ENVIRONMENTAL CHANGES AND HUMAN IMPACT ON LANDSCAPE DEVELOPMENT IN THE UPPER RHINE REGION

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With 5 figures and 1 table
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Summary: The human impact on the environment of the Upper Rhine region and adjacent mountains (Black Forest and Vosges) is studied on the basis of radiocarbon dated pollen diagrams, archaeological findings and the geomorphological interpretation of geoarchives. The investigations show a much higher level and an earlier begin of human interferences than previously assumed. Preferred settlement and farming areas since the onset of sedentarization and farming during Neolithic Times were the warmer and loess covered areas of the lowlands and foothills. However, also the higher zones of the mid-mountain regions were used during climatically favourable periods (i.e. late Neolithic, Bronze Age, Roman Times). Thus a distinct contrast of the intensity of human impact between the lowlands and the highlands does not exist. It can rather be described as an interaction between different natural regions. Noticeable is the connection between changes in the ratio of woodland and open land and the geomorphodynamic processes. Nine main erosion/sedimentation phases can be distinguished due to different levels of land use intensity.

Zusammenfassung: Die naturbedingten und anthropogenen Einflüsse auf die Landschaftsgenese des Oberrheingebiets und der angrenzenden Gebirge (Schwarzwald und Vogesen) werden mit Hilfe interdisziplinärer Arbeitsweisen untersucht. Dazu gehören die ^{14}C-gestützte Pollenanalyse sowie die Auswertung von archäologischen Funden und Geoarchiven an Aufschlüssen und in Bohrprofilen. Die Forschungsergebnisse zeigen, dass der Einfluss des wirtschaftenden Menschen auf die Landschaft stärker war und auch früher einsetzte als bislang angenommen wurde. Bevorzugte Gebiete der frühen Besiedlung und landwirtschaftlichen Nutzung waren seit dem Neolithikum die wärmeren und von fruchtbaren Böden bedeckten Lössgebiete des Tieflandes und der Vorberge. Dennoch zeichnet sich bereits seit dieser Zeit auch die erste Nutzung der höheren Berglagen im Schwarzwald und in den Vogesen ab. Entsprechend verringerte sich seit dem Neolithikum und der Bronzezeit der deutliche Gegensatz zwischen dem siedlungsfeindlichen Gebirge und dem Tiefland, vor allem aber in der Kelten- und Römerzeit, womit auch die Wechselwirkungen zwischen den verschiedenen naturräumlichen Einheiten zunahmen. Auffallend ist die Verbindung zwischen der Veränderung des Wald-Offenland-Verhältnisses und der geomorphologischen Prozesse. Entsprechend der intensiven Nutzung des Raumes können neun Sedimentationsphasen (Kolluvien und Auenlehme) unterschieden werden. Dabei ist neben der verstärkten Abtragung und Sedimentation (z. B. in der Römerzeit und im Hochmittelalter) die Abnahme bzw. das Ausbleiben von Auensedimenten in den klimatisch ungünstigen Zeitabschnitten des Holozäns auffallend (z. B. am Übergang Bronze-/Eisenzeit oder während der Völkerwanderungszeit).

Keywords: Human impact, environmental history, pollen analysis, Upper Rhine Valley, Black Forest, Vosges

1 Introduction: study area and aim of research

This paper is based on recent results of the research training group "Formation and Development of Present-Day Landscapes", which was supported by the Deutsche Forschungsgemeinschaft (German Research Foundation) from 2001 to 2008 (DFG-GRK 692). The investigations are centred on the landscape of the Upper Rhine region, which covers the plain of the Upper Rhine Lowlands and the adjacent mountain zones of the Black Forest and the Vosges (Fig. 1). The hypothesis of the research programme stated that the human impact on the formation and development of this landscape has been much greater than previously thought (Mäckel and Steuer 2003; Mäckel et al. 2004, 2007). The aim of the studies is the reconstruction of the palaeoenvironmental changes and the human impact on the landscape history during the Holocene. Above that the interplay of climatic influences on anthropogenic activities and their response to environmental processes in different natural regions are to be investigated. The paper also includes the results origi-

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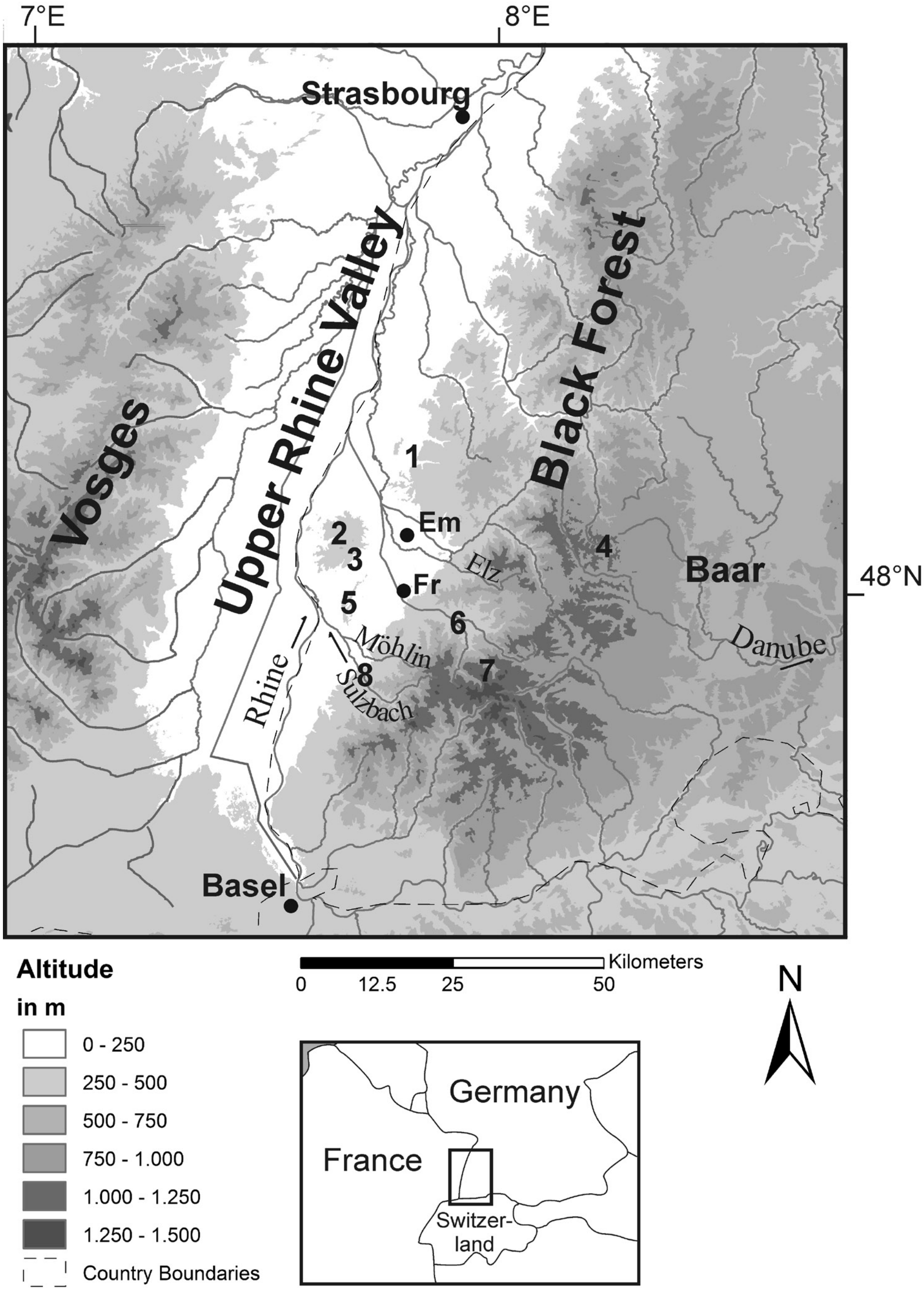

