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The concept of the Pleistocene periglacial cover beds in central Europe: A review

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ABSTRACT

In low mountain areas of central Europe, Pleistocene periglacial conditions and relevant processes have led to the formation of cover beds. In general, Holocene soils are not developed in bedrock, but they have formed in periglacial cover beds. Their occurrence and characteristics control the spatial distribution of soils, and thus periglacial sediments are a useful tool for soil mapping and soil survey. The concept of periglacial cover beds distinguishes four main layers: topmost, upper, middle and basal periglacial cover bed. The upper and middle layers contain loess, whereas the basal one consists entirely of bedrock. The loess content causes an increase of site-specific soil ecological quality in comparison to soils formed directly on bedrock. The occurrence and characteristics of the cover beds is reviewed, summarizing the present state-of-the-art.

1. Introduction

In central European low mountain areas, Holocene soils developed mainly from periglacial cover beds. These periglacial sediments control the formation of soil type, the distribution of soils, and ecological conditions of a landscape. Therefore, several studies in Germany have focused on the role of periglacial cover beds, and a concept of periglacial cover beds related to their occurrence and spatial distribution was primarily developed for German low mountain areas (Schilling and Wiefel, 1962; Semmel, 1966). Recently, the concept was applied and transferred to further study areas including the Swiss Plateau (Mailänder and Veit, 2001) and Lower Austria in the northern Vienna Forest (Damm and Terhorst, in press; Terhorst et al., 2009). Kleber (1997) investigated periglacial cover beds amongst others in the Russian Plane and the northeastern Great Basin with the adjacent Rocky Mountains (USA). In central European low mountain regions, studies dedicated to unconformities in soils are numerous. Moreover, the concept of periglacial cover beds is involved in the German mapping key for soils (AG Boden, 2005). However, it is still disregarded in Soil Science and is more closely related to the field of Soil Geography.

Most soils did not develop in situ as weathering products of specific bedrock. The parent material corresponds to solifluction layers of variable composition, which formed under Pleistocene periglacial conditions. Blanckenhorn (1895) provided the first evidence of debris layers and proved their non-glacial genesis in the "Taunus" low mountain area in the Rhenish Massif. During this time, periglacial debris was inadvertently interpreted as basal till. Later, Müller (1954) pointed out the relevance of periglacial layers for modern soils in the northern Rhenish massif, and Biebelriether and Sperber (1958) provided similar results for the Spessart region.

Although from the 1960s numerous papers were published related to this topic, most textbooks of Soil Science still disregarded the studies, as mentioned by Sauer (2002). There are only a few exceptions, such as Fiedler and Hunger (1970), Rehfuess (1981), and Kuntze et al. (1994). The German soil mapping key did not involve the concept until the 4th edition (AG Boden, 2005).

Nevertheless, the assumption that the involvement into the official German mapping key for soils might cause a broader acceptance inside the field of Soil Science was too optimistic, as shown (e.g.) by the 'Travel guidebook to Soils of Germany', published by the German Federal Environmental Agency ('Reiseführer zu den Böden Deutschlands'; Umweltbundesamt, 2001), which ignores the concept of periglacial stratification completely. In general, the widespread lithological stratification of soils cannot be learned from textbooks. Therein, the parent material is described as homogeneous bedrock (Bleich et al., 1987; Mückenhausen, 1993; Scheffer et al., 2010).

However, more recent case studies and results of soil mapping have demonstrated an overall inhomogeneity and stratification of the parent material in soils of low mountain areas (Bibus, 1985; Kösel, 1996; Terhorst, 2007) and underlined the importance of the concept for soil survey, environmental aspects, and applied tasks (Bibus and Terhorst, 2001; Scholten, 2003; Sauer and Felix-Henningsen, 2006; Damm and Terhorst, in press). Nevertheless, genesis and age of periglacial cover beds are still subject to critical

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discussion (Völkel et al., 2002; Semmel, 2005; Semmel and Thiemeyer, 2005).

In the present review article, described soil profiles are designated to illustrate the stratification of the soils in low mountain areas. It aims to highlight the formation of the cover beds under periglacial conditions. Furthermore, it is shown that the concept of periglacial cover beds as contained in the German soil mapping key is greatly applicable for field surveys (c.f. Semmel, 2007).

2. The concept of the periglacial cover beds

To classify periglacial cover beds, a concept was originally developed by Schilling and Wiefel (1962), Semmel (1966) and, recently, applied to more practical formulations (Felix-Henningsen et al., 1991; Semmel, 1993; Sauer, 2002; Völkel et al., 2002; Lorz and Phillips, 2006; Terhorst, 2007). In central European regions, particularly in low mountain areas, Holocene soil formation took place in periglacial cover beds that were mainly formed during the last glacial period. There is evidence of older periglacial cover beds as well (Terhorst and Felix-Henningsen, 2009).

