

# Soils in the vicinity of Wageningen

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## **Background information for participants of the ISRIC Spring School 2017**

'World Soils and their Assessment' excursion  
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## Introduction

When the Wageningen Landbouw Hogeschool (“Agricultural School”) was founded as a precursor of Wageningen University in 1876 the site has not been arbitrarily chosen. Wageningen lies in the centre of a multi-faceted landscape that offers multiple opportunities for agricultural and environmental research. And it allows as many fascinating insights into soils and their relationship to the landscape history.

In the south, the lower Rhine, Meuse and Waal have created a vast alluvial plain, bringing partly calcareous substrates from as far away as the Swiss Alps. In the north, east and west of the municipal territory stretches a (peri-)glacially influenced landscape. It has exciting features such as ice-pushed ridges, deep depressions, dry side valleys, and cover sand depositions. What a great opportunity to explore 200,000 years of landscape history in just one day! And where else in Europe can one find materials from far away locations such as Norway or Switzerland in one place?

The Spring School course ‘World Soils and their Assessment’ is exploring the soils of this area in particular, with stops at 6 excursion points (see Figure 1):

# Location and map of the excursion area

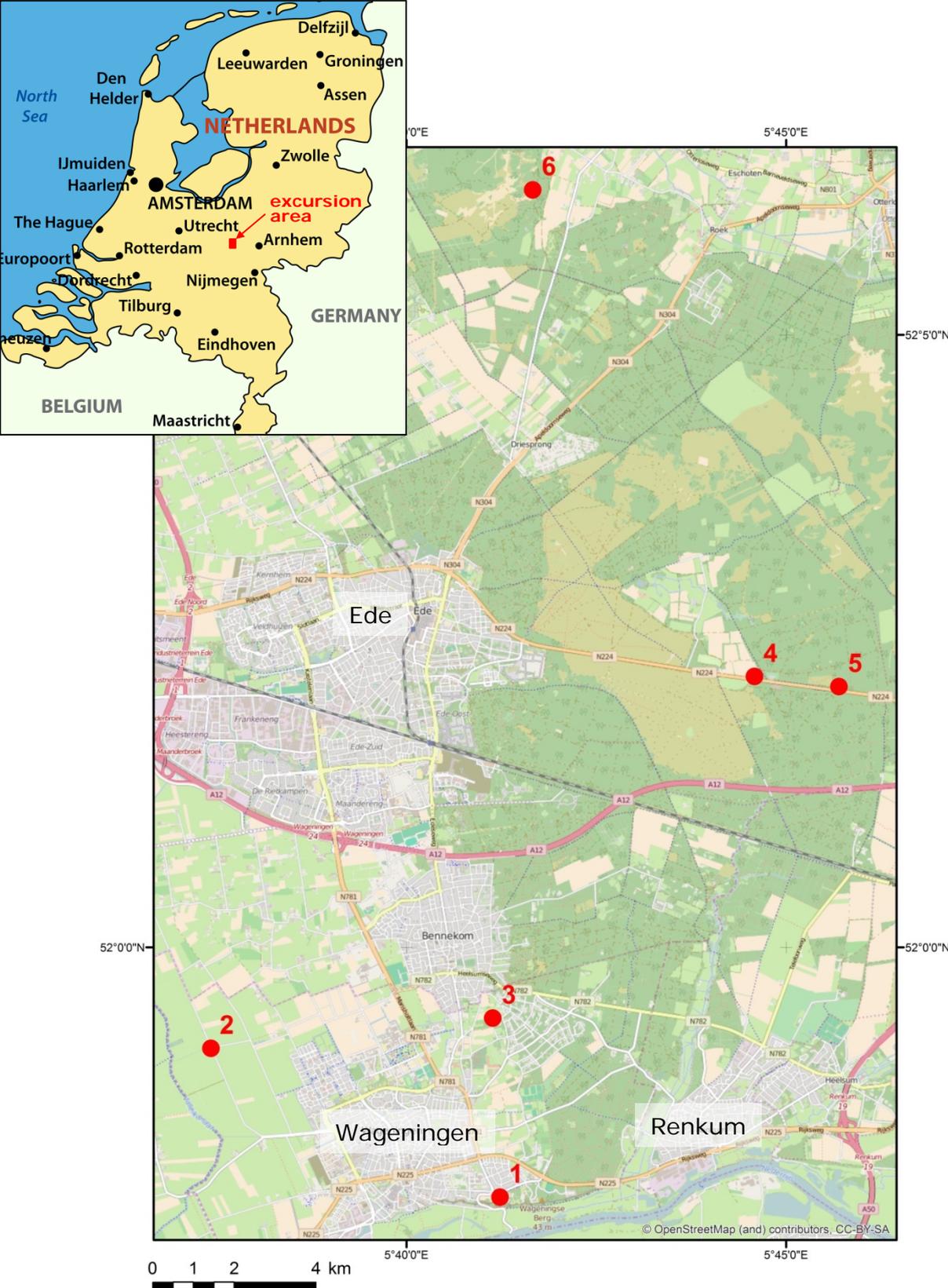


Figure 1: Location and map of the area with excursion points indicated.

