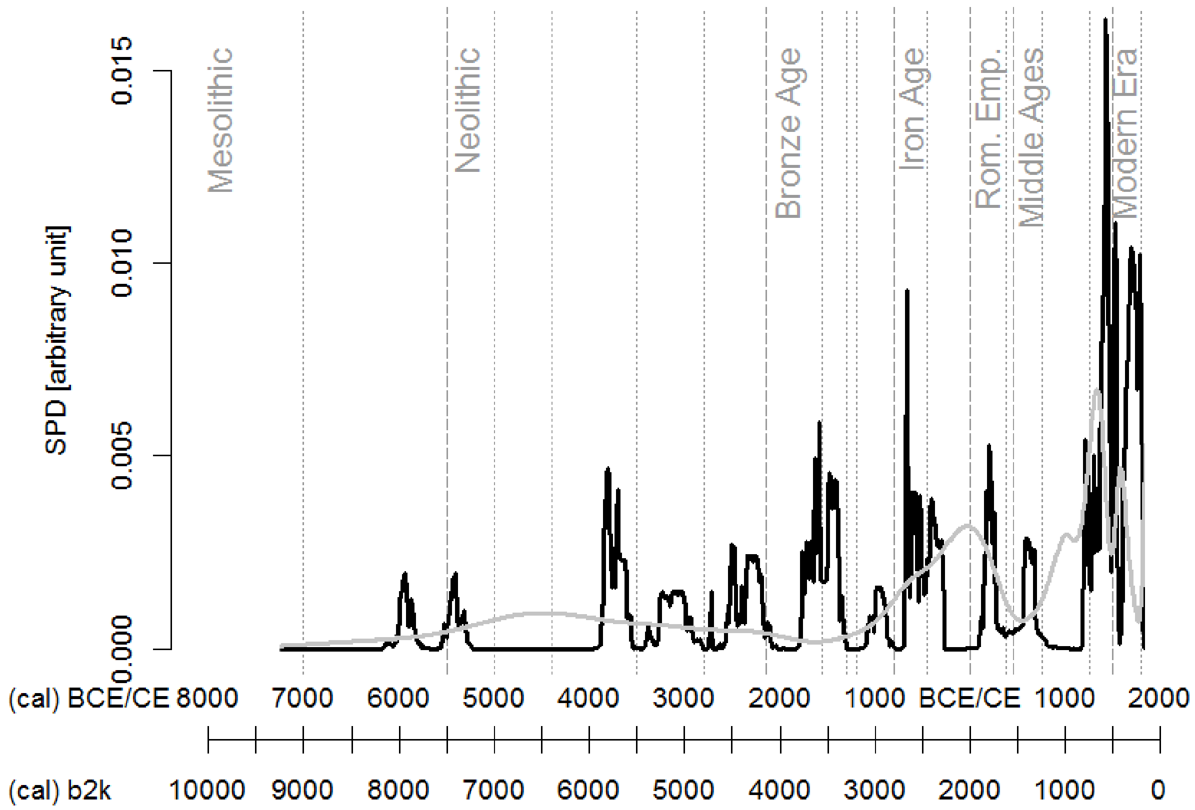

Fig. 8: Summed probability density (SPD) curves of ages from anthropogenic soil-erosion derived colluvial deposits. Grey line: OSL data (n=28), black line: AMS14C data (n=41).

Summing up the SPDs of radiocarbon and luminescence ages, seven main phases of increased probability of colluviation can be differentiated as distinct maxima from several secondary peaks with lower probability (Fig. 9). The oldest peak dates to around 3800 cal BCE, i.e. the younger Neolithic (1), and is followed by smaller peaks of increased probability for colluvial formation during the late Neolithic to early Bronze Age. Temporary sediment sinks on slopes can accumulate colluvial deposit for a certain time before the material is eroded and transported further downslope, thereby resetting the physical signal for OSL dating which results in a younger age. This is known as the cascade model of colluvial formation, which might be an explanation for the minimal available information about Neolithic colluvial deposits (Lang and Hönscheidt, 1999). Increased colluviation is calculated for the middle Bronze Age (2) and Latène Period (3). The main deposition phase (4) around 100 CE is connected to the Romans and their land use.

The following Migration period shows decreased colluviation. From the high Middle Ages onwards the probability of colluvial formation is doubled. Colluviation increases even more to the end of the high Middle Ages (5) and around 1300 (6) and 1600 cal CE (7).

In southern Baden, west of the Black Forest, Mäckel et al. (2002) found a similar colluviation sequence. During the early and middle Bronze Age, colluviation increased, which might be explained by a major increase in the area of open land during the transition from the Neolithic to the Bronze Age (Mäckel et al., 2003). This is in accordance with the presented SPD curve showing increasing colluviation in the Bronze Age. The increased colluviation can be interpreted as increased land use intensity, which often starts with deforestation. The phase of higher colluviation is followed by a decrease and a subsequent increase until Roman times. During the Migration period little colluviation occurred. Colluviation increases again from the Middle Ages to Modern Times.

A study from southern Germany, including the Baar, used 60 OSL ages and found three phases of increased soil erosion derived colluviation (Lang, 2003). These phases are in the Latène Period (2.1 ka) and the high Middle Ages (1.2 ka and 0.9 ka). Further minor peaks occur in the Urnfield Period, the final Neolithic and the early to middle Neolithic. The comparison shows that the increased colluviation probability in loess hills is different from the probability presented in this study. This might be explained by different land use dynamics with time and the properties of the soils. Hoffmann et al. (2008) studied phases of increased geomorphic stability and activity of different sediments in Germany and came up with phases of increased relative probability for geomorphologic activity dating to exactly the same time periods as the colluviation phases on the Baar.

4.2 Possible causes for the main phases of colluviation

Precipitation, topography, vegetative cover, plant species, and soil properties determine the general likelihood of soil erosion, but the most important factor is land use as influenced by and interacting with the above environmental aspects. Important elements of agrarian land use are tillage, field size and crop rotation (c.f. Bork, 1989); further human impact originates from deforestation for hunting, grazing, building of infrastructure, mining, or charcoal production.

The characteristics and ages of several colluvial deposits point to varying land use patterns since the Neolithic. At the Fuerstenberg and Magdalenenberg sites, the colluvial signal starts with the Neolithic, whereas in Spaichingen and Grueningen the oldest ages point to a human influence from the Bronze Age onwards. The type of land use cannot be determined from the occurrence of colluvial deposits alone, but it seems most likely that is was agrarian land use after deforestation, since there is no evidence of other land use activities like deforestation for hunting, grazing, building of infrastructure, mining, or charcoal production. The colluvial deposits contain only some ceramic sherds and charcoal pieces are not layered, but occur randomly distributed within soil horizons. This points to the sites being used for agriculture rather than as a settlement area (Häbich, 2009). The widely spread multilayered thick colluvial deposits containing only a few artifacts/ceramics, cannot be explained without invoking the presence and activity of humans increasing soil erosion. The simple differentiation between natural and anthropogenic processes causing colluviation based on the absence or presence of artifacts (Mäckel et al., 2003) cannot be adopted here.

A helpful concept is the *boundary A* by Edgeworth et al. (2015), which separates the natural ground surface from the human-modified soil profile or sediment stratigraphy. The boundary A in the soil profiles of the Baar region marks the transition between *in situ* soil with little or no human influence and the colluvial deposits (Fig. 2 to Fig. 6). Thus it gives an impression of the paleorelief, not considering later soil erosion of the colluvial material. It also illustrates the dimensions of the formative forces of humans on the landscape.

To illustrate the discussion of the potential causes of the identified seven main phases of colluvial deposition we compiled the key information in Figure 9.

The oldest main colluviation phase (1) falls in a wetter and colder period of the younger Neolithic (Haas et al., 1998; Jäger, 2002; Negendank, 2004). Therefore, the peak indicating higher colluvial deposition can be explained by higher erosion due to higher precipitation. ^{14}C production rates point to variable solar activity reaching a local minimum during that time. Lower ^{14}C production rates are often correlated with colder temperatures and higher amounts of ice raft debris in the northern hemisphere (Engels and van Geel, 2012; Kromer and Friedrich, 2007). Despite some reconstructions pointing to colder climate, alpine and continental glaciers did not advance (Koch and Clague, 2006). Climate reconstruction from the NGRIP GICC05 shows no

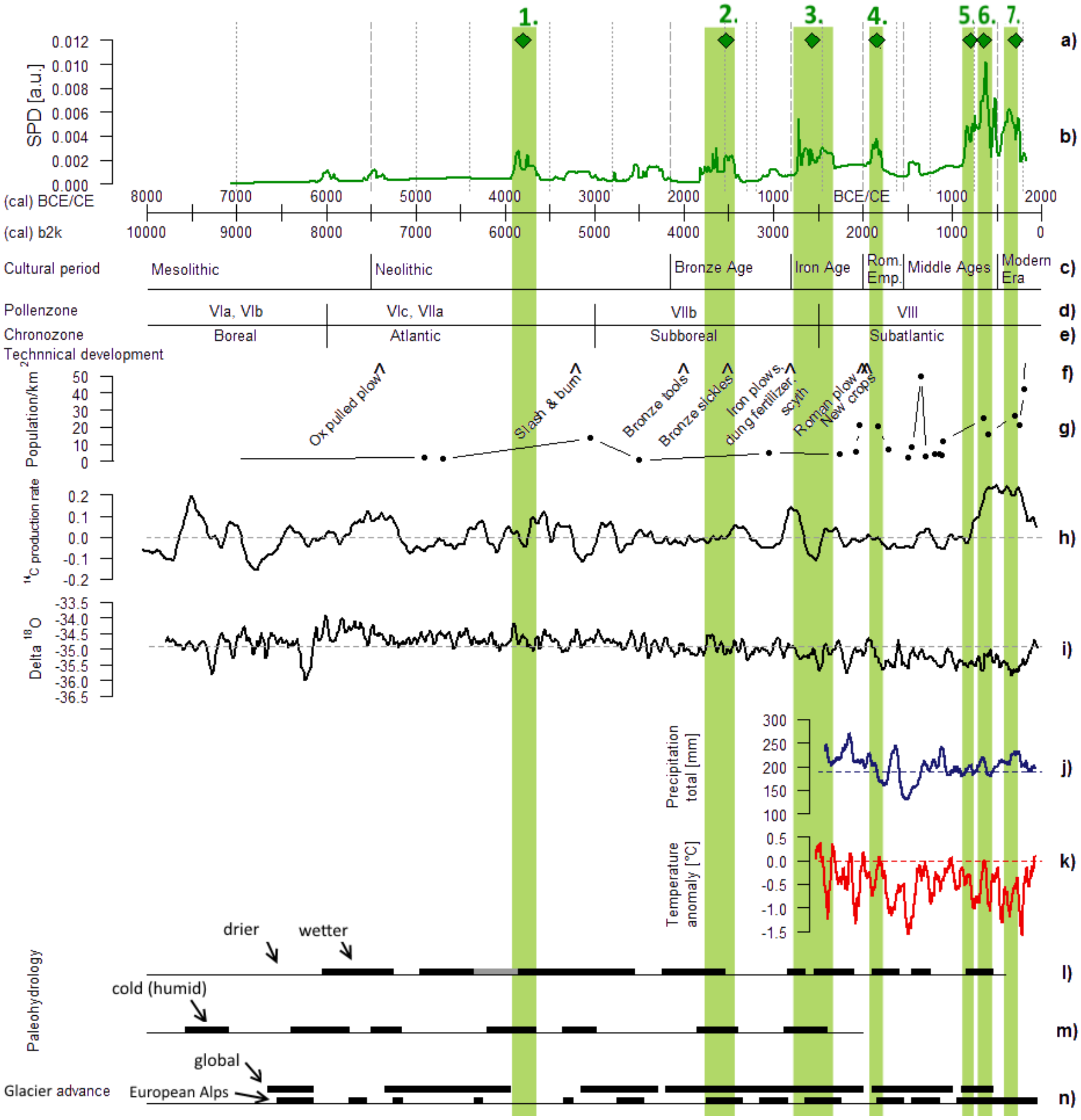

Fig. 9: Main colluviation phases of the Baar compared to paleoenvironmental data. a) Seven main colluviation phases; b) Combined SPD of radiocarbon and OSL ages from the Baar; c) Cultural periods in South Germany; d) Jesse-Godwin pollenzones after Godwin, 1975 in Anderson et al. (2007); e) Chronozones after Mangerud et al. 1975 in Anderson et al. (2007); f) Technical innovations (Lal et al., 2007; Tinner et al., 2003); g) Population density in central Europe (Henning, 1994; Zimmermann, 1996); h) Anomalies of atmospheric 14C production rates compared to the mean (Kromer and Friedrich, 2007); i) δ 18 O [‰] record from NGRIP1, 100 year means compared to the mean of all δ 18 O values (GICC05, NGRIP Members, 2004; Vinther et al., 2006); j) Tree ring based reconstruction of precipitation from April to June in central Europe with respect to the 1901-2001 period (dashed line), 50 year means of yearly data (Büntgen et al., 2011); k) Tree ring based reconstruction of summer (June-August) temperature anomalies in central Europe with respect to 1990-2000, 50 year means of yearly data (Büntgen et al., 2011); l) Wet phases in central Europe (Jäger, 2002); m) Cold and humid phases in central Europe until 2000 BP (Haas et al., 1998); n) Glacial fluctuations during the Holocene (Koch and Clague, 2006).

clear pattern of δ ^{18}O during that time (NGRIP Members, 2004). Nevertheless, despite the above mentioned factors, the onset of sedentism and agriculture seems to be the most likely trigger for colluviation. The first evidence of agriculture in the region stems from cereal pollen from the late Atlantic period (about 4850-3150 cal BCE). These cereal pollen were found in bogs just north of the study area and in the Black Forest: hazel (*Corylus avellana*), birch (*Betula*) and pine (*Pinus*) pollen increased and fungi of wheat (*Triticum L.*), rye (*Secale cereale*) or barley (*Hordeum vulgare*) appeared at the same time (Rösch, 2000). Results from dendrochronological studies date the beginning of the anthropogenic influence on the environment to 2700 BCE or even 4000 BCE (Kromer and Friedrich, 2007), the latter date strengthens the connection between human activities and the increased colluviation occurring in the younger Neolithic.

The second main depositional phase (2) from the early to middle Bronze Age falls in the final phase of a cold and humid period (Haas et al., 1998; Negendank, 2004; Schönwiese, 1995). Lake levels were low (Magny et al., 2003) and glaciers advanced in the European Alps (Koch and Clague, 2006). The advance of glaciers can be taken as an indicator for longer cold and wet periods. The ^{14}C production rates show an indifferent to positive trend during the time period (Kromer and Friedrich, 2007). This supports a climate change to a warmer and drier state. Population density was still very low and may not have had an influence on colluviation during this period, but the development of ards, bronze tools, and pulled plows seem to increase the sensitivity of soils at gentle rolling hills to erosion and colluvial deposition (Lal et al., 2007; Teuber et al., 2017 [submitted]; Tinner et al., 2003). This development in agricultural techniques may have intensified the formation of colluvial deposits. This phase of increased colluviation ends with the beginning of a dry period around 1400 CE (Haas et al., 1998; Jäger, 2002; Schönwiese, 1995). The luminescence ages clearly point to an increased base level of colluviation from that period onwards (approx. 1000 BCE-250 CE).

The increased probability of colluviation during the Iron Age (3) results from the data of the eastern and southern Baar and falls in a cold and humid phase (Haas et al., 1998; Jäger, 2002; Schönwiese, 1995) with decreasing land use intensity (Dotterweich, 2008), advancing Swiss glaciers (Glaser et al., 2005; Koch and Clague, 2006), low ^{14}C production rates (Kromer and Friedrich, 2007) and δ ^{18}O levels (NGRIP Members, 2004). Climate reconstruction from pollen points to a strong decrease of summer temperatures during that phase, but also lower summer precipitation (Büntgen et al., 2011). This rather unfavorable climate might have resulted in the formation of spatially different intensities of colluvial deposit development. During the Iron Age, smelting of iron ore may have been a likely land use consuming much wood or charcoal, if mined and refined in the region. This technology would have been used in kilns at local spots, rather than on a wider landscape, leading to deforestation but not necessarily to charcoal deposition in soils. Dotterweich (2008) assumes lower percentages of fields and grasslands compared to woodlands and forests during that time, which could strengthen the idea of naturally occurring small forest fires or deforestation for smelting as a source of the few charcoals in the western Baar. Colluviation seems to have taken place in Spaichingen in particular and marginally in Fuerstenberg, but no Iron Age datings could be obtained from the western Baar so far.

The colluviation phase (4) during the Roman Empire (around 100 CE) is also reported in other studies and areas (James et al., 2014; van der Leeuw and The ARCHAEOMEDES research team, 2005). This is the only phase falling into a rather dry and warm period, the so called Roman optimum (Büntgen et al., 2011; Haas et al., 1998; Schönwiese, 1995). The increased probability of colluviation can be correlated with Roman progress in agricultural techniques, improving settlement infrastructure (van der Leeuw and The ARCHAEOMEDES research team, 2005), increasing population (Zimmermann, 1996), the use of limestone to make cement, and higher land use intensity (Dotterweich, 2008; Jäger, 1994). Contradictory to a warming climate, Jäger (2002) reconstructed a wet phase, and Koch and Clague (2006) suggested glacier advance in the European Alps. Those differences might be due to local climatic phenomena. The following climate pessimum and the decline of population density during Migration time (Zimmermann, 1996) led to decreased colluviation across the Baar.

A minor peak of increased colluviation in the Merovingian Period is coeval with the population density peak, which is otherwise not clearly mirrored in the colluvial stratigraphy. Zimmermann (1996) offers corrections to population density for that time, which could point to a wide range of population density across the area, leading to large differences on a small spatial scale. This might support the observation that the highest population density (up to that time) only led to a minor increase of colluviation (around 600 CE) at the investigated sites.

Toward the end of the high Middle Ages (5) colluviation increased strongly and led to a doubled probability of the formation of colluvia from then onwards, which agrees with elevated population density (Zimmermann, 1996) and increased soil erosion (Bork, 1989). Human influence during the Medieval Climate Optimum in the high Middle Ages is visible in the OSL SPD and also in the vegetation record. Near the Magdalenenberg site, walnut (*Juglans regia*) remains and pollen were found (Rösch, 1999), which indicate relatively high temperatures or possibly trade connections to a region, where walnut trees grew naturally.

Heavy rainfall events and intensive land use for agriculture are supposed to have been the main triggers for soil erosion and formation of colluvial deposits around 1300 CE in central Europe (Bork, 1998; Dotterweich, 2008; Dotterweich and Dreibrodt, 2011), when additionally, the area of arable land reached a local high (James, 2013; Lang et al., 2003). Catastrophic events (e.g. heavy rainfall and flooding, drought, war, epidemic diseases) seem to have had a major shaping impact on landscapes (Dotterweich and Dreibrodt, 2011). Precipitation reconstruction shows an increase (Büntgen et al., 2011; Jäger, 2002) and temperatures reconstructed from trees dropped (Büntgen et al., 2011). ^{14}C production rates increase from the high Middle Ages to the Modern Era (Kromer and Friedrich, 2007), but that is hardly reflected in climate parameters. Only about 100 years later in the late Middle Ages, the area covered by forests reached a local peak, but forest was then continuously reduced in favor of agricultural land (Dotterweich, 2008; Jäger, 1994; James, 2013). From the Middle Ages onwards, continuous agricultural land use can be shown through pollen analysis; mainly rye *(Secale cereale)*, wheat *(Triticum aestivum),* spelt *(Triticum spelta)*, and hemp *(Cannabis sativa)* were grown across the Baar (Sudhaus, 2005).

Increased probable colluviation around 1300 cal CE (6) and 1600 cal CE (7) follows increasing and rapidly declining population density (Henning, 1994). Human population declines in the cold and wet period of the beginning of and later during the pronounced Little Ice Age (Jäger, 2002; Schönwiese, 1995) with advancing glaciers in the Alps (Glaser et al., 2005; Koch and Clague, 2006) and high lake levels (Magny et al., 2003). But despite the unfavorable climatic conditions, agricultural land use (fields and grassland) reached a peak in the late Middle Ages (Dotterweich, 2008; Jäger, 1994). The increased colluviation might be explained by the need for further intensification of land use and increasing plowing depth for higher yields (Benecke et al., 2003; Dreibrodt et al., 2010a; Lang and Hönscheidt, 1999). This shows that environmental factors as triggers for soil erosion and the formation of colluvial deposits became less important. Human presence and agricultural techniques become more and more important and progressively control slope processes (Hoffmann et al., 2008; Hudson et al., 2015; Kaplan et al., 2009; Verstraeten et al., 2009; Zolitschka et al., 2003).

5 Synthesis

Colder humid phases, in general, seem to be correlated with higher accumulation of colluvial material. In the southern and western Baar the oldest colluvial deposits date to the beginning of the Neolithic. In the eastern Baar and on top of a plateau, human influence is detectable from the Bronze Age onward. SPDs show main depositional phases for the Baar region in the younger Neolithic, the early to middle Bronze Age, the Iron Age, Roman Empire and from the high Middle Ages onwards. But colluviation is not a linear process, but is based on erosion and intermediate storage of soil material on slopes (Fuchs and Lang, 2009), so that the main deposition times found here have to be seen as an approximation of periods with increased human activities. We demonstrated that a number of variables, particularly climate, population density, and land use control soil erosion and accumulation from the Neolithic to Iron Age. During that time, reconstructions of climate parameters point to climate being the main controlling factor and population density and land use being indirect factors.

From the Roman Period onward, human activities are the main drivers of soil erosion and thus for the formation of colluvial deposits. The sensitivity of landscapes to erosion is mainly controlled by land use, since land use disturbs the vegetation cover and loosens the soil, thereby making soils, especially on slopes, prone to soil erosion. Climate and population pressure are indirect factors forcing changes in the intensity and kind of land use (Lang, 2003; Zolitschka, 2002; Zolitschka et al., 2003). In this context rainfall finally triggers soil erosion. Therefore the formation of colluvial deposits can be seen as a pseudo-natural (Häbich, 2009) or quasi-natural process (Rathjens, 1979) because it results from anthropogenic actions, but the process itself is natural.

6 Conclusions

Analyzing multilayered colluvial deposits in the vicinity of archaeological finds adds human activities and their influence on landscapes to the reconstruction of geomorphodynamic (un)stable periods. Phases of geomorphodynamic instability can be correlated with the phases of formation of colluvial deposits. We conclude that colluvial deposits can be used as a local proxy with a high spatial resolution regarding land use. However, to go from a local to a more general signal for a region a comparative evaluation of the local colluvial information is necessary to extrapolate colluvial deposition phases, possible driving forces, and human activities to a broader region. Thus, based on the colluvial chronostratigraphy of the four investigated sites on the Baar and including archaeological and paleoenvironmental information the general land use history of the Baar can be reconstructed.

Archaeopedological analyses of 26 soil profiles (with 130 colluvial layers) including 69 OSL and AMS ^{14}C ages of sediments and charcoal fragments demonstrated that colluvial deposits, in combination with other archaeological and environmental data, can be used as a regional proxy for inferring land use on the Baar. The main findings lead to the following conclusions:

- Multilayered colluvial deposits can be found even at upper slope and mid-slope positions, caused by the unknown palaeorelief and the site-specific land use history.
- Pedological and chronological data create a more accurate picture of past human activities, and they complement archaeological knowledge about settlements and human activities in a region.
- Main depositional phases are reconstructed from site specific pedo- and chronostratigraphies. In the southern and western area of the Baar the formative element of human activities on landscapes started with the beginning of the Neolithic. In the eastern Baar and on a plateau in the western Baar, human influence is detectable particularly from the Bronze Age onward.
- SPDs show main depositional phases for the Baar region in the younger Neolithic, the early to middle Bronze Age, the Iron Age, the Roman Empire, and from the high and late Middle Ages onwards. This points to land use change and more intense land use on the Baar in different time periods.
- The increased colluviation probability of the Baar region is different to the probability of gentle rolling loess regions. This might be explained by different land use dynamics with time and soil material and different paleoenvironmental conditions.

- The correlation of SPDs with other environmental variables, like paleoclimate, shows that most phases of intensified colluviation occur in periods with higher precipitation and lower temperatures.
- Additionally, colluviation seems to follow population density, as shown for the Roman Empire and the Migration periods. This points to a coupled influence of climate and humans controlling colluviation, at least from the Romans onward when population reached a certain threshold.
- Colluvial deposits do not indicate the activity of foraging societies, since colluviation needs time and intense land use to manifest human activity. The onset of colluviation in the Neolithic fortifies the early anthropogenic hypothesis and the influence of human induced land use change on soil erosion and accumulation and thereby landscape change.

Our results show that the integrated application of archaeological, pedological, and paleoenvironmental analyses and knowledge, i.e. archaeopedology, helps to get a better understanding of regional land use patterns in time and space. Regional archaeopedological analyses display the human potential to change and modify landscapes, and demonstrate this as early as prehistoric times.

Author contribution

Jessica Henkner, Peter Kühn, Thomas Scholten, Thomas Knopf and Jan Ahlrichs designed the study and JH carried it out. JH prepared the manuscript with contributions from all co-authors. Markus Fuchs was responsible for OSL dating. Sean Downey contributed the script to calculate the SPDs and helped with the interpretation. Bruce James and Sandra Teuber contributed particularly to the interpretation and discussion of the results.

Acknowledgements

This study is part of the Collaborative Research Center 1070 ResourceCultures (SFB1070) financed by the German Research Foundation (DFG). The study was also supported by the Graduate School of the University of Maryland, College Park and the Institutional Strategy of the University of Tübingen (DFG, ZUK 63).

We are grateful to many student helpers and technical assistants from the Tübingen University, who worked in the field and the lab, especially Christoph Behnke, Dominik Birkenmaier and Rita Mögenburg. We are especially grateful to Kurt Rilling and Michael Kösel from the Landesamt für Geologie, Rohstoffe und Bergbau for great input and discussions in the field. The many farmers, who supported our work by allowing us to work on their land, are acknowledged. Thanks to Dr. Einar Eberhardt for support with the translation of KA5 classification to WRB and FAO. Thanks go to Richard Szydlak, who drew the catenas after drafts by JH. Johanna Lomax and Andrea Junge (all Justus-Liebig-University Gießen) supported the luminescence dating. Thanks to Barret Wessel, who made useful comments on the manuscript. We also thank two unknown reviewers for their helpful comments and suggestions.

References

Ad-hoc-AG Boden (Ed.), 2005. Bodenkundliche Kartieranleitung. KA5, 5., verb. und erw. Aufl. ed. Schweizerbart, Stuttgart, 438 S.

Ahlrichs, J., Henkner, J., Schmidt, K., Scholten, T., Kühn, P., Knopf, T., 2017 submitted. Bronzezeitliche Siedlungsdynamiken zwischen der Baar und angrenzenden Naturräumen, in: Transporte, Transportwege und Transportstrukturen. Jahressitzung der Arbeitsgemeinschaft Bronzezeit, Tübingen. 30.-31. Oktober 2015, Tübingen.

Ament, H., 1977. Zur archäologischen Periodisierung der Merowingerzeit. Germania 55, 133–140.

Badische Historische Kommission (Ed.), 1904a. Topographisches Wörterbuch des Großherzogtums Baden: Band 1. Carl Winter's Universitätsbuchhandlung, Heidelberg.

Badische Historische Kommission (Ed.), 1904b. Topographisches Wörterbuch des Großherzogtums Baden: Band 2, Heidelberg.

Benecke, N., Donat, P., Gringmuth-Dallmer, E., Willerding, U. (Eds.), 2003. Frühgeschichte der Landwirtschaft in Deutschland. Beier & Beran. Archäologische Fachliteratur, Langenweissbach.

Bettis, E.A., 2003. Patterns in Holocene colluvium and alluvial fans across the prairie-forest transition in the midcontinent USA. Geoarchaeology 18 (7), 779–797. doi:10.1002/gea.10087.

Blume, H.-P., Brümmer, G.W., Horn, R., Kandeler, E., Kögel-Knabner, I., Kretzschmar, R., Stahr, K., Wilke, B.-M., 2010. Scheffer/Schachtschabel. Lehrbuch der Bodenkunde, 16. Aufl ed. Spektrum, Akad. Verl., Heidelberg, Berlin, XIV, 569 S.

Bocquet-Appel, J.-P., 2011. When the world's population took off: the springboard of the Neolithic Demographic Transition. Science (New York, N.Y.) 333 (6042), 560–561. doi:10.1126/science.1208880.

Bork, H.-R., 1989. Soil erosion during the past millennium in Central Europe and its significance within the geomorphodynamics of the Holocene, in: Ahnert, F. (Ed.), Landforms and Landform Evolution in West Germany, Frankfurt a. M., pp. 121–131.

Bork, H.-R., 1998. Landschaftsentwicklung in Mitteleuropa: Wirkungen des Menschen auf Landschaften, 1. Aufl. ed. Klett-Perthes, Gotha [u.a.], 328 S.

Bork, H.-R., 2006. Landschaften der Erde unter dem Einfluss des Menschen. Wissenschaftliche Buchgesellschaft, Darmstadt, 207 S.

Bronk Ramsey, C., 2009. Bayesian Analysis of Radiocarbon Dates. Radiocarbon 51 (01), 337–360. doi:10.1017/S0033822200033865.

Buchta-Hohm, S., 1996. Das alamannische Gräberfeld von Donaueschingen: Schwarzwald-Baar-Kreis. Theiss, Stuttgart, 67 pp.

Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D.C., Trouet, V., Kaplan, J.O., Herzig, F., Heussner, K.-U., Wanner, H., Luterbacher, J., Esper, J., 2011. 2500 years of European climate variability and human susceptibility. Science 331 (6017), 578–582.

Christ, K., 1960. Antike Münzfunde Südwestdeutschlands: Münzfunde, Geldwirtschaft und Geschichte im Raume Baden-Württembergs von keltischer bis in alamannische Zeit. 2, Heidelberg.

Crutzen, P.J., Stoermer, E.F., 2000. The "Anthropocene". Global Change Newsletter 41, 17–18.

Della Casa, P., 2013. Switzerland and the Central Alps, in: Fokkens, H., Harding, A. (Eds.), The Oxford handbook of the European Bronze Age, 1. ed. ed. Oxford Univ. Press, Oxford, pp. 706–722.

Don, A., Schumacher, J., Scherer-Lorenzen, M., Scholten, T., Schulze, E.-D., 2007. Spatial and vertical variation of soil carbon at two grassland sites — Implications for measuring soil carbon stocks. Geoderma 141 (3-4), 272–282. doi:10.1016/j.geoderma.2007.06.003.

Dotterweich, M., 2008. The history of soil erosion and fluvial deposits in small catchments of central Europe: Deciphering the long-term interaction between humans and the environment — A review. Geomorphology 101 (1-2), 192–208. doi:10.1016/j.geomorph.2008.05.023.

Dotterweich, M., Dreibrodt, S., 2011. Past land use and soil erosion processes in central Europe. PAGES news 19 (2), 49–51.

Downey, S.S., Bocaege, E., Kerig, T., Edinborough, K., Shennan, S.J., 2014. The neolithic demographic transition in Europe: correlation with juvenility index supports interpretation of the summed calibrated radiocarbon date probability distribution (SCDPD) as a valid demographic proxy. PloS one 9 (8), e105730. doi:10.1371/journal.pone.0105730.

Dreibrodt, S., Lomax, J., Nelle, O., Lubos, Carolin Clara Marie, Fischer, P., Mitusov, A., Reiß, S., Radtke, U., Nadeau, M.-J., Grootes, P.M., Bork, H.-R., 2010a. Are mid-latitude slopes sensitive to climatic oscillations? Implications from an Early Holocene sequence of slope deposits and buried soils from eastern Germany. Geomorphology 122 (3-4), 351–369. doi:10.1016/j.geomorph.2010.05.015.

Dreibrodt, S., Lubos, Carolin Clara Marie, Terhorst, B., Damm, B., Bork, H.-R., 2010b. Historical soil erosion by water in Germany: Scales and archives, chronology, research perspectives. Quaternary International 222 (1-2), 80–95. doi:10.1016/j.quaint.2009.06.014.

Eberhardt, E., Schad, P., Berner, T., Lehmann, C., Walthert, L., Pietsch, D., 2013a. Ableitungsschlüssel zur Klassierung von Böden nach WRB 2007: aus Daten der KA 5-Nomenklatur. Handbuch. Version 1.0, Hannover, Berlin.

Eberhardt, E., Schad, P., Berner, T., Lehmann, C., Walthert, L., Pietsch, D., 2013b. Ableitungsschlüssel zur Klassifizierung von Böden nach WRB 2007: aus Daten der KA 5-Nomenklatur. Handbuch, Hannover, Berlin.

Eberhardt, E., Schad, P., Berner, T., Lehmann, C., Walthert, L., Pietsch, D., 2014. Ableitungsschlüssel KA5 (2005) nach WRB (2007). Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) (de).

Eckmeier, E., Pätzold, S., Lehndorff, E., Gerlach, R., 2011. Geochemische Untersuchungen von Böden zur Rekonstruktion der prähistorischen Landnutzungsgeschichte, in: Bork, H.-R., Meller, H., Gerlach, R. (Eds.), Umweltarchäologie - Naturkatastrophen und Umweltwandel im archäologischen Befund. 3. Mitteldeutscher Archäologentag vom 7. bis 9. Oktober 2010 in Halle (Saale), pp. 37–45.

Edgeworth, M., Richter, D.d., Waters, C.N., Haff, P.K., Neal, C., Price, S.J., 2015. Diachronous beginnings of the Anthropocene: The lower bounding surface of anthropogenic deposits. The Anthropocene Review 2 (1), 33–58. doi:10.1177/2053019614565394.

Eggert, M.K.H., Samida, S., 2013. Ur- und Frühgeschichtliche Archäologie, 2., überarb. und aktualis. Aufl ed. Francke, Tübingen, Basel, XI, 334 S.

Emadodin, I., Reiß, S., Bork, H.-R., 2011. Colluviation and soil formation as geoindicators to study long-term environmental changes. Environ Earth Sci 62 (8), 1695–1706. doi:10.1007/s12665-010-0665-5.

Engels, S., van Geel, B., 2012. The effects of changing solar activity on climate: Contributions from palaeoclimatological studies. J. Space Weather Space Clim. 2, A09. doi:10.1051/swsc/2012009.

Fischer, E., 1936. Beiträge zur Kulturgeographie der Baar. Dissertation, Freiburg i. Br.

Food and Agriculture Organization of the United Nations (FAO), 2006. Guidelines for soil description, 4th ed. Food and Agriculture Organization of the United Nations, Rome, 97 pp.

Fuchs, M., Lang, A., 2009. Luminescence dating of hillslope deposits—A review. Geomorphology 109 (1-2), 17–26. doi:10.1016/j.geomorph.2008.08.025.

Fuchs, M., Will, M., Kunert, E., Kreutzer, S., Fischer, M., Reverman, R., 2011. The temporal and spatial quantification of Holocene sediment dynamics in a meso-scale catchment in northern Bavaria, Germany. The Holocene 21 (7), 1093–1104. doi:10.1177/0959683611400459.

Fyfe, R.M., Woodbridge, J., Roberts, N., 2015. From forest to farmland: pollen-inferred land cover change across Europe using the pseudobiomization approach. Global change biology 21 (3), 1197–1212. doi:10.1111/gcb.12776.

Gebhardt, H. (Ed.), 2007. Geographie Baden-Württembergs: Raum, Entwicklung, Regionen. Kohlhammer, Stuttgart, 376 S.

Glaser, R., Ammann, B., Brauer, A., Heiri, O., Jacobeit, J., Lotter, A.F., Luterbacher, J., Maisch, M., Magny, M.J., Pfister, C., Tinner, W., Veit, H., Wanner, H., 2005. Palaeoclimate within the river Rhine catchment during Holocene and historic times. erd 59, 251–275.

Glinka, K.D., 1927. Dokuchaiev's ideas in the development of pedology and cognate sciences. The Academy, Leningrad.

Guggisberg, M.A., 2008. Chronologische Fixpunkte der späten Hallstatt- und frühen Latènezeit: Der Beitrag der klassischen Archäologie., in: Hessisches Landesmuseum Darmstadt, Landesamt für Denkmalpflege Hessen, Archäologie und Paläontologie (Eds.), Der Glauberg in keltischer Zeit. Zum neuesten Stand der Forschung ; öffentliches Symposium 14. - 16. September 2006 Darmstadt. Habelt, Wiesbaden, pp. 159–170.

Haas, J.N., Richoz, I., Tinner, W., Wick, L., 1998. Synchronous Holocene climatic oscillations recorded on the Swiss Plateau and at timberline in the Alps. The Holocene 8 (3), 301–309. doi:10.1191/095968398675491173.

Häbich, S., 2009. Umweltbedingte und anthropogene Geomorphodynamik im europäischen Hauptwasserscheidengebiet des Mittleren Schwarzwald. Dissertation. Institut für Physische Geographie und Institut für Kulturgeographie der Universität Freiburg, Freiburg i. Br.

Hanöffner, A., 2005. Spaichingen (Lkr. Tuttlingen). Fundberichte aus Baden-Württemberg 28 (2), 141.

Heizmann, K., 1968. Die abgegangen Wohnplätze des Kreises Tuttlingen. Tuttlinger Heimatblätter 2, 26–44.

Helbig, H., Klerk, P.d., Kühn, P., Kwasniowski, J., 2002. Colluvial sequences on till plains in Vorpommern (NE Germany). Zeit fur Geo Supp 128, 81–100.

Henning, F.-W., 1994. Das vorindustrielle Deutschland 800 bis 1800, 5., durchges. und erg. Aufl. ed. Schöningh, Paderborn, 323 pp.

Hettich, M., 1984/85. 4000 Jahre – Ein Steinbeil der Jungsteinzeit auf Villinger Gemarkung. Geschichts- und Heimatverein Villingen 9 (1), 9–13.

Hilgard, E.W., 1914. Soils. Macmillan, New York.

Hoffmann, T., Lang, A., Dikau, R., 2008. Holocene river activity: analysing 14C-dated fluvial and colluvial sediments from Germany. Quaternary Science Reviews 27 (21-22), 2031–2040. doi:10.1016/j.quascirev.2008.06.014.

Hübener, W., 1972. Beiträge der frühgeschichtlichen Archäologie zur Geschichte der Baar, in: Müller, W. (Ed.), Villingen und die Westbaar. Konkordia, Bühl, pp. 42–55.

Hudson, P., Goudie, A.S., Asrat, A., 2015. Human Impacts on Landscapes: Sustainability and the role of Geomorphology. Zeit fur Geo Supp 59 (2), 1–5. doi:10.1127/zfg_suppl/2015/S-59201.

IUSS Working Group WRB, 2015. World reference base for soil resources 2014: International soil classification system for naming soils and creating legends for soil maps. Update 2015. World soil resources reports 106, Rome, 191 pp.

Jäger, H., 1994. Einführung in die Umweltgeschichte. Wiss. Buchges, Darmstadt, VI, 245 S.

Jäger, K.-D., 2002. Oscillations of the water balance during the Holocene in interior Central Europe—features, dating and consequences. Quaternary International 91 (1), 33–37. doi:10.1016/S1040-6182(01)00100-8.

James, B.R., Blum, W.E.H., Dazzi, C., 2014. Bread and Soil in Ancient Rome: A Vision of Abundance and an Ideal of Order Based on Wheat, Grapes, and Olives, in: Churchman, G.J., Landa, E. (Eds.), The soil underfoot. Infinite possibilities for a finite resource. CRC Press/Taylor and Francis, Boca Raton, pp. 153–174.

James, L.A., 2013. Impacts of Early Agriculture and Deforestation on Geomorphic Systems, in: Shroder, J.F. (Ed.), Treatise on geomorphology. Elsevier/Acad. Press, Amsterdam, pp. 48–67.

Jarvis, A., Reuter, H.I., Nelson, A., Guevara, E., 2008. Hole-filled SRTM for the globe Version 4: CGIAR-CSI SRTM 90m Database.

Jenisch, B., Lohrum, B., Rösch, M. (Eds.), 1999. Die Entstehung der Stadt Villingen: Archäologische Zeugnisse und Quellenüberlieferung, 573 pp.

Jenny, H., 1994. Factors of soil formation: A system of quantitative pedology, Unabridged, unaltered republ., new foreword ed. Dover Publ, New York, 281 pp.

Kadereit, A., Kühn, P., Wagner, G.A., 2010. Holocene relief and soil changes in loess-covered areas of south-western Germany: The pedosedimentary archives of Bretten-Bauerbach (Kraichgau). Quaternary International 222 (1-2), 96–119. doi:10.1016/j.quaint.2009.06.025.

Kaenel, G., Müller, F., 1999. Einleitung, in: Müller, F. (Ed.), Die Schweiz vom Paläolithikum bis zum frühen Mittelalter. vom Neandertaler zu Karl dem Grossen. Band 4, pp. 13–27.

Kaplan, J.O., Krumhardt, K.M., Zimmermann, N.E., 2009. The prehistoric and preindustrial deforestation of Europe. Quaternary Science Reviews 28 (27-28), 3016–3034. doi:10.1016/j.quascirev.2009.09.028.

Kleber, A., 2006. "Kolluvium" does not equal "colluvium". Zeit fur Geo Supp 50 (4), 541–542.

Knopf, T., 2012. Neue Forschungen im Umland des Magdalenenbergs, in: Wege und Transport. Beiträge zur Sitzung der AG Eisenzeit während der 80. Verbandstagung des West- und Süddeutschen Verbandes für Altertumsforschung e.V. in Nürnberg 2010. 80. Verbandstagung des West- und Süddeutschen Verbandes für Altertumsforschung e.V., Nürnberg. 2010, pp. 209–220.

Knopf, T., Ahlrichs, J., Henkner, J., Scholten, T., Kühn, P., 2015. Archäologische und bodenkundliche Untersuchungen zur Besiedlungs- und Landnutzungsgeschichte der Baar. Schriften des Vereins für Geschichte und Naturgeschichte der Baar 58, 9–24.

Knopf, T., Seidensticker, D., 2013. Archäologische Untersuchungen auf der Baar: das Umland des "Fürstengrabhügels" Magdalenenberg. Archäologische Ausgrabungen in Baden-Württemberg, 116–121.

Koch, J., Clague, J.J., 2006. Are insolation and sunspot activity the primary drivers of Holocene glacier fluctuations? PAGES news 14 (3), 20–21.

Kösel, M., Rilling, K., 2002. Die Böden der Baar - ein Beitrag zur regionalen Bodenkunde Südwestdeutschlands. Schriften des Vereins für Geschichte und Naturgeschichte der Baar 45, 99–128.

Kraft, G., Lehmann, G., Thaer, A.D., Thiel, H. (Eds.), 1880. Albrecht Thaer's Grundsätze der rationellen Landwirthschaft, Berlin.

Kreutzer, S., Dietze, M., Burow, C., Fuchs, M.C., Schmidt, C., Fischer, M., Firedrich, J., Mercier, N., Smedley, R.K., Durcan, J., King, G., 2016. Comprehensive Luminescence Dating Data Analysis. R package.

Kromer, B., Friedrich, M., 2007. Jahrringchronologien und Radiokohlenstoff: Ein ideales Gespann in der Paläoklimaforschung. Geographische Rundschau 59 (4), 50–55.

Lal, R., Reicosky, D.C., Hanson, J.D., 2007. Evolution of the plow over 10,000 years and the rationale for no-till farming. Soil & Tillage Research 93 (1), 1–12. doi:10.1016/j.still.2006.11.004.

Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg (LUBW) (Ed.), 2008. Böden als Archive der Natur- und Kulturgeschichte: Grundlagen und beispielhafte Auswertung, Dez. 2008, 1. Aufl. ed. LUBW, Karlsruhe, 19 S.

Lang, A., 2003. Phases of soil erosion-derived colluviation in the loess hills of South Germany. CATENA 51, 209–221.

Lang, A., Bork, H.-R., Mäckel, R., Preston, N., Wunderlich, J., Dikau, R., 2003. Changes in sediment flux and storage within a fluvial system: Some examples from the Rhine catchment. Hydrol. Process. 17 (16), 3321–3334. doi:10.1002/hyp.1389.

Lang, A., Hönscheidt, S., 1999. Age and source of colluvial sediments at Vaihingen–Enz, Germany. CATENA 38 (2), 89–107. doi:10.1016/S0341-8162(99)00068-5.

Lazar, S., 2005. Bodenzustandsbericht Baar, 1st ed. Landesamt für Umweltschutz Baden-Württemberg, Karlsruhe, 195 pp.

Leopold, M., Völkel, J., 2007a. Colluvium: Definition, differentiation, and possible suitability for reconstructing Holocene climate data. Quaternary International 162-163, 133–140. doi:10.1016/j.quaint.2006.10.030.

Leopold, M., Völkel, J., 2007b. Quantifying prehistoric soil erosion—A review of soil loss methods and their application to a Celtic square enclosure (Viereckschanze) in Southern Germany. Geoarchaeology 22 (8), 873–889. doi:10.1002/gea.20199.

Lewis, S.L., Maslin, M.A., 2015. Defining the anthropocene. Nature 519 (7542), 171–180. doi:10.1038/nature14258.

Liebig, J., 1840. Die organische Chemie in ihrer Anwendung auf Agricultur und Physiologie, Braunschweig.

Lomax, J., Kreutzer, S., Fuchs, M., 2014. Performance tests using the Lexsyg luminescence reader. Geochronometria 41 (4), 327–333. doi:10.2478/s13386-013-0174-x. http://dx.doi.org/10.2478/s13386-013-0174-x.

Lüning, J., 1996. Erneute Gedanken zur Benennung der neolithischen Perioden. Germania 74 (1), 233–237.

Mäckel, R., Schneider, R., Friedmann, A., Seidel, J., 2002. Environmental changes and human impact on the relief development in the Upper Rhine valley and Black Forest (South-West Germany) during the Holocene. Zeit fur Geo Supp 128, 31–45.

Mäckel, R., Schneider, R., Seidel, J., 2003. Anthropogenic impact on the landscape of southern Badenia (Germany) during the Holocene - Documented by colluvial and alluvial sediments. Archaeometry 45 (3), 487–501. doi:10.1111/1475-4754.00123.

Mäder, A., Sormaz, T., 2000. Die Dendrodaten der beginnenden Spätbronzezeit (Bz D) von Elgg ZH-Breiti. Jahrbuch der Schweizerischen Gesellschaft für Ur- und Frühgeschichte 83, 65–78. doi:10.5169/seals-117627.

Magny, M.J., Bégeot, C., Guiot, J., Peyron, O., 2003. Contrasting patterns of hydrological changes in Europe in response to Holocene climate cooling phases. Quaternary Science Reviews 22 (15-17), 1589–1596. doi:10.1016/S0277-3791(03)00131-8.

Maise, C., 2001. Zur Untergliederung der Stufe Ha C/D1 im Breisgau. Fundberichte aus Baden-Württemberg 25, 389–461.

Miehlich, G., 2009. Böden als Archive der Natur- und Kulturgeschichte. MNA Berichte 1, 76–85.

Miller, F.P., 2006. Planet and Human Society, Soil as a Heritage of. Encyclopedia of Soil Science, 1288–1293.

Milne, G., 1935. Some suggested units of classification and mapping particularly for East African Soils. Soil Research 4, 183–198.

Mook, W.G., van der Plicht, J., 1999. Reporting 14C Activities and Concentrations. Radiocarbon 41 (3), 227–239.

Müller, J., Lohrke, B., 2011. Neue absolutchronologische Daten für die süddeutsche Hügelgräberbronzezeit. Germania 87, 25–38.

Murray, A.S., Wintle, A.G., 2000. Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. Radiation Measurements 32 (1), 57–73. doi:10.1016/S1350-4487(99)00253-X.

Negendank, J.F.W., 2004. The Holocene: considerations with regard to its climate and climate archives, in: Fischer, H. (Ed.), The climate in historical times. Towards a synthesis of holocene proxy data and climate models. Springer, Berlin, London, pp. 1–12.

NGRIP Members, 2004. High-resolution record of Northern Hemisphere climate extending into the last interglacial period. Nature 431 (7005), 147–151. doi:10.1038/nature02805.

Nicolay, A., Raab, A., Raab, T., Rösler, H., Bönisch, E., Murray, A.S., 2014. Evidence of (pre)historic to modern landscape and land use history near Jänschwalde (Brandenburg, Germany), in: Engel, M., Brückner, H. (Eds.), Geoarchaeology. Exploring terrestrial archives for evidence of human interaction with the envionment, vol. 2. Borntraeger, pp. 7–31.

Niller, H.-P., 2001. Wandel prähistorischer Landschaften: Kolluvien, Auenlehme und Böden: Archive zu Rekonstruktion vorgeschichtlicher anthropogener Landschaftsveränderungen im Lößgebiet bei Regensburg. erd 55 (1), 32–48.

Nübling, V., 1990. Spaichingen (Lkr. Tuttlingen). Fundberichte aus Baden-Württemberg 15, 534.

Nübling, V., 2005. Donaueschingen. Fundberichte aus Baden-Württemberg 28 (2), 122–124.

Paret, O., 1932. Die Siedlungen des römischen Württemberg: Die Römer in Württemberg III, Stuttgart.

Parnell, A.C., 2016. Bchron: Radiocarbon Dating, Age-Depth Modelling, Relative Sea Level Rate Estimation, and Non-Parametric Phase Modelling.

Parnell, A.C., Haslett, J., Allen, J.R.M., Buck, C.E., Huntley, B., 2008. A flexible approach to assessing synchroneity of past events using Bayesian reconstructions of sedimentation history. Quaternary Science Reviews 27 (19-20), 1872–1885. doi:10.1016/j.quascirev.2008.07.009.

Pietsch, D., Kühn, P., 2014. Buried soils in the context of geoarchaeological research—two examples from Germany and Ethiopia. Archaeol Anthropol Sci. doi:10.1007/s12520-014-0180-9.

Poppi, L.K., 1991. The Archaeological Sources, in: Moscati, S., Arslan, E.A., Vitali, D. (Eds.), The Celts. Rizzoli, New York, pp. 42–50.

Rathjens, C., 1979. Die Formung der Erdoberfläche unter dem Einfluß des Menschen: Grundzüge der Anthropogenetischen Geomorphologie. Teubner, Stuttgart, 160 pp.

Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg, 2013. Geologische Grundflächen - Geologische Karte von Baden-Württemberg 1:50 000: blattschnittfreie Geodaten der Integrierten geowissenschaftlichen Landesaufnahme (GeoLa).

Reich, L., 1859. Die badische Landschaft Baar. Badenia oder das badische Volk (1), 431–461.

Reimer, P., 2013. IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. Radiocarbon 55 (4), 1869–1887. doi:10.2458/azu_js_rc.55.16947.

Reimer, P., Brown, T.A., Reimer, R.W., 2004. Discussion: Reporting and calibration of post-bomb 14C Data. Radiocarbon 46 (3), 1299–1304.

Revellio, P., 1933. Unsere Heimat: Heimatfunde des Kreises Villingen. Buchdruckerei T. Revellio, Hüfingen.

Revellio, P., 1935. Aus der Geschichte der Baar im Mittelalter: Schwarzwald Baar Kreis Villingen. M. Link, Schwenningen.

Richter, D.d., Bacon, A.R., Brecheisen, Z., Mobley, M.L., 2015. Soil in the Anthropocene. IOP Conf. Ser.: Earth Environ. Sci. 25, 12010. doi:10.1088/1755-1315/25/1/012010.

Rösch, M., 1999. Ernährung und Umwelt im mittelalterlichen Villingen. Botanische Untersuchungen an archäologischen Bodenfunden, in: Jenisch, B., Lohrum, B., Rösch, M. (Eds.), Die Entstehung der Stadt Villingen. Archäologische Zeugnisse und Quellenüberlieferung, pp. 365–573.

Rösch, M., 2000. Long-term human impact as registered in an upland pollen profile from the southern Black Forest, south-western Germany. Vegetation History and Archaeobotany 9 (4), 205–218. doi:10.1007/BF01294635.

Ruddiman, W.F., 2013. The Anthropocene. Annu. Rev. Earth Planet. Sci. 41 (1), 45–68. doi:10.1146/annurev-earth-050212-123944.

Sangmeister, E. (Ed.), 1993. Zeitspuren: Archäologisches aus Baden, 1. Aufl. ed. Kehrer, Freiburg i. Br., 240 pp.

Schaetzl, R.J., 2013. Catenas and Soils, in: Shroder, J.F. (Ed.), Treatise on geomorphology. Elsevier/Acad. Press, Amsterdam, pp. 145–158.

Schauer, P., 1971. Die Schwerter in Süddeutschland, Österreich und der Schweiz I: Griffplatten-, Griffangel- und Griffzungenschwerter, München, X, 264, 154 S.

Schmid, B., 1991. Die urgeschichtlichen Funde und Fundstellen der Baar: Eine Auswertung des Bestandes. Band 1: Text und Tafeln. Schäuble Verlag, Rheinfelden.

Schmid, B., 1992. Die urgeschichtlichen Funde und Fundstellen der Baar: Eine Auswertung des Bestandes. Band 2: Katalog. Schäuble Verlag, Rheinfelden.

Schönwiese, C., 1995. Klimaänderungen: Daten, analysen, prognosen. Springer-Verlag, Berlin, xiii, 224.

Schröder, K.H., 2001. Naturräumliche Grundlagen der Landesgeschichte, in: Schwarzmaier, H., Schaab, M. (Eds.), Handbuch der baden-württembergischen Geschichte. Band 1. Allgemeine Geschichte. Von der Urzeit bis zum Ende der Staufer, pp. 1–27.

Schroedter, T.M., Dreibrodt, S., Hofmann, R., Lomax, J., Müller, J., Nelle, O., 2013. Interdisciplinary interpretation of challenging archives: Charcoal assemblages in Drina Valley alluvial and colluvial sediments (Jagnilo, Bosnia and Herzegovina). Quaternary International 289, 36–45. doi:10.1016/j.quaint.2012.02.030.

Siegmund, A., 2006. Der Klimacharackter der Baar - ein regionales Querprofil, in: Siegmund, A. (Ed.), Faszination Baar. Porträts aus Natur und Landschaft, 2 ed. Mory, Donaueschingen, pp. 115–132.

Spindler, K., 1977. Aus der Geschichte: Vor- und Frühgeschichte, in: Gutknecht, R. (Ed.), Der Schwarzwald-Baar-Kreis. Heimat und Arbeit. K. Theiss, Stuttgart, pp. 56–84.

Spindler, K., 1979. Zur Topographie der Villinger Altstadt. Fundberichte aus Baden-Württemberg 4, 391–413.

Spindler, K. (Ed.), 1996. Der Magdalenenberg bei Villingen: Ein Fürstengrabhügel des 7. vorchristlichen Jahrhunderts, Stuttgart.

Spindler, K., 2004. Der Magdalenenberg bei Villingen im Schwarzwald: Bilanz nach 30 Jahren, in: Hänsel, B. (Ed.), Parerga Praehistorica Jubiläumsschrift zur Prähistorischen Archäologie. 15 Jahre UPA, Bonn, pp. 135–160.

Steinhof, A., Altenburg, M., Göbel, M., Machts, H., 2017. Sample preparation at the Jena 14C laboratory. Radiocarbon 59 (3), 815–830. 10.1017/RDC.2017.50.

Stockhammer, P.W., Massy, K., Knipper, C., Friedrich, R., Kromer, B., Lindauer, S., Radosavljevic, J., Wittenborn, F., Krause, J., 2015. Rewriting the Central European Early Bronze Age Chronology: Evidence from Large-Scale Radiocarbon Dating. PloS one 10 (10), e0139705. doi:10.1371/journal.pone.0139705.

Stoll, H., Gehring, E., 1938. Vor- und frühgeschichtliche Karte von Rottweil und Umgebung, Rottweil.

Sudhaus, D., 2005. Paläoökologische Untersuchungen zur spätglazialen und holozänen Landschaftsgeschichte des Ostschwarzwaldes im Vergleich mit den Buntsandsteinvogesen. Freiburger Geographische Hefte 64.

Surovell, T.A., Byrd Finley, J., Smith, G.M., Brantingham, P.J., Kelly, R., 2009. Correcting temporal frequency distributions for taphonomic bias. Journal of Archaeological Science 36 (8), 1715–1724. doi:10.1016/j.jas.2009.03.029.

Teuber, S., Ahlrichs, J., Henkner, J., Knopf, T., Kühn, P., Scholten, T., 2017 [submitted]. Soil-Cultures – the adaptive cycle of agrarian soil use in Central Europe. Ecology and Society.

Tinner, W., Lotter, A.F., Ammann, B., Conedera, M., Hubschmid, P., van Leeuwen, J.F.N., Wehrli, M., 2003. Climatic change and contemporaneous land-use phases north and south of the Alps 2300 BC to 800 AD. Quaternary Science Reviews 22 (14), 1447–1460. doi:10.1016/S0277-3791(03)00083-0.

van der Leeuw, S.E., The ARCHAEOMEDES research team, 2005. Climate, hydrology, land use, and environmental degradation in the lower Rhone Valley during the Roman period. Comptes Rendus Geoscience 337 (1-2), 9–27. doi:10.1016/j.crte.2004.10.018.

Verstraeten, G., Lang, A., Houben, P., 2009. Human impact on sediment dynamics — quantification and timing. CATENA 77 (2), 77–80. doi:10.1016/j.catena.2009.01.005.

Wagner, E., Haug, F. (Eds.), 1908. Fundstätten und Funde aus vorgeschichtlicher, römischer und alamannisch-fränkischer Zeit im Großherzogtum Baden: Band 1: Das Badische Oberland: Kreise Konstanz, Villingen, Waldshut, Lörrach, Freiburg, Offenburg, Tübingen, 298 pp.

Wagner, H., 2014. Von der Steinzeit zur Stadt Neue Forschungen zur Besiedlungsgeschichte des Fürstenbergs. Schriften des Vereins für Geschichte und Naturgeschichte der Baar 57, 33–62.

Weber, G., 1991/1992. Die neuentdeckte Siedlung "Laible": und die spätlatènezeitliche Besiedlung Villingens und Umgebung. Geschichts- und Heimatverein Villingen 16, 34–40.

Weber-Jenisch, G., 1994. Villingen-Schwenningen. Fundberichte aus Baden-Württemberg 19 (2), 77–78.

Wunderlich, J., 2000. Prähistorische und historische Bodenerosion im Amöneburger Becken - Abgeleitet aus einer Sequenz datierter Kolluvien. Berichte der Kommission für Archäologische Landesforschung in Hessen 5, 9–16.

Wysocki, D.A., Zanner, C.W., 2006. Landscape Elements, in: Lal, R. (Ed.), Encyclopedia of soil science. Volume 2, 2nd ed. ed. Taylor & Francis, New York, Abingdon, Oxon, pp. 1008–1012.

Zimmermann, A., 1996. Zur Bevölkerungsdichte in der Urgeschichte Mitteleuropas, in: Campen, I., Hahn, J., Uerpmann, M. (Eds.), Spuren der Jagd - die Jagd nach Spuren. Festschrift für Hansjürgen Müller-Beck. Mo Vince, Tübingen, pp. 49–61.

Zolitschka, B., 2002. Late Quaternary sediment yield variations - natural versus human forcing. Zeit fur Geo Supp 128, 1–15.

Zolitschka, B., Behre, K.-E., Schneider, J., 2003. Human and climatic impact on the environment as derived from colluvial, fluvial and lacustrine archives—examples from the Bronze Age to the Migration period, Germany. Quaternary Science Reviews 22 (1), 81–100. doi:10.1016/S0277-3791(02)00182-8.