Fig. 1: Location map of the study area in the Upper Rhine region. The sample sites mentioned in the text are marked by numbers: 1 Emmendinger foothill zone, 2 Kaiserstuhl, 3 Wasenweiler Ried, 4 Triberg, 5 Tuniberg, 6 Basin of Zarten, 7 Angelsbachkar, 8 Sulzbach valley; Em = Emmendingen, Fr = Freiburg

nating from two priority programmes founded by the Deutsche Forschungsgemeinschaft, which were carried out in the same region between 1985 and 2000 (Mäckel and Zollinger 1995; Mäckel and Friedmann 1998, 1999; Mäckel et al. 2002, 2003). The results of the RhineLUCIFS-Project (Land use and climatic impact on fluvial systems during the period of agriculture, 2001-2005), were also incorporated (Lang et al. 2003; Seidel 2004; Dikau et al. 2005; Seidel and Mäckel 2007).

The study area encompasses different natural units of the Upper Rhine region (Fig. 1). According to variations of altitude, climate, vegetation and soil formation various sites were selected, which represent a specific environment and show different responses to natural changes and/or human impact. The Upper Rhine Graben is a major sediment sink within the Rhine basin, whereas the Black Forest and the Vosges are sediment sources. The lowland sites with favourable loess soils and a milder climate were compared with the cooler and moister uplands of the Black Forest and the Vosges, i.e. with the formerly glaciated sites and the upper reaches and watersheds of the mountain rivers.

An emphasis is put on the relation of closed forest to open land and the historical differences of land use and erosion intensities in the course of landscape development. The time slice focused on within the research training group ranges from the onset of agriculture during the Neolithic time (5500 cal. BC) to the present. Another aspect of the study is the highland-lowland interaction during the course of settlement.

2 Methods

The natural and anthropogenic changes to the environment that occurred in the Upper Rhine region and adjacent mountains during the Holocene can only be analysed by detailed interdisciplinary studies with research methods both from natural science and humanities (according to Brückner and Gerlach 2007). In this paper the natural and anthropogenic changes in the palaeo-environment were mainly reconstructed by pollen analyses supported by ^{14}C-dating and the evaluation and interpretation of colluvial and alluvial sediments.

Pollen analyses were performed continuously with different sub-sampling intervals and processed using standard techniques (Fægri and Iversen 1989). Exotic spores (Lycopodium) were added to allow calculation of pollen concentration. Identification of pollen and spores is based on reference material and published keys (e.g. Moore et al. 1991; Reille 1992). The chronologies are based on ^{14}C-data. For this study all pollen analyses in the Upper Rhine region where considered. The conclusions are mainly based on the ^{14}C-dated pollen diagrams with a focus on the analysis performed in the mentioned research programmes (Friedmann 2000; Lechner 2005; Sudhaus 2005).

The evaluation of natural geoarchives is supported by more than two hundred radiocarbon dates. Radiocarbon dating was carried out to obtain information on the age of sediment bodies connected with geomorphological processes. Various organic materials in the colluvial and fluvial deposits were used for ^{14}C-analysis such as peat layers, pieces of wood and/or charcoal. Sediment layers of different age within one vertical profile mark the beginning and the end of cut and fill phases. Time inversion happens due to reworking and redeposition of older material in the alluvial plain. Therefore the dates only mark a *post quem* status.

In connection with borehole profiles and transects geophysical methods were practised to determine the thickness of different sediment layers. Among others the use of high resolution geoelectric techniques brought useful results in the Upper Rhine Lowlands and in the Black Forest mountain zones along the main European watershed (Häbich et al. 2007; Burg 2008).

3 Landscape development under the human impact during the Holocene

3.1 Environmental changes and human activity during Neolithic Times

In the Southern Upper Rhine Lowlands the sample cores originate from the Wasenweiler Ried fen, which developed in the palaeo-channel of the Eastern Rhine river located between the loess covered Kaiserstuhl and the Tuniberg hills (Fig.1, no. 5). The Eastern Rhine course ceased to exist as a continuous stream at the end of the late glacial (Wuerm). The ages of the ^{14}C-dated peat at the channel base differ in the Eastern Rhine channels (Friedmann 2000; Lechner 2005). In general they represent two main phases of peat development. The first one started already at the end of the Younger Dryas and lasted throughout the Preboreal time. During the drier Boreal peat growth ceased. In most Eastern Rhine channels the development of peat started again between 8330 to 6185 cal. BC in the wetter and warmer Atlantic (Mäckel et al. 2002). For this period no remarkable human influence can be detected in the pollen diagrams of the Wasenweiler Ried, while the natural vegetation is characterized by pine forests (*Pinus* spec.). According to the pollen spectrum, the climate was probably drier than today (Friedmann 2000). Due to climatic changes towards a warmer environment during the early Atlantic, the pine forests declined and species such as oak (*Quercus* spec.), elm (*Ulmus* spec.) and ash (*Fraxinus excelsior*) immigrated. In correspondence with the widespread hazel (*Corylus avellana*), a hazel-rich mixed deciduous forest developed. Oak, and later elm and lime, became the dominant trees in the forest. About 4000 cal. BC the first pollen of cereals and farming weeds occurred in the Southern Upper Rhine Plain (Friedmann 2000). In the ^{14}C-dated pollen diagrams of the foot hills of Emmendingen (Fig. 1, no. 1) the first pollen of cereals also appeared during Neolithic Age (Schneider 2000). Woodland grazing and later the existence of pastures can be recognized by the increase of grass pollen at the end of the Neolithic. As a consequence of sedentarization and woodland clearing for fields and pastures the percentage of arboreal pollen declines, while non-arboreal pollen values indicate the increase of open land. Around ca. 2800 cal. BC the first pollen of Cerealia-type are detectable in the central parts of the Wasenweiler Ried as shown in the pollen diagrams of Lechner (2005), while in the Eastern part of the fen single cereal pollen grains are recognized over 1000 years earlier (Friedmann 2000).

