THE ABC SOIL TYPES: PODZOLUVISOLS, ALBELUVISOLS OR RETISOLS?

A review

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ABSTRACT
At an archaeological excavation site in central Belgium, we found whitish soil material interspersing a clay illuviation horizon under a Roman road. Starting from this case, we will illustrate how insights into soil formation and soil geography are relevant for understanding landscape evolution and archaeology. We do this by focusing on the 'Abc' soil types, which are silt-loam soils that are well-drained and have a mottled and discontinuous clay illuviation horizon. In Belgium, these soils are, almost exclusively, found under ancient forests. To explain their formation, two hypotheses have been proposed. A first assumes that chemical weathering leads to the degradation of the clay illuviation horizon, a process enhanced by the acidifying effect of forest vegetation. A second hypothesis explains their morphology as relict features from periglacial phenomena. We further review how views on their formation were reflected in Soil Taxonomy (*Glossudalfs*), the FAO legend of the soil map of the world (*Podzoluvisols*) and in the World Reference Base for soil resources (*Albeluvisols* and *Retisols*). If we accept the hypothesis that the morphology of the Abc soil types has to be attributed to periglacial phenomena, Abc soil types must have been more widespread before deforestation. Agricultural activities promoted the homogenisation of the subsoil and the fading of their morphologic characteristics. A Roman road would have prevented such a homogenisation process. These insights help elucidate the evolution of past and current landscapes.

KEYWORDS
soil formation, archaeology, Soil Taxonomy, World Reference Base, Belgian soil classification

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1. What got under a Roman road?

In the town of Asse, at an archaeological excavation site of the Roman Period (Magerman et al., 2013), we found a bleached and light-textured soil layer over a clay enriched horizon (Figure 1). The clay illuviation horizon was interspersed with clear whitish tongues, originating from the bleached horizon (Figure 1b). Strikingly, the light-textured soil material only occurred under the remnants of a Roman road and under a pile of Roman tiles. In contrast, a nearby soil profile under agricultural land did not have such bleached material (Figure 1c). Understanding the occurrence, or absence, of such soil patterns in both vertical and horizontal space, requires insights into soil forming processes. Why did this bleached soil only occur under the Roman artefacts? Did the Romans use such whitish soil material as a foundation for their construction works?

Insight into the genesis and the geography of the different soil types is crucial for understanding both current and past land-uses. This knowledge is particularly important when field soil scientists have to help explaining the palaeo-environment at archaeological excavation sites. Prof. em. Dr. Roger Langohr has greatly contributed to developing and spreading such insights. First, and foremost, by conducting detailed field research to elucidate the formation of soil types similar to those we encountered in Asse. Secondly, by his tireless dedication for teaching his insights to students and colleagues, both in Belgium and abroad. In his paper on the pedology and evolution of land-use in the silt-loam belt of Belgium, Roger Langohr concludes that a pedological approach for studying the evolution of landscapes can provide new data, complementary to those provided by other scientific disciplines such as forestry, archaeology, and history (Langohr, 1986).

The aim of this contribution is to illustrate the relevance of understanding soil formation and soil geography in relation to land-use, landscape evolution, and archaeology by focusing on the **'Abc** soil types' as defined by the legend of the soil map of Belgium[1]. First, we explain what the **Abc** soil types are and where they occur in Belgium. Secondly, we review the hypotheses that have been put forward to explain the formation of these soil types. We want to highlight how the views on their formation have influenced past and current international soil classification systems, particularly the American Soil Taxonomy system, the FAO-Unesco legend of the Soil Map of the World, and its successor the World Reference Base for soil resources. Finally, we reflect on the importance of understanding soil formation in relation to studying past and current land-uses. With these objectives in mind, an exhaustive review of the soil formation of silty-loam soils in Belgium is out of scope.

2. What is an Abc soil type?

The soil profile shown in Figure 2 illustrates the typical morphological characteristics of an **Abc** soil type. Soil surveyors (Baeyens, 1959a, 1959b; Louis, 1959) have described this soil type as having a thick forest litter covering a thin black mineral Ah horizon. The E horizon penetrates deep into the Bt horizon with very distinct grey and ochre coloured spots. Remnants of clayey silt appear isolated in a transition horizon (EB horizon), where clay coatings on the structural elements disappear and are replaced by a fine sandy, floury material. The cavities of the old roots – referring to the whitish tongues penetrating into the Bt horizon – are filled with material from the overlying E horizon. These morphological characteristics are ascribed not only to leaching of clay, but also to the very acidic nature of the soils resulting in the destruction of clay minerals. The process of acidification resulting into the destruction of clays has been referred to as 'podzolization' (Baeyens, 1959a; Louis, 1973) and has also been linked to the process of ferrolysis (Aurousseau, 1990; Bouma et al., 1990).

Following the definitions of the legend of the soil map of Belgium, soil types belonging to the soil series **Abc** have a silt or silt-loam texture (**A..**), are well-drained (**.b.**), and have a clay illuviation (Bt) horizon in the subsoil (**..c**) that is strongly mottled and discontinuous (Maréchal and Tavernier, 1974). Maréchal and Tavernier further clarify that it corresponds to the sols *podzoliques* of the French authors, the *Pseudogleye* and the *Fahlerden* of the German authors, and, in part, with the 'Gray Brown Podzolic soils' of the American authors or according to the then-new American Soil Taxonomy classification system, the order of the *Alfisols* such as *Glossudalfs, Ferrudalfs* and *Aqualfs*.

In general, the soils of Belgium were mapped following the standard soil classification system explained below. Only the soils of the coastal plain were mapped according to geomorphological and lithostratigraphic criteria (Dondeyne et al., 2014; Maréchal and Tavernier, 1974). As the definition of the **Abc** soil type illustrates, the standard Belgian soil classification system is based on morphogenetic properties readily identifiable in the field. A three-letter code allows representing a soil series: the first letter corresponds to the soil textural class, the second to the drainage status, and the third to the soil profile development. Variants are recognised based on (i) the occurrence of lithic discontinuities forming a substratum, (ii) the admixture of parent materials, e.g. limestone

1 Codes (or symbols) from the legend of the soil map of Belgium are indicated in **bold**. Names from international soil classification systems, both of the Soil Taxonomy and the World Reference Base for soil resources are indicated in *italic*.