Manuscript II

Land use dynamics derived from colluvial deposits and bogs in the Black Forest, Germany

Henkner, Jessica[1,2]; Ahlrichs, Jan J.[1,3]; Fischer, Elske[4]; Knopf, Thomas[1,3]; Rösch, Manfred[4]; Scholten, Thomas[1,2]; Kühn, Peter [1,2]

Journal of Plant Nutrition and Soil Science 181/2 (2018) 240-260, DOI: 10.1002/jpln.201700249

[1] SFB1070 ResourceCultures, Gartenstr. 29, 72074 Tübingen, Germany

[2] Department of Geosciences, Soil Science and Geomorphology, Eberhard Karls University Tübingen, Rümelinstr. 19-23, 72070 Tübingen, Germany

[3] Institute for Pre- and Protohistory and Medieval Archaeology, Eberhard Karls University Tübingen, Burgsteige 11, Schloss Hohentübingen, 72070 Tübingen, Germany

[4] Landesamt für Denkmalpflege Baden-Württemberg, Fischersteig 9, 78343 Gaienhofen-Hemmenhofen, Germany

[5] Department of Geography, Justus-Liebig-University Giessen, Senckenberstr. 1, 35390 Giessen, Germany

[6] Institute for Pre- and Protohistory and Near Eastern Archaeology, Marstallhof 4, 69117 Heidelberg, Germany

Abstract

The Black Forest is considered to be a rather unfavorable area, having a short vegetation period, low mean annual temperatures, high precipitation, and a pronounced relief. These conditions do not favor agricultural land use and thus it is widely accepted that people only began using the land intensively during the Middle Ages. In this integrated study 17 soil profiles, two peat bogs and a database of archaeological finds were used to reconstruct past land use impacts on the environment. AMS–^{14}C datings of charcoals, luminescence datings of colluvial deposits, archaeological finds and pollen records indicate land use already during the Neolithic. This pre- medieval land use might be related to seasonal settlements dominated by pastoralism and the use of wood or bedrock to build settlements and infrastructure or as energy supply. There is new evidence of human activity dating back to the Bronze and Iron Age, which is a discrepancy to the absence of archaeological finds in the direct vicinity of the studied sites. With the beginning of the Middle Ages land use practices changed, most likely with the expansion and intensification of agricultural land use, which coincides with the increasing use of natural resources in the Black Forest. Hence, the main phases of colluvial deposition date to the Middle Ages and Modern Times. Increased contents of As, Cr, Cu, Pb, or Zn in medieval colluvial deposits might indicate smelting or mining, even though there are no known archeological sites pointing to such activities nearby. Whereas the pattern of colluvial deposition in the southeastern Black Forest points to distinct, but local land use in pre-medieval times and to intensified and widespread land use since the Middle Ages, thick and multi-layered colluvial deposits indicate intensive land use in the neighboring Baar region since the Neolithic. The different land use patterns of these two regions originate from the rather favorable conditions for agriculture in terms of soils, climate, and topography in the Baar region compared to the unfavorable conditions in the Black Forest.

1 Introduction

Colluvial soils are formed in the correlate sediments of human induced soil erosion on slopes and are valuable archives for land use and landscape history (Leopold and Völkel, 2007; Fuchs et al., 2010; Henkner et al., 2017). With increasing land use intensity, the formation of colluvial deposits on slopes and in depressions is more likely. Pollen records are also archives showing human influence on the environment, i.e., vegetation, which dates back to the Neolithic in case of the Black Forest (Rösch, 2000, 2012; Rösch and Tserendorj, 2011), thus, the area can be considered a cultural landscape. Low mountain ranges like the Black Forest are classic examples of unfavorable landscapes, which are generally characterized as being less productive for agriculture because of poor environmental conditions (e.g., soils, topography, cli- mate, and accessibility favorable areas are often loess covered, having fertile soils, low relief intensity, and a sufficient climate to practice agriculture and were, therefore, supposedly settled earlier (Seidl, 2006; Henkner et al., 2017; Kühn et al., 2017). The interpretation of landscapes as favorable and unfavorable is a relative concept to evaluate the quality of an environment to serve a certain purpose. Thus, landscapes can be unfavorable to grow crops, but at the same time, very favorable in order to use the forest, water or geo- logical resources. In this study, the Black Forest is identified as an unfavorable landscape to practice agriculture and settle permanently, compared to the adjacent Baar area, which, in these terms, is a favorable landscape. Despite the long duration of land use in unfavorable areas, broad and interdisciplinary studies of land use and settlement dynamics are rare.

This study combines pedological, archaeological, and palynological knowledge to use colluvial deposits and bogs as archives of land use and vegetation history in the southeastern Black Forest. The dating of colluvial deposition is the key to reconstruct periods of enhanced human impact, specifically intensified land use. The main research questions are:

(1) When did land use begin in the southeastern Black Forest?

(2) Which are the main phases of colluvial deposition across the southeastern Black Forest?

(3) Do heavy metal contents, pollen or archaeological finds point to specific types of land use during the corresponding time period?

(4) Do land use pattern differ between unfavorable (Black Forest) and favorable areas (Baar)?

2 Study area

2.1 Regional setting and vegetation history

Surface and ground waters of the central southeastern Black Forest in southwest Germany (Fig. 1) are the headwaters of the Danube River, resulting in shallow valleys and gentle hills, compared to the adjacent Rhenanian Black Forest with deeply incised valleys and steep slopes and the rather flat plateau of the Baar in the East. The study area consists of granitic basement and paragneiss and has an elevation ranging from 600 to 1150 m asl.

During the last glacial period most of the study area was periglacialy overprinted, which is still documented by periglacial layers (Reichelt, 1996, 1997; LGRB, 2013a). Because of the wide distribution of periglacial slope deposits, they frequently are the parent material for soils, as it is the case for the soils of this study. Cambisols typically form in periglacial layers. They are associated with Podzols and Stagnosols depending on topography, changes in parent material, water availability, and land use (Kösel and Rilling, 2002; LGRB, 2013a). The crystalline bedrock and the high mean annual precipitation led to rather acidic soils in the Black Forest. With the transition to the Baar, a fluvial sandstone becomes dominant and loess deposits occur (LGRB, 2013b).

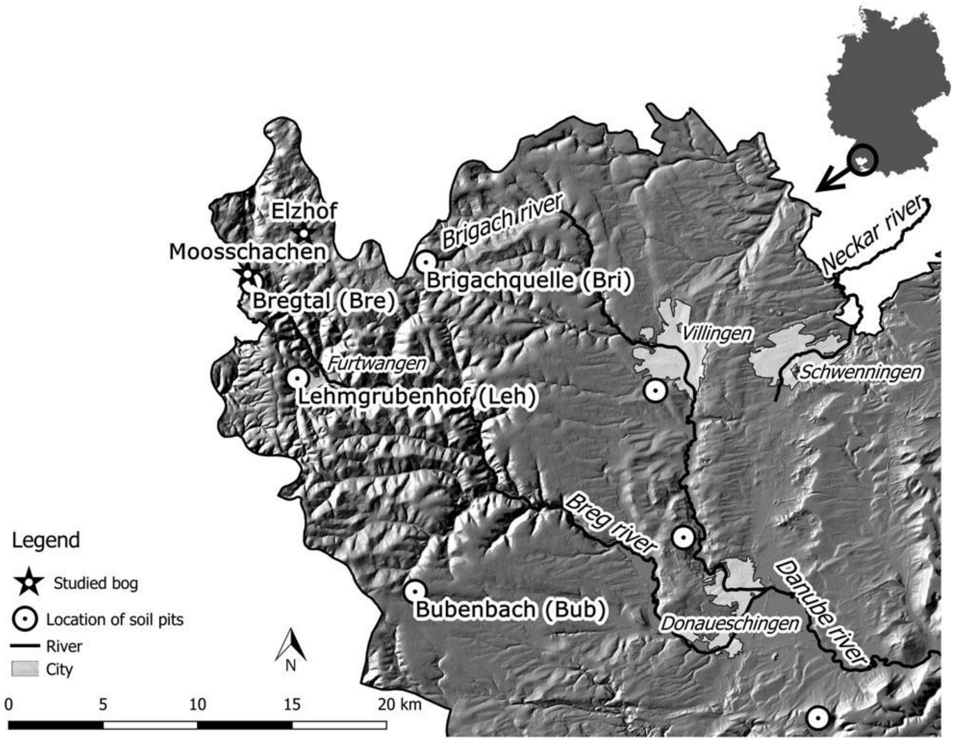

Fig. 1: Topographic SRTM image (*Jarvis* et al. 2008) of the southeastern Black Forest in the West and the flat areas of the Baar region with selected cities in the East. Studied bogs and soil pit locations are marked and named. Further soil pit locations in the Baar area are only marked.

Lower temperatures, higher precipitation (decreasing to the East), and higher wind speed are characteristics of the climate of the Black Forest compared to neighboring areas. Mean annual precipitation is about 1250 mm and mean annual temperature 6.5°C (Furtwangen, 955 m asl, AM Online Projects, 2017). Climate history in the Black Forest shows climate optima during the

Roman Period, the high Middle Ages and the Modern Period, and pessima during the Migration Period and the Little Ice Age (Schönwiese, 1995; Blümel, 2002; Glaser, 2013).

Table 1: Location and characteristics of the archaeopedological study sites. The compilation originates from field work and information about geology (*Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg* 2013b) and soils (*Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg* 2013a).

Site:	**Breg valley (Bre)**	**Brigach (Bri)**	**Upper Lehmgrubenhof (Leh)**	**Bubenbach (Bub)**
UTM:	32437828.78 5326886.94	32446393.03 5328402.04	32438205.32 5323550.92	32447141.82 5312796.92
Geology				
	Triberg Granite (biotite granite, light grey, intermediate to coarse grained); dykes; quaternary slope deposits	Paragneiss (biotite and/or cordierite containing gneiss); dykes; loose rocks from Triberger Granite and sandstone (Sankt Peter Formation); quaternary slope deposits	Paragneiss (biotite and/or cordierite containing gneiss), associated with hornblende-biotite-gneiss and gneiss (feldspar, quartz, biotite, muscovite, hornblende, garnet, cordierite, sillimanite); diorite porphyry dykes; quaternary slope deposits	Reddish Eisenbach Granite (mica, feldspar, muscovite); granitic porphyry dykes; quaternary slope deposits
Main Soil Types (WRB)				
	Cambisol; Gleysol	Cambisol; Gleysol	Cambisol; Gleysol	Cambisol; Podzol; Gleysol
Vegetation				
	grassland; bog nearby	grassland	grassland	grassland
Topography				
	SW-facing; inclination: 4-10%; back- to footslope position; river valley	SE-facing; inclination 2-5%; footslope; river valley	SE-facing; inclination 2-5%; back- to footslope position; river valley	E-facing; inclination 3-18%; back-to toeslope position; river valley
Hydrology				
	drained; Breg river	spring of the Brigach river; drained; artificial ponds are filled with sediment	drained; Rhine river tributary (Hübschenbach)	Danube river tributary (Bubenbächle)
Altitude				
	1020-1031 m asl	928-940 m asl	1049-1062 m asl	921-952 m asl
Land use				
	pasture and hay meadow	pasture	field and pasture	hay meadow; former potato field

The Holocene vegetation history of the Black Forest shows a reforestation of the last glacial steppe vegetation, initially by shrubs and dwarf shrubs as Salix, Betula nana, Juniperus, and Hippophaë, then by rather open forest with Pinus sylvestris and Betula alba, followed by the immigration and expansion of Corylus and later mixed oak forest (Lang,2005). The natural immigration sequence was Picea, Abies, and then Fagus and with the expansion of shade trees like Abies and Fagus (4000–4500 BCE), the Black Forest acquired distinct vegetation patterns showing a dominance of Abies until 1000 CE. In the southern Black Forest, Picea became a minor component from about 3000 BCE at least in elevations above 1000 m asl.

The selection of four archaeopedological sites (Fig. 1, Tab. 1) followed archaeological findings (Tab. 2) and field surveys. The Brigach (Bri) and Breg (Bre) sites were chosen according to archaeological finds from the Latène Period and the Roman Empire. At the Bubenbach (Bub) and Lehmgrubenhof (Leh) sites, finds point to land use and settlement beginning in the Middle Ages. Table 1 gives some important site characteristics to understand the landscape and the parent material for soil formation.

2.2 Settlement and land use history

There are no Paleolithic or Mesolithic sites known in the southeastern part of the central Black Forest (Lais, 1937). Considering the evidence of Paleolithic and Mesolithic land use in other parts of the Black Forest (Stoll, 1932, 1933; Pasda, 1996; Schneider, 2000) it seems likely that the south- eastern Black Forest was penetrated sporadically during these periods. However, there are a few Neolithic sites with flints, stone axes, stone tools, and pottery fragments (Spindler, 1977; Pape, 1978; Nübling, 1990; Schmid, 1991, 1992). In addition, several finds from the western Baar point to seasonal land use at the edge of the southeastern Black Forest (Ahlrichs et al., 2016). The low density of Neolithic finds in the southeastern Black Forest is the result of different factors. First of all, the archaeological understanding is that most parts of the Black Forest were only used on a seasonal basis for pastoralism. This kind of subsistence is difficult to trace, because pastoralists act in small and mobile groups (Valde-Nowak, 1999; Valde-Nowak and Kienlin, 2002). Secondly, ceramics are scarcely preserved, because of acidic soils and harsh winters, accelerating weathering (Geilmann and Spang, 1958; Schiffer, 1987; Sommer, 1991). Thirdly, as a result of the recent dense vegetation cover and the absence of arable land, the accessibility and visibility of prehistoric sites is considerably reduced (Lais, 1937). Finally, Neolithic sites are often located below the modern surface and are therefore mostly discovered by chance, e.g., during construction works (Lais, 1937). Colluvial deposits show that even in areas with gentle rolling slopes, land use can trigger soil erosion leading to coverage of archaeological sites (Ahlrichs et al., 2016; Henkner et al., 2017).

Bronze Age and Iron Age sites are mostly unknown in the southeastern Black Forest (cf Tab. 2). The absence of finds is usually explained by avoidance of this landscape due to its harsh environmental conditions (Gradmann, 1922, 1931, 1948; Revellio, 1961; Denecke, 1992), but it might as well be explained by the above-mentioned source-critical factors. The latter explanation is supported by increasing evidence indicating Bronze and Iron Age land use in the northern Black Forest (Frenzel, 1982; Wieland, 2009; Wagner, 2014). During the Latène period smelting of iron was performed in the in the northern Black Forest (Gassmann et al., 2006; Rösch et al., 2007), in contrast to the southeastern Black Forest with only few single finds. For example, the renovation of a chapel at the spring of the Breg river (1958) led to the discovery of pottery fragments from the Latène Period and Roman Empire (Schmid, 1992). Another find is an iron ingot in form of a sword, which was interpreted as a trading product lost on a trading route connecting the Baar with the Rhine valley (Humpert, 1991; Fingerlin, 2006). The trading route through the Black Forest was also used during Roman times (Fingerlin, 2006).

Roman coins from 10–300 CE (Revellio, 1957) were found near the site Lehmgrubenhof, and a relief from 10–100 CE (Revellio, 1938) was found at the Brigach spring site. The engraved stone depicts three gods, including Diana Abnoba, the Roman goddess of the Black Forest (Focke, 1956; Kotterba, 1996). This stone can be interpreted as an indicator for the ritual use of the spring (Krüger, 1938; Maier, 2006).

With the transition to the Middle Ages, land use intensified as indicated by an increase in archaeological site density. Enhanced land use intensity occurred during the so-called “landnam” period when new settlements were founded especially during 1000–1200 CE (Grees, 2007; Knopf et al., 2012), leading to increased deforestation documented in historical sources and pollen records (Brückner, 1981; Friedmann, 2002; Rösch, 2013). People used the natural resources of the Black Forest for various economic purposes: wood was used for building infrastructure, as an energy source, and for charcoal production; sand was used to produce glass. Iron ore, silver, and lead were mined and the granite was used as a building material. Pastures and small fields followed on the deforested land (Häbich, 2009)

Table 2: Archaeological finds in a 2 km radius around the four sites in the southeastern Black Forest.

Epoch	Period (duration; references)	Site	Finds	Interpretation	References
Neolithic					
	5500-2150 BCE (*Lüning* 1996)				
Bronze Age					
	2150-800 BCE (*Della Casa* 2013; *Mäder* and *Sormaz* 2000)				
Iron Age					
	Hallstatt Period (800-450 BCE; *Guggisberg* 2008; *Maise* 2001)				
	Latène Period (450 BCE- ±1; *Kaenel* and *Müller* 1999; *Poppi* 1991)	Bre	Pottery	Settlement?	(Wieland 1996)
Roman Empire					
	Roman Empire (±1 -375 CE;)	Bri	Stone relief	Ritual site?	(*Maier* 2006)
		Bre	Pottery	Settlement?	(Wieland 1996)
	Migration Period (375-450 CE;)				
Middle Ages					
	Merovingian Period (450-750 CE; *Ament* 1977)				
	High Middles Ages (750-1250 CE; *Sangmeister* 1993)				
	Late Middle Ages (1250-1500 CE)				
	Middle Ages in general	Bri	Church	Church	local records
		Bri	Stone mounds and pits	Mining	(*Dehme* 1940)
		Bre	Church	Church	(Wieland 1996)
		Bre	Earth walls	Fortification?	local records
		Bub	Pottery and Slag	Iron smelting	local records
		Bub	Stone mounds and pits	Mining	local records

3 Methods

3.1 Field methods

At the sites Brigach, Breg, Lehmgrubenhof, and Bubenbach the description and sampling of 17 soil profiles, aligned in four catenas, was carried out in 2015. The soil pit locations were chosen to represent a detailed stratigraphy of colluvial depos- its. The soil profile description and classification follows the German soil mapping guidelines and classification system (Ad-hoc-AG Boden, 2005), the FAO guidelines for soil description (FAO, 2006), and the world reference base for soil resources 2014 (Eberhardt et al., 2013, 2014; IUSS Working Group WRB, 2015). Anthropogenic colluvial deposits lacking any autochthonous pedogenic properties are designated “M” horizons after the German classification system, thereby including colluvial deposits into the pedological nomenclature. We use the term “colluvial deposit” to describe and differentiate M horizons from others with different sedimentological and pedogenic developments (Henkner et al., 2017). The German soil type “Kolluvisol” is defined by at least 40 cm thick colluvial deposits. Kolluvisols or “colluvial soils” can include several individual colluvial deposits formed during dif- ferent deposition events covering another soil type, sediment or rock (Ad-hoc-AG Boden, 2005). The “boundary A” marks the boundary between the colluvial deposits as an anthropo- genic sediment and the natural soil, sediment or bedrock (Edgeworth et al., 2015). The course of the boundary A can give information about the former land surface. A total of 161 bulk samples and 140 volumetric samples were taken.

Peat cores for pollen analysis were taken from bog profiles from Elzhof (32U 439905, 5329912, 940 m asl) and Moosschachen/Martinskapelle (32U 436878, 5327838, 1085 m asl; Fig. 1). Both are small raised bogs with an area of approximately 4 ha, situated near the village of Schoenwald in the southeastern Black Forest. In the centers of these two raised bogs, cores were taken with a Russian sampler, containing

4.0 m bog peat, superimposed on clay and mud at Elzhof, and 3.3 m bog peat superimposed on 0.4 m fen peat and clay at Moosschachen. The Elzhof core was sampled almost every 1 cm, resulting in 248 samples, and the Moosschachen core was sampled in an interval of mostly 12 cm, resulting in 72 samples.

3.2 Laboratory methods

All analyses were done on fine soil (< 2 mm). Soil pH was determined using a soil-to-solution (CaCl2, H20) ratio of 1:2.5 (Blume et al., 2010). Total C and N contents [mass %] were analyzed using oxidative heat combustion at 1150°C in a He atmosphere. Because of the low pH (< 6.9) and no known sources of inorganic C, total C equals soil organic C (SOC). Texture was determined by X-ray granulometry for grain sizes < 20 mm and combined sieving for grain sizes from 2000 mm to 20 mm.

A reverse aqua regia digestion was done for analyzing total heavy metal contents (DIN ISO 11466: 1997-06) using a HNO3 and HCl solution in a ratio of 1:3. Samples were digested using the program ‘‘E 701 Soil aqua regia’’ in the microwave (Start, MLS GmbH, Leutkirch). Solutions were analyzed for Cd, Cu, Cr, Ni, Pb, Zn, Hg, and As by use of ICP-OES (Optima 5300DV, Perkin Elmer Inc.). Used wavelengths were 228.802 nm for Cd, 327.393 nm for Cu, 267.716 nm for Cr, 231.604 nm for Ni, 220.353 nm for Pb, 206.2 nm for Zn, 194.168 nm for Hg, and 188.979 nm for As (Nölte, 2003).

Optically stimulated luminescence (OSL) dating was applied to estimate the deposition ages of the colluvial deposits. The coarse grain (90–200 mm) quartz fraction was prepared and measured with a single-aliquot regenerative-dose protocol after Murray and Wintle (2000) for equivalent dose (De) determinations. All luminescence measurements were carried out at the luminescence laboratory of the Justus-Liebig-University in Giessen. For data analysis, the R luminescence package (Kreutzer et al., 2016) was used. Therefore, small aliquots with a diameter of 1–2 mm were measured. Skewness of the equivalent dose distribution can result from partial bleaching or in situ redeposition, in which case a minimum age model was used.

AMS-^{14}C dating of charcoal fragments found within the colluvial deposits was done at the Max Plank Institute Jena and gives further evidence about maximum ages of colluvial deposits and human presence. The pretreatment was done using an ABOx (acid-base-oxidation) procedure (Steinhof, 2013; Steinhof et al., 2017). The calibration of the 14C ages was done with OxCal 4.2 using the IntCal13 calibration curve (Bronk Ramsey, 2009; Reimer et al., 2013).

Pollen samples were treated using HCl, hot HF if necessary, chloration, and acetolysis, and staining in glycerol (Berglund and Ralska-Jasiewiczowa, 1986). Data evaluation was done using Taxus (Rösch et al., unpubl.) and Tilia (Grimm, 1991). The relation between organic and minerogenic matter was determined as loss-on-ignition, sampling in 1 cm intervals (Berglund and Ralska-Jasiewiczowa, 1986). After drying for 12 h at 1020°C and weighing, the material was heated at 550°C for 2 h and weighed again. The difference in weight is the portion of organic matter. AMS-^{14}C dating on 27 peat bulk samples was carried out in the laboratories of Erlangen and Poznan. The calibration of the dates and construction of the Bayesian time and deposition models was done with OxCal 4.2 (Bronk Ramsey, 2009), assuming a recent age for the bogs surfaces. Cerealia adventives and species like Plantago lanceolata, Rumex and Urtica, as well as the total of non- arboreal pollen (NAP), were used as indicators of human impact (Behre, 1981; Rösch, 2014).

4 Results

4.1 Colluvial deposits

In contrast to the published soil maps (LGRB, 2013a), colluvial soils cover much of the studied slopes, even in upper backslope positions, overlying periglacial layers and are linked to alluvial sediments in toeslope positions. In this study, 58 colluvial deposits were identified in 17 soil profiles, with an average of three colluvial deposits per profile. Most soils were classified (IUSS Working Group WRB, 2015) as Dystric Cambisols (n = 12), and some profiles include the ‘‘Chromic’’ qualifier. The other soils are (Dystric) Protic Colluvic (Skeletic) Regosols (n = 5) situated in backslope positions (Henkner et al., 2017, submitted).

4.1.1 Breg valley

Colluvial soils in the upper Breg river valley (Fig. 2) show a typical distribution at the headwaters of the Danube tributary. Colluvial deposits occur first at the backslope (at auger Bhr18) and continue with varying depth downwards to the valley bottom (Bhr5). The profile Bre3 is situated in a former depression filled with two colluvial deposits overlying a cambic horizon. Around the profiles Bre1 and Bre2, the thick- ness of the colluvial deposits reaches a maximum of about 90 cm. The datings point to several phases of deposition and erosion since the Iron Age and Roman Empire, which is consistent with archaeological finds (Tab. 2, Fig. 7). However, the two colluvial deposits of Bre2 [BCE 90-CE 310 (GI 310), cal BCE 980–800 (P 12861)] are older than the ones of Bre1. Colluvial deposits of Bre1 [cal CE 1180–1250 (P 12687), cal CE 1030–1160 (P 12690)] date to the high Middle Ages. In the third colluvial deposit of Bre1, dated to 1030–1160 cal CE (P12690), a Cretaceous chert (Fig. 3), identified as a broken Neolithic blade, was found. This artefact was obviously relocated and incorporated into the soil much later.

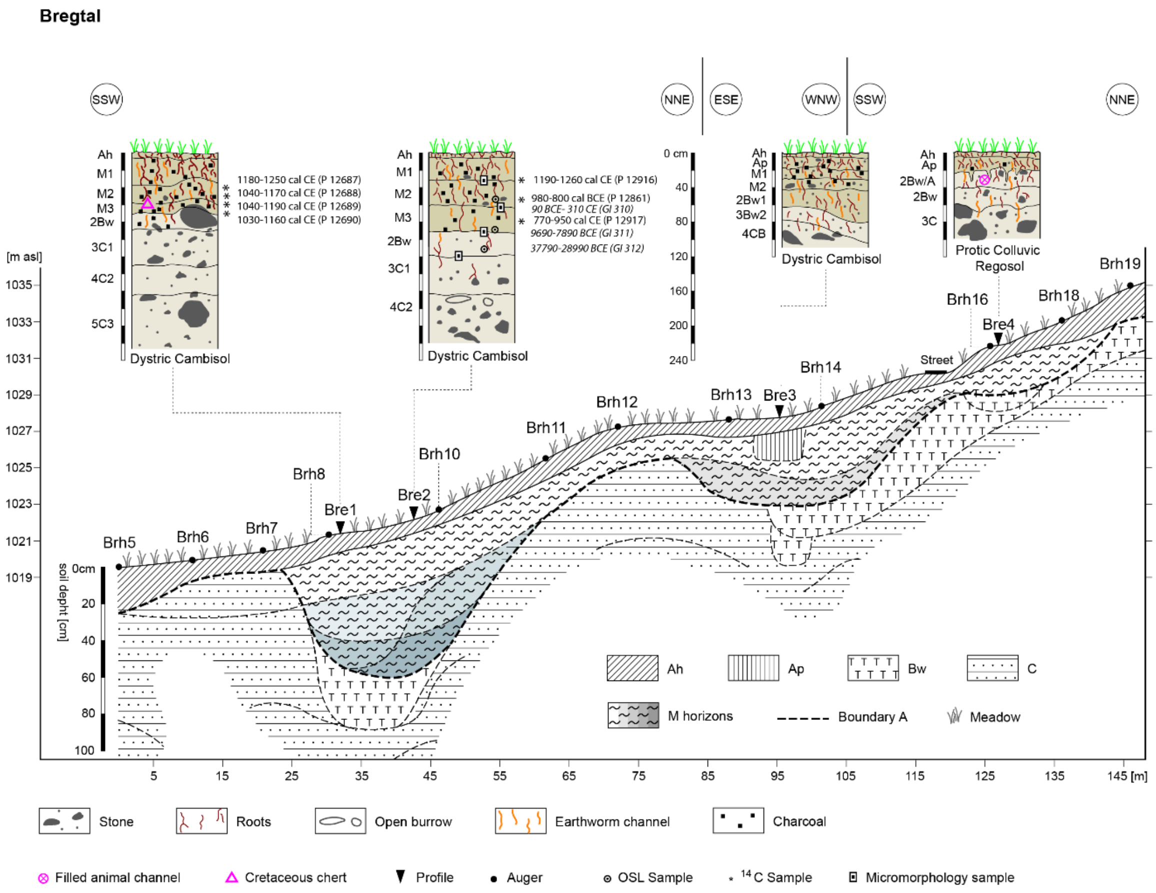

Fig. 2: Catena at the Breg river valley.

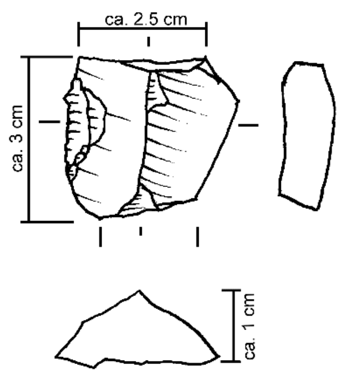

Fig. 3: The Cretacous chert found in Bre1 in 60 cm depth, interpreted as a Neolithic blade fragment.

4.1.2 Brigach spring

The colluvial deposits above the spring of the Brigach River (Fig. 4) are distributed according to land use and the course of the river. In the lower part of the soil pits, strong redoximorphic features are present, and the four colluvial deposits (visible in Fig. 4) are not continuously distributed. Further upslope the thickness of colluvial deposits decreases rapidly.

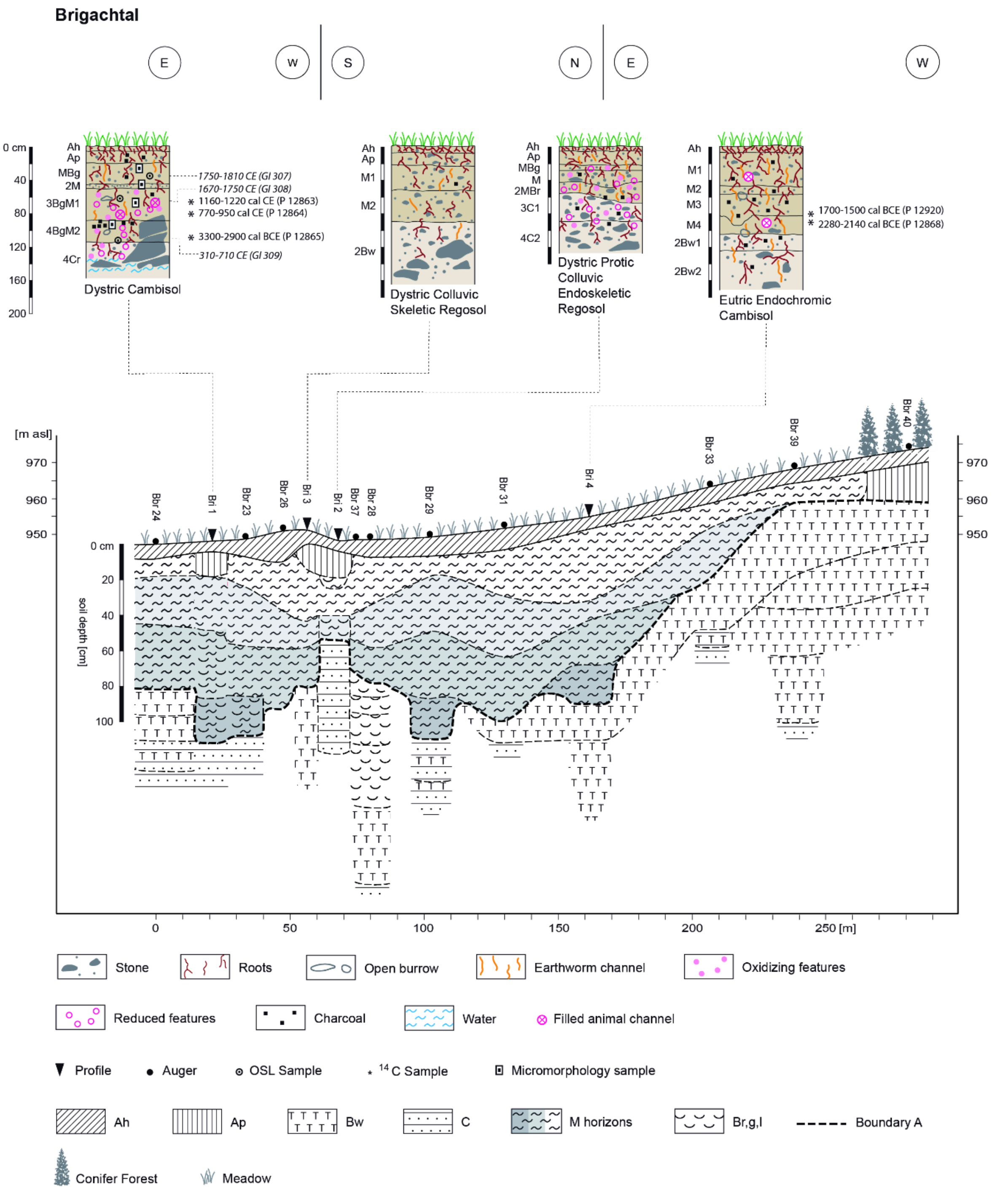

Fig. 4: Catena near the spring of the Brigach river.

The main colluvial deposition took place during the Middle Ages and the Modern time. The Neolithic [cal BCE 3330–2900 (P 12865)] charcoal in soil profile Bri1 stems from a layer of charcoals in the upper part of a colluvial deposit, while the corresponding OSL sample [CE 310–710 (GI 309)] dates to the Merovingian Period. Charcoal pieces sampled at 80 (M3) and 90 cm

(M4) depth in the Bri4 profile on the backslope date to the Bronze Age [cal BCE 1700–1500 (P 12868), cal BCE 2280–2140 (P 12920)]. The great sampling depth, the old charcoal ages, and the much younger OSL ages of Bri1 might indicate a later relocation of the charcoal fragments. None of the ages of the colluvial deposits correlate with the age of the stone relief at the Brigach spring, dating to the Roman Empire (Maier, 2006).

4.1.3 Upper Lehmgrubenhof

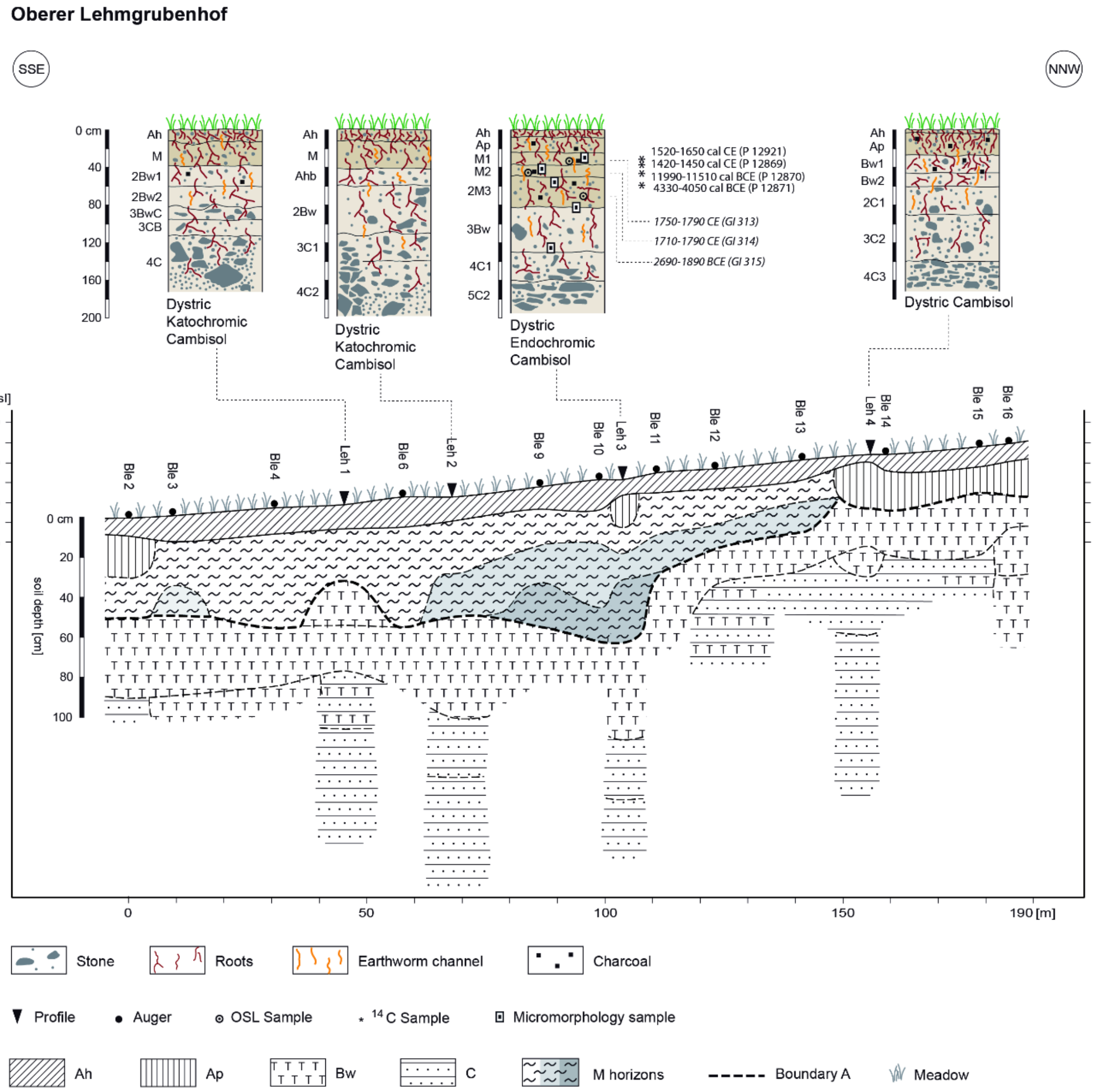

Fig. 5: Catena at the site Upper Lehmgrubenhof.

The catena at the Upper Lehmgrubenhof (Fig. 5) presents a distribution of relatively thin colluvial deposits. The Lehmgrubenhof farm uses a grassland/pasture and fields rotation every 10–20 years. Today, the gently inclining slope is used as a cow pasture. On the summit and shoulder (above Leh4) only a relict plow horizon, overlying a cambic horizon, was found. Colluvial deposits occur from the upper backslope (Ble13) downwards with a maximum thickness in the middle of the backslope (Leh3; Ble10-Ble9). Colluvial deposits cover the periglacial slope deposits. The rock fragment content (gneiss and a few dioritic dyke rock fragments) of all soil profiles is low in the colluvial part, but increases with increasing depth in the periglacial slope deposits. The former land surface was undulating, as shown by the wavy boundary A. An artificial pond, which is now filled with sediment, was situated at the lower part of the backslope (below Ble2). AMS-^{14}C and OSL ages from the lowest colluvial deposit in Leh3 point to land use around the transition from the Neolithic to the Bronze Age [cal BCE 4330–4050 (P 12871), BCE 2690–1890 (GI 315)], which is the oldest OSL age in the southeastern Black Forest. The Young Neolithic charcoal could indicate earlier human activities and might have been incorporated or redeposited during the Final Neolithic. The overlying colluvial deposits date to the Late Middle Ages to Early Modern Period [cal CE 1420–1450 (P 12869), cal CE 1520–1650 (P 12921), CE 1750–1790 (GI 313), CE 1710–1790 (GI 314)], but also include a Mesolithic charcoal fragment [cal BCE 11990–11510 (P 12870)].

4.1.4 Bubenbach

At the Bubenbach site (Fig. 6) colluvial deposits cover the complete backslope down to the footslope, where colluvial deposits alternate with alluvial deposits. The slope is used as a hay meadow. The obviously short duration of land use, beginning at the earliest during the Early Modern era [cal CE 1520–1660 (P 12873), cal CE 1510–1640 (P 12922)], led to a maximum thickness of the colluvial deposits of 50 cm. The thickest colluvial deposit is found in the profile Bub4, which is situated on the backslope, just above a street functioning as a sediment trap. Further upslope, the thickness of colluvial deposits decreases rapidly. The former land surface was rolling, as inferred from the wavy boundary A. Granite is the most important component of the rock fragments found in the soil profile, but also sandstone and granitic porphyric dyke fragments are present.

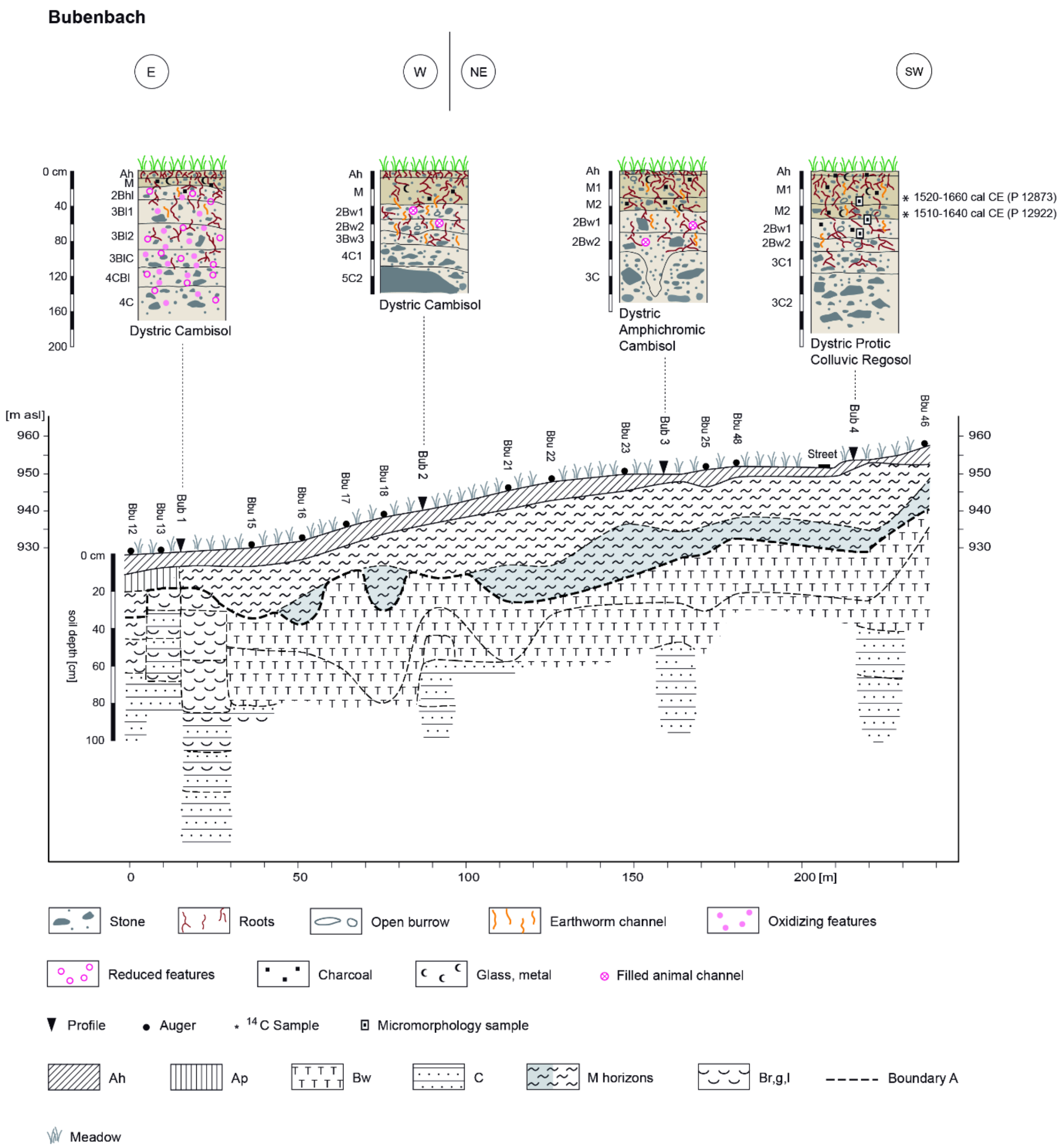

Fig. 6: Catena in Bubenbach.

4.2 Chronostratigraphy

Based on the datings (Fig. 7; Henkner et al., 2017, submitted) and the cultural periods, five phases of colluvial deposition can be distinguished (Fig. 7). The oldest phase (1) dates from the Younger Neolithic to the Early Bronze Age and includes ages from the Lehmgrubenhof and Brigach sites. The second phase (2) dates from the Early Bronze Age to the Roman Empire. These older phases are represented by only few datings and are characterized by minor intensity of colluviation. The third phase (3) from the Migration Period to the Late Middle ages is a main phase of colluvial deposition at the sites Brigach and Breg. The fourth (4) phase, dating to the Early Modern Period, can be interpreted as a main colluviation phase at the sites Bubenbach and Lehmgrubenhof. The fifth (5) phase covers the recent Modern Era.

A comparison of the physically correct radiocarbon and OSL ages shows that the radiocarbon ages have to be considered as maximum ages, since they are generally 100–3500 years older than OSL ages from the same depth and horizon. Under the assumption that the charcoal was produced in an anthropogenic setting, the radiocarbon ages can be interpreted as proxies for human activity or presence. The OSL ages of colluvial deposits refer to the time of sediment deposition and, thus, to periods of intensive land use which led to soil erosion and accumulation.

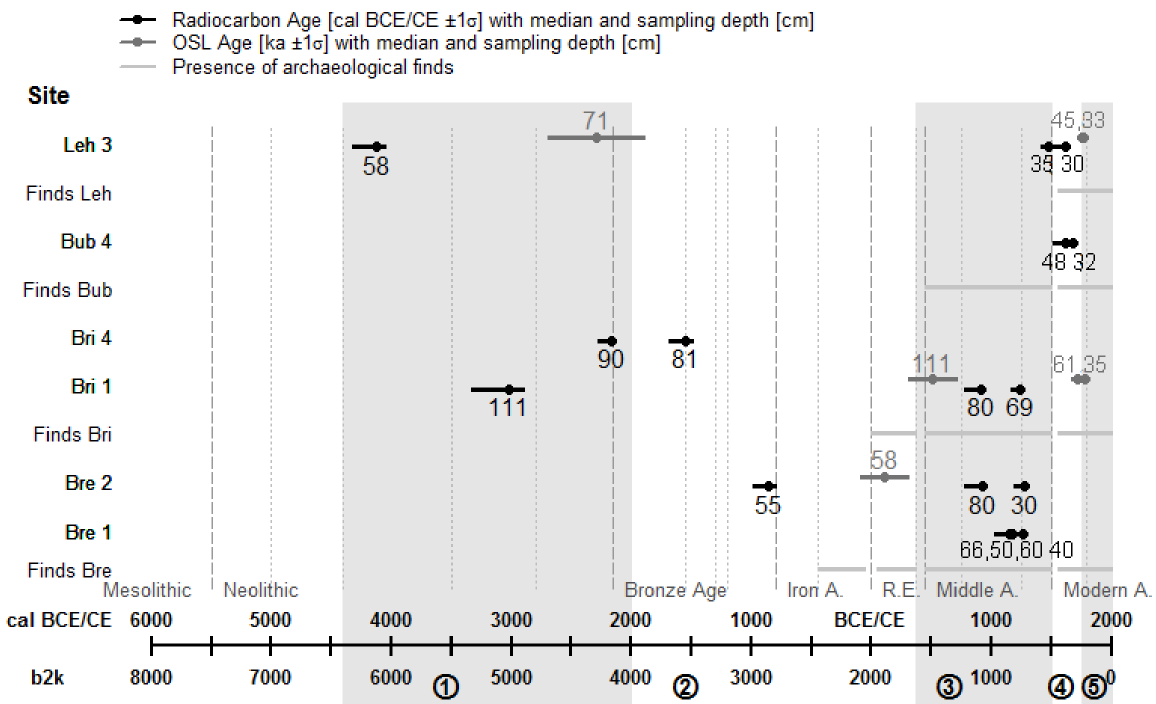

Fig. 7: Radiocarbon and luminescence datings of colluvial deposits in the eastern Black Forest related to cultural periods. The background color indicates different time slices or colluviation phases and the circled numbers give the age group: (1) = Younger to early Bronze Age, (2) = Bronze Age to Roman Empire, (3) = Migration Period to Late Middle Ages, (4) = Early Modern Period, (5) = Modern Era.

4.3 Heavy metal contents

Cd content was mostly and Hg content was always below the detection limit (0.2 mg kg–1 for Cd and 0.54 mg kg–1 for Hg). Therefore, Cd and Hg were excluded from further interpretation. The geologic background levels of heavy metal contents (LGRB, 2016) are given in Fig. 8. Contents of heavy metals were grouped according to the distribution with depth and colluviation period (Fig. 8). Contents of all analyzed heavy metals are mostly within the median range of the geologic background values (LGRB, 2016). The exception is As, which has a broad range but is generally above the geologic background level.

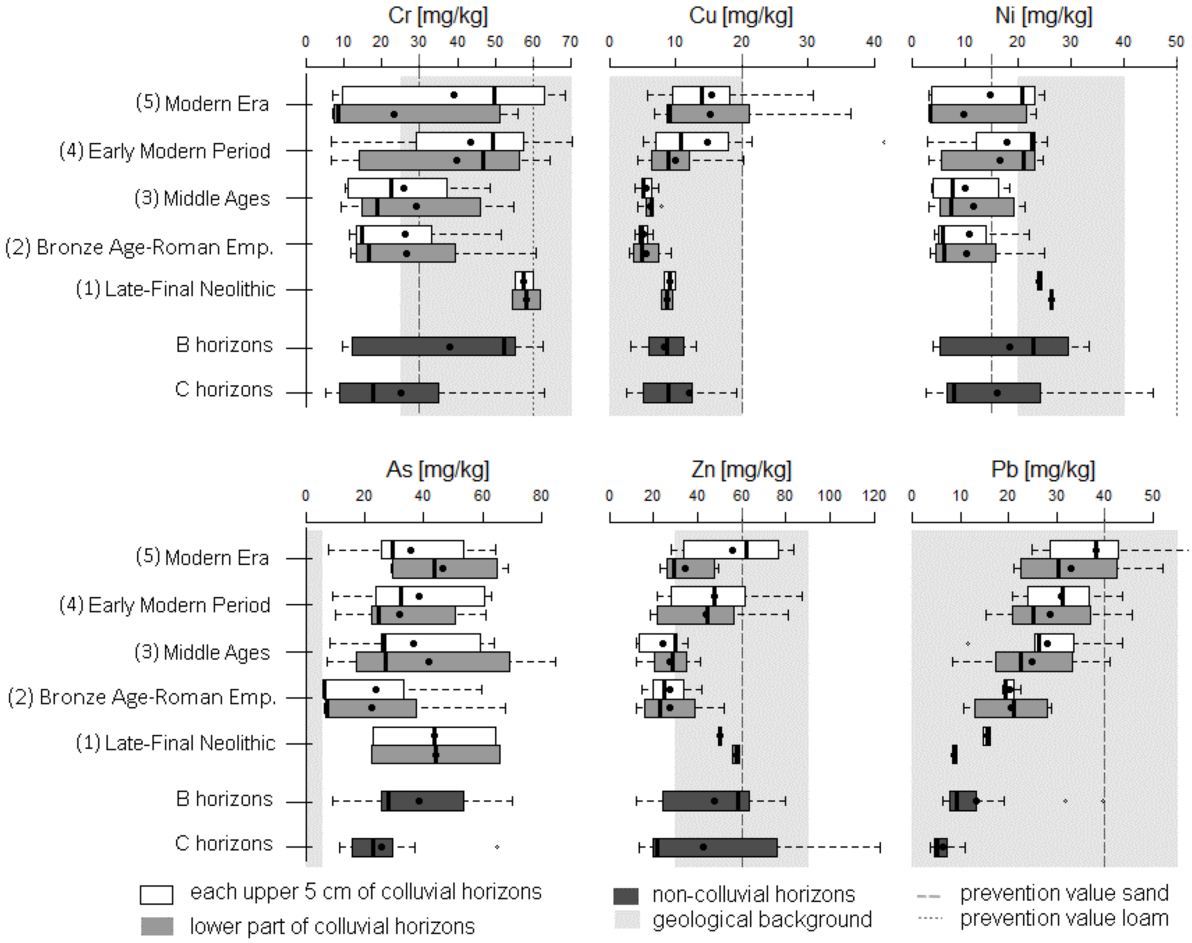

Fig. 8: Heavy metal contents according to the approximate age and soil horizon type (colluvial deposits, B or C horizons). Note different scales for each metal. The grey background displays the median range of the geological background content (*Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg* 2016). Prevention values according to *Bundesministerium der Justiz und für Verbraucherschutz* (1998); no prevention value exists for As.

The depth function of heavy metal contents is different in all investigated profiles (Fig. 9). The sites Brigach spring and Lehmgrubenhof have similar contents of Cr, Ni, and Zn than the Breg valley and Bubenbach sites. The sites Brigach and Lehmgrubenhof have predominantly higher heavy metal con- tents and the same bedrock type (paragneiss). Small peaks of increased or decreased heavy metal contents occur, but a general trend can hardly be noticed with depth. In a redoximorphic colluvial deposit (50–88 cm depth) dated to the Middle Age of Bri1 the contents of As, Cr, Zn, and Pb are increased. In contrast, the contents of As, Cr, and Pb are lower in the underlying Merovingian and the overlying modern colluvial deposits. The Bre1 profile shows maximum contents of As and Pb in a colluvial deposit from the high Middle Ages and in the underlying subsoil horizon (38–90 cm depth). A few meters upslope in soil profile Bre2, the Pb content reaches a local minimum in the medieval colluvial deposit and a local peak in an Iron Age deposit. Local maximum contents of Zn, Cr, Pb, and Cu at the Lehmgrubenhof site occur in modern colluvial deposits and seem to be related to the geologic parent material since the heavy metal content is increasing with depth. Zn and Ni contents even exceed the median of the geologic background values in the lower C horizons (LGRB, 2016). The anthropogenic input of heavy metals at the Bubenbach site, i.e., extreme Cu and Pb contents in colluvial deposits, result in higher heavy metal contents than the average span of the median of the geologic background.

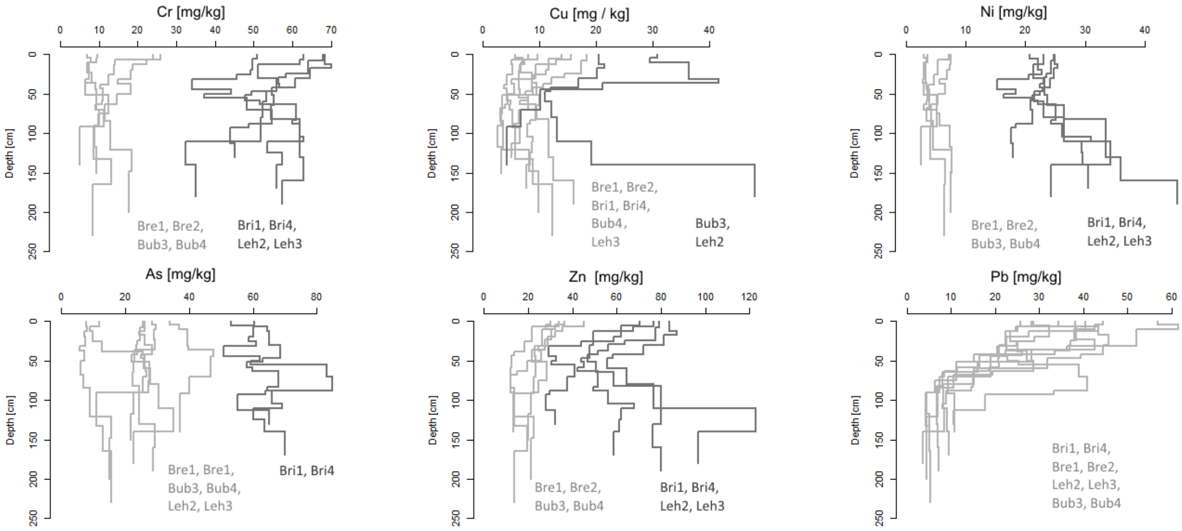

Fig. 9: Depth functions of selected heavy metals [mg kg^{-1}] grouped related to similarity.

Pb content generally decreases with depth and can therefore be interpreted as an anthropogenic phenomenon. The contents of Cr, Ni, and Zn are even below the geologic background, which might be related to the low soil pH and, thus, relocation of heavy metals. The As contents of all soil profiles are above the median of the geological background, but mostly below the 90th percentile and correspond to the contents of the B horizons. Outliers of As content (> 60 mg As kg–1, above the 90th percentile) occur in Bre1, Bri1, and Bri4.

Pearson's correlation index (Tab. 3) shows that the particle size and pH value are the most important parameters predicting heavy metal content. There is a strong correlation between the particle sizes and pH for Cr, Zn, and Ni contents, whereas Cr and Ni contents are strongly correlated to each other. Only Pb content correlates positively with SOC and Cu content, which in turn correlates with sand content.

Table 3: Pearson's correlation coefficient of soil properties of the colluvial deposits (A and M horizons, number = 60) on the upper right panel and significance levels on the lower left. Bold = Correlation values >0.5 or <-0.5, ° = not normal distributed values.

	SOC	**pH °**	**BD**	**Sand**	**Clay °**	**Silt**	**As °**	**Cr °**	**Pb**	**Zn**	**Ni °**	**Cu**
SOC		-0.23	-0.16	-0.44	0.35	**0.51**	-0.09	0.35	**0.54**	**0.55**	0.27	-0.41
pH °	0.083		-0.05	**0.51**	**-0.54**	-0.48	-0.35	**-0.86**	0.26	**-0.71**	**-0.84**	0.29
BD	0.230	0.704		0.39	-0.38	-0.39	-0.20	-0.17	-0.18	-0.10	-0.20	0.08
Sand	0.000	**0.000**	0.002		**-0.96**	**-0.96**	**-0.56**	**-0.76**	-0.21	**-0.71**	**-0.76**	0.50
Clay °	0.006	**0.000**	0.004	**0.00**		**0.88**	**0.65**	**0.79**	0.15	**0.73**	**0.81**	**-0.51**
Silt	**0.000**	0.000	0.002	**0.00**	**0.00**		0.43	**0.70**	0.29	**0.72**	**0.68**	**-0.54**
As °	0.496	0.007	0.127	**0.00**	**0.00**	0.001		0.49	-0.04	0.36	**0.54**	-0.35
Cr °	0.006	**0.000**	0.194	**0.00**	**0.00**	**0.000**	0.00		-0.08	**0.85**	**0.99**	-0.46
Pb	**0.000**	0.044	0.169	0.11	0.27	0.023	0.77	0.545		0.27	-0.13	**-0.52**
Zn	**0.000**	**0.000**	0.455	**0.00**	**0.00**	**0.000**	0.00	**0.000**	0.037		**0.84**	**-0.75**
Ni °	0.040	**0.000**	0.135	**0.00**	**0.00**	**0.000**	**0.00**	**0.000**	0.333	**0.000**		-0.45
Cu	0.001	0.028	0.533	0.00	**0.00**	**0.000**	0.01	**0.000**	**0.000**	**0.000**	0.000	

4.4 Vegetation history

The radiocarbon ages (Henkner et al., 2017, submitted) of Elzhof provide a consistent time-depth model (Fig. 10). Two be calibrated reliably and had to be excluded before calculating the time model. Especially at Elzhof, peat growth slowed down in the upper 35 cm, most probably caused by artificial drainage during the Middle Ages or Modern Times. Therefore, the uppermost pollen sample was estimated to date to 1300 CE. The two pollen profiles show a record of the forest-dominated vegetation history of the last 8000 years. The Elzhof profile (Fig. 11) shows the typical central European succession (Firbas, 1949). Around 4000 BCE peaks of Abies and Fagus pollen are accompanied by peaks of Tilia, Vaccinium type, Calluna, Sphagnum, and first traces of human indicators such as cereals and Plantago lanceolata. After their final in- crease around 3300 BCE the shade trees Abies and Fagus dominate the pollen record until 1000 CE. No further traces of human impact are visible until 2000 BCE. Around 1000 BCE a slight increase of NAP suggests an increased human impact on vegetation. With the beginning of the Roman Empire, deforestation indicates a stronger human impact, but reforestation occurred during the Migration Period. The human impact increases from the Early Middle Ages onwards and Abies decreases around 700 CE. Fagus decreases around 1400 CE and Pinus, Picea, and NAP dominate the pollen record since then. A high number of Pinus pollen reflects the recent vegetation of the peat bog, where a forest of Pinus mugo ssp. rotundata developed after drainage. During the Middle Ages and Modern Times, deforestation increases and the anthropogenic impact on the vegetation cover, as shown by the pollen record, is high.

The Moosschachen pollen profile (Fig. 12) shows a similar vegetation record. Abies and Fagus expand around 3700 BCE, and Abies dominates the pollen record until 700 CE and Fagus until 1400 CE. The record shows < 5% NAP from 2000 BCE until the end of the High Middle Ages. Pollen concentrations of cereals and other indicators of human impact remain very low and scattered. Distinct human impact is not indicated before 1400 CE, when pollen of cereals, Plantago lanceolata, and other human indicator pollen occur, along with an increase of charred particles and a decrease of organic matter.

