Late glacial environmental history and early soil formation in Northwest Switzerland.

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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 Bølling interstadial.

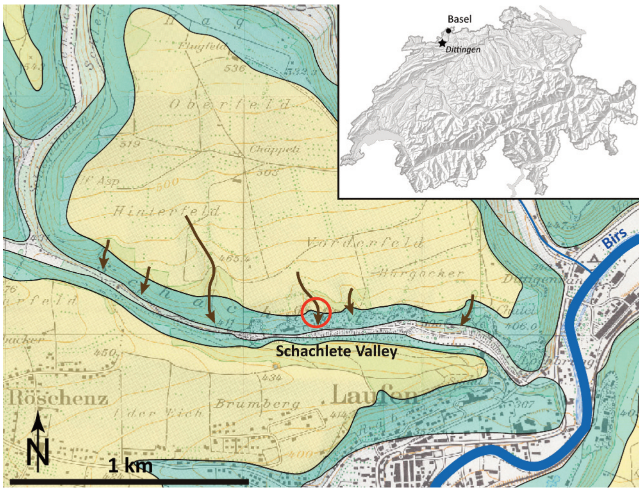

Figure 1: *Red circle: Faunal site Dittingen-Schachlete; Arrows: Gullies; Yellow: loess loam deposits on the plateaus; Green: Jurassic limestones. Graphics: David Brönnimann, based on geological atlas 1:25'000 of Switzerland and Braillard 2006, Fig. 4.2. Reproduced with the authorisation of swisstopo (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.*