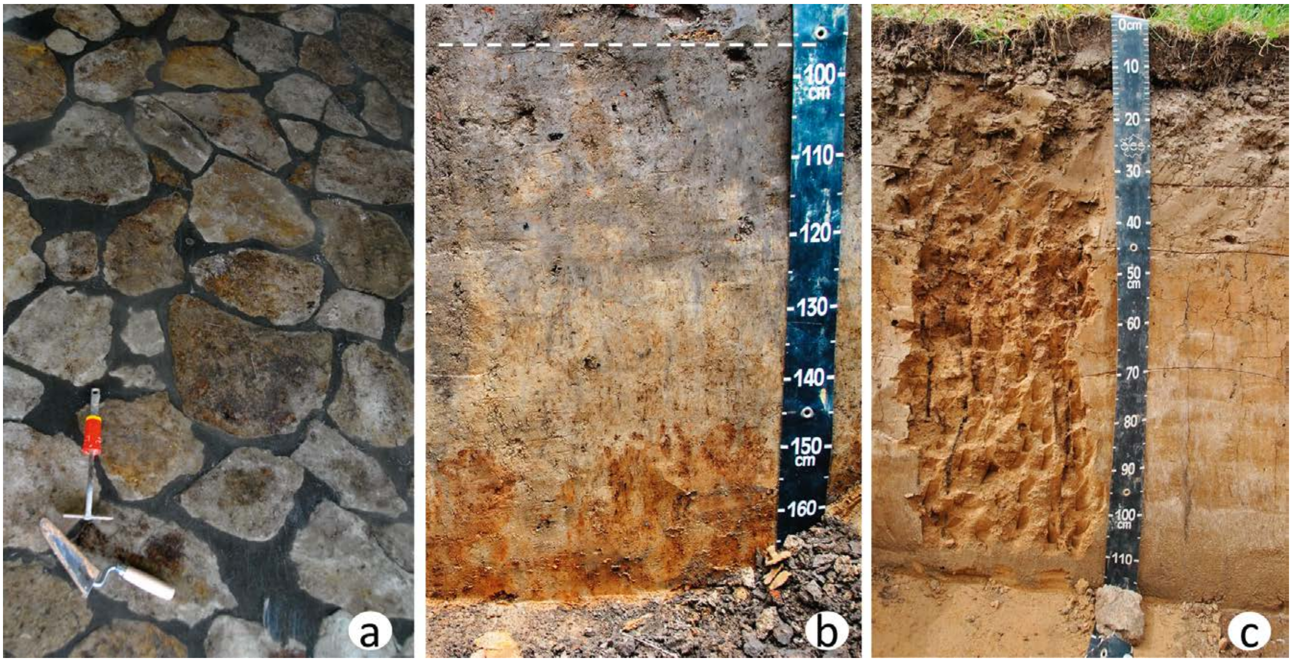


Figure 1. a. Reconstructed Roman road excavated in Asse (Belgium).

b. Bleached soil material (115-150 cm) occurred under a pile of Roman tiles found at the level of the dashed line. The bleached soil material interspersed an underlying clay illuviation horizon (>150 cm).

c. A nearby profile under agricultural land did not have such bleached soil material, nor did it have any whitish tongues. Photos: S. Dondeyne.

in a soil otherwise derived from loess, and (iii) variations in the profile development, e.g. the occurrence of a *Fragic* horizon. Variations in the depth or thickness of particular characteristics are indicated as soil phases. Codes for variants and phases are indicated with a prefix or suffix code to the series code. Hence, a soil type is defined by the code for the soil series and either explicitly combined with a code for a particular variant or phase, or implicitly by the absence of such a code. For example, by adding the code **...0** to the series code **Abc**, soil type **Abc0** is explicitly defined for having a strongly mottled Bt horizon occurring at a depth greater than 40 cm (Dondeyne et al., 2014), but implicitly the information is also conveyed that it does not have a lithic discontinuity within the first 120 cm. If such a substratum would occur, it would be indicated explicitly with a prefix code.

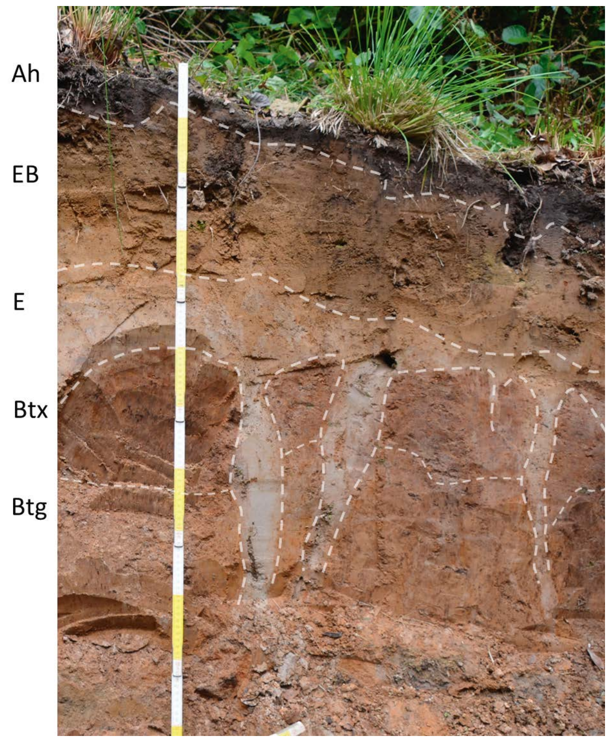


Figure 2. Example of the Abco soil type from the Sonian Forest (Belgium). Below a thin humus rich Ah horizon is a yellowish brown intermediate EB horizon. It has a weakly developed soil structure and a silty-loam texture. The subsequent bleached E horizon has been affected by clay eluviation and dissolution of Fe oxides. In the upper part, the clay illuviation horizon is compact, but non-cemented (Btx), impeding water and plant roots from penetrating; in the lower part oxido-reductimorphic mottles are prominent (Btg). Photo: S. Dondeyne.