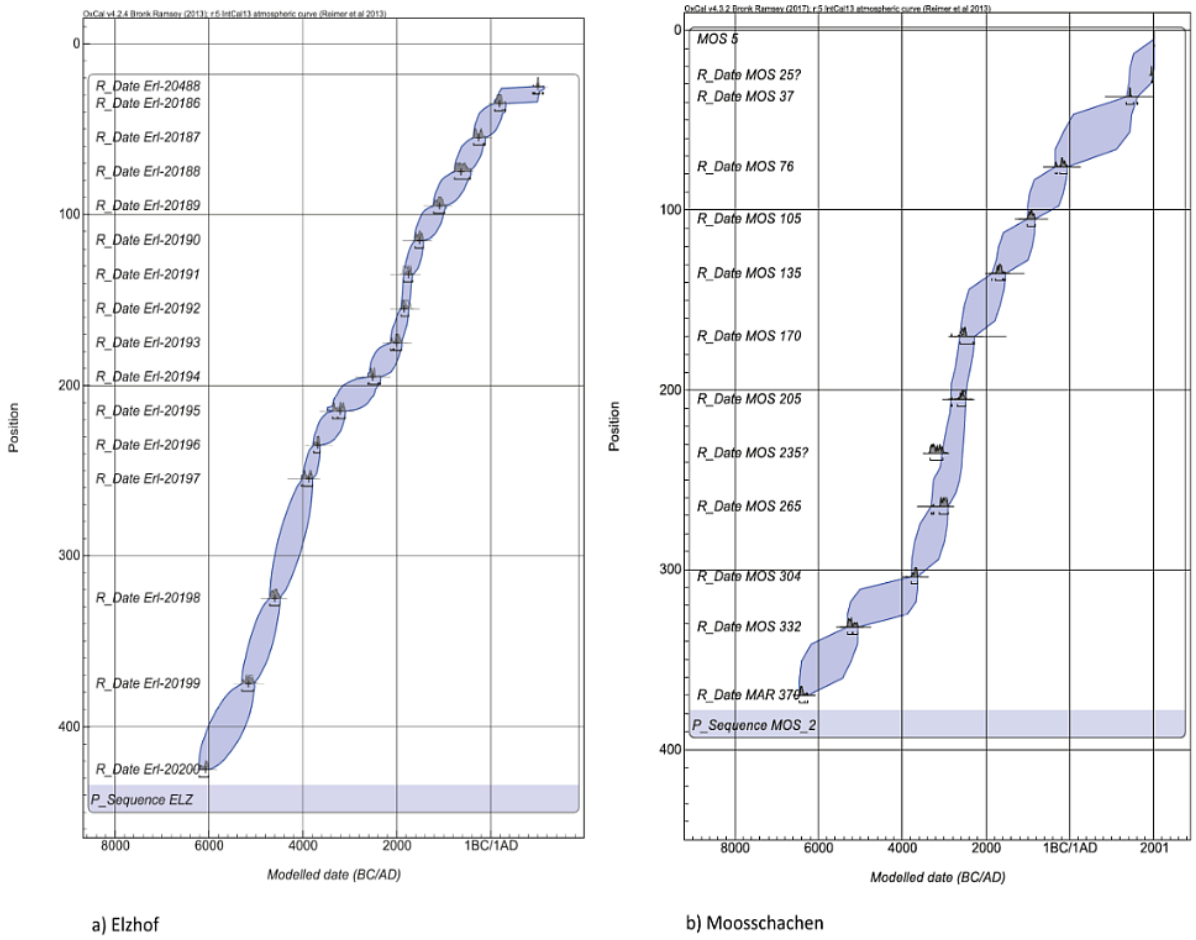

Fig. 10: Deposition models for the pollen sequences of a) Elzhof and b) Moosschachen.

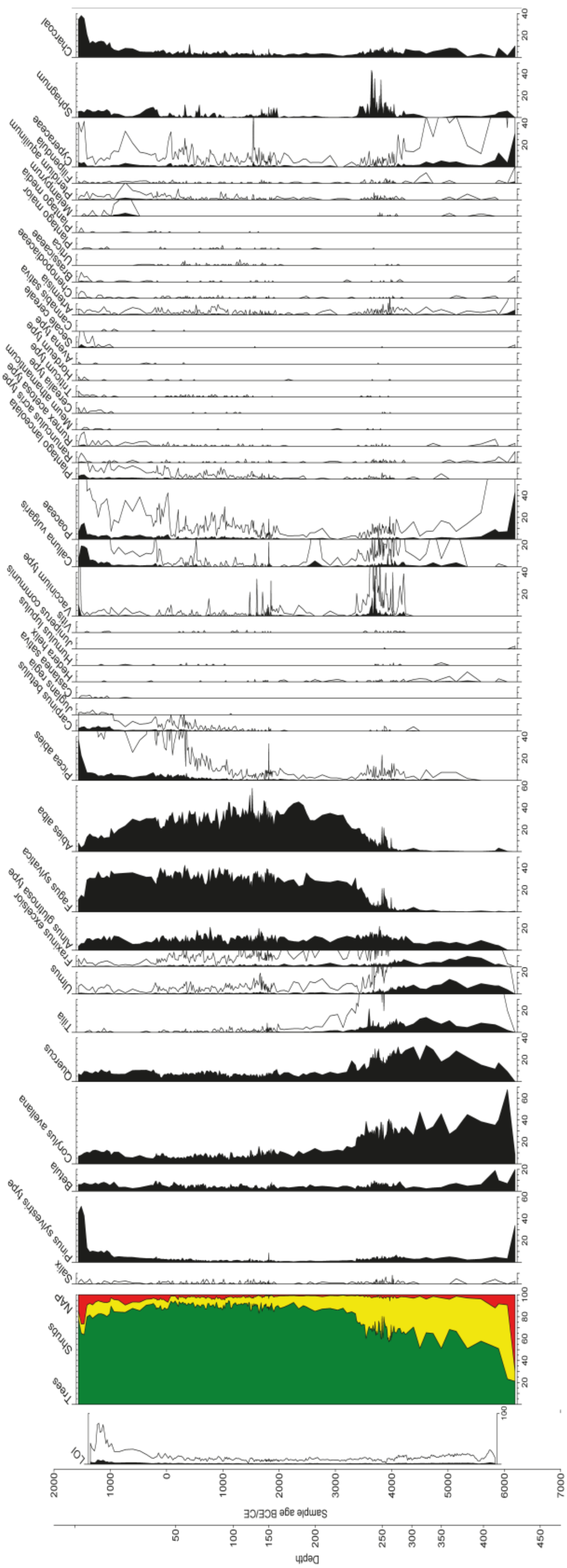

Fig. 11: Pollen profile of Elzhof (the white curves are tenfold inflated).

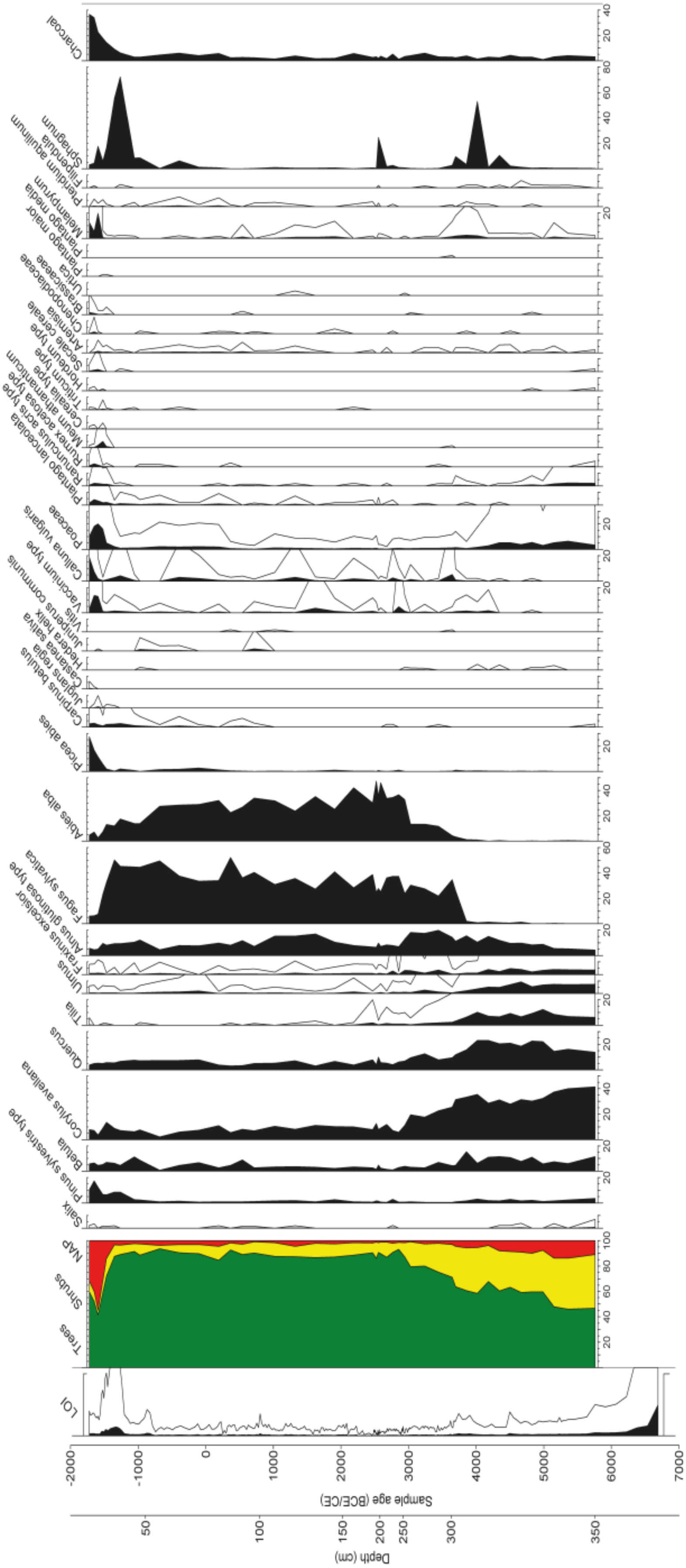

Fig. 12: Pollen profile of Moosschachen (the white curves are tenfold inflated).

5 Discussion

5.1 Interpreting heavy metal contents

The distribution of anthropogenic heavy metal contents would be expected to decline with soil profile depth and to increase if heavy metals originate from the underlying rock. Since the studied colluvial soils are mainly influenced by materials from up slope positions through periglacial and colluvial processes, such processes need to be considered to understand the distribution of heavy metals along slopes. Selective horizontally or vertically increased amounts of certain heavy metals would point to anthropogenic input and, thus, land use. Usually the heavy metals Pb, Cu, Zn, Cr, and Ni are supposed to have the best explanatory power for historic land use, since they are known to have been used (Schell, 1998; Gonnelli and Renella, 2013; Mertens and Smolders, 2013; Oorts, 2013; Steinnes, 2013). Cu and Zn are components of bronze and might have ended up in soils near smelting sites. Cr and Ni could have been used as secondary components for bronze or they could have been included in the used ore. Pb was used by the Romans and during the Middle Ages in, e.g., water pipes. Cd and As were used mainly since around 1900 CE, thus, they can be interpreted as proxies for recent land use (Völkel, 2003; Smolders and Mertens, 2013). Since the mobility of heavy metals in the soil is largely influenced by pH, soil organic matter and clay content (Young, 2013), results from the Black Forest have to be cautiously interpreted, due to a low pHCaCl2 of mostly 4–5. Zn is mobile at $pH < 6$, Ni at $pH < 5.5$, whereas As, Cr, Cu, and Pb get mobilized at $pH < 4.5$ (Schimming, 2011). Additionally, anthropogenically increased heavy metal contents bound to aggregate surfaces are easier to mobilize than naturally occurring heavy metals (Filipinski 1989; Blume et al., 2010). A relocation of heavy metals with percolating water is likely, given the long time period, low pH, and redox conditions. Nevertheless, peaks of different metals occur in some of the profiles, which do not correlate with other soil parameters (pH, SOC, texture). Thus, they might be interpreted as resulting from anthropogenic input into the colluvial deposit.

The increased contents of Cu, Ni, As, and Zn in the subsoils of the Lehmgrubenhof profiles seem to stem from the weathering product of the underlying paragneiss, which has higher contents of these heavy metals. The oldest colluvial deposits contain less heavy metals than the C horizons. The pH values, Zn, Pb, Cu, and Cr contents increase from the oldest colluvial deposit to the former plow horizon (Ah, Ap, M1) indicating modern agricultural practices using fertilizer or liming.

5.2 Early land use in the southeastern Black Forest

5.2.1 Mesolithic and Neolithic (Phase 1)

Two samples of colluvial deposits and charcoal date to the Mesolithic and might indicate Mesolithic land use. The dated charcoal at Lehmgrubenhof [cal BCE 11990–11510 (P 12870)] seems to be an old charcoal being relocated in the soil profile, given the Late Neolithic OSL age [BCE 2690–1890 (GI 315)] of the underlying colluvial deposit. The Mesolithic OSL age from the Breg valley [BCE 9690–7890 (GI 311)] obtained from the base of the colluvial deposit might result from a mixture of the colluvial deposit with the underlying periglacial layer and is thus not related to the time of the formation of the colluvial deposit.

Neolithic human impact is recorded in the Brigach river valley and at the Lehmgrubenhof, where radiocarbon [cal BCE 4330–4050 (P 12871,) cal BCE 3330–2900 (P 12865), cal BCE 2280–2140 (P 12920)], and OSL ages [BCE 2690–1890 (GI 315)] point to initial land use during the Neolithic. Single charcoal fragments can result from naturally occurring forest fires, but the rather cold and wet climate in Central European low mountain ranges (Schönwiese, 1995; Jäger, 2002) and the domination of poorly flammable species like Abies and Fagus (Robin et al., 2014) make the occurrence of frequent natural forest fires unlikely. From the Younger Neolithic to the Iron Age, the land might have been used sporadically and locally. There is no correspondence to archaeological finds in the vicinity of the Black Forest sites, except for the Neolithic blade found in the medieval colluvial deposit of soil profile Bre1. Archaeobotanical and archaeological analyses in that area showed phases of land use during the Younger and Final Neolithic (Valde-Nowak and Kienlin, 2002; Rösch, 2009). Additionally, land use was detected during the Younger Neolithic in the neighboring Baar Region (Ahlrichs et al., 2016; Henkner et al., 2017). Land use in the southeastern Black Forest might have included small scale (wood) pasture, deforestation, hunting, and mining, which might have led to minimal colluvial deposition. During the Younger Neolithic it was probably associated with pastoral activity, where shepherds moved their livestock from the western Baar into the Black Forest for summer pasture (Ahlrichs et al., 2016). This scenario does not necessarily lead to the formation of colluvial deposits, but it might explain the

Neolithic and Bronze Age charcoal fragments at Lehmgrubenhof [cal BCE 4330–4050 (P 12871)], Brigach spring [cal BCE 3330–2900 (P 12865), cal BCE 2280–2140 (P 12920), cal BCE 1700–1500 (P 12868)], and possibly also in the Breg valley [cal BCE 980–800 (P 12861)]. A charcoal layer at the bottom of the 4BgM2 horizon of Bri1 (88–113 cm), dated to the late Roman Empire and Merovingian Period [CE 310–710 (GI 309)], contains at least one probably relocated Neolithic charcoal fragment [cal BCE 3330–2900 (P 12865)]. The Neolithic charcoal points to early land use. Further Final Neolithic and Bronze Age charcoal fragments in soil profile Bri4 [cal BCE 2280–2140 (P 12920), cal BCE 1700–1500 (P 12868)] sup- port the interpretation of some kind of land use at the site, which prevented soil erosion, and is therefore not recorded in OSL dated colluvial deposits. Later on, those charcoal pieces became incorporated into colluvial deposits, when (subsistence) agriculture was intensified and unsustainable land use began leading to soil erosion and accumulation. The pollen re- cord from Elzhof also points to initial human activities during the Younger Neolithic. The human impact during the Late Neolithic and Early Bronze Age is rather weakly documented in both pollen profiles. At the Lehmgrubenhof colluvial deposition sets in during the Final Neolithic, at the Brigach and Breg river valleys firstly during the Roman Empire (or late Latène Period).

As in other landscapes, Neolithic human impact is normally not connected with a distinct increase of NAP, and colluvial deposits are rare (Kalis et al., 2003). The reason for the lim-ited explanatory power of the human impact proxies (occurrence of NAP, well stratified colluvial deposits, and archaeological finds) may lie in different land use systems, as was demonstrated in studies in more favorable areas (Rösch et al., 2014). Land was used typically in small clearings, possibly with some kind of a ‘‘plenter’’ system, using selective cutting (Schütz, 2001). Pollen precipitation may also have been influenced by the ‘‘glade effect’’, which describes the increase of arboreal pollen as a result of landscape opening (Feeser and Dörfler, 2014).

The sites Brigach and Breg are situated near the springs of Danube tributaries flowing east and traversing the Baar region, the localization might point to the river valleys giving access to the landscape and connecting the Black Forest with the Baar (Revellio, 1935). Colluvial deposits at the site Lehmgrubenhof also indicate Neolithic land use, but in contrast to the sites Brigach and Breg it is not situated next to a river. However, the etymology of the site’s name might indicate more favorable conditions, pointing to loamy soil compared to the surrounding sandy acidic soils, which might have been a reason for people to settle at this site.

5.2.2 Bronze Age, Iron Age, and Roman Empire (Phase 2)

OSL datings barely depict colluvial deposition during most of the Bronze and Iron Age in the southeastern Black Forest. One possible reason is that the practiced land use did not lead to soil erosion and colluvial deposition. Another possibility is that the intensive land use and soil erosion during the Middle Ages led to erosion of earlier deposited colluvium. In this case, OSL dating of colluvial deposits would result in medieval ages. The occurrence of few charcoal fragments [cal BCE 1700–1500 (P 12868), cal BCE 980–800 (P 12861)] and the absence of archaeological finds in the vicinity of the sites might support this explanation. Other studies, however, reported Bronze and Iron Age colluvial deposits in this area, which may point to a bias of site selections. Despite of absent area-wide colluvial deposits, weak evidence of human activity is given through frequent occurrence of cereal pollen (Triticum-type). After 2000 BCE (Bronze Age) the concentrations of human indicator pollen increase moderately but remain at a low level until the Roman Empire at Elzhof and until the High Middle Ages at Moosschachen. There is a continuing discussion about the origins of human indicator pollen in low mountain ranges (Firbas, 1949; Grosse-Brauckmann, 1978; Hölzer and Hölzer, 2003; Rösch, 2012). We hypothesize that non wind-pollinated types of pollen, such as from Cerealia, and wind-pollinated sources from small herbs, like Plantago lanceolata, are not transported over long distances in wooded areas like the Black Forest. Therefore, the pollen evidence, especially of the Elzhof site, can be interpreted as a sign of small-scale prehistoric human impact in the vicinity of the bogs, within distances of a few kilometers.

A peak of Pb occurs in a colluvial deposit interpreted to have formed at the end of the Late` ne Period and during the Roman Empire [BCE 90-CE 310 (GI 310)], which indicates human influence. The increased Pb content is most likely of anthropogenic origin, since it correlates to no other analyzed soil variable, like pH or SOC content. Pb might result from silver mining, where it is a by-product. Pb was also used in water pipelines and plugs during the Roman Empire, but nothing is known about the mining of Pb ore in this area of the Black Forest during the Iron Age.

During the Roman Empire human indicator pollen became more abundant at the Elzhof site. Furthermore, archaeological finds point to human presence in the Breg and Brigach river valley during the Roman Empire, and human presence led to the beginning of colluvial deposition as interpreted from the OSL ages [BCE 90-CE 310 (GI 310), CE 310–710 (GI 309)]. Additionally, roads connecting the Rhine river valley with the Gaeu landscape northeast of the Black Forest are known from the Roman period. However, prehistoric human impact is weaker in the southeastern Black Forest than in the northern Black Forest (Rösch, 2012) and much weaker than in the Lake Constance area (Fischer et al., 2010; Rösch and Lechterbeck, 2016).

5.3 Main colluviation phases and intensified land use

5.3.1 Land use during the Middle Ages (Phase 3)

Paleoclimate reconstruction based on tree rings (Büntgen et al., 2011) shows an increase of summer temperature and precipitation from the Merovingian Period to High Middle Ages (Medieval Optimum), leading to increased settlement activities and agricultural land use (Zimmermann et al., 2009; Zimmermann, 2012; Schreg, 2014), resulting in the formation of colluvial deposits at the sites Brigach and Breg. This phase of colluvial deposition can be interpreted as the first main colluviation phase. It is in good accordance with archaeological finds and the increase of human indicator pollen concentrations in the nearby bogs. In the Early Middle Ages, an intensification of agrarian production and change at the expense of livestock breeding, which had been important during the Migration Period, took place (Schreg, 2014). Traditional medieval land use in the central and southern Black Forest typically focused on animal husbandry, with small-scale agriculture, extensive forest pasture, small clearings, and mining (Häbich, 2009). Mining activities or the use of iron ore is also visible from heavy metal peaks (Pb, As, Cr, Zn) in the soil profiles in the Breg and Brigach river valley (Bre1, Bri1). As contents are increased to about 26 mg kg^{-1} at 38–90 cm depth in Bre1 (M2, M3, 2Bw), even though pH is constant and SOC and clay contents are decreasing with depth. Therefore, As can be interpreted as resulting from anthropogenic input most likely during the High Middle Ages. The fact, that the As peak includes the 2Bw horizon might point to leaching or land use practices preventing soil erosion before land use techniques changed and soil erosion and accumulation took place. The As contents of about 15 mg kg^{-1} in C horizons of Bre1 and Bre2 suggests that the local granite contains As, but cannot explain the strong increase in the upper horizons. The colluvial deposit of Bri1 at 50–88 cm depth (3 BgM1) shows increased contents of Pb, As, Zn, and Cr. In this case, these higher contents are correlated with the clay, silt, and SOC contents. Given the high groundwater table and high precipitation, the increase of these contents might result from a relocation within the soil profile and cannot be interpreted as a doubtless indication of land use like mining, smelting, or making brass and bronze items during the High Middle Ages. The high contents of Pb, As, Zn, and Cr suggest that this type of land use was practiced during the High Middle Ages or Modern Times. Zn and Pb contents are highest near the soil surface, pointing to a very recent input.

The late Middle Ages show a different temporal pattern of summer temperature and precipitation, and very few colluvial deposits date to that period. The occurrence of the Black Death around 1350 CE influenced population dynamics (Cohn Jr., 2008; Schmid et al., 2015). Fewer people probably used less land and the more stable environment prevented soil erosion and, thus, colluvial deposition.

5.3.2 Modern land use (Phase 4 and 5)

During the second main colluvial deposition phase in the Early Modern Period, colluvial deposits formed at three investigated sites in the southeastern Black Forest. Precipitation increased and was higher than the average of 1901–2000 (Büntgen et al., 2011). Summer temperatures were lower, but also slightly increasing (Büntgen et al., 2011). Population density increased (Zimmermann, 2012) and is thought to have triggered the increased formation of colluvial deposits.

It is the first colluvial deposition at the site Bubenbach. At the Lehmgrubenhof site, deposition sets in again after a deposition gap from the Bronze Age to the Middle Ages. The number of archaeological finds and the amounts of cereal and other NAP increase until the end of the Early Modern Period. There are, however, several modern peaks of heavy metal contents, especially Pb content is increased in the younger colluvial deposits. At the Bubenbach site Pb and Cu contents increase in the upper horizons (Ah, M1, M2), which might result from medieval or modern anthropogenic input through smelting or using pesticides on agricultural fields. Since then, the proportions of human indicator pollen and colluvial deposition decrease. This might be a result of a shift from arable farming to animal husbandry and thus towards a higher ratio of pastures or generally a less intensive land use because of economic reasons.

5.4 Land use dynamics in unfavorable and favorable areas

In the unfavorable Black Forest colluvial deposition and, thus, intensified land use began in the Neolithic at two sites. Land use seems to have been practiced locally and not continuously at these sites. Only during the Middle Ages, colluviation increased and spread. Therefore, it can be concluded that land use intensified. In the favorable Baar area (Henkner et al., 2017) the formation of colluvial deposits occurred more frequently, suggesting more intensive land use than in the Black Forest. On the Baar seven main phases of colluvial deposition are discussed in Henkner et al. (2017): (1) during the Younger Neolithic (> 3800 BCE), (2) the early to middle Bronze Age (> 1550 BCE), (3) the Iron Age (> 500 BCE), (4) the Roman Empire (> 100 CE) and (5, 6, 7) from the high Middle Ages onwards (> 1200 CE, 1300 CE, 1600 CE). The intensity of the phases of increased colluvial deposition is increasing with time, which can be explained by the increasing influence of humans rather than changing environmental conditions. Climate reconstructions alone do not explain the colluvial pattern in the Baar region (Henkner et al., 2017). Even though colluvial deposition and, thus, land use patterns are much reduced in the Black Forest, humans can be seen as the main controlling factor in the Black Forest, too.

6 Conclusions

This paleo-ecological study, in which we integrated phases of colluvial deposits with results of archaeology and palynology, led to the following conclusions

- Also sites without archaeological evidence of prehistoric human activity record former land use in colluvial deposits.
- The pattern of colluvial deposition points to little and only local, sporadic, low intensity land use during pre-medieval times in the southeastern Black Forest.
- Main phases of colluvial deposition are the High and Late Middle Ages and the Early Modern Era, indicating intensive land use during those periods.
- Pollen analysis indicates the beginning of human impact during the Younger Neolithic and an increase in the concentrations of cereal type pollen and other NAP during the

Middle Ages and Early Modern Era, supporting the archaeopedological findings and pointing to agricultural land use during the Middle Ages.

- Higher heavy metal contents in medieval and modern colluvial deposits indicate anthropogenic input, but they are not specific for a certain type of land use.
- Land use might have spread from the Baar region into the Black Forest, since it was settled earlier, more intensively and more continuously than the southeastern Black Forest.

Author contribution

Jessica Henkner, Peter Kühn, Thomas Scholten, Thomas Knopf and Jan Ahlrichs designed the archaeopedological study and JH carried it out. JH prepared the manuscript with contributions from all co-authors. Manfred Rösch and Elske Fischer designed the pollen study and analyzed and interpreted the pollen record.

Acknowledgements

This study is part of the Collaborative Research Center 1070 ResourceCultures (SFB1070) and is financed by the German Research Foundation (DFG).

We are grateful to many student helpers and technical assistants from the Tübingen University, who worked in the field and the lab, especially Dominik Birkenmaier, Sophie Neubaur, Mario Ahnert and Rita Mögenburg (all Eberhard Karls University Tübingen). We are especially grateful to Kurt Rilling and Michael Kösel from the Landesamt für Geologie, Rohstoffe und Bergbau for great input and discussions in the field. Special thanks also go to Prof. Bruce James for many fruitful discussions and the proofreading of the manuscript. The many farmers, who supported us by allowing us to work on their land, are acknowledged. Thanks Markus Siegeris for the characterization of the Neolithic blade. Thanks to Dr. Einar Eberhardt for support with the translation of KA5 classification to WRB and FAO. Thanks go to Richard Szydlak, who drew the catenas after drafts by JH and Mario Ahner. Andrea Junge (Justus-Liebig-University Gießen) supported the luminescence dating. We also thank the two unknown reviewers for their very helpful comments and suggestions.

References

Ad-hoc-AG Boden (Ed.) (2005): Bodenkundliche Kartieranleitung. KA5. Schweizerbart, Stuttgart, 438 S.

Ahlrichs, J., Henkner, J., Teuber, S., Schmidt, K., Scholten, T., Kühn, P., Knopf, T. (2016): Archaeological and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory: A Case Study from the Western Baar, SW Germany, in Kolodziejczyk, P., Kwiatkowska-Kopka, B.: Landscape as impulsion for culture: research, perception & protection: Landscape in the past & forgotten landscapes. Cracow Landscape Monographs 2, Cracow, pp. 39–49.

Behre, K.-E. (1981): The interpretation of anthropogenic indicators in pollen diagrams. *Pollen Spores* 23, 225–245.

Berglund, B. E., Ralska-Jasiewiczowa, M. (Eds.) (1986): Handbook of the Holocene palaeoecology and palaeohydrology. Blackburn Press, Caldwell, N.J.

Blume, H.-P., Brümmer, G. W., Horn, R., Kandeler, E., Kögel-Knabner, I., Kretzschmar, R., Stahr, K., Wilke, B.-M. (2010): Scheffer/Schachtschabel. Lehrbuch der Bodenkunde. Spektrum, Akad. Verl., Heidelberg, Berlin, XIV, 569 S.

Blümel, W. D. (2002): 20.000 Jahre Klimawandel und Kulturgeschichte - von der Eiszeit in die Gegenwart. - Wechselwirkungen. *Wechselwirkungen - Jahrbuch aus Lehre und Forschung der Universität Stuttgart.*

Bronk Ramsey, C. (2009): Bayesian Analysis of Radiocarbon Dates. *Radiocarbon* 51, 337–360.

Brückner, H. (1981): Die Entwicklung der Wälder des Schwarzwaldes durch die Nutzung vergangener Jahrhunderte und ihre heutige Bedeutung, in Liehl, E.: Der Schwarzwald: Beiträge zur Landeskunde. Veröffentlichungen des Alemannischen Instituts Freiburg i.Br 47, Bühl/Baden, pp. 155–180.

Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D. C., Trouet, V., Kaplan, J. O., Herzig, F., Heussner, K.-U., Wanner, H., Luterbacher, J., Esper, J. (2011): 2500 years of European climate variability and human susceptibility. *Science* 331, 578–582.

Cohn, S. K., JR. (2008): Epidemiology of the Black Death and Successive Waves of Plague. *Medical History* 27, 74–100.

Denecke, D. (1992): Siedlungsentwicklung und wirtschaftliche Erschließung der hohen Mittelgebirge in Deutschland: Ein historisch-geographischer Forschungsüberblick, in Fehn, K., Bender, H., Brandt, K., Denecke, D., Irsigler, F., Janssen, W., Krings, W., Müller-Wille, M., Nitz, H.-J., Oberbeck, G., Schich, W.: Siedlungsforschung. Archäologie - Geschichte - Geographie: Die besiedlung der höheren Mittelgebirge 10, Bonn, pp. 9–47.

Eberhardt, E., Schad, P., Berner, T., Lehmann, C., Walthert, L., Pietsch, D.: Ableitungsschlüssel zur Klassifizierung von Böden nach WRB 2007: aus Daten der KA 5-Nomenklatur, Hannover, Berlin.

Eberhardt, E., Schad, P., Berner, T., Lehmann, C., Walthert, L., Pietsch, D. (2014): Ableitungsschlüssel KA5 (2005) nach WRB (2007). Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).

Edgeworth, M., Richter, D. d., Waters, C. N., Haff, P. K., Neal, C., Price, S. J. (2015): Diachronous beginnings of the Anthropocene: The lower bounding surface of anthropogenic deposits. *The Anthropocene Review* 2, 33–58.

Feeser, I., Dörfler, W. (2014): The glade effect: Vegetation openness and structure and their influences on arboreal pollen production and the reconstruction of anthropogenic forest opening. *Anthropocene* 8, 92–100.

Filipinski, M. (1989): Pflanzenaufnahme und Lösbarkeit von Schwermetallen aus Böden hoher geogener Anreicherung und zusätzlicher Belastung. Dissertation, Göttingen.

Fingerlin, G. (2006): Vom Oberrhein zur jungen Donau: Die Straße durch den südlichen Schwarzwald in keltischer, römischer und frühalamannischer Zeit. *Archäologische Nachrichten aus Baden* 72/73, 62–73.

Firbas, F. (1949): Spät- und nacheiszeitliche Waldgeschichte Mitteleuropas nördlich der Alpen: Band 1: Allgemeine Waldgeschichte. Gustav Fischer, Jena.

Fischer, E., Rösch, M., Sillmann, M., Ehrmann, O., Liese-Kleiber, H., Voigt, R., Stobbe, A., Kalis, A. J., Stephan, E., Schatz, K., Posluschny, A. (2010): Landnutzung im Umkreis der

Zentralorte Hohenasperg, Heuneburg und Ipf: Archäobotanische und archäozoologische Utnersuchungen und Modellberechnungen zum Ertragspotential von Ackerbau und Viehhaltung, in Krausse, D., Beilharz, D.: "Fürstensitze" und Zentralorte der frühen Kelten: Abschlusskolloquium des DFG-Schwerpunktprogramms 1171 in Stuttgart, 12-15. Oktober 2009. Teil II. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg 120. K. Theiss, Stuttgart, pp. 195–265.

Focke, F. (1956): Das Dreigötterrelief von der Brigachquelle. *Badische Fundberichte* 20, 123–126.

Food and Agriculture Organization of the United Nations (FAO) (2006): Guidelines for soil description. Food and Agriculture Organization of the United Nations, Rome, p. 97.

Frenzel, B. (1982): Vegetationsgeschichtliche und paläoökologische Probleme des Schwarzwaldes, in Winkel, H.: Geschichte und Naturwissenschaft in Hohenheim: Beiträge zur Natur-, Agrar-, Wirtschafts- und Sozialgeschichte Südwestdeutschlands Festschrift für Günther Franz zum 80. Geburtstag, Sigmaringen, pp. 239–263.

Friedmann, A. (2002): Die Wald- und Landnutzungsgeschichte des Mittleren Schwarzwaldes. *Berichte zur deutschen Landeskunde* 76, 187–205.

Fuchs, M., Fischer, M., Reverman, R. (2010): Colluvial and alluvial sediment archives temporally resolved by OSL dating: Implications for reconstructing soil erosion. *Quaternary Geochronology* 5, 269–273.

Fuchs, M., Henkner, J., Scholten, T., Knopf, T., Kühn, P. (2017): OSL datings of colluvial deposits in southwestern Germany. A data table of the project SFB1070-B02.

Gassmann, G., Rösch, M., Wieland, G. (2006): Das Neuenbürger Erzrevier im Nordschwarzwald als Wirtschaftsraum während der Späthallstatt- und Frühlatènezeit. *Germania* 84, 273–306.

Geilmann, W., Spang, A. (1958): Eine Beobachtung zur Schnelligkeit der Zerstörung keramischer Scherben auf der Erdoberfläche. *Die Kunde N.F.* 9/1-2, 93–94.

(1998): Gesetz zum Schutz vor schädlichen Bodenveränderungen und zur Sanierung von Altlasten (Bundes-Bodenschutzgesetz - BBodSchG): BBodSchG.

Glaser, R. (2013): Klimageschichte Mitteleuropas: 1200 Jahre Wetter Klima Katastrophen. Mit Prognosen für das 21. Jahrhundert. Primus, Darmstadt.

Gonnelli, C., Renella, G. (2013): Chromium and Nickel, in Alloway, B. J.: Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavalability. Environmental Pollution 22. Springer, Dordrecht, pp. 313–334.

Gradmann, R. (1922): Zur Geographie der Vor- und Frühgeschichte. *Geographische Zeitschrift* 28, 26–29.

Gradmann, R. (1931): Süddeutschland II: Die einzelnen Landschaften, Stuttgart.

Gradmann, R. (1948): Altbesiedeltes und jungbesiedeltes Land. *Studium Generale* 1, 163–177.

Grees, H. (2007): Zur Diskussion um die Siedlungsgenese in Südwestdeutschland, in Gebhardt, H.: Geographie Baden-Württembergs: Raum, Entwicklung, Regionen. Schriften zur politischen Landeskunde Baden-Württembergs 36. Kohlhammer, Stuttgart, pp. 200–213.

Grimm, E. (1991): Tilia 1.2: Tilia Graph 1.18. Illinois State Museum, Research and collection center, Springfield, Illinois.

Grosse-Brauckmann, G. (1978): Absolute jährliche Pollenniederschlagsmengen an verschiedenen Beobachtungsorten in der Bundesrepublik Deutschland. *Flora* 167, 209–247.

Häbich, S. (2009): Umweltbedingte und anthropogene Geomorphodynamik im europäischen Hauptwasserscheidengebiet des Mittleren Schwarzwald. Dissertation, Albert Ludwigs Universität, Freiburg i. Br.

Henkner, J., Ahlrichs, J., Downey, S. S., Fuchs, M., James, B. R., Knopf, T., Scholten, T., Teuber, S., Kühn, P. (2017a): Archaeopedological analyses of colluvium: A proxy for regional land use history in southwest Germany. *CATENA* 155, 93–113.

Henkner, J., Scholten, T., Knopf, T., Fischer, E., Rösch, M., Kühn, P. (2017b): AMS-14C datings of charcoals from colluvial deposits and pollen from bogs in southwestern Germany.

Henkner, J., Scholten, T., Kühn, P.: Archaeopedological analysis of colluvial deposits in favourable and unfavourable areas: Reconstruction of land use dynamics in SW Germany. Soil description, soil properties and ages of colluvial deposits in SW Germany. A SFB1070-B02 data table. *Dryad Digital Repository.*

Henkner, J., Scholten, T., Kühn, P. (2017c): Soil profile descriptions of mainly colluvial soils in southwestern Germany. A SFB1070-B02 data table.

Hölzer, A., Hölzer, A. (2003): Untersuchungen zur Vegetations- und Siedlungsgeschichte im Großen und Kleinen Muhr an der Hornisgrinde (Nordschwarzwald). *Mitt. Ver. forstl. Standorstk. Forstpflanzenzücht.* 42, 31–44.

Humpert, J. (1991): Eine römische Straße durch den südlichen Schwarzwald. *Archäologische Nachrichten aus Baden* 45, 19–32.

IUSS Working Group WRB: World reference base for soil resources 2014: International soil classification system for naming soils and creating legends for soil maps, Rome.

Jäger, K.-D. (2002): Oscillations of the water balance during the Holocene in interior Central Europe—features, dating and consequences. *Quaternary International* 91, 33–37.

Jarvis, A., Reuter, H. I., Nelson, A., Guevara, E. (2008): Hole-filled SRTM for the globe Version 4: CGIAR-CSI SRTM 90m Database.

Kalis, A. J., Merkt, J., Wunderlich, J. (2003): Environmental changes during the Holocene climatic optimum in central Europe - human impact and natural causes. *Quaternary Science Reviews* 22, 33–79.

Klima & Wetter Furtwangen: Climate-data.org.

Knopf, T., Baum, T., Scholten, T., Kühn, P. (2012): Landnutzung im frühen Mittelalter?: Eine archöäopedologische Prospektion im mittleren Schwarzwald. *Archäologisches Korrespondenzblatt* 42, 123–133.

Kösel, M., Rilling, K. (2002): Die Böden der Baar - ein Beitrag zur regionalen Bodenkunde Südwestdeutschlands. *Schriften des Vereins für Geschichte und Naturgeschichte der Baar* 45, 99–128.

Kotterba, M. (1996): Diana Abnoba – Göttin des Schwarzwaldes und seiner Straßen. *Archäologische Nachrichten aus Baden* 55, 6–44.

Kreutzer, S., Dietze, M., Burow, C., Fuchs, M. C., Schmidt, C., Fischer, M., Firedrich, J., Mercier, N., Smedley, R. K., Durcan, J., King, G. (2016): Comprehensive Luminescence Dating Data Analysis. R package.

Krüger, F. (1938): Ein einheimischer Bildstein von der Brigachquelle aus römischer Zeit: Ein keltisches Heiligtum an der Brigachquelle. *Badische Fundberichte* 14, 67–71.

Kühn, P., Lehndorff, E., Fuchs, M. (2017): Late Pleniglacial to Holocene Pedogenesis and Formation of Colluvial Deposits in Central Europe (Gambach, Germany). *CATENA* 154, 118–135.

Lais, R. (1937): Die Steinzeit im Schwarzwald. *Badische Fundberichte* 13, 29–66.

Lang, G. (2005): Seen und Moore des Schwarzwaldes als Zeugen spätglazialen und holozänen Vegetationswandels stratigraphische, pollenanalytische und großrestanalytische Untersuchungen. dem Andenken an Erich O. Oberdorfer (1905 - 2002) gewidmet, Karlsruhe.

Leopold, M., Völkel, J. (2007): Colluvium: Definition, differentiation, and possible suitability for reconstructing Holocene climate data. *Quaternary International* 162-163, 133–140.

Maier, F. (2006): Der Bildstein von der Brigachquelle bei St. Georgen: (Schwarzwald Baar Kreis). *Germania* 84, 415–429.

Mertens, J., Smolders, E. (2013): Zinc, in Alloway, B. J.: Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavalability. Environmental Pollution 22. Springer, Dordrecht, pp. 465–493.

Murray, A. S., Wintle, A. G. (2000): Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements* 32, 57–73.

Nölte, J. (2003): ICP-Emissionsspektrometrie für Praktiker: Grundlagen, Methodenentwicklung, Anwendungsbeispiele. Wiley-VCH, Weinheim.

Nübling, V. (1990): Königsfeld im Schwarzwald, Buchenberg (Schwarzwald-Baar-Kreis). *Fundberichte aus Baden-Württemberg* 15, 522–523.

Oorts, K. (2013): Copper, in Alloway, B. J.: Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavalability. Environmental Pollution 22. Springer, Dordrecht, pp. 367–394.

Pape, W. (1978): Bemerkungen zur relativen Chronologie des Endneolithikums am Beispiels Südwestdeutschlands und der Schweiz, Tübingen.

Pasda, C. (1996): Anmerkungen zur Mittelsteinzeit im Schwarzwald. *Archäologische Nachrichten aus Baden* 55, 3–5.

Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg (2013a): Bodenkundliche Grundflächen. - Bodenkarte von Baden-Württemberg 1 50 000: blattschnittsfreie Geodaten der Integrierten geowissenschaftlichen Landesaufnahme (GeoLa).

Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg (2013b): Geologische Grundflächen - Geologische Karte von Baden-Württemberg 1:50 000: blattschnittfreie Geodaten der Integrierten geowissenschaftlichen Landesaufnahme (GeoLa).

Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg (2016): WMS LGRB-BW HW_GEO: Geogene Grundgehalte (Hintergrundwerte) in den petrogeochemischen Einheiten von Baden-Württemberg 1 :300 000, http://maps.lgrb-bw.de/.

Reichelt, G. (1996): Zum eiszeitlichen Geschehen im Mittelschwarzwald (I) - Interpretation einer geomorphologischen Karte. *Schriften des Vereins für Geschichte und Naturgeschichte der Baar* 39, 182–189.

Reichelt, G. (1997): Zum Eiszeitgeschehen im Mittelscharzwald (2): Der Schellenberg bei Donaueschingen als Eiszeitlandschaft. *Schriften des Vereins für Geschichte und Naturgeschichte der Baar* 40, 207–217.

Reimer, P. (2013): IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. *Radiocarbon* 55, 1869–1887.

Revellio, P. (1935): Aus der Geschichte der Baar im Mittelalter: Schwarzwald Baar Kreis Villingen. M. Link, Schwenningen.

Revellio, P. (1938): Ein einheimischer Bildstein von der Brigachquelle aus römischer Zeit: Fundbericht und Beschreibung. *Badische Fundberichte* 14, 65–67.

Revellio, P. (1957): Ein Fund römischer Münzen bei Furtwangen, Kr. Donaueschingen. *Germania* 35, 124–127.

Revellio, P. (1961): Die Besiedlung des Schwarzwaldrandes westlich und südlich von Villingen.: Sonderdruck aus dem Einwohnerbuch von Villingen und Umgebung, Villingen-Schwenningen.

Robin, V., Bork, H.-R., Nadeau, M.-J., Nelle, O. (2014): Fire and forest history of central European low mountain forest sites based on soil charcoal analysis: The case of the eastern Harz. *The Holocene* 24, 35–47.

Rösch, M. (2000): Long-term human impact as registered in an upland pollen profile from the southern Black Forest, south-western Germany. *Vegetation History and Archaeobotany* 9, 205–218.

Rösch, M. (2009): Vom Korn der frühen Jahre: Sieben Jahrtausende Ackerbau und Kulturlandschaft. *Denkmalpflege in Baden-Württemberg* 38, 157–164.

Rösch, M. (2012): Vegetation und Waldnutzung im Nordschwarzwaldwährend sechs Jahrtausenden anhand von Profundalkernen aus dem Herrenwieser See. *Standort Wald* 47, 43–64.

Rösch, M. (2013): Land use and food production in Central Europe from the Neolithic to the medieval period: Change of landscape, soils and agricultural systems according to archaeobotanical data, in Kerig, T.: Economic archaeology: From structure to performance in European archaeology. Universitätsforschungen zur prähistorischen Archäologie 237. Habelt, Bonn, pp. 109–127.

Rösch, M. (2014): Offenheit als vegetationsgeschichtlicher Begriff: Definition, Proxidaten, Problematik. *Archäologie - Geschichte - Geographie,* 9–28.

Rösch, M., Fischer, E., Kleinmann, A., Lechterbeck, J., Tserendorj, G., Wick, L. (2014): Bronzezeitliche Landnutzung im diachronen Vergleich - Fallbeispiele aus Südwestdeutschland, in Nessel, B., Heske, I., Brandherm, D.: Ressourcen und Rohstoffe in der Bronzezeit: Nutzung - Distribution - Kontrolle, Wünsdorf, pp. 13–26.

Rösch, M., Gassmann, G., Wieland, G. (2007): Keltische Montanindustrie im Schwarzwald – eine Spurensuche, in Zimmer, S.: Kelten am Rhein: Akten des dreizehnten Internationalen Keltologiekongresses: Proceedings of the thirteenth International Congress of Celtic Studies. Archäologie, Ethnizität und Romanisierung. Beihefte der Bonner Jahrbücher 58/1, pp. 263–278.

Rösch, M., Lechterbeck, J. (2016): Seven Millennia of human impact as reflected in a high resolution pollen profile from the profundal sediments of Litzelsee, Lake Constance region, Germany. *Veget Hist Archaeobot* 25, 339–358.

Rösch, M., Tserendorj, G. (2011): Der Nordschwarzwald - Früher besiedelt als gedacht?: Pollenprofile belegen ausgedehnte vorgeschichtliche Besiedlung und Landnutzung. *Denkmalpflege in Baden-Württemberg* 40, 66–73.

Schell, K. (1998): Differenzierung und Charakterisierung kolluvialer Archive anhand von Schwermetallen in einer prähistorischen Siedlungskammer im Nördlinger Ries. Dissertation, Eberhard Karls Universität, Tübingen.

Schiffer, M. B. (1987): Formation Processes of the Archaeological Record, Albuquerque.

Schimming, C.-G. (2011): Kontamination von Böden: Metalle, in Blume, H.-P., Horn, R., Thiele-Bruhn, S. O. H.: Handbuch des Bodenschutzes: Bodenökologie und -belastung ; vorbeugende und abwehrende Schutzmaßnahmen. 4th ed. Wiley-VCH, Weinheim, pp. 325–362.

Schmid, B. (1991): Die urgeschichtlichen Funde und Fundstellen der Baar: Eine Auswertung des Bestandes. Band 1: Text und Tafeln. Schäuble Verlag, Rheinfelden.

Schmid, B. (1992): Die urgeschichtlichen Funde und Fundstellen der Baar: Eine Auswertung des Bestandes. Band 2: Katalog. Schäuble Verlag, Rheinfelden.

Schmid, B. V., Büntgen, U., Easterday, W. R., Ginzler, C., Walloe, L., Bramanti, B., Stenseth, N. C. (2015): Climate-driven introduction of the Black Death and successive plague reintroductions into Europe. *Proceedings of the National Academy of Sciences of the United States of America* 112, 3020–3025.

Schneider, R. (2000): Landschafts- und Umweltgeschichte im Einzugsgebiet der Elz. Dissertation, Albert Ludwigs Universität, Freiburg i. Br.

Schönwiese, C. (1995): Klimaänderungen: Daten, analysen, prognosen. Springer-Verlag, Berlin, xiii, 224.

Schreg, R. (2014): Uncultivated landscapes or wilderness? Early medieval land use in low mountain ranges and flood plains of Southern Germany. *European Journal of Post-Classical Archaeologies,* 69–98.

Schütz, J.-P. (2001): Der Plenterwald und weitere Formen strukturierter und gemischter Wälder. Parey, Berlin, p. 207.

Seidl, A. (2006): Deutsche Agrargeschichte. DLG-Verl., Frankfurt, M., 376 S.

Smolders, E., Mertens, J. (2013): Cadmium, in Alloway, B. J.: Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavalability. Environmental Pollution 22. Springer, Dordrecht, pp. 283–312.

Sommer, U. (1991): Zur Entstehung archäologischer Fundvergesellschaftungen Versuch einer archäologischen Taphonomie, Bonn.

Spindler, K. (1977): Aus der Geschichte: Vor- und Frühgeschichte, in Gutknecht, R.: Der Schwarzwald-Baar-Kreis: Heimat und Arbeit. Heimat und Arbeit. K. Theiss, Stuttgart, pp. 56–84.

Steinhof, A. (2013): Data Analysis at the Jena 14C Laboratory. *Radiocarbon* 55, 282–293.

Steinhof, A., Altenburg, M., Göbel, M., Machts, H. (2017): Sample preparation at the Jena 14C laboratory. *Radiocarbon* 59, 815–830, 10.1017/RDC.2017.50.

Steinnes, E. (2013): Lead, in Alloway, B. J.: Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavalability. Environmental Pollution 22. Springer, Dordrecht, pp. 395–410.

Stoll, H. (1932): Mesolithikum aus dem Ostschwarzwald. *Germania* 16, 91–97.

Stoll, H. (1933): Urgeschichte des Oberen Gäues, Öhringen.

Valde-Nowak, P. (1999): Neolithic penetration of European Mid Mountains. *Archaologica Polonia* 37, 3–12.

Valde-Nowak, P., Kienlin, T. L. (2002): Neolithische Transhumanz in den Mittelgebirgen: Ein Survey im westlichen Schwarzwald. *Prähistorische Zeitschrift* 77, 29–75.

Völkel, J. (2003): Bodenbelastung durch Schwermetalle, in Leibniz-Institut für Länderkunde: Nationalatlas Bundesrepublik Deutschland 2. Spektrum Akad. Verl, Berlin, pp. 112–113.

Wagner, H. (2014): Lange vor den Klöstern: Das Kinzigtal von der Steinzeit bis zur Römerzeit. *Die Ortenau* 94, 425–442.

Wieland, G. (2009): Vorgeschichtliche Höhensiedlungen am Rand des Nordschwarzwaldes: Überlegungen zur eisenzeitlichen Besiedlung eines besonderen Naturraumes, in Biel, J., Heiligmann, J., Krausse, D.: Landesarchäologie: Festschrift für Dieter Planck zum 65. Geburtstag. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg Bd. 100. Theiss, Stuttgart, pp. 193–205.

Young, S. D. (2013): Chemistry of Heavy Metals and Metalloids in Soils, in Alloway, B. J.: Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavalability. Environmental Pollution 22. Springer, Dordrecht, pp. 51–95.

Zimmermann, A. (2012): Cultural cycles in Central Europe during the Holocene. *Quaternary International* 274, 251–258.

Zimmermann, A., Hilpert, J., Wendt, K. P. (2009): Estimations of Population Density for Selected Periods Between the Neolithic and AD 1800. *Human Biology* 81, Article 13.

Manuscript III

Archaeopedological analysis of colluvial deposits in favourable and unfavourable areas: Reconstruction of land use dynamics in SW Germany

Henkner, Jessica[1,2]; Ahlrichs, Jan[1,3]; Downey, Sean[4], Fuchs, Markus[5], James, Bruce[6], Junge, Andrea[5]; Knopf, Thomas[1,3]; Scholten, Thomas[1,2]; Kühn, Peter [1,2]

Royal Society Open Science 5 (2018), DOI: 10.1098/rsos.171624

[1] SFB1070 ResourceCultures, Gartenstr. 29, 72074 Tübingen, Germany

[2] Department of Geosciences, Soil Science and Geomorphology, Eberhard Karls University Tübingen, Rümelinstrasse 19-23, 72070 Tübingen, Germany

[3] Institute for Pre- and Protohistory and Medieval Archaeology, Eberhard Karls University Tübingen, Burgsteige 11, Schloss Hohentübingen, 72070 Tübingen, Germany

[4] Department of Anthropology, University The Ohio State University, 4034 Smith Laboratory, 174 West 18th Street, Columbus, OH, 43210, USA

[5] Department of Geography, Justus-Liebig-University Gießen, Senckenberstr. 1, 35390 Gießen, Germany

[6] Department of Environmental Science and Technology, University of Maryland, 0220 Symons Hall, College Park, MD 20742 USA

Abstract

Colluvial deposits, as the correlate sediments of human induced soil erosion, depict an excellent archive of land use and landscape history as indicators of human-environment interactions. This study establishes a chronostratigraphy of colluvial deposits and reconstructs past land use dynamics in the Swabian Jura, the Baar and the Black Forest in SW Germany.

In the agriculturally favourable Baar area multiple main phases of colluvial deposition, and thus intensified land use, can be identified from the Neolithic to the Modern Times. In the unfavourable Swabian Jura increased colluvial deposition began later compared to the more favourable areas in the Baar. The same holds true for the unfavourable areas of the Black Forest, but intensified land use can only be reconstructed for the Middle Ages and Early Modern times instead of for the Bronze and Iron Age as in the Swabian Jura. Land use intensity and settlement dynamics represented by thick, multi-layered colluvial deposits increase in the Baar and the Black Forest during the Middle Ages. In-between those phases of geomorphodynamic activity and colluviation, stable phases occur, interpreted as phases with sustainable land use or without human presence.

1 Introduction

The spread of agriculture through central Europe, starting about 7500 years ago, changed food production and population densities [1]. The establishment of sedentary lifestyles resulted in increased and diversified food production for subsistence purposes and also production of surpluses for sale, labour specialization and social complexity [2]. It also led to increased alteration of the natural landscape [3,4]. This crucial change of the relationship between humans and the environment can be traced with archaeopedological methods. Thus, soils are records of past land use [5,6] and they are resources to learn about past human-environment interactions. Archaeopedology is defined as the study of site formation history, cultural chronology, land use (change), and environmental change; and it allows us to answer archaeological questions with pedological methods [7–9]. In our study archaeopedological methods include soil description, chemical and physical soil analyses, and dating of colluvial deposits and charcoal fragments. The used methods do not allow to infer the type of land use and thus the term land use comprises all forms of human land use such as deforestation, mining, village establishment or infrastructure building, and farming (i.e. cultivation and animal husbandry). The latter marks the beginning of a more intense and permanent anthropogenic land use, which led to widespread formation of colluvial deposits. Hunter and gatherer populations also used the land and depended on the soil, but non-sedentary societies had smaller impacts on soil erosion and colluvial deposition than agricultural societies [10]. Colluvial deposits are the correlating sediments of human-induced soil erosion and as such their distribution is mainly controlled by topography, precipitation, and human activities [11]. Larsen et al. 2016 [12] state that land use, rather than soil erosion rates and discharge into the oceans, controls temporary sediment storage on slopes which means the analysis of colluvial deposits on slopes and in depressions is ideal to reconstruct land use change.

The use of colluvial deposits as records of the past is based on the assumption that intensified land use, as caused by agriculture, results in soil erosion and temporary storage of sediments along slopes or in depressions (Fig. 1). Thus, phases of land use may be correlated to colluvial deposition, which means these deposits can be interpreted as a proxy for human presence, land use, and settlement during a specific period of time. The term "geomorphodynamic activity" was coined by Rohendburg [13,14] to describe phases of increased slope erosion triggered by an accentuated precipitation regime and thereby changed vegetation cover during the Pleistocene. In this study the terms geomorphodynamic activity or stability are used to describe whether slope deposits are being eroded or stable. Thus, they are broken down to a local or site-specific scale to describe phases of soil erosion and colluvial deposition which are not necessarily connected to climate, but instead are linked to land use changes triggering soil erosion. Due to slope stability and the supporting influence of vegetation, pedogenic processes take place mainly during stable phases, whereas geomorphodynamic activity leads to redeposition and soil loss [15,16]. The reconstruction of phases with intensified (unsustainable) land use also draws attention to periods of time without colluvial deposition, which separate the different, stratified layers of colluvial deposits. These might have been time periods without agricultural land use or with some kind of low-intensity activities that preserved soil in place. The occurrence of soil erosion and deposition depends on environmental conditions (e.g. topography, soil, climate), population density, technological knowledge and practices (e.g. agriculture, trade, rituals, valuations), and other factors. In addition, anthropogenic colluvial deposits have to be distinguished from natural slope deposits, formed by periglacial processes, bioturbation or soil creep, regardless of land use practices [12,17,18].

This study aims to reconstruct human-environment interactions by analysing land use dynamics in SW Germany through a series of “site biographies” that are primarily based on OSL dating of colluvial deposits and AMS-^{14}C dating of included charcoal fragments. A site biography can be understood as the chronostratigraphy of colluvial deposition and thus is a local reconstruction of deposition and land use phases, including soil and environmental properties, such as organic carbon content, particle size distribution, heavy metal content, and topography. Studying such site specific soil mosaics in space and over time can enhance our understanding of human-environment relationships (i.e. land use dynamics). After a thorough archaeological investigation of settlement history we used an interdisciplinary approach to select archaeopedological study sites. This allowed us to coordinate the field and laboratory analyses with the interpretation of colluvial soils as records of former land use to provide insights into an expansive archive on the land. The local history of the corresponding slopes is stored in colluvial deposits which can show a high temporal resolution. Previous studies showed that colluvial deposits are most often found in toe- and footslope positions but they also reach backslopes or may be stored temporarily in sinks on slopes depending on small scale topography, precipitation, and land use history [9,12,19–22]. The study of many local sites in different landscapes thereby provides an opportunity to reconstruct a regional land use history.

The focus of this study is on soils as a natural resource and basis for land use, especially agricultural land use. The term “resource” is understood as an analytical concept with a constructivist perspective: as a base to create, maintain or alter social relations, units, and identities within the framework of culturally shaped beliefs and practices. It thus includes a wide variety of tangible and intangible means, dynamic social processes of turning something into a resource, and social contexts [23,24], it thereby includes many possible explanations of pull factors to settle land. The resource concept provides a new analytical approach to interpret archaeological and archaeopedological data about settlement and land use dynamics. It makes it possible to question the natural deterministic model [25] to describe settlement dynamics through time and includes socio-cultural explanations. It can be hypothesized that the perception of the quality of a landscape is defined by its usefulness and whether it subsequently was seen and treated as an unfavourable or favourable one.

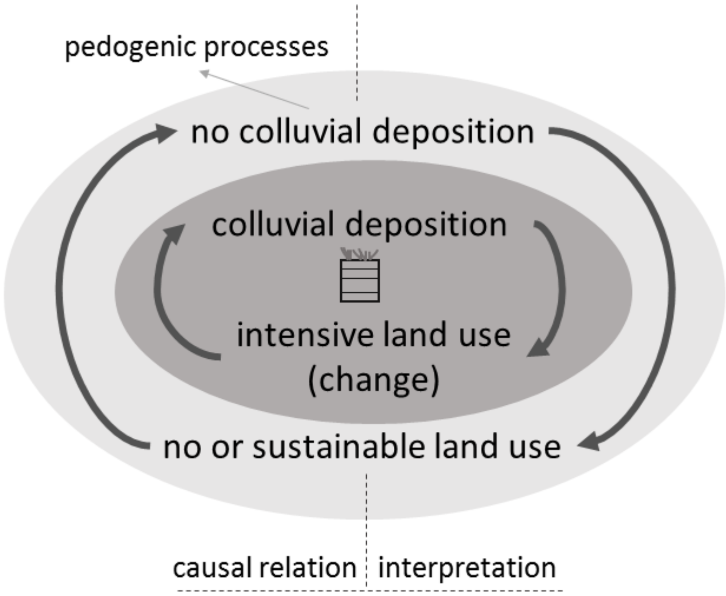

Fig. 1: Schematic diagram of the interpretation and causal relationship between colluvial deposition and land use. Dark grey= geomorphodynamic activity, light grey= geomorphodynamic stability.