## Soil forming factors

### Surface Geology

On the mainland of north-western Europe coarse-textured materials occur at the surface over extended areas. These sediments mostly derive from the mountainous region south and east of the Netherlands, i.e. Belgium, Germany and Switzerland. They were deposited during the Early and Middle Pleistocene by precursors of the rivers Scheldt, Meuse, Rhine, Ems, Weser, and Elbe, forming a wide alluvial plain in Germany.

During the Saalian (Germany: Riss; U.K.: Wolstonian) glaciation at the end of the Middle Pleistocene (200,000-125,000 years ago, Figure 2), a continental ice cap which had its centre in the Scandinavian highlands, extended to the south and covered a large part of the NW European lowlands, including also half of the Netherlands. Ice tongues intruded and scoured out pre-existing river valleys and pushed up the sandy and gravelly alluvial sediments, forming basins, hills and ridges. In the North of the Netherlands ground moraine is found in isolated areas; fluvio-glacial deposits occur along many of the ridges which mark the glacial valleys.

North of Wageningen, the glacier used an existing valley system, the "Gelder Valley", which formerly was a part of the Rhine valley. In this process, materials were accumulated and pushed upwards along the flanks, forming the Wageningen-Ede push moraine, and the parallel Utrechtse Heuvelrug (Figure 4). The glacier finally came to a standstill near Wageningen, pretty much at where Excursion point 1 is located.

During the following interglacial stage (Eemian, U. K.: Ipswichian) with temperate climatic conditions, the relief was levelled through erosion and mass wasting, but remnants of the glacial valleys and ice-pushed ridges still can be recognized in the present-day landscape.

The last glaciation (Weichselian) was marked by a renewed advance of the Scandinavian ice sheet which, however, only reached the north of the Netherlands. In the area not covered by the ice, periglacial conditions prevailed, and in the arctic desert large parts of the landscape became covered with eolian sands of homogeneous grain size distribution (150-210 $\mu$ m). These "cover sands" have further contributed to the levelling of the topography, accumulating in great thickness in the valleys and depressions and being virtually absent on the highest ice-pushed ridges and in some isolated patches of the ground moraine; The eolian character of the deposits is evident from the well-sorted fine sandy texture and the slightly undulating relief with irregular depressions and somewhat higher elongated elevations which are considered to be remnants of longitudinal and parabolic dunes. At the end of the Weichselian (13,000-10,000 years ago), the youngest cover sand was deposited as ridges with a west-east orientation (cover sand ridges). The dominant mineral in the cover sands is

quartz, which constitutes 65-90% of the minerals. Feldspars range from 5-15%. The percentage of heavy minerals such as augite, hornblende, epidote etc. normally does not exceed 10% but commonly occurs in quantities of less than 5 %.