3. Where do Abc soil types occur?

While soils with mottled and discontinuous clay illuviation horizons are widespread in Belgium, the particular **Abc** soil types are almost exclusively mapped in the Sonian Forest south-east of Brussels and the Meerdaal Forest, somewhat more to the east (Figure 3). They have, however, also been reported to occur in the Bertem Forest, which is a small forest north-west of Meerdaal Forest (Brahy et al., 2000; Vancampenhout and Deckers, 2010). These are all ancient forests, as the 18th century topographic map of Ferraris indicates (Figure 3b). In the northern part of the country, soil types with mottled or discontinuous clay illuviation horizons are mostly formed in loamy-sandy soils (textural class **L..**, and **P..**) or even in sandy soils (textural class **S..**). In the southern part of the country, vast areas with silt-loamy soils (textural class **A..**) have weakly expressed mottled or discontinuous B horizon and have been mapped as soil type **Aba(b)**.

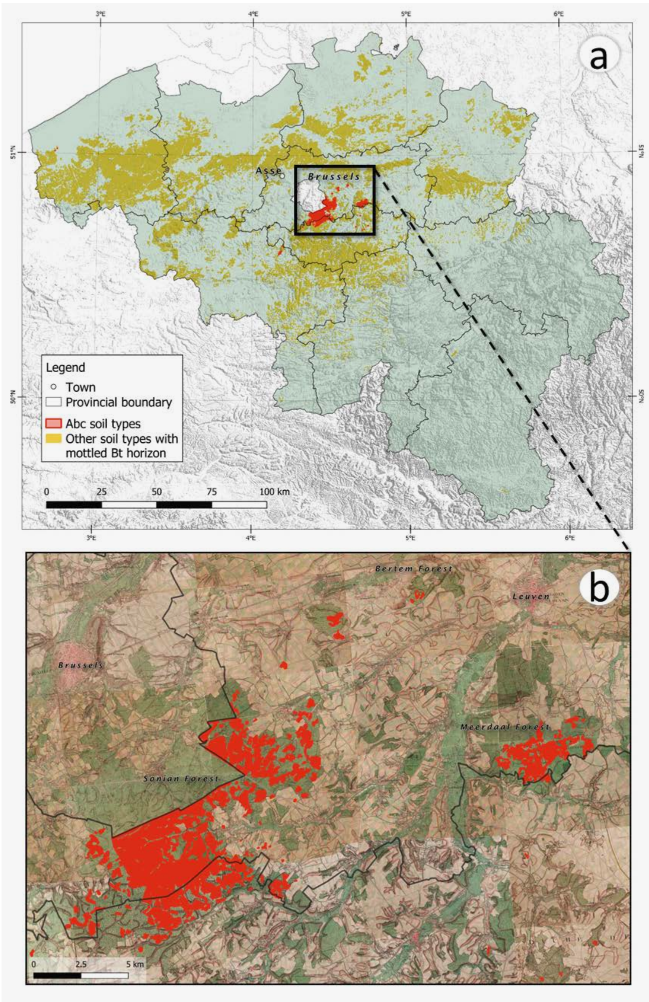


Figure 3. Distribution of Abc soil types:

a. in Belgium with the indication of other soils with mottled Bt horizons;

b. within the ancient Sonian and Meerdaal forests as shown on the 18th century Ferraris map. Note, the Region of Brussels is not covered by the digital soil map.

Data sources: https://dov.vlaanderen.be/ & http://geoportail.wallonie.be/.

4. How are Abc soil types formed?

Two hypotheses have been put forward to explain the formation of the enigmatic soil patterns found in **Abc** soil types. The first hypothesis assumes that a chemical weathering leads to a dissociation of clay and iron oxides under temporary reducing conditions, and a mobilisation of clay by the leaching and degradation of the clay itself. A second hypothesis postulates that the whitish tongues are relicts of glacial or periglacial phenomena.

4.1. DEGRADATION OF THE CLAY ILLUVIATION HORIZON

The synthesis we present here largely draws on Schaetzl and Thompson (2015). The hypothesis assumes that in a first stage of soil profile development the clay illuviation (Bt) horizon thickens and gets ever more clayey with time. Whereas in warm, humid climates the Bt horizon clay mineralogy can become dominated by low-activity clays, in temperate climates most Bt horizons develop to a certain point, after which they begin to degrade as the upper part of the soil gets increasingly acidic and leached. Subsequently, it is assumed that a process of ferrolysis sets in, causing clay minerals in the upper part of the Bt horizon to become unstable. The ferrolysis process is seen as the driving force behind the degradation of the Bt horizon (Bartelli, 1973; Schaetzl and Thompson, 2015). Initially, the Bt horizon degrades at the top and along permeable ped-faces and pores. The secretion from plant roots, which are preferentially located at these sites, enhance the degradation of the clays by acidifying these areas (Louis, 1973). The clays, their weathering products, and Fe-oxides are then leached and translocated, resulting in a pattern of whitish tongues penetrating the clay illuviation horizon (Hardy et al., 1999). Ultimately, this process leads to the formation of a degraded Bt horizon with an irregular upper boundary marked by narrow to broad penetrations of tongues of the bleached material (E horizon) into the Bt horizon (Figure 4). Often, the upper part of the Bt horizon is very dense and firm, but brittle when taken out and put under moderate pressure, and is referred to as a *fragipan*. The extraordinary compactness of the fragipan makes it very easily recognisable, both while augering and in a soil profile. Its consistency is very firm and its plasticity reduced; its structure is roughly flaky or platy and very clearly developed (Tavernier and Maréchal, 1957). In general, fragipans are considered pedogenic horizons, though their formation is not well understood (Bockheim and Hartemink, 2013; Soil Survey Staff, 1975). At least there seems to be some consensus that the formation of the fragipan requires a stage whereby the soil structure collapses under the influence of loading and wetting (Bockheim and Hartemink, 2013). Finally, the hypothesis assumes that the degradation process of the clay illuviation horizons also affects the fragipan as illustrated in Figure 4 (Schaetzl and Anderson, 2005; Smalley et al., 2016; Szymański et al., 2011; Smalley et al., 2016).