This paper focuses on the Swabian Jura and its land use history, which will be compared to the Black Forest [26] and the Baar area [22]. The regional focus of the study comprises favourable and unfavourable areas in low mountain ranges for practicing agriculture due to the specific conditions of climate, topography, and soils. Bourke [27] states that crops and grass species need a minimum mean air temperature of at least 6°C over a period of six month to grow and be harvested. Overall however, the differentiation between favourable and unfavourable areas [28] has to be understood as a concept to distinguish areas and highlight differences. The attribution of favourable or unfavourable, however, always depends on the perspective and the intention of the user, and it may change with time and context. A favourable landscape for practicing agriculture can turn into an unfavourable landscape by soil degradation or climate change. Another scenario could be that agriculture might lose its importance because other economically more valuable raw materials such as iron, silver or gold were found. In the latter scenario the landscape would be seen as favourable for mining and exploitation of raw materials, instead of agriculture, which means a shift of perspective and context. The agriculturally favourable Baar area, can also be seen as being rather unfavourable because of a large number of days when temperatures drop below 0°C, dense fog and less fertile soils [29], as compared to other more favourable, loess covered areas nearby with warmer temperatures and more fertile soils. Unquestionably unfavourable landscapes, however, are the Black Forest and the plateau of the Swabian Jura, currently having low mean annual temperature, high precipitation, infertile soils, and in case of the Black Forest steep slopes.

The main questions of this paper are:

- How are colluvial deposits distributed on the plateau of the western Swabian Jura and how are they related to past land use?
- How did land use dynamics change through time considering favourable and unfavourable areas in SW Germany?
- What might have been the reason to settle and use certain areas, while others were not used?
- How can geomorphodynamically stable periods be explained, i.e. phases without the formation of colluvial deposits?

2 Regional Setting

The study area is located in SW Germany and includes the south-eastern Black Forest, the Baar and the western Swabian Jura (Fig. 2). The focus of this paper lies on four archaeopedological sites situated on the plateau of the Swabian Jura, a low mountain range of Jurassic origin belonging to the cuesta landscape. The high plateau of the Swabian Jura, with an inclination mostly below 10%, has several peaks of about 1000 m altitude and consist of plateaus separated by rivers. The mean annual temperature is about 4-7°C and the mean annual precipitation is 1000 mm. It is characterized by limestone, covered by periglacial slope deposits and colluvial deposits. At present, the environmental conditions are harsh and unfavourable for practicing agriculture. The cuesta drops abruptly about 200-400 m in altitude into the Baar area, having rather favourable environmental conditions [22]. The south-eastern Black Forest is characterized by a high relief intensity, high annual precipitation, low mean temperatures, and acidic soils [26].

The four study sites on the Swabian Jura are presently used as grassland, cropland or woodland and have slightly different site characteristics (Tab. 1). The sites Boettingen (Boe), Koenigsheim (Koe), and Russberg (Rus) belong to an area called "Grosser Heuberg" on the Swabian

Jura, which has a long settlement history, despite rather unfavourable conditions. The site Lindenberg (Lin) is located further west.

Tab. 1: Location and characteristics of Swabian Jura sites. The compilation originates from field work and information about geology [30] and soils [31].

Site:	Russberg (Rus)	Lindenberg (Lin)	Koenigsheim (Koe)	Boettingen (Boe)
UTM:	32U485944 5319526	32T475990 5315709	32U490366 5327191	32U484337 5328676
Geology	dense late Jurassic limestone (Unterer Massenkalk); marl; Holocene slope deposits	layered late Jurassic limestone (Wohlgeschichtete Kalke Formation); Holocene slope deposits	late Jurassic dolomite and crystalline limestone (Zuckerkornkalk); dense limestone (Unterer Massenkalk); Quaternary slope and weathered deposits	layered late Jurassic limestone (Wohlgeschichtete Kalke Formation); Quaternary slope and weathered deposits
Main Soil Types (WRB)	Regosol; Cambisol	Regosol; Cambisol	Cambisol; Regosol	Cambisol; Regosol
Vegetation	woodland; cropland	woodland; cropland	grassland; cropland	grassland
Topography	W-facing; inclination:2-20%; beginning of a V-shaped valley	upper end of depression on plateau; SE-facing; 2-10% inclination	S-facing; inclination 2-5%; back- to footslope position of a depression	S-facing; inclination 2-4%; back-to footslope position
Hydrology	no surface water; no drainage	no surface water; no drainage	no surface water; no drainage	no surface water; no drainage
Altitude	830-850 m asl	900-920 m asl	870-890 m asl	930-940 m asl
Land use	forestry; farming	forestry; farming	farming; hay meadow	hay meadow

2.1 Settlement and land use history of the western Swabian Jura and the Heuberg

There are no known Mesolithic (9600-5500 BCE) or Early Neolithic (5500-5000 BCE) sites on the high plateau of the Swabian Jura in the study area. The oldest find is a so-called "shoe-last celt" (Schuhleistenkeil) dated to the Early Neolithic, found in the vicinity of Talheim, near the Lindenberg site. This find is interpreted as a sign of temporary land use in the valleys of the western Swabian Jura during the Early Neolithic [32]. Further single finds e.g. a stone axe were on the plateau of the Swabian Jura and were dated to the Neolithic [32,33]. The earliest archaeological evidence of a settlement on the western Swabian Jura dates to the Final Neolithic (2800-2150 BCE) and consists of pottery fragments, stone axes, and flint artefacts found on the Dreifaltigkeitsberg near Spaichingen [34,35].

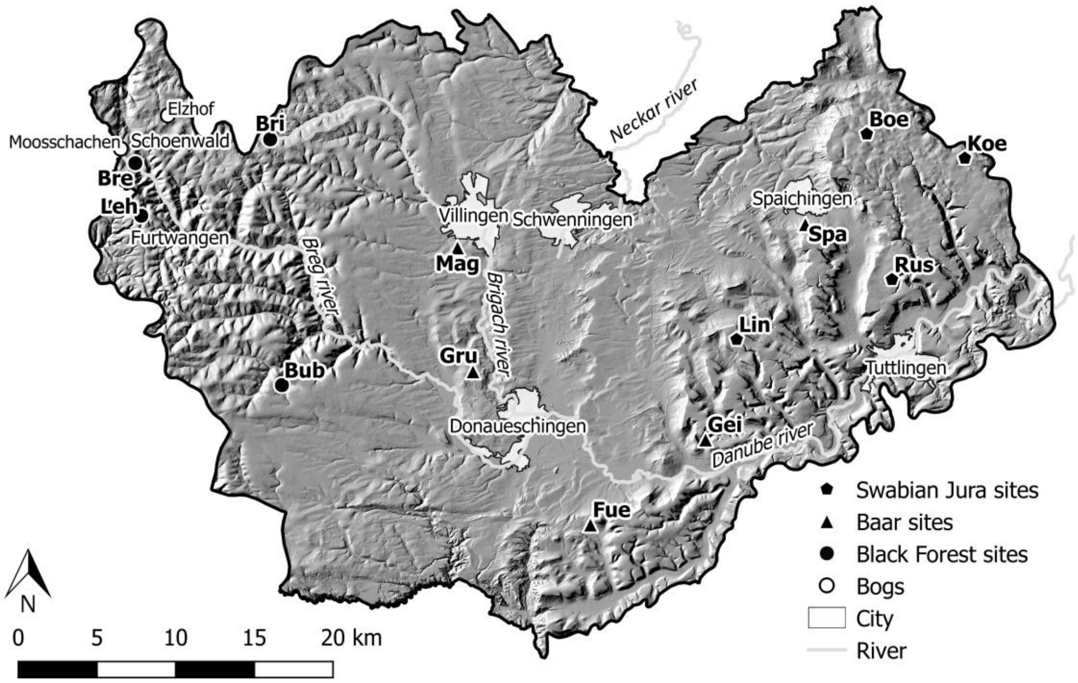

Fig. 2: Study area in SW Germany with all archaeopedological and palynological study sites, major rivers and cities. The site names are abbreviations usually from the nearest villages: Boe=Boettingen, Bre=Breg valley, Bri=Brigach, Bub=Bubenbach, Fue=Fuerstenberg, Gei=Geisingen, Gru=Grueningen, Koe=Koenigsheim, Leh=Lehmgrubenhof, Lin=Lindenberg, Mag=Magdalenenberg, Rus=Russberg, Spa=Spaichingen. The Swabian Jura and Black Forest are considered to be unfavourable areas, whereas the Baar is the favourable area. The background map depicts the relief [36].

There are no archaeological Early Bronze Age (2150-1550 BCE) sites known on the Swabian Jura. Temporary land use is indicated by a burial site found in Boettingen dated to the Middle Bronze Age (1550-1300 BCE) [37]. There are a few Late Bronze Age (1300-1200 BCE) sites known in river valleys, but none on the Swabian Jura itself. However, during the late Urnfield period (Urnfield period 1200-800 BCE), archaeological finds point to an expansion of populated areas, indicated by several hilltop settlements where intensified land use was practiced on the western edge of the Swabian Jura, coupled to land use in adjacent narrow river valleys. The expansion of the populated area from the favourable Baar area to unfavourable areas such as the Swabian Jura has been explained by external pressures for example drastic climatic changes or overpopulation, and human conflicts in the Baar [37–39]. This explanation, however, is not supported by local archaeological data [40].

Hoards and the deposition of metal artefacts in bogs as well as at springs of larger rivers such as the Neckar reveal a fundamental change in the perception of landscapes during the Urnfield period. This development can also be seen on the high plateau of the Heuberg. Here, two sites, Götzenaltar and the Heidentor near Koenigsheim and Boettingen, may have been used for ritual purposes during the Urnfield period. The Götzenaltar is a large limestone block, located on a small hill. The Heidentor is a natural rock formation with the shape of a wide gate. This site is located on a steep slope at the edge of a mountain range called 'Oberburg' above the village of Egesheim [34]. Numerous pottery fragments suggest that repeated visits were made to both sites [37,41]. At the Heidentor the pottery was thrown through the rock formation downslope. The rock formations can be considered ritual sites [40], because they fulfil the criteria of extraordinariness and repetition introduced by Colpe 1970 [42]

With the transition to the Iron Age (800-±10 BCE/CE), the land use pattern changes considerably on the Heuberg. A reduction of settlement activities can be observed on the Swabian Jura, since only one site on the Heuberg actually dates to the early Hallstatt period (Hallstatt period 800-450 BCE), but during the late Hallstatt period, settlement activity increases again [37]. A change in the conceptualization of landscapes can be interpreted from an increasing number of ritual sites on the western Baar and Swabian Jura [43–45]. Examples of ritual sites are the Götzenaltar and the Heidentor, used during the Iron Age as well as during the Urnfield period [32,46], or a large deposit of sherds from pottery vessels near Lindenberg [47,48]. The distribution of settlements and burial sites on the Heuberg indicates a land use pattern related to the ritual use of the Heidentor. The majority of the settlements are located in the south-western part of the Heuberg, while the burial mounds lie mainly in the area between the settlements and the Heidentor and no sites could be found in the direct vicinity of the Heidentor. Thus, the landscape can be differentiated in the “landscape of the living” (settlements), the “landscape of the dead” (burial sites) and the “void” (no sites) [40]. This pattern of land use was culturally constructed with the intention to keep the ritual site in spatial and cultural seclusion, which is typical for places used for transitional rituals. The Latène period (450-±10 BCE/CE) is characterized by a decline of settlement activities on the Swabian Jura, during which very few settlements, such as the one on the Dreifaltigkeitsberg near Spaichingen, are still populated [35]. On the Heuberg, the seclusion of the Heidentor was maintained until the end of the middle Latène period. As soon as the ritual activities stopped, the settlement pattern changed, and the formerly empty areas close to the Heidentor were populated during the late Latène period [40].

During the Roman Empire (±10 BCE/CE-375 CE) settlements were concentrated on the Baar and the adjacent river valleys. Other than a Roman coin hoard found in the eighteenth century, there is hardly any evidence for Roman settlements on the Swabian Jura [49]. With the Merovingian period (450-750 CE) comes an intensification of land use in the large valleys of the Danube, Breg and Brigach rivers, and smaller rivers on the Swabian Jura, in contrast to the sparse archaeological sources on the Heuberg. During the Middle Ages (450-1500 CE) the settlement pattern changed and was dominated by scattered settlements without obvious concentration in certain landscapes. During the High Middle Ages (750-1250 CE) settlement activities intensified on the Heuberg.

3 Methods

3.1 Field

Field work was carried out from 2013 to 2015 with the permission of landowners and tenants. Field work included the description of 15 soil profiles on the Swabian Jura and additionally 53 soil pits in the Baar and the Black Forest. The soil profiles were described following the German soil classification system [50], the FAO 2006 [51], and the WRB 2015 [52]. The German classification system uses the horizon designation *M* (M = Lat. *Migrare*, to migrate) for anthropogenic colluvial horizons lacking other pedogenic properties. Since it is important to differentiate colluvial horizons from others with different pedogenic development, we use the M horizon together with the FAO nomenclature. German soil types were translated into WRB using translation software [53,54] and a manual check.

The soil profiles are located along catenas reaching from the upper slope to foot slope positions. Catenas represent a series of soil profiles along a slope having different characteristics due to differences in topography, parent material, drainage, erosion or deposition [55]. The locations of catenas and soil profiles were chosen to represent a stratigraphy of colluvial deposits in close proximity to known prehistoric activities. Samples for dating were collected from colluvial deposits showing the most detailed pedostratigraphy and being characteristic for the site. In order to prevent sampling bias for specific time periods soil samples for dating were collected consistently from all soil horizons, in which sampling was possible.

At the Swabian Jura sites a total of 166 bulk samples and 128 volumetric samples (each consisting of 3 x 100 cm^3 subsamples) were taken from all horizons. From each colluvial horizon, the upper 5 cm were sampled separately, and colluvial horizons thicker than 20 cm were split into thinner sampling units. The sampling and dating strategy allows us to reconstruct the chronology of colluvial deposition and to reconstruct phases of land use at different sites.

3.2 Laboratory

Total C and N contents [mass %] were analysed using oxidative heat combustion at 1150 °C in a He atmosphere (element analyzer “vario EL III”, Elementar Analysesysteme GmbH, Germany, in CNS mode). Soil organic C content (SOC) was determined using: SOC = C_{total}-$CaCO_3$ x 0.1200428. Bulk density [g cm^{-3}] was gravimetrically determined (cf. [56]). Carbonate content was determined volumetrically by CO_2 evolution using a Calcimeter (“Calcimeter”, Eijkelkamp, Giesbeek).

To estimate depositional ages of the colluvial sediments, optical stimulated luminescence (OSL) dating was applied, using opaque steel cylinders with a diameter of 4.5 cm for sampling. For equivalent dose (D_e) determinations, the coarse grain (90-200 µm) quartz fraction was prepared and measured with a single-aliquot regenerative-dose (SAR) protocol after Murray and Wintle 2002 [57]. All luminescence measurements were carried out at the luminescence laboratory of the Justus-Liebig-University in Giessen, using a Freiberg Instruments Lexsyg reader [58]. For data analysis, the R luminescence package [59] was used.

To avoid modern bleaching by bioturbation, soil material from the upper 30 cm of the profiles was not sampled for OSL dating. In consequence, colluvial deposition of the Modern era might be underrepresented. This might also apply to older colluvial deposits, because of the generally better preservation of younger deposits. However, the general suitability of OSL dating on colluvial deposits is shown in numerous studies, despite issues of partial bleaching (e.g. [5,60,61]). Most soil samples have good properties for luminescence dating, showing a bright luminescence signal. Therefore, small aliquots with a diameter of 1-2 mm were measured. In the case of significant skewness of the equivalent dose distribution, a minimum age model [62] was used. Skewness can result from partial bleaching, e.g. by bioturbation.

AMS-^{14}C dating of charcoal fragments found within the colluvial deposits was carried out at the laboratories of Erlangen, Jena, Mannheim, and Poznan. The pretreatment was done using the ABA (acid-base-acid) or, in case of samples measured in Jena, by an ABOx (acid-base-oxidation) procedure [63]. The conversion of the ^{14}C isotope ratios in calendar and calibrated ages was done with OxCal 4.2 using the IntCal13 calibration curve [64,65]. If the pretreatment omitted all contaminations and the charcoal fragment was incorporated when the colluvial deposit formed, the age of the charcoal represents the age of the layer plus the time span from the death of the tree to deposition, i.e. the charcoal age is an upper limit for the age of the colluvial horizon.

The basic assumption for the interpretation of charcoal ages is that no relocation within the soil profile occurred. Occasionally, we encountered sample ages which appeared to be out of sequence in relationship to other dated samples within a soil profile. In those cases, where the majority of ages formed a clear stratigraphic sequence, and certain charcoal samples dated to much older or younger times than expected due to their sampling location within the sequence, we assumed relocation of those samples by natural processes of bioturbation or redeposition. Age inconsistencies may also be due to the use or re-use of old timber because the samples date to the time when the tree grew, rather than the time when the wood was processed and used. These confounding effects can also explain charcoal ages which are older than OSL ages.

Because of these complications, the presence of charcoal in a colluvial stratum may indicate human burning activity rather than the age of colluvial deposition. However, it is important to consider the possible deposition conditions by assessing the abundance and distribution of charcoal within the soil profile before inferring either a natural or anthropogenic cause. It is assumed that many isolated charcoal fragments appearing in a soil stratum are more likely a result of consecutive inputs and anthropogenic origin. In contrast, layered charcoal fragments more likely indicate a natural deposition following, e.g. a forest fire.

The radiocarbon calibration process can also introduce additional errors if particular ages are associated with problematic parts of the calibration curve ("wiggles" or nonlinearities of the calibration curve), which result in extremely large and non-normal standard error estimates, even for very precisely dated samples. Another factor limiting the explanatory power for older periods might be that younger charcoal samples can be overrepresented because of better preservation and an increasing probability of destructive processes such as erosion and weathering [66–68].

Thus, radiocarbon ages from charcoal fragments could be older, younger, or of the same age than OSL samples, depending on site taphonomy and age calibration. The true age of the formation of colluvial deposits is not necessarily dated with the radiocarbon or luminescence method. Because of the difficulties in interpreting the chronologies on individual soil profiles, we employed a statistical approach for analysing radiocarbon and OSL ages that involved calculating summed probability density (SPD) plots [69,70].

Only the available radiocarbon and OSL ages from colluvial layers with a high reliability, based on the comparison of other luminescence and ^{14}C ages, and the stratigraphic context, were used in this process. To meet the critique on SPDs [71] sampling should be representative in a way that the probability of having a sample dating to a certain period, should have the same relation to the number of sites for all periods [72]. Soil pit locations were purposefully sampled from archaeological contexts; however, within each soil pit, soil material for dating was sampled from the top to the bottom of the vertical pit wall, and from within each identifiable and dateable layer. Because of this, the distribution of the age samples represents a continuous, temporal sample and therefore, the resulting SPD curves from the ^{14}C and OSL ages and error distributions are valid and representative profiles of the colluviation intensity of these sites through time. To calculate SPDs, uncalibrated radiocarbon ages and errors were used and calibrated using the statistical software package Bchron [73] and the calibration curve IntCal13 [64]. The SPD for the OSL ages was generated by sampling from a Gaussian distribution for each date where the OSL ages and their standard errors define the mean and standard deviation of each distribution. The different age probability curves are summed and plotted.

In order to contextualize our study area in the larger region, we extracted 737 Neolithic and Early Bronze Age radiocarbon ages from the RADON database [74] and calculated a regional SPD. To get a representative dataset we included ages from following areas: southwest Germany (Baden-Württemberg n=556), the Swiss lowlands (Schaffhausen n=18, Zürich n=100, Basel-Stadt n=0, Basel-Land n=14, Thurgau n=14, Aargau n=8, Solothurn n=3, Jura n=10) and eastern France (Elsass n=0, Franche Comte n=13, Lothringen n=0, Haut Rhin n=0).

4 Results

The results of the archaeopedological project are archived online at Dryad [75]. This repository contains the overview from the project “Favour - Disfavour? Development of Resources in Marginal Areas” as part of the collaborative research centre SFB1070 ResourceCultures. The results [75] contain the field description of all 68 soil profiles, the laboratory results of 728 bulk soil samples, and a total of 47 OSL and 93 radiocarbon ages. The focus of this paper is on four sites with a total of 15 soil profiles located on the Swabian Jura.

4.1 Colluvial deposits on the Swabian Jura

The field analyses of colluvial deposits usually lead to a site biographical interpretation of soil development, colluvial deposition, and a wider interpretation about environmental change and land use. This process to assess the geomorphodynamic situation leads to the interpretation of geomorphodynamically stable and instable phases, concerning soil erosion and deposition triggered by land use. Following our interpretation, geomorphodynamically stable phases are characterized by thin or no colluvial deposits, whereas thick and multilayered colluvial deposits containing many artefacts indicate geomorphodynamic instability, most likely caused by land use (Fig. 1). Multilayered colluvial deposits can be covered by deposits having a fully developed topsoil horizon indicating a phase of environmental stability and thus surface horizon development and pedogenic processes. If this surface horizon is covered by new colluvial deposits it can be concluded that the site has undergone alternating phases of geomorphodynamic instability and stability, in other words alternating phases of land use including colluvial deposition and phases of no land use with predominantly natural vegetation cover or phases where sustainable land use techniques were used. This site biography can be interpreted using ages, archaeological knowledge, soil chemical and physical results, and further (paleo)environmental data to reconstruct site-specific land use dynamics.

4.1.1 Lindenberg

The soils at the Lindenberg site (Fig. 3) are developed in sediments on limestone covered by colluvial deposits. The two upper soil profiles (Lin3, Lin4) consist of colluvial material covering a clay rich (> 60% clay) soil type, Terra fusca. The subsoil is dominated by a very high limestone content. The lower profiles Lin1 and Lin2 do not include Terra fusca material. Lin2 has the thickest colluvial deposits with four layers. Lin1 is partly eroded, which can be explained by its position on the shoulder of a slope of a V-shaped valley of the Weissenbach, a Danube tributary. The archaeological finds in the direct vicinity date to the Neolithic and Bronze Age, and then to the Roman Empire, the Middle Ages and the Modern Times. The pattern of archaeopedological

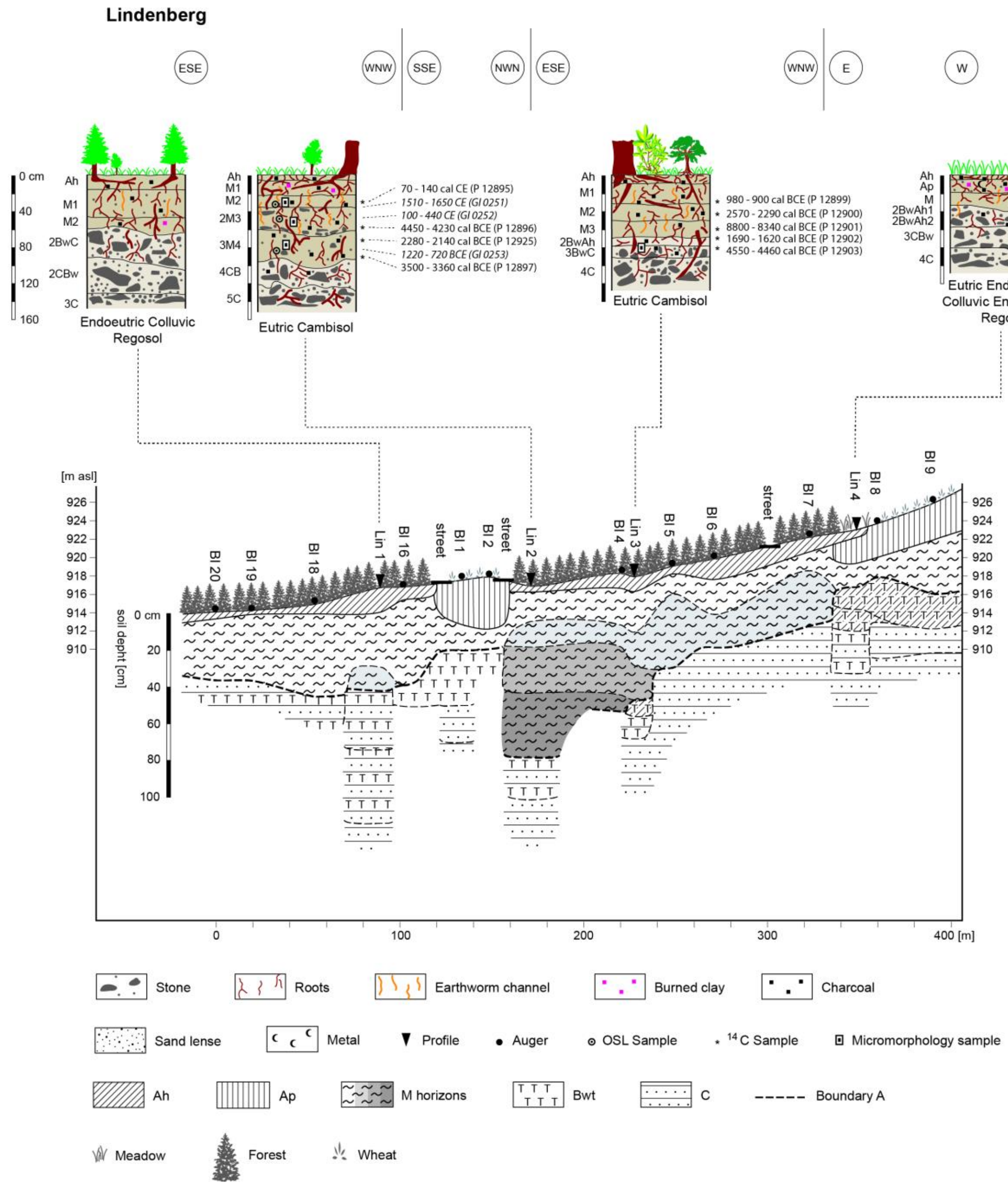

Fig. 3: Catena and soils at the Lindenberg site, situated on the backslope.

ages is almost the same. The earliest human presence manifests itself through dated charcoals during the Neolithic, but more intensive land use leading to colluvial deposition sets in only during Bronze Age. At the Lindenberg no colluvial deposits or charcoals dating to the Middle

Ages were found. The Early Mesolithic charcoal (cal BCE 8800-8340, P12901, Lin3) points to very early land use or natural forest fire.

4.1.2 Boettingen

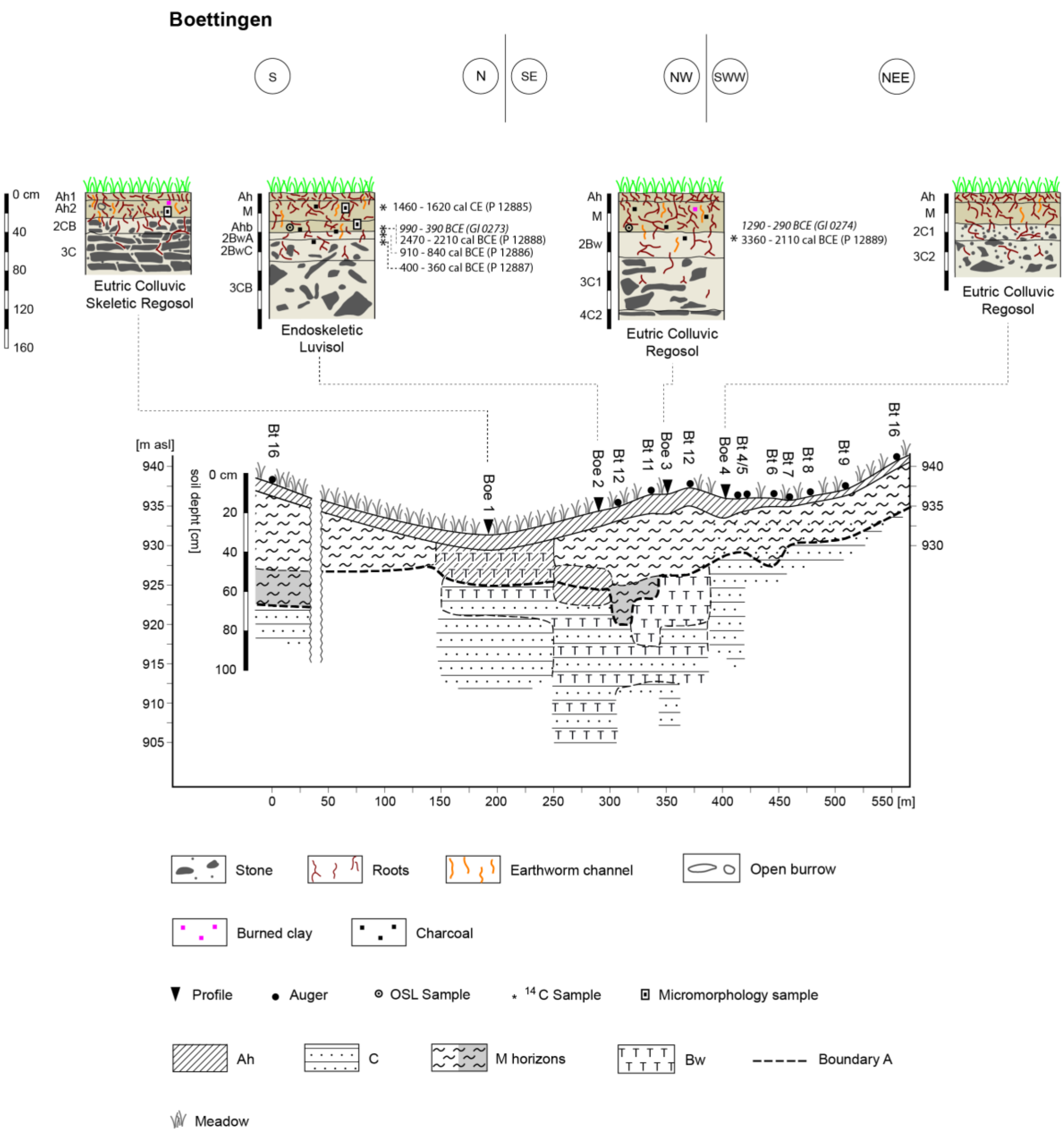

Fig. 4: Catena and soils at Boettingen, situated from toeslope to backslope.

The area around Boettingen (Fig. 4) is known to have been used since the Bronze Age. The thickest colluvial deposit, however, includes only two colluvial layers (auger Bt11, Bt12) at the foot of a slightly terraced slope. The profile (Boe2) in the same position shows a former surface horizon with high SOC content underneath the colluvial deposit and above the subsoil. The colluvial deposit dates to the Bronze/Iron Age (BCE 1290-290, GI0274, Boe3) and contains

Modern and Neolithic charcoals (cal CE 1460-1620, P12885, Boe2; cal BCE 2470-2210, P12888, Boe2). The flat areas (Boe1) show bioturbation by animals and smaller soil organisms down to 30 cm when a mixed horizon of subsoil and weathered limestone rocks begins.

4.1.3 Koenigsheim

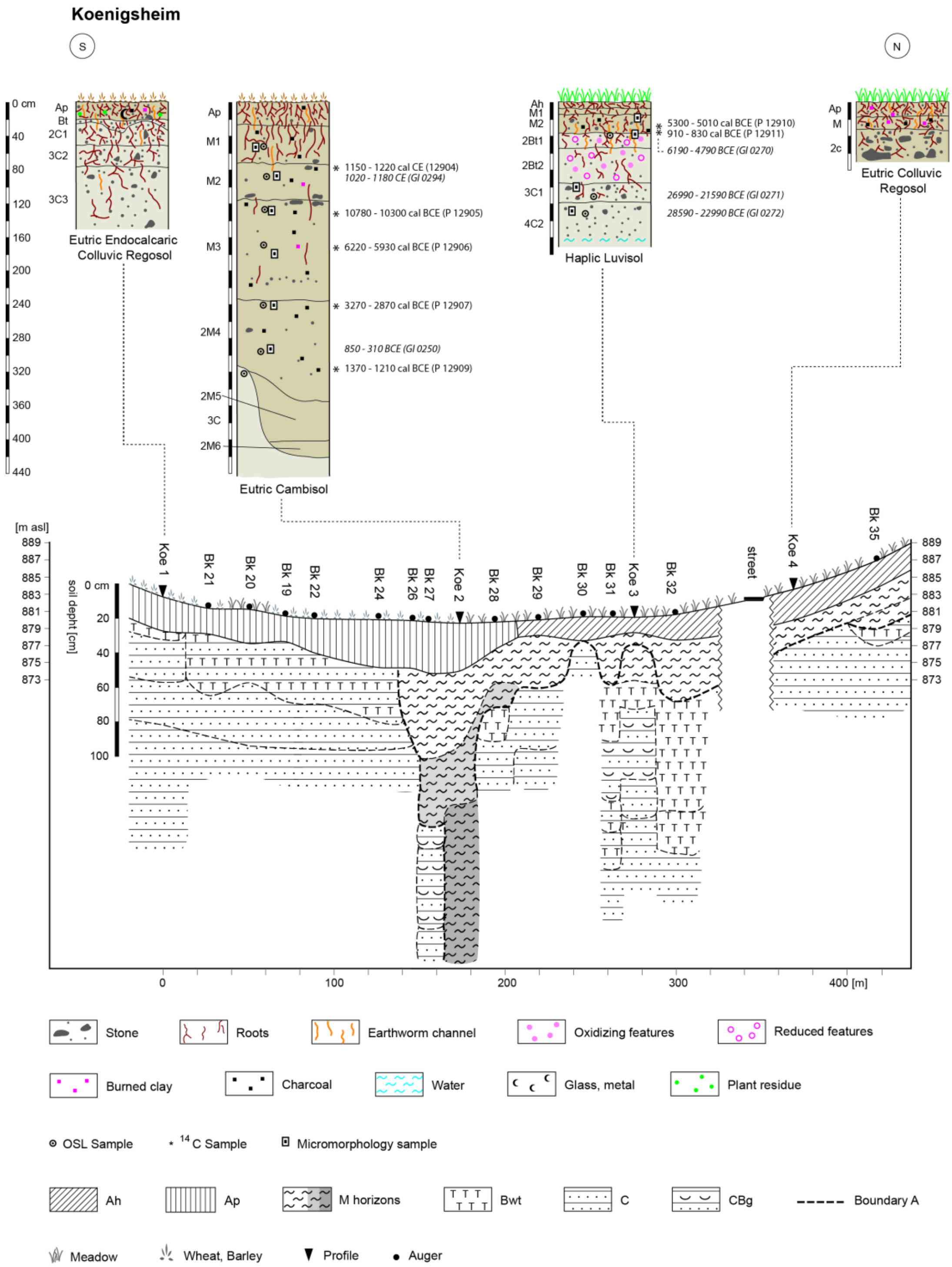

Fig. 5: Catena and soils at Koenigsheim, situated in a depression.

The site Koenigsheim (Fig. 5) is situated in a shallow depression, surrounded by mixed and coniferous forest and the village of Koenigsheim. Light brown colluvial deposits are mostly limited to a depth of 40 cm (Koe4, Koe3) or to the plough depth (Koe1). Underneath the colluvial deposit subsoil horizons occur, which were formed in periglacial layers. Lower horizons especially are dominated by coarse limestone fragments. A special feature of the catena is the soil profile Koe2, a completely filled doline. The doline is around 3 m deep and now filled with dark brown clayey colluvial deposits, which can be separated into four layers. The dark brown soil material does not occur in the surrounding area. The OSL ages suggest that the subsidence of the doline might have taken place in the transition of the Bronze to Iron Age. The lower part of the lowest M horizon (M4, 233-320 cm) dates to the Hallstatt period (BCE 850-310, GI0250) and contains a Middle to Late Bronze Age charcoal (cal BCE 1370-1210, P12909). The upper part of the same horizon contains a Late Neolithic charcoal (cal BCE 3270-2870, P12907) and the overlying M3 horizon even contains Late Mesolithic and Late Palaeolithic charcoals (cal BCE 6220-5930, P12906; cal BCE 10780-10300, P 12905). It can be assumed that the M3 horizon reflects a balancing of the relief and functioned as a soil surface during the Middle Ages. The doline must have been filled with pedosediments (redeposited soil) within around 1000 years from the Iron Age to the Roman Empire, since the OSL and calibrated ^{14}C ages of the M2 horizon date to the High Middle Ages (CE 1020-1180, GI0249; cal CE1150-1220, P12904).

Archaeological finds point to land use during the Urnfield period, the Iron Age and from the Middle Ages onwards. This pattern is supported by the archaeopedological ages, but additionally charcoals date back to the Neolithic and even Mesolithic.

4.1.4 Russberg

The soils at the Russberg site (Fig. 6) are developed from the same geology as in Koenigsheim and the settlement history is also very similar, indicating land use during the Hallstatt period and from the Middle Ages onwards. The soil profiles are situated on a plateau, which is covered by shallow colluvial deposits overlying limestone rich subsoils. Only the upper end of a v-shaped valley of a small Danube tributary contains thick multi-layered colluvial deposits (Rus2, Rus3). And the rest of the v-shaped valley was exposed to intense erosion and has only thin soils. Charcoal ages from these sites support archaeological findings and date to the Iron Age (cal BCE 400-360 P12893, Rus3; cal BCE 410-380, P12894, Rus3; cal BCE 540-230, P12891, Rus2), Roman

Empire (cal CE 260-400, P12892, Rus3), Middle Ages (cal CE1150-1230, BE3606.1.1, Rus2; cal CE 1150-1250, BE4527.1.1, Rus2) and Modern times (cal CE 1670-1940, P12924, Rus3). The lowest colluvial horizon of Rus2 contains an Early Mesolithic charcoal (cal BCE 11040-10910, BE3607.1.1), which is most likely relocated within the soil profile, e.g. by bioturbation.

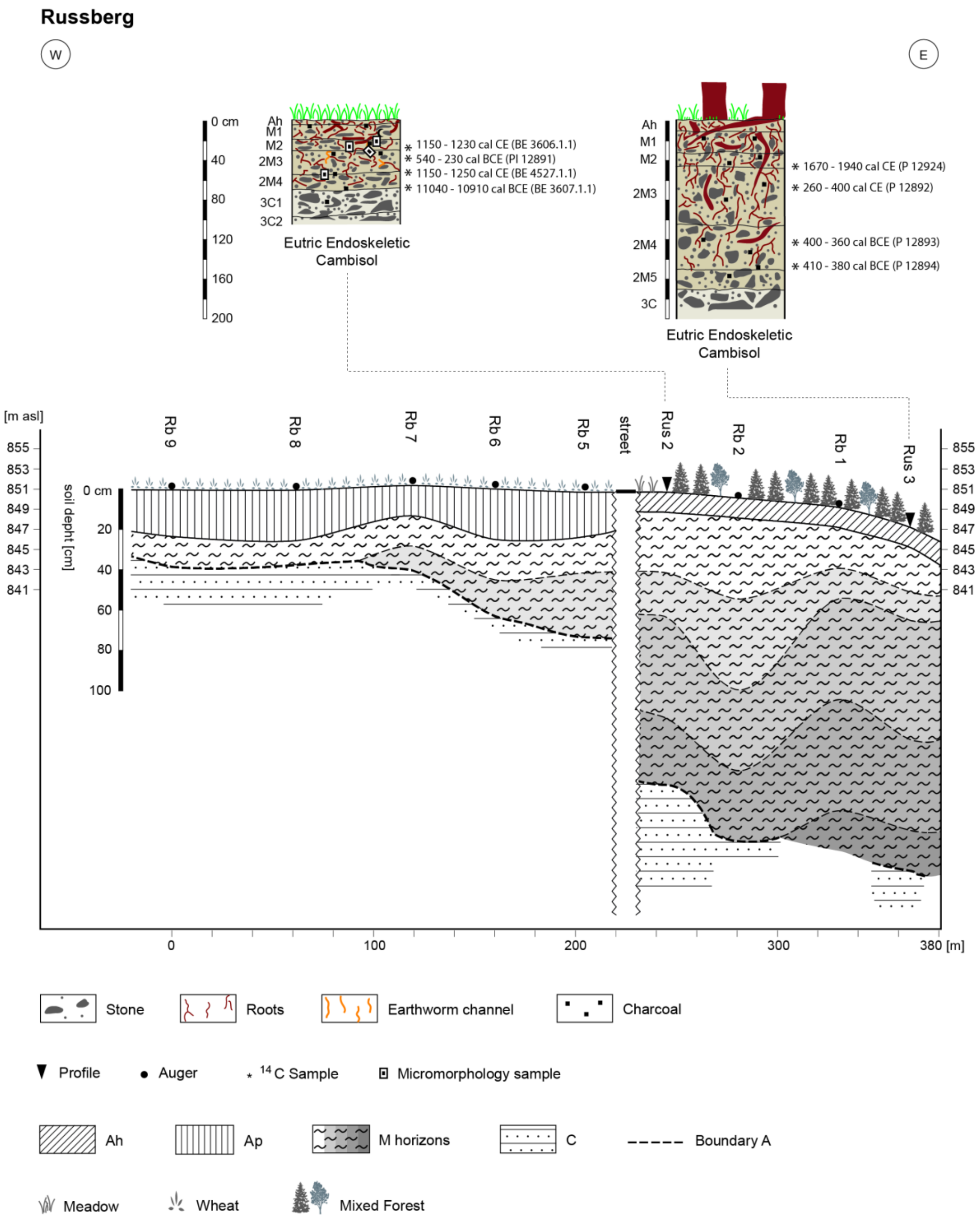

Fig. 6: Catena and soils near Russberg, situated on shoulder and backslope.

4.2 Chronostratigraphy

The chronostratigraphy of colluvial deposits, inferred from dated charcoals, on the Swabian Jura indicates that intensified land use and land use change began in the Mesolithic at the sites Koenigsheim, Russberg and Lindenberg. The onset of continuous land use (cultivation) seems to have started during the Neolithic (Fig. 7). Neolithic charcoals were found in colluvial deposits at Lindenberg, Koenigsheim and Boettingen. The oldest OSL ages of colluvial deposits, however, date to the Late Bronze Age and Urnfield period. This onset of luminescence ages indicates an

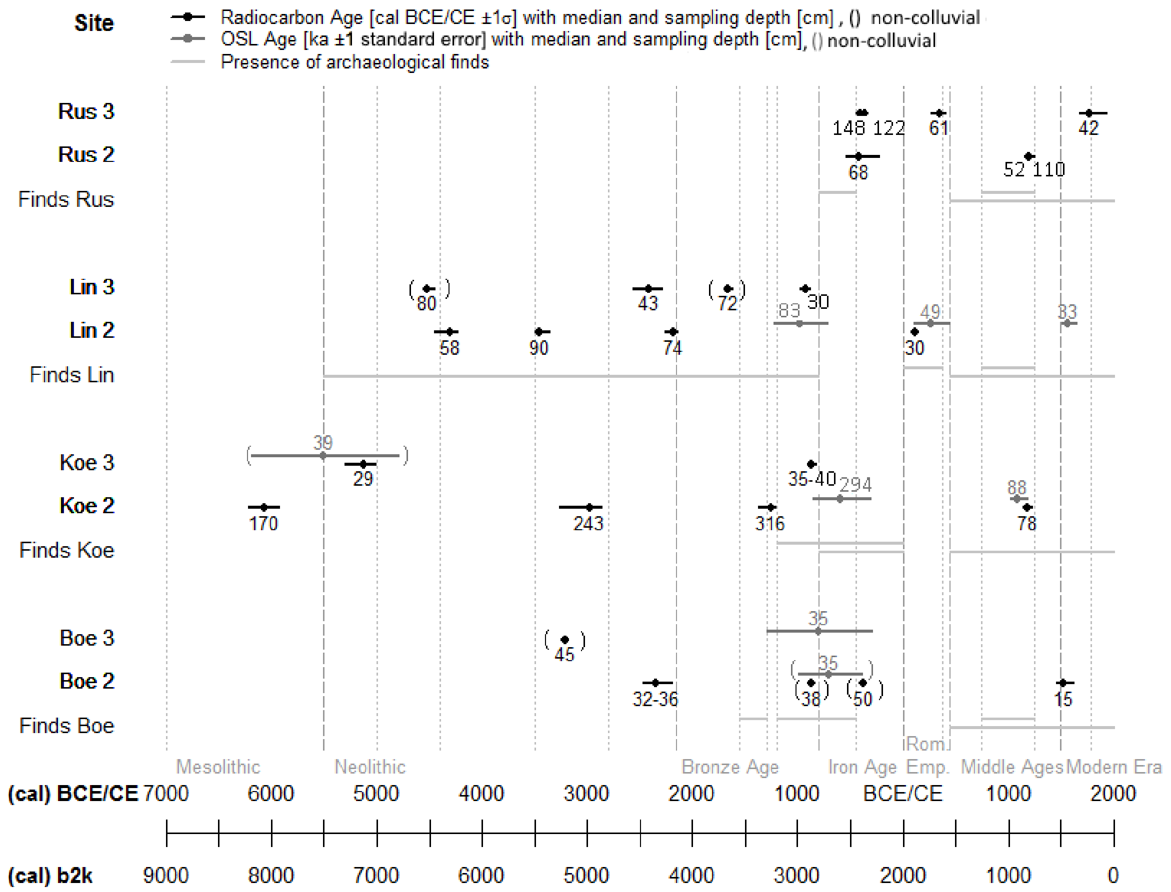

Fig. 7: AMS-^{14}C and OSL ages of colluvial deposits on the western Swabian Jura compared to known archaeological finds at each site from the Neolithic to the Modern Era. The dashed lines mark archaeological epochs and the dotted line archaeological periods.

intensification of agricultural land use or land use change from the Late Bronze Age to the Hallstatt period. Land use is not detectable during the Roman Empire at the sites Boettingen and Koenigsheim using colluvial deposits as a proxy, which indicates the absence or low-impact of human activities on the environment. Charcoals dating to the Iron Age were found in colluvial deposits at the Russberg site. At Lindenberg and Russberg colluvial deposits and charcoals were

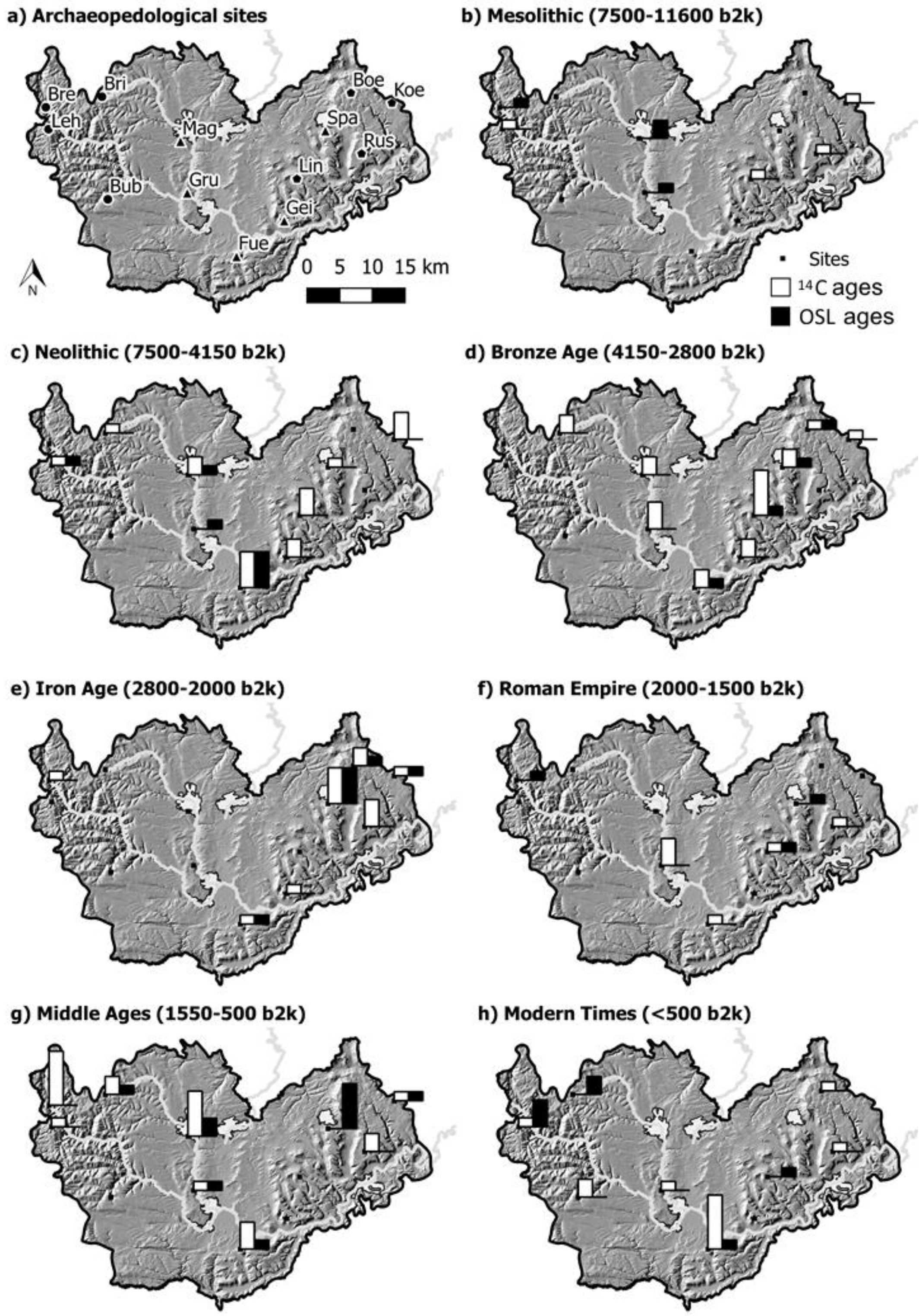

Fig. 8a-h): ^{14}C AMS- and OSL ages across the study area in different periods from the Mesolithic to Modern times. The height of the black bars indicates the number of OSL ages at the respective site. The range is from 1 to 5. The height of the white bars indicates the number of ^{14}C ages at the site. The range is 1 to 6. The Swabian Jura sites (*pentagon*) and the Black Forest sites (*circle*) are situated in unfavourable areas, whereas the Baar sites (*triangle*) are characterized as favourable (in 8a). The background map depicts the topography after [36].

found dating to the Roman Empire. Despite the well documented archaeological knowledge of the Middle Ages, medieval colluvial deposits were only found at Russberg and Koenigsheim.

Even though the environmental conditions on the western Swabian Jura are very similar, differences in land use dynamics between the investigated sites can be inferred from colluvial deposits and dated charcoals.

The comparison of ages of colluvial deposits from the Swabian Jura with ages of colluvial deposits from the Black Forest (Fig. 8) shows that these two unfavourable areas were differently settled and used. The south-eastern Black Forest shows only local land use before the Middle Ages, whereas the Swabian Jura seems to have had similar land use dynamics as the western Baar. Human land use activities were detected to have been early at the central Baar area, but no colluvial deposits were found during the Iron Age.

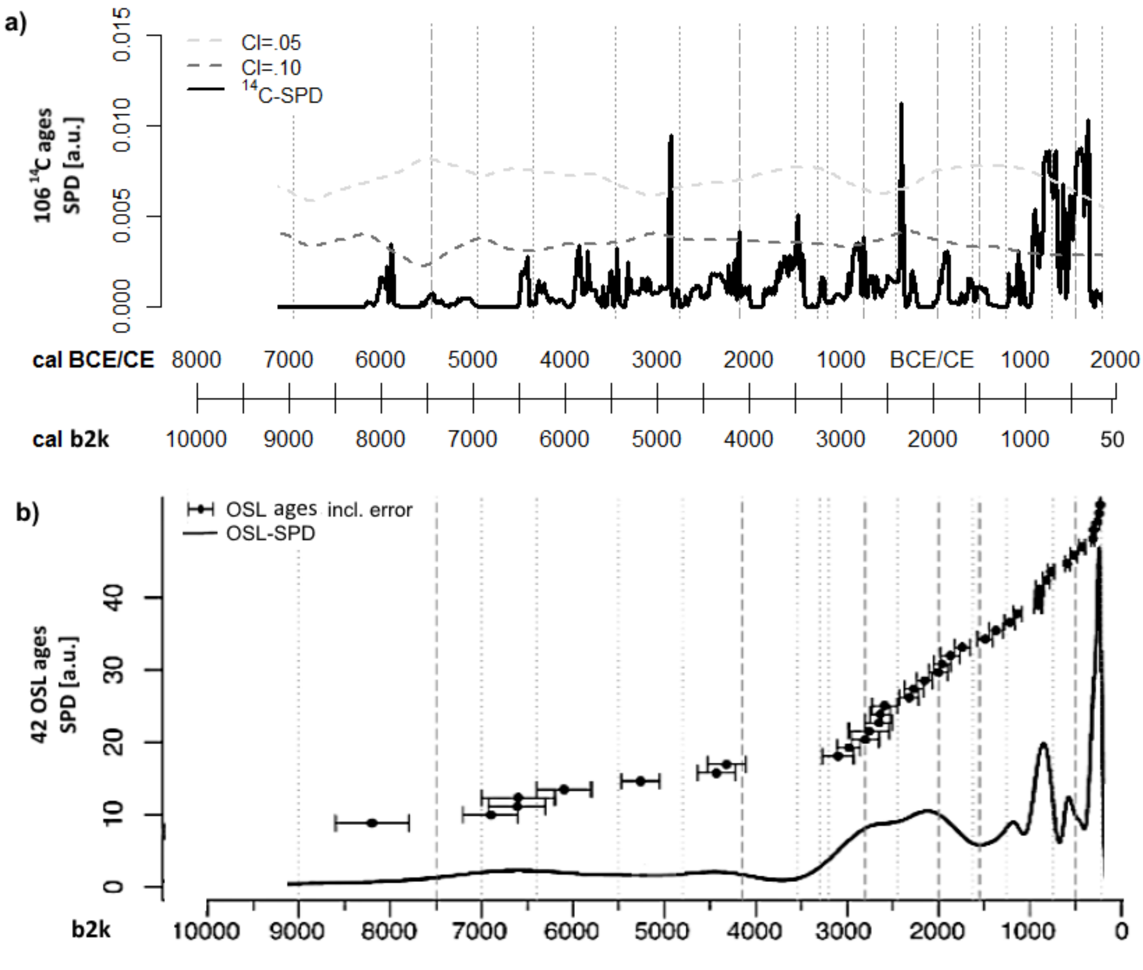

Fig. 9: SPDs calculated for the whole study area including the Baar, Black Forest and Swabian Jura. Showing the indication of the periods as dotted lines and the epochs are dashed. a) SPD using 106 ^{14}C ages, b) SPD using 42 OSL ages.

Calculating SPDs using all ages from colluvial deposits found in the Baar, the Swabian Jura and the Black Forest results in a ^{14}C-SPD (Fig. 9a) showing many peaks within the confidence intervals. These may result from the calibration error. It is shown that the probability of charcoal occurrence increases during the Neolithic, indicating increasing human activity in the study area, analogue to the interpretation of charcoal as an indirect proxy for demographic levels [70]. Cluster of peaks above the confidence intervals (0.05 and 0.10), e.g. during the Bronze and Iron Age and from the High Middle Ages to Early Modern period, reliably indicate phases of high human activity.

Based on the OSL-SPD (Fig. 9b), the probability of colluvial deposits is very low during the Neolithic, but shows an increase from the Late Bronze to the Iron Age. The possibility of colluvial deposition is even higher during the High Middle Ages and the Early Modern period.

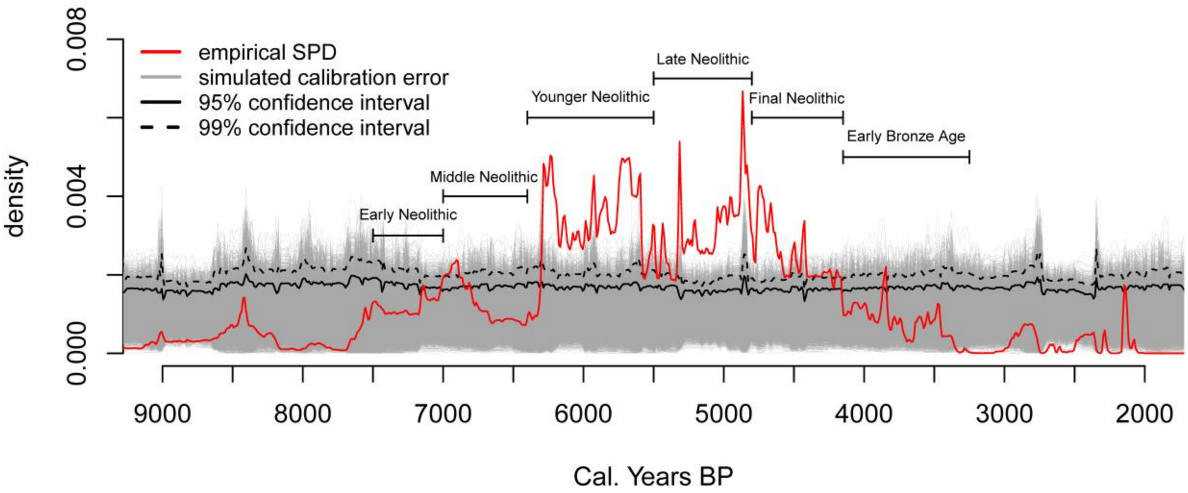

Fig. 10: SPD of radiocarbon ages from the RADON database [74], showing the confidence intervals and periods. The RADON database focuses on ages from the Neolithic and Early Bronze Age.

To put the data into a larger context a SPD of radiocarbon ages from southwestern Germany, eastern France and the Swiss lowlands (from the RADON database [74]) was calculated (Fig. 10). The database and thus the SPD is focused on the Neolithic and Early Bronze Age and shows a clear increase of human impact at the transition from the Early to the Middle Neolithic (around 5000 cal BCE), followed by a rapid decline during the Middle Neolithic. A strong signal dates to the Younger and Late Neolithic, which can be separated into two phases because the SPD drops below the confidence interval and into the error margin. The Final Neolithic and Early Bronze Age show a general decline in radiocarbon ages and thus human activity, however, it should be noted that the RADON database focuses on the Neolithic, and the decline apparent in this figure may be in part due to edge effects.

5 Discussion

Regarding the pre- and early historic land use, radiocarbon dating of charcoals in colluvial deposits and OSL-dating of colluvial deposits provide numerous new insights, since they add knowledge about time periods so far missing in the archaeological record. Our data show the value of using two different dating methods. Radiocarbon dating of charcoals is precise but difficult to interpret in relation to the timing of the formation of colluvial deposits because the charcoal fragments are prone to dislocation (the extent of which cannot be measured) by bioturbation within the soil, superficial relocation with runoff water, or later incorporation into the soil. In most cases the dating of charcoals gives a maximum age of the formation of the related colluvial layer, which in some cases can be more than 3000 years older, than the corresponding OSL age of the colluvial layer (e.g. [5,76,77]). In some cases, the results of both dating methods yield similar or even the same results, which gives a robust chronostratigraphy of colluvial deposits (cf. profile Mag1 in [22]). Both dating techniques give physically correct ages, however, given the dynamics of colluvial deposition processes, OSL ages seem to be – in most instances – more reliable in giving a model age of the period of time during which the dated colluvial layer was formed. However, there might be a time lag between the trigger of soil erosion and the time of deposition. In any case, all dating results have to be discussed and evaluated in their geomorphological/pedological context. The compilation and comparison with other data from the same region will give a robust regional chronostratigraphy of colluvial deposits. An additional factor is the time lag between the age of the settlement, or respectively, the time period during which the slope was used and the time when the colluvial layer was deposited. However, the link between colluvial deposition and land use or settlement activities is not always reliable. This study showed the concurrence of colluvial deposits and known archaeological sites in the area, but we could not establish a direct relation to a certain settlement, mainly because there are only few studied ancient settlements in the area. More studies are needed to establish this relation between archaeologically known settlement and land use sites and colluvial deposition in the direct vicinity.