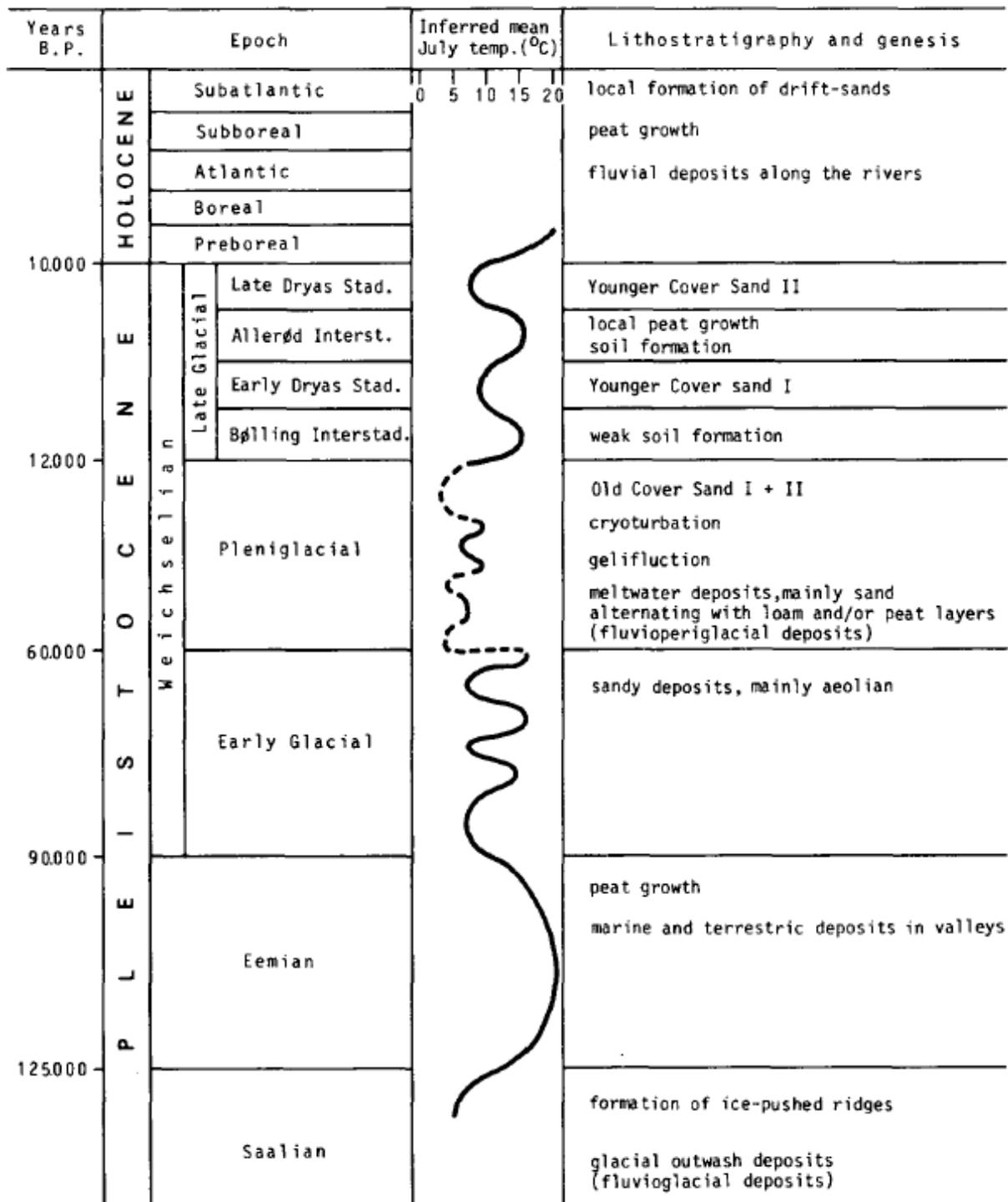


Figure 2: Chronostratigraphy of the central and eastern part of the Netherlands (source: Deutsche Bodenkundliche Gesellschaft, 1986)