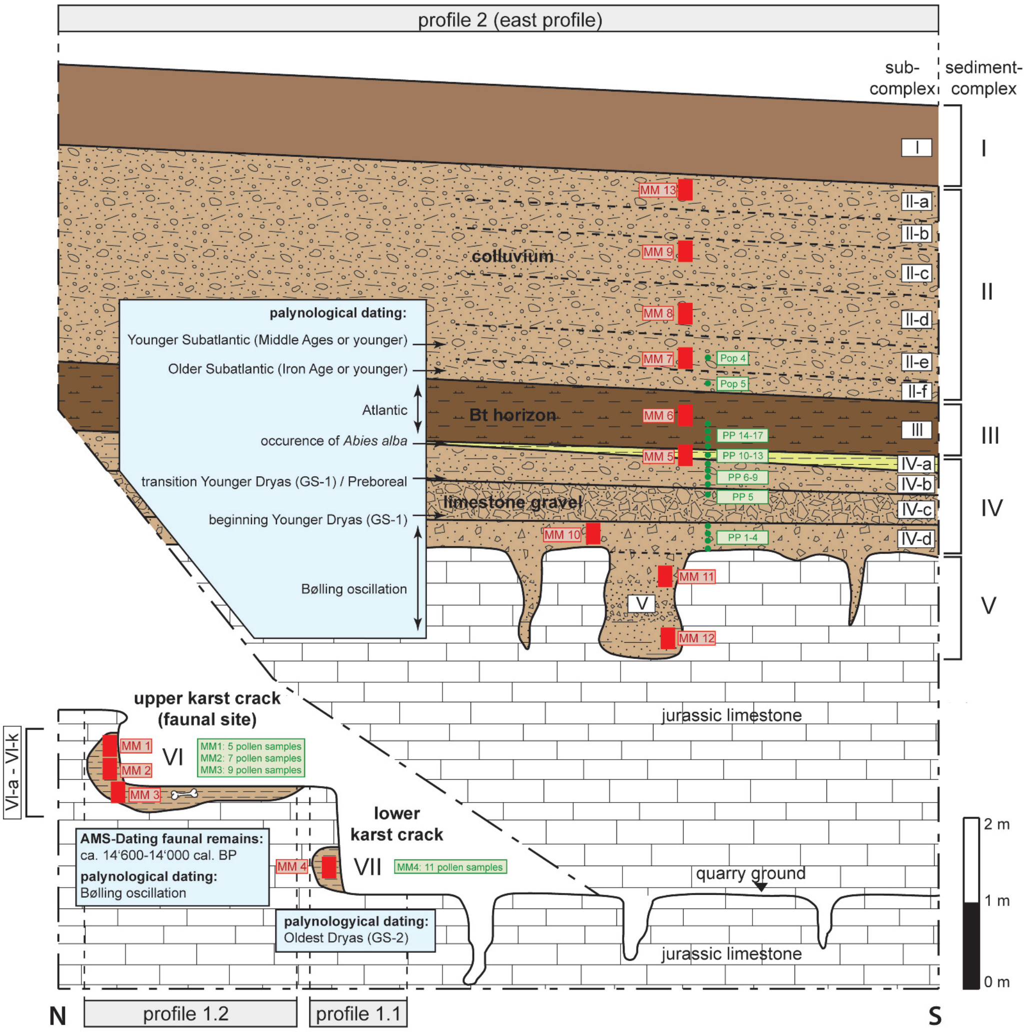

Figure 3: *Schematic north-south profile with the lower (profile 1.1; VII) and the upper karst crack (P1.2; VI) and the east profile (profile 2) with another karst fissure (V) and colluvial deposits (I-IV). Sediment complexes and subcomplexes are given to the right. Red: soil monolith samples (micromorphology). 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.*