5.1 Land use dynamics on the Swabian Jura, the Baar, and the Black Forest

5.1.1 Mesolithic

The Mesolithic overview (Fig. 8) shows that there are two sites on the Baar and one in the Black Forest having Mesolithic OSL ages. The OSL age from the Black Forest is likely to result from a contamination of the colluvial sample with underlying periglacial sediment. The Mesolithic samples of the Baar might be interpreted as the beginning of colluvial deposition and thus long term and intensive land use during the Mesolithic in the area. Traditionally Mesolithic communities are not expected to practice agriculture or clear forests, but they disturbed the natural forest vegetation, which is visible in many pollen diagrams through the presence of microcharcoals. These microcharcoals are linked to burning and forest clearance [78–80]. Divišová and Šída [81] offer the explanation of forest clearings as social phenomena out of fear and anxiety about the environmental surroundings. The increased use of wild plants during the Mesolithic [81,82] might have led to local agriculture and the transition to the Neolithic culture [70,83,84]. There is a long time discussion about the interpretation of proxies for Mesolithic agriculture: the practice of agriculture during the Mesolithic is inferred from cereal pollen found in bogs in central Europe, especially in Switzerland [85,86]. Behre [87] contrasted that the interpretation of Mesolithic agriculture is often based on single pollen finds described as cereal pollen, where it could also be pollen of wild forms of cereal-type pollen and is therefore, not reliable as a proxy for agriculture.

Charcoals from Russberg, Koenigsheim and Lindenberg indicate land use during the Mesolithic on the Swabian Jura. The lack of archaeological Mesolithic sites on the Swabian Jura is most likely a result of the nomadic way of life during this epoch [88]. Forager societies usually had smaller settlements and thus less influence on the environment therefore, it is much more difficult to detect their former presence in an area [70]. In this way Mesolithic charcoals can only be an indirect indication of human presence or they can be interpreted as being caused by natural processes such as wildfires.

Our archaeopedological results add another proxy to the discussion about Mesolithic agriculture. As we interpret the finding of many charcoals in soils as an indirect proxy for human presence and land use, some forms of land use can undoubtedly be shown for the Mesolithic. The

Mesolithic OSL ages can be interpreted as a reference of open landscapes, probably due to agricultural land use, thus, as an early development or adaptation to a new lifestyle (cf. [84]). The beginning of colluvial deposition and the increased number of charcoals with the transition from the Mesolithic to the Neolithic clearly points at intensive and continuous land use and consequently at sedentary and agricultural life styles.

5.1.2 Neolithic

The onset of an area-wide sedentary and agricultural society can be dated to the Neolithic. The number of Neolithic charcoals on the Swabian Jura and the Baar is higher than in the western study area (Fig. 8). Neolithic charcoal fragments of Lindenberg, Koenigsheim, and Boettingen can be interpreted as proxies of temporary land use on the Swabian Jura, possibly within the framework of a seasonal pasture economy. So far, land use was only known from the Heuberg area, which is the first known indication of land use at these sites during the Neolithic. Pollen records from the south-eastern Black Forest [26] date the first occurrence of human indicator pollen to the Younger Neolithic. The oldest phase of colluvial deposition on the Baar dates to the Younger Neolithic (~3700 BCE, [22]) and correlates with a wetter and colder period [89]. Additionally, decreasing atmospheric ^{14}C production rates [90] and increased ice rafted debris in the northern hemisphere [91] indicate these conditions. Temperature reconstructions using lake levels [92] and pollen data [93], in contrast, indicate drier and warmer conditions. Despite these contrasting climate reconstructions colluviation seems to be triggered by the onset of agricultural land use. The increased signal of human activities during the Neolithic (charcoals, pollen, colluvial deposits, and archaeological finds) found across our study area point at an increased regional human impact on the landscape from the Neolithic onwards, which is in agreement with the SPD calculated from the RADON database [74] including samples from a wider region (Fig. 10).

Shennan, Downey et al. [1] date the earliest farming in southern Germany to around 5450 cal BCE and reconstruct the first significant agriculture-driven boom of population density from 5200-4950 cal BCE followed by a rapid decline, the bust-phase during the Middle Neolithic. The Younger and Late Neolithic are characterized by several minor boom-bust phases and led to a steady decline during the Final Neolithic and Early Bronze Age, which is mirrored by the trend of the RADON based SPD. The first increase of population levels during the Early Neolithic is shown by Shennan and Edinborough [72] for all of Germany. The difference in our results is the trend during the Younger Neolithic, where only low population levels were reconstructed. Compared to this study the archaeopedological dates presented in this study seem to have a delayed trend picturing the peaks in the Late Neolithic. This difference likely results from the smaller dataset of the study area, excluding some favourable areas and well-studied archaeological locations, thus, maybe truly depicting later and less intense development in the area. Pollen records from the south-eastern Black Forest [26], in contrast, mirror the increase of population with the onset of human indicator pollen.

5.1.3 Bronze Age

OSL ages provide the earliest evidence for land use on the south-western Swabian Jura during the Early Bronze Age. Archaeological finds point at land use only during the Middle Bronze Age and Urnfield period on the Heuberg, but the archaeopedological OSL and ^{14}C ages of Boe3 and Koe2 indicate land use during the Late Bronze Age. For the Urnfield period the archaeological record and archaeopedological data correlate well indicating land use. Further, intensive land use is indicated on the Baar marking a main colluviation phase (~1400 BCE, [22]) and also at one site in the south-eastern Black Forest (Fig. 8). The increased colluvial deposition coincides with a cold and humid climate [89] with especially cold summers as reconstructed by pollen data [93], but again low lake levels [92] and an indifferent, global trend of atmospheric ^{14}C production [90] and the occurrence of ice rafted debris [91]. It is the transition to a dry period [94,95].

5.1.4 Iron Age

Archaeological records and archaeopedological data correlate well during the Hallstatt and the Latène period on the western Swabian Jura. There is first evidence of land use at the site Russberg. The mining of bean ore and secondary land use (i.e. agriculture) might have triggered colluvial deposition on the Swabian Jura [96,97]. The overall impression is a decline of used land during the Iron Age since there were very few data from the south-eastern Black Forest and the Baar area. The exceptions are the sites Fuerstenberg and Spaichingen. In Spaichingen, located at the lower slope of Swabian Jura cuesta, there are four ^{14}C and four OSL ages indicating a major phase of land use at this site, which correlates with archaeological findings [37]. This local phase of increased colluviation on the Baar and the Swabian Jura (~500 BCE, [22]) falls in a cold period [90,93,98]. The rather unfavourable climate in addition to low land use intensity [99] and population density [100] might have resulted in the formation of spatially different intensities of colluvial deposition.

5.1.5 *Roman Empire*

In contrast to the expected intensification of land use and soil erosion, land use related soil erosion seems to have declined towards the Roman Empire. Only two Roman charcoal fragments and one OSL age date to this period at the Swabian Jura sites, indicating a generally low land use intensity. Samples from Lin2 complement the archaeological evidence of Roman settlements. Even though there are known Roman settlements on the Baar, this is not visible in colluvial deposits. The Spaichingen site is located near a formerly productive spring and next to a Roman road connecting Tuttlingen and Rottweil north of Spaichingen [101], but only one age falls into the period of the Roman Empire. Charcoal fragments dated to the Roman Empire found in Grueningen indicate increased human activities or colluvial deposition [22], which is the only main colluviation phase falling into a dry and warm period [93,98]. The triggering activity might have been practicing agriculture on the fields to support a Roman castrum a few kilometres south near Huefingen, which supposedly accommodated about 1000 soldiers [102,103]. The wood of the Black Forest might have been used by the Romans [104], but these activities did not lead to an increase of colluvial deposition in the Black Forest. It can be interpreted that the selected logging sites were not intensively used by the Romans.

5.1.6 *Middle Ages*

Land use and settlements are archaeologically well documented on the Swabian Jura during the Middle Ages. The high to late medieval climate was warm until the Little Ice Age and the transition to the early Modern period [93,98,105]. The forests were cut purposefully to use the wood or to clear areas for farming or animal husbandry having left less than 20% of the forest cover during that period [99,106,107]. A striking situation is the limited archaeopedological record on the Swabian Jura, with only two sites dating to the late High Middle Ages. However, considering the entire study area, especially the Baar area, the increased colluviation and land use becomes apparent. One explanation for the low record of colluvial deposition on the Swabian

Jura could be that these sites were not particularly used for agriculture. Another point could be the potential incorporation of medieval colluvial deposits into the modern Ap horizon.

5.2 Geomorphodynamically stable times – dating the gaps of colluvial deposition

The reconstruction of phases of colluvial deposition allows us in return to infer phases of relative geomorphodynamic stability and the formation of colluvial deposits, without soil erosion (Fig. 1). These phases are the deposition gaps between colluvial layers. The duration of these stable periods is the difference between the ages of the colluvial horizons. The underlying older horizon would have served as a land surface during that time and therefore it was hypothesized that it might show different pedogenic properties (such as an enrichment in SOC or heavy metals).

To reconstruct geomorphodynamically stable times we used all available data from the project (see supplement data and [22,26]). For examples the upper 88 cm of colluvial material in soil profile Bri1 [26]) are not distinguishable by dating and were deposited during Modern times. The underlying colluvial horizon dates to the Roman Empire and Merovingian period, and can thus be interpreted as having served as a land surface at some point during the High and Late Middle Ages. The environmental conditions during those roughly 1000-1500 years might have been geomorphodynamically stabile with little to no or sustainable land use, or it might have been an active land surface with deposition and erosion, which might have eroded the possibly medieval soil. The dated charcoals pre-date the OSL ages of the respective colluvial horizons, but they also indicate a time gap at 88 cm depth. An enrichment of soil chemicals would point to the soil horizon being used as a land surface, however, no such enrichment could be shown for the measured elements in the depth of 88-93 cm. Instead, the lower part of the covering colluvial horizon is enriched in SOC, Ni, Pb, Cr, and clay [26]. This can be interpreted as relicts of former land use and a reworking of the used former land surface into the modern soil horizon.

Leh3 also has a depositional gap between the lowermost colluvial horizon (2M3), dating to the Neolithic to Bronze Age transition, and the covering (M2) colluvial horizon at 51 cm depth, dating to Modern times. The 2M3 horizon was therefore the land surface for about 3600-4500 years. Charcoal ages indicate an even longer land use/deposition gap of about 5500-6000 years between the Late Neolithic and the High Middle Ages. However, soil chemical analyses show only very slight enrichment of SOC in the upper part of 2M3 and similar contents of Cr, Ni, Pb, and clay in the lower part of M2 and the upper part of 2M3. Human effects on pedogenic properties seem to be weak given the long duration of potential land use.

The profile Spa4 shows three packages of colluvial deposits, the oldest of which developed during the Middle Bronze Age to Urnfield period (3M6) and was the land surface for about 200-1500 years until the covering colluvial deposits were formed during the Iron Age and Roman Times (3M5, 3M4, 3M3). Roman deposits might have been the land surface for 500-1000 years until they were covered by medieval deposits (2M2, M1). The boundary between the medieval and Roman-time deposits at 88 cm depth has differences in properties, i.e. an increase of Ni, clay, and SOC above the boundary and an increase of Cu below 88 cm.

Profile Lin2 contains two potential former land surfaces, the lower one at around 60 cm depth for 800-1700 years during the Iron Age and the upper boundary between colluvial layers at 35 cm for 1000-1500 years during the Middle Ages. Except for the different ages of colluvial horizons, the soil shows no differences between the properties of "neighbouring" colluvial horizons.

The hypothesis of increased SOC contents in the upper part of a potential former land surface as a result of elevated input by plants has to be declined. The comparison (Tab. 2) shows that the SOC content of the upper 5 cm of the lower colluvial horizon on average is slightly lower (-0.09%) than that of the above lying colluvial horizon. Considering the complete colluvial horizon, the difference is more pronounced (-0.39%). There are no correlations of SOC content differences with the time period or the length of the time gap, the latter can be understood as the duration of potential land use. It can be concluded that, if a lower colluvial horizon was a former land surface, the upper part with the Ah horizon (enriched in SOC) must have been reworked into the overlying colluvial horizon and/or transported downslope by erosion. This might also explain the tendency of higher SOC contents in the lower part of the colluvial horizons. The overall pattern of declining SOC contents with increasing depth has to be kept in mind.

SOC/N ratios, in contrast, are slightly higher (0.24%) in the upper 5 cm of colluvial horizons and are generally higher (0.42%) in the lower colluvial horizon, compared to the directly covering colluvial horizon. This comes from lower N contents in the lower parts or it may picture the generally higher rate of N content decline with depth compared to the depth function of the SOC content across the whole soil profile. The higher C/N ratios might depict the influence of the former land surface.

Tab. 2: Comparison of SOC contents between soil horizons separated by a potential former land surface. SOC difference a = SOC difference between immediate sampled depth increments (subsamples of neighbouring soil horizons). SOC difference b = SOC difference of the two "neighbouring" soil horizons. Positive differences indicate a higher SOC content in the upper sample. Time gap refers to the difference between the relevant OSL ages.

Site	Depth [cm]	Upper horizon	Lower horizon	SOC difference a [%]	SOC difference b [%]	Time gap [years]	Period of the potential land surface
Rus3	46	M2	2M3	-0.30	-1.30	1270-1680	Middle Ages
Rus3	105	2M3	2M4	0.03	-0.35	610-800	Latène period-Roman
Lin2	35	M2	2M3	0.01	-0.12	1070-1550	Middle Ages
Lin2	60	2M3	3M4	-0.05	-0.61	820-1660	Iron Age
Spa4	88	2M2	3M3	0.00	0.04	440-1040	Roman-Merovingian
Spa4	195	3M5	3M6	0.02	0.23	230-1330	Hallstatt period
Spa1	145	M4	2M5	-0.17	-0.09	800-1400	Roman -Merovingian
Mag1_14	60	M2	M3	-0.39	-0.68	700-3500	Middle Ages-Late Neolithic
Leh3	51	M2	2M3	0.31	-0.57	3600-4480	Middle Ages-Middle Bronze Age
Bri1	88	3BgM1	4BgM2	-0.32	-0.48	960-1440	Roman -Merovingian

6 Conclusions

Analysis of archaeopedological age determinations suggest that land use leading to local long lasting effects on the landscape began during the Mesolithic, but OSL ages and OSL-SPDs suggest that only during the Neolithic intensified land use resulted in colluvial deposition on certain sites. However, widespread colluvial deposits appeared only during the Urnfield period and Iron Age, suggesting a significant human impact on the landscape during these times. Major phases of colluvial deposition also occur during the High Middle Ages and the Early Modern period, perhaps indicating unsustainable land use. But what drove land use changes in the past? One oft-cited cause of settlement and land use change is the climate [25]. For example, a warming climate might make territory at higher altitudes available to settlers. Following this climate-forcing hypothesis in SW Germany, it would suggest that the Black Forest and the Swabian Jura should have been settled later than was the Baar, and only when the climate was warmer. Climate fluctuations are documented within the Holocene [108] and might be helpful to explain settlement dynamics. The favourable Baar area was indeed settled and used earlier than the western Swabian Jura and the south-eastern Black Forest, but those two unfavourable areas are also different from each other. Blümel [107] argues that a certain stability and therefore predictability of ideally favourable climate conditions can encourage the development of cities and trade, because they benefit from a reliable surplus production in the surrounding areas and food supply for the city population [107]. Following this supposition, favourable climatic conditions can be understood as stable and foreseeable conditions without sudden changes and within certain limits of temperature and precipitation [108].

However, the spatio-temporal distribution of the colluvial deposits analysed in this study cannot only be explained by varying environmental conditions. Soil erosion and accumulation of colluvial deposits is dependent on precipitation, which explains the correlation with time periods with higher precipitation and lower temperatures. Particularly temperature, precipitation, relief, natural resources and soil are environmental variables, which can be understood as framework conditions, needed to be within certain limits to allow settlements and land use. Cultural variables such as trading, religion, state evasion, conflicts, technical progress, and population pressure seem to explain the detailed form of land use dynamics.

Raw materials (such as ore, wood, rock, salt) have always been available in the Black Forest and Swabian Jura but were not used at all points in time, which indicates that cultural conditions might have played a crucial role in the distribution of settlements and used land. Such cultural conditions might have been the rise of the population density, which led to an intensification of land use as it is shown for the beginning of the Neolithic (Fig. 10; [72]). Another explanation is the state of the technological development, which allowed people to use raw materials in a new way. Religious practices, trade or communication might also influence the use of raw materials as resources. The economic, cultural, political or social need for resources in favourable areas might explain the use of nearby unfavourable (in terms of soil and climate) areas such as low mountain ranges of the Black Forest and the Swabian Jura. Other explanations might be to evade state interference by inhabiting marginal areas [109] or the retreat to secluded areas for religious reasons. Once these unfavourable areas were occupied, social dynamics come into play and changing environmental conditions do not necessarily lead to the abandonment. Diversification of land use for example might have made it possible to continuously use unfavourable areas, sustained by the buffering capacity and resilience of societies [110,111].

The analysis of colluvial deposits analysed and reported in this study contributes to national and international efforts to protect soils as a natural non-renewable resource. In some cases, these soils also act as archives of past human activities which can provide insights into societal and environmental sustainability. It is also necessary to know about the past to assess and think about recent activities and possible future (un)intended outcomes. Colluvial deposits combine all three topics and are thus ideal research objects to reconstruct past land use change and the human-environment relation.

Data accessibility. The data used in this paper are stored at Dryad: (http://dx.doi.org/10.5061/dryad.rh67h)[75]. These are Excel spreadsheets (.xlsx) and .csv files which contain the soil descriptions, soil laboratory results, and AMS-14C and OSL dating results. Additional information and supplementary data about this project are published [19,26]. This publication is part of the dissertation by J.H., which will be available online (https://publikationen.unituebingen.de/xmlui/handle/10900/42126).

Authors' contribution. J.H., P.K., T.S., T.K. and J.A. designed the study and J.H. carried it out. J.H. prepared the manuscript with contributions from all co-authors. M.F. and A.J. were responsible for OSL dating. S.D. contributed the calculation of the SPDs and helped with the interpretation. B.J. contributed to the interpretation and discussion of the results. All the authors gave their final approval for publication.

Competing interests. We declare we have no competing interests.

Funding. This study is part of the Collaborative Research Center 1070 Resource Cultures (SFB1070) financed by the German Research Foundation (DFG). The study was also supported by the Graduate School of the University of Maryland, College Park and the Institutional Strategy of the University of Tübingen (DFG, ZUK 63).

Acknowledgements. We are grateful to many student helpers and technical assistants from Tübingen University, who worked in the field and the laboratory, especially Christoph Behnke, Dominik Birkenmaier, Sabrina Auch-Schwelk, Felix Martin Hoffmann and Rita Mögenburg. We are especially grateful to Kurt Rilling and Michael Kösel from the Landesamt für Geologie, Rohstoffe und Bergbau for great input and discussions in the field. The many farmers who supported our work, by allowing us to work on their land, are acknowledged. Thanks are expressed to Dr Einar Eberhardt for support with the translation of KA5 classification to WRB and FAO. Thanks go to Richard Szydlak, who drew the catenas after drafts by J.H. and Mario Ahner. We are also thankful for the valuable comments and specific remarks by two unknown reviewers and the editors of Royal Society Open Science.

References

[1] Shennan, S. J., Downey, S. S., Timpson, A., Edinborough, K., Colledge, S., Kerig, T., Manning, K. & Thomas, M. G. 2013 Regional population collapse followed initial agriculture booms in mid-Holocene Europe. *Nature Communications* **4**, 2486.

[2] Banks, W. E., Antunes, N., Rigaud, S. & d'Errico, F. 2013 Ecological constraints on the first prehistoric farmers in Europe. *Journal of Archaeological Science* **40**, 2746–2753.

[3] Tieskens, K. F., Schulp, C. J.E., Levers, C., Lieskovský, J., Kuemmerle, T., Plieninger, T. & Verburg, P. H. 2017 Characterizing European cultural landscapes. Accounting for structure, management intensity and value of agricultural and forest landscapes. *Land Use Policy* **62**, 29–39.

[4] Antrop, M. 2005 Why landscapes of the past are important for the future. *Landscape and Urban Planning* **70**, 21–34.

[5] Fuchs, M. & Lang, A. 2009 Luminescence dating of hillslope deposits—A review. *Geomorphology* **109**, 17–26.

[6] Kühn, P., Lehndorff, E. & Fuchs, M. 2017 Late Pleniglacial to Holocene Pedogenesis and Formation of Colluvial Deposits in Central Europe (Gambach, Germany). *CATENA* **154**, 118–135.

[7] Nikiforoff, C. C. 1943 Introduction to paleopedology. *American Journal of Science* **241**, 194–200.

[8] Fritzsch, D. 2011 *Mikromorphologische und archäopedologische Untersuchung von Böden und Sedimenten der bronzezeitlichen Siedlung Tell Chuera, Nord-Syrien*. Dissertation. Frankfurt.

[9] Pietsch, D. & Kühn, P. 2017 Buried soils in the context of geoarchaeological research—two examples from Germany and Ethiopia. *Archaeol Anthropol Sci* **9**, 1571–1583.

[10] Miller, F. P. 2006 Planet and Human Society, Soil as a Heritage of. *Encyclopedia of Soil Science*, 1288–1293.

[11] Mitusov, A., Mitusova, O. E., Wendt, J., Dreibrodt, S. & Bork, H.-R. 2014 Correlation of colluvial deposits with the modern land surface and the problem of slope profile description. *Geomorphology* **220**, 30–40.

[12] Larsen, A., Robin, V., Heckmann, T., Fülling, A., Larsen, J. R. & Bork, H.-R. 2016 The influence of historic land-use changes on hillslope erosion and sediment redistribution. *The Holocene* **26**, 1248–1261.

[13] Dalchow, C. 1989 *Vorlesungsauswertungen Heinrich Rohdenburg: Geoökologie, Geomorphologie.* Catena-Paperback. Cremlingen-Destedt: Catena-Verl.

[14] Rohdenburg, H. 1970 Morphodynamische Aktivitäts- und Stabilitätszeiten statt Pluvial- und Interpluvialzeiten. *Eiszeitalter und Gegenwart* **21**, 81–96.

[15] Jenny, H. 1994 *Factors of soil formation. A system of quantitative pedology*, Unabridged, unaltered republ., new foreword. New York: Dover Publ.

[16] Emadodin, I., Reiß, S. & Bork, H.-R. 2011 Colluviation and soil formation as geoindicators to study long-term environmental changes. *Environ Earth Sci* **62**, 1695–1706.

[17] Hughes, M. W., Almond, P. C. & Roering, J. J. 2009 Increased sediment transport via bioturbation at the last glacial-interglacial transition. *Geology* **37**, 919–922.

[18] Kleber, A., Terhorst, B., Bullmann, H., Hülle, D., Leopold, M., Müller, S., Raab, T., Sauer, D., Scholten, T. & Dietze, M. *et al.* 2013 Subdued Mountains of Central Europe. In *Mid-latitude slope deposits (cover beds)* (ed. A. Kleber & B. Terhorst), pp. 9–93. Amsterdam, London: Elsevier Science.

[19] Houben, P. 2012 Sediment budget for five millennia of tillage in the Rockenberg catchment (Wetterau loess basin, Germany). *Quaternary Science Reviews* **52**, 12–23.

[20] Hoffmann, T. 2015 Sediment residence time and connectivity in non-equilibrium and transient geomorphic systems. *Earth-Science Reviews* **150**, 609–627.

[21] Houben, P., Hoffmann, T., Zimmermann, A. & Dikau, R. 2006 Land use and climatic impacts on the Rhine system (RheinLUCIFS). Quantifying sediment fluxes and human impact with available data. *CATENA* **66**, 42–52.

[22] Henkner, J., Ahlrichs, J., Downey, S. S., Fuchs, M., James, B. R., Knopf, T., Scholten, T., Teuber, S. & Kühn, P. 2017 Archaeopedological analyses of colluvium: A proxy for regional land use history in southwest Germany. *CATENA* **155**, 93–113.

[23] Hardenberg, R., Bartelheim, M. & Staecker, J. 2017 The 'Resource Turn'. A Sociocultural Perspective on Resources. In *ResourceCultures. Sociocultural Dynamics and the Use of Resources - Theories, Methods, Perspectives* (ed. A. Scholz, M. Bartelheim, R. Hardenberg & J. Staecker), pp. 13–24. Tübingen: Universität Tübingen.

[24] Bartelheim, M., Hardenberg, R., Knopf, T., Scholz, A. & Staecker, J. 2015 'ResourceCultures' - A Concept for Investigatin the Use of Resources in Different Societies. In *Persistent Economic Ways of Living. Production, Distribution, and Consumption in Late Prehistory and Early History* (ed. A. Danielisová & M. Fernández-Götz), vol 35, pp. 39–49. Budapest: Archaeolingua.

[25] Coombes, P. & Barber, K. 2005 Environmental determinism in Holocene research: causality or coincidence? *Area* **37**, 303–311.

[26] Henkner, J., Ahlrichs, J., Fischer, E., Fuchs, M., Knopf, T., Rösch, M., Scholten, T. & Kühn, P. 2018 Land use dynamics derived from colluvial deposits and bogs in the Black Forest, Germany. *J. Plant Nutr. Soil Sci.* **181**, 240–260.

[27] Bourke, A. 1984 Impact of climatic fluctuations in Euroean agriculture. Central Europe. In *The climate of Europe. Past, present and future ; natural and man-induced climatic changes; a European perspective* (ed. H. Flohn & R. Fantechi), pp. 269–296. Dordrecht u.a.: Kluwer.

[28] Gebhardt, H. 2007 Räumliche kontraste innerhalb Baden-Württembergs. In *Geographie Baden-Württembergs. Raum, Entwicklung, Regionen* (ed. H. Gebhardt), pp. 54–102. Stuttgart: Kohlhammer.

[29] Siegmund, A. 2006 Der Klimacharackter der Baar - ein regionales Querprofil. In *Faszination Baar. Porträts aus Natur und Landschaft* (ed. A. Siegmund), 2nd edn, pp. 115–132. Donaueschingen: Mory.

[30] Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg. 2013 *Geologische Grundflächen - Geologische Karte von Baden-*

Württemberg 1:50 000. blattschnittfreie Geodaten der Integrierten geowissenschaftlichen Landesaufnahme (GeoLa).

[31] Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau (LGRB) Baden Württemberg. 2013 *Bodenkundliche Grundflächen. - Bodenkarte von Baden-Württemberg 1 : 50 000. blattschnittsfreie Geodaten der Integrierten geowissenschaftlichen Landesaufnahme (GeoLa).*

[32] Schmid, B. 1992 *Die urgeschichtlichen Funde und Fundstellen der Baar. Eine Auswertung des Bestandes. Band 2: Katalog.* Altertumswissenschaften, vol 12. Rheinfelden: Schäuble Verlag.

[33] Lais, R. 1933 *Der Kaiserstuhl. Eine Naturgeschichte des Vulkangebirges am Oberrhein.* Freiburg i. Br.

[34] Biel, J. 1987 *Vorgeschichtliche Höhensiedlungen in Südwürttemberg-Hohenzollern.* Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg, vol 24. Stuttgart: Landesamt für Denkmalpflege Regierungspräsidium Stuttgart.

[35] Müller, D. & Nübling, V. 2010 *Die Befestigungen auf dem Dreifaltigkeitsberg bei Spaichingen. Vor- und frühgeschichtliche Befestigungen 21.* Atlas archäologischer Geländedenkmäler in Baden-Württemberg, vol 2.21. Stuttgart.

[36] Jarvis, A., Reuter, H. I., Nelson, A. & Guevara, E. 2008 *Hole-filled SRTM for the globe Version 4. CGIAR-CSI SRTM 90m Database.*

[37] Schmid, B. 1991 *Die urgeschichtlichen Funde und Fundstellen der Baar. Eine Auswertung des Bestandes. Band 1: Text und Tafeln.* Altertumswissenschaften, vol 11. Rheinfelden: Schäuble Verlag.

[38] Paret, O. 1961 *Württemberg in vor- und frühgeschichtlicher Zeit.* Stuttgart.

[39] Revellio, P. 1932 *Aus der Ur- und Frühgeschichte der Baar.* Schwenningen: M. Link.

[40] Ahlrichs, J. 2017 *Ur- und frühgeschichtliche Siedlungsdynamiken zwischen Gunst- und Ungunsträumen in Südwestdeutschland. eine Fallstudie zur Baar und den angrenzenden Naturräumen des Schwarzwaldes und der Schwäbischen Alb.* Dissertation. Tübingen.

[41] Dehn, R. & Klug, J. 1992 Fortführung der Grabungen am Heidentor bei Egesheim, Kreis Tuttlingen. *Archäologische Ausgrabungen in Baden-Württemberg*, 99–103.

[42] Colpe, C. 1970 Theoretische Möglichkeiten zur Identifizierung von Heiligtümern und Interpretation von Opfern in ur- und parahistorischen Epochen. In *Vorgeschichtliche Heiligtumer und Opferplatze in Mittel- und Nordeuropa* (ed. H. Jankuhn), pp. 18–39. Göttingen: Vandenhoeck & Ruprecht.

[43] Pankau, C. 2008 Hallstattzeitliche Opferplätze auf der Schwäbischen Ostalb? In *Ritus und Religion in der Eisenzeit. Beiträge zur Sitzung der AG Eisenzeit während der Jahrestagung des Mittel- und Ostdeutschen Verbandes für Altertumsforschung e. V. in Halle an der Saale 2007* (ed. C. Eggl), pp. 115–124. Langenweißbach: Beier & Beran.

[44] Parzinger, H. 1995 *Die Býčí-skála-Höhle. Ein hallstattzeitlicher Höhlenopferplatz in Mähren.* Römisch-Germanische Forschungen, vol 54. Mainz am Rhein: von Zabern.

[45] Spindler, K. 1992 Der hallstattzeitliche Scherbenfund von Dellingen, Gern. Bräunlingen-Waldhausen, im Schwarzwald. In *Festschrift zum 50jährigen Bestehen des Institutes für Ur- und Frühgeschichte der Leopold-Franzens-Universität, Innsbruck* (ed. A. Lippert), pp. 543–567. Bonn: Habelt.

[46] Bauer, S. & Kuhnen, H.-P. 1995 Ein »Starker Ort«: Der frühkeltische Opferplatz bei Egesheim Lkr. Tuttlingen. In *Heiligtümer und Opferkulte der Kelten* (ed. A. Haffner), pp. 51–54. Stuttgart.

[47] Klug-Treppe, J. 2008 Geschirrdepot oder Opferplatz? Fragen zu einem ungewöhnlichen Fundkomplex von der Baar. *Archäologische Nachrichten aus Baden* **76/77**, 26–28.

[48] Reim, H. 2012 Felstürme, Höhlen, heilige Zeichen. In *Die frühe Eisenzeit zwischen Schwarzwald und Vogesen = Le Premier âge du Fer entre la Forêt-Noire et les Vosges* (ed. Regierungspräsidium Stuttgart Landesamt für Denkmalpflege), pp. 146–179: Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart.

[49] Blessing, E. 1999 *Kolbingen und die Herrschaft Werenwag: Geschichte eines Dorfes auf dem Heuberg in der ehemaligen Herrschaft Werenwag.* Horb am Neckar: Geiger.

[50] Ad-hoc-AG Boden. 2005 *Bodenkundliche Kartieranleitung. KA5*, 5., verb. und erw. Aufl. Stuttgart: Schweizerbart.

[51] FAO. 2006 *Guidelines for soil description*, 4th edn. Rome: Food and Agriculture Organization of the United Nations.

[52] IUSS Working Group WRB. 2015 *World reference base for soil resources 2014, Update 2015. International soil classification system for naming soils and creating legends for soil maps.* World soil resources reports, vol 106. Rome: FAO.

[53] Eberhardt, E., Schad, P., Berner, T., Lehmann, C., Walthert, L. & Pietsch, D. 2014 *Ableitungsschlüssel KA5 (2005) nach WRB (2007):* Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).

[54] Eberhardt, E., Schad, P., Berner, T., Lehmann, C., Walthert, L. & Pietsch, D. 2013 *Ableitungsschlüssel zur Klassierung von Böden nach WRB 2007. aus Daten der KA 5-Nomenklatur. Handbuch.* Version 1.0. Hannover, Berlin.

[55] Schaetzl, R. J. 2013 Catenas and Soils. In *Treatise on geomorphology* (ed. J. F. Shroder), pp. 145–158. Amsterdam: Elsevier/Acad. Press.

[56] Don, A., Schumacher, J., Scherer-Lorenzen, M., Scholten, T. & Schulze, E.-D. 2007 Spatial and vertical variation of soil carbon at two grassland sites — Implications for measuring soil carbon stocks. *Geoderma* **141**, 272–282.

[57] Murray, A. S. & Wintle, A. G. 2000 Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements* **32**, 57–73.

[58] Lomax, J., Kreutzer, S. & Fuchs, M. 2014 Performance tests using the Lexsyg luminescence reader. *Geochronometria* **41**, 327–333.

[59] Kreutzer, S., Dietze, M., Burow, C., Fuchs, M. C., Schmidt, C., Fischer, M., Firedrich, J., Mercier, N., Smedley, R. K. & Durcan, J. *et al.* 2016 *Comprehensive Luminescence Dating Data Analysis. R package.*

[60] Fuchs, M., Will, M., Kunert, E., Kreutzer, S., Fischer, M. & Reverman, R. 2011 The temporal and spatial quantification of Holocene sediment dynamics in a meso-scale catchment in northern Bavaria, Germany. *The Holocene* **21**, 1093–1104.

[61] Kadereit, A., Kühn, P. & Wagner, G. A. 2010 Holocene relief and soil changes in loess-covered areas of south-western Germany: The pedosedimentary archives of Bretten-Bauerbach (Kraichgau). *Quaternary International* **222**, 96–119.

[62] Cunningham, A. C. & Wallinga, J. 2012 Realizing the potential of fluvial archives using robust OSL chronologies. *Quaternary Geochronology* **12**, 98–106.

[63] Steinhof, A., Altenburg, M., Göbel, M. & Machts, H. 2017 Sample preparation at the Jena 14C laboratory. *Radiocarbon* **59**, 815–830.

[64] Reimer, P. 2013 IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. *Radiocarbon* **55**, 1869–1887.

[65] Bronk Ramsey, C. 2009 Bayesian Analysis of Radiocarbon Dates. *Radiocarbon* **51**, 337–360.

[66] Surovell, T. A., Byrd Finley, J., Smith, G. M., Brantingham, P. J. & Kelly, R. 2009 Correcting temporal frequency distributions for taphonomic bias. *Journal of Archaeological Science* **36**, 1715–1724.

[67] Lang, A. 2003 Phases of soil erosion-derived colluviation in the loess hills of South Germany. *CATENA* **51**, 209–221.

[68] Eckmeier, E., Pätzold, S., Lehndorff, E. & Gerlach, R. 2011 Geochemische Untersuchungen von Böden zur Rekonstruktion der prähistorischen Landnutzungsgeschichte. In *Umweltarchäologie - Naturkatastrophen und Umweltwandel im archäologischen Befund. 3. Mitteldeutscher Archäologentag vom 7. bis 9. Oktober 2010 in Halle (Saale)* (ed. H.-R. Bork, H. Meller & R. Gerlach), pp. 37–45.

[69] Parnell, A. C., Haslett, J., Allen, J.R.M., Buck, C. E. & Huntley, B. 2008 A flexible approach to assessing synchroneity of past events using Bayesian reconstructions of sedimentation history. *Quaternary Science Reviews* **27**, 1872–1885.

[70] Downey, S. S., Bocaege, E., Kerig, T., Edinborough, K. & Shennan, S. J. 2014 The neolithic demographic transition in Europe: correlation with juvenility index supports interpretation of the summed calibrated radiocarbon date probability distribution (SCDPD) as a valid demographic proxy. *PloS one* **9**, e105730.

[71] Bleicher, N. 2013 Summed radiocarbon probability density functions cannot prove solar forcing of Central European lake-level changes. *The Holocene* **23**, 755–765.

[72] Shennan, S. J. & Edinborough, K. 2007 Prehistoric population history. From the Late Glacial to the Late Neolithic in Central and Northern Europe. *Journal of Archaeological Science* **34**, 1339–1345.

[73] Parnell, A. C. 2016 *Bchron: Radiocarbon Dating, Age-Depth Modelling, Relative Sea Level Rate Estimation, and Non-Parametric Phase Modelling.*

[74] Hinz, M., Furholt, M., Müller, J., Raetzel-Fabian, D., Rinne, C., Sjögren, K.-G. & Wotzka, H.-P. 2012 RADON - Radiocarbon dates online 2012. Central European database for the Neolithic and Early Bronze Age, 1–4. www.jungsteinsite.de. Accessed status of April 2017.

[75] Henkner, J., Scholten, T. & Kühn, P. 2018 Data from: Archaeopedological analysis of colluvial deposits in favourable and unfavourable areas: reconstruction of land use dynamics in SW Germany. Soil description, soil properties and ages of colluvial deposits in SW Germany. A SFB1070-B02 data table. *Dryad Digital Repository.*

[76] Leigh, D. S., Gragson, T. L. & Coughlan, M. R. 2016 Colluvial legacies of millennial landscape change on individual hillsides, place-based investigation in the western Pyrenees Mountains. *Quaternary International* **402**, 61–71.

[77] Schroedter, T. M., Dreibrodt, S., Hofmann, R., Lomax, J., Müller, J. & Nelle, O. 2013 Interdisciplinary interpretation of challenging archives: Charcoal assemblages in Drina Valley alluvial and colluvial sediments (Jagnilo, Bosnia and Herzegovina). *Quaternary International* **289**, 36–45.

[78] Vera, F.W.M. 2000 *Grazing Ecology and Forest History:* CABI.

[79] Pokorný, P., Šída, P., Chvojka, O., Žáčková, P., Kuneš, P., Světlík, I. & Veselý, J. 2010 Palaeoenvironmental research of the Schwarzenberg Lake, southern Bohemia, and exploratory excavations of this key Mesolithic archaeological area. *PAMÁTKY ARCHEOLOGICKÉ* **101**, 5–38.

[80] Bos, J. A. A. & Urz, R. 2003 Late Glacial and early Holocene environment in the middle Lahn river valley (Hessen, central-west Germany) and the local impact of early Mesolithic people? Pollen and macrofossil evidence. *Veget Hist Archaebot* **12**, 19–36.

[81] Divišová, M. & Šída, P. 2015 Plant Use in the Mesolithic Period. Archaeobotanical Data from the Czech Republic in a European Context – a Review. *Interdisciplinaria Archaeologica* **6**, 95–106.

[82] Holst, D. 2010 Hazelnut economy of early Holocene hunter–gatherers. A case study from Mesolithic Duvensee, northern Germany. *Journal of Archaeological Science* **37**, 2871–2880.

[83] Bocquet-Appel, J.-P. 2011 When the world's population took off: the springboard of the Neolithic Demographic Transition. *Science (New York, N.Y.)* **333**, 560–561.

[84] Isern, N. & Fort, J. 2012 Modelling the effect of Mesolithic populations on the slowdown of the Neolithic transition. *Journal of Archaeological Science* **39**, 3671–3676.

[85] Tinner, W. 2008 Reply. Evidence for Late-Mesolithic agriculture? A reply to Karl-Ernst Behre. *Quaternary Science Reviews* **27**, 1468–1470.

[86] Tinner, W., Nielsen, E. H. & Lotter, A. F. 2007 Mesolithic agriculture in Switzerland? A critical review of the evidence. *Quaternary Science Reviews* **26**, 1416–1431.

[87] Behre, K.-E. 2006 Evidence for Mesolithic agriculture in and around central Europe? *Veget Hist Archaeobot* **16**, 203–219.

[88] Kind, C.-J. 2006 Die letzten Jäger und Sammler. Das Mesolithikum in Baden-Württemberg. *Denkmalpflege in Baden-Württemberg* **35**, 10–17.

[89] Negendank, J.F.W. 2004 The Holocene: considerations with regard to its climate and climate archives. In *The climate in historical times. Towards a synthesis of holocene proxy data and climate models* (ed. H. Fischer), pp. 1–12. Berlin, London: Springer.

[90] Kromer, B. & Friedrich, M. 2007 Jahrringchronologien und Radiokohlenstoff. Ein ideales Gespann in der Paläoklimaforschung. *Geographische Rundschau* **59**, 50–55.

[91] Engels, S. & van Geel, B. 2012 The effects of changing solar activity on climate. Contributions from palaeoclimatological studies. *J. Space Weather Space Clim.* **2**, A09.

[92] Magny, M. J. 2004 Holocene climate variability as reflected by mid-European lake-level fluctuations and its probable impact on prehistoric human settlements. *Quaternary International* **113**, 65–79.

[93] Davis, B.A.S., Brewer, S., Stevenson, A. C. & Guiot, J. 2003 The temperature of Europe during the Holocene reconstructed from pollen data. *Quaternary Science Reviews* **22**, 1701–1716.

[94] Schönwiese, C. 1995 *Klimaänderungen. Daten, analysen, prognosen.* Berlin: Springer-Verlag.

[95] Jäger, K.-D. 2002 Oscillations of the water balance during the Holocene in interior Central Europe—features, dating and consequences. *Quaternary International* **91**, 33–37.

[96] Rösch, M., Gassmann, G. & Wieland, G. 2007 Keltische Montanindustrie im Schwarzwald – eine Spurensuche. In *Kelten am Rhein: Akten des dreizehnten Internationalen Keltologiekongresses. Proceedings of the thirteenth International Congress of Celtic Studies*. Archäologie, Ethnizität und Romanisierung (ed. S. Zimmer), pp. 263–278.

[97] Gassmann, G., Augstein, M. & Rösch, M. 2014 Archäologisch-naturwissenschaftliche Untersuchungen einer späthallstatt-/frühlatènezeitlichen Siedlung mit Eisenerzverhüttung bei St. Johann-Würtingen auf der Schwäbischen Alb / Guntram Gassmann und Melanie Augstein. Mit einem Beitr. von Manfred Rösch. *Fundberichte aus Baden-Württemberg* **34**, 237–278.

[98] Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D. C., Trouet, V., Kaplan, J. O., Herzig, F., Heussner, K.-U. & Wanner, H. *et al.* 2011 2500 years of European climate variability and human susceptibility. *Science* **331**, 578–582.

[99] Dotterweich, M. 2008 The history of soil erosion and fluvial deposits in small catchments of central Europe: Deciphering the long-term interaction between humans and the environment — A review. *Geomorphology* **101**, 192–208.

[100] Zimmermann, A. 1996 Zur Bevölkerungsdichte in der Urgeschichte Mitteleuropas. In *Spuren der Jagd - die Jagd nach Spuren. Festschrift für Hansjürgen Müller-Beck* (ed. I. Campen, J. Hahn & M. Uerpmann), pp. 49–61. Tübingen: Mo Vince.

[101] Paulus, K. E. 1876 *Beschreibung des Oberamts Spaichingen*. Digitale Volltext-Ausgabe bei Wikisource URL: https://de.wikisource.org/w/index.php?title=Seite:OASpaichingen0116.jpg&oldid=2073814, 28.9.2013rd edn. Stuttgart: H. Lindemann.

[102] Eckerle, K. 2005 Hüfingen (VS). Kastell, Bad und Gutshof. In *Die Römer in Baden-Württemberg. Römerstätten und Museen von Aalen bis Zwiefalten* (ed. D. Planck), pp. 127–132. Stuttgart: Theiss.

[103] Ahlrichs, J., Henkner, J., Teuber, S., Schmidt, K., Scholten, T., Kühn, P. & Knopf, T. 2016 Archaeological and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory: A Case Study from the Western Baar, SW Germany. In *Landscape as impulsion for culture: research, perception & protection. Landscape in the past & forgotten landscapes* (ed. P. Kolodziejczyk & B. Kwiatkowska-Kopka), vol 2, pp.

39–49. Cracow: Institute of Archeology Kraków, Institute of Landscape Architecture Kraków.

[104] Ludemann, T. 1999 Zur Brennstoffversorgung einer römischen Siedlung im Schwarzwald. In *Archäologie als Sozialgeschichte. Studien zu Siedlung, Wirtschaft und Gesellschaft im frühgeschichtlichen Mitteleuropa*. Festschrift für Heiko Steuer zum 60. Geburtstag (ed. S. Brather & H. Steuer), pp. 165–172. Rahden/Westf.: Leidorf.

[105] Dergachev, V. A., Raspopov, O. M., Damblon, F., Jungner, H. & Zaitseva, G. I. 2007 Natural Climate Variability During the Holocene. *Radiocarbon* **49**, 837–854.

[106] Kaplan, J. O., Krumhardt, K. M. & Zimmermann, N. E. 2009 The prehistoric and preindustrial deforestation of Europe. *Quaternary Science Reviews* **28**, 3016–3034.

[107] Blümel, W. D. 2006 Klimafluktuationen – Determinanten für Kultur- und Siedlungsgeschichte. *Nova Acta Leopoldina NF* **94**, 13–36.

[108] Maise, C. 1998 Archäoklimatologie. Vom Einfluss nacheiszeitlicher Klimavariabilität in der Ur- und Frühgeschichte. *Jahrbuch der Schweizerischen Gesellschaft für Ur- und Frühgeschichte* **81**, 197-235.

[109] Scott, J. C. 2009 *The art of not being governed. An anarchist history of upland Southeast Asia.* Yale agrarian studies series. New Haven: Yale Univ. Press.

[110] Gronenborn, D., Strien, H.-C. & Lemmen, C. 2017 Population dynamics, social resilience strategies, and Adaptive Cycles in early farming societies of SW Central Europe. *Quaternary International* **446**, 54–65.

[111] Redman, C. L. 2005 Resilience Theory in Archaeology. *American Anthropologist* **107**, 70–77.

Manuscript IV

SoilCultures – the adaptive cycle of agrarian soil use in Central Europe

An interdisciplinary study using soil scientific and archaeological research

Teuber, Sandra [1,2]; Ahlrichs, Jan [2,3]; Henkner, Jessica[1,2]; Knopf, Thomas [2,3]; Kühn, Peter [1,2,4]; Scholten, Thomas [1,2,4]

Ecology and Society (accepted for publication)

[1] Eberhard Karls University Tübingen, Faculty of Geoscience, Research Area Geography, Chair of Soil Science and Geomorphology

[2] Eberhard Karls University Tübingen, SFB 1070 ResourceCultures

[3] Eberhard Karls University Tübingen, Faculty of Philosophy, Institute of Prehistory, Early History and Medieval Archaeology

[4] Eberhard Karls University Tübingen, Faculty of Geosciences, Laboratory for Soil Science and Geoecology

Abstract

Today's global challenges, e.g. food security, are not unprecedented in human history. Starting with the Neolithic Transition, the agricultural sector and society underwent several cultural and technological changes and endured natural challenges. These challenges and changes are analyzed by using the adaptive cycle metaphor and the social-ecological system as tools to show the complexity of human-environment interactions and their development. The analysis relies on archaeological, pedological and botanical research, demonstrating the importance of interdisciplinary work. The agricultural system as a social-ecological system persisted in Central Europe for 7000 years and underwent an adaptive cycle from the Neolithic Transition to Industrialization. With agriculture's mechanization, a second adaptive cycle started. The resilience of agrarian soil use for thousands of years shows that agriculture, as a human-environmental interaction, is adaptive to change. Understanding past agricultural challenges and changes using archaeological and soil scientific data puts the present development into a new perspective. A cultural perspective on soils might trigger soil protection and sustainable land use in a technical as well as political domain. Applying social-ecological system and adaptive cycle concepts to this interdisciplinary reconstruction of agrarian soil use illustrates their usefulness for archaeology and soil science.

1 Introduction

Global climate change, degradation and erosion of soils as well as rising social inequality and food insecurity comprise today's major human challenges (Tilman et al. 2002, Blum and Eswaran 2004, Luterbacher et al. 2004, Battisti and Naylor 2009, Lal 2010, Foley et al. 2011). Studies of past human-environment interactions show that these are not unprecedented in history (Costanza et al. 2007, Caseldine and Turney 2010, Büntgen et al. 2011). Agriculture, as a system based on human-environmental interaction, also has an impact on societies and the environment in Central Europe since its origin and spread from the Near East around 9500 BCE (Evans 2012).

The development of the agricultural system is analyzed using the concepts of the adaptive cycle and the social-ecological system (Gunderson and Holling 2002). The adaptive cycle is repeatedly used in research, e.g. on the bioenergy sector in Northern Germany (Grundmann et al. 2012) or on the resilience of two contrasting social-ecological systems (Carpenter et al. 2001). Dorren and Imeson (2005) used it to develop a framework on soil erosion for Southern Limburg. Beier et al. (2009) investigated Forest Management in Alaska, and Allison and Hobbs (2004) expanded the use of the adaptive cycle to economics in their analysis of the Western Australian Agricultural Region. Zimmermann (2012) used a specification of the adaptive cycle to improve the understanding of mobility structures in prehistoric Europe. These examples show dynamic social-ecological systems, and demonstrate that the adaptive cycle is a useful tool to investigate the development of such systems.

In the following, agrarian soil use as a social-ecological system will be introduced and analyzed using the adaptive cycle metaphor. Due to limited written sources for prehistoric times, the analysis focuses on archaeological, pedological, palynological and historical records that have been published by scientists of the respective disciplines. The aim is to investigate changes in agrarian soil use observable for the variables soil, crop and technology. Is the adaptive cycle useful to explain changes over several thousand years? What major changes led to a restructuring of the social-ecological system? Are the developments in the Neolithic comparable to Industrialization? If so, are there implications for soil use in the future?

2 Agrarian soil use as a social-ecological system

A social-ecological system (SES) is characterized by the integration of natural and social components (Berkes and Folke 1998, Berkes et al. 2003, Berkes 2004). SESs shape the world, and to understand them, it is necessary to split the bigger systems into smaller parts. However, the smaller systems remain part of other SESs. The present analysis focuses on agrarian soil use as a SES, which is part of a bigger SES and in turn can be broken up in smaller SES on any temporal or spatial scale. The adaptive cycle metaphor (Gunderson and Holling 2002) is used as a theoretical framework for the narrative of agricultural history in Central Europe.

The main variable of the SES agrarian soil use is soil, which has been used agriculturally since the Neolithic Transition. This use, or more precisely deforestation, has led to changes in the landscape and soil through erosion and accumulation processes. Under forests, the natural vegetation in Central Europe, erosion is minor because the roots of the vegetation stabilize the soil, preventing its erosion, and the canopy slows the rainfall (Pimentel and Kounang 1998, Geißler et al. 2012). Thus, the erosion and accumulation of soil material is connected to changes in the vegetation cover. Prior to the Neolithic transition this is related to climate events (Dreibrodt et al. 2010a). After the Neolithic transition, land use change induced by humans led to erosion and the development of so called colluvial deposits on foot slopes (Lang 2003, Leopold and Völkel 2007). The original reason of deforestation, e.g. clearance for fields or overgrazing, is difficult to determine, however, the analysis of colluvial deposits with ^{14}C- and luminescence dating, archaeobotanical, and soil scientific research methods gives insight into the past (Eckmeier et al. 2007, Kadereit et al. 2010, Bogaard et al. 2013, Bakels 2014, Pietsch and Kühn 2014, Henkner et al. 2017). In international literature, the term colluvial deposit is unclearly connected to land use. Hereafter, the term anthropogenic colluvium will be used when referring to soils, which studies suggest to have formed due to land use change and agriculture.

Other variables of the SES agrarian soil use are climate and crops. Changes in crop plants are observable via archaeobotanical analyses (Rösch 1996). Crop refers to cereals, i.e. barley, wheat, rye, etc., and excludes fruit, vegetables and nuts. Climate change can be traced in ice cores, lake and ocean sediments, corals, tree rings, fossil leaves and changes in pollen communities (Caseldine and Turney 2010, Aranbarri et al. 2014). The effect of climate on the settlement pattern of a region is discussed by experts (Berglund 2003, Zolitschka et al. 2003). While it is likely that climate change had an impact on agricultural practices, the extent is not visible in the archives available for prehistoric times. Even with written sources, these refer to weather events and not climate per se. Therefore, climate effects on the SES agrarian soil use will not be considered here.

The observable variable concerning society is the technological development of tools. The variable knowledge is difficult to define for times when no written sources exist. It is assumed here that technological development is accompanied by an increasing knowledge. Knowledge/technology are used as one variable, which is traceable in archaeological finds.

Thus, as detailed above, this study focuses only on observable variables that can be appropriately analyzed in the SES agrarian soil use, specifically soil, crops, and technology.

3 The adaptive cycle of the SES agrarian soil use

The adaptive cycle was developed to explain ecosystem dynamics. It is composed of four phases, the r-phase of exploitation, the K-phase of conservation, the Ω-phase of release or creative destruction, and the α-phase of reorganization (Holling et al. 2002a, Holling and Gunderson 2002). This cycle is shaped by three properties: the potential of a system for change, the degree of connectedness between internal variables and processes, and the adaptive capacity of a system, its resilience as a measure of its vulnerability to unexpected shocks (Holling 2001). Holling and Gunderson (2002) state that the α-phase starts a process of reorganization during which potential and resilience are high but connectedness is low. During the r-phase resilience remains high and connectedness low. In the K-phase connectedness increases while resilience decreases. The system becomes more vulnerable to disturbance. Due to this vulnerability, a disturbance can cause creative destruction in the Ω-phase in which potential is low. The sudden shift from Ω- to α-phase leads to a new cycle with loose connections, high resilience and an increasing potential. In this phase, different recombinations are possible making the outcome of the reorganization unpredictable (Holling and Gunderson 2002).

The adaptive cycle shows that systems are dynamic. The SES agrarian soil use developed over time and while some processes led, for example, to a deterioration of soil properties, overall development enabled the SES to grow and diversify. With the help of the adaptive cycle narrative, the emergence of our present-day agricultural system is analyzed. Changes of or within the variables of the SES affect the adaptive cycle that shape the SES and determine its resilience or vulnerability to unpredictable shocks (Holling 2001).

The variables analyzed are soil, crops and knowledge/technology. Soil formation is a slow and complex process (Stockmann et al. 2014) and soil is therefore a slowly changing variable. However, erosion events can be fast and lead to abrupt changes of the variable concerning its further use (Auerswald et al. 2009). The anthropogenic colluvial deposits are used as archives of land use. The slowly changing variable crop affects the SES through the introduction of new crops, visible in archaeobotanical records (tab. 1, organized chronologically from Neolithic to Modern Times). The variable knowledge/technology influences the SES through fast changes implemented by humans, traceable in the archaeological record.

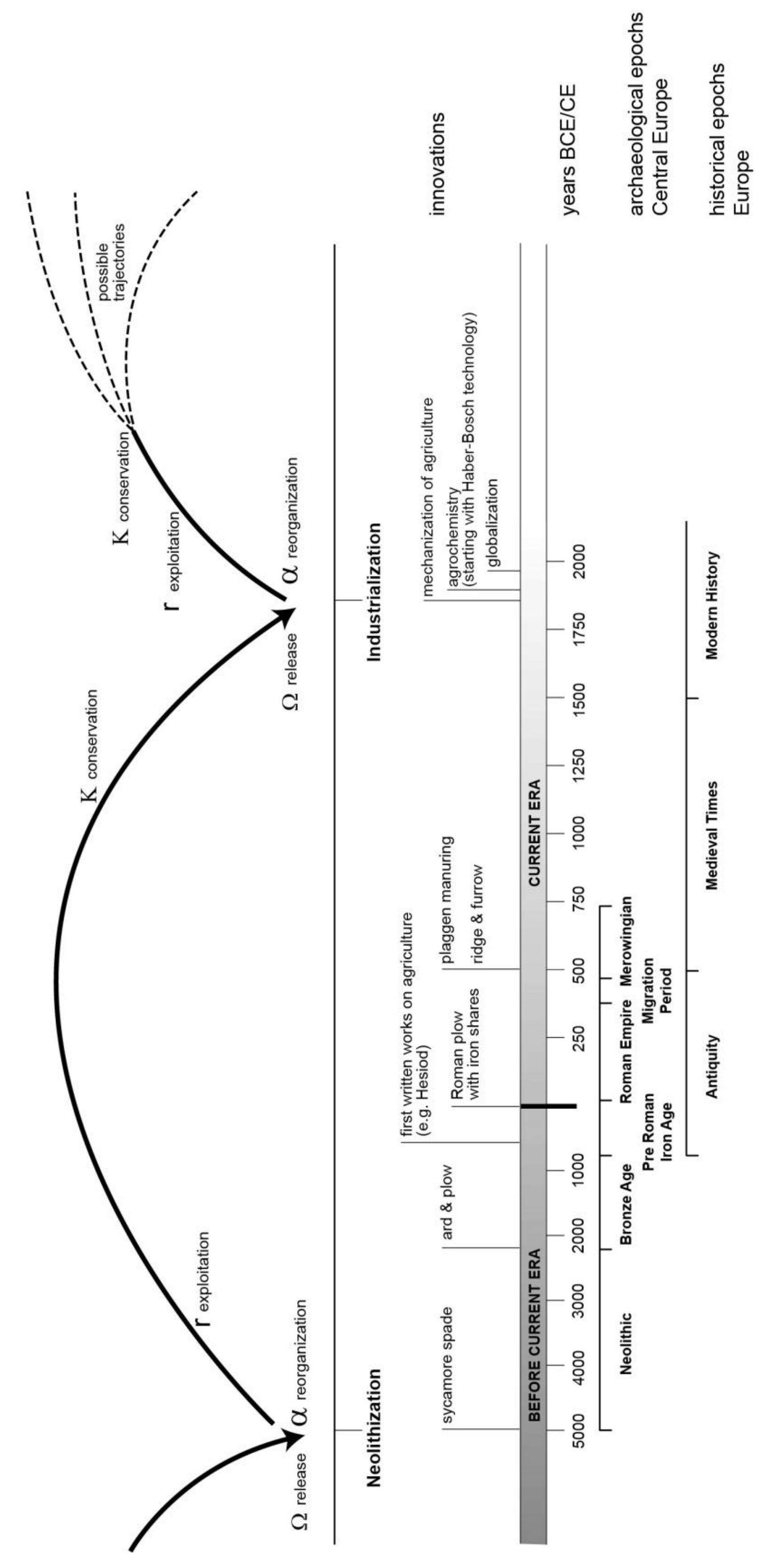

Fig. 1: The adaptive cycles of agrarian soil use in time, modified from Holling (2001) and Gronenborn et al. (2014).

Tab. 1: Several archaeobotanical studies that investigated the crops used in Central Europe in (pre-) historic times. The crops are named according to the study cited.