In general, the disconformities are caused by solifluction processes in the former active layer, on top of the former permafrost table. A series of characteristic features occur inside the periglacial layers, such as ice wedges, cryoturbation structures, wavy boundaries, clasts concentrated between the boundaries of the layers, high bulk density, and an admixture of loess. Periglacial cover beds are widespread in low mountain areas and show systematic stratification.

Four main Pleistocene periglacial strata, formed by solifluction processes, can be distinguished:

1st The underlying basal periglacial cover bed, or basal layer (according to Mailänder and Veit, 2001) is composed of bedrock present in the surrounding slopes (Fig. 1). During the formation of the basal layer, bedrock and periglacial debris formed the surface before the onset of loess accumulation. The basal bed is therefore almost free of allochthonous material. Rock fragments are usually oriented parallel to the slope.

2nd The middle periglacial cover bed or intermediate layer (Mailänder and Veit, 2001) can be superimposed on the basal periglacial cover bed and is mainly found in sheltered morphological positions (Fig. 1). In addition to material originating from bedrock, this layer contains loess as well. According to the German Mapping key for soils (AG Boden, 2005) intercalated clasts are diagnostic. Where solifluction has reworked pure loess, a definitive classification is difficult (Sauer, 2002). Most authors assume a Late Glacial formation of this cover bed (e.g. Semmel, 1996; Mahr, 1998; Hülle et al., 2009).

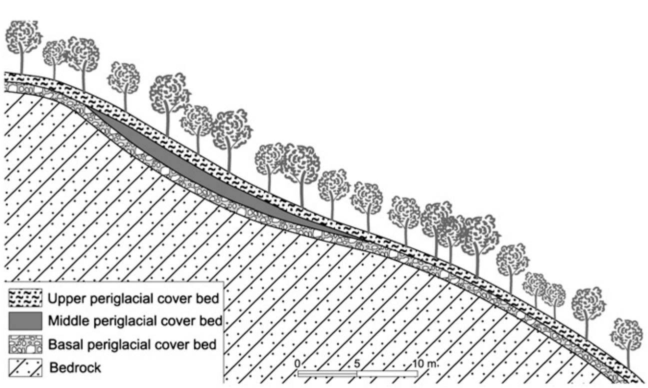


Fig. 1. Scheme of distribution and geomorphological dependence of the occurrence of periglacial cover beds in central European low mountain regions.

3rd The upper periglacial cover bed is widespread with a homogenous thickness of 30–70 cm, thus reflecting the depth of the former active layer (Fig. 1). This cover bed has enhanced silt contents in comparison to the underlying soil horizons. The silt component is derived from Late Glacial loess deposition, and contains minerals which have been transported long distances. This stratum can be distinguished macroscopically and microscopically from the other cover beds. In general, it consists of rock fragments and loess.

In central European areas, the upper periglacial cover bed shows a volcanic component, which comprises the minerals characteristic of the Laacher See Tephra (LST), namely brown amphibole, titanite, and augite. LST is widespread in central Europe and exhibits the described combination of minerals, thus being easily distinguished from other tephra (Fig. 2). LST constitutes the most important stratigraphic marker in Late Glacial deposits in central Europe. The eruption of the Laacher See volcano is dated to 12,900 BP (Schmincke, 2000, 2006), and the LST can be used as a chronostratigraphic marker for the formation age of the upper periglacial cover bed. After the deposition of volcanic minerals, the aeolian and volcanic components were admixed with bedrock by solifluction. The age of the last solifluction phase as recorded in the upper periglacial cover bed is

