Abstract

In 1996, well preserved deer bones, antler fragments and black grouse bones were found in a filled karst crack. Those animal remains were discovered in a limestone quarry in the Jura Mountains near Dittingen (canton Basel-Landschaft, Northwest Switzerland). The site is located in a gully of a dry valley beneath a loess covered high plain. In the framework of an archaeological excavation, the karst crack filling and overlying sediments (hill-washed loess, soils and colluviums) were documented. Samples for granulometry, geochemistry, micromorphology and palynology were analysed. The animal remains derived from the karstic fissure were radiocarbon dated to the early Bølling Interstadial (14'800 to 14'200 cal. BP). In addition, the palynological study shows that the overlying gully sediments were deposited between the Younger Dryas and the Middle Ages. The interdisciplinary investigation of the sediments revealed new insights into early soil formation processes, morphogenetic events and the vegetation history of periglacial environments. The new results clearly show that soil formation started immediately in the early Late Glacial. Decalcification and clay illuviation quickly developed in the course of intense vertical water flow through the sediment. It is therefore evident that luvisol development took place during the Late Glacial Interstadial (Bølling-Allerød Interstadial).

Introduction

The end of the last glaciation and the start of the rewarming in the Late Glacial was a time of great change not only for the areas covered by glaciers but also for the ones that were not covered by ice. While the development of the region’s vegetation has been thoroughly researched using palynological investigations (e.g. Becker et al. 2006; Lotter et al. 2012; Ammann et al. 2013a; Guélat & Richard 2014), far less is known about the geomorphological and pedological changes that occurred during the same time (Langohr & Sanders 1985; Kühn 2003; Kühn et al. 2010). This is because the Holocene soil formation processes have altered the late glacial soils to such an extent that it is rare to find Late Glacial soils preserved in their original form. The Late Glacial faunal site Dittingen-Schachlete forms a rare exception to this rule. Several karst cracks at the bottom of a dry valley were filled in with reworked loess and covered by massive colluvial deposits. Therefore, the karst cracks were protected from the effects of the Holocene soil formation processes. By this means, transported clods of soil and other pedorelicts were preserved. In other words, the cracks’ infilling can be used as an archive of Late Glacial soil formation processes.

Faunal site Dittingen-Schachlete

The faunal site Dittingen-Schachlete is located approximately 15 km southwest of Basel in Northwest Switzerland (Fig. 1). This area assigned to the Jura Mountains (Faltenjura), which are characterised by high plateau made of Jurassic limestones with plunging flanks and a thin Last Glacial loess cover (Braillard 2006) (Fig. 1). The rims of the plateau are traversed by several dry valleys which function as gullies. The site of Dittingen-Schachlete is situated in a gully at the bottom of the slope of “Vorderfeld”, a high plateau covered with loess (Fig. 1 and Fig. 2).

State of the art

The faunal site Dittingen-Schachlete was discovered when several karst cracks filled with brown loam outcropped during the extension of a quarry. In 1996, during this extension, faunal remains including a nearly complete antler were found in a karst crack which was 2 meters deep and 1.5 meters wide (Fig. 3, profile 1.2). An excavation to rescue the remains was initiated immediately (Fig. 2) and large numbers of red deer bones as well as remains of rabbits and black grouse were discovered. In addition to this, sediment and soil monolith samples as well as pollen and mollusc samples were taken from different profiles. In 1999, the first results were published (Rentzel et al. 1999). The actual interdisciplinary evaluation (Brönnimann et al. 2015) took place 15 years later as part of a larger research project about the Upper Palaeolithic in canton Basel-Landschaft. For this project, 30 14C AMS dating results were recalibrated and reinterpreted. Thanks to this, the faunal site Dittingen-Schachlete could be dated to the time period between 14'600 and 14'000 cal. BP, corresponding to the Bolling interstadial.
Figure 1: Red circle: Faunal site Dittingen-Schachlete; Arrows: Gullies; Yellow: loess loam deposits on the plateaus; Green: Jurassic limestones. Graphics: David Brönnimann, based on geological atlas 1:25'000 of Switzerland and Braillard 2006, Fig. 4.2. Reproduced with the authorisation of swisstopo (BA16121).

Figure 2: The faunal site Dittingen-Schachlete during the excavation in 1996. Centre: Topmost karst crack with faunal remains (profile 1.2). East wall of the quarry’s pit (profile 2) to the right. Photo: Archaeological Service Canton Basel-Landschaft.

