Cent. Eur. J. Geosci. • 2(1) • 2010 • 32-40
DOI: 10.2478/v10085-009-0038-z

VERSITA

Central European Journal of **Geosciences**

Interglacial complex and solcomplex

Research Article

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Received 8 August 2009; accepted 31 October 2009

Abstract: All younger Pleistocene interglacials form interglacial complexes. The term interglacial complex is a short term for a tight complex of interglacials, interstadials and breviglacials, separating a complex of warm periods from the long glacial periods (euglacials). In the terrestric environment the interglacial complexes are represented by soil clusters (solcomplexes). Therein which occur interglacial and interstadial soils of different types in the loess environment separated by thin beds of loess or loess derivates (breviglacials). This article considers the mutilation and simulation of solcomplexes. Frequently, fossil solcomplexes present themselves as diminished to a few soils or to one single soil. This mutilation of solcomplexes can be due to soil convergence (soils of different warm periods – interglacials, interstadials – merge to form optically one soil), syn-solcomplex erosion or post-solcomplex erosion and sometimes to soil disguise. Conversely solcomplexes may be simulated by narrowing of soils which belong to different interglacial complexes and moreover by soil divergence (splitting of a soil of one single warm period by an interlayer of rock) or by reworked soil sediment.

Keywords: euglacial • breviglacial • soil convergence • soil divergence • syn-solcomplex erosion • post-solcomplex erosion

1. Introduction

In many outcrops in the terrestric environment two thick glacial sedimentary bodies are separated by only one single fossil soil marking an interglacial period. In the loess environment it is often a Bt horizon. On the other hand we know that all the younger Pleistocene interglacial periods are represented as complexes of interglacial and interstadial soils or beds. Thus, these warm complexes always should appear as concurrent soil clusters (solcomplexes). Indeed, they are found in special places. But mostly they appear more or less reduced. This study deals with the sedimentological processes occuring during and after the deposition of solcomplexes, processes that lead to reduction of solcomplexes, but also with processes that simulate solcomplexes. This sedimentological treatment mainly uses examples from the solcomplexes of the Rhine loess record (Figure 1), the stratigraphy, dating and analysis of which has been previously published in both German and English [1–10].

2. Definitions

To aid understanding some terms such as soil convergence, soil divergence and interglacial complex respective solcomplex are defined.

Soil convergence happens when soils of different warm periods (interglacials, interstadials) merge to form