Author	Period	Region	Analysis	Crops identified in analysis
Bogaard et al. (2013)	Neolithic	Europe (examples in this table from Central Europe)	whole grains from the same stratigraphic unit	einkorn (Triticum monococcum), emmer (T. dicoccum), free-threshing wheat, naked barley (Hordeum vulgare), lentil (Lens culinaris), pea (Pisum)
Kirleis et al. (2012)	Neolithic	N-Germany	charred plant remains	(naked) barley (Hordum vulgare), emmer (T. dicoccum), einkorn (T. monococcum), naked wheat (T. aestivum)
Bogaard et al. (2011)	Neolithic	Vaihingen, Enz, Germany	chaff (glume base)	einkorn (T. monococcum), emmer (T. dicoccum), 'new type', opium poppy (Papaver somniferum), feathergrass (Stipa)
Herbig (2009)	Neolithic	Lake Constance/Upper Swabia, SW-Germany	archaeobotanical (profile columns, surface samples)	emmer (T. dicoccon Schrank), einkorn (T. monococcum L.), tetraploid naked wheat (T. durum Desf./turgidum L.), naked barley (Hordeum vulgare ssp. nudum), opium poppy (Papaver somniferum L.), flax (Linum usitatissimum L.), single finds of pea (Pisum sativum L.), lentil (Lens culinaris L.)
Rösch (1987, 1993)	Neolithic to Bronze Age	Lake Constance, SW-Germany	pollen analysis	naked wheat (T. aestivum/durum), barley (Hordeum vulgare L.), emmer (T. dicoccum), einkorn (T. monococcum L.), flax (Linum usitatissimum L.), opium poppy (Papaver somniferum L.), spelt (T. spelta), millet (Panicum miliaceum), pulses
Rösch (1996)	Late Neolithic to Bronze Age	SW-Germany	pollen analysis, charred plant macro remains	einkorn (T. monococcum), emmer (T. dicoccum), naked wheat (T. turgidum s.l.), barley (Hordeum vulgare), spelt (T. spelta), millet (Panicum miliaceum)
Kanstrup et al. (2014)	Neolithic to Iron Age	Denmark	charred archaeobotanical cereal remains, isotope analysis	emmer (T. dicoccum), spelt (T. spelta), naked barley (Hordeum vulgare, var. Nudum)
Hubbard (1980)	Neolithic to Medieval period	Europe	analysis of charred remains and pottery imprints	Barley (Hordeum vulgare), emmer (T. dicoccum & dicoccoides), einkorn (T. monococcum & bocoticum), millet (Panicum miliaceum), oat (Avena sativa &

				strigosa), wheat (T. aestivum s.l.), rye (Secale cereale)
Mäckel et al. (2003)	Neolithic to Medieval period	Upper Rhine Lowlands, S-Black Forest, SW-Germany	pollen analysis, evaluation of fossil soils	4000 BC: cerealia
Hjelle et al (2012)	Neolithic to Medieval period	Norway	pollen analysis, charred grains	charred grains of Hordeum vulgare (present from Late Neolithic to Early Bronze Age), cerealia pollen, mainly Hordeum type, but also Avena and Triticum type (Early Iron Age)
Behre (1992)	Neolithic to Medieval period	Central Europe	carbonized grains, pollen diagram	rye (Secale cereale) rare in Neolithic, increasing during pre-Roman Iron Age and Roman period and great increase in the Middle Ages
Wieckowska et al. (2012)	Neolithic to modern times	Großer Eutiner See, N-Germany	pollen analysis	Triticum- and Averna-type pollen, Secale (Iron Age onward), Hordeum (Iron Age onward)
Dreßler et al. (2006)	Neolithic to modern times	Lake Dudinghausen, N-Germany	pollen analysis	Hordeum, Triticum, Secale (Medieval period onwars) --> cereal pollen increased in Modern times
Rösch (1998)	Neolithic to modern times	SW-Germany	review	T. dicoccum, T. monococcum, Hordeum vulgare, T. aestivum/durum, T. spelta (minor in Neolithic but increase in Bronze Age), Secale cereale (minor in Neolithic but increase in Bronze Age), Panicum miliaceum (from Bronze Age on), Setaria italica (from Bronze Age on), Avena (from Bronze Age on), Oryza sativa (from Late Medieval period on), Zea mays (from modern times on), Linum usitatissimum, Papaver somniferum, Brassica rapa, Camelina sativa, Cannabis sativa (minor from Iron Age on), Pisum sativum, Lens culinaris, Vicia ervilia (few in Neolithic and in Iron Age), Vicia faba (from Bronze Age on), Vicia sativa (few in Roman and High Medieval times)
Rösch and Tserendorj (2011)	Bronze Age	Huzenbacher See, SW-Germany	pollen analysis	cerealia, secale (Medieval period)

Gauthier and Richard (2009)	Bronze Age	Lake Bourget, France	pollen analysis	cerealia
Stika and Heiss (2013)	Bronze Age	Europe	review	barley, emmer, einkorn, spelt, free-threshing wheat, millet, oat, rye
Dreslerova et al. (2013)	Bronze Age to Early Iron Age	Czech Republic	charred plant macro-remains	emmer (T. dicoccum Schübl.), barley (Hordeum vulgare L.), millet (Panicum miliaceum L.), spelt (T. spelta L.), later also naked wheat (T. aestivum L./compactum Host./durum Desf./turgidum L.), very low numbers of oat (Avena sativa L.) and rye (Secale cereale L.)
Kerig and Lechterbeck (2004)	Bronze Age to Medieval period	Lake Steisslingen, SW-Germany	pollen analysis	Triticum, Hordeum, Cerealia, rye (Iron Age)
Rösch et al. (1992)	Roman to post-Medieval period	SW-Germany, N-Switzerland	review	Roman Period (1st-3rd century A.D.): Panicum miliaceum, T. spelta, Secale cereale, Hordeum vulgare, T. aestivum, T. monococcum; in native Germania T. monococcum, Hordeum vulgare and Secale cereale Late Roman period (3rd-5th century A.D.): one site investigated on upper Danube with Hordeum vulgare, T. speta and Avena sp.; T. aestivum, T. monococcum and Secale cereale (less than 10 %) Merovingian period (6th/7th century A.D.): Avena sp., Hordeum vulgare, T. spelta, T. aestivum, T. monococcum, Secale cereale Carolingian-Ottonian period (8th-10th century A.D.): T. aestivum, T. spelta, Avena sp., T. monococcum, Hordeum vulgare and Secale cereale High Medieval period (11th-13th centruy A.D.): Secale cereale, T. spelta, T. monococcum, Avena sp., Hordeum vulgare, Panicum miliaceum, T. aestivum Early modern period (16th-19th century A.D.): Panicum miliaceum, Avena sp., Hordeum vulgare, T. aestivum, Secale cereale, T. spelta

Rebourg et al. (2003)	1493/1539	S-Spain/Germany	literature review, genetic markers	maize (Zea mays ssp. mays): several introductions
Hawkes and Francisco-Ortega (1993)	1567/1574	Gran Canaria/Tenerife	literature review	potato (Solanum tuberosum/Ipomoea batatas)
Cassman (1999)	1967-1997	global	harvested area	wheat (T. aestivum L.), rice (Oryza sativa L.), maize (Zea mays L.)

Societal changes, environmental factors or a combination of both can lead to disturbances of the SES resulting in a reorganization of the system. After the disturbance and release, the system is reorganized and a new phase of exploitation starts. The SES agrarian soil use underwent one adaptive cycle from the Neolithic Transition to the Industrial Revolution (fig. 1). Through the use of soil, the introduction of crops and new agrarian tools during the Neolithic Transition, people settled down and produced higher food quantities (Childe 1936, Holling et al. 2002b). The Industrial Revolution marks the beginning of a second adaptive cycle with the industrialization of agriculture and food production, simultaneously changing society by increasing the work force of the secondary and tertiary sector. In between those two r-phases, the majority of society practiced agriculture (Evans 2012). The main crops of Central Europe remained similar to the ones introduced during the Neolithic, with the exception of potato or maize, introduced after the “discovery” of the American continent during the K-phase (Hawkes and Francisco-Ortega 1993, Rösch 1998, Rebourg et al. 2003). The soil cultivation depended on man and animal labor. The technology improved from the spade to the ard to the plow during the r-phase. While there was a succession of agricultural improvements, this development is similar to the r- and K-specialists that settle in a new habitat, as described by Holling and Gunderson (2002). Furthermore, Fath et al. (2015) state, that in social systems many small scale adaptive cycles occur during the r- and K-phase of a bigger adaptive cycle, resulting in a prolonged K-phase of continued development and influencing the interplay between fast and slowly changing variables. Fath et al. (2015) introduced a refined concept, consisting of the r-, K-, K_{lim}-, Ω- and α-stage, and applied that to business management. The r-stage has innovations, provides the possibility to test the innovations, and the spirit is entrepreneurial. In the K-stage, knowledge on best practices exist, and the previously established standards are accepted. In the added K_{lim}-stage, crisis plans come into action, which need technologies and cooperation to implement them. In the Ω-stage, improvisation is important and access to a minimum of resources is required, while new actors and new knowledge need to be accepted. In the subsequent α-stage experimenting and development of prototypes is a key competence, which requires certain resources and a willingness to try new paths (Fath et al. 2015). If this is applied to the adaptive cycles of agrarian soil use, it can be shown, that the r-phase of the first and the second adaptive cycle of agrarian soil use indeed was shaped by innovations and entrepreneurial or experimental spirit. In the following K-phases, the previously introduced innovations are accepted and best practice methods develop, e.g. the development and continuous use of the plow throughout the millennia. The K_{lim}-stage could be represented by the development of motorized agrarian tools during industrialization, to facilitate work and free the workforce for the growing industry. In the Ω-stage, the new machines were accepted and in the α-stage experimenting with the new technology occurred and new pathways of agrarian soil use were explored. Further, the development of new tools during the first adaptive cycle was accompanied by smaller adaptive cycles within the social system, which in turn prolonged the K-phase of the big adaptive cycle agrarian soil use. In the sections that follow, the terminology of Holling and Gunderson (2002) will be used, excluding the K_{lim}-stage of Fath et al. (2015). However, there will be references to the latter.

4 Analysis of the SES agrarian soil use in central Europe

Beginning approximately 40,000 to 45,000 years ago the anatomically modern humans replaced the Neanderthals in Europe (Mellars 2004, Pinhasi et al. 2012, Hublin 2015). When the ice shields retreated after the Late Glacial Maximum (Hughes and

Gibbard 2015), a new α-phase of the ecological system started with plant species and fauna spreading into the now ice-free space (Holling and Gunderson 2002), where soil formation processes started (Terberger et al. 2004). The adaptive cycle was influenced by climatic changes, and different species occupied these areas during the Early Holocene including hunter and gatherer populations (Bos 2001, Tinner and Lotter 2001, Crombé et al. 2011, Giesecke et al. 2011). During the Mesolithic, hunting and gathering was the subsistence form of life (Uerpmann 2007, Bailey and Spikins 2008, Tolksdorf et al. 2009, Prummel and Niekus 2011); the impact on the soil remained small. When humans settled down and developed agriculture, they influenced the adaptive cycles of local ecosystems and the SES agrarian soil use began.

4.1 The r-phase of the adaptive cycle: The Neolithic transition in Central Europe

Agriculture and agrarian soil use spread from the Near East (Davison et al. 2006, Tresset and Vigne 2011). The time of the Neolithic Transition varies throughout Europe (Ammerman and Cavalli-Sforza 1971, Gkiasta et al. 2003, Coward et al. 2008). Several approaches exist on how this transition took place, e.g. people practicing agriculture moving in (demic diffusion) or spreading of the agricultural idea (cultural diffusion) over the continent (Haak et al. 2005, Davison et al. 2006, Larson et al. 2007, Gronenborn and Petrasch 2010, Lemmen et al. 2011, Zvelebil et al. 2012, Brandt et al. 2015). Whether demic or cultural diffusion happened, with the Neolithic Transition the SES agrarian soil use began. The Neolithic transition marks the onset of the reorganization (α-phase) and the start of the r-phase of the SES agrarian soil use in Central Europe (fig. 1). The SES variable soil became important to the sedentary people. They cleared forests for timber, fuel and fields, changing the water and nutrient cycles, and influencing soil formation processes (Bork et al. 2006, Kaplan et al. 2009, Gerlach and Eckmeier 2012, Ellis et al. 2013). On slopes, the clearing of forests led to erosion and the subsequent formation of anthropogenic colluvium in valleys and depressions along slopes (Leopold and Völkel

2007, Houben 2012, Mitusov et al. 2014). With the beginning of the Neolithic, an increase of slope deposits is visible in Central Europe (Dreibrodt et al. 2010b), e.g. at the Wetterau, Central Germany (Houben et al. 2013), and at Albersdorf, Northern Germany (Reiß et al. 2009). However, anthropogenic colluvial deposits dating to the Neolithic remain scarce, maybe because erosion was not widespread or because they were redeposited (Zolitschka et al. 2003) or later soil formation processes altered them. However, erosion events are also traceable in lake sediments, e.g. at Lake Belau, N. Germany, dating to the middle Neolithic (Dreibrodt et al. 2010b).

The SES variable crops emerged during the Neolithic (tab. 1). Archaeobotanical analyses show a vegetation change with sedentariness (Rösch 1987). Most of the crops domesticated in the Near East arrived in Europe with the Linear Pottery Culture and the Funnel Beaker Culture (Bakels 2014). The crops grown are similar in all Central European regions (Coward et al. 2008), with einkorn, emmer, wheat and barley being most common (Herbig 2009, Bogaard et al. 2011, Bogaard et al. 2013). Domesticated animals were also present in Central Europe (Doppler et al. 2015).

The knowledge/technology variable of the SES is indirectly visible by archaeological findings: near Cologne, an excavated well of the Linear Pottery Culture revealed a spade made out of sycamore that dates to 5057 BCE (Mueller 2015). The spade is one of the earliest finds concerning soil cultivation, with the Linear Pottery Culture being the initial phase of the Neolithic (5500–2200 BCE) in Central Europe (Price et al. 2001, Eggert and Samida 2013). Another well excavated at the Baltic Coast of Northern Germany revealed Middle Neolithic artefacts, and archaeobotanical studies indicate agricultural land use (Brozio et al. 2014). The well was used during the Funnel Beaker Culture (4100–2800 BCE), the first sedentary culture in northern Germany (Kirleis et al. 2012, Brozio et al. 2014, Whitehouse and Kirleis 2014).

Soil quality and the proximity to fresh water seem to have been relevant for the settlement of regions (Lüning 2000, Rösch et al. 2002, Zolitschka et al. 2003, Fries 2005, Davison et al. 2006, Banks et al. 2013, Brozio et al. 2014). During the Neolithic, the SES agrarian soil use was in the r-phase of exploitation by transforming the landscape to adjust it to the new human needs connected to sedentariness. The arrival of the crop plants, the development of tools and the onset of erosion show the emergence of the SES agrarian soil use. However, during this phase of the general SES agrarian soil use Gronenborn et al. (2014) propose that the Linear Pottery Culture underwent an entire adaptive cycle. This demonstrates that the adaptive cycle consists of different spatial and temporal scales that influence the system as a whole, also taking into account the smaller and faster cycles within social systems that influence the variables of a bigger adaptive cycle (Fath et al. 2015). The adaptive cycle of the Linear Pottery Culture had an influence on the SES agrarian soil use but the changes within this cycle did not lead to an alteration of the SES itself.

After the Neolithic Transition, the SES agrarian soil use remained in the r-phase through Bronze and Iron Age. Plow marks in the soil, excavated ards in Northern Italy and East Frisia, as well as rock carvings in Northern Italy and Sweden, show new agricultural methods and tools (Schultz-Klinken 1981, Tegtmeier 1993, Egg and Pare 1995, Fries 1995, Behre 1998, Zich 1999). The use of metal started with the Bronze Age (2200–800 BC) and continued through the pre-Roman Iron Age (800–15 BC), which consists of the Hallstatt and the La Tène period (Eggert and Samida 2013). Main innovations are sickles during the Bronze Age and scythes during the Iron Age (Jockenhövel 1994, Egg and Pare 1995). The use of metal shows a technological development and an assumed increase of knowledge, leading to mining activities that exploited previously unused natural resources, e.g. in the Black Forest, SW-Germany (Gassmann et al. 2006). The change of the knowledge/technology variable is seen as a development from spade to ard to plow, that can be explained using the approach of Fath et al. (2015), that several small scale adaptive cycles can affect the r- and K-phase of a bigger cycle. However, this knowledge did not develop due to agrarian soil use but was used in an agricultural context later: the late La Tène hoard of Bad Buchau-Kappel in South Germany shows the diversity of iron objects with pliers, knives, sickles, scythes, etc. (Jockenhövel 1993), tillage tools were not found. In the agriculturally important hoard in Urach, Southern Germany, plow-shares were also absent (Fries 1995). The ards of the type Døstrup, found in Denmark, were used during pre-Roman Iron Age for soils under tillage, while the Walle type ard was used to break up formerly unused soils (Fries 1995). The latter and Early Iron Age ard shares found in the Netherlands (Sanden 1994) point to similar tillage practices in the Bronze and Iron Ages. The results show that metallurgy developed but was not initially used for agricultural purposes. However, in the Bronze Age cattle traction was established and used for pulling the ard or carts (Bartosiewicz 2013), e.g. facilitating soil cultivation.

The SES variable crops changed little from Neolithic to Bronze and Iron Age (tab. 1). However, the soil variable shows an increase of anthropogenic colluvial deposits at the beginning of the Bronze Age and again in the Iron Age (Dreibrodt et al. 2010b). Bronze Age anthropogenic colluvial deposits were found at Albersdorf, Northern Germany (Reiß et al. 2009), at the Frauenberg in Bavaria (Lang et al. 2003) and at the Wetterau, where colluviation also happened during the Early Iron Age (Houben et al. 2013). Turbidites in Black Forest lakes also begin in the Bronze Age (Rösch and Tserendorj 2011). The reason for the increased anthropogenic colluviation could be more settlements or increased deforestation for fuel purposes for metallurgy.

Research on Celtic fields in the Netherlands indicates an intensive agricultural system in the late Iron Age with shorter fallow periods, higher manuring intensity and changes in tillage practices (Spek et al. 2003). The change of management practices and the development of the Celtic fields shows a further development of agriculture (Jankuhn 1977). However, we argue that the SES agrarian soil use remained in the r-phase of exploitation. According to the adaptive cycle proposed by Holling and Gunderson (2002), the creative destruction and reorganization is a fast process. In the archaeological record, in pedological studies and in palynology, changes are observable. However, these changes are slow, happening over centuries rather than decades. They can be interpreted as tests of the new innovations, which are characteristic of the r-phase (Fath et al. 2015), with entrepreneurial spirit leading to evolving management practices using the innovations. The use of metal indicates a greater knowledge of metallurgy and facilitated work, e.g. bronze sickles and scythes for harvesting. However, the tools used for tillage probably remained similar to the ard found in Walle, East Frisia that dates to the Bronze Age as the ard shares in the Netherlands suggest (Schultz-Klinken 1981, Sanden 1994, Behre 2000). The development of these tools can be seen as a smaller adaptive cycle that occurred in the SES metallurgy and affected the SES agrarian soil use.

4.2 Transition to the K-phase: conservation of agriculture in Central Europe

In Antiquity, knowledge concerning agriculture was written down and documented. Greek and Roman scholars wrote the first European literary works on agriculture. Among them were Hesiod's „*Érga kaì hemérai*", Cato's „*De agri cultura*", Varro's „*Res rusticae*" and Columella's „*De re rustica*" (quoted from Winiwarter 2006). These works were mainly written for the owners of *latifundia*, i.e. large landowners (James et al. 2014). Columella described a test to determine soil fertility: after digging a hole, the dug soil was refilled. If the soil formed a mound, the soil was fertile; if the refill formed a hollow the soil was poor (McNeill and Winiwarter 2004). This approach tests the aggregate stability of a soil, which depends on soil texture, soil organic matter, biological activity and the mineral content of a soil. The texts show that the SES agrarian soil use moved toward the K- or conservation phase (fig. 1), with changes within smaller and faster sub-systems influencing the adaptive cycle (Fath et al. 2015). The traditions and land management practices were written down and the importance of "good" practices was stressed. However, it is important to note, that the knowledge documented in the literary works of the agrarian writers might not have been applied to agriculture north of the Alps (Deschler-Erb and Akeret 2011), necessitating historical, archaeological, palynological and pedological analyses to understand former land use changes.

During the Roman period, Central Europe underwent different developments. In the South and West, the Romans controlled the provinces *Germania inferior* and *superior* as well as *Raetia* (Ausbüttel 2011). The Roman influence led to the establishment of *villae rusticae*, Roman forts and towns (Heiligmann 1996, Wilson 2006). A *villa rustica* is an agrarian production center (Groot and Deschler-Erb 2015) and e.g. in Bavaria, Germany the production area belonging to one villa was approximately 50 ha (Leopold et al. 2010). In present-day South Germany, *villae rusticae* were usually established along the Roman roads, which made new areas accessible (Humpert 1995, Kerig and Lechterbeck 2004, Fingerlin 2008). For the area north and east of the Limes, there are few written sources, e.g. Caesars "*de bello gallico"* or Ptolemaios "*Geographike Hyphegesis"* (Nüsse et al. 2011). It should be noted, that those descriptions might reflect stereotypical depictions of barbarians (Erdrich 2001). The written sources show a Roman viewpoint, which is in itself valuable, but to understand the SES agrarian soil use and its adaptive cycle, we need to consider all variables. Therefore, interdisciplinary approaches are used, such as the study of the Vecht river valley, located in the present-day Dutch-German border area (van Beek and Groenewoudt 2011). Archaeobotanical analyses show a continuation of the crop variable (tab. 1). In SW-Germany, spelt was the most common crop (Rösch 2009).

Analyses at Lake Belau in Schleswig-Holstein and Lake Holzmaar in Rhineland-Palatinate (Dreibrodt et al. 2010b) show the contrast of the soil-variable between the two regions. While at Lake Belau soil erosion increased during pre-Roman Iron Age and decreased during the Roman period, leading to a slower input of material into the lake; the situation at Lake Holzmaar is different: the input of material during the period of the Roman Empire was greater than in the pre-Roman Iron Age (Dreibrodt et al. 2010b). Anthropogenic colluvial deposits dating to Roman times are also found at the

Kaiserstuhl, SW-Germany (Mäckel et al. 2003). This shows how difficult it is to reconstruct general agricultural practices for Central Europe for that period. Furthermore, the increasing need for building material resulted in deforestation with its maximum extent around 250 CE (Büntgen et al. 2011), which affects soil erosion processes.

Agricultural technology was developed during Roman times leading for example to the use of iron in spades. In present day Germany, spades were found that date to the 1st to 3rd century and were fully made of iron (Mueller 2015). In Gallic provinces a plow with two small wheels pulled by 4-6 oxen was used (Schneider 2007). Virgil described the "Roman plow" around 1 CE, which had iron shares (Lal et al. 2007). The further development of existing tools and the existence of written sources concerning the agricultural practices indicate the K-phase where connectedness increases, including knowledge and technology needed for successful agriculture. The variable soil shows erosion and colluviation processes. However, agrarian soil use is still connected to animal and man power with similar tools. These tools have been improved but no invention happened that altered the actual practice of agrarian soil use.

The K-phase continued during Medieval Times (500–1500 CE), an epoch that comprises many different dynasties, societal and regional developments (Fried 2009). In Medieval Times, the texts of the Roman agricultural writers were still copied. Further, Isidore of Seville wrote a short encyclopedia, discussing plowing sequence and manuring, and Walafrid Strabo wrote a poem about 24 garden plants (Winiwarter 2006). This shows that certain groups of people wanted to conserve and improve the knowledge of agricultural practices, indicating the K-phase of the adaptive cycle. However, agricultural practices seem to have relied on traditional practices, which were not necessarily related to the documented knowledge (Dotterweich 2013).

It is suggested that rye became a crop plant during the Medieval period, even though traces of rye were found dating to the Neolithic (Behre 1992). The proportion of the different crops changes over time and from region to region, but the plants used are the ones introduced in the course of the Neolithic/Bronze/Iron Age/Roman Period (tab.1).

The soil variable was slowly treated differently, because fertilization became increasingly part of agriculture during Medieval Times (Behre 2000). Furthermore, the variables soil and knowledge/technology became interconnected. Plaggen-manuring was practiced in Northern Europe, ridge and furrow was prevalent (Behre 1976, Blume and Leinweber 2004, Haasis-Berner 2012, van Mourik et al. 2012), traces of which are found in the landscape today. For plaggen-manuring the topsoil of adjacent areas was cut and distributed on the agricultural fields, leading to the development of heath in the cutting areas while enabling the cultivation of winter rye on the fields (Pape 1970, Behre 2000). The ridge and furrow developed due to the change from the ard to the moldboard or heavy plow, which turned the soil in one direction towards the middle of the field, and permitted agriculture on heavy clay soils (Seidl 2006, Haasis-Berner 2012, Andersen et al. 2016). The micro-relief of the ridge and furrow fields enabled agricultural success in dry and moist years. On the ridge, harvest was good even in years with a lot of rainfall, while the furrow provided enough water during a dry year (Linke 1979). The three field system, growing two crops alternating with fallow, also spread and is observable in the archaeobotanical record (Rösch et al. 1992).

Erosion and colluviation increased during Medieval Times (Zolitschka et al. 2003, Dreibrodt et al. 2010b, Henkner et al. 2017). Mining activities led to a rapid deforestation but also to new regulations prohibiting forest clearing in certain areas (Steuer 1993). Deforestation for agricultural purposes continued, leading to erosion and the formation of anthropogenic colluvial deposits, e.g. in SW-Germany in the Kraichgau dating to 980–1330 CE (Kadereit et al. 2010) or in the Black Forest around the Krumpenschloß between the ninth and 15th century CE (Knopf et al. 2012). In the area of Göttingen, several refilled gullies were discovered in the 1950s (Bork 2006). Research suggests that in 1342, a heavy precipitation event in Central Europe caused erosion in the low mountain ranges that led to the formation of gullies, which were later refilled by pedosediments (Bork et al. 2006). This is supported by a study at the catchment of Lake Belau in Schleswig-Holstein (Dreibrodt 2005) and another study at the Wolfsgraben, Bavaria (Dotterweich et al. 2003, Schmitt et al. 2003). Investigations at the Frickenhauser See, Bavaria, show that between 1000 and 1870 CE intensive soil erosion took place (Enters et al. 2006). These archives thus show an intensification of land use. However, humans still practiced agriculture with the help of tools and animals used for traction, the SES agrarian soil use was not reconstructed as such but remained in the K-phase.

Soil erosion increased again during the 18th century (Dotterweich 2013), after a phase of land abandonment at the end of the Medieval Times (Dreßler et al. 2006, Fraser 2011), which might have happened due to a combination of erosion, crop failure and the plague. Extreme weather events were documented (Dreibrodt et al. 2010b), e.g. the flood of 1783/84 appeared in newspapers, letters and was recorded by meteorological stations across Central Europe (Brázdil et al. 2010). Analyses of sedimentation rates of the river Rhine’s catchment show increased sedimentation in floodplains and formation of anthropogenic colluvial deposits (Hoffmann et al. 2009).

During the 19th century, the scientific analysis of soil increased. Albrecht Daniel Thaer, Justus von Liebig, Charles Darwin and Vasilii V. Dokuchaev wrote their important works on soils (Liebig 1841, Thaer 1880, Darwin 1890, Evtuhov 2006). Thaer focused on agriculture and the relevance of humus and crop rotation (Feller et al. 2003b), Liebig tried to develop a mineral fertilizer (Montgomery 2010). Darwin focused on the formation of humus and the importance of worms (Brown et al. 2003, Feller et al. 2003a, Feller et al. 2006, Brevik and Hartemink 2010). Dokuchaev introduced the soil profile dividing it into A-, B-, and C-horizons, and stressed that soils should be seen as an independent research object (Evtuhov 2006, Brevik and Hartemink 2010). These works show that the variable soil had become a research topic. The variable knowledge was increasingly interlinked with the practical soil use, at least considering the landowners, not necessarily the peasants. The increasing knowledge eventually led to the development of new tools, which resulted in the creative destruction and reorganization of the SES agrarian soil use.

4.3 The Ω- and α-phase of the SES agrarian soil use and the beginning of a new cycle

With industrialization, the SES agrarian soil use moved through the Ω-phase of creative destruction and the α-phase of reorganization (fig. 1). The different variables changed considerably.

A change of the knowledge/technology variable is observable in new machines, but also resulted in global societal changes. Technological advances, such as the invention of the steam engine led to motorization and mechanization of agricultural practices (Bergmann 1970, Gessner 1976, Hahn 2011). The machine manufacturer Fowler invented the plowing engine (Seidl 2006), and the blacksmith John Deere marketed a plow that grew in importance with the invention of the tractor (Lal et al. 2007). Increasing knowledge and technology led to new fertilizers. Industrialized nitrogen production using the Haber-Bosch technology increased cereal yield in Germany between 1918 and 1938 by app. 50% (Niedertscheider et al. 2014). These developments were closely connected to the use of fossil fuels (Schumacher 1993). The use of new technologies changed the strong link between agriculture and animal husbandry, because animals were no longer needed for traction and manure (Lambin et al. 2001). Traditional crop rotation practices and fallow were also abandoned due to cheap nitrogen availability (Montgomery 2010). This development marks the r-phase of exploitation where growth is accomplished with new efficient technologies. The innovations are tested and entrepreneurial spirit dominates, as proposed by Fath et al. (2015). It also starts the process towards a knowledge-based society, which influenced the agricultural sector (Uekoetter 2012), and raised the work force in the secondary and tertiary sector (Hahn 2011), leading additionally to urbanization (Antrop 2004) and globalization (Robertson 1992, Levitt 1999). The global trade involves among others food, fertilizer, fodder, raw material needed for agriculture and agrarian technology. Information exchange is enabled by the internet and relatively cheap transportation. This global development means that we can no longer consider regional practices when analyzing the SES agrarian soil use.

The SES variable crop changed with the introduction of genetically modified organisms and the widespread use of pesticides, herbicides and fungicides. Fewer crop plants are used in agriculture today. The crops variable is closely related to the knowledge variable of society because genetically modified organisms developed through human interference (Tiedje et al. 1989, Anklam et al. 2002). Furthermore, society today depends on few crops, namely wheat, rice and maize (Cassman 1999), e.g. Triticum aestivum became the dominant crop in 1920s SW-Germany (Rösch et al. 1992). Monocultures of such crops are a new phenomenon, e.g. rice (Shen et al. 2004).

The soil variable is still prone to erosion but also to other forms of degradation such as compaction and nutrient depletion. Soil erosion increased with changes of plowing intensities due to bigger and more powerful machines, and the heavy machinery enhances soil compaction (Lal et al. 2007). In Europe, an erosion rate of more than 1 t ha^{-1} y^{-1} is regarded as unsustainable (Verheijen et al. 2009). Today, erosion in Europe ranges between 3 and 40 t ha^{-1} y^{-1}, impairing the soil's productivity, which is becoming more important as the global population grows (Verheijen et al. 2009).

Another soil related aspect of the new adaptive cycle is the increase of global fertilizer use by 700% in the last 40 years (Foley et al. 2005), leading to changes in the N- and P-cycles (Smil 1999, 2000). While N can be generated using the Haber-Bosch method, most of the P used in agriculture is of phosphate rock origin and non-renewable. The mining of these reserves, mostly located in China, the USA and Morocco, has tripled since World War II (Cordell et al. 2009) and there has been a global increase of 20 % in P-fertilizer use between 2000 and 2008, (MacDonald et al. 2011). Losses of P and N affect off-site ecosystems, e.g. eutrophication of lakes and marine ecosystems, and influence global warming and biodiversity, e.g. through N_2O, NO, NO_3 and NH_3 (Tilman et al. 2002, Lal et al. 2011). The C-cycle also changed with the dependency on fossil fuels, leading to an increase of atmospheric greenhouse gases from 280 ppm CO_2-equivalent at the beginning of industrialization to 430 ppm in 2005 (Falkowski et al. 2000, Aertsens et al. 2013). Present fertilizer production relies on fossil fuels and contributes to the CO_2 emissions, as does the use of agricultural machinery, land use change in form of deforestation, and fertilization (Canadell et al. 2007, West et al. 2010).

The dependence on fossil fuels indicates a growing rigidity of the SES, which would point towards the end of the K-phase of the adaptive cycle. However, innovative concepts combine the use of new technology and knowledge with alternative or traditional agricultural practices, e.g. carbon sequestration in soils. Agroforestry, hedgerows, low or no tillage and cover crops affect erosion, biodiversity, nutrient leaching, soil organic matter and C-sequestration (Aertsens et al. 2013). This points toward the small and fast adaptive cycles influencing the big adaptive cycle agrarian soil use and exploring alternative pathways to the challenges of the present. However, the global cropland under no-till is only 9% (Lal 2013). In present-day Germany, no-tillage is practiced on 1463 km^2, equaling 1.3%, while on 110775 km^2 conservation or conventional tillage is used (Statistisches Bundesamt 2016). This shows that even in a highly industrialized country, with rapidly increasing knowledge, no-till is only practiced by few. This supports the suggestion that we are in the K-phase of conservation because the majority of agrarian soil use depends on mineral fertilizers and tillage practices with big machinery. Whether a new Ω-phase is approaching depends on today's decisions. These rely on studies conducted by different scientists, e.g. concerning the functioning of the N-cycle. A long-term field study in France showed, that cover crops reduced N-leaching, while no-till did not result in a significant N sequestration (Constantin et al. 2010). A study in New Zealand showed, that the effectiveness of cover crops on preventing N-leaching depended on sowing dates and on soil type, and is influenced by weather variability (Teixeira et al. 2016). The results suggest that site-specific practices and holistic management approaches are necessary to develop the agricultural sector towards more sustainability. However, interdisciplinary approaches are needed to communicate these new findings to soil users and society in general, which might also pave the way to greater food security and equality worldwide (Godfray et al. 2010, Lal et al. 2011, Altieri 2012, Scholten 2014). Further, the development in the social component of the SES needs to be investigated in order to determine the effect of small and fast adaptive cycles on the big adaptive cycle of the SES agrarian soil use.

5 Conclusion

The adaptive cycle narrative is useful to examine the changes occurring in a social-ecological system (SES), such as the changes of the agrarian soil use SES over the last millennia. The narrative helps understanding changes of and within the SES over time while focusing on important variables, in the presented case soil, crops, knowledge/technology. This approach could also be important for archaeological and soil scientific research in general, as the concept of SESs and adaptive cycles can be applied to broader developments within social ecological systems, as shown in this study. It might also be used to connect individual case studies to international contexts.

The adaptive cycle of the SES agrarian soil use started with the Neolithic Transition and sedentariness. During the Neolithic, the Bronze and Iron Age the adaptive cycle was in the r-phase. Innovative tools and ideas developed which enabled the societies to successfully practice agriculture. With Antiquity, the SES moves into the K-phase, where the knowledge concerning agricultural practices is documented by written sources and best practice methods are determined. During the Medieval and Modern Times, the general knowledge and agricultural knowledge in particular increases. Furthermore, agricultural tools are improved by e.g. using iron in plow shares, thus incorporating the adaptive cycle of the SES metallurgy. With industrialization, the SES moves through the Ω-phase of release or creative destruction and the α-phase of reorganization. The SES changed considerably with the α-phase, leading to a separation of animal husbandry and arable farming and a new r-phase after the mechanization of agriculture. This is comparable to the establishment of agriculture in the Neolithic due to the big innovations that changed the SES. The Neolithic transition led to sedentariness, so that first settlements and probably new societal structures developed. The Industrial Revolution enabled a diversified society with more people working outside the agrarian business due to the innovations of the r-phase. The knowledge and technology variable are interconnected in both r-phases, e.g. in the development of the plow and the Haber-Bosch method. After industrialization and mechanization, agrarian soil use no longer means work of animals and men, but work of machines. This has new consequences for the soil variable, comparable to the consequences of deforestation, which subjected the soil to erosion after the establishment of fields since the Neolithic. The new impact on soil includes compaction, nutrient depletion, and other forms of soil degradation. The crops used in agriculture were first introduced in the Neolithic. They were used in different proportions during the last millennia. With industrialization, new genetically modified organisms were developed, connecting the variables crop and knowledge/technology. The crop variable underwent another change, as we depend on a limited variety of crop plants for nutrition today.

A difference between the two adaptive cycles is the speed of the transition from r- to K-phase, which lasted several millennia in the first cycle but happened in the course of decades in the second. The increasing knowledge of the first K-phase, which started with the Greek and Roman agricultural writers and culminated among others with Thaer, Liebig and Darwin, eventually had a vast effect on surplus production and technological development that resulted in a reorganization of the SES and the second adaptive cycle. The knowledge is still increasing steadily and technological development has led to a high-tech agribusiness, depending on computers, GIS, fertilizers and more. These new developments also affect the soil and crops used. To investigate these effects interdisciplinary work is needed, to ensure the resilience of the SES agrarian soil use without detrimental effects on soil, crops, knowledge/technology, and climate. These interdisciplinary studies should include various disciplines, among others soil science, sociology, anthropology, climatology, but also history and archaeology, to understand the past developments of and within a region. The SES and adaptive cycle could be used to structure the research in advance, due to the focus on specific variables, while also including the systems approach and acknowledging the connection between natural and social systems. Further challenges for these studies include that small scale and fast adaptive cycles in the social system need to be investigated in order to understand the development of the big cycle of agrarian soil use. As we are in the K-phase of the adaptive cycle, small and fast adaptive cycles in the social system will determine how long the system remains in the present phase. If innovations and traditions are combined and lessons from the past, e.g. concerning erosion, are learned, the new K-phase might last for an extended time. However, if this does not happen, a new Ω-phase might result in a reorganization of the system with an unknown outcome. The variety of possible responses to global, regional and local challenges requires scientists from different fields to investigate the different variables of the SES agrarian soil use to understand the processes and interactions between and within the variables. This might contribute to the resilience of the SES and lead to new policies on a global scale. Interdisciplinary research helped us understand the adaptive cycle of the SES from the Neolithic to Industrialization. It is also necessary to develop a resilient agrarian soil use for the future.

6 Literature cited

Aertsens, J., L. de Nocker, and A. Gobin. 2013. Valuing the carbon sequestration potential for European agriculture. *Land Use Policy* 31:584–594.

Allison, H. E., and R. J. Hobbs. 2004. Resilience, Adaptive Capacity, and the "Lock-in Trap" of the Western Australian Agricultural Region. *Ecology and Society* 9(1):3.

Altieri, M. A. 2012. Convergence or Divide in the Movement for Sustainable and Just Agriculture. Pages 1–9 *in* E. Lichtfouse, editor. *Organic Fertilisation, Soil Quality and Human Health*. Springer, Netherlands.

Ammerman, A. J., and L. L. Cavalli-Sforza. 1971. Measuring the Rate of Spread of Early Farming in Europe. *Man, New Series* 6(4):674–688.

Andersen, T. B., P. S. Jensen, and C. V. Skovsgaard. 2016. The heavy plow and the agricultural revolution in Medieval Europe. *Journal of Development Economics* 118:133–149.

Anklam, E., F. Gadani, P. Heinze, H. Pijnenburg, and G. van den Eede. 2002. Analytical methods for detection and determination of genetically modified organisms in agricultural crops and plant-derived food products. *European Food Research and Technology* 214(1):3–26.

Antrop, M. 2004. Landscape change and the urbanization process in Europe. *Landscape and Urban Planning* 67(1-4):9–26.

Aranbarri, J., P. González-Sampériz, B. Valero-Garcés, A. Moreno, G. Gil-Romera, M. Sevilla-Callejo, E. García-Prieto, F. Di Rita, M. P. Mata, M. Morellón, D. Magri, J. Rodríguez-Lázaro, and J. S. Carrión. 2014. Rapid climatic changes and resilient vegetation during the Lateglacial and Holocene in a continental region of south-western Europe. *Global and Planetary Change* 114:50–65.

Auerswald, K., P. Fiener, and R. Dikau. 2009. Rates of sheet and rill erosion in Germany — A meta-analysis. *Geomorphology* 111(3-4):182–193.

Ausbüttel, F. M. 2011. Die Gründung und Teilung der Provinz Germania. *Klio - Beiträge zur Alten Geschichte* 93(2):392–410.

Bailey, G., and P. Spikins, editors. 2008. *Mesolithic Europe*. Cambridge University Press, New York.

Bakels, C. 2014. The first farmers of the Northwest European Plain: some remarks on their crops, crop cultivation and impact on the environment. *Journal of Archaeological Science* 51:94–97.

Banks, W. E., N. Antunes, S. Rigaud, and F. d'Errico. 2013. Ecological constraints on the first prehistoric farmers in Europe. *Journal of Archaeological Science* 40(6):2746–2753.

Bartosiewicz, L. 2013. Animals in Bronze Age Europe *in* H. Fokkens, and A. Harding, editors. *The Oxford Handbook of the European Bronze Age*. Oxford University Press, Oxford.

Battisti, D. S., and R. L. Naylor. 2009. Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat. *Science* 323:240–244.

Behre, K.-E. 1976. Beginn und Form der Plaggenwirtschaft in Nordwestdeutschland nach pollenanalytischen Untersuchungen in Ostfriesland. *Neue Ausgrabungen und Forschungen in Niedersachsen* 10:197–224.

Behre, K.-E. 1992. The history of rye cultivation in Europe. *Vegetation History and Archaeobotany* 1:141–156.

Behre, K.-E. 1998. Landwirtschaftliche Entwicklungslinien und die Veränderung der Kulturlandschaft in der Bronzezeit Europas *in* B. Hänsel, editor. *Mensch und Umwelt in der Bronzezeit Europas*. Oetker-Voges Verlag, Kiel.

Behre, K.-E. 2000. Frühe Ackersysteme, Düngemethoden und die Entstehung der Nordwestdeutschen Heiden. *Archäologisches Korrespondenzblatt* 30:135–151.

Beier, C. M., A. L. Lovecraft, and F. S. Chapin. 2009. Growth and Collapse of a Resource System: an Adaptive Cycle of Change in Public Lands Governance and Forest Management in Alaska. *Ecology and Society* 14(2):5.

Berglund, B. E. 2003. Human impact and climate changes—synchronous events and a causal link? *Quaternary International* 105(1):7–12.

Bergmann, K. 1970. *Agrarromantik und Großstadtfeindschaft*. Verlag Anton Hain, Meisenheim am Glan.

Berkes, F. 2004. Rethinking Community-Based Conservation. *Conservation Biology* 18(3):621–630.

Berkes, F., J. Colding, and C. Folke, editors. 2003. *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge University Press, Cambridge, UK.

Berkes, F., and C. Folke, editors. 1998. Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. Cambridge University Press, Cambridge, UK.

Blum, W. E., and H. Eswaran. 2004. Soils for Sustaining Global Food Production. *Journal of Food Science* 69(2):37–42.

Blume, H.-P., and P. Leinweber. 2004. Plaggen Soils: landscape history, properties, and classification. *Journal of Plant Nutrition and Soil Science* 167(3):319–327.

Bogaard, A., R. Fraser, T. H. E. Heaton, M. Wallace, P. Vaiglova, M. Charles, G. Jones, R. P. Evershed, A. K. Styring, N. H. Andersen, R.-M. Arbogast, L. Bartosiewicz, A. Gardeisen, M. Kanstrup, U. Maier, E. Marinova, L. Ninov, M. Schäfer, and E. Stephan. 2013. Crop manuring and intensive land management by Europe's first farmers. *Proceedings of the National Academy of Sciences* 110(31):12589–12594.

Bogaard, A., R. Krause, and H.-C. Strien. 2011. Towards a social geography of cultivation and plant use in an early farming community: Vaihingen an der Enz south-west Germany. *Antiquity* 85:395–416.

Bork, H.-R. 2006. *Landschaften der Erde unter dem Einfluss des Menschen*. Primus Verlag (Wissenschaftliche Buchgesellschaft), Darmstadt.

Bork, H.-R., S. Dreibrodt, and A. Mieth. 2006. Die langfristigen Wirkungen von Witterungsextremen auf Umwelt und Gesellschaft. Pages 11–22 *in Klimawandel -*

Klimafolgen - Naturkatastrophen und deren Auswirkungen auf Umwelt und Gesellschaft (Rostock, 20.10.2006), Rostock.

Bos, J. A. 2001. Lateglacial and Early Holocene vegetation history of the northern Wetterau and the Amöneburger Basin (Hessen), central-west Germany. *Review of Palaeobotany and Palynology* 115(3-4):177–204.

Brandt, G., A. Szécsényi-Nagy, C. Roth, K. W. Alt, and W. Haak. 2015. Human paleogenetics of Europe--the known knowns and the known unknowns. *Journal of Human Evolution* 79:73–92.

Brázdil, R., G. R. Demarée, M. Deutsch, E. Garnier, A. Kiss, J. Luterbacher, N. Macdonald, C. Rohr, P. Dobrovolný, P. Kolář, and K. Chromá. 2010. European floods during the winter 1783/1784: scenarios of an extreme event during the 'Little Ice Age'. *Theoretical and Applied Climatology* 100(1-2):163–189.

Brevik, E. C., and A. E. Hartemink. 2010. Early soil knowledge and the birth and development of soil science. *Catena* 83:23–33.

Brown, G. G., C. Feller, E. Blanchart, P. Deleporte, and S. S. Chernyanskii. 2003. With Darwin, earthworms turn intelligent and become human friends. *Pedobiologia* 47(5-6):924–933.

Brozio, J. P., W. Dörfler, I. Feeser, W. Kirleis, S. Klooß, and J. Müller. 2014. A Middle Neolithic well from Northern Germany: a precise source to reconstruct water supply management, subsistence economy, and deposition practices. *Journal of Archaeological Science* 51:135–153.

Büntgen, U., W. Tegel, K. Nicolussi, M. McCormick, D. Frank, V. Trouet, J. O. Kaplan, F. Herzig, K.-U. Heussner, H. Wanner, J. Luterbacher, and J. Esper. 2011. 2500 Years of European Climate Variability and Human Susceptibility. *Science* 331:578–582.

Canadell, J. G., C. Le Quéré, M. R. Raupach, C. B. Field, E. T. Buitenhuis, P. Ciais, T. J. Conway, N. P. Gillett, R. A. Houghton, and G. Marland. 2007. Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proceedings of the National Academy of Sciences* 104(104):18866–18870.

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From Metaphor to Measurement: Resilience of What to What? *Ecosystems* 4(8):765–781.

Caseldine, C. J., and C. Turney. 2010. The bigger picture: towards integrating palaeoclimate and environmental data with a history of societal change. *Journal of Quaternary Science* 25(1):88–93.

Cassman, K. G. 1999. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. *Proceedings of the National Academy of Sciences* 96:5952–5959.

Childe, V. G. 1936. *Man makes himself.* Watts, London.

Constantin, J., B. Mary, F. Laurent, G. Aubrion, A. Fontaine, P. Kerveillant, and N. Beaudoin. 2010. Effects of catch crops, no till and reduced nitrogen fertilization on nitrogen leaching and balance in three long-term experiments. *Agriculture, Ecosystems & Environment* 135(4):268–278.

Cordell, D., J.-O. Drangert, and S. White. 2009. The story of phosphorus: Global food security and food for thought. *Global Environmental Change* 19(2):292–305.

Costanza, R., L. Graumlich, W. Steffen, C. Crumley, J. Dearing, K. Hibbard, R. Leemans, C. Redman, and D. Schimel. 2007. Sustainability or Collapse: What Can We Learn from Integrating the History of Humans and the Rest of Nature? *AMBIO: A Journal of the Human Environment* 36(7):522–527.

Coward, F., S. Shennan, S. Colledge, J. Conolly, and M. Collard. 2008. The spread of Neolithic plant economies from the Near East to northwest Europe: a phylogenetic analysis. *Journal of Archaeological Science* 35(1):42–56.

Crombé, P., J. Sergant, E. Robinson, and J. de Reu. 2011. Hunter–gatherer responses to environmental change during the Pleistocene–Holocene transition in the southern

North Sea basin: Final Palaeolithic–Final Mesolithic land use in northwest Belgium. *Journal of Anthropological Archaeology* 30(3):454–471.

Darwin, C. 1890. The Formation of Vegetable Mould through the Action of Worms with Observation on their habits. D. Appleton & Company, New York.

Davison, K., P. Dolukhanov, G. R. Sarson, and A. Shukurov. 2006. The role of waterways in the spread of the Neolithic. *Journal of Archaeological Science* 33(5):641–652.

Deschler-Erb, S., and Ö. Akeret. 2011. Archäobiologische Forschungen zum römischen Legionslager von Vindonissa und seinem Umland: Status quo und Potenzial. *Jahresbericht Gesellschaft Pro Vindonissa*:13–36.

Doppler, T., C. Gerling, V. Heyd, C. Knipper, T. Kuhn, M. F. Lehmann, A. W. Pike, and J. Schibler. 2015. Landscape opening and herding strategies: Carbon isotope analyses of herbivore bone collagen from the Neolithic and Bronze Age lakeshore site of Zurich-Mozartstrasse, Switzerland. *Quaternary International*.

Dorren, L. K. A., and A. C. Imeson. 2005. Soil erosion and the adaptive cycle metaphor. *Land Degradation & Development* 16(6):509–516.

Dotterweich, M. 2013. The history of human-induced soil erosion: Geomorphic legacies, early descriptions and research, and the development of soil conservation—A global synopsis. *Geomorphology* 201:1–34.

Dotterweich, M., A. Schmitt, G. Schmidtchen, and H.-R. Bork. 2003. Quantifying historical gully erosion in northern Bavaria. *Catena* 50:135–150.

Dreibrodt, S. 2005. Detecting heavy precipitation events during the Holocene from soils, gully fills, colluvia and lake sediments – examples from the Belauer See catchment (northern Germany). *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften* 156(4):573–588.

Dreibrodt, S., J. Lomax, O. Nelle, C. Lubos, P. Fischer, A. Mitusov, S. Reiss, U. Radtke, M. Nadeau, P. Meiert Grootes, and H.-R. Bork. 2010a. Are mid-latitude slopes sensitive to climatic oscillations? Implications from an Early Holocene sequence of slope deposits and buried soils from eastern Germany. *Geomorphology* 122:351–369.

Dreibrodt, S., C. Lubos, B. Terhorst, B. Damm, and H.-R. Bork. 2010b. Historical soil erosion by water in Germany: Scales and archives, chronology, research perspectives. *Quaternary International* 222(1-2):80–95.

Dreßler, M., U. Selig, W. Dörfler, S. Adler, H. Schubert, and T. Hübener. 2006. Environmental changes and the Migration Period in northern Germany as reflected in the sediments of Lake Dudinghausen. *Quaternary Research* 66(1):25–37.

Eckmeier, E., M. Rösch, O. Ehrmann, M. W. Schmidt, W. Schier, and R. Gerlach. 2007. Conversion of biomass to charcoal and the carbon mass balance from a slash-and-burn experiment in a temperate deciduous forest. *The Holocene* 17(4):539–542.

Egg, M., and C. Pare. 1995. Die Metallzeiten in Mitteleuropa und im Vorderen Orient: Die Abteilung Vorgeschichte im Römisch-Germanischen Zentralmuseum. Verlag des Römisch-Germanischen Zentralmuseums, Mainz.

Eggert, M. K. H., and S. Samida. 2013. *Ur- und Frühgeschichtliche Archäologie.* 2. Auflage edition. Narr Francke Attempto Verlag GmbH + Co.KG, Tübingen.

Ellis, E. C., J. O. Kaplan, D. Q. Fuller, S. Vavrus, K. Klein Goldewijk, and P. H. Verburg. 2013. Used planet: A global history. *Proceedings of the National Academy of Sciences* 110(20):7978–7985.

Enters, D., A. Lücke, and B. Zolitschka. 2006. Effects of land-use change on deposition and composition of organic matter in Frickenhauser See, northern Bavaria, Germany. *The Science of the total environment* 369(1-3):178–187.

Erdrich, M. 2001. Rom und die Barbaren: Das Verhältnis zwischen dem Imperium Romanum und den germanischen Stämmen vor seiner Nordwestgrenze von der späten römischen Republik bis zum Gallischen Sonderreich. Philipp von Zabern, Mainz.

Evans, S. 2012. Agricultural Production and Environmental History *in* J. M. Pilcher, editor. *The Oxford Handbook of Food History.* Oxford University Press, Oxford.

Evtuhov, C. 2006. The Roots of Dokuchaev's Scientific Contributions: Cadastral Soil Mapping and Agro-Environmental Issues. Pages 125–148 *in* B. P. Warkentin, editor. *Footprints in the Soil: People and Ideas in Soil History*. Elsevier, Amsterdam, Oxford.

Falkowski, P., R. J. Scholes, E. Boyle, J. Canadell, D. Canfield, J. Elser, N. Gruber, K. Hibbard, P. Högberg, S. Linder, F. T. Mackenzie, B. Moore III, T. Pedersen, Y. Rosenthal, S. Seitzinger, V. Smetacek, and W. Steffen. 2000. The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System. *Science* 290:291–296.

Fath, B. D., C. A. Dean, and H. Katzmair. 2015. Navigating the adaptive cycle: an approach to managing the resilience of social systems. *Ecology and Society* 20(2):24.

Feller, C., E. Blanchart, and D. H. Yaalon. 2006. Some Major Scientists (Palissy, Buffon, Thaer, Darwin and Muller) Have Described Soil Profiles and Developed Soil survey Techniques Before 1883. Pages 85–105 *in* B. P. Warkentin, editor. *Footprints in the Soil: People and Ideas in Soil History*. Elsevier, Amsterdam, Oxford.

Feller, C., G. G. Brown, E. Blanchart, P. Deleporte, and S. S. Chernyanskii. 2003a. Charles Darwin, earthworms and the natural sciences: various lessons from past to future. *Agriculture, Ecosystems & Environment* 99(1-3):29–49.

Feller, C. L., L. J.-M. Thuriès, R. J. Manlay, P. Robin, and E. Frossard. 2003b. ”The principles of rational agriculture” by Albrecht Daniel Thaer (1752–1828). An approach to the sustainability of cropping systems at the beginning of the 19th century. *Journal of Plant Nutrition and Soil Science* 166(6):687–698.

Fingerlin, G. 2008. Vom Oberrhein zur jungen Donau: Die Straße durch den südlichen Schwarzwald in keltischer, römischer und frühmittelalterlicher Zeit. *Die Schriften des Vereins für Geschichte und Naturgeschichte der Baar* 51:47–58.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty, and P. K. Snyder. 2005. Global Consequences of Land Use. *Science* 309:570–574.

Foley, J. A., N. Ramankutty, K. A. Brauman, E. S. Cassidy, J. S. Gerber, M. Johnston, N. D. Mueller, C. O'Connell, D. K. Ray, P. C. West, C. Balzer, E. M. Bennett, S. R. Carpenter, J. Hill, C. Monfreda, S. Polasky, J. Rockström, J. Sheehan, S. Siebert, D. Tilman, and Zaks, David P M. 2011. Solutions for a cultivated planet. *Nature* 478:337–342.

Fraser, E. D. 2011. Can economic, land use and climatic stresses lead to famine, disease, warfare and death? Using Europe's calamitous 14th century as a parable for the modern age. *Ecological Economics* 70(7):1269–1279.

Fried, J. 2009. *Das Mittelalter: Geschichte und Kultur.* 3. Auflage edition. C.H. Beck, München.

Fries, J. C. 1995. Vor- und frühgeschichtliche Agrartechnik auf den Britischen Inseln und dem Kontinent: Eine vergleichende Studie. Verlag Marie Leidorf GmbH, Espelkamp.

Fries, J. E. 2005. Methodische Überlegungen zur Ressource Boden. *Archäologische Informationen* 28(1&2):139–147.

Gassmann, G., M. Rösch, and G. Wieland. 2006. Das Neuenbürger Erzrevier im Nordschwarzwald als Wirtschaftsraum während der Späthallstatt- und Frühlatènezeit. *Germania* 84:273–306.

Geißler, C., P. Kühn, M. Böhnke, H. Bruelheide, X. Shi, and T. Scholten. 2012. Splash erosion potential under tree canopies in subtropical SE China. *Catena* 91:85–93.

Gerlach, R., and E. Eckmeier. 2012. Prehistoric Land use and Its Impact on Soil Formation since Early Neolithic. Examples from the Lower Rhine Area. Pages 11–16 *in* W. Bebermeier, R. Hebenstreit, E. Kaiser, and J. Krause, editors. *Landscape Archaeology. Proceedings of the International Conference Held in Berlin, 6th – 8th June 2012*, Berlin.

Gessner, D. 1976. Agrarverbände in der Weimarer Republik: Wirtschaftliche und soziale Voraussetzungen agrarkonservativer Politik vor 1933. Dissertation. Universität Köln, Köln.

Giesecke, T., K. D. Bennett, Birks, H. John B., A. E. Bjune, E. Bozilova, A. Feurdean, W. Finsinger, C. Froyd, P. Pokorný, M. Rösch, H. Seppä, S. Tonkov, V. Valsecchi, and S. Wolters. 2011. The pace of Holocene vegetation change – testing for synchronous developments. *Quaternary Science Reviews* 30(19-20):2805–2814.

Gkiasta, M., T. Russell, S. Shennan, and J. Steele. 2003. Neolithic transition in Europe: the radiocarbon record revisited. *Antiquity* 77(295):45–62.

Godfray, H. C. J., J. R. Beddington, I. R. Crute, L. Haddad, D. Lawrence, J. F. Muir, J. Pretty, S. Robinson, S. M. Thomas, and C. Toulmin. 2010. Food Security: The Challenge of Feeding 9 Billion People. *Science* 327:812–818.

Gronenborn, D., and J. Petrasch, editors. 2010. *Die Neolithisierung Mitteleuropas: Internationale Tagung, Mainz 24. bis 26. Juni 2005*. Verlag des Römisch-Germanischen Zentralmuseums Mainz.

Gronenborn, D., H.-C. Strien, S. Dietrich, and F. Sirocko. 2014. 'Adaptive cycles' and climate fluctuations: a case study from Linear Pottery Culture in western Central Europe. *Journal of Archaeological Science* 51:73–83.

Groot, M., and S. Deschler-Erb. 2015. Market strategies in the Roman provinces: Different animal husbandry systems explored by a comparative regional approach. *Journal of Archaeological Science: Reports* 4:447–460.

Grundmann, P., M.-H. Ehlers, and G. Uckert. 2012. Responses of agricultural bioenergy sectors in Brandenburg (Germany) to climate, economic and legal changes: An application of Holling's adaptive cycle. *Energy Policy* 48:118–129.

Gunderson, L. H., and C. S. Holling, editors. 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Island Press, Washington, D.C.

Haak, W., P. Forster, B. Bramanti, S. Matsumura, G. Brandt, M. Tänzer, R. Villemy, C. Renfrew, D. Gronenborn, K. W. Alt, and J. Burger. 2005. Ancient DNA from the First European Farmers in 7500-Year-Old Neolithic Sites. *Science* 310:1016–1018.

Haasis-Berner, A. 2012. Relikte mittelalterlicher Landnutzung: Der ehemalige Ort Mauchen (Lkr. Breisgau-Hochschwarzwald). *Denkmalpflege in Baden-Württemberg. Nachrichtenblatt des Landesdenkmalamtes*(1):54–55.

Hahn, H.-W. 2011. *Die industrielle Revolution in Deutschland.* Oldenbourg Wissenschaftsverlag GmbH, München.

Hawkes, J. G., and J. Francisco-Ortega. 1993. The early history of the potato in Europe. *Euphytica* 70:1–7.

Heiligmann, J. 1996. Vormarsch auf die Schwäbische Alb: Das Kastell Urspring *in* Ulmer Museum, editor. *Römer an Donau und Iller: Neue Forschungen und Funde.* Jan Thorbecke Verlag GmbH & Co., Sigmaringen.

Henkner, J., J. J. Ahlrichs, S. S. Downey, M. Fuchs, B. R. James, T. Knopf, T. Scholten, S. Teuber, and P. Kühn. 2017. Archaeopedology and chronostratigraphy of colluvial deposits as a proxy for regional land use history (Baar, southwest Germany). *Catena* 155:93–113.

Herbig, C. 2009. Recent archaeobotanical investigations into the range and abundance of Neolithic crop plants in settlements around Lake Constance and in Upper Swabia (south-west Germany) in relation to cultural influences. *Journal of Archaeological Science* 36(6):1277–1285.

Hoffmann, T., G. Erkens, R. Gerlach, J. Klostermann, and A. Lang. 2009. Trends and controls of Holocene floodplain sedimentation in the Rhine catchment. *Catena* 77(2):96–106.

Holling, C. S. 2001. Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems* 4(5):390–405.

Holling, C. S., and L. H. Gunderson. 2002. Resilience and Adaptive Cycles. Pages 25–62 *in* L. H. Gunderson, and C. S. Holling, editors. *Panarchy: Understanding Transformations in Human and Natural Systems.* Island Press, Washington, D.C.

Holling, C. S., L. H. Gunderson, and D. Ludwig. 2002a. In Quest of a theory of Adaptive Change. Pages 3–22 *in* L. H. Gunderson, and C. S. Holling, editors. *Panarchy: Understanding Transformations in Human and Natural Systems.* Island Press, Washington, D.C.

Holling, C. S., L. H. Gunderson, and G. D. Peterson. 2002b. Sustainability and Panarchies. Pages 63–103 *in* L. H. Gunderson, and C. S. Holling, editors. *Panarchy: Understanding Transformations in Human and Natural Systems.* Island Press, Washington, D.C.

Houben, P. 2012. Sediment budget for five millennia of tillage in the Rockenberg catchment (Wetterau loess basin, Germany). *Quaternary Science Reviews* 52:12–23.