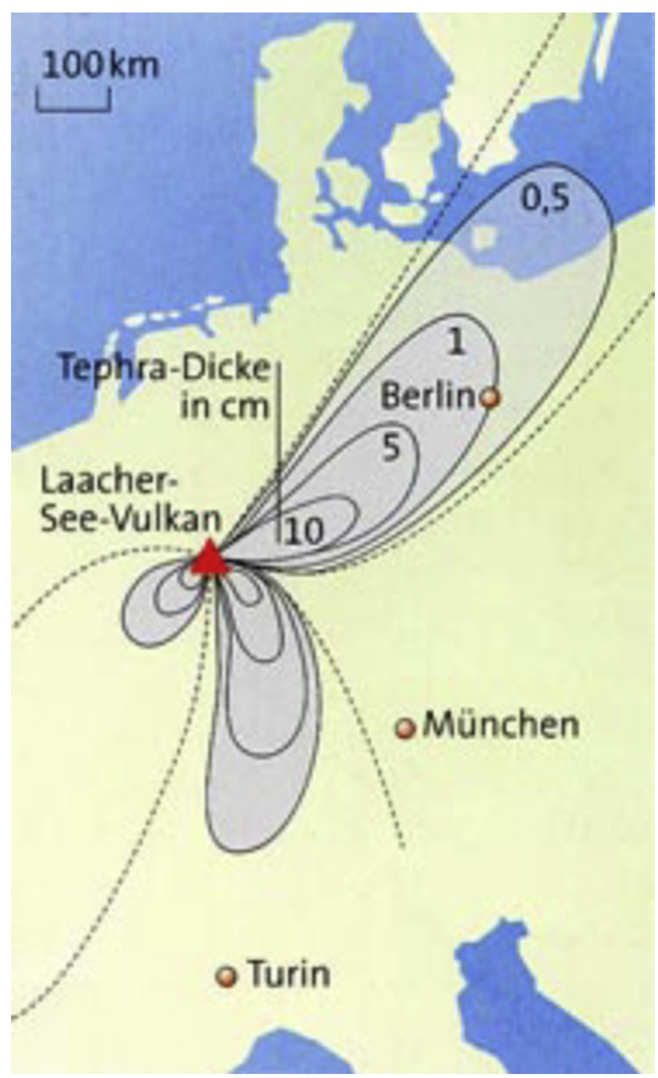


Fig. 2. Distribution and isopach map of major Laacher See Tephra fans (Schmincke, 2000).

definitely younger than the LST, 12,900 BP. Beyond this date, there is only one period of periglacial conditions documented in central Europe – the Younger Dryas, representing a timespan between 12,700 and 11,600 BP (Litt et al., 2003). Consequently, the solifluction formation of the upper cover bed can definitely be dated to the Younger Dryas (Semmel, 1993; Sauer, 2002). This knowledge can be transferred to regions where the upper periglacial cover bed can be identified without presence of the LST minerals.

In the context of the concept, the most frequent stratification corresponds to the superimposition of the upper periglacial layer on top of the basal one (Fig. 1). In general, the occurrence of the upper periglacial cover bed is almost ubiquitous (Semmel, 1968; Sauer and Felix-Henningsen, 2006). Absence of the cover bed is interpreted as a sign of anthropogenic induced erosion (Semmel, 1966; Terhorst, 2007). In preferentially sheltered geomorphological positions, such as platforms or smooth paleochannels, the middle periglacial cover bed is preserved (Fig. 1).

4th The youngest cover bed is the uppermost periglacial layer, which occurs at altitudes above 500 m and in exposed positions, where consolidated bedrock is exposed in the upper slopes. Frequently, it is difficult to distinguish the uppermost periglacial layer from anthropogenic ones (see Altermann et al., 2008). It occurs rarely and is not of importance for this discussion.

3. Substrata homogeneity versus inhomogeneity

In general, exposures of bedrock of German low mountain areas show that the horizons near the surface have been modified. Fig. 3 presents an example of a Cambisol situated in the Taunus, where Variscan folded clay schists are oriented following the present day slope inclination. The inclination of the clasts increases, resulting in an orientation of the long axes parallel to the slope in the upper 50 cm of the Cambisol. Simultaneously, the orientation of the coarse components is variable. In the basal parts of the profile, the clasts are characterized by an orientation across the slope, whereas they rotate to a position parallel to the slope near the surface. Thus, the described phenomena indicate solifluction, respectively soil creeping (Washburn, 1973).

In substrates, which contain only single rock fragments or which are free of clasts, redeposition is not as evident. Cambisols on top of clayey-silty Bunter Sandstone seem to form primarily in the bedrock (Fig. 4). However, in extensive exposures there is evidence of redeposition as well. For instance, the same Cambisol contains large blocks and rock fragments of sandstones, which in general wedge out in the upper slope. Thus, the blocks moved downwards and are characterized by a slope parallel orientation.

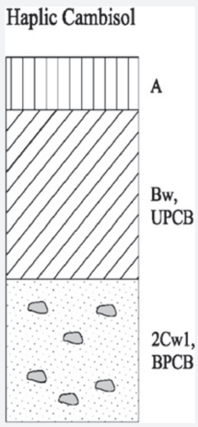
Fig. 3. Upper periglacial cover bed on top of Paleozoic schists near Lorsbach/Taunus, Rhenish massif (Germany).

Fig. 4. Cambisol inside the upper periglacial cover bed on top of the basal periglacial cover bed, SE Neukirchen/Fulda-Werra Mountains (Germany).