Figure 3: Schematic north-south profile with the lower (profile 1.1; VII) and the upper karst crack (P1.2; VI) and the east profile (profile 2) with another karst fissure (V) and colluvial deposits (I-IV). Sediment complexes and subcomplexes are given to the right. Red: soil monolith samples (micromorphology). Green: palynological samples. Dark brown layers: high content of clay. Yellow layers: calcareous loam. Drawing: David Brönnimann, based on Rentzel et al. 1999, Fig. 3.
Late glacial environmental history and early soil formation in Northwest Switzerland

Materials and methods

The karst crack infilling - which is interspersed with animal bones - was sampled geoarchaeologically and palynologically (Fig. 3; profile 1.2). Further samples were taken from a second karst fissure situated lower than the first one (profile 1.1). A large east profile (profile 2) made it possible to investigate the covering loamy deposits, which were about 5 m thick.

A total of 15 block samples and 12 sediment samples were used for the geoarchaeological investigations. The block samples were impregnated with epoxy resin and then cut into polished sections of 1 cm thickness using a diamond saw. 23 thin sections were produced, which were described with the help of a binocular and a polarising microscope with 8-630x magnification (Bullock 1985; Goldberg & Macphail 2006). Methods used for sedimentological and geochemical analyses are described in Braillard et al. (2004).

The palynological results are based on 25 samples from the east profile (profile 2) and a series of samples that were taken from the block samples M1-4 with a distance of 1 cm between the different samples (Fig. 3). They were processed into 4-6 cm³ samples, because only minor pollen concentrations were to be expected. They were then prepared chemically-physically using hydrofluoric acid (HF 40%) and acetolysis according to the standardised methods used for palynology (Moore et al. 1991). The pollen concentration was estimated by adding a defined dose of Lycopodium spor tablets (Stockmarr 1971). The preserved specimen were analysed with the microscope with 400x magnification.

Results

The deposits of the geologically and palynologically examined profiles were divided into 7 sediment complexes - some of which were further divided into subcomplexes. Sediment complex V (karst crack in-
filling in profile 2) will not be treated in this paper as it has not been dated. The results are presented in Tab. 1-2 and in Fig. 4.

**Sediment complex VII - lowermost karst crack infilling (Oldest Dryas GS-2)**

The infilling of the lowermost karst crack (profile 1.1) consists of a calcareous silty brown loam with mollusc shell fragments, earthworm granules, and some limestone components. The pollen spectrum is characterised by grasses (Poaceae), sedges (Cyperaceae), wormwood (Artemisia), sunrose (Helianthemum), goosefoot (Chenopodiaceae), and other heliophilous herbs (Tab. 1). These taxa prefer treeless pioneer habitats and are considered typical for the Late Glacial cold steppe, just as the cold steppe itself is a characteristic of the Oldest Dryas. The occurrence of single juniper (Juniperus communis), sea buckthorn (Hippophaë rhamnoides), dwarf willow (Salix) and heather (Ericaceae) pollen prove that (prostrate) shrubs were growing in convenient locations as well. Another characteristic element of these Late Glacial steppe formations is the dwarf birch (Betula nana). Profile 1.1 could be correlated neither to the upper fissure (profile 1.2) nor to the east profile (profile 2).

**Sediment complex VI - karst crack infilling with faunal remains (Bølling interstadial GI-1e)**

The sediment complex VI comprises the loamy gravelly infilling of the topmost karst crack (profile 1.2) and the faunal remains embedded in the infilling. It is a stratified sequence of slightly clayey silt layers and loamy gravel layers, which have been divided into several subcomplexes. Iron-manganese precipitations and other indicators of hydromorphology as well as transported mollusc shell fragments and earthworm granules can be found in all
subcomplexes (Fig. 5.1 and Fig. 5.2). The geoarchaeological results show that this infilling was eroded on the plateau and washed into the karst crack as reworked loess featuring pedorelicts of early soil formation processes.