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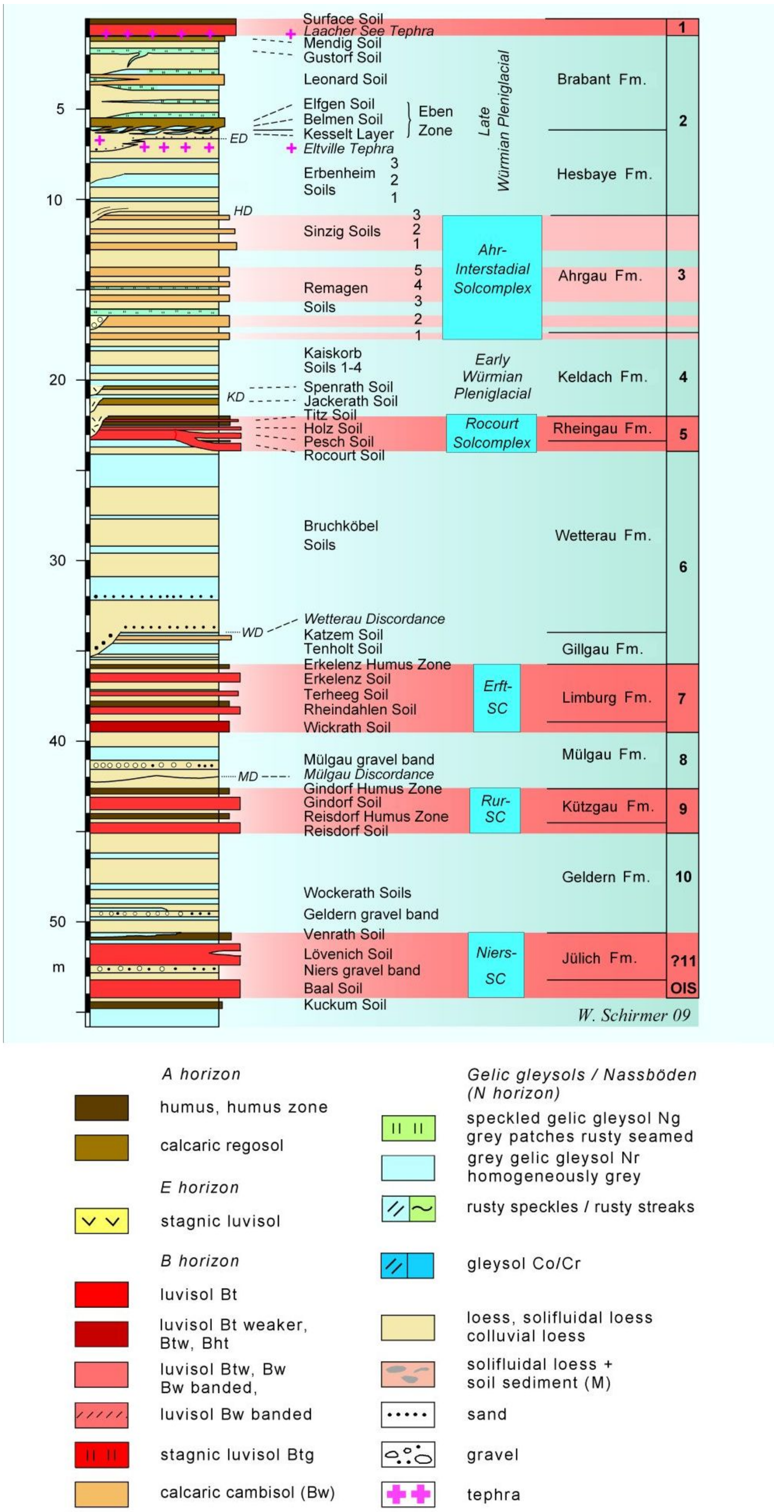

Figure 1. The Rhein loess record. ED = Eben Discordance, Fm. = Formation, HD = Hesbaye Discordance, KD = Keldach Discordance, MD = Mülgau Discordance, WD = Wetterau Discordance.
Legend for Figures 1, 2, 4 and 5.

optically one soil.

Soil divergence happens when soil formation from one and the same period is interrupted by any interlayer of rock (hard rock or soft rock) and continues its formation on top of this interlayer.

Interglacial complex An early record showing that interglacials in loess deposits are developed as soil clusters was given by Kukla et al. in 1961 [11]. In 1969 Kukla [12] recorded from Červený kopec close to Brno that each of the last nine interglacials had developed as a soil complex. In 1970 he showed that these solcomplexes correlate to clusters of warm peaks of deep sea sediments [13], nowadays this is common knowledge.

Later, soil clusters (solcomplexes) representing an interglacial complex were frequently found. The solcomplexes of the Rhine loess record (Figure 1) comprise 2-4 Bt horizons accompanied by humus zones and sometimes gelic gleysols. Interglacial soils alternate with interstadial soils. The deposits separating the single fossil soils of a solcomplex represent loess or loess derivates. This means, warm periods of different kinds (interglacials as well as interstadials) are separated by shorter cold periods, so-called breviglacials sensu Schirmer 1999 [1, 4]. These breviglacials may be accompanied by erosional processes that commonly are smooth enough to save parts of the whole solcomplex. This contrasts with the long cold periods, the euglacial periods, during which redeposition and erosion is strong enough to remodel the morphology to a great extent.

From this follows: An interglacial solcomplex is a cluster of preferably terrestric and minor semiterrestric soils which are comprised of at least one interglacial period, but sometimes two or more, and a range of interstadial periods. These warm periods are separated by thin loess layers representing breviglacials. As a whole the solcomplex with its soils and breviglacial loesses forms a long period of quiescence of the landscape. Neither thick essential accumulation nor greater erosion occurs during the long period of duration of such a solcomplex [1, 4].