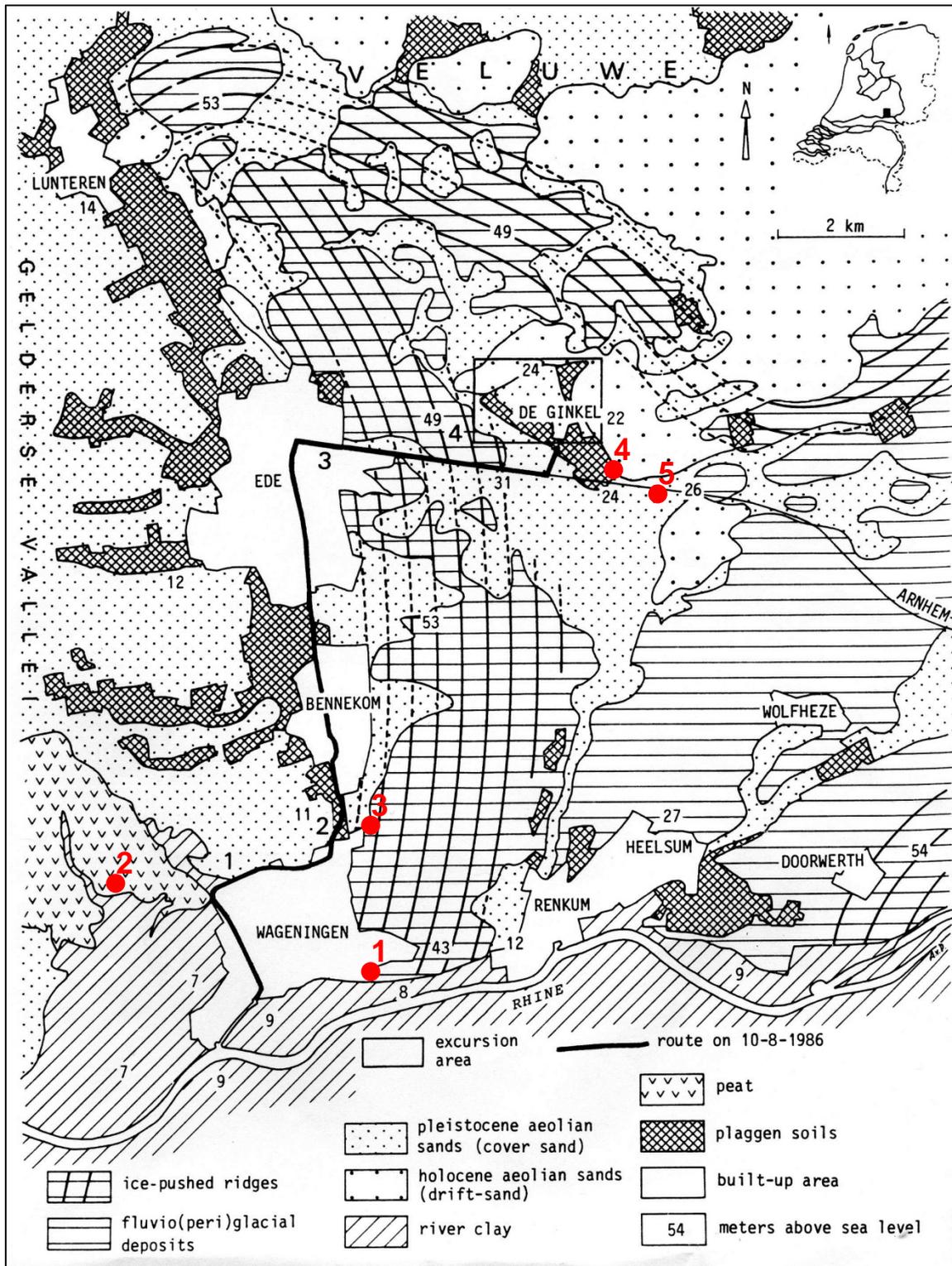


Figure 3: Physiographic map of the sandy district north of Wageningen, with location of excursion points indicated (source: Deutsche Bodenkundliche Gesellschaft, 1986)

Before the Saalian glaciation the rivers Rhine and Meuse were flowing in northern and northwestern direction. When the Scandinavian ice sheet penetrated the Netherlands and pushed up a series of ridges, the northern access to the North Sea was blocked and the course of the rivers was deviated in westerly direction.

After the retreat of the ice, the rivers continued their westerly course, creating the broad flood plain of the contemporary Rhine and Meuse. Today, the Holocene deposits of this meandering system are at the surface, forming the parent material of the soils. The coarser textured, buried deposits of the Pleistocene braided river system are found at a depth of 3 m or deeper. A rough distinction can be made between the sediments and soils of a) the stream-belt, and b) the flood basin. The former includes the zone along the river channel built up by point bar deposits and bank deposits. Soils developed on natural levees commonly are medium-textured in the upper part of the profile (loam, clay loam, silty clay loam and silty clay), gradually becoming sandier with depth. The channel repeatedly diverted its course and fresh sediments buried older deposits, thereby interrupting the sedimentary cycle. As a result, the profile may show a great variety of textural changes with depth. The flood basin (also called backswamp) is the zone along the meandering river but at some distance from the actual channel. This area is flooded only during periods of very high water when the river overflows its banks - after it has deposited the coarser material on the natural levees. In contrast with the natural levees, which make up the most elevated zone along the river because they repeatedly receive fresh sediments, the flood basin is the lowest part of the flood plain. The poorly drained conditions of these areas promote the growth of peat. Figure 4 illustrates the distribution of landscape elements in the river landscape south of Wageningen.