The lowermost subcomplexes VI-i and VI-k are only slightly calcareous. This indicates that their closer surroundings was decalcified to a greater extent. Thanks to a juniper phase of short duration followed by an expansion of birch woodlands, these layers can be dated to the early Bølling interstadial (GI-1e). As the subcomplexes VI-h and VI directly above the lowermost subcomplexes VI-i and VI-k are dominated by birch (*Betula*) and Scotch pine (*Pinus sylvestris*) (Tab. 1), it can be assumed that the subcomplexes correspond to the birch phase of the Bølling interstadial (GI-1e). The pollen preservation in the topmost subcomplexes VI-a to VI-e is strikingly poor. While the high concentration of fern pollen suggests that they came from a closed forest, the birch and pine pollen, which are corroded to a great extent, could originate from either the Bølling or Allerød interstadial or both (GI-1e-c). However, the 14C AMS dated bones embedded in the subcomplexes VI-f to VI-b indicate that the entire karst crack infilling should be classified as belonging to the Bølling interstadial, especially as the bones are well preserved which suggests a high sedimentation rate. The loamy karst crack infilling’s clayey, silty groundmass is completely decalcified in the sediment complex VI. Even more similarities between the sediment complex VI and IV-d become apparent when looking at the respective sediment’s compositions: the decalcified groundmass of IV-d features an abundance of inwashed gastropod fragments, earthworm granules, and several reworked clay cutan fragments (Fig. 5.4). The composition is the same as for sediment complex VI. Another feature of the sediment complex is the presence of rounded clods of an eroded Bt horizon (Fig. 5.3).

**Sediment complex IV-c - Late Glacial debris accumulation (Younger Dryas GS-1?)**

The limestone gravel layer (IV-c) lies on top of the Late Glacial reworked loess IV-d, thereby forming a distinct stratigraphic boundary between the two layers. As the layer below can be dated palynologically to the Late Glacial (IV-d) and the layer above to the Early Holocene (IV-b), it can be assumed that the sediment complex IV-c is attributed to the Younger Dryas (GS-1). Several other archives gave hints of periglacial processes of erosion and displacement during the marked climate deterioration of the GS-1 (e.g. Brauer *et al.* 1999; Litt *et al.* 2003; Vannière *et al.* 2004; Magny *et al.* 2006). The gravelly layer IV-c shows that the same development took place in Dittingen-Schachlete.

**Sediment complex IV-b - a phase of stability during the Early Holocene (Preboreal / Boreal)**

The sediment complex IV-b is the first to feature pollen of mesophilous deciduous trees such as hazel (*Corylus avellana*), oak (*Quercus*), and lime (*Tilia*), which suggests that the complex dates to the Early Holocene (Preboreal / Boreal). As more closed woodlands developed, the surface became more stable and the sedimentation rate declined. All these developments are seen as characteristic for the Early Holocene. A large number of the components embedded in the clayey-silty decalcified groundmass suggest that a part of the sediment complex consists of reworked topsoil material (earthworm granules, gastropod fragments) or reworked soil material of a Bt horizon. Furthermore, the sediment complex IV-b’s topmost pollen sample records the immigration of silver fir in the Middle Holocene (*Abies alba*) into the area, which is seen as indicative for the beginning of the Middle Holocene.

**Sediment complex IV-a and III - accumulation of reworked loess in the Atlantic and soil formation processes**

The sediment complexes IV-and III, which have been palynologically dated to the Atlantic, are homogenous silty loams, which are calcareous at the bottom (IV-a), but completely decalcified and very clayey at the top (III). The sediment complexes are
rereading process.

Table 2: Results of the palynological analysis of the east profile (P2, sediment complex III-IV).

<table>
<thead>
<tr>
<th>Profile sample</th>
<th>Profile</th>
<th>Pollen type</th>
<th>Pollen concentration</th>
<th>Pollen sum (numb. pollen/cm²)</th>
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<td>2 151</td>
<td>III</td>
<td>1</td>
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<td>PP14</td>
<td>2 129</td>
<td>III</td>
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<td>1</td>
</tr>
<tr>
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<td>2 123</td>
<td>IV-a</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>2 114</td>
<td>IV-a</td>
<td>1</td>
<td>1</td>
</tr>
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<td>III</td>
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Environmental History

The geoarchaeological and palynological results enable us to reconstruct not only the local vegetation history during the Late Glacial and the Early Holocene, but also the displacement and soil formation processes therefore foster a better understanding of the soil development. Thus, by taking into consideration the results from other regional and supra-regional research, we can trace the environmental history of Northwest Switzerland during the Late Glacial and Early Holocene.