It is known that spreading of loess deposits occurs predominantly in depressions, downslope or hollow positions that shows a climate development more differentiated than in plateau position. In addition, those locations tend to remain more protected from erosion than other morphological positions.

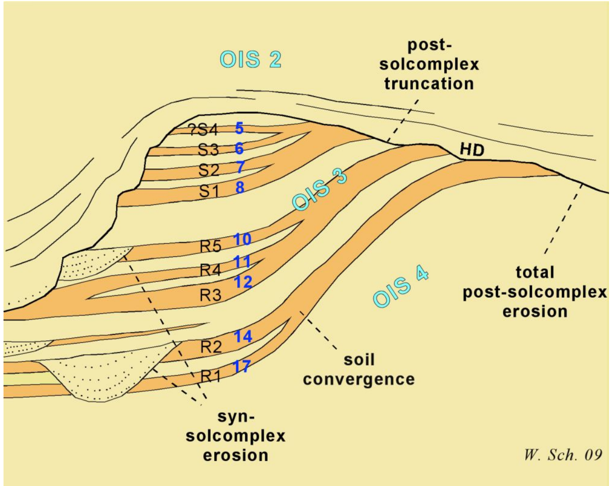

Figure 2. Scheme of mutilation of a solcomplex by convergence, syn-solcomplex erosion and post-solcomplex erosion. The scheme is shown on the example of the Ahr interstadial solcomplex (OIS 3) (brown) of the Rhine loess record which is sandwiched between the Keldach Formation and the Hesbaye Formation. HD = Hesbaye Discordance, OIS = Oxigene Isotope Stage, R1-R5 = Remagen Soils, S1-S4 = Sinzig Soils, blue numbers 5-17 = affiliation to Greenland Interstadials 5-17. The loesses of the Keldach Formation (OIS 4) below and the Hesbaye Formation (OIS 2) on top of the Ahrgau Formation (OIS 3) are not shown differentiatedly. Legend see Figure 1.

3. Mutilation of solcomplexes

3.1. Mutilation of solcomplexes in general

From the knowledge that younger interglacial periods always exist as interglacial solcomplexes it follows that in cases where we find an isolated fossil Bt horizon within a loess section it represents a mutilated interglacial complex. This mutilation may result from different processes [9] (see Figure 2):

1. The mutilation may be an optical phenomenon where the solcomplex, elsewhere spread, has simply been converged to optically one soil due to thinning of the sediment interlayer (soil convergence).

2. In other cases, during breviglacial periods erosional processes may have removed some limbs of the solcomplex formed shortly before (syn-solcomplex truncation). May be, erosion removed the whole early solcomplex developed up to this stage (total syn-solcomplex erosion).

3. A third case is the postdepositional truncation of the solcomplex after its very end at the beginning of the next euglacial period (post-solcomplex trun-

cation). Also here the whole solcomplex may be eroded (total post-solcomplex erosion).

3.2. Rhein loess record and mutilation of its solcomplexes

The following characters of a solcomplex are shown in the example of the Rhein loess record (Figure 1). It exhibits four well differentiated interglacial solcomplexes attributed to OIS 5, 7, 9 and possibly 11. Each solcomplex shows an individual character concerning the composition of its different soil types [2–4]. In addition, the last glacial is biparted by an interstadial solcomplex, the Ahr Solcomplex that can incontestably be attributed to the OIS 3 [2, 3]. All three above mentioned cases of mutilation occur with these solcomplexes. For locations see Figure 3.

3.2.1. Erft Solcomplex (OIS 7)

In the loess pit of the brickyard Gillrath in Erkelenz (Figure 4) the solcomplex, allocated to OIS 7 interglacial complex, the Erft Solcomplex, reduces from a eight-membered solcomplex within a depression to a six-membered at the slope. In his most complete form the Erft Solcomplex consists of a soil cluster of eight eye-catching soils: the red Wickrath Soil (Btw horizon), the red Rheindahlen Soil (Bt) merging towards the depression to a gley (Cr), the grey brown Rheindahlen Humus Zone (Ah), the red brown Terheeg Soil (Bw), the light grey Erkelenz Marker (speckled gelic gleysol, Ng; not a dust storm marker sensu G. Kukla), a blue grey gelic gleysol (Nr), the red Erkelenz Soil (Bt) and the grey brown Erkelenz Humus Zone (Ah). The stagnic soils (E-Btg) that occur on top of the Bt horizons are disregarded. Outside the depression this soil cluster reduces to six soils (see Figure 1 and Figure 4 left edge); the Terheeg Soil and the grey gelic gleysol (Nr) fade away.