This process is reflected by the results of the laboratory analyses (Table 1). The loamy substrate below the Haplic Cambisol shows higher contents of clay (I/3: 21.7%) as well as in medium sand fraction, whereas the silt content is significantly reduced in comparison to the upper periglacial cover bed (I/1). The silt content reaches 34.6% in I/1, and in particular coarse silt is 16.3%, three times higher than in the underlying cover beds. This indicates admixture of aeolian sediments. The distribution of heavy minerals in the upper periglacial cover bed is striking (Table 1). In contrast to the basal bed, it contains the minerals augite, brown amphibole, and titanite. The latter represent the diagnostic heavy mineral association designated to the volcanic components of the LST. This type of stratified Cambisol is characteristic of Bunter Sandstone regions in German low mountain areas in well-drained slopes, with intermediate precipitation rates.

In lower slope sections, in leeward position and in dells, the middle periglacial cover bed occurs intercalated with the upper and basal ones (Fig. 5). This intermediate periglacial cover bed (2) is notably loess-rich. In general, a Bt or Bg horizon is present in the middle periglacial cover bed. The resulting soil group consists of Luvisols and Planosols (acc. to IUSS Working Group WRB, 2006), and transitions between both soils. Fig. 5 illustrates this layer imbedded in a small channel structure. In this case, the upper

Table 1
Grain size distribution, heavy minerals and profile sketch of a Haplic Cambisol (c.f. Fig. 4). UPCB = upper periglacial cover bed, BPCB = basal periglacial cover bed. Grain size: pipette analysis acc. to Köhn.



Sample No.	Horizon	Grain size in mm (weight %)						
		<0.002	0.002 - <0.0063	0.0063 - <0.02	0.02 - <0.063	0.063 - <0.2	0.2 - <0.63	0.63 - <2
I/1	Bw	9.3	6.1	12.2	16.3	34.3	19.5	2.3
I/2	Cw1	10.2	4.0	6.0	6.6	35.4	35.9	1.6
I/3	Cw2	21.7	4.4	7.8	6.4	32.7	25.1	2.1
		Heavy minerals. grain %						
		Augite	Brown Amphib.	Titanite	Tourmaline	Zircon	Topaz	Rutile
I/1	Bw	14	45	9	18	11	2	1
I/2	Cw1	-	-	-	87	10	-	3
I/3	Cw2	-	-	-	79	19	1	1

periglacial cover bed (1) overlapped the middle periglacial cover bed (2). The latter is underlain by a loess-free bi-partite basal layer (3) of pale medium sand.

The silt content is enhanced in the upper and the middle periglacial cover bed (Table 2, II/1 and 2). In particular, the coarse silt fraction is significantly increased (17.1% and 25.9%), reflecting aeolian input. The clay content is 23.7% in the middle periglacial cover bed, and the sand content is the lowest in the profile. The enhanced clay content is, on the one hand, related to the occurrence of clay cutans, indicating clay illuviation originating from the superimposed horizons. On the other hand, similar profiles without the occurrence of the middle periglacial cover bed never show a Bt horizon, indicating that higher clay content may be attributed to a sedimentary origin. Heavy minerals (Table 2) indicate stratification of the cover beds. The upper periglacial cover bed contains augite, titanite, and brown amphibole, representing the volcanic component of the LST (II/1), which is only present in traces in the underlying middle periglacial layer (II/2) and completely absent in the basal cover beds (II/3 and 4). The basal periglacial layers are composed of stable minerals originating from the bedrock, including tourmaline, zircon and rutile. Overall, strong differences in coarse fraction, rock content, grain size distribution and heavy mineral association document the stratification in the described profile.

In general, heavy mineral analyses indicate the inhomogeneity and stratification of the soil parent material. In numerous Luvisols formed in loess, stratification of the parent material between the E and Bt horizons is present. Table 3 lists the results of heavy mineral analyses for a stratified Luvisol. The data clearly show the occurrence of the LST minerals augite (clinopyroxene), brown amphibole, and titanite in the E horizon, which corresponds to the upper periglacial cover bed (Table 3, III/1–III/4). Similar results were obtained in the infilling of the pseudomorphic replacement of an ice wedge, which contains material from the upper horizon (Table 3, III/6). The samples of the Bt horizon are characterized by reduced content of LST minerals; in particular, augite and titanite show low values (Table 3, III/5 and III/7).