The Last Glacial Maximum (LGM) - Loess accumulation and cryogenic sedimentation

In the Last Glacial Maximum (LGM) in Northwest Switzerland, periglacial dry-cold conditions with cold steppe vegetation prevailed (Ammann & Lotter 1989; Ammann et al. 2013b) and the karst cracks were sealed with ice (Campy 1990). During this time, aeolian sediments (loess) accumulated on the plateau. While these sediments could reach a thickness of several meters in the Sundgau and the Upper Rhine Region, the ones in the high plateau on the borders of the Birs Valley measured no more than a metre (Braillard 2006; Rentzel et al. 2009). Among the cracks, the frost action led to the formation of cryogenic deposits; whereas, in wide valleys, large amounts of gravel were accumulated by braided river systems. Between 30'000 und 11'000 cal. BP fluvial accumulation processes were responsible for the formation of the Lower Terrace in the Rhine valley (Kock et al. 2009). The Birs River accumulated gravel deposits of similar dimensions in the Delémont Basin (Guélat 2009, 2011; Guélat & Richard 2014). These processes of fluvial aggradation of gravel continued until the Oldest Dryas. It is because of these dynamic events the chances for Upper Palaeolithic sites to be preserved and discovered in a fluvial environment are very low.
Oldest Dryas (GS-2) - the beginning of decalcification processes

The precipitation increased strikingly in the course of the Oldest Dryas (GS-2), while the aeolian sedimentation decreased (Litt et al. 2003; Jöris et al. 2009). Palynological data suggests that, during that time, the site was part of patchy treeless tundra dominated by dwarf-shrub and steppe vegetation. Due to this, thin top soil could develop. Intense water percolation caused by thaw processes initiated soil decalcification. A partially decalcified loess, with traces of soil fauna (earthworm granules and gastropods), was washed into the lowest karst crack (sediment complex VII; profile 1.1).

Bølling interstadial (GI-1e) - decalcification and clay accumulation, first birch woods

The beginning of the Bølling interstadial (GI-1e; 14'600-14'500 cal. BP) is characterised by a mass expansion of juniper (Juniperus communis). At the same time, the wet climate intensified the processes of superficial erosion. This caused the karst cracks to be filled in gradually (sediment complex VI-k and VI-I) and a first covering layer to be deposited on top of the bedrock’s surface (IV-d). The high sedimentation rate ensured that animals that fell into the cracks were covered quickly by sediments and that therefore their bones were well preserved. As remains of red deer and black grouse were found, it can be assumed that the vegetation was a mosaic of juniper stands, open birch woods, and treeless grasslands. The results from the pollen analysis support this assumption.

In the course of the Bølling interstadial, birch trees gradually replaced the juniper shrubs. The area was dominated by open birch woods, (Becker 2003; Magny et al. 2006). Due to continuous vertical water percolation, a clay illuviation horizon below a topsoil was formed. Eroded clods enclosed in the karst crack (VI) and the lowermost covering layer (IV-d) hint at the soil horizons that were formed on the plateau. Therefore, we can postulate that a first luvisol (WRB 2006) was present in the vicinity during the Bølling interstadial.

Allerod interstadial (GI-1c to GI-1a) - a phase of stability, pine woodlands

In the sediments of Dittingen-Schachlete, it is difficult to discern the Allerod interstadial (GI-1c - 1a), which started around 13'900 cal. BP and lasted about 1'200 years. From a sedimentological and palynological point of view, the deposits display a hiatus between the Bølling interstadial and the Younger Dryas. This hiatus could be the result of a decrease in the processes of erosion and sedimentation. This could be triggered by the expansion of pine (Pinus sylvestris), which started during the Bølling interstadial and intensified in the Allerod interstadial to form closed pine forest, as shown for the Swiss Plateau and the Black Forest (Becker et al. 2000; Magny et al. 2003; Magny et al. 2006; Jöris et al. 2009). The pine’s expansion led to a phase of stability. This would explain why the pollen preservation in the topmost Bølling layers is not in a better state and why no Allerod layers are preserved at all. It can therefore be assumed that the Late Glacial luvisol continued to develop under the birch and pine wood cover. At the same time, in the Delémont Basin fluvioglacial system changed from braided river deposits to a meandering system with loamy deposits (Guélat 2009). This supports the image of a landscape covered with forests so that erosional processes were reduced.