In the 1950s, when the standard legend of the soil map of Belgium was developed, the hypothesis of the chemical degradation of the clay illuviation horizon was generally accepted. Figure 5, adapted from one of the explanatory notes of the soil map, illustrates how the development of soil profiles with strongly mottled or discontinuous clay illuviation horizons **(..c)** was seen as an intermediate between a soil with a homogenous clay illuviation horizon **(..a)** and a Prepodzol **(..f)**, which would ultimately develop into a Podzol **(..g)**.

As indicated in Figure 5, soils with profile development **..c** are correlated with *Glossudalfs*. These are soils belonging to the Soil Taxonomy order of the *Alfisols* with an *Udic* moisture regime and with a *Glossic* horizon. In the most recent edition of the Key to Soil Taxonomy, the Glossic horizon is still seen as a result of the degradation of a clay illuviation horizon in which clay and free iron oxides are removed (Soil Survey Staff, 2014). In the FAO-Unesco legend of the Soil Map of the World, these soils were named *Podzoluvisols* (FAO, 1988). The name *Podzoluvisol* reflects the view that these soils have a clay illuviation horizon akin to the *Luvisols*, but that have been subjected to a 'podzolization' process (Driessen and Dudal, 1991).

4.2. RELICTS OF GLACIAL OR PERIGLACIAL PHENOMENA

Early on, as an alternative hypothesis to the process of chemical degradation due to 'podzolization' and/or ferrolysis, several authors have argued that the formation of fragipan soils could be linked to the permafrost (Fitzpatrick, 1956; Grossman and Carlisle, 1969; Lozet and Herbillon, 1971). Roger Langohr, with his co-authors, has been a leading scholar documenting and explaining how soil-forming processes under periglacial conditions may have led to the formation of the morphological characteristics typical for the **Abc** soil types. Through detailed field studies in the Sonian Forest, Roger Langohr and co-workers demonstrated that the bleached tongues form a typical polygonal pattern that can reach up to a depth of 120 cm (Figure 6). The fragipan is consolidated to such an extent that tree roots cannot penetrate through it. Contrary to the belief that roots formed the tongues, it is rather the roots that follow the polygonal cracks. The most compelling case for this argument is made in the paper by Brigitte van Vliet-Lanoë and Roger Langohr published in Catena,

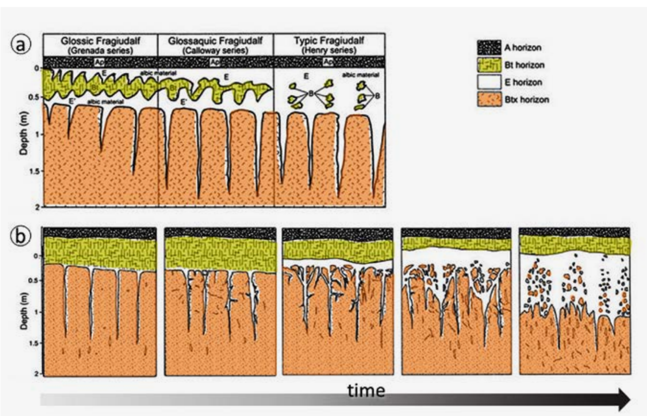


Figure 4. Two schematic representations illustrating the assumed degradation process of the clay illuviation (Bt/Btx) horizons due to acidification of the soils under a humid-temperate climate and leading to the formation of discontinuous Bt horizons.

a. Development and degradation sequence of fragipan soils developed in loess in the lower Mississippi Valley as proposed by Bartelli (1973).

b. Profile scale degradation of a clay illuviation horizon with a fragipan as proposed by Lindbo et al. (2000). Source: adapted from Schaetzl and Anderson (2005).

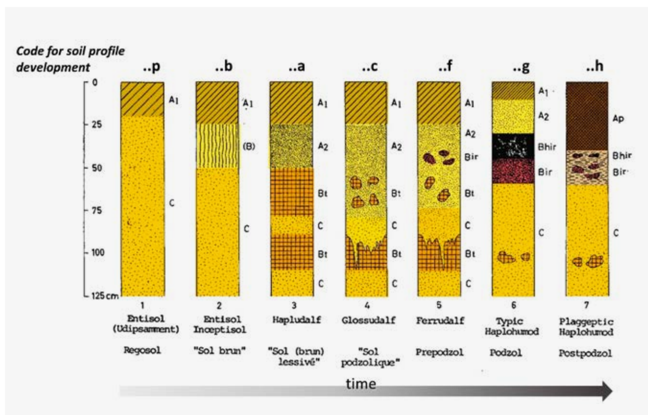


Figure 5. Stages of soil profile development in chronologic order. The code for soil profile development as used in the Belgian soil map legend is given on the first line. On the two lowest lines, correlations are given with the American and the French classification systems. Soil profile development '..c' is seen as an intermediate stage between soil with a clay enrichment horizon and a Prepodzol. Note that following the FAO designations for horizons (FAO, 2006), the A1 horizon corresponds to Ah or Ap, A2 to E, (B) to Bw, and Bir to Bs. Source: adapted from Ameryckx and Leys (1960).

where the authors compare typical permafrost features with the distribution and the physical, macromorphological, and micromorphological properties of fragipans (Van Vliet and Langohr, 1981). The common oxido-reductimorphic features must be regarded as relicts, as these soils are nowadays well-drained (Langohr, 1986; Langohr and Sanders, 1985). The assumption that clay minerals in soils with textural contrast and *Albeluvic* properties would be destroyed through a process of ferrolysis has been debunked by Van Ranst and De Coninck (2002), who show that the formation of the bleached E horizon is due to clay translocation.