The distribution and occurrence of the specific periglacial cover beds in areas with varying topography influence the ecological sustainability of a site. The Bunter Sandstone sites characterized by the bedding of the upper periglacial cover bed overlying the basal one support oligotrophic *Pinus* and *Picea* forest, whereas sites formed by upper, middle and basal periglacial cover beds reflect meso to eutrophic conditions. The latter are efficient and nutrient-rich sites related to occurrence of deciduous (*Galio odorati-Fagetum*) mixed forest.

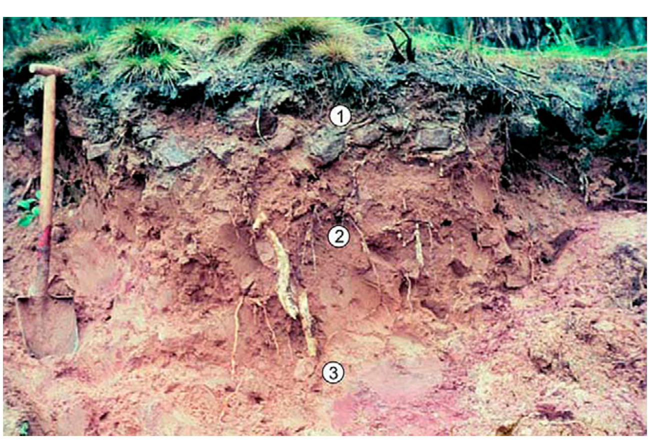


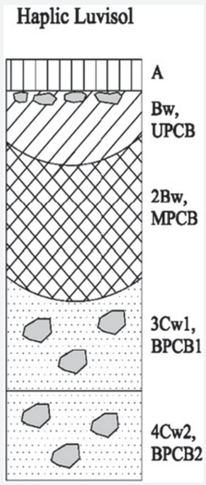
Fig. 5. Upper periglacial cover bed (1), middle periglacial cover bed (2), and basal periglacial cover bed (3), W Rhina/Fulda-Werra Mountains (Germany).

4. Is there a periglacial induced inhomogeneity?

Several soil profiles show pedogenetic differences between the specific horizons, which do not originate from periglacial sediments. For instance, on top of Roman walls of the Limes, there are Luvisols with intense sedimentological differences in the soil horizons (Semmel, 1993).

Furthermore, there is evidence of stratification in soil profiles in tropical areas where periglacial processes can be excluded. Fig. 6 shows a tropical brownish Acrisol consisting of an E and Bt horizon on top of strongly weathered reddish Ferrasol. At the boundary of the horizons, a stoneline of small rounded stone fragments indicates a disconformity in the profile. The parent material of

Table 2
Grain size distribution, heavy minerals and profile sketch of a Haplic Luvisol (c.f. Fig. 5). UPCB = upper periglacial cover bed, MPCB = middle periglacial cover bed, BPCB = basal periglacial cover bed. Grain size: pipette analysis acc. to Köhn.



Sample No.	Horizon	Grain size in mm (weight %)						
		<0.002	0.002 - <0.0063	0.0063 - <0.02	0.02 - <0.063	0.063 - <0.2	0.2 - <0.63	0.63 - <2
II/1	Bw	8.7	5.9	11.7	17.1	32.0	21.7	2.7
II/2	2Bw	23.7	4.9	7.8	25.9	19.2	15.1	3.4
II/3	3Cw1	6.1	5.7	6.7	6.9	29.2	38.2	7.0
II/4	4Cw2	21.9	5.9	6.1	6.6	27.2	29.7	2.6

Sample No.	Horizon	Heavy minerals. grain %							
		Augite	Brown Amphib.	Titanite	Granite	Tourmaline	Zircon	Topaz	Rutile
II/1	Bw	15	45	5	2	17	12	2	2
II/2	2Bw	3	1	-	3	47	45	-	1
II/3	3C1	-	-	-	-	79	18	-	3
II/4	4C2	-	-	-	-	84	13	-	3

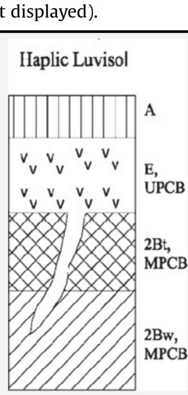
the topsoil can be interpreted as a hillwash sediment, as is characteristic for numerous tropical soils (Semmel, 1978; Bibus, 1983). The grain size fractions as well as the heavy mineral distribution record differences in the individual horizons (Table 4). There are significant variations in clay and sand content. The content of all sand fractions is enhanced in the upper parts of the profile and reduced in the lower parts. Thus, it is evident that pedogenetic processes cannot cause coarsening, but sedimentation processes can. Heavy mineral analyses show that rutile is only present in the E and Bt horizons of the Acrisol, but is absent from the underlying horizons belonging to the Ferralsol. Tourmaline is absent in the topsoil, whereas the lower parts of the profile contain tourmaline (Table 4).