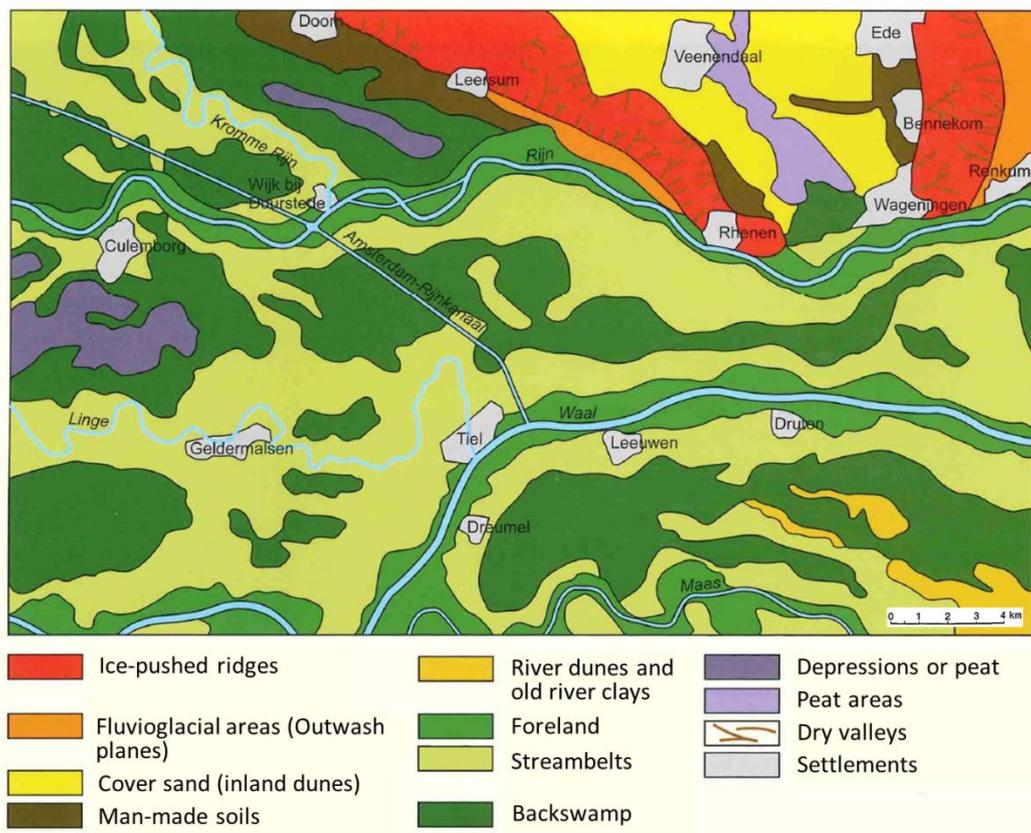


Figure 4: Landscape elements of the fluvial district south-west of Wageningen (source: Jongmans et al. 2012: *Landschappen van Nederland*, adapted)

## Climate

At the end of last glaciation climatic conditions became milder and moister. From then on, throughout the Holocene, the climate has been, with some variations, more or less similar to the present climate. The mean annual temperature at de Bilt (central Netherlands) is around 10°C and mean annual precipitation is 800-900 mm (Table 1).

**Table 1: Long-term average and extreme climate data, period 1981-2010**  
(<http://www.knmi.nl>)

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Max. temp. (°C)	5,6	6,4	10,0	14,0	18,0	20,4	22,8	22,6	19,1	14,6	9,6	6,1	14,1
Min. temp. (°C)	0,3	0,2	2,3	4,1	7,8	10,5	12,8	12,3	9,9	6,9	3,6	1,0	6,0
Avg. temp. (°C)	3,1	3,3	6,2	9,2	13,1	15,6	17,9	17,5	14,5	10,7	6,7	3,7	10,1
Avg. precipitation (mm)	69,6	55,8	66,8	42,3	61,9	65,6	81,1	72,9	78,1	82,8	79,8	75,8	832,5
Hours of sunshine	62,3	85,7	121,6	173,6	193,9	207,2	206,0	187,7	138,3	112,9	63,0	49,3	1601,6

Due to the seasonal variation of climatic parameters, the evapotranspiration also varies throughout the year. Between October and March a precipitation surplus of 300 mm is built up, whereas a maximum deficit of 100-150 mm accumulates between April to September (Huisman et al. 1998). The mean annual evapotranspiration for the whole of the Netherlands is in the order of 550 mm, leading to an average yearly precipitation excess of 200 mm. The precipitation excess results in a net leaching of the soils (De Bakker 1979).

## Vegetation

As a consequence of the amelioration of the climate, the vegetation changed from a tundra into a forest, with the full forest sequence of the Holocene epoch. Early Holocene vegetation, mainly consisting of *Pinus* (pine) and *Betula* (birch), was succeeded by *Corylus* (hazel), *Ulmus* (elm) and *Quercus* (oak), and later *Tilia* (linden), *Fraxinus* (ash) and *Alnus* (alder), and still later *Fagus* (beech) and *Carpinus* (hornbeam). Late Holocene vegetation was characterized by forests with *Quercus* and *Fagus* on the "poor sands" and *Quercus* and *Betula* on the "very poor sands", whereas *Alnus* dominated in the wet locations.

Before human interference, these rather monotonous forests covered large parts of the Netherlands during the Holocene. As a result of extensive land cultivation there is virtually no natural vegetation left in the Netherlands. In contrast to climate, the role of natural vegetation on various soil formation, except for formation of peat soil, is less well understood and probably of minor importance compared to the impact of agricultural land use (van der Veer 2006).