Ampe et al. (2015) explain that during the last glaciation eolian loess was deposited in central Belgium until about 15,000 years BP. Later, under subarctic vegetation and during the relatively warm and humid Bølling-Allerød interstadials (ca. 14,700 – 12,800 years BP) *Chernozem*-like soils developed with a thick organic matter-rich surface horizon. The leaching of carbonates was then initiated and clay migration resulted in the formation of a clay illuviation horizon (Bt). Subsequently, during the permafrost of the Younger Dryas (ca. 12,800 to 11,500 BP), polygonal patterns of desiccation cracks developed that extended into the Bt horizon. Fragipans were formed through freeze-drying and due to the pressure from ice on the prismatic soil structures. Stagnation of water above the permafrost layer, as well as during the very humid Atlanticum period (ca. 7500 to 5000 years BP), led to the formation of oxido-reductimorphic mottling that persists until today. Decalcification, clay migration, and bioturbation continued during the Holocene. The process is illustrated in Figure 7 and shows that where forests prevailed, soils with leached tongues were preserved. Soils under agriculture were subjected to erosion and had their profile homogenised as a consequence of agricultural activity and bioturbation.

This hypothesis is fundamentally different from the hypothesis of chemical degradation of the clay illuviation

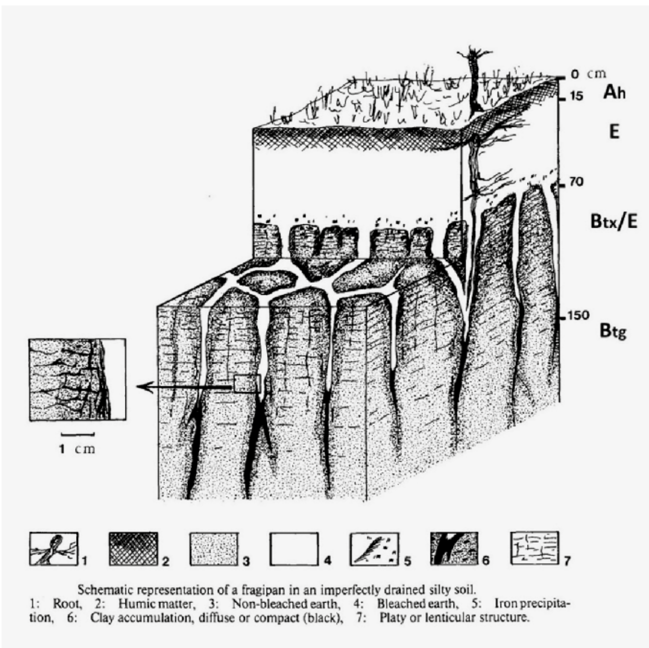


Figure 6. Schematic representation of a soil with a pronounced bleached (E) horizon interspersing a clay illuviation with a fragipan in the upper-part (Btx/E) and with oxido-reductimorphic features (Btg). The polygonal pattern of bleached material – defined as Albeluvic tongues – and the presence of a fragipan are best explained as remnants of periglacial process, whereby a prior formed clay illuviation horizon (Bt) was subjected to freeze-drying, leading to the formation of desiccation cracks. The clay minerals and Fe-oxides leached in permafrost conditions, leading to the formation of the E horizon, which, upon thawing, slid into the polygonal cracks. Source: adapted from (Van Vliet and Langohr (1981).

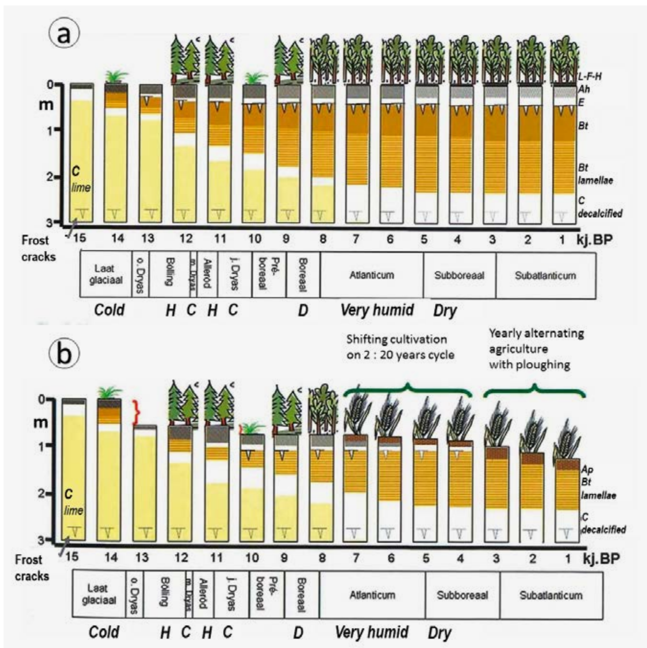


Figure 7. Soil formation in eolian loess deposits starting from the late glacial period to the present. (a) Evolution under a forest on a plateau position (b) and under agriculture on a sloping position. Legend: H = humid period; C = cold period.
Source: adapted from: Ampe et al. (2015).