However, the described soil profiles differ significantly from the periglacial cover beds of European low mountain areas. On the one hand, rock fragments in periglacial cover beds are oriented and well-sorted, which is not observed in the tropical profiles. Furthermore, ice wedges with pseudomorphic replacements and cryoturbations (Fig. 7 and Fig. 8) are related to past periglacial environments.

There are parallels between Pleistocene periglacial cover beds and recent examples (Semmel, 1987), notably in the distribution of rock fragments in the upper periglacial cover bed and recent active layers. Fig. 9 shows a debris layer on top of clay schists on SE Spitsbergen. The basal part of the debris layer, which is situated above the permafrost table, is coarser in comparison to the upper part. This is related to alternating short-term freezing, which affects mainly the upper part of the debris at night during late summer and autumn, resulting in more intensified mechanical weathering. A further explanation for this widespread phenomenon is due to a long-term variation in the depth of the summer active layer. The latter becomes reduced with increasing density of vegetation. Therefore, inside an older and thicker debris layer, a younger shallow layer is developed (Fig. 10). Superimposition by additional material from the upper slope can occur as well.

The genesis of the cover beds, debris, and solifluction layers under periglacial conditions is also indicated by their age. The upper periglacial cover bed covers the middle and basal ones and is classified by the age of the eruption of the Laacher See volcano (12,900 BP). Thus, the underlying cover beds must be older and are therefore of Pleistocene age. Formation under vegetation cover during interstadial or interglacial environments is not possible.

Table 3
Heavy minerals and profile sketch of a Haplic Luvisol. UPCB = upper periglacial cover bed, MPCB = middle periglacial cover bed. The percentages of other minerals are lower than 4% (not displayed).



Sample No.	Horizon	Heavy Minerals. grain %								
		Augite	Brown Amphib.	Titanite	Anatase	Epidote	Green Amphib.	Mica	Tourmaline	Zircon
III/1	A	4	24	7	11	6	2	12	12	20
III/2	E1	5	28	5	6	5	1	17	13	18
III/3	E2	4	29	7	7	8	3	20	12	10
III/4	E3	4	26	6	7	6	2	21	12	12
III/5	2Bt	2	10	1	10	14	9	-	27	23
III/6	Wedge	3	32	4	5	10	3	16	11	13
III/7	2Bw	4	7	1	12	14	8	-	33	21

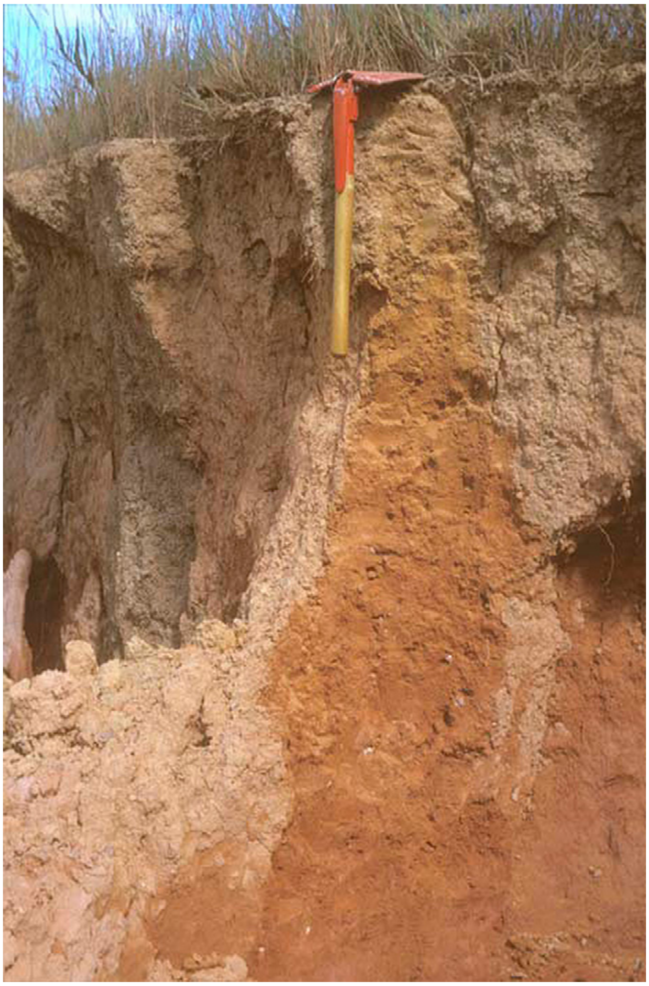


Fig. 6. Stratified Acrisol by Diamantina/Minas Gerais (Brazil). A small stoneline is visible at the base of the lighter topsoil, which forms the lower boundary to the underlying brown soil. Below the spate, a characteristic Ferralsol is present.