Warmer and drier climatic conditions than today, especially warmer summers, existed during the period of Neolithic settlement (Holocene climate optimum). The beginning of permanent settlements and agriculture was also documented by Burg (2008) in the Southern Upper Rhine Lowlands. The population density was probably higher than ever before as shown by a higher density of archaeological findings (Mischka et al. 2003; Mischka 2007). However, farmers preferred the fertile and easier manageable loess soils, which were also highly erodable. Sediment derived from soil erosion did not reach the floodplain and river channels in most cases, but was re-deposited on the slopes as colluvium. Therefore we find only a few locations with alluvial sediments representing the first Holocene alluvial sedimentation phase in the Upper Rhine region according to Mäckel and Friedmann (1999) (Tab. 1). In contrast, the colluvial sediments show depths of several metres. They bury shards of Neolithic cultures, for example of the Wauwil group (4400 to 4200 BC according to Dieckmann 1990) in the Kaiserstuhl area (Mäckel et al. 2002).

Striking is the occurrence of a fossil black clay layer below the alluvial or colluvial covers in many parts of the Upper Rhine Lowlands (Schneider 2000; Mäckel et al. 2002; Seidel 2004; Mäckel and Sudhaus 2008). Its genesis is not fully understood (e.g. Erkens at al. 2009), the time of development is defined by radiocarbon dating and took place during warmer and drier periods of the Boreal and early Atlantic (Schneider 2000; Seidel 2004). Therefore it can be used as an important Holocene indicator horizon. The black clay layer is mainly conserved in relics in the study area (Fig. 2). The truncated and partially removed marker horizon in connection with Neolithic findings points to the degradation of the black clay layer under human impact.

Table 1: Colluvial and alluvial sedimentation phases in the Black Forest and in the Upper Rhine Lowlands during the Holocene dated by artefacts and ^{14}C-analyses (compiled after Mäckel et al. 1998, 2001; Mäckel and Friedmann 1999; Seidel 2005; Sudhaus 2005; Häbich et al. 2005). Abbr.: cs = colluvial sedimentation, as = alluvial sedimentation, 1 = low, 2 = medium, 3 = high sedimentation (according to intensity, volume and composition of the sediment body)

Sedimentation phase		Cultural period (cal. BC/AD)		Sedimentation gap	Locality			
					Kaiserstuhl / lowlands	Foot hills	Black Forest: river valleys	Black Forest: watershed
1		Neolithic (5000-2000)			cs 2, as 1	cs 2, as 1	as 1	
2		Bronze Age (2000-800)			cs 1, as 1	cs 1	as 1	cs 1
3	a	Iron Age	Hallstatt (800-400)	gap 1	cs 2	cs 1, as 2		
	b		Laténe (400-0)		cs 2	as 2	as 2	
4		Roman Period (0-300/400)		gap 2	cs 2, as 1	as 2	as 1	cs 1
5		Early Medieval times (7th-12th ct.)		gap 3	cs 2		as 1	cs 1, as 1
6		High Middle Ages (10th-12th ct.)				as 3	as 1	cs 1, as 1
7		Late Medieval times (14th-15th ct.)					as 3	cs 1, as 2
8		Modern times (17th + 18th ct.)				as 2	cs 3	as 2

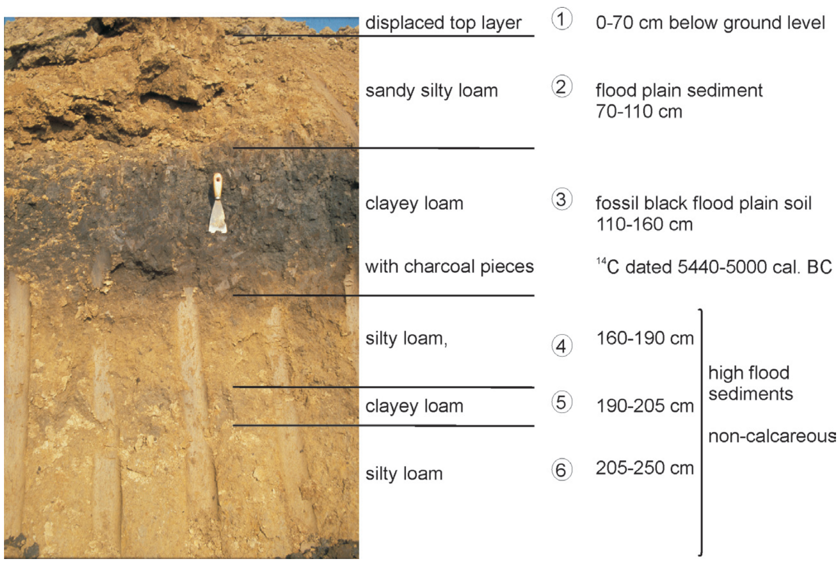

Fig. 2: The black clay layer exposed in the retention basin of Hausen, Möhlin River Valley. Photo R. Mäckel 22.05.2001, interpretation after Seidel (2004)

The black clay layer is widespread in the valleys of the Rhine and its tributaries. Comparable studies originate from the Northern part of the Upper Rhine Valley (Dambeck 2005; Erkens et al. 2009; Thiemeyer et al. 2005), the Neckar (Terhorst 2000), the Lahn drainage area (Mäckel 1969; Rittweger 2000) and the Wetterau (Houben 2002). The period of development was also determined by the stratigraphy of the deposits, archaeological findings and radio-carbon dating, confirming the above mentioned time range. However, their genesis is interpreted differently in the lower Rhine basin. There, a chernosem like soil is correlated with the regular burning of woody material by man at the surface. This activity during Neolithic settlement finally led to a dark burnt horizon (Gerlach et al. 2006; Eckmeier et al. 2008). The same idea was also discussed for the existence of the black clay layer in the Upper Rhine Valley (Seidel 2004; Mischka 2007; Burg 2008).