Younger Dryas (GS-1) - reactivation of morphodynamic processes

Several Pollen archives from Switzerland and Germany have demonstrated that the Younger Dryas was associated with a far colder and dryer climate and an opening of the Late Glacial forests (Lotter et al. 1992; Becker et al. 2000; Litt et al. 2003; Magny et al. 2003; Magny et al. 2006; Ammann et al. 2013a), as well as with a reactivation of erosion processes (Becker et al. 2000; Magny et al. 2006). Profile 2.1 of the faunal site Dittingen-Schachlete records such processes. The cryoclastic, gravelly accumulation IV-c, which has been indirectly dated to the Younger Dryas (GS-1) suggests intense morphodynamic processes. The same has been shown for a reactivation of gravel aggradation in the Delémont Basin (Guélat 2009; Guélat & Richard 2014), which underlines that fluvial and colluvial processes have become increasingly dynamic.

Early and Middle Holocene - accumulation of reworked loess

The so-called Preboreal birch peak in sediment complex IV-b palynologically delineates the Holocene warming and deforestation, which began around 11'600 cal. BP. From a sedimentological point of view, a marked decline of the sedimentation rate can be noted, which intensifies in the course of the Holocene as a mixed oak forest was establishing. In the Delémont Basin, the Birs has developed a meandering river system with fine grained flood-plain deposits (Guélat 2009; Guélat & Richard 2014). The upper part of the sediment complex IV-b records the beginning of the Middle Holocene (Atlantic) with the first appearance of silver fir. In pollen records
from the Swiss plateau, the beginning of the Abies expansion is dated to about 8500-8000 cal. BP. The appearance of silver fir is accompanied with a decrease of the sedimentation rate, which is indicative of long-lasting stable conditions. The younger sediment complexes (IV-a to III) demonstrate a reactivation of erosion processes, temporary phases of stability followed by soil formation (III), and colluvial processes from the Iron Age or Roman Period onwards.

**Conclusion**

The faunal site Dittingen-Schachlete is an important archive of landscape history for the Swiss Jura Mountains and beyond, especially concerning the Late Glacial, as it permits valuable insights into the development of vegetation and soil. This importance is owing to the site’s location at the bottom of a sloping high plateau covered with loess and the karst cracks into which reworked loess has been washed in during the Late Glacial. As a result of this, the Late Glacial soil relicts, after it was eroded on the plateau and deposited in the karst cracks, were protected from Holocene soil formation and were therefore preserved in their original form. This rare situation made it possible to gain an insight into the pedological processes that occurred during the Late Glacial. In the process of evaluating the site, the close collaboration between geoarchaeology and palynology, turned out to be a valuable approach for the reconstruction of the environmental history.

The results show that the decalcification of Last Glacial loess cover began already in the course of the Oldest Dryas (GS-2). Moreover, we can show that clay illuviation processes and the formation of an initial Bt horizon first appeared in the Bølling interstadial (GI-1). Later during the Allerød interstadial (GI-1c-a), a luvisol developed. This observation contradicts several soil formation models, which believe that luvisols began to develop only later in the Middle Holocene (e.g. Schalich 1977, 1988; Scheffer et al. 2002; Altermann et al. 2005). However, pedological studies from France, Belgium and North Germany came to similar results as this study, in that they attest that decalcification and illuviation processes started considerably earlier (Slager & van de Wetering, H. T. J. 1977; Langohr & Sanders 1985; Langohr 1990; van Vliet-Lanoë 1990; Fechner et al. 1997b; Fechner et al. 1997a; Langohr 2001; Kühn 2003). Furthermore, it became apparent that we cannot assume that the vegetation and the soil developed in a linear way. Quite the opposite is the case. We must start from the premise that the Early Holocene’s history was changeable, with oscillating processes, and with dynamic as well as stable phases.

Reconstructing the Late Glacial sedimentation and vegetation history also made it possible to estimate the Upper Palaeolithic legacies that have survived until today. On the basis of environmental reconstructions, we can evaluate different ecotopes and ecological niches, as well as assess complex taphonomic processes. This is an essential prerequisite in order to locate Upper Palaeolithic sites. Thus, this study will prove to be a useful basis for future projects that seek to prospect and evaluate Late Glacial geoarchaeology and palynology.

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**References**


Vocation préhistoire

Hommage à
Jean-Marie Le Tensorer