## Time

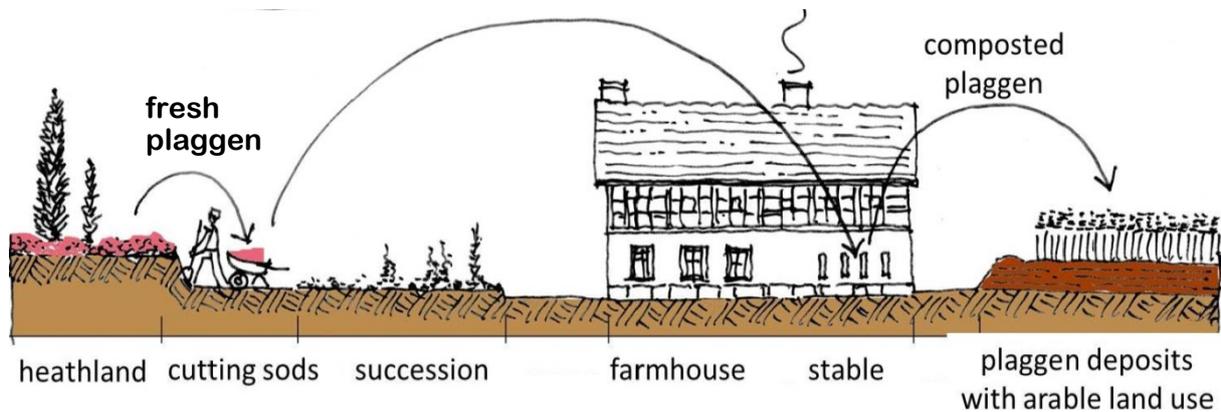
The time span available for the formation of the soils we find in this area today is set by the ice ages. Soil formation started at the beginning of the Holocene (10,000 years BP) with decalcification and weathering of minerals. This is inferred from a deep excavation in the western part of The Netherlands. In this excavation it was demonstrated that the Late Weichselian cover sands were drowned by the rising sea and were covered with peat and lagoonal deposits, preserving the pre-existing soils. The excavation was large enough to expose the undulating topography of the cover sands, showing the same toposequence of soils as in the actual landscape in the eastern part of the country: Gleysols (Aquepts) in the brook valleys and Podzols (Spodosols) on the low ridges and in the depressions. Pollen analysis proved that the Spodosols were formed under forest, mainly *Pinus sylvestris* and *Betula*, whereas *Alnus* dominated in the brook valleys. The age of the peat overlying the buried soil (determined by pollen analysis and C14 methods) dated back to about 7,000 years BP. From these observations it is inferred that the buried soils were already decalcified and podzolized before being covered with 15 to 20 m of Holocene deposits (Pons 1959). Apparently, soil formation in the sandy material under consideration started after sedimentation and had already proceeded to a stage more or less comparable to the actual soils at about 7,000 years BP.

## Man

Human influence first became evident in the Middle Holocene (the late-Mesolithic era, about 5,000-6,000 years BP). Ever since, man has been increasingly active and the forests were gradually cut down for agricultural purposes. From early medieval times onward, crops were produced in small clearings in the forests, topographically situated on low ridges amidst the wet depressions and the valley bottoms of small streams. During the following centuries extensive sheep grazing accelerated the disappearance of the forests: sheep prevented the regrowth of trees. The forests gave way to heaths with a low shrub vegetation: on the wet places dominantly cross-leaved heath (*Erica tetralix*) and on the dry sites ling (*Calluna vulgaris*). This process reached its peak in the middle of last century. At that time about 50% of the sandy soils of The Netherlands were covered with heath.

The above-mentioned shifting cultivation system changed most probably gradually into the *plaggen* management system (Figure 5). For many centuries - from about 1,000 AD until the introduction of fertilizers around 1880 - land use was: arable crops on the low ridges with Podzols and grassland for the cattle in the small brook valleys with sandy Gleysols. Arable crops were rye, buckwheat and oats, later mangolds and potatoes; after rye Swedish turnips were often grown as a second crop. The heathlands were communal lands, in contrast with the private arable fields and the grassland. The soils, mainly (gleyic) Podzols, were used as rough grazing land for a special breed of sheep. The flock had to

spend the night in the sheepfold so that all the droppings could be collected. In these pens, and also in the cowsheds heather sods were used as bedding material.



**Figure 5: Schematic display of *plaggen* management in north-west Europe (source: Thierer 2008)**

The introduction of fertilizers in the 1880's changed this system completely. The heathland was neither needed anymore as rough grazing land nor as a source of manure for the arable land. A large area was reclaimed and converted into arable land and grassland (limed and fertilized). Part of the heathland was reforested, mainly with Scots Pine (*Pinus sylvestris*). In 1866 there were more than 600,000 ha of heathlands; today less than 60,000 ha remain! The increased arable area enabled the farmers to use straw as bedding material in the barns, tables, consequently the introduction of fertilizers brought the plaggen management system to an end.