In contrast to the Upper Rhine Lowlands, the Southern Black Forest and the Northern Vosges, the pollen diagrams from the Central Black Forest (i.e. Angelsbachkar, no. 7 in Fig. 1 and Schurtenseekar, f in Fig. 3) show no human influence on the vegetation cover for the Neolithic Age (Friedmann 2000, 2002). A phenomenon for this period is the mass spreading of fir (*Abies alba*) and beech (*Fagus sylvatica*) in the Black Forest and the Vosges, which are typical representatives for the montane zones of these mountains even today. In the upper catchments of the Black Forest rivers, i. e. Schiltach and Elz, the initial growth of peat bogs increased in the Atlantic Period and continued far into the Subboreal showing no anthropogenic influence (Mäckel and Zollinger 1989; Schneider 2000; Häbich et al. 2005). According to the pollen analyses of sites in the Black Forest and the Vosges by Rösch (2000) and Sudhaus (2005) the first major clearing phase in the Holocene was detected at the end of the Neolithic Age to the early Bronze Age marking the first severe regional environmental interference. These different results show that the clear environmental contrast between the montane zones and the favourable lowlands only existed for a few high mountain areas during that time. During the warm period of the Neolithic Age the altitude with the associated relative differences in climate was not a limiting factor to colonization and land use.

3.2 Climatic changes and human impact on the environment during the Bronze Age

The environmental conditions during the Bronze Age and the changes resulting from human impact can be best discussed on the basis of pollen diagrams. The examples of the Wasenweiler Ried profiles represent the situation in the area around the Kaiserstuhl (location 2 in Fig. 1), the nearby loess covered plains and the Rhine terraces (Friedmann 2000; Lechner 2005). In the first period of the Bronze Age, open land increases (especially agricultural land) as indicated by elevated frequencies of cereals, weeds and grasses, which point to an extensive agricultural colonization and animal husbandry. Oak (*Quercus* spec.) decreases during the same time. On the basis of archaeological findings we can suggest a population density higher than ever before.

The second period of the Bronze Age is characterized by a change to moister and cooler climate conditions marked by an extension of woodland (especially oak, hazel and beech) and a decrease in agricultural land. This fact can also be observed in the declining values of Cerealia-pollen types and an increase in tree pollen in the diagrams of the Upper Rhine Lowlands, Wasenweiler Ried (Friedmann 2000; Lechner 2005) and in the foothills near Emmendingen (Schneider 2000). Human influence on the environment can also be demonstrated by the increase of geomorphological processes. Alluvial and colluvial sediments were mainly found in the preferred settlement areas of the Upper Rhine Lowlands, e.g. in the surroundings of the Kaiserstuhl, on the loess covered Rhine terraces and in the foothills of the adjacent mountains. They can be correlated with the second Holocene sedimentation phase according to Mäckel and Friedmann (1999) (Tab. 1). An apparent contrast to the Neolithic is the higher proportion of alluvial deposits, which document the higher rate of soil erosion and transport to the river channels. Due to higher rainfall, the rate of erosion increased in the first stage. Gradually the vegetation recovered and caused a reduction of hill wash activity in the second period.

Another example of human impact on the environment during the Bronze Age refers to the Basin of Zarten (Zartener Becken, location 6 in Fig. 1) in the western Black Forest. The basin is drained by the Dreisam river-system. Detailed studies on the sediment layers incorporating frequent artifacts could be carried out at exposures which arose in connection with the construction of the main road B 31-East (Friedmann and Mäckel 1998b). The newly constructed river channel for the Krummbach cuts through different Holocene terrace levels and the Wuerm glacial terrace. These terraces were common settlement areas for the growing population. The earliest alluvial deposits found could be dated back to Neolithic times (Mäckel et al. 2002). Most likely an extraordinary natural event caused the flooding and sedimentation on the alluvial plain, because no archaeological findings are associated with its deposition. Artefacts dating into the Bronze Age were the oldest found in the alluvial sediments together with ^{14}C-dated charcoal samples. The higher amount of sediments point to the fact that the woodland was presumably not only cleared on the basin floor but also on the adjacent hill slopes. Fine material was washed from the unprotected surfaces into the rivers and redeposited in the floodplains. The high amount of stones and boulders in these alluvial deposits indicate catastrophic flood events (Mäckel and Friedmann 1999).

The Bronze Age is marked by a bipartition caused by climatic change. It finally ends about 800 cal. BC with a climate depression: a change to a cooler and moister climate. Connected to the climatic conditions is the relation in the distribution of woodland and agricultural land. The other important phenomenon in the study area is the marked contrast between the climatically favoured loess areas of the Upper Rhine Lowlands and higher elevations of the Black Forest. Despite of the results from the relatively open Basin of Zarten there seems to be no human impact on the vegetation cover in the adjacent Black Forest and in the Vosges as illustrated in the pollen diagrams (Friedmann 2000; Sudhaus 2005). Only in the Southern Black Forest human impact is detected in the pollen diagram of Steerenmoos (Rösch 2000).

Also striking are the comparatively stable conditions of the valleys with regard to geomorphodynamic activities. No colluvial and alluvial sediments were recognized in connection with archaeological findings and peat formed in the valleys during this period, e.g. in the upper Elz (Schneider 2000) and Schiltach rivers (Mäckel and Zollinger 1989; Mäckel 2001; Häbich et al. 2005).