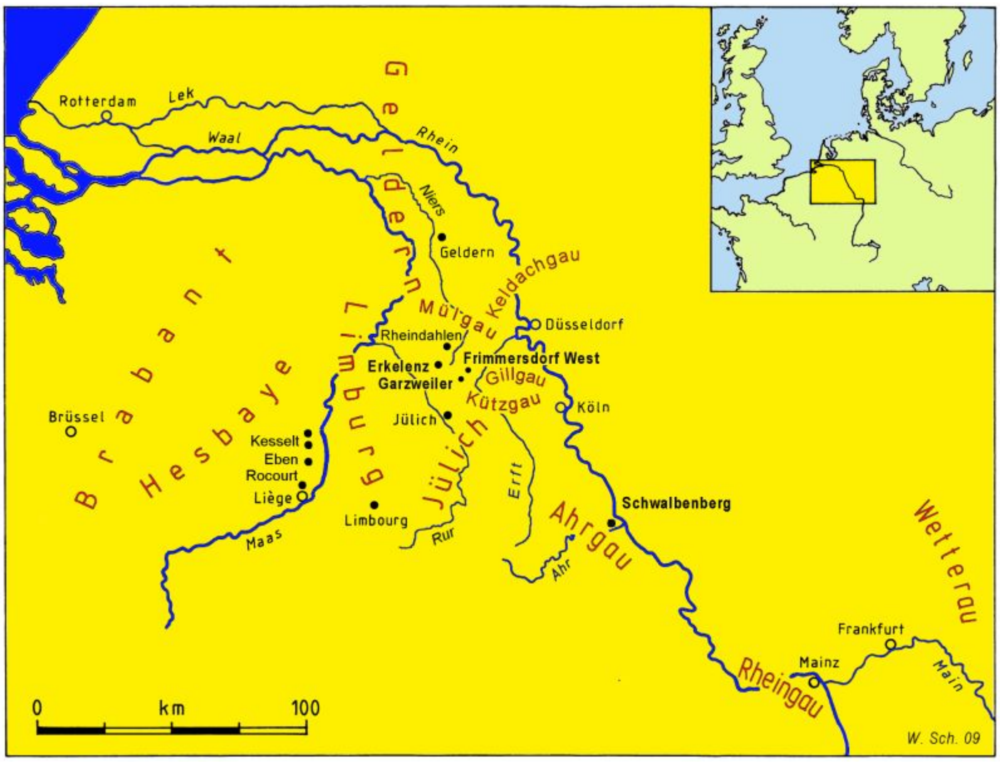

Figure 3. Location map for the mentioned localities of the Rhine loess record.

Merging from the depression the soil cluster diminishes thereby showing features as tapering of breviglacial beds, syn-solcomplex erosion and soil disguise:

1. Tapering of breviglacial beds: The Rheindahlen Humus Zone, in normal position sitting tightly upon the Rheindahlen Soil, detaches towards the depression from the Rheindahlen Soil giving space for cold deposits as thin-sheeted alluvial loess, colluvial soil creep (M) and colluvial loess – an assembledge of cold temperate deposits forming a breviglacial period. The loess below the Rheindahlen Humus Zone at the slope of the depression is still slightly humic and loses this character downslope. This case demonstrates that the convergence of soils is due to a decrease in thickness of sediment deposit inbetween.

2. Syn-solcomplex erosion: Gelic gleysols frequently are combined with erosional processes. Thus, the striking speckled gelic gleysol in the midst of the Erft Solcomplex, the Erkelenz Marker, gives space for a further red brown soil at its base, the Terheeg Soil. Conspicuous is that the solum relic is only preserved at the slope and in the higher part of the depression. Both upslope as well as towards the deepest part of the depression the Terheeg Soil is cut by the Erkelenz Marker. This case provides a typical syn-solcomplex erosion taking off parts of the solcomplex.