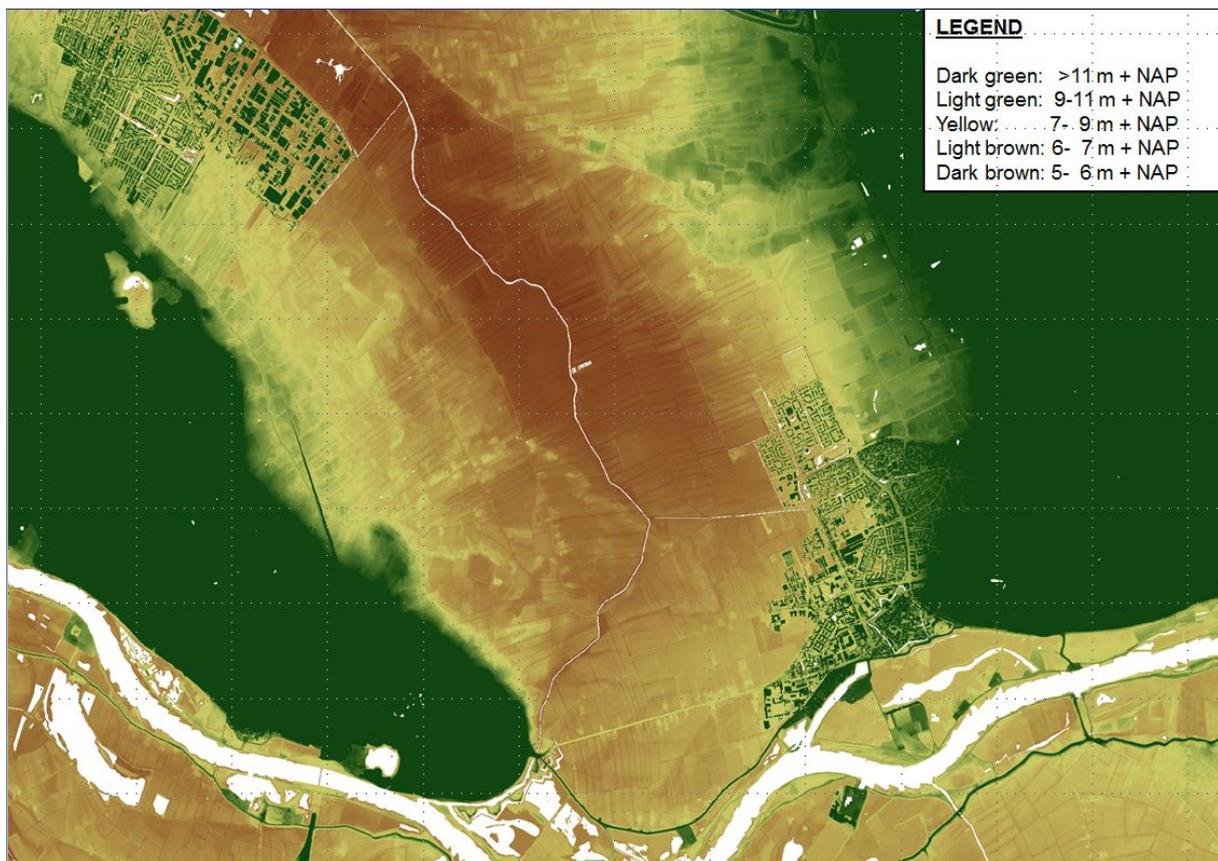
Land use changed considerably in the last decades. From mixed arable/dairy farms, farming on the Pleistocene sandy soils changed into nearly completely dairy systems. The rye practically disappeared and was replaced by maize for silage, and a large area of the arable land changed into grassland. The original grasslands as well as these new grasslands are regularly re-sown (a kind of long-term leys) in order to improve their production capability.

In the Fluviatile District south of Wageningen, first clear evidence of human occupation dates back to the Bronze Age (about 3,000 years before present), but it was not before about the year 1,100 AD that the people - their settlements being continually imperilled by flooding - began to curb and check the rivers. Dykes were build alongside the river creating temporarily flooded "forelands" mainly used for pasture. In many areas – e.g. also in the Wageningse uiterwaarden – forelands have been used for digging up the surface layers of clay, to be used for the manufacture of bricks. After establishment of the dykes the streambelts and flood basins were no more flooded, except for some short, ill-fated periods when, at very high water, the dyke burst. Today, many of the places where such a catastrophic event took place, can be recognized by a curvature of the dyke which has been rebuilt around the deep pond.

## Soil forming processes

### Accumulation of organic matter

The fluvio-glacial basin in between the two ice-pushed ridges of Ede-Wageningen and Utrechtse Heuvelrug, the "Gelder Valley", is among the lowest-lying areas of the excursion area (Figure 6). After the retreat of the glacier, it has subsequently been filled with sediments.