3.3 Climatic Changes and human-landscape-interaction during the pre-Roman Iron Age

The times at the end of the Bronze Age and in the beginning of the pre-Roman Iron Age have been widely reported as the main Holocene climatic pessimum (Schönwiese 1995). Again the climatic alteration caused a change in agriculture and settlement as also confirmed in other regions of Central Europe (Zolitschka et al. 2003). The final result in the Upper Rhine region was an extension of woodland at the expense of abandoned agricultural fields and pastures as shown in the pollen diagrams (Friedmann 2000; Lechner 2005). During that time the study area belonged to the heartland of the Celts (Fischer 1981). The Celtic epochs are distinguished between the Hallstatt culture (8th to 4th century BC) and the Latène culture (4th to 1st century BC). The settlements during the Hallstatt time were concentrated in the warmer and loess covered areas of the foothill zone

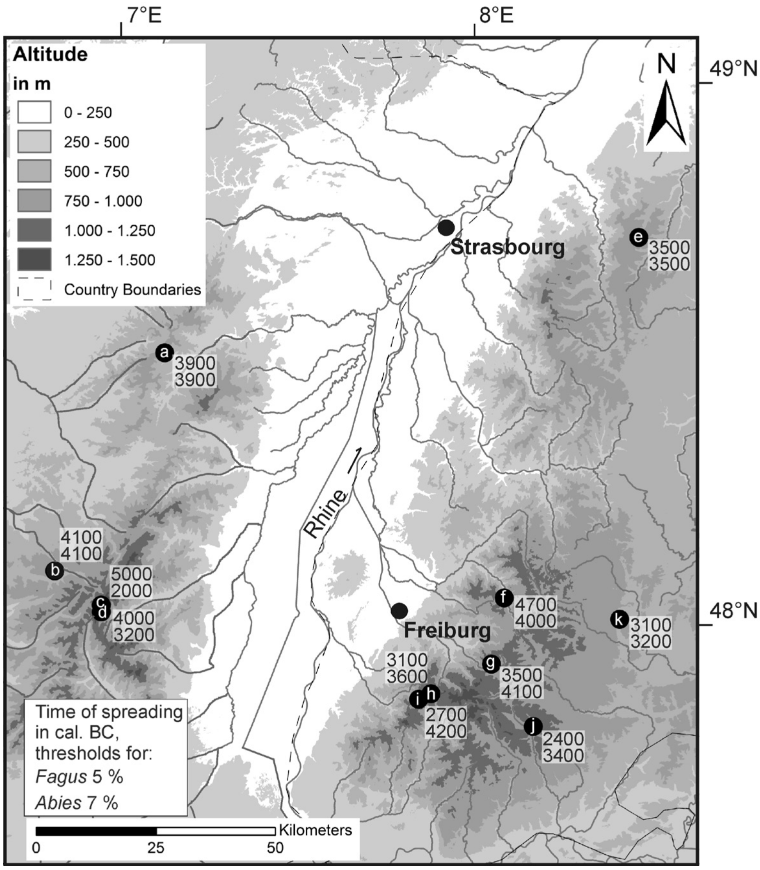

Fig. 3: Mass spreading of the fir (*Abies alba*) and the beech (*Fagus sylvatica*) as typical representatives for the montane vegetation zone of the Black Forest and the Vosges. The numbers give the time (cal. BC) of first appearance in the pollen diagrams based on ^{14}C-data by Friedmann (2000, 2002) and Sudhaus (2005). The letters mark some selected sample sites: a. Rond Pertuis supérieure (Sudhaus 2005); b. La Goutte Loiselot (Edelman 1985); c. Altenweiher (De Valk 1981); d. Feigne d'Artimont (Janssen et al. 1975); e. Wildsee (Radke 1973); f. Schurtenseekar (Friedmann 2000, 2002); g. Breitnau-Neuhof (Rösch 1989); h. Notschreimoor (Lang 2005); i. Glashofwaldkar (Friedmann 2000); j. Steerenmoos (Rösch 2000); k. Plattenmoos (Sudhaus 2005; Sudhaus et al. 2006)

and in the surrounding of the Kaiserstuhl. Higher rainfall caused the development of peat in moister depressions and on the valley floors, e. g. in the loess valleys of the Kaiserstuhl (Friedmann and Mäckel 1998a).

The altered conditions of climate and vegetation also caused a change in the geomorphodynamics. The concentration of overland flow during rainy seasons led to incision of the rivers in the foothills and on the adjacent terrace plains. The effects could be studied in the excavations at Ettenheim (north of Emmendingen, Fig. 1 and 2), where the important marker layer of the Holocene, the black floodplain clay, was incised by channels, captured or removed at the beginning of the pre-Roman Iron Age. At the bottom of such a channel, a shard of the Hallstatt culture was found. The channels were filled up by fluvial sands during the time of the Hallstatt culture as demonstrated by ^{14}C-dated charcoal pieces and finally covered by alluvial loam (Schneider 2000; Seidel 2004).

A noticeable human influence on the environment arose again during the Latène culture. This is shown by a decrease in woodland and an increase in open land in the pollen diagrams of the Upper Rhine Lowlands and in the western Black Forest (Friedmann 2000). The agricultural activities are documented by a higher percentage of cereals, weeds and pasture grasses. These changes indicate the extension of farming areas used by a growing population and an increasing number of settlements (Wieland 2003). Therefore many findings of the Latène Age were made in colluvial or alluvial sediments (Holocene sedimentation phase 3b, Tab. 1). The agricultural and pastoral use of the hill slopes and the improved farming techniques implements