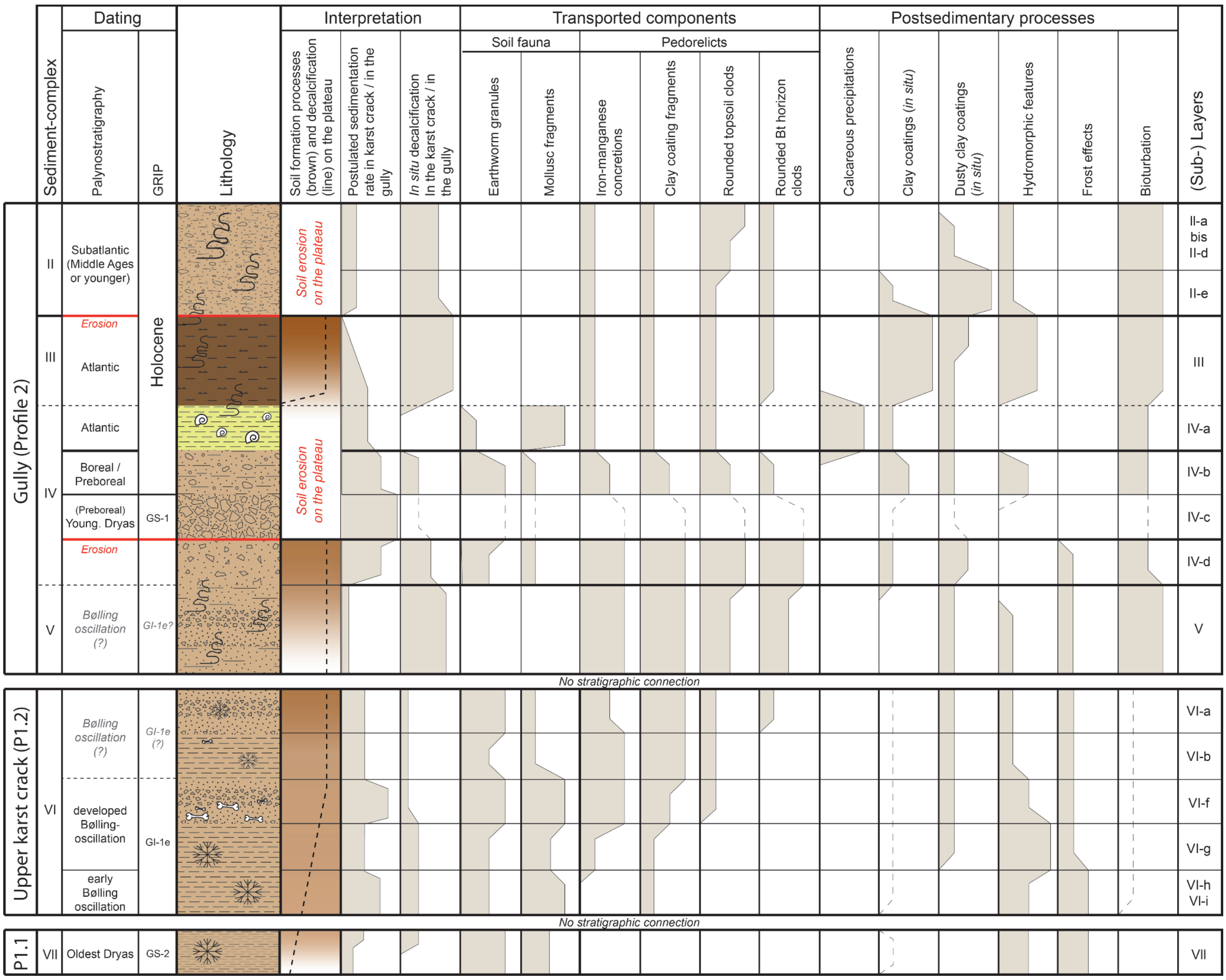

Figure 4: Schematic illustration of the micromorphological results including integrated palynological dating and a graphic interpretation of the different pedological processes. The estimations are semi-quantitative (absent - sporadic - constant - frequent). Drawing: David Brönnimann.

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 cm^3 samples, because only minor pollen concentrations were to be expected. They were then prepared chemical-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* spore 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-