horizon by 'podzolization' and/or ferrolysis processes, even though it still entails a physical degradation of the Bt horizon during a period of permafrost. Given these new insights, in the first edition of the World Reference Base for soil resources (ISSS–ISRIC–FAO, 1998) – i.e. the international soil classification system that evolved from the FAO-Unesco legend of the soil map of the world – the *Podzoluvisols* were redefined as *Albeluvisols*. *Albeluvisols* have, within 1 metre from the surface, a clay illuviation horizon with an irregular or discontinuous upper boundary, due to deep tonguing of bleached soil material into the illuviation horizon. *Albeluvisols* are required to have *Albeluvic* tonguing starting at the upper boundary of the clay illuviation horizon. The *Albeluvic* tongues consist of whitish (i.e. *Albic*) soil material with the tongues having greater depth than width. In clayey Bt horizons they need to be at least 5 mm wide, in silty Bt horizons at least 10 mm wide, and in silt-loam or loamy Bt horizons they need to be coarser than 15 mm. They also must occupy at least 10 percent of the volume in the first 10 cm of the Bt horizon, measured on both vertical and horizontal sections. However, during field testing in Norway, Poland and Russia of the 2nd edition of the World Reference Base (IUSS Working Group WRB, 2007), it became evident that the definition of the *Albeluvisols* was too restrictive. The requirement for having *Albeluvic* tonguing resulted in the exclusion of a wide range of soils that do have clay illuviation horizons with reticular patterns of bleached material and which can equally be attributed to relict features from periglacial conditions. When comparing the soil profile in Figure 8 with the example in Figure 2, or with the scheme in Figure 6, it is clear that it lacks the typical *Albeluvic* tonguing in a polygonal pattern. It, however, has a clear pattern of coarser textured *Albic* material within the clay illuviation horizon (Btg/E). The interfingering coarser-textured *Albic* material is found both as vertical and horizontal whitish intercalations on the faces and edges of soil aggregates. This feature corresponds to what has been defined as *Retic* properties in the 3rd edition of the World Reference Base (IUSS Working Group WRB, 2015).

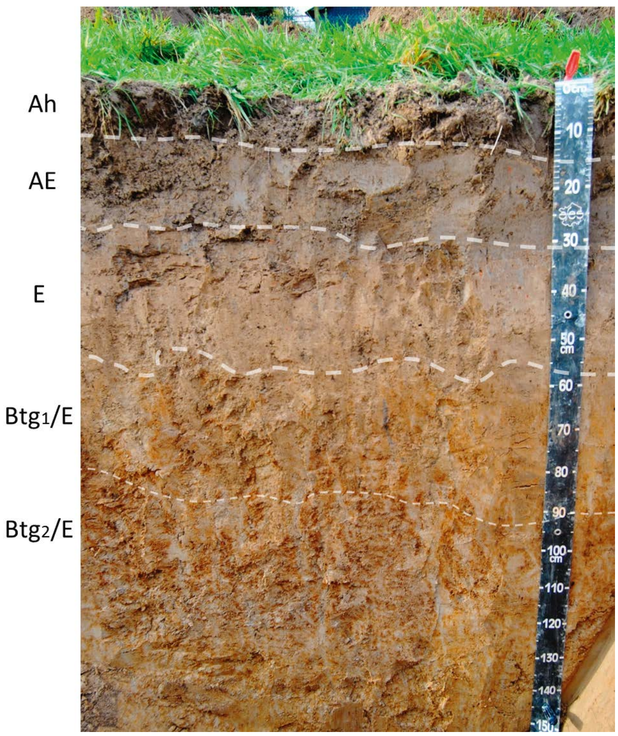


Figure 8. Example of a soil under pasture (Dilbeek, Belgium) with a strongly mottled Bt horizon (Btg/E), but which does not meet the characteristic polygonal pattern of Albeluvic tonguing. This reticular pattern can however also be attributed to periglacial phenomena. In the 3rd edition of the World Reference Base for soil resources, it qualifies as a *Eutric Stagnic Retisol* (*Siltic*), in the Belgian classification system it is a *Acco* soil type. Photo: S. Dondeyne.

Hence, in the latest edition of the World Reference Base, the *Albeluvisols* have been replaced by the broader group of *Retisols*. Many soils that had been mapped as *Podzoluvisols* in Russia also fit the definition of the *Retisols*. In the Belgian soil classification system, such soils are indeed also recognised for having a mottled Btg horizon **(..c)**. Concerning the **Abc** soil type presented in Figure 2, following the 3rd edition of the World Reference Base for soil resources, this soil is a *Dystric Glossic Fragic Retisol* (*Siltic*). With the qualifier *Dystric* standing for the low level of exchangeable basic cations linked to the acidic nature of the soil; *Glossic* for the clear bleached tongues interspersing the clay illuviation horizon, *Fragic* for the fragipan, and *Siltic* for the silt-loam texture.

5. What do we learn from this?

If we accept the hypothesis that the morphology of the **Abc** soil types has to be attributed to periglacial phenomena, what does this tell us about the enigmatic soil pattern found under a Roman road in Asse? We found that the *Dystric Glossic Fragic Retisol* (*Siltic*) of the **Abc** soil types is well preserved in the ancient forests of central Belgium, as these areas have never, or hardly ever, been under agriculture. Reciprocally, it means that before deforestation, the **Abc** soil types must have been more widespread. Buried *Albeluvisols* have indeed been found in central Belgium in a study of Holocene dry valley sediments (Rommens et al., 2007). It is only through human agency that these soils developed a homogenous clay illuviation horizon. Liming and manuring promoted the activity of earthworms and particularly of *Lumbricus terrestris*. Earthworms are favoured by the European mole (*Talpa europaea*) and their combined actions will have contributed to the homogenisation of the E and the Bt horizons. Following Langohr (2001), we can thus conclude that the *Haplic Luvisols* (soil types **Aba**) have been formed as a consequence of human alteration of the landscape. In Asse, the remnants of the Roman road, as well as the pile of Roman tiles, must have obstructed earthworms and moles from homogenising the soil. The observations in Asse confirm that in pre-Roman and Roman times the **Abc** soil types must have been much more common than they are today. In Asse, we did not only learn about a Roman settlement and Roman infrastructural works, but we also found a window into what the soils and landscapes were like 2000 years ago. The case thus illustrates how understanding soil formation processes helps to understand the evolution of the landscapes as well as past and current land-uses. Such insights are indeed complementary to what we can learn from ecology, forestry, archaeology, and history.