3. Soil disguise: Within the depression between the Erkelenz Marker and the Erkelenz Soil a grey gelic gleysol (Nr) is inserted. It appears to taper off towards upslope. Presumably it is thinning and weakening and thus disguised by the lower Bw horizon of the luvisol of the Erkelenz Soil.

Post-solcomplex erosion of the Erft Solcomplex: The strongest erosion affecting the Erft Solcomplex is that of the Wetterau Discordance (Figure 4). It takes away the whole Erft Solcomplex even within the 250 m long Erkelenz outcrop. This big erosion phase stratigraphically does not immediately follow the Erft Solcomplex. Normally this complex is followed by the Gillgau Formation (Figure 1). Later the big Wetterau erosion removes the Gillgau Formation and older loess deposits, forming a new and deep erosional relief (Figure 5). It is the strongest and deepest erosion registered widespread over the Lower Rhine Basin [4, 6, 7].

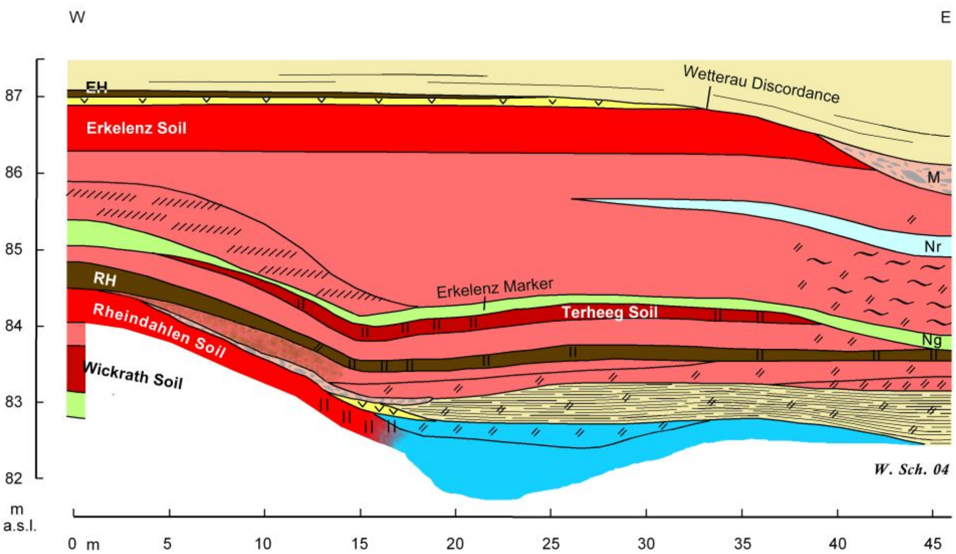

Figure 4. Section Erkelenz 25 shows the Erft Solcomplex (OIS 7) in a depression. Between the Rheindahlen and the Erkelenz Soil the Terheeg Soil (Bw horizon) is visible at a length of 35 m at the border of a depression only.
EH = Erkelenz Humus Zone, M = soil sediment, Ng = speckled gelic gleysol, Nr = grey gelic gleysol, RH = Rheindahlen Humus Zone. Legend see Figure 1.