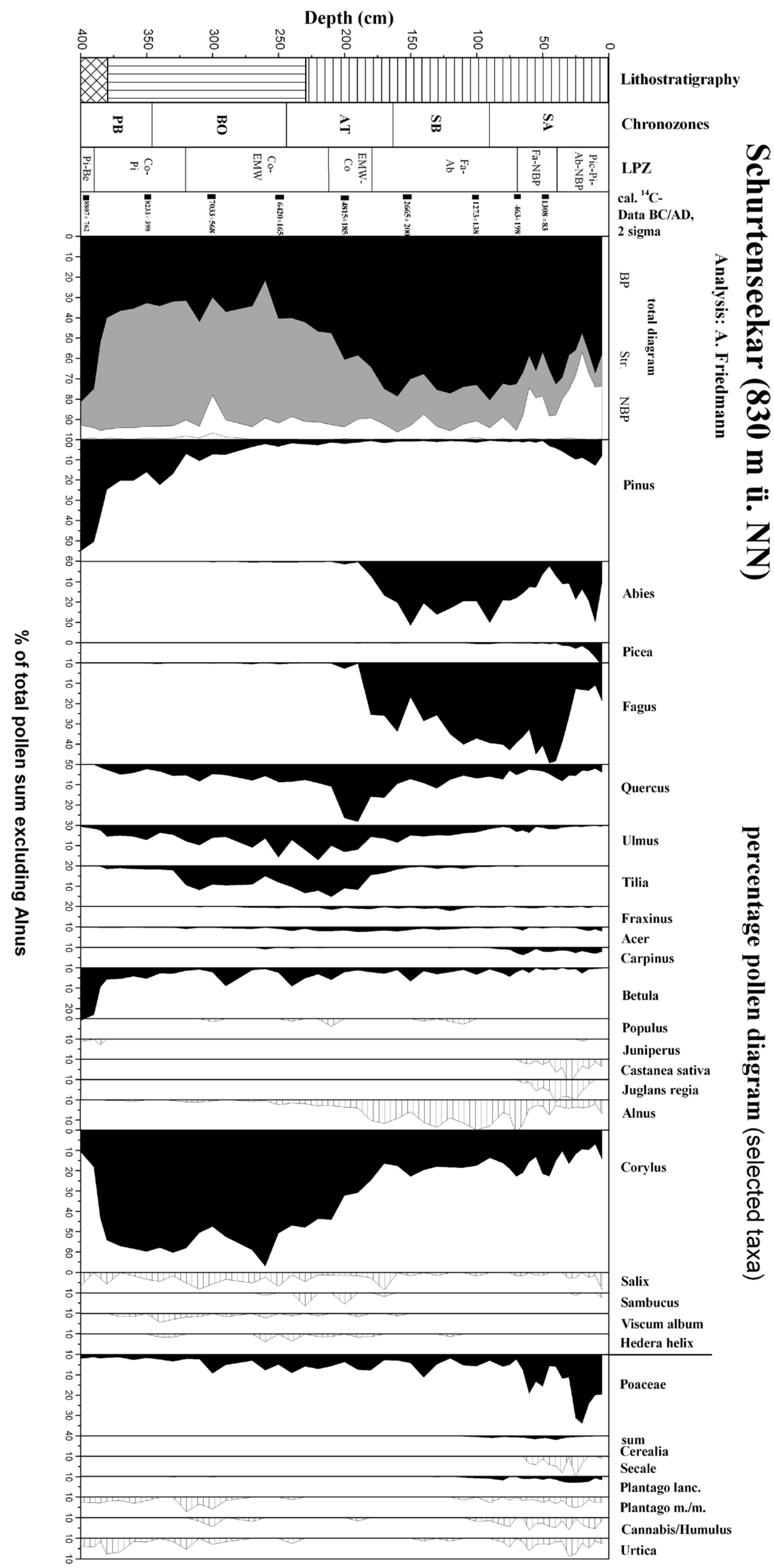

Fig. 4: Pollen diagram of the Schurtenseekar, Black Forest. The peat core was taken from a mire which developed in a glacial cirque. The lithology of the profile consists from the bottom to the top of *Phragmites*-, sedge- and *Sphagnum* peat. Only selected taxa are given, striped percentage curves are multiplied by 10 (modified after FRIEDMANN 2002)

caused higher soil erosion, including the deposition of not only fine but also coarse material. A striking feature is the occurrence of coarse sediment material in the Möhlin and Sulzbach valleys. The high amount of coarse fluvial material can be linked to the penetration of the Celtic groups into the Black Forest, where they cleared woodland for the first time on a large scale and began agriculture and animal husbandry. The fluvial deposits in the Basin of Zarten can be related to the Celtic fortification of Tarodunum, which was investigated in several detailed studies (e.g. Dehn 1999).

At that time settlements also extended to unfavourable areas in the Rhine Lowlands. Human influence on the riparian forest in the middle Upper Rhine region becomes visible in the pollen diagrams for the first time (Lechner 2005). In the Northern section also Dambeck (2005) explains the geomorphological dynamics which led to the development of the youngest meander generation with the anthropogenic influences in connection to changing climatic conditions.

In the valleys of the Möhlin and Sulzbach rivers (Southern Black Forest and foothill zone of the Markgräflerland, Fig. 1) and in the Glotter River, slags and shards of the Latène culture were found in fluvial sediments. Combined with ^{14}C-dated charcoal fragments these findings are suitable to verify the prehistoric mining activities during the Latène culture and the effects on vegetation and on geomorphodynamic processes. The ore mining during this time was also proved by a heavy-metal analysis of the corresponding sediments (Foellmer 1999).

3.4 Environmental changes during the Roman Period

The anthropogenic influence on the environment increased during the Roman period (1st to 4th century AD in the study area) through agricultural land use, military camps, road construction and settlements as well as mining. These Roman activities are confirmed by several archaeological studies in the Upper Rhine region (Steuer 2002; Nuber 2005; Faustmann 2005; Burg 2008). The pollen diagrams of the Upper Rhine Lowlands show an increase in cereal and pasture grass-pollen and a decrease in arboreal pollen (Friedmann 2000; Lechner 2005). The peak of the Cerealia pollen type points to an extension of agricultural fields, from which fine material could be eroded by water and wind. Noticeable is the occurrence of new plants such as walnut (*Juglans regia*) and sweet chestnut (*Castanea sativa*), which were probably brought to this area by the Romans together with wine (*Vitis vinifera*). The pollen spectrum also points on a shift to a drier and warmer climate than today (climate optimum of the Roman time). This change is also reflected in the modified settlement pattern, which were built up at formerly moist places such as valley floors and alluvial plains potentially endangered by flooding (Mischka et al. 2003; Faustmann 2005). Lechner (2005) and Beck and Blöck (2007), for example, report on the existence of roads and settlements with intensive land use (villae rusticae) in the area located between the Kaiserstuhl and the Tuniberg, even at the formerly moister sites of the Wasenweiler Ried fen. Colluvial and alluvial sediments with Roman artefacts and ^{14}C-dated charcoal originated from sites in the favourable settlement areas such as the Kaiserstuhl and the foothill zones. In addition, Roman relics can also be found in some river valleys of the Black Forest, e.g. near Tennenbach (Mäckel et al. 2003), in the Basin of Zarten (Mäckel et al. 2002) and in the Eastern Black Forest adjacent to the Baar (Sudhaus 2005) (Fig. 1). The corresponding deposits of the Roman time belong to the fourth Holocene sedimentation phase according to Mäckel and Friedmann (1999). Intensive silver mining during the Roman period was also archaeologically confirmed in the Sulzbach valley (Goldenberg 2003; Burg 2008). However, alluvial sediments correlated with Roman mining were not found in the upper section of the Sulzbach River. The reason might be the higher erosion and transport rate of the montane river. Therefore the sediments of Roman age were found at the exit of the river from the mountain zone into the Upper Rhine Valley (Mäckel and Zollinger 1995).