References

Ameryckx, J. and Leys, R., 1960. Bodemkaart van België : Verklarende tekst bij het kaartblad: Wetteren 56W. IWONL/IRSIA.

Ampe, C., Langohr, R., Van Ranst, E., Finke, P.A., Deckers, S., and Poesen, J., 2015. Hoofdstuk 5: Bodem. In: *Geologie van Vlaanderen* (Ed. M. Borremans), 260-338. Academia Press, Gent.

Aurousseau, P., 1990. A Microscopic and Mineralogical Study of Clay Degradation in Acid and Reducing Conditions. *Developments in Soil Science,* 19, 245–255.

Baeyens, L., 1959a. Bodemkaart van België: Verklarende tekst bij het kaartblad: Tervuren 102E. IWONL/IRSIA.

Baeyens, L., 1959b. Bodemkaart van België : Verklarende tekst bij het kaartblad: Hamme-Mille 103E. IWONL/IRSIA.

Bartelli, L.J., 1973. Soil development in loess in the southern Mississippi Valley. *Soil Science,* 115, 254–260.

Bockheim, J.G. and Hartemink, A.E., 2013. Soils with fragipans in the USA. *Catena,* 104, 233–242.

Bouma, J., Fox, C.A., and Miedema, R., 1990. Micromorphology of hydromorphic soils: Applications for soil genesis and land evaluation. *Developments in Soil Science*, 257–278.

Brahy, V., Deckers, J., and Delvaux, B., 2000. Estimation of soil weathering stage and acid neutralizing capacity in a toposequence Luvisol-Cambisol on loess under deciduous forest in Belgium: Weathering and acid neutralizing capacity in soil on loess. *European Journal of Soil Science*, 51, 1–13.

Dondeyne, S., Vanierschot, L., Langohr, R., Van Ranst, E., and Deckers, J.A., 2014. The soil map of the Flemish region converted to the 3rd edition of the World Reference Base for soil resources (41 map sheets at scale 1:40 000, 1 map sheet at 1:250 000). KU Leuven, Universiteit Gent, Vlaamse Overheid, Brussels.

Driessen, P.M. and Dudal, R. (Eds.) 1991. The major soils of the world: lecture notes on their geography, formation, properties and use. Wageningen University, The Netherlands and Katholieke Universiteit Leuven, Belgium, Wageningen.

FAO, 1988. FAO/Unesco Soil Map of the World. Revised legend with corrections, World Resources Report. Reprinted, with corrections, as Technical Paper 20, ISRIC, Wageningen, 1994, FAO, Rome.

FAO, 2006. Guidelines for soil description, 4th edition. Food and Agriculture Organization of the United Nations, Rome.

Fitzpatrick, E.A., 1956. An indurated soil horizon formed by permafrost. *Journal of Soil Science*, 7, 248–254.

Grossman, R.B. and Carlisle, F.J., 1969. Fragipan soils of the Eastern United States. *Advances in Agronomy,* 237–279.

ISSS–ISRIC–FAO, 1998. World Reference Base for soil resources, World soil resources reports. Food and Agriculture Organization of the United Nations, Rome.

IUSS Working Group WRB, 2007. World Reference Base for soil resources 2006. First update 2007. A framework for international classification, correlation and communication. FAO, Rome.

IUSS Working Group WRB, 2015. World Reference Base for soil resources 2014: international soil classification system for naming soils and creating legends for soil maps. Update 2015. FAO, Rome.

Langohr, R., 1986. La pédologie et l'évolution de l'utilisation des terres dans la région limoneuse de Belgique. *Hommes et Terres du Nord*, 2, 94–97.

Langohr, R., 2001. L'anthropisation du paysage pédologique agricole de la Belgique depuis le Néolithique ancien - Apports de l'archéopédologie. *Étude et Gestion des Sols*, 8, 103–118.

Langohr, R. and Sanders, J., 1985. The Belgian loess belt in the last 20000 years: evolution of soils and relief in the Zonien Forest. In: *Soils and Quaternary Landscape Evolution* (ed. J. Boardman). Wiley and Sons, Chichester, New York.

Lindbo, D.L., Rhoton, F.E., Hudnall, W.H., Smeck, N.E., Bigham, J.M. and Tyler, D.D., 2000. Fragipan Degradation and Nodule Formation in Glossic Fragiudalfs of the Lower Mississippi River Valley. *Soil Science Society of America Journal*, 64, 1713–1722.

Louis, A., 1959. Bodemkaart van België : Verklarende tekst bij het kaartblad: Uccle 102W. IWONL/IRSIA.

Louis, A., 1973. Carte des sols de la Belgique: Texte explicatif de la planchette de La Hulpe 116E. IWONL/IRSIA.

Lozet, J.M. and Herbillon, A.J., 1971. Fragipan soils of Condroz (Belgium): Mineralogical, chemical and physical aspects in relation with their genesis. *Geoderma,* 5, 325–343.

Magerman, K., De Beenhouwer, J., Saerens, S. and Lodewijckx, M., 2013. Archeologische prospectie met ingreep in de bodem: Asse-Nerviërstraat 60-2013 - 2013/159. Rapporten AGILAS vzw 2, 114.

Maréchal, R. and Tavernier, R., 1974. Atlas van België. Commentaar bij de bladen 11 A en 11 B, uittreksels van de bodemkaart, bodemassociaties: Pedologie. Nationaal Comité voor Geografie, Commissie voor de Nationale Atlas, Koninkrijk België.

Rommens, T., Verstraeten, G., Peeters, I., Poesen, J., Govers, G., Van Rompaey, A., Mauz, B., Packman, S. and Lang, A., 2007. Reconstruction of late-Holocene slope and dry valley sediment dynamics in a Belgian loess environment. *The Holocene,* 17, 777–788.

Sanders, J. and Sys, Ch., 1988. Bodemkaart van België : Verklarende tekst bij het kaartblad: Wakken 68E. IWONL/IRSIA.