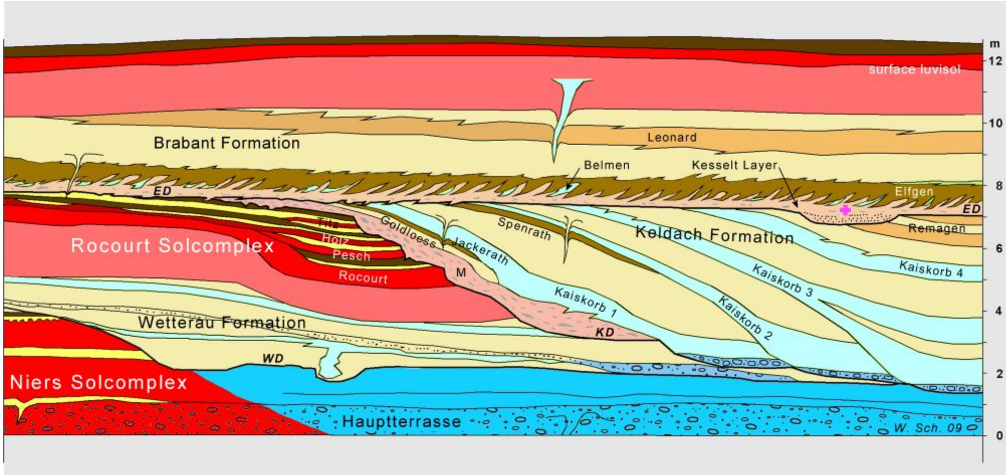

Figure 5. Scheme of the loess formations and solcomplexes exposed in the open-cast mine of Garzweiler since 1998. Legend see Figure 1.

3.2.2. Rocourt Solcomplex (OIS 5)

In the opencast mine of Garzweiler the solcomplex corresponding to the OIS 5 interglacial complex (the Rocourt Solcomplex), shrinks from a seven-membered soil cluster at the slope toe of a small valley to a small four-membered soil band in the flat position (Figure 5). In the most complete form the Rocourt Solcomplex consists of a soil cluster of seven conspicuous soils: the red Rocourt Soil (Bt horizon), the dark brown Rocourt Humus Zone (Ah), the brownish red Pesch Soil (Bt), the grey-brown red Holz Soil (Bht), the dark brown Holz Humus Zone (Ah), the yellow-brown Titz Soil (Btw) and the dark brown Titz Humus Zone (Ah). The stagnic soils on top of each of the Bt horizons are disregarded. Outside the depression this soil cluster is reducing to four soils. Rocourt Humus Zone, Pesch Soil and Titz Soil disappear and in some places the Holz Soil, too. Thus, in many outcrops only one luvisol (Rocourt Soil) and two humus zones (Holz and Titz Humus Zones) are left.

Syn-solcomplex erosion and convergence within the Rocourt Solcomplex: Commonly the breviglacial period after an interglacial luvisol is a stage of loess influx but also of solifluction and erosion. Thus, all Bt horizons are truncated to a certain degree missing their A and E horizon and upper parts of the Bt horizon. In this regard the breviglacial preceding the Holz Soil appears to be very effective. In most cases it eroded down into the Rocourt Soil. However, the erosion was flat enough to preserve essential parts of the Bt horizon of the Rocourt Soil. No section was found where the Holz Soil occurred without an underlay of the Rocourt Bt horizon. Breviglacial erosion (syn-solcomplex erosion) is characterised as being flat and soft [6] and it takes away parts of the solcomplex, but part of it always remains untouched. Similarly flat and smooth erosional activities happened during the breviglacial periods after the Holz Soil and Titz Soil. These acivities result in a double layer of the two humus zones, the Holz and the Titz Humus Zone, that readily accompany the torso of the Rocourt Soil in the Lower Rhine area.

The soil cluster reduction here is mainly done by syn-solcomplex erosion. Soil convergence happens in case of the Holz Humus Zone and the Titz Soil.

Post-solcomplex erosion of the Rocourt Solcomplex: Figure 5 shows two main cases of subsequent erosion of the Rocourt Solcomplex. Following the Rocourt Solcomplex (OIS 5) a new euglacial (OIS 4) starts with loess influx accompanied by a big reworking and solifluction phase. Its effect is firstly erosion. It is the widespread Keldach erosion that takes away a great deal of the Rocourt Solcomplex and causes the Keldach Discordance (KD in Figure 5). Secondly the erosion is accompanied by deposition of a mixture of soil and loess (M in Figure 5 from migrating soil sediment). Their deposits are filled into the erosional forms if not washed away. This erosion phase caused many morphological depressions, or renewed and widened existing hollows.

However, in the Garzweiler scheme of the Lower Rhine plateau the most striking erosion took place close to the Late Glacial Maximum (LGM) causing the Eben Discordance (ED in Figure 5) [8]. This discordance is the first palaeo-surface running parallel to the recent surface. It cuts through many older bedding structures even down to the Rocourt Solcomplex, sometimes eroding it away completely.