Hence, the formation only can take place during periglacial conditions.

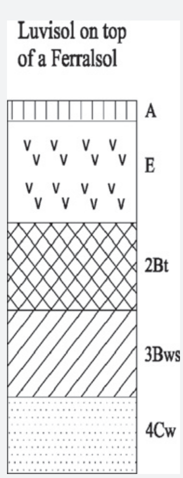
In areas close to the Laacher See volcano between Koblenz and Frankfurt a. Main, the upper periglacial cover bed invariably overlies the LST (Semmel, 2002). In several peat bogs of NW-Hessen, the upper periglacial cover bed containing Laacher See Tephra was present at the base of Preboreal peat (Fig. 11). Thus, the upper periglacial cover bed is older than Holocene age, but younger than the LST of the late Allerød. For these sites, it is clear that the formation by solifluction of the upper periglacial cover bed could only take place during the cooling period of the Younger Dryas. This means, according to the present chronological scale, the timespan between 11,600 and 12,700 BP (Litt et al., 2003). Earlier studies classified the upper layer in soil horizons as aeolian material only, and solifluction was not considered (e.g. Schönhals, 1957).

The cooling during the Younger Dryas is recorded by palaeobotanical results (Litt and Stebich, 1999). However, the existence of forest tundra vegetation does not provide favourable conditions for the formation of amorphous solifluction layers. At present, the latter develop best in vegetation-free zones of the frost debris zone. Nevertheless, beside the conditions of the plant cover, there was permafrost during the Younger Dryas, which was not only limited to the uplands, but in the basin of Neuwied as well. In this area, Frechen and Rosauer (1959) found ice wedges (pseudomorphic replacements) in redeposited material of the LST. Fig. 12 shows the pseudomorphic replacement of a former ice wedge by flood loam deposits. According to Renssen and Vandenberghe (2003), the area of discontinuous permafrost during the Younger Dryas reached the southern part of Germany. The reconstruction is based on terrestrial periglacial data and is in conflict with marine proxies (see discussion in Renssen and Vandenberghe, 2003).

5. Stratigraphic discussion

The chronological classification of the upper periglacial cover bed is under discussion. Rohdenburg (1988) found a sediment profile, where an older upper periglacial cover bed was intercalated between Upper Pleniglacial loess and LST. On top of the LST, a younger upper periglacial cover bed was present as well. This

Table 4
Grain size distribution, heavy minerals and profile sketch of a Luvisol on top of a Ferralsol (c.f. Fig. 6). Grain size: pipette analysis acc. to Köhn. The percentages of other minerals are between 1 and 23% (not displayed).



Sample No.	Horizon	Grain sizeinmm (weight %)						
		<0.002	0.002 - <0.0063	0.0063 - <0.02	0.02 - <0.063	0.063 - <0.2	0.2 - <0.63	0.63 - <2
I V/1	E	23.1	9.2	8.9	6.9	39.5	8.9	3.5
I V/2	2Bt	33.5	11.0	12.1	9.0	26.8	6.2	1.4
I V/3	3Bws	32.8	10.9	13.1	9.9	25.8	6.6	0.9
I V/4	4Cw	16.4	15.1	26.3	13.0	22.5	6.2	0.5

Sample No.	Horizon	Heavy minerals. grain %				
		Epidote	Disthene	Rutile	Tourmaline	Zircon
I V/1	E	30	36	+	-	11
I V/2	2Bt	42	29	+	17	10
I V/3	3Bws	42	27	-	18	13
I V/4	4Cw	81	1	-	3	14

Fig. 7. Upper periglacial cover bed and pseudomorphic replacement of an ice wedge by Ariendorf/Lower central Rhine area (Germany). The pale loess-bearing substrate has filled in the former ice wedge posterior to the disappearance of the permafrost. The sedimentary infilling contains minerals of the Laacher See Tephra, whereas in the gravel body of the Rhine terrace the LST is not present.

specific sequence classifies the upper cover bed as Late Glacial and not as a formation of the Younger Dryas according to Rohdenburg (1988). Investigations in the Alpine Foreland (Kösel, 1996) revealed two layers belonging to the upper periglacial cover bed.

Fig. 8. Cryoturbations inside the upper periglacial layer (Frankfurt a. Main, airport).

Fig. 9. Stratified debris layer in an active layer, Barents-Island/SE-Spitzbergen (Norway). The active layer on top of the permafrost consists in the lower parts of coarser material. In general, a more intensive breaking in the upper part is due to numerous frost and thaw processes.