A sharp contrast can be recognized in the loess covered lowlands. Due to the dry and warm conditions, nearly no river channels could incise in the Upper Rhine Lowlands. Former erosion lines drowned in a surplus of hill wash material, which was transported after heavy rain falls from the unprotected slopes into depressions. As a consequence the characteristic loess valleys with flat floors (Lößsohlentälchen) developed in the Kaiserstuhl, the Tuniberg and in the foothills (Friedmann and Mäckel 1998a). The widespread Roman influence on soil erosion and sedimentation is also documented in maps showing the distribution of alluvial and colluvial sediments in this area (Mäckel et al. 2003).

The pollen diagrams from the Black Forest (i.e. Schurtenseekar and Glashofwaldkar, Fig. 3 and 4) show the marked human influence on the vegetation pattern in the mountain areas during the Roman Period (FRIEDMANN 2000). Woodland clearing continued from pre-Roman Iron Age and intensified in the Roman Period. This development is documented in the increase of non-arboreal pollen and a decrease of arboreal pollen. The latter fact can be related to the widespread use of timber for buildings (houses, bridges, ships) as well as for mining activities. The economic use of timber, especially *Abies* wood, is also documented by KÜSTER (1994) for the Roman time on the basis of several pollen diagrams in the Central European mountains. He even used the *Abies* decline in ^{14}C-dated diagrams as a time marker.

3.5 Environmental changes during Medieval Times

With the retreat of the Romans the population density declined and many settlements were abandoned. The mining activities also came to a standstill. In many sides the expansion of woodlands and soil formation indicate a phase of geomorphodynamic stability. The Germanic land acquisition (Alamannic landnam, 4th and 5th century AD) and the consolidation phase (6th and 7th century AD) only had significant influence on the environment in the loess covered and climatically favoured settlement areas of the Upper Rhine Lowlands and in the foothills of the Black Forest according to the archaeological sites mapped by STEUER (2002). Alluvial sediments from that time were found only in palaeo-channels of the Elz River and Rhine River north of the Kaiserstuhl (Holocene sedimentation phase 5, Tab. 1), which were verified by ^{14}C-dated charcoal fragments (SCHNEIDER 2000). However, comparable fluvial deposits do not exist in the valleys of the Central and Southern Black Forest. The lack of these sediments can be explained by land use changes and vegetation development. The pollen diagrams of the Black Forest and the Upper Rhine Lowlands show a decrease in the cultivation of cereals and an extension of grassland (meadows and pastures) and partially woodland regeneration (FRIEDMANN 2002). These land use changes can be correlated with a climatic deterioration during the pessimum of the time of migrating Germanic tribes, which is marked by considerable cooling. In many parts of the Upper Rhine Plain, for example in the Wasenweiler Ried, this development resulted in increased water-logging and peat growth. The cooler and moister climate conditions are further supported by higher frequencies of alder (*Alnus* spec.) in the pollen diagrams from the lowlands (LECHNER 2005). The spreading of woodland and grassland led to a better protection against soil erosion and might provide a possible explanation for the absence of an alluvial sedimentation phase in the Black Forest valleys during Alamannic times (sedimentation gap 1, cf. Tab. 1).

In the Black Forest an increased alluvial sedimentation recurred in connection with the medieval monastic and manorial colonization (10th to 12th century AD), which can be correlated with a warmer and drier climate (medieval climatic optimum). SUDHAUS and ZOLLINGER (2006) report on the existence of walnut in the Eastern Black Forest and the Baar. Human impact is also documented in the occurrence of medieval meadow loam deposits and colluvial sediments (Holocene sedimentation phases 6 and 7, Tab. 1). However, in the main European watershed area (Rhine – Danube) between Triberg and St. Georgen (Fig. 1, no. 4) the human influence on vegetation and soil erosion was evident. This happened long before the monastery St. Georgen (founded 1084) started with an effective colonization programme documented by radiocarbon dated charcoal in colluvial sediments, wood remains in peat and pollen analysis (HÄBICH et al. 2005, 2007; SUDHAUS et al. 2008; HÄBICH 2009).

The high sedimentation rate continued throughout Modern times (phase 8, Tab. 1). Today, the alluvial sediment cover accumulated on the top of the coarse deposits has a thickness between 50 and 150 cm in the valleys of the Black Forest. The greatest thickness (up to 275 cm) was found in the Tennenbach valley, east of Emmendingen (Fig. 1). Detailed studies on fluvial activity and river history were carried out in the last years in the upper reaches of the Schiltach river (MÄCKEL 2001; HÄBICH et al. 2005; HÄBICH 2009), for the Elz drainage area (SCHNEIDER 2000; SEIDEL 2000, 2004) and for the Sulzbach valley (BURG 2008). The results show an intensive influence of various economic measures on the development of the river channels and valley floors of the Black Forest. These include among others the widespread impact of mining, drainage management, energy production for mills, transport for timber as well as glass and charcoal production (LUDEMANN 1996, 2006; LUDEMANN and NELLE 2002; GOLDENBERG and STEUER 2004; STEUER 2004; NÖLKEN 2005). The high consumption of timber for various uses is documented by the decline of arboreal pollen in the mountain pollen diagrams. Noticeable is the abrupt decline of fir and the increase of cereals during the High Middle Ages (FRIEDMANN 2000, 2002). In the Northern Vosges a fir-beech-forest was completely destructed for charcoal production in the context of mining activity. This human activity led to a spread of hazel (*Corylus avellana*) and birch (*Betula* spec.). Agriculture is also intensive as demonstrated by an increase of Cerealia pollen type and the occurrence of hemp (*Cannabis sativa*) (Sudhaus 2005).

The human interference, in addition to catastrophic events such as heavy rainfall or sudden snow melting, temporarily led to extreme flooding and earth slips (Dostal 2005; Dostal and Thiem 2003). Climatic deterioration often caused a change in land use and of the intensity of geomorphological processes such as soil erosion. Compared to the intensive use of natural resources during Latène and Roman times the human impact on the environment was much greater which is documented in the higher rate of erosion and well-dated alluvial sediments of the valley floors. With the medieval colonization of the montane zones the highland-lowland-interaction was completed for nearly all parts of the investigation area.

4 Conclusions

With the aid of ^{14}C-dated pollen investigations, geomorphological and sedimentological methods the environmental history of the Upper Rhine area (lowlands and adjacent mountains) could be reconstructed for the Holocene. The hypothesis that the environment was much more influenced by human impact than previously suggested could be proved by archaeological findings in anthropogenically caused landforms and deposits. However, there exists a marked difference in the degree of influence in the various natural units of the study area. The frequency and concentration of ^{14}C-data derived from samples in alluvial and colluvial sediments document the different phases during the Holocene along a transect from the Rhine across the Black Forest (Fig. 5).