Schaetzl, R.J. and Anderson, S., 2005. *Soils: Genesis and Geomorphology*. Cambridge University Press, New York.

Schaetzl, R.J. and Thompson, M.L., 2015. *Soils: Genesis and Geomorphology*, Second edition. Cambridge University Press, New York.

Smalley, I.J., Bentley, S.P. and Markovic, S.B., 2016. Loess and fragipans: Development of polygonal-crack-network structures in fragipan horizons in loess ground. *Quaternary International,* 399, 228–233.

Soil Survey Staff, 1975. Keys to Soil Taxonomy. USDA, Natural Resources Conservation Service.

Soil Survey Staff, 2014. Keys to Soil Taxonomy. Twelfth Edition, 2014. USDA, Natural Resources Conservation Service.

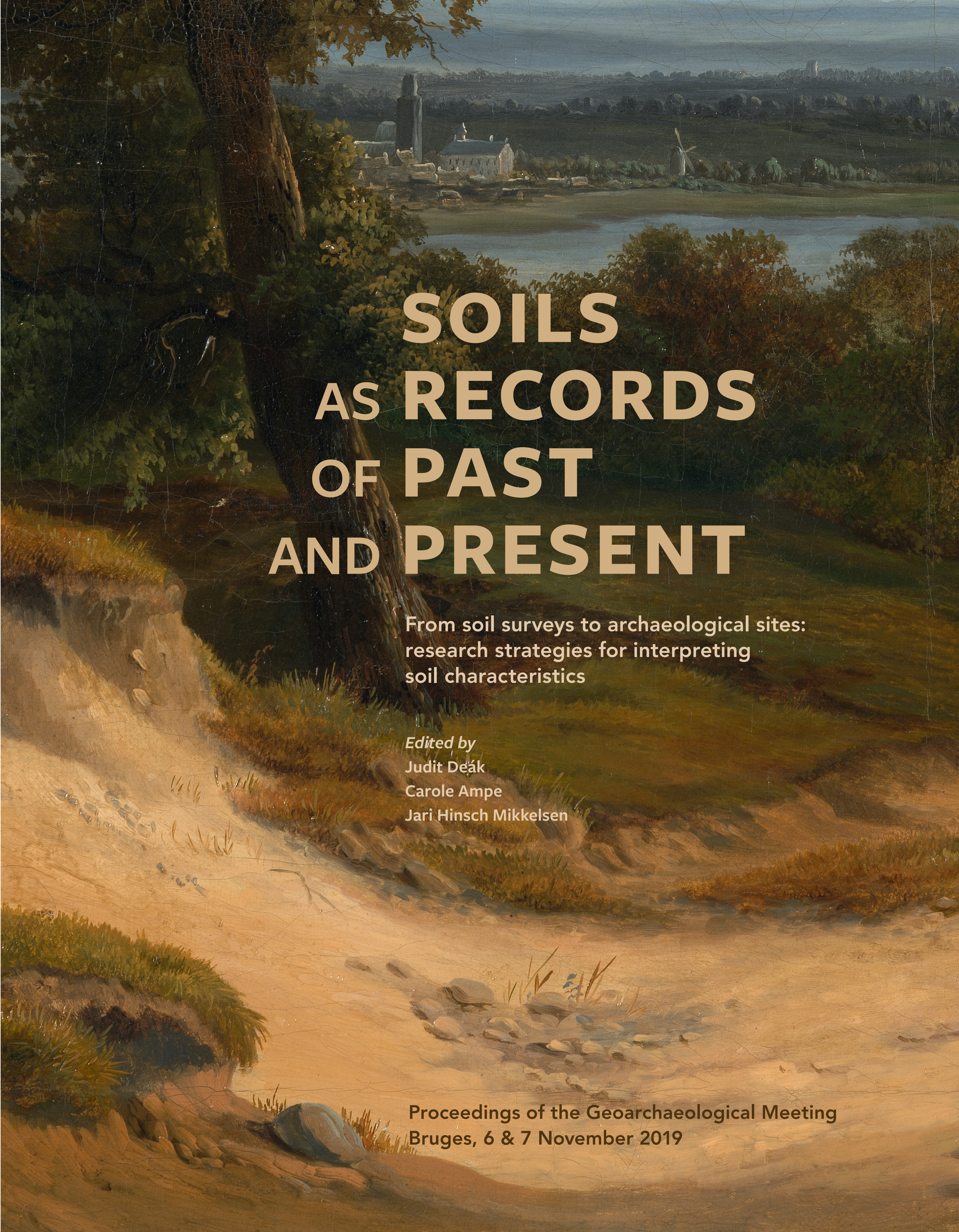
Szymański, W., Skiba, M. and Skiba, S., 2011. Fragipan horizon degradation and bleached tongues formation in Albeluvisols of the Carpathian Foothills, Poland. *Geoderma*, 167–168, 340–350.

Tavernier, R. and Maréchal, R., 1957. Les sols à fragipan de la région condrusienne. *Pedologie*, 7, 199–203.

Van Ranst, E. and De Coninck, F., 2002. Evaluation of ferrolysis in soil formation. *European Journal of Soil Science,* 53 (4), 513-520.

Van Vliet, B. and Langohr, R., 1981. Correlation between fragipans and permafrost with special reference to silty Weichselian deposits in Belgium and northern France. *Catena* 8, 137–154.

Vancampenhout, K. and Deckers, J., 2010. Orphans in soil classification: Musing on Palaeosols in the World Reference Base system. In: Soil Solutions for a changing World, Proceedings of the 19the World Congress of Soil Science, p. 5. Brisbane, Australia.



SOILS AS RECORDS OF PAST AND PRESENT

From soil surveys to archaeological sites: research strategies for interpreting soil characteristics

Edited by
Judit Deák
Carole Ampe
Jari Hinsch Mikkelsen

Proceedings of the Geoarchaeological Meeting
Bruges, 6 & 7 November 2019

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