However, the younger and upper layer yielded an age prior to the Allerød.

Different results were obtained by Völkel and Leopold (2001), who investigated several peat bogs, for example in the Rhön area. They found the upper periglacial cover bed exclusively below the Allerød peat, without any evidence for periglacial processes. These findings are in contrast to the results which are recorded in the Eifel maars. There, the sediment sequence showed an almost inorganic layer between the peat material, which is intercalated between the LST (12,900 BP) and the Ulmener Tephra (11,000 BP). The inorganic layer demonstrates an opening of the vegetation cover (c.f. Litt and Stebich, 1999).

As described in further studies (e.g. Muscheler et al., 2008), there is evidence of repeated periglacial conditions in the central European low mountain areas, which were favourable for the formation of solifluction layers. There was never evidence of a situation where the upper periglacial cover bed declined below the material of the LST. On steep slopes, debris layers consist of relatively pure and thin bands of LST alternating with stony debris strata. However, the latter contain LST as well, thus indicating formation after the deposition of LST. In the area of the Hochtaunus (Rhenish Massif), the debris shows similar percentages of LST to those of the original tephra (Semmel, 1968). The findings of Völkel and Leopold (2001) may be explained through an older solifluction

Fig. 10. Ice wedge close to the Passhytta/central Spitzbergen (Norway). The upper boundary of the ice wedge coincides with the basal boundary of the summer active layer.

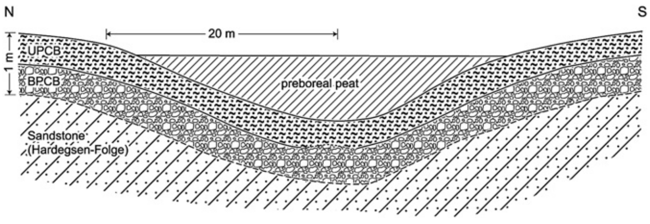


Fig. 11. Preboreal peat below the upper periglacial cover bed in N-Waldeck/Hessen (Germany). The upper periglacial cover bed contains the minerals of the Laacher See Tephra of the Allerød. Therefore the formation of the solifluction layer has to be classified to the Younger Dryas (Horn and Semmel, 1985).

layer situated below the bog and which could not be differentiated in the cores, although those authors excluded the explanation.

The well-known ice wedge polygons in the LST layers (Frechen and Rosauer, 1959) are rarely considered in the literature. There is only one exception, in the paper of Isarin (1997). This phenomenon, although relatively infrequent, does occur (Kleber, 2004). In general, periglacial ice wedges are rare in pre-Allerød sequences, which is similar to present permafrost areas (Semmel, 1987; Fried et al., 1993). Consequently, the absence of pseudomorphic ice wedge replacements cannot be considered as proof for the absence of permafrost.

In applying the occurrence of LST as a dating and differentiation tool, it must be considered that post-sedimentary mixing in the underlying stratum cannot be excluded totally. Primarily biogenic interference could occur in underlying horizons and layers (Sabel, 1983). In this case, however, the content of the LST is essentially lower, as in the upper periglacial layer (Fried, 1984).

Furthermore, if an upper periglacial cover bed could possibly be younger than expected, that would imply formation after the Younger Dryas, during the Holocene. In the relevant literature, there are reports of the LST in Holocene layers, caused by anthropogenic impact. The upper periglacial cover bed containing LST is the first horizon to be removed and accumulated in form of soil sediments during agricultural use and forest clearing. Hence, LST components are common in Holocene colluvial sequences (cf. Semmel, 1999; Fröhlich et al., 2005; Terhorst, 1997, 2007). In general, the upper periglacial cover bed is a widespread and ubiquitous phenomenon in the low mountain areas which have been affected by Pleistocene periglacial conditions. The absence of the cover bed in forest areas is an effective tool to estimate soil erosion and former human impact on a landscape.

Fig. 12. Pseudomorphic replacement of an ice wedge in the excavation of the nuclear power plant of Mülheim-Kärlich/Neuwied Basin (Germany). On both sides of the spate, LST (Laacher Tephra) is present, overlain by brown flood loam. The fload loam is replacing a polygonal net of former ice wedges in the tephra.

Periglacial conditions and relevant processes have led to the formation of cover beds, which caused an increase of soil ecological quality in comparison to soils formed directly in bedrock. In particular, the loess components ameliorated wide areas. The concept of the periglacial cover beds can be applied to studies of landscape formation, anthropogenic impact, and to applied topics concerning soil mapping, hydrology and land use.

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