Houben, P., M. Schmidt, B. Mauz, A. Stobbe, and A. Lang. 2013. Asynchronous Holocene colluvial and alluvial aggradation: A matter of hydrosedimentary connectivity. *The Holocene* 23(4):544–555.

Hublin, J.-J. 2015. The modern human colonization of western Eurasia: when and where? *Quaternary Science Reviews* 118:194–210.

Hughes, P. D., and P. L. Gibbard. 2015. A stratigraphical basis for the Last Glacial Maximum (LGM). *Quaternary International* 383:174–185.

Humpert, J. 1995. Ziele und Methoden der Altwegeforschung am Beispiel einer römischen Straße von der Baar in den Breisgau. *Die Schriften des Vereins für Geschichte und Naturgeschichte der Baar* 38:11–23.

James, B. R., W. E. Blum, and C. Dazzi. 2014. Bread and Soil in Ancient Rome: A Vision of Abundance and an Ideal of Order Based on Wheat, Grapes, and Olives. Pages 153–173 *in* G. J. Churchman, and E. R. Landa, editors. *The Soil Underfoot: Infinite Possibilities for a Finite Resource.* CRC Press.

Jankuhn, H. 1977. *Einführung in die Siedlungsarchäologie.* Walter de Gruyter, Berlin, New York.

Jockenhövel, A. 1993. Eisengewinnung im Mittelgebirgsraum. Pages 70–74 *in* H. Steuer, and U. Zimmermann, editors. *Alter Bergbau in Deutschland*. Konrad Theiss Verlag, Stuttgart.

Jockenhövel, A. 1994. Umwelt - Landwirtschaft - Ernährung *in* A. Jockenhövel, and W. Kubach, editors. *Bronzezeit in Deutschland*. Konrad Theiss Verlag, Stuttgart.

Kadereit, A., P. Kühn, and G. A. Wagner. 2010. Holocene relief and soil changes in loess-covered areas of south-western Germany: The pedosedimentary archives of Bretten-Bauerbach (Kraichgau). *Quaternary International* 222(1-2):96–119.

Kaplan, J. O., K. M. Krumhardt, and N. Zimmermann. 2009. The prehistoric and preindustrial deforestation of Europe. *Quaternary Science Reviews* 28:3016–3034.

Kerig, T., and J. Lechterbeck. 2004. Laminated sediments, human impact, and a multivariate approach: a case study in linking palynology and archaeology (Steisslingen, Southwest Germany). *Quaternary International* 113(1):19–39.

Kirleis, W., S. Klooß, H. Kroll, and J. Müller. 2012. Crop growing and gathering in the northern German Neolithic: a review supplemented by new results. *Vegetation History and Archaeobotany* 21(3):221–242.

Knopf, T., T. Baum, T. Scholten, and P. Kühn. 2012. Landnutzung im Frühen Mittelalter: Eine Archäopedologische Prospektion im Mittleren Schwarzwald. *Archäologisches Korrespondenzblatt* 42(1):123–133.

Lal, R. 2010. Managing soils for a warming earth in a food-insecure and energy-starved world. *Journal of Plant Nutrition and Soil Science* 173(1):4–15.

Lal, R. 2013. Enhancing ecosystem services with no-till. *Renewable Agriculture and Food Systems* 28(02):102–114.

Lal, R., J. A. Delgado, P. M. Groffman, N. Millar, C. Dell, and A. Rotz. 2011. Management to mitigate and adapt to climate change. *Journal of Soil and Water Conservation* 66(4):276–285.

Lal, R., D. C. Reicosky, and J. D. Hanson. 2007. Evolution of the plow over 10,000 years and the rationale for no-till farming. *Soil and Tillage Research* 93(1):1–12.

Lambin, E. F., B. L. Turner, H. J. Geist, S. B. Agbola, A. Angelsen, J. W. Bruce, O. T. Coomes, R. Dirzo, G. Fischer, C. Folke, P. S. George, K. Homewood, J. Imbernon, R. Leemans, X. Li, E. F. Moran, M. Mortimore, P. S. Ramakrishnan, J. F. Richards, H. Skånes, W. Steffen, G. D. Stone, U. Svedin, T. A. Veldkamp, C. Vogel, and J. Xu. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11(4):261–269.

Lang, A. 2003. Phases of soil erosion-derived colluviation in the loess hills of South Germany. *Catena* 51(3-4):209–221.

Lang, A., H.-P. Niller, and M. M. Rind. 2003. Land degradation in Bronze Age Germany: Archaeological, pedological, and chronometrical evidence from a hilltop settlement on the Frauenberg, Niederbayern. *Geoarchaeology* 18(7):757–778.

Larson, G., U. Albarella, K. Dobney, P. Rowley-Conwy, J. Schibler, A. Tresset, J.-D. Vigne, C. J. Edwards, A. Schlumbaum, a. Dinu, A. Baˇlaˇçsescu, G. Dolman, A. Tagliacozzo, N. Manaseryan, P. Miracle, L. van Wijngaarden-Bakker, M. Masseti, D. G. Bradley, and A. Cooper. 2007. Ancient DNA, pig domestication, and the spread of the Neolithic into Europe. *Proceedings of the National Academy of Sciences* 104(39):15276–15281.

Lemmen, C., D. Gronenborn, and K. W. Wirtz. 2011. A simulation of the Neolithic transition in Western Eurasia. *Journal of Archaeological Science* 38(12):3459–3470.

Leopold, M., T. Plöckl, G. Forstenaicher, and J. Völkel. 2010. Integrating pedological and geophysical methods to enhance the informative value of an archaeological prospection – The example of a Roman villa rustica near Regensburg, Germany. *Journal of Archaeological Science* 37(7):1731–1741.

Leopold, M., and J. Völkel. 2007. Colluvium: Definition, differentiation, and possible suitability for reconstructing Holocene climate data. *Quaternary International* 162-163:133–140.

Levitt, T. 1999. The Globalization of Markets. Pages 249–266 *in* R. Z. Aliber, and R. W. Click, editors. *Readings in International Business: A Decision Approach*. Third printing. MIT Press, Cambridge, Massachusetts, London, England.

Liebig, J. 1841. Die organische Chemie in ihrer Anwendung auf Agricultur und Physiologie. Verlag von Friedrich Vieweg und Sohn, Braunschweig.

Linke, M. 1979. Zur Verbreitung, Form und Entstehung altmärkischer Wölbäcker. *Hercynia N. F.* 16(4):431–439.

Lüning, J. 2000. Steinzeitliche Bauern in Deutschland - die Landwirtschaft im Neolithikum. Verlag Dr. Rudolf Habelt GmbH, Bonn.

Luterbacher, J., D. Dietrich, E. Xoplaki, M. Grosjean, and H. Wanner. 2004. European Seasonal and Annual Temperature Variability, Trends, and Extremes Since 1500. *Science* 303:1499–1503.

MacDonald, G. K., E. M. Bennett, P. A. Potter, and N. Ramankutty. 2011. Agronomic phosphorus imbalances across the world's croplands. *Proceedings of the National Academy of Sciences* 108(7):3086–3091.

Mäckel, R., R. Schneider, and J. Seidel. 2003. Anthropogenic Impact on the Landscape of Southern Badenia (Germany) during the Holocene - Documented by Colluvial and Alluvial Sediments. *Archaeometry* 45(3):487–501.

McNeill, J. R., and V. Winiwarter. 2004. Breaking the Sod: Humankind, History, and Soil. *Science* 304(5677):1627–1629.

Mellars, P. 2004. Neanderthals and the modern human colonization of Europe. *Nature* 432:461–465.

Mitusov, A. V., O. E. Mitusova, J. Wendt, S. Dreibrodt, and H.-R. Bork. 2014. Correlation of colluvial deposits with the modern land surface and the problem of slope profile description. *Geomorphology* 220:30–40.

Montgomery, D. R. 2010. Dreck: Warum unsere Zivilisation den Boden unter den Füßen verliert. oekom verlag, München.

Mueller, K. 2015. Der Spaten - ein Bodenbearbeitungsgerät im Wandel der Zeit. Pages 199–208 *in* H.-P. Blume, and R. Horn, editors. *Persönlichkeiten der Bodenkunde V: Beiträge zum 350. Jubiläum der Christian-Albrechts- Universität zu Kiel.* Vorträge der Arbeitsgruppe Geschichte der Bodenkunde im Rahmen der Jahrestagung der Deutschen Bodenkundlichen Gesellschaft im September 2013 in Rostock. R. Horn und K. H. Mühling.

Niedertscheider, M., T. Kuemmerle, D. Müller, and K.-H. Erb. 2014. Exploring the effects of drastic institutional and socio-economic changes on land system dynamics in Germany between 1883 and 2007. *Global environmental change human and policy dimensions* 28:98–108.

Nüsse, H.-J., C. Marx, and D. Lelgemann. 2011. Germania magna - Ein neuer Blick auf eine alte Karte: Entzerrte geographische Daten des Ptolemaios für die antiken Orte zwischen Rhein und Weichsel. *Germania* 89(1-2):115–153.

Pape, J. C. 1970. Plaggen soils in the Netherlands. *Geoderma* 4(3):229–255.

Pietsch, D., and P. Kühn. 2014. Buried soils in the context of geoarchaeological research—two examples from Germany and Ethiopia. *Archaeological and Anthropological Sciences*.

Pimentel, D., and N. Kounang. 1998. Ecology of Soil Erosion in Ecosystems. *Ecosystems* 1(5):416–426.

Pinhasi, R., M. G. Thomas, M. Hofreiter, M. Currat, and J. Burger. 2012. The genetic history of Europeans. *Trends in genetics TIG* 28(10):496–505.

Price, T. D., R. A. Bentley, J. Lüning, D. Gronenborn, and J. Wahl. 2001. Prehistoric human migration in the Linearbandkeramik of Central Europe. *Antiquity* 75(289):593–603.

Prummel, W., and M. J. Niekus. 2011. Late Mesolithic hunting of a small female aurochs in the valley of the River Tjonger (the Netherlands) in the light of Mesolithic aurochs hunting in NW Europe. *Journal of Archaeological Science* 38(7):1456–1467.

Rebourg, C., M. Chastanet, B. Gouesnard, C. Welcker, P. Dubreuil, and A. Charcosset. 2003. Maize introduction into Europe: the history reviewed in the light of molecular data. *TAG. Theoretical and applied genetics. Theoretische und angewandte Genetik* 106(5):895–903.

Reiß, S., S. Dreibrodt, C. C. M. Lubos, and H.-R. Bork. 2009. Land use history and historical soil erosion at Albersdorf (northern Germany) — Ceased agricultural land use after the pre-historical period. *Catena* 77(2):107–118.

Robertson, R. 1992. *Globalization: Social Theory and Global Culture.* SAGE Publications, London, Thousand Oaks, New Delhi.

Rösch, M. 1987. Der Mensch als landschaftsprägender Faktor des westlichen Bodenseegebietes seit dem späten Atlantikum. *Eiszeitalter und Gegenwart* 37:19–29.

Rösch, M. 1996. New approaches to prehistoric land-use reconstruction in south-western Germany. *Vegetation History and Archaeobotany* 5:65–79.

Rösch, M. 1998. The history of crops and crop weeds in south-western Germany from the Neolithic period to modern times, as shown by archaeobotanical evidence. *Vegetation History and Archaeobotany* 7:109–125.

Rösch, M. 2009. Vom Korn der frühen Jahre: Sieben Jahrtausende Ackerbau und Kulturlanschaft. *Denkmalpflege in Baden-Württemberg. Nachrichtenblatt des Landesdenkmalamtes* 38(3):157–164.

Rösch, M., O. Ehrmann, L. Herrmann, E. Schulz, A. Bogenrieder, J. P. Goldammer, M. Hall, H. Page, and W. Schier. 2002. An experimental approach to Neolithic shifting cultivation. *Vegetation History and Archaeobotany* 11:143–154.

Rösch, M., S. Jacomet, and S. Karg. 1992. The history of cereals in the region of the former Duchy of Swabia (Herzogtum Schwaben) from the Roman to the Post-medieval period: results of archaeobotanical research. *Vegetation History and Archaeobotany* 1:193–231.

Rösch, M., and G. Tserendorj. 2011. Florengeschichtliche Beobachtungen im Nordschwarzwald (Südwestdeutschland). *Hercynia N. F.* 44:53–71.

Sanden, W. v. d. 1994. Early Iron age ard shares from Drenthe, the Netherlands. Tools & Tillage: A journal on the history of the implements of cultivation and other agricultural processes 7(2):103–106.

Schmitt, A., M. Dotterweich, G. Schmidtchen, and H.-R. Bork. 2003. Vineyards, hopgardens and recent afforestation: effects of late Holocene land use change on soil erosion in northern Bavaria, Germany. *Catena* 51:241–254.

Schneider, H. 2007. *Geschichte der antiken Technik*. C.H. Beck oHG, München.

Scholten, T. 2014. Mensch und Boden. *Praxis Geographie*(1):4–7.

Schultz-Klinken, K.-R. 1981. Haken, Pflug und Ackerbau: Ackerbausysteme des Saatfurch- und Saatbettbaues in urgeschichtlicher und geschichtlicher Zeit sowie ihr Einfluß auf die Bodenentwicklung. August Lax Verlagsbuchhandlung, Hildesheim.

Schumacher, E. F. 1993. Small is beautiful: A study of economics as if people mattered. Vintage Books, London.

Seidl, A. 2006. *Deutsche Agrargeschichte*. DLG-Verlags-GmbH, Frankfurt am Main.

Shen, J., R. Li, F. Zhang, J. Fan, C. Tang, and Z. Rengel. 2004. Crop yields, soil fertility and phosphorus fractions in response to long-term fertilization under the rice monoculture system on a calcareous soil. *Field Crops Research* 86(2-3):225–238.

Smil, V. 1999. Nitrogen in crop production: An account of global flows. *Global Biogeochemical Cycles* 13(2):647–662.

Smil, V. 2000. Phosphorus in the Environment: Natural Flows and Human Interferences. *Annu. Rev. Energy Environ.* 25:53–88.

Spek, T., W. Groenman-van Waateringe, M. Kooistra, and L. Bakker. 2003. Formation and Land-Use History of Celtic Fields in North-West Europe - An Interdisciplinary Case Study at Zeijen, The Netherlands. *European Journal of Archaeology* 6(2):141–173.

Statistisches Bundesamt. 2016. Produktionsmethoden: Bodenbearbeitungsverfahren landwirtschaftlicher Betriebe auf Ackerflächen im Wirtschaftsjahr 2009/2010. [online] URL: https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/LandForstwirtschaftFischerei/Produktionsmethoden/Tabellen/BodenbearbeitungsverfahrenLB.html.

Steuer, H. 1993. Von der Steinzeit bis zum Mittelalter - Erzgewinnung als Spiegel der Epochen. Pages 7–15 *in* H. Steuer, and U. Zimmermann, editors. *Alter Bergbau in Deutschland*. Konrad Theiss Verlag, Stuttgart.

Stockmann, U., B. Minasny, and A. B. McBratney. 2014. How fast does soil grow? *Geoderma* 216:48–61.

Tegtmeier, U. 1993. Neolithische und bronzezeitliche Pflugspuren in Norddeutschland und den Niederlanden. Magisterarbeit, Bonn.

Teixeira, E. I., P. Johnstone, E. Chakwizira, J. d. Ruiter, B. Malcolm, N. Shaw, R. Zyskowski, E. Khaembah, J. Sharp, E. Meenken, P. Fraser, S. Thomas, H. Brown, and D. Curtin. 2016. Sources of variability in the effectiveness of winter cover crops for mitigating N leaching. *Agriculture, Ecosystems & Environment* 220:226–235.

Terberger, T., P. de Klerk, H. Helbig, K. Kaiser, and P. Kühn. 2004. Late Weichselian landscape development and human settlement in Mecklenburg-Vorpommern (NE Germany). *Eiszeitalter und Gegenwart* 54:138–175.

Thaer, A. D. 1880. Albrecht Thaer's Grundsätze der rationellen Landwirthschaft. Wiegandt, Hempel & Parey, Berlin.

Tiedje, J. M., R. K. Colwell, Y. L. Grossman, R. E. Hodson, R. E. Lenski, R. N. Mack, and P. J. Regal. 1989. The Planned Introduction of Genetically Engineered Organisms: Ecological Considerations and Recommendations. *Ecology* 70(2):298–315. [online] URL: http://www.jstor.org/stable/1937535.

Tilman, D., K. G. Cassman, P. A. Matson, R. L. Naylor, and S. Polasky. 2002. Agricultural sustainability and intensive production practices. *Nature* 418:671–677.

Tinner, W., and A. F. Lotter. 2001. Central European vegetation response to abrupt climate change at 8.2 ka. *Geology* 29(6):551–554.

Tolksdorf, J. F., K. Kaiser, S. Veil, N. Klasen, and H. Brückner. 2009. The Early Mesolithic Haverbeck site, Northwest Germany: evidence for Preboreal settlement in the Western and Central European Plain. *Journal of Archaeological Science* 36(7):1466–1476.

Tresset, A., and J.-D. Vigne. 2011. Last hunter-gatherers and first farmers of Europe. *Comptes rendus biologies* 334(3):182–189.

Uekoetter, F. 2012. Die Wahrheit ist auf dem Feld: Eine Wissensgeschichte der deutschen Landwirtschaft. Vandenhoeck & Ruprecht GmbH, Göttingen.

Uerpmann, H.-P. 2007. Von Wildbeutern zu Ackerbauern: Die Neolithische Revolution der menschlichen Subsistenz. *Mitteilungen der Gesellschaft für Urgeschichte* 16:55–74.

van Beek, R., and B. Groenewoudt. 2011. An Odyssey along the River Vecht in the Dutch-German border area: A Region Analysis of Roman-period Sites in Germania Magna. *Germania* 89(1-2).

van Mourik, J. M., A. C. Seijmonsbergen, R. T. Slotboom, and J. Wallinga. 2012. Impact of human land use on soils and landforms in cultural landscapes on aeolian sandy substrates (Maashorst, SE-Netherlands). *Quaternary International* 265:74–89.

Verheijen, F., R. Jones, R. J. Rickson, and C. J. Smith. 2009. Tolerable versus actual soil erosion rates in Europe. *Earth-Science Reviews* 94(1-4):23–38.

West, P. C., H. K. Gibbs, C. Monfreda, J. Wagner, C. C. Barford, S. R. Carpenter, and J. A. Foley. 2010. Trading carbon for food: global comparison of carbon stocks vs. crop yields on agricultural land. *Proceedings of the National Academy of Sciences* 107(46):19645–19648.

Whitehouse, N. J., and W. Kirleis. 2014. The world reshaped: practices and impacts of early agrarian societies. *Journal of Archaeological Science* 51:1–11.

Wilson, R. J. A. 2006. What's New in Roman Baden-Württemberg? *Journal of Roman Studies* 96:198–212.

Winiwarter, V. 2006. Prolegomena to a History of Soil Knowledge in Europe. Pages 177–215 *in* J. R. McNeill, and V. Winiwarter, editors. *Soils and Societies: Perspectives from environmental history.* 2nd rev. ed. The White Horse Press; White Horse Press, Isle of Harris, UK.

Zich, B. 1999. Das Hügelgräberfeld von Flintbek nach zwanzig Ausgrabungsjahren. *Jahrbuch für das ehemalige Amt Bordesholm 1*:1–52.

Zimmermann, A. 2012. Cultural cycles in Central Europe during the Holocene. *Quaternary International* 274:251–258.

Zolitschka, B., K.-E. Behre, and J. Schneider. 2003. Human and climatic impact on the environment as derived from colluvial, fluvial and lacustrine archives—examples from the Bronze Age to the Migration period, Germany. *Quaternary Science Reviews* 22(1):81–100.

Zvelebil, M., M. C. Lillie, J. Montgomery, A. Lukes, P. Pettitt, and M. P. Richards. 2012. The emergence of the LBK: Migration, memory and meaning at the transition to agriculture. Pages 133–148 *in* E. Kaiser, J. Burger, and W. Schier, editors. *Population Dynamics in Prehistory and Early History: New Approaches by Using Stable Isotopes and Genetics.* de Gruyter, Berlin, Boston.

Manuscript V

Archäologische und bodenkundliche Untersuchungen zur Besiedlungs- und Landnutzungsgeschichte der Baar

Knopf, Thomas [1, 2]; Ahlrichs, Jan [1, 2]; Henkner, Jessica [1, 3]; Scholten, Thomas [1, 3]; Kühn, Peter [1, 3]

Schriften des Vereins für Geschichte und Naturgeschichte der Baar 58 (2015) 9-24

[1] SFB1070 ResourceCultures, Gartenstr. 29, 72074 Tübingen, Germany

[2] Institute for Pre- and Protohistory and Medieval Archaeology, Eberhard Karls University Tübingen, Burgsteige 11, Schloss Hohentübingen, 72070 Tübingen, Germany

[3] Department of Geosciences, Soil Science and Geomorphology, Eberhard Karls University Tübingen, Rümelinstrasse 19-23, 72070 Tübingen, Germany

Die Landschaft der Baar ist im Vergleich zu den benachbarten Räumen des Schwarzwalds und der Schwäbischen Alb ein Gunstraum: Die Böden sind agrarisch besser nutzbar, die Hangneigungen sind geringer. Und wegen der geringeren Meereshöhe sind die Durchschnittstemperaturen höher und es gibt weniger Frosttage.[1] Diese naturräumlichen Faktoren spielten bei der Besiedlung der Baar durch ur- und frühgeschichtliche Menschen eine wichtige Rolle, da deren Subsistenz auf dem Anbau von Getreiden und Hülsenfrüchten gründete. Unser Kenntnisstand zur Archäologie der Baar ist vergleichsweise gering. Es gibt nur wenige systematische Untersuchungen, etwa archäologische Ausgrabungen, aber eine größere Anzahl von Lesefundstellen prähistorischer Keramik.

Der folgende Beitrag stellt Methoden und erste Ergebnisse zweier Forschungsprojekte an der Universität Tübingen vor, die sich Teilen der Baar bzw. der Baar als Teil eines größeren Raumes angenommen haben. Im ersten Teil geht es um ein bereits abgeschlossenes, auf das Umland des Magdalenenbergs am Westrand der Baar konzentriertes Projekt, wo neben Feldbegehungen mit dem Ziel, neue Fundstellen zu entdecken, auch bodenkundliche Untersuchungen sowie eine kleine Ausgrabung durchgeführt wurden. Im zweiten Teil geht es um ein Ende 2013 begonnenes und noch bis 2017 laufendes Projekt, das sich mit der Frage nach der Aufsiedlung der benachbarten Gebiete des Schwarzwalds und der Schwäbischen Alb von der Baar aus beschäftigt. Hierbei sollen eine Gesamtbetrachtung aller bekannten archäologischen Fundstellen sowie systematische bodenkundliche Untersuchungen helfen zu klären, wann und warum Menschen von Gunst- in Ungunsträume gingen, um dort zu siedeln bzw. dortige Ressourcen zu nutzen.

Ausgangspunkt für die Untersuchung des Umlands des späthallstattzeitlichen Großgrabhügels Magdalenenberg war die Frage nach dem Siedlungs- und Wirtschaftssystem der Hallstattzeit auf der Baar.[2] Zwar steht mit der vollständig ausgegrabenen Begräbnisstätte wenig südlich von Villingen ein ganz exzeptioneller Fundplatz zur Verfügung, über weitere Grabhügel und vor allem Siedlungen ist jedoch wenig bekannt. Dabei liegen sowohl in der Nähe als auch im weiteren Umland zahlreiche einzelne Grabhügel oder kleine Gruppen von Grabhügeln, die auf der Übersichtskarte mit roten Kreisen markiert sind. Anders sieht es bei den dazugehörigen Siedlungen aus. Im näheren Umkreis ist lediglich die befestigte kleine Höhensiedlung des „Kapf“ westlich von Villingen bekannt, die gehört (in der Übersicht markiert durch ein rotes Quadrat).

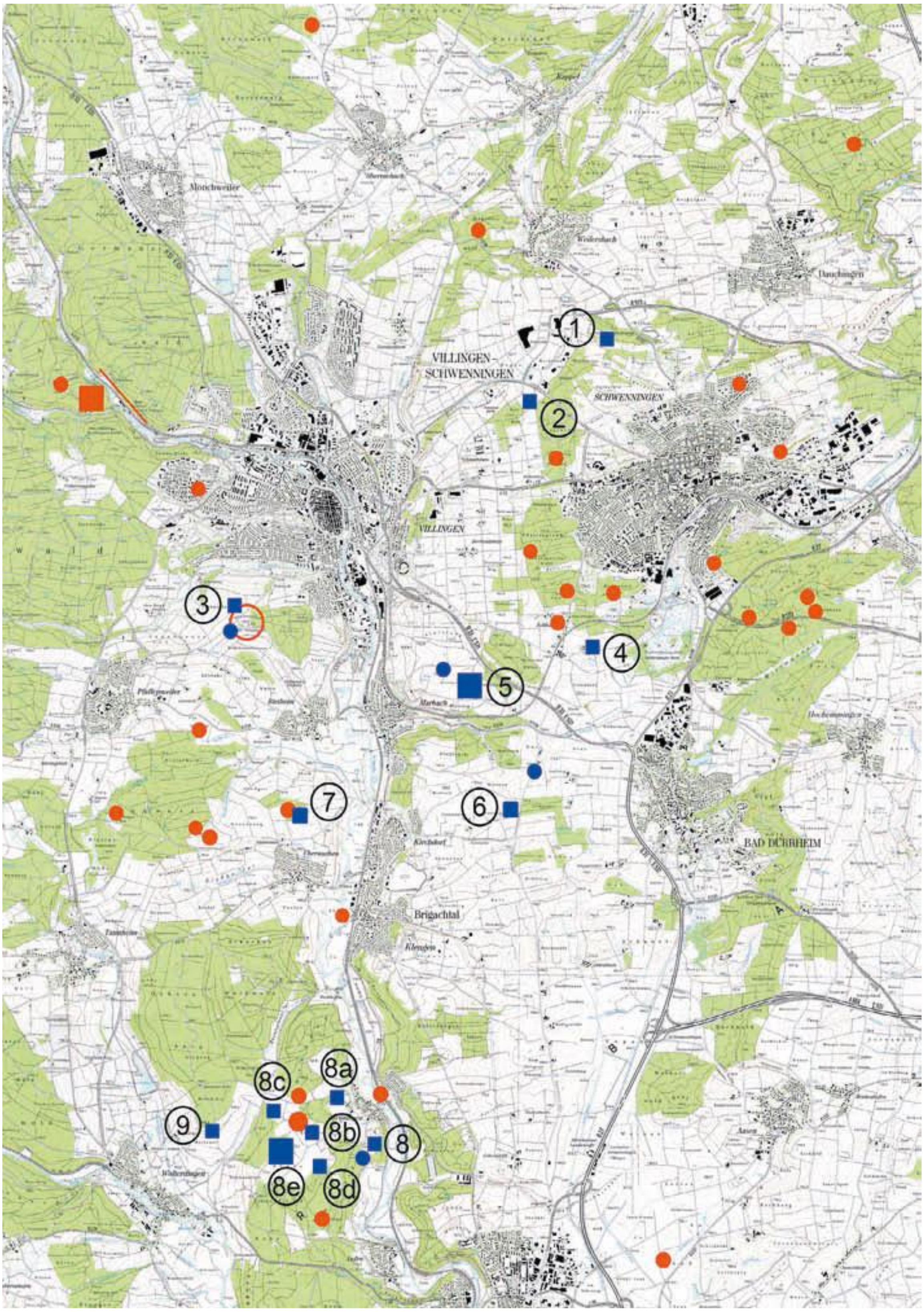

Fig. 1: Fundstellen im Umland des Magdalenenbergs: Bereits bekannte Fundstellen der Eisenzeit sind rot markiert, die Hügel durch Kreise, die Siedlung „Kapf“ durch das rote Quad-rat, ein Eisenerzgang als Linie um den Magdalenenberg. Blau markiert sind die aufgrund von archäologischen Begehungen seit 2010 neu entdeckten Fundstellen.

Fig. 2: Aktuelle Erosionsspuren auf der Baar nördlich von Rietheim. Foto: Thomas Knopf.

WOLFGANG HÜBENER hatte 1972 die Befunde und Funde der kleineren archäologischen Ausgrabung der 1950er- Jahre auf dem Kapf ausgewertet und die annähernde Übereinstimmung der Belegungsdauer des Kapfs und des Magdalenenbergs während Hallstatt D1 (um 600 v. Chr.) festgestellt.[3] Für Hübener wie auch für KONRAD SPINDLER, den Ausgräber des Magdalenen- bergs,[4] stand zudem fest, dass der Kapf die zum Magdalenenberg gehörige Siedlung sein müsse. Entscheidend für die Argumentation war, dass der immerhin 4 km entfernte Kapf schlichtweg die einzige bekannte Siedlung im Umfeld war. Betrachtet man aber vergleichbare Großgrabhügel etwa in Hochdorf oder bei der Heuneburg[5], wo die zugehörigen Siedlungen viel näherliegen, so erheben sich starke Zweifel zumindest an der Ausschließlichkeit des damals behaupteten Zusammenhangs von Hügel und Siedlung am Schwarzwaldrand. HÜBENER selbst hatte bereits betont, dass der im Zentralgrab des Magdalenenbergs bestattete „Fürst" wohl kaum seinen „Wohnsitz" auf dem Kapf gehabt haben dürfte; dafür sei die Anlage „zu bescheiden".[6]

Wo aber lagen die übrigen Siedlungen, seien es einzelne Höfe oder Gehöfte oder weilerartige Anlagen? Sehr wahrscheinlich in räumlicher Nähe und Sichtweite zu den Bestattungsplätzen.

Wir gehen davon aus, dass jeder Grabhügel auch eine zugehörige Siedlung in der Nähe – nur wenige Hundert Meter entfernt – besessen hat. Diese wurden aber kaum einmal entdeckt. Das liegt zum einen an den wenigen Bodeneingriffen, die bei einem kleinen Gehöft zu erwarten sind: wenige unscheinbare Pfostengruben, nur vereinzelte Keller- bzw. Abfallgruben oder Grubenhäuser. Bestanden solche Siedlungen nur kurze Zeit, ist die Chance, dass sie bei Baumaßnahmen entdeckt werden, gering. Zum anderen hat die Erosion im Laufe der Jahrhunderte viele Dezimeter, zuweilen sogar Meter Boden material abgetragen und umgelagert. Dadurch sind vorgeschichtliche Reste im Boden entweder zerstört oder überdeckt worden. Schließlich haben auf der Baar nur selten systematische Begehungen von Ackerflächen stattgefunden. Nur so jedoch lassen sich angepflügte Siedlungen entdecken, bevor sie durch akute Baumaßnahmen zerstört werden.

Fig. 3: Lesefunde von bronze- und eisenzeitlicher Siedlungskeramik westlich von Grüningen (Nr. 8e). Foto: Dirk Seidensticker / Thomas Knopf.

Mit Studierenden der Universität Tübingen wurden 2010 etwa 100 Hektar Ackerflächen in einem Umfeld von 5–10 km um den Magdalenenberg abgelaufen und Scherben auf den Feldern aufgesammelt.[7] Dabei konnte an mehreren Stellen vorgeschichtliche Keramik gefunden werden. Die handgemachte Grobkeramik des täglichen Bedarfs erlaubt nur teilweise eine genaue zeitliche Einordnung, doch an zwei Stellen deuten massive Streuungen von Scherben auf Siedlungs- plätze hin: Westlich von Grüningen siedelten Menschen wohl schon in der Bronzezeit und danach evtl. auch noch in der Eisenzeit (8e in der Übersicht). Eine weitere Siedelfläche der Bronze- / Eisenzeit wurde östlich von Marbach entdeckt (5 in der Übersicht). Die übrigen Scherben können entweder ebenfalls Siedlungsreste, aber auch zerstörte Gräber anzeigen. Insgesamt konnte mit den Acker-Prospektionen gezeigt werden, dass noch Siedlungsreste aufgefunden werden können. Hier müssten weitere gezielte archäologische Untersuchungen, etwa auch geomagnetische Prospektionen, im Umfeld der bekannten Grabhügel folgen.

Neben der Frage der Siedlungen wurde auch die wirtschaftliche Grundlage der hallstattzeitlichen Siedler auf der Baar diskutiert. Prinzipiell geht man bei besiedelten Gunsträumen im oben genannten Sinne von Landwirtschaft und Bodennutzung als Grundlage aus. Die Lage am Westrand der Baar, in Sichtweite des Schwarzwalds, auf rund 700 m Höhe ließ jedoch bei den im Magdalenenberg Bestatteten die Frage aufkommen, ob nicht noch etwas Anderes die ökonomische Basis bildete. Konrad Spindler ließ daran keinen Zweifel: Der im Zentralgrab Bestattete sei ein „Eisenherr“ gewesen.[8] Funde von abgerundeten Geröllen in einigen Nachbestattungen des Magdalenenbergs deutete er als Schlegel, mit denen Eisenerz abgebaut worden wäre. Grundlage dieser Vermutung war die Existenz von Eisenerzgängen im nahen Schwarzwald, insbesondere aber im direkten Umfeld der Siedlung auf dem Kapf.[9] Dieses Erz war im Mittelalter abgebaut worden, für ältere Zeiten fehlte aber jeder Nachweis. Inzwischen haben Untersuchungen der vermeintlichen Geröllschlegel gezeigt, dass diese weder zum Abbau noch zum Zerkleinern von Eisenerz verwendet wurden. Auch ist die Qualität der hier anstehenden Erze bei weitem nicht so gut wie derjenigen im Nordschwarzwald – im Neuenbürger Revier – nachweislich im 5./4. Jh. v. Chr. abgebauten und verhütteten Erze.[10] Schließlich haben auch eigene Begehungen im dem Magdalenenberg nahegelegenen Schwarzwald, und hier insbesondere im Umfeld der Erzgänge von Eisenbach und Vöhrenbach, bisher keinerlei alte Schlacken erbracht. Somit ist zwar eine Verhüttung im geringen Umfang nicht auszuschließen, aber sie dürfte kaum für eine wirtschaftliche Blüte ausgereicht haben. Wichtigste Grundlage war daher wohl doch die Landwirtschaft mit ihren beiden Bestandteilen, dem Ackerbau und der Viehhaltung.[11]

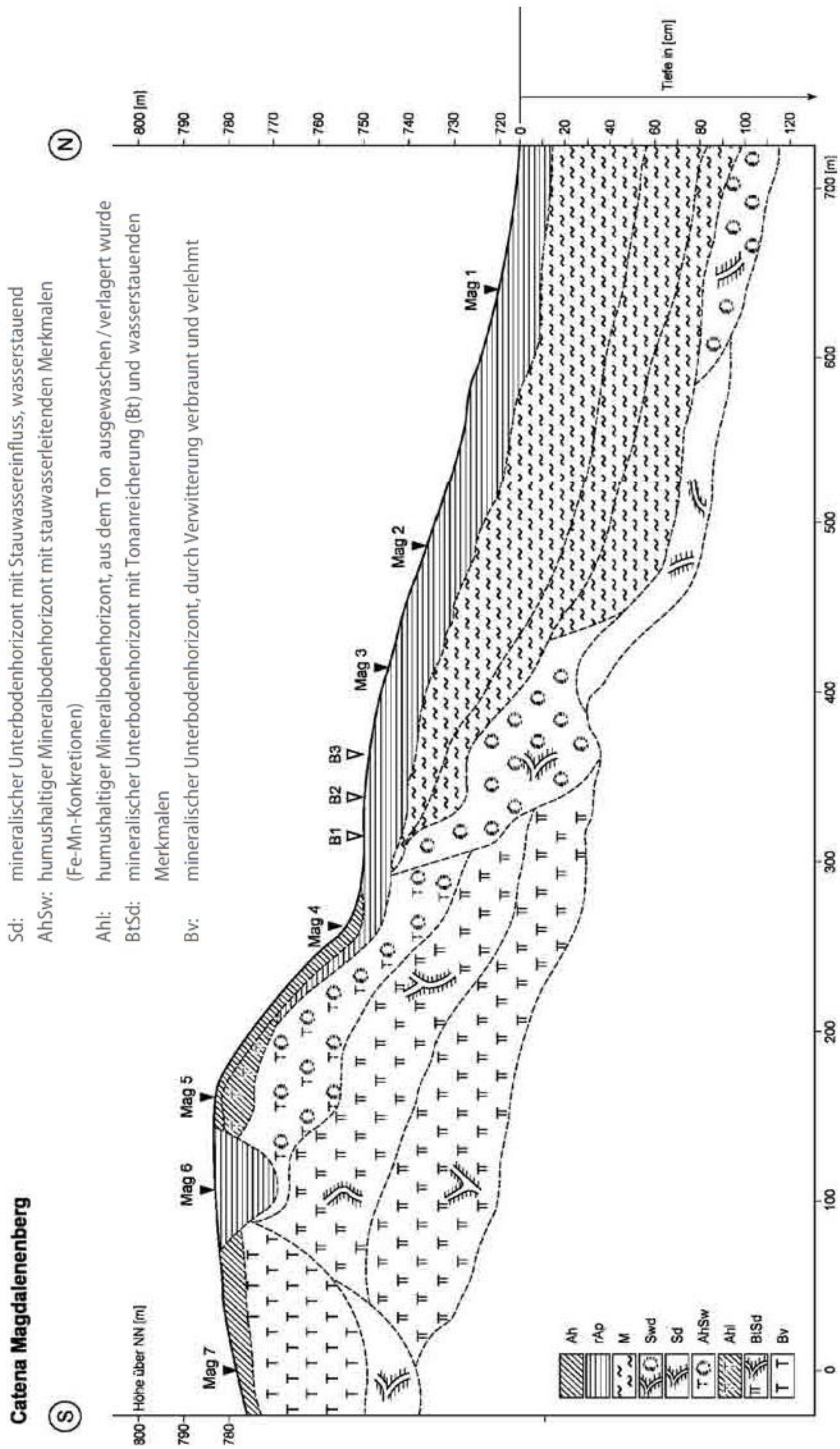

Fig. 4: Reihe von Bodenprofilen, sogenannte „Catena“ (lat. „Kette“), am Warenberg nahe des Grabhügels.

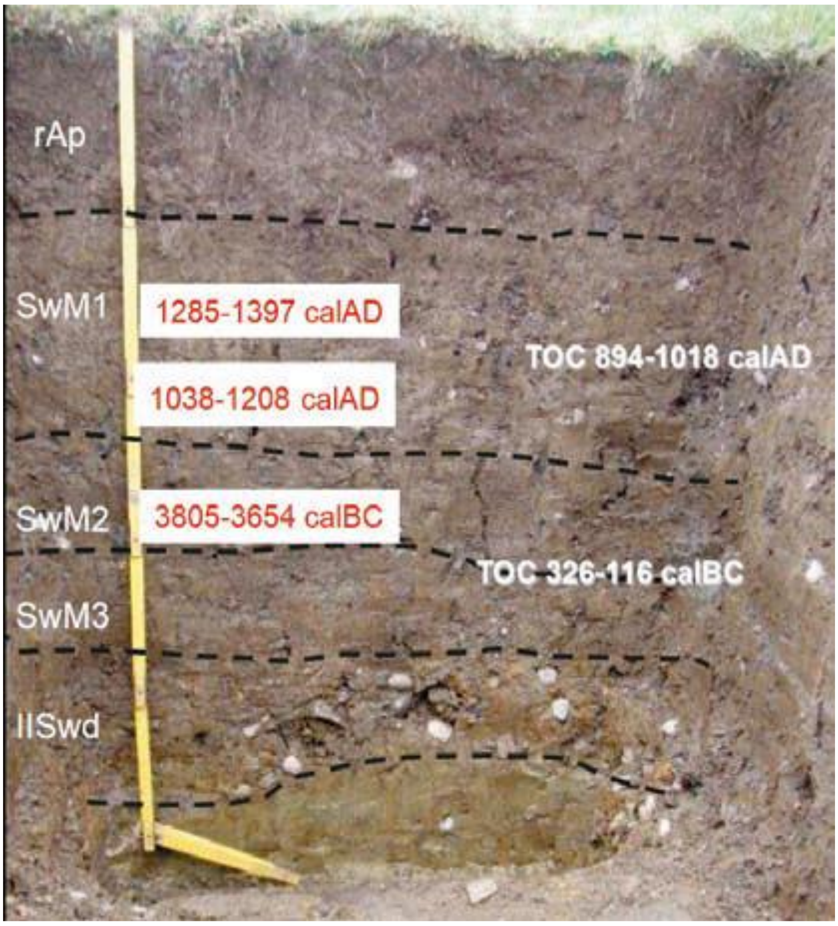

Fig. 5: Bodenkundliches Profil „Mag 1“ in der Warenbachaue mit Datierungen. Die Kolluvien erbrachten hier sowohl ein jungsteinzeitliches Datum aus dem 4. Jahrtausend v. Chr. als auch ein Datum aus der Jüngeren Eisenzeit (3.–1. Jahrhundert v. Chr.) und für die oberen Bereiche hochmittelalterliche Daten. In Rot sind Datierungen anhand von Holzkohlen angegeben, in Weiß Datierungen anhand der organischen Gesamtsubstanz (Total Organic Carbon). Erstere geben den Zeitpunkt der Entstehung des ehemaligen Holzes an, Letztere sind Mischdaten, da hier der gesamte Kohlenstoff datiert wird. Beides muss bei der Interpretation berücksichtigt werden.

Sollte eine intensive Landnutzung durch den Anbau von Feldfrüchten schon in der Urgeschichte stattgefunden haben, so müsste dies entsprechende Spuren hinterlassen haben. Von Anfang an waren deshalb archäopedologische Untersuchungen, d. h. bodenkundliche Forschungen im archäologischen Kontext, Bestandteil des Forschungsprojekts.[12] Begonnen wurde im engeren Umfeld des Magdalnenbergs. Schon durch erste Bohrungen mit einem einfachen 1-m-Bohrstock konnten Kolluvien nachgewiesen werden, d. h. Bodenmaterialien, die durch Wasser erodiert und am Mittelhang bis Unterhang wieder abgelagert wurden. Zudem zeigten Bohrungen, dass im Waldgebiet „Laible“ ein alter Ackerboden erhalten geblieben ist. Hier bestanden also in früherer Zeit Ackerflächen, deren Alter aber bisher unbekannt ist. Im Jahr 2010 wurde eine Reihe von Profilgruben (siehe Abbildung oben), beginnend im Wald hangabwärts zum Warenbach hin, angelegt. Das am tiefsten gelegene Profil lieferte etwa 80 cm mächtige kolluviale Schichten, die mittels 14C-Datierungen zeitlich eingeordnet wurden.

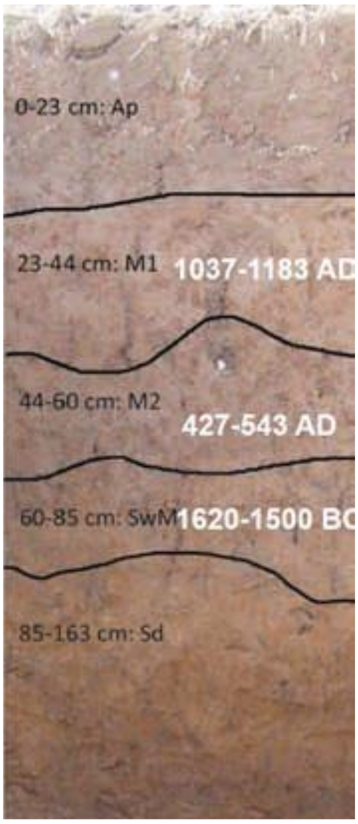

Fig. 6: Bodenkundliches Profil „Grü 8“ westlich von Grüningen, südlich der Nummer 8e, mit 14C-Datierungen in die späte Frühbronzezeit (17./16. Jh. v. Chr.), das Frühmittelalter (5./6. Jh. n. Chr.) und wiederum das Hoch- mittelalter (11./12. Jh. n. Chr.).

Durch die ^{14}C-Methode kann das Entstehungsalter von Hölzern oder Pflanzenresten ermittelt werden. Bei der Interpretation dieser Daten ist aber im Einzelfall zu entscheiden, ob entweder das Maximalalter für die Kolluvienentstehung oder die Bildungszeit der organischen Bodensubstanz (Humus) ermittelt wird. Wenn nämlich humusreiches Bodenmaterial (in der Regel zuerst die Krume) erodiert und am Unterhang wieder abgelagert wird, kann ältere organische Bodensubstanz im Zuge der Umlagerung eingemischt werden. Dann kann die ^{14}C-Datierung dieses eingemischten Materials zu einem höheren Alter führen als dem tatsächlichen der Kolluvienentstehung. Wenn aber, umgekehrt, dieser Erosions- und Akkumulationsprozess mehrfach stattfand und zu einer Stapelung von Kolluvien führt, so ist zu fragen, wie lange das jeweilige Kolluvium an der Oberfläche lag und durch Pflanzenbewuchs und Bodenlebewesen jüngeres humusreiches Material eingemischt werden konnte. In diesem Fall führt die 14C-Datierung der nachträglich eingemischten organischen Substanzen zu einem jüngeren Alter als dem tatsächlichen der Kolluvienentstehung.

Fig. 7: Ausgrabungsszene südwestlich des Magdalenenbergs. Fotos: Thomas Knopf

Ähnlich wie bei Scherbenfunden auf Äckern kann auch bei Kolluvienstandorten nicht von vornherein gesagt werden, welche ur- und frühgeschichtlichen bzw. mittelalterlichen Zeitabschnitte angetroffen werden. Bisher sind noch keine hallstattzeitlichen Kolluvien entdeckt worden, allerdings ist die Zahl der datierten Profile noch zu gering, um daraus allgemeine Schlüsse ziehen zu können. Hochinteressant bleibt indes die Tatsache, dass beginnend im Neolithikum, aber auch in der Bronze- und Eisenzeit und schließlich in allen mittelalterlichen Zeiten Kolluvien nicht nur auf der Baar, sondern auch im gesamten süddeutschen Raum entstanden.[13] Weitere archäopedologische Forschungen, wie die im Folgenden beschriebenen, können genauere Angaben an weiteren Standorten ermitteln.

Nach den Prospektionen des Jahrs 2010 standen für 2012 finanzielle Mittel für eine kleinere archäologische Ausgrabung im Umfeld des Magdalenenbergs zur Verfügung.[14] Vorausgegangen war eine Analyse von sogenannten LiDAR- Daten (Light Detection And Ranging). Die mittels Befliegung und Laserabtastung der Erdoberfläche gewonnenen digitalen Geländemodelle zeigen selbst flache, im Gelände selbst kaum mehr wahrnehmbare Strukturen relativ deutlich. So wurden auch in der Nähe des Magdalenenbergs auffällige Merkmale entdeckt. Im einen Fall scheint es sich um einen (Grab-?)Hügel zu handeln. Die Funktion eines langgestreckten, breiten, wallartigen Befundes konnte nur mit Hilfe einer archäologischen Untersuchung geklärt werden.[15]

Fig. 8: Archäologische Befunde und Steinplatten im Grabungsschnitt südwestlich des Magdalenenbergs.

Zunächst wurde mit einem Bagger ein etwa 1,2 m breiter und rund 30 m langer Schnitt angelegt. Da nach einem ersten Abtrag des Oberbodens keinerlei archäologische Strukturen zu entdeckten waren, wurde vorsichtig tiefer gegangen und bei ersten Anzeichen dunkler Verfärbungen von Hand weitergearbeitet. So wurde im hangabwärts gelegenen Bereich des Schnittes eine Reihe von archäologischen Befunden (Grube, Pfostengrube, Gräbchen) freigelegt, die allerdings keinerlei Fundmaterial enthielten und deshalb zunächst nicht zeitlich eingeordnet werden konnten. Im hangaufwärts gelegenen Teil des Grabungsschnittes wurde eine Art Steinpflasterung entdeckt. Meist trapezförmige, flache Steinplatten lagen häufig Stein an Stein, bildeten allerdings keinen durchgehenden Belag. Die Funktion dieser Steine erschließt sich nicht ohne weiteres. Allerdings könnte der obertägig sichtbare „Wall“ damit in Verbindung stehen. Dieser bildet nämlich keine von Menschen direkt errichtete Anlage, sondern ist als Kolluvium zu werten, wie die Schichten im Profil des Grabungsschnittes zeigten. Möglicherweise wurde das weiter oben am Hang erodierte Bodenmaterial an dieser Stelle im mittleren Hangbereich durch die hier liegende „Steinpflasterung“ gebremst und staute sich hier zu der wallartigen Struktur. Damit ist aber noch nichts über die ursprüngliche Funktion der Steine ausgesagt. Ihre Ausdehnung und genauere Interpretation könnten wohl nur durch größer flächige Ausgrabungen einer Klärung nähergebracht werden.

Die hier wie aus den beiden tieferen Kolluvien entnommenen Proben bzw. Holzkohlen wurden mit Hilfe der ^{14}C-Datierung beginnend im 6. Jt., der bandkeramischen Zeit, bis ins 3. Jt. v. Chr. datiert. Eine solche neolithische Besiedlung an dieser Stelle ist äußerst überraschend, sind doch die naturräumlichen Bedingungen nicht eben optimal. Unklar aber bleibt, ob es sich um Siedlungsspuren handelt oder ob die Gruben und Gräbchen andere Funktionen hatten. Im Zusammenhang damit steht sicher ein vor einigen Jahren in der Nähe gefundenes neolithisches Steinbeil (heute im Franziskanermuseum Villingen-Schwenningen). Sicher ist, dass die Befunde z. T. durch Erosion abgetragen, später dann aber von Kolluvien überdeckt wurden. Aus den beiden unteren Kolluvienschichten liegen

^{14}C-Datierungen aus dem 3. Jt. v. Chr. und der späten Bronzezeit (1200–800 v. Chr.) vor.[16] Zwar wurde die Frage nach der hallstattzeitlichen Nutzung des Geländes noch nicht beantwortet, doch haben die unerwarteten Befunde neue Fragen aufgeworfen. Die Baar scheint jedoch, auch in ihren Randlagen, schon sehr früh intensiv ackerbaulich genutzt worden zu sein.

Inwiefern diese frühen Bewohner der Baar von hier aus auch in den Schwarzwald und auf die Schwäbische Alb ausgriffen, wird in einem zweiten Forschungsprojekt untersucht, das unter dem Titel „Gunst / Ungunst: Ressourcenerschließung in Marginalräumen" gemeinschaftlich von Archäologen und „RessourcenKulturen" durchgeführt wird.[17] Dabei werden Ressourcen als Mittel der Etablierung, Erhaltung und Veränderung sozialer Beziehungen in unterschiedlichen Zeiten und Regionen untersucht, wobei Ressourcen hier nicht nur materiell, als Rohstoffe wie Holz oder Erz, verstanden werden, sondern auch immateriell, etwa als Wissen oder religiöse Praktiken. Alle diese Ressourcen, auch die materiellen, sind aber zunächst kulturell definiert, werden also erst zur Ressource, wenn sie entsprechend wahrgenommen werden. Beispielsweise spielte im Mittelalter Schweröl keine Rolle und war in diesem Sinne keine Ressource, obwohl Fundstätten bekannt waren. Seit dem 19. Jahrhundert aber ist Schweröl ein Grundstoff der chemischen Industrie und wesentlicher Energieträger und wird so als Ressource wahrgenommen.

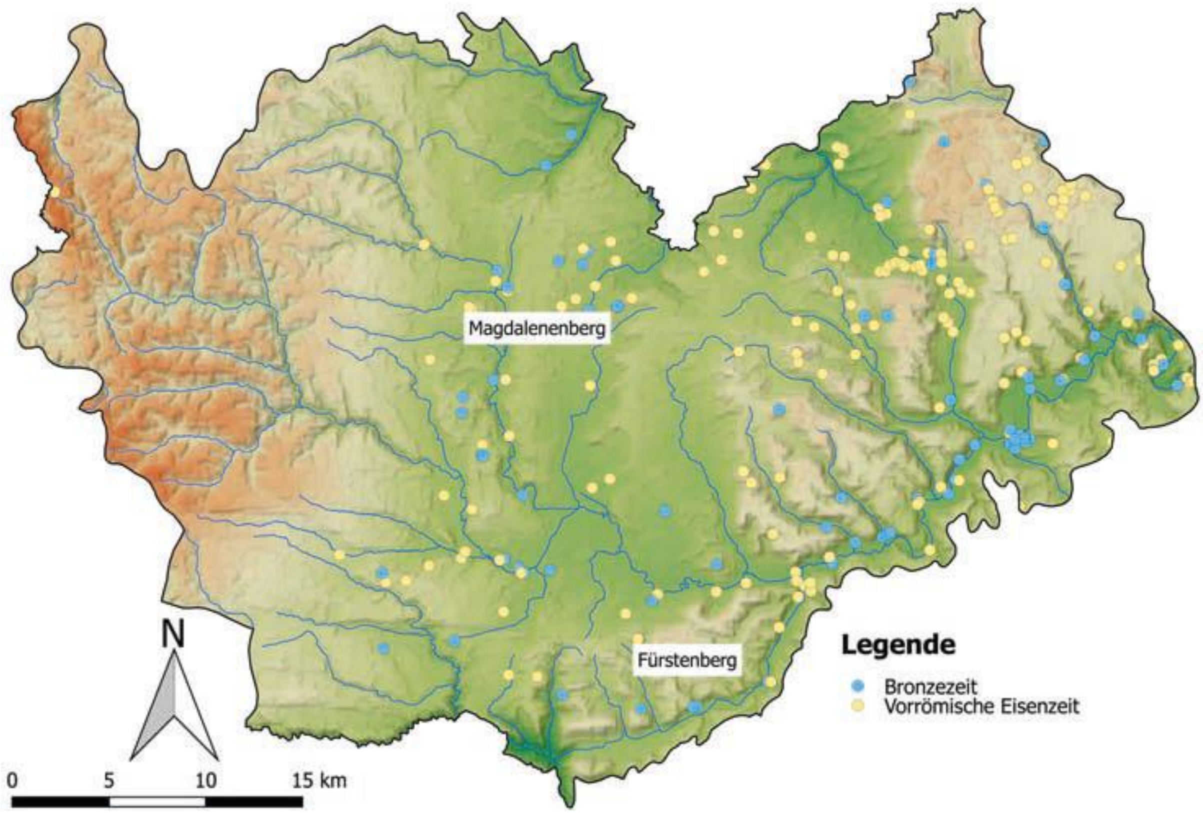

Fig. 9: Archäologische Fundstellen der Bronze- und vorrömischen Eisenzeit. Kartierung: Jan Ahlrichs.

Die Frage, warum sich Menschen zu bestimmten Zeiten aus günstigen – und daher schon seit dem Neolithikum intensiv besiedelten Räumen – in weniger günstige Räume begeben haben, um dort zu siedeln bzw. bestimmte Ressourcen zu nutzen, wurde lange Zeit durch eine sogenannte „Klimahypothese“ beantwortet, nach der in wärmeren Perioden auch die eher ungünstigeren Räume für eine dauerhafte Nutzung geeignet gewesen seien. Dagegen geht die im Rahmen des Sonderforschungsbereiches „RessourcenKulturen“ diskutierte „Ressourcenhypothese“ davon aus, dass auch kulturell geprägte Vorstellungen von Räumen und Ressourcen bzw. der Bedarf nach bestimmten Ressourcen in den Gunsträumen dafür gesorgt haben, dass Menschen die zuvor als ungünstig erachteten Gebiete besiedelten.

Im Vordergrund des Teilprojekts B02 steht die Ressource Boden. Die Nutzung des Bodens mit entsprechenden Bodenbearbeitungstechniken und die partielle Entwaldung führten meist zu Bodenverlagerungen und zur Bildung von Kolluvien, die nach aufeinander folgenden Erosionsphasen überwiegend in konkaven Hangfußbereichen[18] oder als Dellen- und Talfüllungen anzutreffen sind. Phasen der Kolluvienbildung können mit Besiedlungsphasen und Phasen der agrarischen Nutzung zeitlich korreliert werden.[19]

Infolge des engen räumlichen Zusammenhangs von Abtrags- und Auftragsfläche ermöglicht die Analyse von Kolluvien die präziseste zeitliche Einordnung von Erosionsereignissen.

Anhand einer Korrelation von kolluvialen Archiven als Anzeiger von Landnutzungsphasen mit einer ressourcenbezogenen Besiedlungsgeschichte der Baar sowie des angrenzenden Schwarzwalds und der westlichen Schwäbischen Alb sollen Klima- und Ressourcenhypothesen geprüft werden. Hinzu kommen archäobotanische Untersuchungen an Pollen aus Mooren des Schwarzwalds und der Baar. Gerade für den Schwarzwald, über dessen frühe Besiedlung wir vergleichsweise wenig wissen, kann die Untersuchung der Vegetation und ihrer Veränderungen Einblicke in die Landnutzungs- und Besiedlungsgeschichte geben. Erste Beprobungen haben bereits stattgefunden.

Für die Rekonstruktion der Besiedlungsgeschichte der drei Regionen wurden alle bekannten archäologischen Fundstellen in eine Datenbank aufgenommen, die eine Auswertung nach Zeiten und Räumen, auch Kleinregionen, erlaubt. Durch moderne Geographische Informationssysteme (GIS) können die Fund- plätze mit Karten aller Art korreliert werden und Beziehungen hergestellt werden, etwa zwischen den Siedlungen der Bronzezeit und den Gewässern oder den besten Ackerböden in der Region. Die Analyse der Fundstellen und ihrer Verbreitung zu unterschiedlichen Zeiten soll zeigen, wann und wo ein Ausgreifen von der Baar in die benachbarten Räume stattgefunden hat. Dabei sind stets auch quellenbedingte Lücken der Überlieferung und der Auffindung zu berücksichtigen, denn Funde können zerstört, überdeckt oder überbaut werden, und die Tätigkeit von Sammlern und ehrenamtlichen Beauftragten der Denkmalpflege kann dazu führen, dass ganze Fundlandschaften erst entstehen oder auch unentdeckt bleiben.

Parallel zu den archäologischen und archäobotanischen Untersuchungen werden auch archäopedologische Untersuchungen in der Nähe von archäologischen Fundstellen durchgeführt, da davon auszugehen ist, dass im Umfeld ur- und frühgeschichtlicher Siedlungen auch agrarische Tätigkeiten stattfanden und zu Erosion und Kolluvienbildung geführt haben. Zuerst wurden weitere Profile in der Nähe des Magdalenenbergs angelegt. Zusätzlich zu den beschriebenen, im Rahmen des DFG-Projektes 2010 durchgeführten Datierungen mit der ^{14}C-Methode wurden auch

Proben für die sogenannte Lumineszenzdatierung entnommen, um die genannten Unsicherheiten der ^{14}C-Datierung einzugrenzen und um Bodenmaterial zu datieren, dass gar keine organischen Reste oder Humus enthält.

Fig. 10: Bodenkundliches Profil westlich von Grüningen (etwa zwischen Nr. 8b und 8c). Foto: Jessica Henkner.

Mit der Lumineszenzmethode kann der Zeitraum datiert werden, in dem ein Sediment zum letzten Mal belichtet wurde, d. h. der Sonnenstrahlung ausgesetzt war. Dies funktioniert auch für Kolluvien, da während des Umlagerungsprozesses das Bodenmaterial, wenn auch nur kurzzeitig, der Sonne ausgesetzt wird. Dies reicht, um die „Lumineszenzuhr auf Null zu stellen“. Werden die zu datierenden Minerale (Quarz oder Feldspäte) wieder überdeckt, fängt die Lumineszenzuhr an zu „ticken“. Wenn bei der Beprobung kein Licht oder andere Energie (z. B. Hitze) zugeführt wird, kann damit der Bildungszeitraum für das Kolluvium ermittelt werden.[20] Aus den zu erwartenden Datierungen der Erosionsphasen im Umfeld des Magdalenenbergs werden möglicherweise die eisenzeitlichen Nutzungen des Geländes – neben dem hallstattzeitlichen Grabhügel ist in geringer Entfernung eine mittel- bis spätlatènezeitliche Siedlung bekannt – besser verständlich.