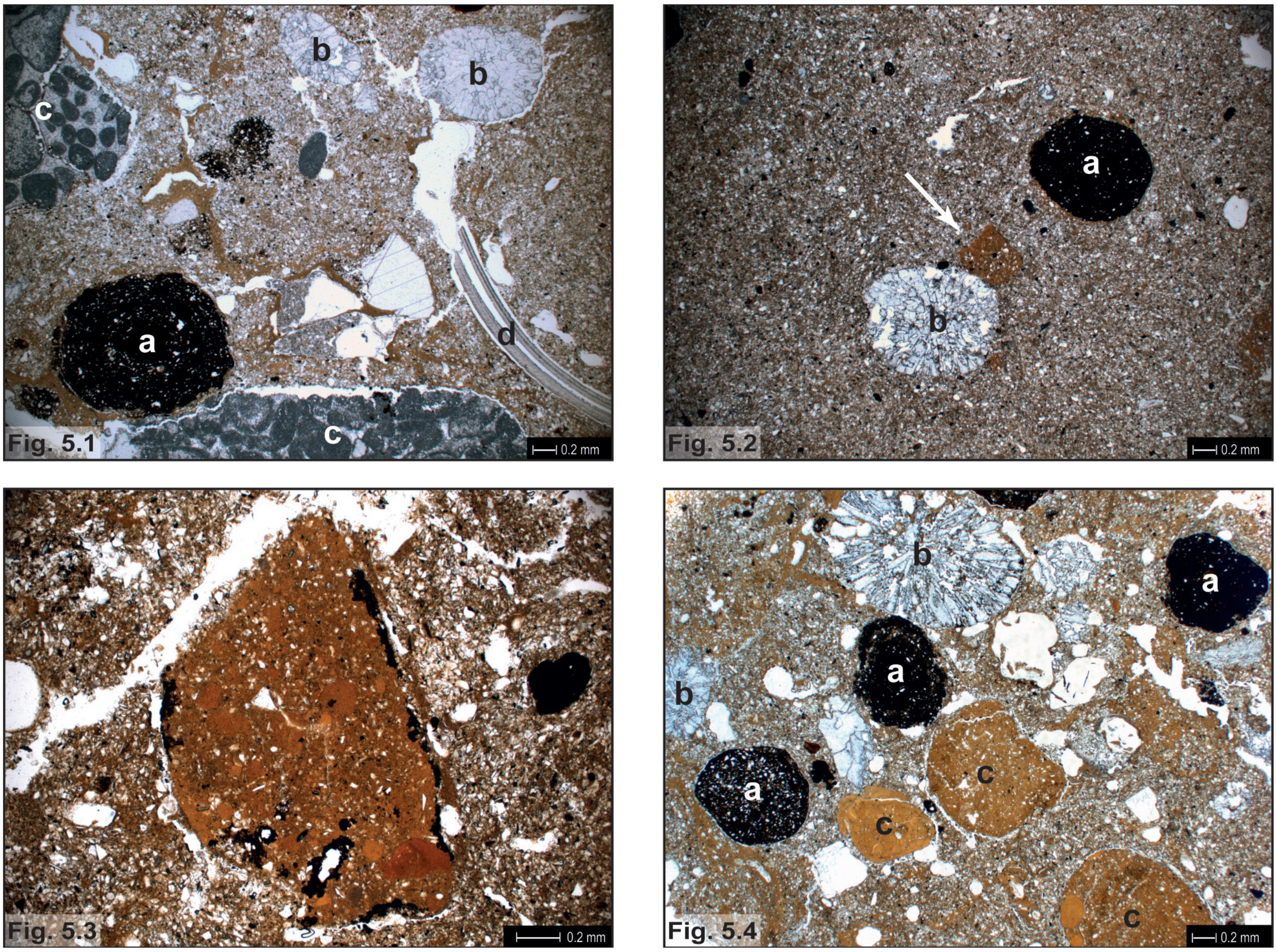

***Figure 5:** Microphotos. 5.1: Washed-in, decalcified, reworked loess accumulation in karst crack with transported, rounded components: a)iron-manganese precipitation; b) earthworm granules; c) limestone gravel; d) mollusc shell fragment. Sample 2.1; layer VI-g; 25x magnification; PPL (plane polarized light). 5.2: Washed-in, decalcified, reworked loess accumulation in karst crack with transported, rounded components: a) iron-manganese precipitation; b) earthworm granule with clayey loam attached to it (arrow). Sample 1.2; layer VI-c; 25x magnification. PPL; 5.3: Reworked loess with transported, rounded, clod of a clayey loam of a Bt horizon (luvisol). Sample 11.1; layer V; 50x magnification; PPL. 5.4: Reworked loess with transported, rounded components: a) iron-manganese precipitation; b) earthworm granules; c) clod of a clayey loam. Sample 10.2; layer IV-d; 25x magnification; PPL.*

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 (*Hippophoaë 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 surrounding 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 top layers VI-g to VI-a. However, the abundance of gastropod shells and earthworm granules (Fig. 5.1 and 5.2) indicate that the decalcification process did not occur inside the karst fissure but already outside the crack as a result of early soil formation processes. Fragmented clay cutans that were illuviated into the fine sediment are further indicators of early soil formation processes during the Bølling interstadial.

Sediment complex IV-d - Late Glacial reworked loess (Bølling and Allerød interstadial GI-1)

The clayey-silty loam (IV-d), which was found in the east profile (profile 2) immediately above the fissured bedrock, comprises limestone components. Due to its composition, the loam can be interpreted as reworked loess. Despite the pollen conservation being only poor, we were able to discern a juniper phase from the early Bølling interstadial at the profile's base. The layers situated above display birch and Scotch pine woods from the Bølling and the Allerød interstadial. This indicates that the lowermost sediment deposited at the same time as the karst crack infilling 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