Cumulative frequency distributions of floodplain ^{14}C-ages for the whole Rhine catchment, including some of the dates shown in figure 5a, indicate an increased floodplain deposition for the Late Glacial-Holocene transition (1100-9000 BC) (Hoffmann et al. 2009). This is verified for the Upper Rhine Valley but not for the Black Forest. The reason might be the fact, that the uplands are rather regions of denudation and in the smaller valleys it is more likely that sediments are eroded by later fluvial activity. The following stable floodplain environment for the Upper Rhine Valley lasted until 8000 BC only, whereas it lasted until 5000 BC for the whole Rhine catchment

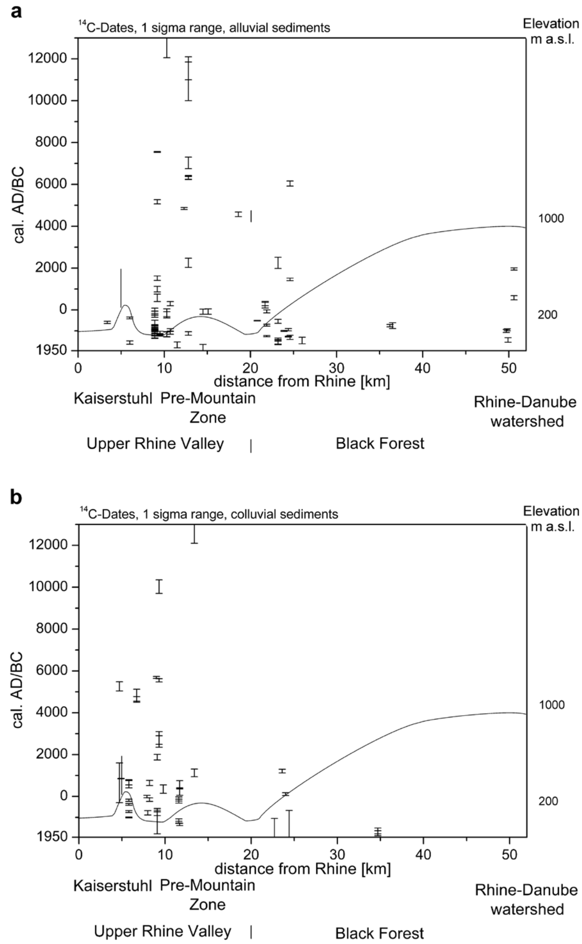

Fig. 5: Frequency of ^{14}C-data from samples of alluvial and colluvial sediments along a transect from the Rhine Lowlands across the Black Forest. There exist a higher amount of ^{14}C-data at favourable sites

(Hoffmann et al. 2009). From 8000 BC onwards moreover continuously floodplain sediments where deposited, also in the lower altitudes of the Black Forest.

Colluvial deposition started in the Neolithic Age at 5500 BC (Fig. 5b). Older dated hillslope sediments are caused either by solifluction during the Late Glacial or they correlate to a first large peak of hill slope deposition in Germany at 7000 BC. In this case they might represent a climate signal (Hoffmann et al. 2008). During the climatically warmer and drier Neolithic Age the favourable settlement areas of the loess-covered lowlands were densely cultivated as can be shown in pollen diagrams and sediments with artefacts. Accordingly, there existed an apparent contrast to areas located in the marginal higher mountains, which show only a few indications of human impact during this warmer period. A stable environment is given for 4000–3000 BC (gap of deposition). The following increase of geomorphologic activity is, by the possible inaccuracy of the dates, not unequivocally related to the beginning of the Bronze Age. Due to intensifying agriculture activities by the growing population from the Bronze Age onwards, the increased geomorphologic activity cannot clearly be related to climate (Hoffmann et al. 2008). 3000 years ago an accelerated increase of sedimentation rates started in the Upper Rhine Valley, while the sedimentation rates in the Rhine delta and Lower Rhine Valley increased more or less linear in time (Hoffmann et al. 2009). A feasible reason for this accelerated increase is a more intensive human impact in the Black Forest, shown also by the first alluvial deposits in the high mountain area.

According to the pollen analyses the Bronze Age is marked by a climatic bipartition. Again human impact is concentrated on favourable sites of the lowlands and intramontane basins. The shift to a wetter and cooler climate during the main Holocene climate pessimum at the end of the Bronze Age and the beginning of the Celtic Age is widely documented in the pollen spectra and in processes such as river incision and the deterioration of the Holocene black clay layer. A significant impact on vegetation and land surface is caused by the increase of settlements and the mining activities during the Latène culture. Besides the lowlands, also accessible sites of the high mountain zones reveal indications of human activities. Obvious are the differences between the Vosges and the Black Forest concerning the time of intensive land use in the high mountain zones. According to the pollen spectra there seems to be a later human impact on the environment in the Southern and Central Vosges, but not in the Northern Vosges.

An increased human influence on the environment can also be recognized during the Roman period. Roman interferences extended not only in the favourable lowlands but also to the formerly wet sites of the Rhine valley and to mires. Human impact was also documented in the high mountain zones of the Black Forest. Summarized, the anthropogenic activities during the Roman period were severe and lead to the most dramatic changes in the study area since the beginning of sedentarization. This fact is also documented in the distribution of alluvial and colluvial sediments. The magnitude of sedimentation for the period of the last 3000 years in the Upper Rhine Valley cannot be explained by the climate change during the Subboreal-Subatlantic transition alone (van Geel et al. 1998), it suggests further the importance of human interference for rising river sediment fluxes (Hoffmann et al. 2008, 2009). For this period the higher amount of sedimentation in the Upper Rhine Valley is probably caused by the far-reaching influence on the environment during Roman Time. This sediment supply also changed the fluvial system of the River Rhine, where incision stalled because of the changed sediment load as a result of human-induced soil erosion (Erkens et al. 2009).

The expansion of woodland and geomorphologic stability with soil development is widely reconstructed for the 4th and the 5th century AD. This fact can be correlated with the climatic deterioration (cooler and wetter than today) and the retreat of the Romans.

A marked change in the relation of woodland and open land took place with the medieval colonization, which was supported by the climatic optimum. Especially in the high mountain zones this is documented in the alluvial and colluvial sediments, the pollen spectra and wood remains in the mires.

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