Im Rahmen des SFB 1070 konnte das Umfeld der durch das DFG-Projekt von 2010 entdeckten Fundplätze westlich von Grüningen einer intensiveren archäopedologischen Analyse unterzogen werden. Dazu wurden bereits untersuchte Profile noch einmal geöffnet und detaillierter – und diesmal auch für die Lumineszenzdatierung – beprobt, aber auch, wie hier zu sehen, neue, große und tiefe Bodenprofile in einer Senke angelegt, die mehrere Meter mächtige Kolluvien mit zwischengeschalteten Lagen von Steinen erbrachten.

Als Untersuchungsort wurde auch der Fürstenberg ausgewählt, dessen Besiedlungsgeschichte durch die Ergebnisse der in den letzten Jahren durchgeführten Begehungen auf dem gesamten Berg sowie Magnetprospektionen auf dem Plateau recht klar nachvollzogen werden kann.[21] Sowohl die früheste Besiedlung im Jungneolithikum als auch weitere Phasen in der Urnenfelder- und Hallstattzeit sind belegt. Danach folgte noch eine römische Besiedlung, bevor dann im Hochmittelalter die intensive Überbauung begann. Somit kann ein hervorragender Abgleich mit den Landnutzungsphasen, wie sie in den Kolluvien in Erscheinung treten, durchgeführt werden. Rund 15 mit dem Bagger angelegte Profile am Südhang und auch Nordhang belegen mächtige Kolluvienschichten von bis zu 2 m Mächtigkeit nicht nur am Unterhang, sondern auch in Mittelhangpositionen.

Auch die Region um Spaichingen ist Ausgangspunkt für weitere Untersuchungen. Über Lesefunde von Scherben hatte HERMANN STOLL hier in den 1930- er-Jahren im Rahmen der archäologischen Landesaufnahme eine Reihe vor allem hallstattzeitlicher Siedlungen entdeckt, die er als „Reste kleiner Einzelhöfe“ oder „mehrere Höfe dicht beieinander“ bezeichnete.[22] Da auch Fundstellen aus anderen Zeiten bekannt sind, gibt es gute Ansatzpunkte zum Abgleich von Funden und Erosionen bzw. Kolluvien.

Die vergleichende Gegenüberstellung von archäologischem Siedlungsbild und Phasen der Kolluvienbildung infolge intensiver und / oder länger dauernder Bewirtschaftung soll Hinweise auf die Nutzung der Ressource Boden über die Zeiten hinweg liefern. Dabei kann auch eine Korrelation mit Klima- kurven erfolgen, um herauszufinden, inwiefern wärmere oder feuchtere Zeitabschnitte mit verstärkter Kolluvienbildung einhergingen. Auch in den der Baar benachbarten Gebieten von Schwarzwald und Alb werden solche archäopedologischen Forschungen in den nächsten beiden Jahren durchgeführt werden. Hier wird es dann im Abgleich mit den auf der

Baar ermittelten Ergebnissen sowohl um die Korrelation mit dem Klima gehen als auch, besonders im Schwarzwald, um die Frage der frühen Besiedlung, die ihren Ausgangspunkt auf der Baar gehabt haben könnte. Vor wenigen Jahren wurden am Fuße des Krumpenschlosses bei Hammereisenbach Kolluvien gefunden, die auf eine Entstehung noch vor der Erschließung des Schwarzwalds durch die Klöster hindeuten.23 Durch die neue Auswertung lassen sich möglicherweise noch weitere Belege für vormittelalterliche Erosionsprozesse infolge einer ur- und frühgeschichtlichen Nutzung finden.

Fig. 11: Bodenkundliches Profil am Südhang des Fürstenbergs. Foto: Jessica Henkner

Autoren

PD DR. THOMAS KNOPF, geb. 1966, ist Privatdozent und wissenschaftlicher Angestellter am Institut für Ur- und Frühgeschichte und Archäologie des Mittelalters an der Eberhard Karls Universität Tübingen. Zugleich ist er wissenschaftlicher Angestellter am Landesamt für Denkmalpflege im DFG- Forschungsprojekt „Südschwarzwald“. Seine Forschungsschwerpunkte sind Sied- lungs- und Umweltarchäologie, Eisenzeit, Keramikforschung und Archäologie Japans. thomas.knopf@uni-tuebingen.de

Prof. Dr. rer. nat. THOMAS SCHOLTEN, geb. 1960, ist Professor für Bodenkunde und Geomorphologie an der Eberhard Karls Universität Tübingen (www.geo.uni-tuebingen.de/soilscience). Forschungsschwerpunkte sind Bodenerosionsforschung und Bodenverbreitung. Thomas Scholten hat in Europa, Zentralasien und im südlichen Afrika geforscht sowie verschiedene internationale Verbundprojekte koordiniert. Er ist Präsident der Deutschen Bodenkundlichen Gesellschaft und in namhaften Organisationen und Gremien beratend tätig. thomas.scholten@uni-tuebingen.de

Dr. rer. nat. PETER KÜHN, geb. 1964, ist Leiter des Labors für Bodenkunde und Geoökologie des Forschungsbereichs Geographie an der Eberhard Karls Universität Tübingen (www.geo.uni-tuebingen.de/soilscience). Forschungsschwerpunkte sind Archäopedologie, Bodengenese, Paläopedologie und Mikromorphologie (www.researcherid.com/rid/A-9146-2009). peter.kuehn@uni-tuebingen.de

JAN J. AHLRICHS M.A., geb. 1987, ist Doktorand im Sonderforschungsbereich 1070

„RessourcenKulturen“ an der Eberhard Karls Universität Tübingen (www.sfb1070.uni-tuebingen.de). Forschungsschwerpunkte sind Siedlungs- und Landschaftsarchäologie in Mittelgebirgen sowie Farbstoffe in ur- und frühgeschichtlicher Zeit. Er betreibt die Webseite www.praehistorische-archaeologie.de. jan.ahlrichs@uni-tuebingen.de

JESSICA HENKNER M.Sc., geb. 1987, ist Doktorandin im Sonderforschungsbereich 1070 „RessourcenKulturen“ an der Eberhard Karls Universität Tübingen (www.sfb1070.uni-tuebingen.de). Forschungsgebiete sind die Archäopedologie, besonders Kolluvien als terrestrische Archive, und Permafrostböden. jessica.henkner@uni-tuebingen.de

Anmerkungen

1 S. LAZAR / K. RILLING: Die Böden der Baar.
In: A. Siegmund (Hrsg.). Faszination Baar. Porträts aus Natur und Landschaft. Donaueschingen 2006, 17–57.

2 Die Untersuchungen wurden 2010 im Rahmen eines Forschungsprojektes von der Deutschen Forschungsgemeinschaft (DFG) finanziell gefördert. Eine weitere Bewilligung erlaubte die unten beschriebene Ausgrabung im Jahr 2012. Den zuständigen Gutachtern sowie Herrn Dr. H.-J. Bienert sei an dieser Stelle gedankt.

3 WOLFGANG HÜBENER: Die hallstattzeitliche Siedlung auf dem Kapf bei Villingen im Schwarzwald. In: KONRAD SPINDLER: Magdalenenberg II. Der hallstattzeitliche Fürstengrabhügel bei Villingen im Schwarzwald 2 (Villingen 1972) 51–90.

4 HÜBENER ebd., 90; K. SPINDLER: Der Magdalenenberg bei Villingen. Ein Fürstengrabhügel des 7. vorchristlichen Jahrhunderts. Führer Arch. Denkmäler Baden-Württemberg 52 (Stuttgart 1999) 31.

5 SIEGFRIED KURZ: Untersuchungen zur Entstehung der Heuneburg in der späten Hallstattzeit. Forsch. u. Ber. Vor- u. Frühgesch. Baden-Württemberg 105 (Stuttgart 2007), I. BALZER: Die Erforschung der Siedlungsdynamik im Umfeld des frühkeltischen Fürstensitzes Hohenasperg, Kr. Ludwigsburg, auf archäologischen und naturwissenschaftlichen Grundlagen. Mit einem Nachtrag „Zu den Anfängen des Projektes“ von JÖRG BIEL. In: D. KRAUSSE /CH. STEFFEN (Hrsg.): Frühe Zentralisierungs- und Urbanisierungsprozesse. Zur Genese und Entwicklung frühkeltischer Fürstensitze und ihres territorialen Umlandes. Kolloquium des DFG-Schwerpunktprogrammes 1171 in Blaubeuren, 9.–11. Oktober 2006. Forsch. u. Ber. Vor- u. Frühgesch. Baden-Württemberg 101 (Stuttgart 2008) 143–161.

6 HÜBENER ebd., 89.

7 Siehe dazu auch THOMAS KNOPF: Neue Forschungen im Umland des Magdalenenbergs. In: C. TAPPERT /CH. LATER / J. FRIES-KNOB- LACH / P. C. RAMSL/P. TREBSCHE / S. WEFERS / J. WIETHOLD (Hrsg.): Wege und Transport. Beitr. Sitzung AG Eisenzeit Nürnberg 2010. Beiträge zur Ur- und Frühgeschichtlichen Archäologie Mitteleuropas 69 (Langenweißbach 2012) 209–220.

8 SPINDLER 1999 a.a.O. 31. Siehe etwa MICHAEL BLIEDTNER /MANFRED MARTIN: Erz- und Minerallagerstätten des Mittleren Schwarzwaldes: Eine bergbaugeschichtliche und lagerstättenkundliche Darstellung (Freiburg 1986).

10 Freundliche Auskunft Dr. G. Gassmann, Tübingen.

11 Siehe auch THOMAS KNOPF: Siedlungswesen und Wirtschaft der Hallstattzeit auf der Baar. In: A. BRÄUNING / W. LÖHLEIN /

S. PLOUIN (Hrsg.): Die frühe Eisenzeit zwischen Schwarzwald und Vogesen. Arch. Inf. Baden-Württemberg 66 (Freiburg 2012) 52–59.

12 Vgl. PETER KÜHN: Archäopedologie. In: S. BRATHER / M. JAGODZISKI: Der wikingerzeitliche Seehandelsplatz von Janów Pomorski (Truso?). Geomagnetische, bodenkundliche und archäologische Untersuchungen 2004–2006. Zeitschrift für Archäologie des Mittelalters, Beiheft 24 (2012) 48–68; DANA PIETSCH /PETER KÜHN. Buried Soils in the Context of Geoarchaeological Research. Archaeological and Anthropological Sciences 2014. doi: 10.1007/s12520-014-0180-9

13 A. LANG: Phases of Soil Erosion-Derived Colluviation in the Loess Hills of South Germany. Catena 51,3–4, 2003, 209–221. doi: 10.1016/S0341-8162(02)00166-2.

14 Den Kolleginnen und Kollegen der Denkmalpflege am Regierungspräsidium Freiburg und Esslingen sei für die Unterstützung herzlich gedankt.

15 Dem Landwirt Clemens Hettich sei für die Erlaubnis, auf der von ihm gepachteten Wiese die Ausgrabung durchzuführen, herzlich gedankt. In diesen Dank eingeschlossen seien auch die Verantwortlichen der Stadt Villingen-Schwenningen, die mit mancherlei Unterstützung aushalfen. Die Fa. Bisswurm stellte darüber hinaus einen Bagger zur Verfügung. Auch dafür sei hier gedankt.

16 Vorbericht zur Grabung: THOMAS KNOPF: Archäologische Untersuchungen auf der Baar: das Umland des „Fürstengrabhügels“ Magdalenenberg. Archäologische Ausgrabungen in Baden-Württemberg 2012 (Stuttgart 2013) 116–121.

17 Die Deutsche Forschungsgemeinschaft (DFG) unterstützte die Arbeiten im Rahmen des Teilprojektes B02 „Gunst / Ungunst: Erschließungsprozesse und Ressourcennutzung in Marginalräumen“ im SFB 1070 RessourcenKulturen, der an der Eberhard Karls Universität Tübingen angesiedelt ist (http://www.sfb1070.uni-tuebingen.de). Wir möchten uns bei den Landwirten bedanken, die uns bei den Geländearbeiten im Jahr 2013 sehr unterstützt haben. Dies sind am Magdalenenberg Herr Hettich, Herr Glatz, Herr Gross, Herr Weber und Herr Hog. Bei Grüningen unterstützen uns die Landwirte Herr Bucher von der Betriebsgemeinschaft Stellenhof und Herr Doser. Am Fürstenberg bedanken wir uns bei Herrn Mayer, Herrn W. Bäurer, Herrn C. Bäurer, Herrn Martin, Herrn Preis, Herrn Rothmund, bei dem Ortsvorsteher Herr Hogg und Herrn Weißhaar für die zusätzlichen Informationen. Ein weiterer Dank für die Unterstützung geht an die Kollegen der Denkmalpflege in Freiburg und Esslingen.

18 H.-R. BORK / H. BORK / C. DALCHOW /

B. FAUST / H.-P. PIORR / T. SCHATZ: Land- schaftsentwicklung in Mitteleuropa – Wirkungen des Menschen auf Landschaften (Gotha 1998); A. J. KALIS / J. MERKT /J. WUNDERLICH: Enviromental Changes During the Holocene Climate Optimum in Central Europe – Human Impact and Natural Causes. Quaternary Science Reviews 22, 2003, 33–79.

19 S. DREIBRODT / J. LOMAX /O. NELLE /C. LUBOS / P. FISCHER / A. MITUSOV / S. REISS / U. RADTKE / M. NADEAU / M. GROOTES /H. R. BORK. Are Mid-Latitude Slopes Sensitive to Climatic Oscillations? Implications from an Early Holocene Sequence of Slope Deposits and Buried Soils from Eastern Germany. Geomorphology 122, 2010,

351–369; M. LEOPOLD / J. VÖLKEL: Colluvium: Definition, Differentiation, and Possible Suitability for Reconstructing Holocene Climate Data. Quaternary International 162/163, 2007, 133–140.

20 M. A. GEYH: Handbuch der physikalischen und chemischen Altersbestimmung (Darmstadt 2005).

21 HEIKO WAGNER /BERTRAM JENISCH. Der Fürstenberg – keltische Siedlung, Grafensitz, Kleinstadt. Archäologische Ausgrabungen in Baden-Württemberg 2011 (Stuttgart

2012) 49–53; HEIKO WAGNER: Von der Steinzeit zur Stadt. Neue Forschungen zur Besiedlungsgeschichte des Fürstenbergs. Schriften des Vereins für Geschichte und Naturgeschichte der Baar 57, 2014, 33–62.

22 Fundberichte aus Schwaben N. F. 8,

1933–1935, 81; H. STOLL / P. GEHRING: Vor- und frühgeschichtliche Karte von Rottweil und Umgebung (Stuttgart 1938).

23 THOMAS KNOPF /TILMANN BAUM /PETER KÜHN /THOMAS SCHOLTEN: Landnutzung im Frühen Mittelalter? Eine archäopedologische Untersuchung im Mittleren Schwarzwald. Archäologisches Korrespondenzblatt 42, 2012, 123–133.

Manuscript VI

Archaeological and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory

A Case Study from the Western Baar, SW Germany

Ahlrichs, Jan [1, 2]; Henkner, Jessica [1, 3]; Teuber, Sandra [1, 3]; Schmidt, Karsten [1, 3]; Scholten, Thomas [1, 3]; Kühn, Peter [1, 3]; Knopf, Thomas [1, 2]

In: Kolodziejczyk, Piotr; Kwiatkowska-Kopka, Beata 2016: Landscape as impulsion for culture: research, perception & protection. *Landscape in the past & forgotten landscapes* 2, 39–49.

[1] SFB1070 ResourceCultures, Gartenstr. 29, 72074 Tübingen, Germany

[2] Institute for Pre- and Protohistory and Medieval Archaeology, Eberhard Karls University Tübingen, Burgsteige 11, Schloss Hohentübingen, 72070 Tübingen, Germany

[3] Department of Geosciences, Soil Science and Geomorphology, Eberhard Karls University Tübingen, Rümelinstrasse 19-23, 72070 Tübingen, Germany

Abstract

The first results of an interdisciplinary research project are discussed: It explores the pre- and early historic settlement dynamics between favorable and unfavorable landscapes in SW Germany using an integrated archaeological/ archaeopedological approach with a focus on colluvial deposits. The study area extends from the eastern slopes of the Black Forest across the Baar to the southwestern part of the Swabian Jura. We provide evidence for continuous land use at the boundary of the Black Forest from the Younger Neolithic onwards. Land use even in gentle rolling areas such as the Baar triggered soil erosion leading to a coverage of archaeological sites with younger sediments at foot-slope and mid-slope positions. We detected phases of land use during the transition from the early to the middle Bronze Age and the Roman period – for which no archaeological indications were available so far. Our combination of different disciplines appeared as a major advantage for the exploration of low mountain areas. Our results also question the commonly held notion, according to which modern marginal areas were perceived as marginal areas in prehistory as well.

1 Introduction

The Black Forest is one of the most famous examples of low mountain ranges, which are commonly the classic marginal areas in Central Europe (Denecke 1992: 9–10). It is the largest and highest low mountain range in Germany. Considering the natural conditions and the historical records, since the early 19th century it was a general agreement that the Black Forest was not continuously inhabited before the High Middle Ages (Brückner 1980: 159–160; Sick 1992; Schaab 2003: 7–12). Thus the Black Forest was thought to have been the last marginal landscape in SW Germany to be settled. Hence it is called “Jungsiedelland”, i.e. late-settled landscape (Gradmann 1948; Gradmann 1964a: 56–89).

This view was generally supported by archaeologists until the 1990s, arguing that the Black Forest was an impenetrable primeval forest, which people avoided whenever they had the chance to do so. Archaeological finds were either ignored or interpreted as evidence of occasional expeditions (Wahle 1973: 6, 10; Sick 1992: 49–53; Schaab 2003: 5–8). Often demographic pressures and conflicts were hypothesized of being the main triggers for enforced movements into the Black Forest (Kullen 1989: 42–43; Schmid 1991: 80–81). However, until the 1990s, no field surveys were conducted to test this hypothesis (Valde-Nowak and Kienlin 2002: 40).

In the early 1990s excavations of Mesolithic open air sites provided evidence for early human presence in the Northern Black Forest (Pasda 1994). They also show that the visibility of the archaeological sites is restricted in low mountain ranges, on the slopes by dense forests and in the valleys due to recent deposits (Pasda 1998). When systematic field surveys were carried out on the western side of the Black Forest in 1999 and 2000, numerous Mesolithic and Neolithic sites were located (Valde-Nowak and Kienlin 2002; Kienlin and Valde-Nowak 2004). Archaeobotanical studies provide additional evidence for early anthropogenic activities in the Neolithic and an unambiguous land use in the following Bronze and Iron Ages in the Northern Black Forest (Rösch 2009; Rösch et al. 2009). It was also possible to connect the land use from the Latène period to the extraction and smelting of iron ores (Gassmann et al. 2006). In addition pollen profiles and alluvial clay deposits are known from the Middle Black Forest holding out the prospect of land use during the Bronze and Iron Ages in this area (Häbich et al. 2005; Sudhaus et al. 2008). Knopf et al. (2012) were able to demonstrate the research potential of colluvial deposits, which provided evidence for intensive land use in the 9th–10th century AD on the east-facing slopes in the Middle Black Forest. Colluvial deposits are the correlate sediments of soil erosion at the base of hill slopes implying considerable human impact on the landscape (Kadereit et al. 2010). They function as archives and can be studied in order to assess the anthropogenic influence on soil, topography and vegetation, i.e. to reconstruct the landscape (Leopold and Völkel 2007; Vogt 2014).

The research from the last two decades opens the demand for a reassessment of the theoretical concepts of marginal and late-settled areas, since these areas were settled earlier than commonly assumed (Andersson 1998; Coles and Mills 1998; Svensson and Gardiner 2009; Holm et al. 2009; Schreg 2014). In this paper we describe two soil profiles on the western Baar and correlate their colluvial stratification with the archaeological record in order to investigate the continuity of the pre- and early historic land use in this region.

2 Research project and study area

The interdisciplinary research project “Favour – Disfavour? Resource development in marginal areas” is within the framework of the Tübingen CRC 1070 “Resource Cultures” (Bartelheim et al. 2015). We use methods from archaeology and soil science in order to investigate pre- and early historic settlement dynamics between favourable and unfavourable regions. One of the objectives is to decipher the period of times during which these regions were developed and what resources were involved in this process. The project seeks to overcome traditional narratives such as conflict situations, demographic pressures and climatic changes as main triggers for movements into unfavourable regions.

The study area extends from the eastern slopes of the Middle Black Forest across the Baar to the south-western part of the Swabian Jura. Due to its continental climate, fertile soils and low terrain intensity the Baar is considered as an old-settled landscape, i.e. “Altsiedellandschaft”. With reference to the agricultural potential of the Baar, both the Black Forest and the Swabian Jura represent unfavourable landscapes, characterized by high annual precipitation (750–1000 mm), low temperatures (4–7 °C) and infertile soils (Siegmund 1999; Kösel and Rilling 2002). Winter and frost periods last several weeks longer compared to the Baar region (Gradmann 1964b: 48–87). Steep slopes and acidic soils are typical for the Black Forest, whereas the high plateau of the Swabian Jura is a landscape mainly dominated by Karst, hence water storage is restricted (Gradmann 1964b: 265–319).

2.1 Research methods

For the archaeological investigation of the study area a database was set up in 2014, based on local archaeological records from State Office for Cultural Heritage Baden-Württemberg and a literature review. It contains 1826 sites covering the period from the early Holocene until the 12th century AD. This database was used to select locations for the investigation of colluvial deposits in the study area. Pieces of charcoal from the colluvial deposits were used for AMS radiocarbon dating. These ^{14}C ages provide the maximum age of colluvial deposition. Since the locations for the pedological investigations were selected on the basis of archaeological data, we are able to discuss the ^{14}C ages of the colluvial sediments on a regional level. However, it is difficult to determine the exact kind of land use strategies, which triggered the formation of the colluvia. Thus the term “land use” cannot be specified here.

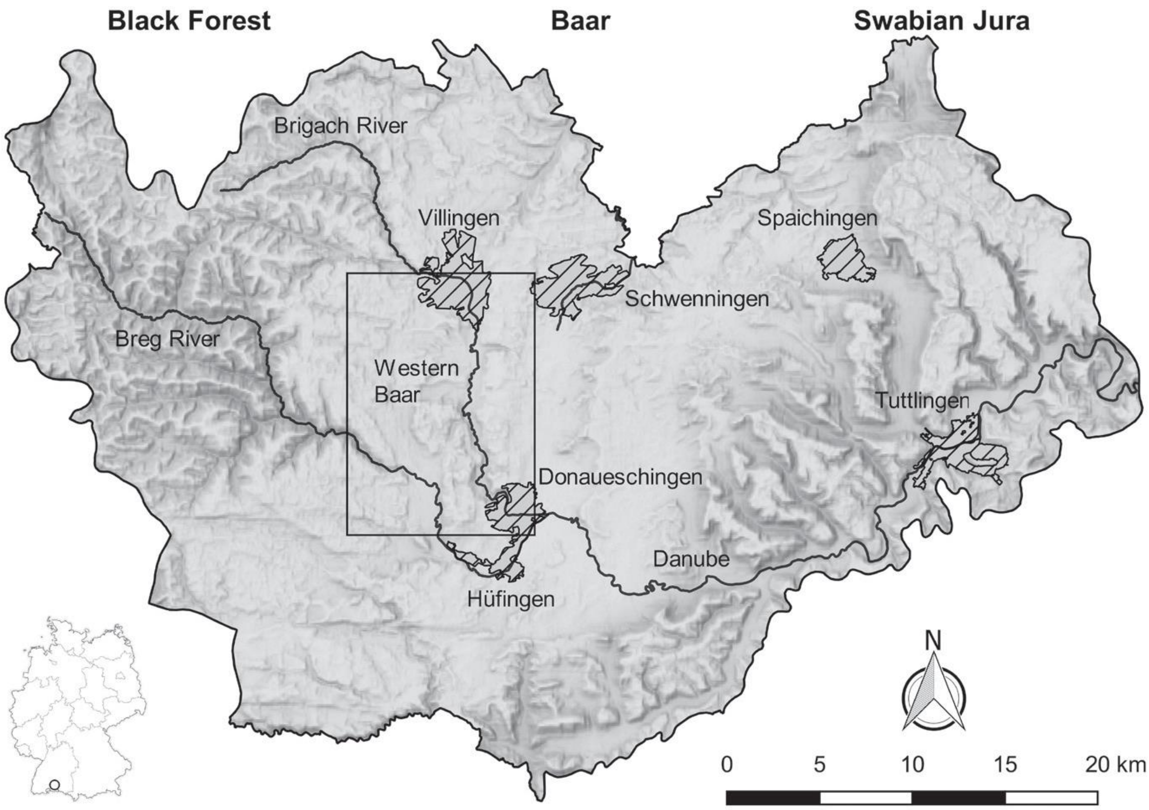

Fig. 1: Study area of the research project "Favour – Disfavour? Resource development in marginal areas".

2.2 Archaeological research in the Baar

In the second half of the 19th century the topographer E. Paulus conducted field surveys in the study area. He was able to map several hitherto unknown prehistoric burial mounds as well as farmsteads and roads from the Roman period (Paulus 1882). At the beginning of the 20th century a comprehensive catalogue of the known prehistoric and early historic finds was published (Wagner 1908). After the First World War, P. Revellio led the archaeological research in the Baar until the 1950s. He collected material at construction sites and carried out rescue excavations as well as field surveys (Revellio 1932; Schmid 1991: 22). Between 1932 and 1935 H. Stoll carried out field surveys in the vicinity of Spaichingen and on the high plateau of the Swabian Jura (Stoll and Gehring 1938). In addition, he wrote a manuscript about the prehistory of the Baar, which was not published due to his early death (Goessler 1948: 442). In the mid-1930s E. Fischer discussed the distribution of the prehistoric sites in relation to the favorable and unfavorable conditions of the natural environment (Fischer 1936). On the occasion of the excavation of the Hallstatt period grave mound Magdalenenberg

K. Spindler (1977) published an additional paper on the settlement history. In the 1980s the last comprehensive reappraisal of prehistoric sites, accompanied by field surveys around Villingen-Schwenningen and Grüningen, was done by B. Schmid (Schmid 1991: 22, 75–76). Lately, surveys were conducted between 2010 and 2012 in the vicinity of the Magdalenenberg and Grüningen (Knopf 2012; Knopf and Seidensticker 2012). In the southern part of the Baar the Fürstenberg was systematically surveyed (Wagner 2014).

2.3 Colluvial deposits at the Magdalenenberg and Grüningen

Considering the numerous mentioned archaeological surveys the sites Magdalenenberg near Villingen and Grüningen were chosen to analyze colluvial deposits. Both sites are located in the western Baar, close to the Black Forest (Fig. 2).

The soil profile 1 at the Magdalenenberg is located downslope on the north facing slope of the Magdalenenberg itself (Knopf et al 2015). The soil consists mainly of colluvial material, underlying periglacial material originates from the Lower Muschelkalk. Different colluvial soil horizons point to different phases of human land use. Almost all ^{14}C ages are in accordance with the colluvial stratigraphy (Tab. 1). An exception in this respect is sample Poz-36954. It was taken at a depth of 65 cm, but is older than the sample Erl-20132 from a depth of 75 cm. Since the physical ages of all samples are correct, it seems likely that this older charcoal sample was rearranged, e.g. due to bioturbation. The upper 70 cm of soil show some redoximorphic features and are affected by clay illuviation and the transportation and accumulation of organic matter. The abundance of redoximorphic features increases with depth, which indicates a water influenced horizon. Today the land is used as a mowing meadow, but the 80 cm colluvial deposition indicates more intense land use over the last nearly 6000 years until 1000 years ago (Tab. 1).

Soil profile 8 from Grüningen shows a very similar picture, but is still used for crop production (Tab. 2). It is situated on a southeast facing slope. The soil consists of 120 cm colluvial material with underlying loess (wind-transported silt-sized sediment in a periglacial environment). The underlying geology (upper Muschelkalk, Trochitenkalk Formation) does not influence soil development because it is covered by loess. The charcoal in the deepest colluvial horizon dates to 2472–2278 cal BC (Erl-20137). The time difference to the upper horizon comprises about 2000 years. This difference is also visible in the distinct redoximorphic features of the lower horizon. Two charcoal samples from the same colluvial horizon are contradicting (Tab. 2). The sample MAMS-12277 was taken at a depth of 72 cm and dated to 1620–1500 cal BC. However, sample Erl-20136, which was taken at a depth of 83 cm and is significantly younger, i.e. 2–177 cal AD. During our fieldwork we discovered artefacts dating to 1300–800 cal BC (Urnfield period) in this profile at a depth of 80 cm. Thus the sample Erl-20136 must have been moved by bioturbation downwards into the older colluvial deposit.

Both sites show a long history of land use alternating with periods of extensive land use visible through the differentiation of the horizons.

Tab. 1: Soil profile from Magdalenenberg (Mag 1).AMS^{14}C ages using charcoal.

Horizon [FAO 2006]	Depth of Horizon [cm]	Age [uncal BP]	Age [cal AD/BC (95,4%; 2 Sigma)]	Labcode	Sampling Depth [cm]
Ap	-25	746 ± 33	1221–1290 cal AD	Erl-20131	-25
Ah1	-60	635 ± 30	1284–1399 cal AD	Poz-36952	-34
Ah1		905 ± 30	1037–1207 cal AD	Poz-36953	-49
Ah2	-70	4970 ± 40	3929–3654 cal BC	Poz-36954	-65
2Bshg	-80	5071 ± 51	3790–3760 cal BC	Erl-20132	-75

Calibrations were done with OxCal 4.2 (IntCal13)

Tab. 2: Soil profile from Grüningen (Gru 8). AMS ^{14}C ages using charcoal.

Horizon [FAO 2006]	Depth of Horizon [cm]	Age [uncal BP]	Age [cal AD/BC (95,4%; 2 Sigma)]	Labcode	Sampling Depth [cm]
Ah1	-65	909 ± 21	1037–1183 cal AD	MAMS 12275	-40
Ah1		1569 ± 21	427–543 cal AD	MAMS 12276	-50
Ah2	-96	3283 ± 25	1620–1500 cal BC	MAMS 12277	-72
Ah2		1918 ± 38	2–177 cal AD	Erl-20136	-83
2Bgh	-120	3889 ± 40	2472–2278 cal BC	Erl-20137	-105

Calibrations were done with OxCal 4.2 (IntCal13)

2.4 Correlation with archaeological data from Magdalenenberg and Grüningen

The medieval ^{14}C-datings from upper horizons of the profile 1 from Magdalenenberg (Mag 1) correlate with archaeological finds and historical records. Phases of high (Poz-36953) and late medieval (Poz-36952 and Erl-20131) land use can be associated with the town of Villingen, which was first mentioned in 817 AD and is close to the site (Jenisch 1999: 35). These deposits may also be related to close-by fortifications from the high-medieval period (Spindler 1979: 371–372; Buchta-Hohm 1996: 122–123). New is the evidence of late Neolithic land use (Poz-36954 and Erl-20132). So far, two Neolithic sites with small finds are known from the immediate vicinity (Fig. 2). In the course of construction works in 1969 several flint implements were discovered less than 1 km to the northeast probably dating to early Neolithic (Schmid 1991: 25). In addition a stone axe was found in 1983, when a farmer prospected one of his fields (Hettich 1984/85). Furthermore, there is a collection with 19 stone axes in the Museum of Villingen. However, the provenience of these finds has not been documented (Schmid 1992: 125–126). While these findings could suggest at best a temporary use of this area, it is now possible to detect an unambiguous phase of land use in the Younger Neolithic through the analysis of colluvial deposits (Knopf and Seidensticker 2012). It seems likely that this land use was accompanied by a long-term existing settlement in the area as well as an increased penetration of the eastern slopes of the Middle Black Forest, which are only a few kilometres away (Fig. 2). This assumption is supported by findings from other parts of the Black Forest. Pollen profiles from the Northern Black Forest indicate a human impact during the Younger Neolithic (Rösch 2009: 342). The surveys of Valde-Nowak and Kienlin (2002: 45–47) provided evidence for an intensified phase of land use during the Younger and Final Neolithic on the western side of the Black Forest as well.

A correlation with adjacent Iron Age settlements has not been possible so far. South of the Magdalenenberg pottery fragments, glass jewellery and so-called “rainbow cups” were collected in the late 1970s and early 1980s, dating to the Latène period (Hettich 1984/85; Weber 1991/92). Another settlement is known from the Gerberstr. 76 in Villingen (Weber-Jenisch 1994). There are two possible explanations for the absence of colluvial deposits from the Latène period in profile Mag 1. The site from Gerberstr. 76 is about 2 km away (Fig. 2). Thus it is possible that the people living there used other fields for agriculture. It should also be borne in mind that the colluvial deposits from Mag 1 only represent the land use from the corresponding slope area on the northern side of the Magdalenenberg. For this reason it cannot be ruled out that the southern slope was agriculturally used during the Latène period. No colluvial deposits date to the Hallstatt period. However, archaeobotanical analysis of sediments from the Magdalenenberg itself revealed that the area was used as pasture land at that time (Fritz 1980: 95–96).

With regard to the mentioned archaeological field surveys profile 8 (Gru 8) from the area west of Grüningen provided surprising results. The medieval colluvial deposit from this profile (MAMS 12275) fits to the earliest historical record of Grüningen from the 12th century (Buchta-Hohm 1996: Tab. 1).

The previous phase of land use during the Merovingian period (MAMS 12276) correlates with contemporaneous cemeteries from the Brigachtal valley (Wagner 1908: 107–108) and Wolterdingen (Buchta-Hohm 1996: 123; Fig. 2).

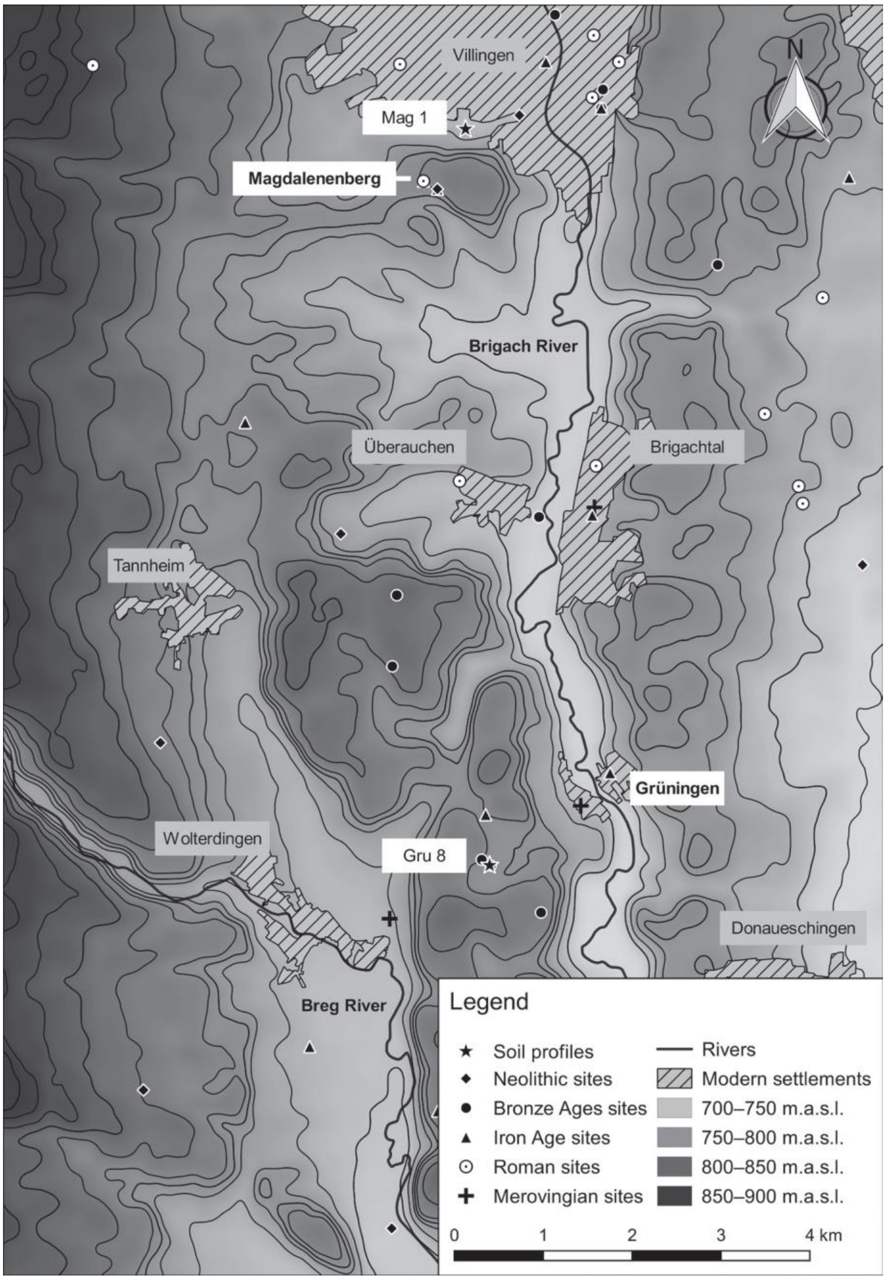

Fig. 2: Soil profiles and archaeological sites in the western Baar.

Unexpectedly, a phase of Roman land use could be detected, sample Erl-20136 dates to the transition from the early to mid-Roman period (Sangmeister 1993: 122). From the nearby area there are no archaeological finds known from this period. The closest Roman sites are located ca. 3–5 km away in Bräunlingen and Überauchen (Thom 1969: 5, 74–75; Fig. 2). However, this colluvial deposit from Gru8 indicates a possible Roman farmstead around Grüningen, which probably was involved in the supply network for the Castrum a few kilometres south in Hüfingen (Mayer-Reppert et al. 1995).

Since the choice of location for Gru8 was oriented towards a potential settlement from the Urnfield period located on the upper slope, colluvial deposits from this period were expected. Indeed the profile revealed a phase of land use from the Bronze Age. Surprisingly the AMS ^{14}C age from sample MAMS 12277 indicates a phase of land use during the 15–17th century cal BC, i.e. at the transition from the early to the middle Bronze Age (Della Casa 2013 : 211). This is in contrast to the archaeological evidence for the Bronze Age settlement of this area (Ahlrichs et al. 2016). The closest known sites from the Early Bronze Age are located in the valley of the Danube (Oberath 2000). The same applies to the nearest Middle Bronze Age settlement, located 4 km to the north-east in the Brigach valley (Schmid 1992: 122–123; Fig. 2). About 1.2km southeast of Gru8 a late Middle Bronze Age burial (Schmid 1991: 37) was discovered and excavated in the 1850s (Schmid 1992: 11–12). Therefore the burial took place at a time when the colluvial deposits already existed. Apart from this site some stone and earth mounds are known from the vicinity, which have not been excavated so far (Knopf et al. 2015). Assuming that land was used in the immediate surroundings of the settlements, there might be at least one settlement dating to the transition from early to middle Bronze Age nearby profile Gru8 (Fig. 2).

Profile Gru 8 does not have a phase of colluviation from the Urnfield period but it contained a deposition of ceramics from this period. It was discovered in 2014, with the base at 80 cm depth and consists of a 16.5 x 15 cm large vessel in which a 6.8 x 7.5 cm small cup was found. No additional artefacts or human remains were found. The intentional deposition of the two vessels is probably related to the contemporaneous settlement in the upper slope area. These kinds of depositions are also known from other settlements from this period (Ahlrichs et al. 2016).

Finally, the thickness of the colluvial deposits from Mag 1 and Gru 8 is not only an indicator for phases of land use. The colluvial stratigraphy also provides source critical information for the question, why there are no archaeological correlates for certain phases of land use, despite the numerous field surveys. The depth of the colluvial deposits shows that the relief intensity is sufficient enough to reduce the visibility of archaeological sites in the field, even if the slope gradient is not high. So far this has only been considered for river valleys with steeper slopes (e.g. Paret 1961: 154–156; Wahle 1973: 2).

3 Concluding remarks

The integrated combination of archaeological and pedological methods provides unambiguous evidence for continuous phases of land use on the western Baar, starting at the latest in the Young Neolithic and lasting until the Middle Ages. Considering the archaeological evidence and the colluvial stratigraphies from Magdalenenberg and Grüningen it seems possible that the Neolithic settlement of the western Baar has been accompanied by a penetration into the Black Forest – perhaps for summer pasture. The thickness and the fine stratigraphy of colluvial deposits indicate that even in areas with gentle slopes such as the western Baar, there might be more archaeological sites that are overlain by younger colluvial deposits.

Bibliography

Ahlrichs, J.J., Henkner, J., Schmidt, K., Scholten, T., Kühn, P. and Knopf, T. (2016). Bronzezeitliche Siedlungsdynamiken zwischen der Baar und angrenzenden Naturräumen. In: D. Neumann and B. Nessel, eds., Transporte, Transportwege und Transportstrukturen. Jahressitzung der Arbeitsgemeinschaft Bronzezeit, Tübingen 30.–31. Oktober 2015. Manuscript submitted for peer-review.

Andersson, H. (1998). Utmark In: H. Andersson, L. Ersgård and, E. Svensson, eds, Outland Use in Preindustrial Europe. Lund Studies in Medevial Archaelogy 20. Lund: Lund University, pp. 5–8. Bartelheim, M., Hardenberg, R., Knopf, T., Scholz, A. and Staecker, J. (2015). 'ResourceCultures': A Concept for Investigating the Use of Resources in Different Societies. In: A. Danielisova and M. Fernández-Götz, eds., Persistent Economic Ways of Living Production, Distribution, and Consumption in Late Prehistory and Early History. Archaeolingua 35. Budapest: Archaeolingua, pp. 39–49.

Brückner, H. (1980). Die Entwicklung der Wälder des Schwarzwaldes durch die Nutzung vergangen er Jahrhunderte und ihre heutige Bedeutung. In: E. Liehland and W.D. Sick, eds., Der Schwarzwald – Beiträge zur Landeskunde. Bühl/Baden: Konkordia, pp. 155–180.

Buchta-Hohm, S. (1996). Das alamannische Gräberfeld von Donaueschingen. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg 56. PhD. Universität Würzburg.

Coles, G. and Mills, C.M. (1998). Clinging on for grim life: an introduction to marginality as an archaeological issue. In: G. Coles and C. M. Mills, eds., Life on the edge: human settlement and marginality. Symposia of the Association for Environmental Archaeology 13. Oxford: Oxbow Books, pp. VII–XII.

Della Casa, P. (2013). Switzerland and the Central Alps. In: A. Harding – H. Fokkens, eds., The Oxford Handbook of the European Bronze Age. Oxford: Oxford University Press, pp. 706–722.

Denecke, D. (1992). Siedlungsentwicklung und wirtschaftliche Erschließung der hohen Mittelgebirge in Deutschland. Ein historisch-geographischer Forschungsüberblick. Siedlungsforschung, 10(1), pp. 9–48. Fischer, E. (1936). Beiträge zur Kulturgeographie der Baar. Badische geographische Abhandlungen 16. PhD. Universität Freiburg.

Fritz, W. (1980). Die aktualistische Rekonstruktion der hallstattzeitlichen Vegetation am Magdalenenberg auf Grund pflanzlicher Subfossilien. In: K. Spindler, ed., Magdalenenberg, Band 6. Villingen: Neckar- Verlag, pp. 27–114.

Goessler, P. (1944–1948). Zur Erinnerung an Dr. Hermann Stoll, gestorben am 10. Dezember 1944.Zeitschrift für Württembergische Landesgeschichte, 8(1), pp. 415–445.

Gradmann, R. (1948). Alt- und jungbesiedeltes Land. Studium generale, 1(3), pp. 163–177.

Gradmann, R. (1964a). Süddeutschland I. Allgemeiner Teil, 2nd ed. Darmstadt: WissenschaftlicheBuchgesellschaft.

Gradmann, R. (1964b). Süddeutschland II. Die einzelnen Landschaften, 2nd ed. Darmstadt:Wissenschaftliche Buchgesellschaft.

Hettich, M. (1984/85). Ein Steinbeil der Jungsteinzeit auf Villinger Gemarkung. Geschichts- und Heimatverein Villingen, 9(1), pp. 9–13.

Jenisch, B. (1999). Die Entstehung der Stadt Villingen. Forschungen und Berichte der Archäologie des Mittelalters in Baden-Württemberg 22. PhD. Universität Tübingen.

Kadereit, A., Kühn, P. and Wagner, G.A., 2010. Holocene relief and soil changes in loess-covered areas of south-western Germany: The pedosedimentary archives of Bretten-Bauerbach (Kraichgau). Quaternary International, 222(1–2), pp. 96–119.

Kienlin, T. L. and Valde-Nowak, P. (2004). Neolithic Transhumance in the Black Forest Mountains, SW Germany. Journal of Field Archaeology, 29(1–2), pp. 29–44.

Knopf, T. (2012). Neue Forschungen im Umland des Magdalenenbergs. In: C. Tappert, C. Later, J. Fries- Knoblach, P.C. Ramsl, P. Trebsche and S. Wefersand J. Wiethold, eds., Wege und Transport. Beiträge zur Sitzung der AG Eisenzeit in Nürnberg 2010. Langenweissbach: Beier & Beran, pp. 209–220.

Knopf, T. and Seidensticker, D. (2012). Archäologische Untersuchungen auf der Baar: das Umland des „Fürstengrabhügels“ Magdalenenberg. Archäologische Ausgrabungen in Baden-Württemberg, 2012(1), pp. 116–122.

Knopf, T., Baum, T., Scholten, T. and Kühn, P. (2012). Landnutzung im frühen Mittelalter. Eine archäopedologische Prospektion im Mittleren Schwarzwald. Archäologisches Korrespondenzblatt, 42(1), pp. 123–133.

Knopf, T., Ahlrichs, J.J., Henkner, J., Scholten, T. and Kühn, P. (2015). Archäologische und bodenkundliche Untersuchungen zur Besiedlungs- und Landnutzungsgeschichte der Baar. Schriften des Vereins für Geschichte und Naturgeschichte der Baar, 58(1), pp. 9–24.

Kösel, M. and Rilling, K. (2002). Die Böden der Baar – ein Beitrag zur regionalen Bodenkunde Südwestdeutschlands. Schriften des Vereins für Geschichte und Naturgeschichte der Baar, 45(1), pp. 99–128.

Kullen, S. (1989). Baden-Württemberg, 3rd ed. Stuttgart: Klett.

Leopold, M. and Völkel, J. (2007). Colluvium: Definition, differentiation, and possible suitability for reconstructing Holocene climate data. Quaternary International, pp. 162–163(1), pp. 133–140.

Mayer-Reppert, P., Balzert, M., Fingerlin, G. and Heim-Wenzler, J. (1995). Brigobannis: Das römische Hüfingen. Führer zu archäologischen Denkmälern in Baden-Württemberg 19.

Stuttgart: Theiss.

Oberath, S. (2000). Ein Beitrag zur Frühbronzezeit in Südwestdeutschland. Fundberichte aus Baden- Württemberg, 24(1), pp. 191–214.

Pasda, C. (1994). Altensteig und Ettlingen – Mesolithische Fundstellen am Rand des Nordschwarzwalds. Fundberichte aus Baden-Württemberg, 19(1), pp. 99–174.

Pasda, C. (1998). Zur Erhaltung steinzeitlicher Fundstellen in Flußtälern der Mittelgebirge – Ein Beispiel aus dem Nordschwarzwald. In: N.J. Conard and C.-J. Kind, eds., Aktuelle Forschungen zum Mesolithikum. Current Mesolithic Research. Urgeschichtliche Materialhefte 12. Tübingen: Mo-Vince, pp. 223–228.

Paret, O. (1961). Württemberg in vor- und frühgeschichtlicher Zeit. Stuttgart: Kohlhammer. Paulus, E. (1882). Archäologische Karte von Württemberg. Stuttgart: K. Statist.

Revellio, P. (1932). Aus der Ur- und Frühgeschichte der Baar. Schwenningen: Link.

Rösch, M. (2009). Botanical evidence for prehistoric and medieval land use in the Black Forest. In: J. Klápště, ed., Medieval Rural Settlement in Marginal Landscapes. Mittelalterliche Siedlung in ländlichen Randgebieten: Ruralia VII, 8th–14th September 2007, Cardiff, Wales, U.K. Turnhout: Brepols, pp. 335–343. Rösch, M., Gassmann, G. and Wieland, G. (2009). Keltische Montanindustrie im Schwarzwald: Eine Spurensuche. In: S. Zimmer, ed., Kelten am Rhein: Akten des dreizehnten Internationalen Keltologiekongresses: Proceedings of the thirteenth International Congress of Celtic Studies: 23. bis 27. Juli 2007 in Bonn. Beihefte der Bonner Jahrbücher 58. Mainz am Rhein: Zabern, pp. 263–278. Sangmeister, E. (1993). Zeitspuren. Archäologisches aus Baden. Freiburg: Kehrer.

Schaab, M. (2003). Beiträge zur Siedlungs- und Wirtschaftsgeschichte des Schwarzwaldes. Veröffentlichungen der Kommission für Geschichtliche Landeskunde in Baden-Württemberg: Reihe B, Forschungen 156. Stuttgart: Kohlhammer.

Schmid, B. (1991). Die urgeschichtlichen Funde und Fundstellen der Baar, Text und Tafeln. Rheinfelden: Schäuble.

Schmid, B. (1992). Die urgeschichtlichen Funde und Fundstellen der Baar, Katalog. Rheinfelden: Schäuble. Schreg, R. (2014). Uncultivated landscapes or wilderness? Early medieval land use in low mountain ranges and flood plains of Southern Germany. European

Journal of Post-Classical Archaeologies, 4(1), pp. 69–98.

Sick, W.-D. (1992). Die Besiedlung der Mittelgebirge im alemannischen Raum. Siedlungsforschung, 10(1), pp. 49–62.

Siegmund, A. (1999). Das Klima der Baar. Mannheimer geographische Arbeiten 51. PhD. Universität Mannheim.

Spindler, K. (1977). Vor- und Frühgeschichte. In: R. Gutknecht, ed., Der Schwarzwald-Baar-Kreis. Stuttgart: Theiss, pp. 56–84.

Spindler, K. (1979). Zur Topographie der Villinger Alstadt. Fundberichte aus Baden-Württemberg, 4(1), pp. 391–392.

Stoll, H. and Gehring, E. (1938). Vor- und frühgeschichtliche Karte von Rottweil und Umgebung. Rottweil: Rottweiler Geschichts- und Altertumsverein.

Sudhaus, D., Rüggeberg, J., Zollinger, G. and Häbich, S. (2008). Pollenanalysen zur Rekonstruktion der Vegetations- und Landschaftsgeschichte im oberen Schiltach-Einzugsgebiet (Mittlerer Schwarzwald). Berichte der Naturforschenden Gesellschaft zu Freiburg i. Br., 98(1), pp. 181–192.

Thom, H. (1969). Die Besiedlung im Bereich der Baar in römischer und alemannischer Zeit nach den archäologischen Funden, Teil B: Katalog. Freiburg: Institut für Ur- und Frühgeschichte.

Valde-Nowak, P. and Kienlin, T.L. (2002). Neolithische Transhumanz in den Mittelgebirgen: Ein Survey im westlichen Schwarzwald. Praehistorische Zeitschrift, 77(1), pp. 29–75.

Vogt, R. (2014). Kolluvien als Archive für anthropogen ausgelöste Landschaftsveränderungen an Beispielen aus der westlichen Bodenseeregion. Materialhefte zur Archäologie in Baden-Württemberg 99. Darmstadt: Theiss.

Wagner, E. (1908). Fundstätten und Funde aus vorgeschichtlicher, römischer und alamannisch-fränkischer Zeit im Großherzogtum Baden, Band 1. Tübingen: Mohr.

Wagner, H. (2014). Von der Steinzeit zur Stadt: Neue Forschungen zur Besiedlungsgeschichte des Fürstenbergs. Schriften des Vereins für Geschichte und Naturgeschichte der Baar, 57(1), 33–62.

Wahle, E. (1973). Beiwort zu den Karten III, 1–2. In: K. H. Schröder and M. Schaab, eds., Historischer Atlas von Baden-Württemberg, Band III. Vor- und Frühgeschichte.

Stuttgart: ////, pp. 1–12.

Weber, G. (1991/92). Die neuentdeckte Siedlung Villingen "Laible": und die spätlatènezeitliche Besiedlung Villingens und Umgebung. Geschichts- und Heimatverein Villingen Jahresheft, 16(1), 34–40.

Weber-Jenisch, G. (1994). Villingen-Schwenningen. Fundberichte aus Baden-Württemberg, 19(2), 77–78.

List of all scientific publications

Henkner, J.; Ahlrichs, J.; Downey, S.; Fuchs, M.; James, B.; Junge, A.; Knopf, T.; Scholten, T.; Kühn, P. (2018): Archaeopedological analysis of colluvial deposits in favourable and unfavourable areas: Reconstruction of land use dynamics in SW Germany. RSOS 5, DOI: 10.1098/rsos.171624.

Henkner, J.; Scholten, T.; Kühn, P. (2018): Data from: Archaeopedological analysis of colluvial deposits in favourable and unfavourable areas: reconstruction of land use dynamics in SW Germany. Dryad, DOI: 10.5061/dryad.rh67h.

Henkner, J.; Ahlrichs, J.; Fischer, E.; Fuchs, M.; Rösch, M.; Scholten, T.; Kühn, P. (2018): Land use dynamics derived from colluvial deposits and bogs in the Black Forest, Germany. JPNSS 181/2, 240-260, DOI: 10.1002/jpln.201700249

Teuber, S.; Ahlrichs, J.; **Henkner**, J.; Knopf, T.; Kühn, P.; Scholten, T. (2017): SoilCultures – The adaptive cycle of agrarian soil use in Central Europe. Ecology and Society. E&S 22/4, DOI: 10.5751/ES-09729-220413

Henkner, J.; Ahlrichs, J.; Downey, S.; Fuchs, M.; James, B.R.; Knopf, T.; Scholten, T.; Teuber, T.; Kühn, P. (2017): Archaeopedological analyses of colluvial deposits: A proxy for regional land use history in southwest Germany. Catena 155, 93-155, DOI: 10.1016/j.catena.2017.03.005.

Henkner, J., Scholten, T., Kühn, P. (2016): Soil organic carbon stocks in permafrost-affected soils in West Greenland. Geoderma 282, 147-159. DOI: 10.1016/j.geoderma.2016.06.021

Ahlrichs, J.; **Henkner**, J.; Teuber, S.; Schmidt, K.; Scholten, T.; Kühn, P.; Knopf, T. (2016): Archaeo-logical and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory: A Case Study from the Western Baar, SW Germany. In: Kolodziejczyk, Kwiatkowska-Kopka (Hg.) 2016 – Landscape as impulsion for culture, Vol. 2, 39–49.

Ahlrichs, J.J., **Henkner**, J., Teuber, J., Schmidt, K., Scholten, Th., Kühn, P., Knopf, Th., Archaeologi-cal and Archaeopedological Approaches to Analyze the Development of Marginal Areas in Prehistory (2016, submitted manuscript).

Knopf, T., Ahlrichs, J., **Henkner**, J., Scholten, T., Kühn, P. (2015): Archäologische und bodenkundliche Untersuchungen zur Besiedlungs- und Landnutzungsgeschichte der Baar. Schriften des Vereins für Geschichte und Naturgeschichte der Baar 58, 9-24.

Henkner J., Heiri C., Tinner R., Wunder J., Brang P. (2014): Auswertung der Stichprobeninventur 2012 im Naturwaldreservat Aletschwald. WSL Berichte 16. Eidg. Forschungsanstalt WSL, Birmensdorf, Switzerland.

Brücker R.; **Henkner** J.; Wunder J.; Brang P.; Heiri C. (2014): Stichprobeninventur 2013 im Natur-waldreservat God da Tamangur, Auswertung mit Kommentaren. Eidg. Forschungsanstalt WSL, Birmensdorf, Switzerland

Conference contributions

Henkner, J.; Scholten, T.; Kühn, P. (2017): Land use dynamics in favorable and unfavorable areas of southwest Germany. DBG Jahrestagung 2017, Göttingen, Germany. [Talk]

Henkner, J.; Ahlrichs, J.; Scholten, T.; Knopf, T.; Kühn, P. (2017): Land use dynamics in favorable and unfavorable areas of southwest Germany. EGU General Assembly 2017, Vienna. [Talk]

Henkner, J.; Ahlrichs, J.; Scholten, T.; Knopf, T.; Kühn, P. (2016): Archaeopedological analysis of land use dynamics in marginal areas in SW Germany. EGU General Assembly 2016, Vienna, Austria [Poster].

Henkner, J., Scholten, T., Ahlrichs, J., Knopf, T., Fuchs, M., Kühn, P. (2015): Kolluvien als Proxy für Landnutzungs- und Besiedlungsgeschichte in Marginalräumen SW Deutschlands. Deutsche Bodenkundliche Gesellschaft (DBG) Jahrestagung 2015, Munich, Germany. [Talk]

Henkner, J. (2015): Importance of the small scale – SOC stocks of permafrost-affected soil in West Greenland. JRC Land Resource Management Unit Meeting "Soil organic carbon stocks in permafrost affected soils in West Greenland, Ispra, Italien. [invited talk]

Henkner, J., Scholten, T., Kühn, P. (2014): Soils as archives for land use and climate change. 13th International Swiss Climate Summer School - Linking Land Use, Land Cover, and Climate. Grindelwald, Switzerland. [Poster]

Henkner, J., Scholten, T., Kühn, P. (2014): Colluvial deposits as proxies for human activities in SouthwestGermany. International Union of Soil Sciences (IUSS) 20th World Congress of Soil Science 2014, Jeju, Korea. [Poster]

Henkner, J., Scholten, T., Kühn, P. (2013): SOC stocks and physical fractions of SOM in permafrost affected soils in West Greenland. EGU General Assembly 2013, Vienna, Austria. [Poster]

Acknowledgements

I gratefully thank Dr. Peter Kühn and Prof. Dr. Thomas Scholten for giving me the opportunity to work in their group, the SFB1070, and more importantly, their support and advice in all situations. I also thank PD Dr. Thomas Knopf and my fellow PhD student Jan Ahlrichs for the good collective work and their archaeological input. I thank Shyamala Subramanian for her helpful administrative support. I especially thank Rita Mögenburg, Sabine Flaiz and many student helpers for their support in the lab. The field work was particularly supported by Dominik Birkenmair, Christoph Behnke, Sabrina Auch-Schwelk, Felix Martin Hoffmann, and Sophie Neubaur, thank you all for your great help and the good times we had out in the field. Without this support the huge amount of field work and my dissertation would not have been possible. The great input of my co-authors, especially Peter Kühn, Bruce James, Thomas Scholten, and Sean Downey was essential to the success of my work. Thank you all!

I am especially grateful to Kurt Rilling and Michael Kösel from the Landesamt für Geologie, Rohstoffe und Bergbau for great input and discussions in the field. The many farmers, who supported my work by allowing me to work on their land, are acknowledged. Thanks to Dr. Einar Eberhardt for support with the translation of KA5 classification to WRB and FAO. Thank you, Richard Szydlak, for doing a great job with the catenas.

I also thank my friends and colleagues Sandra Teuber, Dr. Karsten Schmidt, Diogo Spinola, and Dr. Steffen Seitz for countless talks and discussions about PhD work, organization, and pedology. I am grateful for the good support from the whole Soil Science & Geomorphology working group and the great times we had at conferences. I also want to thank my fellow PhD students and Post-Docs from the Gartenstrasse. It has been great to work with all of you!

Thank you Micah Wilhelm, Tania Polonio, Kevin Gibbons, and Bruce James, who showed me that friendship can arise out of scientific meetings. I am especially thankful to Sandra, Micah and Kevin who improved my English writing.

Last but not least, I would like to thank my family and the Kohrs-Sennock family for their absolute support during the last years! I am very grateful to have you all around! I am especially grateful to Sebastian, Janina and my mum, we all supported each other exceptionally. Thank you!