Pollen sample	Profile	Sediment complex	*Juniperus communis*	*Hippophaë rhamnoides*	*Salix*	*Betula*	*Pinus sylvestris*	*Alnus glutinosa* type	*Poaceae*	*Cyperaceae*	*Artemisia*	*Achillea* type	*Centaurea scabiosa*	*Cirsium*	*Aster* type	*Filago* type	*Chenopodiaceae*	*Helianthemum*	*Linum*	*Plantago* undiff.	*Apiaceae* undiff.	*Brassicaceae*	*Campanula*	*Caryophyllaceae* undiff.	*Thalictrum*	*Trollis europaeus*	*Ericaceae*	*Fabaceae*	*Geranium*	*Lotus*	*Polygonum viviparum*	*Pulsatilla*	*Ranunculus* undiff.	*Rosaceae* undiff.	*Rubiaceae*	*Botrychium*	*Selaginella selaginoides*	*Polypodium vulgare*	Pollensum excl. *Polypodiaceae* &	Pollen sum (numb. pollen / cm3)	*Polypodiaceae*	*Polypodiaceae* - concentration	*Cichoriaceae*	*Cichoriaceae* - concentration
MM1-15	1.2	VI-a					2		1	1			1	1					1																				7	70	285	2850	300	3000
MM1-12	1.2	VI-a					8		1																														9	47	245	1286	250	1313
MM1-9	1.2	VI-a					8		7	4		1									1	2													1			1	25	175	60	420	215	1505
MM1-3	1.2	VI-b					8		5																														13	109	20	168	195	1638
MM1-2	1.2	VI-b					10		6	2			1																										19	200	48	504	240	2520
MM2-16	1.2	VI-e					1																																1	18	40	700	55	963
MM2-13	1.2	VI-e	2				5		4	4		1		1						1		1																	19	200	4	42	500	5250
MM2-12	1.2	VI-e					1		2	3	1			1														1											9	199			3	66
MM2-10	1.2	VI-f																																									180	1890
MM2-8	1.2	VI-f	3			2	25	1	34	15	4		3	1	1		1			2		4		1									1		1	2	2			470	6	27	450	2054
MM2-3	1.2	VI-g					21		15	8	1		3		1																				1	1			51	536	2	21	225	2363
MM2-2	1.2	VI-g	1				12		5	1	1		1	1																						2			24	101			140	588
MM3-12	1.2	VI-g	1				48	1	9	15	2		2	1								2							1				3			5			90	210	10	23	340	793
MM3-11	1.2	VI-g				2	41		6	6	1		1																1				1						59	146	11	27	334	825
MM3-9	1.2	VI-h				3	3		10	2	1		2									1			1											1			24	72	2	6	1200	3600
MM3-7	1.2	VI-h				4	11		5	2			1								1																		25	88	5	18	900	3150
MM3-6	1.2	VI-h	2			2	10	1	20	3	1	2	11	1	2			2			1	1			1								1						61	128	10	21	1600	3360
MM3-5	1.2	VI-h	1			2	13		8	4	1	1	4		1						1				1								1						38	129			720	2439
MM3-3	1.2	VI-i	20	1		1	1		11	15		1	1		1																								52	1560			180	5400
MM3-2	1.2	VI-i	71	1	1	2	7		27	44	1	1	1									1													1				158	4148			155	4069
MM3-1	1.2	VI-i	430	1	2	10	20		126	175	3	5	3		3	1		1			1	4		3	1		1					1	2		1	1			795	12842			530	8562
MM4-15	1.1	VII				1	3		6	3	2		1	1	1							5														1			24	112			550	2567
MM4-12	1.1	VII	4	1		1	8		21	6	11	1	6	3	1		2				2	7		1	1			1					1		1	2			81	396			560	2735
MM4-11	1.1	VII	5	1	1	7	8	1	36	7	3	2	9	2	2		4	3	1	1	1	1		1	1							1	2			3	1		104	248			1300	3102
MM4-9	1.1	VII				1	1		6	1	1														1														11	66			94	564
MM4-7	1.1	VII					3		10	6	2		1		2			1				1					1												27	298			210	2321
MM4-6	1.1	VII	2			2	8		36	13	6		8	3	1			1			2	4				1									2	1	1		91	425			480	2240
MM4-5	1.1	VII	1				9		24	8	4	3	4		1		1					3		1					1				1		1				62	651			277	2909
MM4-4	1.1	VII	17	1	3	1	12	1	95	32	8		4	1	3	3	4	2		2	4	7	1	1	1		1	2	1	1	3		4	1	4	2	1		223	446			880	1760
MM4-3	1.1	VII	1			1	5		16	5	2		1				1	1			1	2																	36	378			160	1680
MM4-2	1.1	VII	8			3	8		40	11	8		1		3	1	2	1			1	4		1	1				1						2				96	630			75	492
MM4-1	1.1	VII	6	1		3	9		65	8	10		1		2	3		1			2	3							2						3				119	658			580	3205

Table 1: *Results of the palynological analysis of the lower and upper karst crack (P1.1 and P1.2, sediment complex VI-VII).*