Thus, post-solcomplex erosion combined with euglacial conditions is much more effective and destructive than syn-solcomplex erosion. It creates completely new landscape shapes and takes away total loess formations [1].

3.2.3. Ahr Solcomplex (OIS 3)

The interstadial Ahr Solcomplex which is appointed to the OIS 3 interstadial complex (Figure 1, 2) should be regarded together with this group of interglacial solcomplexes. Figure 2 that above served as scheme of mutilation processes presents in its middle part the Schwalbenberg section south of Bonn. This profile is the most detailed loess-soil record of OIS 3 existing up to now in Central Europe. Though it is not an interglacial solcomplex it should be treated as an early stage of an interglacial complex that could not fully develop [5]. The largest vertical spread of this solcomplex exhibits eight calcaric cambisols at the Schwalbenberg. Their ages range from roughly 60 to 30 ka BP dated by ^{14}C and TL [2, 3]. It presents three soil groups: The Lower Remagen Soils (Remagen 1 and 2 Soils), the Upper Remagen Soils (R3-R5) and the Sinzig Soils (S1-S3). In Figure 2 a virtual Sinzig Soil 4 is added. As the Ahr Solcomplex at the Schwalbenberg – from the amount of soils, their intensity, their grouping to four Bond cycles, and direct datings – shows detailed correspondence to the Greenland Interstadials (GIS) 6-17 [2, 3, 9] one could expect a missing Sinzig Soil 4 corresponding to GIS 5 which would have been eroded in the recent Schwalbenberg section.

Figure 2 shows the following features:

Most spread development of the solcomplex happens in a former depression.

Convergence is shown towards upslope of each the Lower Remagen Soils, the Upper Remagen Soils and the Sinzig Soils. Nine soils may converge into three soil bands. Currently there is no information on whether these three soil bands converge at any place. Therefore Figure 2 avoids drawing this. Convergence of this solcomplex elsewhere is also known towards downslope [14].

Towards the depression there occurs syn-solcomplex erosion both on top of the Lower (R1-R2) and Upper Remagen Soils (R3-R5). On top of the Sinzig Soils (S1-S4), respectively at the base of the Hesbaye-Formation (OIS 2) post-solcomplex erosion starts. This is the strongest erosion shown in this section. It takes off parts or the whole of the Ahrgau Formation (OIS 3). It produces the widespread Hesbaye-Discordance (HD in Figure 2).

Post-solcomplex erosion takes away first the Sinzig soils or their converged soil band, followed by the Upper Remagen and finally the Lower Remagen Soils, respectively their converged soil bands. This means that the possibility of preservation is lower for the younger soils of the complex, and higher for the older soils. Moreover, soils in general withstand erosion somewhat better than the loess layers inbetween.

The strongest soils of the Ahr Solcomplex are the soils Remagen 2 (R2 in Figure 2), Remagen 3 (R3) and Sinzig 1 (SI) equivalent to GIS 14, 12 and 8 [2, 3, 9]. This means the stronger soils settle in the middle of the Ahr Solcomplex, not in the lowest and uppermost part of it. This is visible in the Schwalbenberg section [9] as well as in the Nussloch section south of Heidelberg where Bibus et al. [15] state within a cluster of five brown soils the middle one (their WB 4 soil) to be the strongest soil. While in Nussloch a diminution of the Ahr Solcomplex to five soils is visible, elsewhere in central Europe there are preserved three soils, e. g. [16, 17], two soils (Figure 5, right edge, and e. g. [18]) or even one soil. In cases of one preserved soil – for example the Lohne Soil in the Rhine-Main area, e. g. [18, 19] – it remains questionable which soil of the eight-membered solcomplex has been preserved at the place described, and whether this one soil is always the same soil among the variety of members of the whole solcomplex. In all these cases the diminution of soils within the Ahr Solcomplex occurs by convergence, by syn-solcomplex truncation and also post-solcomplex truncation.

This initial solcomplex of OIS 3, the Ahr Solcomplex, highlights that the last glacial undoubtly is biparted into two separate euglacial periods. Thus, the last glacial ought to be divided into an OIS 4 glacial and an OIS 2 glacial – the latter is the real Weichselian or Würmian glacial – separated by the Ahr Interstadial Complex [5].