Pollen sample	Profile	cm under edge profile	Sediment complex	*Juniperus communis*	*Salix*	*Betula*	*Pinus sylvestris* type	*Corylus avellana*	*Alnus glutinosa* type	*Quercus*	*Ulmus*	*Fraxinus*	*Tilia*	*Abies alba*	*Poaceae*	*Cyperaceae*	*Artemisia*	*Achillea* type	*Centaurea scabiosa*	*Filago* type	*Rumex*	*Apiaceae* undiff.	*Brassiaceae*	*Caryophyllaceae* undiff.	*Thalictrum*	*Rubiaceae*	*Botrychium*	*Selaginella selaginoides*	Pollensum excl. *Polypodiaceae* & *Cichoriaceae*	Pollen sum (numb. pollen / cm^3)	*Polypodiaceae*	*Polypodiaceae* - concentration	*Cichoriaceae*	*Cichoriaceae* - concentration
PP17	2	151	III																												8	67	5	42
PP16	2	140	III				2				1				1								1						5	53	6	63	16	168
PP15	2	134	III																												4	42	4	42
PP14	2	128	III			1	2	10	2	8	6	1	18	45	4	4			1	1		1				1			105	551	101	530	12	63
PP13	2	123	IV-a					1			1	1		1	1														5	21	20	84	4	17
PP12	2	114	IV-a										3		1	1													5	21	20	84	4	17
PP11	2	108	IV-a					2	1	1	1		3	21	2	3								1					35	184	19	100	1	5
PP10	2	105	IV-a										1	1	1														3	25	2	17	3	25
PP9	2	93	IV-b				1	1	3				2	3	1	1													12	84	5	35	1	7
PP8	2	87	IV-b					1					2		2														5	26	4	21	5	26
PP7	2	78	IV-b			1	1	1				1	1																5	53	1	11	1	11
PP6	2	70	IV-b		2	27	19	1		1			1		2	2	1	1			1	1	1						60	158	7	18	13	34
PP5	2	60	IV-c			4	3		1						2	1		1		1						1	1		15	105	6	42	6	42
PP4	2	30	IV-d				4								1							1							6	63	1	11	8	84
PP3	2	21	IV-d				2		1						3	3													9	95			32	336
PP2	2	15	IV-d			1	1								2	2	1												7	37			100	525
PP1	2	10	IV-d	2		1									27	12	2	1	3	1					1			3	53	186			440	1540

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

reworked loess deposits with an abundance of transported pedorelicts (Fig. 5.4), which originated from an eroded luvisol. Therefore, a developed luvisol must already have been formed on the plateau in the Atlantic. This luvisol was then truncated by severe erosion processes and was later redeposited at the bottom of the slope. It is not possible to determine whether these extreme colluvial processes were due to human activities (e.g. clearing woodland) or not. Furthermore, soil formation occurred during a longer phase of stabilisation on the reworked loess layers IV-a and III, which resulted in the development of a Bt horizon of several decimetre thickness (III).

Sediment complexes I and II - colluvial deposits

A thick loamy and gravelly colluvial deposit with only a low pollen frequency is located on top of the Middle Holocene layers. Despite the scarcity of pollen, indicators of land use at the base of the sediment complex II-f can be found. Additionally, in the above situated sediment complex II-e, hornwort (*Anthoceros agrestis*) and ray (*Secale cereale*) were attested. Therefore, it can be assumed that the area was also used for agriculture in the Middle Ages and that it was this agricultural use of the area which influenced these colluvial processes.

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 cryoclastic 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). At slope sides, the frost action led to the formation of cryoclastic 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-l) 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.

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

In the sediments of Dittingen-Schachlete, it is difficult to discern the Allerød 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 Allerød 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 Allerød 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 fluvial 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 palynogically 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, thebeginning 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.

Acknowledgment

We would particularly like to thank Jürg Sedlmeier for his scientific inputs and fruitful discussions. We also owe an immeasurable debt of thanks to the Archaeological Service of canton Basel-Landschaft for making the emergency excavation of 1996 and the profile survey of 2011 possible. Furthermore, we also thank Bruno Baur und Trudi Meier (University of Basel) for the malacological analyses, to Beatrix Ritter (University of Basel) for the sedimentological and geochemical laboratory work, to Thomas Beckmann (Braunchweig, Germany) for making the thin sections, to Georges Bonani (ETH Zurich) and Klaas van der Borg (Utrecht University) for the 14C AMS dating and to Olivia Klee for the English translation.

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