4. Simulation of solcomplexes

4.1. Soil neighbourhood due to erosional phases

Solcomplexes, however, may also be simulated. During periods of euglacial loess deposition enormous reworking and erosion activity produces deeply carving unconformities. Due to those discordances luvisols of different interglacial periods may lie in a tight neighbourhood simulating solcomplexes. Thus, by subdividing a loess stack, evidencing these discordances is as important as recognizing fossil soils. Therefore large walls to be cleaned are necessary to follow fossil soils as well as discordances, which both are a testament to the former landscape surfaces.

4.2. Soil divergence

Another case of simulating solcomplexes is soil divergence in contrast to soil convergence. Soil divergence happens when soil formation in a distinct warm period is interrupted by an event that covers the soil with a rock deposit, e. g. volcanic rock, flood deposit, colluvium, talus deposit, debris flow deposit. After this event soil formation continues. Finally, both soils framing the event belong to the same warm period and thus they may simulate a solcomplex.

4.3. Soil sediment

Reworking of soils may simulate autochthonous soils. Figure 4 and 5 show reworked soil sediment (M) each in the beginning of a new cold phase. This preferably happens after the end of a solcomplex during the early phase of a new euglacial. Figure 5 shows the soil sediment (M material) during the early Keldach Formation infilled into the erosional hollow form of the Keldach Discordance. Moreover, the Eben Discordance (also in the same Figure 5) presents a reworked layer at its base with reworked soil material, known as the Kesselt Layer. Figure 4 shows soil sediment originating from the Erkelenz Soil in connection with the Wetterau Discordance.
Reworked soil deposits occur also in breviglacial phases, although only to a minor extent. Figure 4 presents an example of soil sediment reworked from the Rheindahlen Soil creeping downslope to the small valley bottom exposed.

5. Conclusion

Interglacial periods in the younger Pleistocene occur as clusters of warm periods (interglacials and interstadials) intersected by short cold periods (breviglacials). These clusters of warm periods containing one or more interglacials are called interglacial complexes. In the terrestric environment it is rare for interglacial complexes to be found fully developed with all warm and cold members known so far. Its preservation needs more sediment input than output during a breviglacial. Favoured places are mainly depressions or lee positions. Outsite favoured places the interglacial complexes are mutilated sometimes down to one single soil or are even completely eroded. The same applies to the single interstadial complex, known up to now, the Ahr Interstadial complex of OIS 3.
Consequently, much discussion has been raised about what happened in-between a full and reduced solcomplex and how to connect the residual members of the solcomplex.
Lack of sediment input results in the merging of soils from different soil forming periods. Thus, the solcomplex seems to be reduced. In-between the full and reduced solcomplex happened mutilation of the complex that comprises soil convergence, syn-solcomplex erosion or post-solcomplex erosion, sometimes soil disguise.
As a consequence, in case a warm period complex is represented by one soil only it has to be considered that:

1. this soil represents only one member of the whole cluster,
2. it might represent some merged members of the cluster,
3. it need not to represent the same one soil from this cluster exposed in the next outcrop.

Of course, there is a certain probability for the preservation of the strongest soil of a group due to better resistance from erosion for its higher clay content and density. There is also a chance for better preservation for the basal soils of a group because of their greater distance to the erosional front.
Moreover, identifying certain members of a solcomplex by dating is very difficult, because the tight time sequence of the members of a solcomplex lies mostly within the tolerance of the dating values.
A separate topic is that solcomplexes may be simulated. Finding a solcomplex in small outcrops it has to be proved whether the tight lying soils origin from different solcomplexes. The neighbourhood of soils might be due to an erosional event which simulates a solcomplex of soils that in fact belong to different solcomplexes. Another issue of simulating solcomplexes is soil divergence. An intercalation of a deposition during the ongoing process of soil formation can simulate a solcomplex, where indeed the lower and upper soil separated by the intercalation belong to the same soil formation.
All these contingencies point out that for a reliable stratigraphical context a large outcrop is essential. The Rhine loess record has been established mainly in opencast mines or large brickyards.

Acknowledgements

Thanks are due to two unknown reviewers and for editorial improvement of the English style.

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