**Figure 6: Southern part of the "Gelder Valley"; NAP = Normaal Amsterdams Peil (source: AHN.nl)**

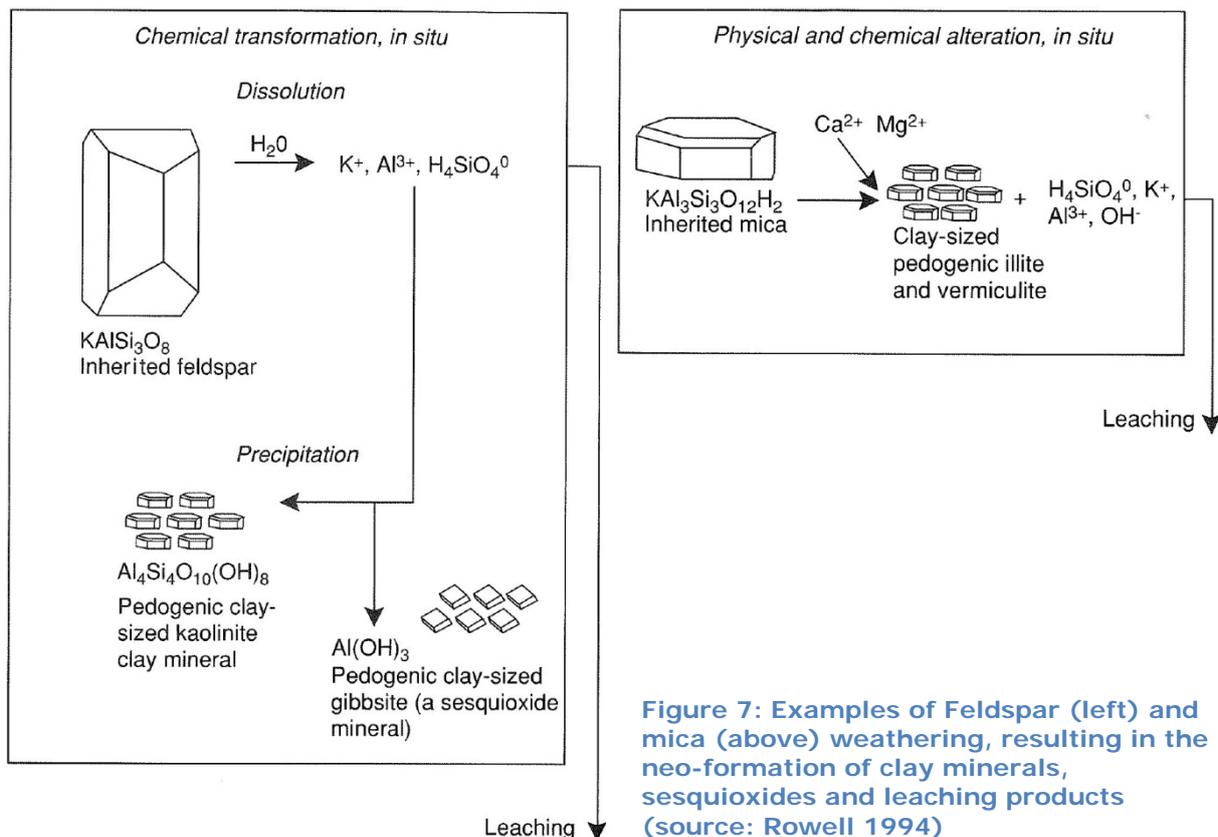
Close to the river Rhine the basin has been subjected to the dynamics of a backswamp. Soil profiles show multiple sequences of peat formation during periods of waterlogging, and soil formation under drier regimes. The construction of embankment dykes, in combination with artificial drainage, substantially changed these dynamics, practically preventing formation of new peat in most areas.

Accumulation of organic matter can also happen in freely draining soils. With quartz as the main mineral the chemical setting in the excursion area is mostly acid and nutrient-poor. Under these conditions soil decomposer and mixing organisms are relatively few in number and organic matter tends to accumulate on the soil surface with little mixing with underlying mineral matter. In FAO (2006), such organic layers are described as "O" horizons, with suffixes designating the degree of decomposition of the organic material: Oi (slightly

decomposed, including leaf litter), Oe (moderately decomposed), and Oa (highly decomposed). Other terminologies use L (litter layer), F (fermentation layer), and H (humic layer) instead.

### Weathering: Mineral neo-formation, and brunification

The manifold processes connected to physical and chemical weathering has turned the sandy substrates in the excursion area into soils over the last 10,000-13,000 years. Quartz is most resistant to weathering, so that deposition areas of finer materials often show more advanced soil formation than those of coarser substrates. In a process called the neo-formation of minerals (or “loamification”) primary minerals such as feldspars and mica are being transformed into secondary, clay minerals.

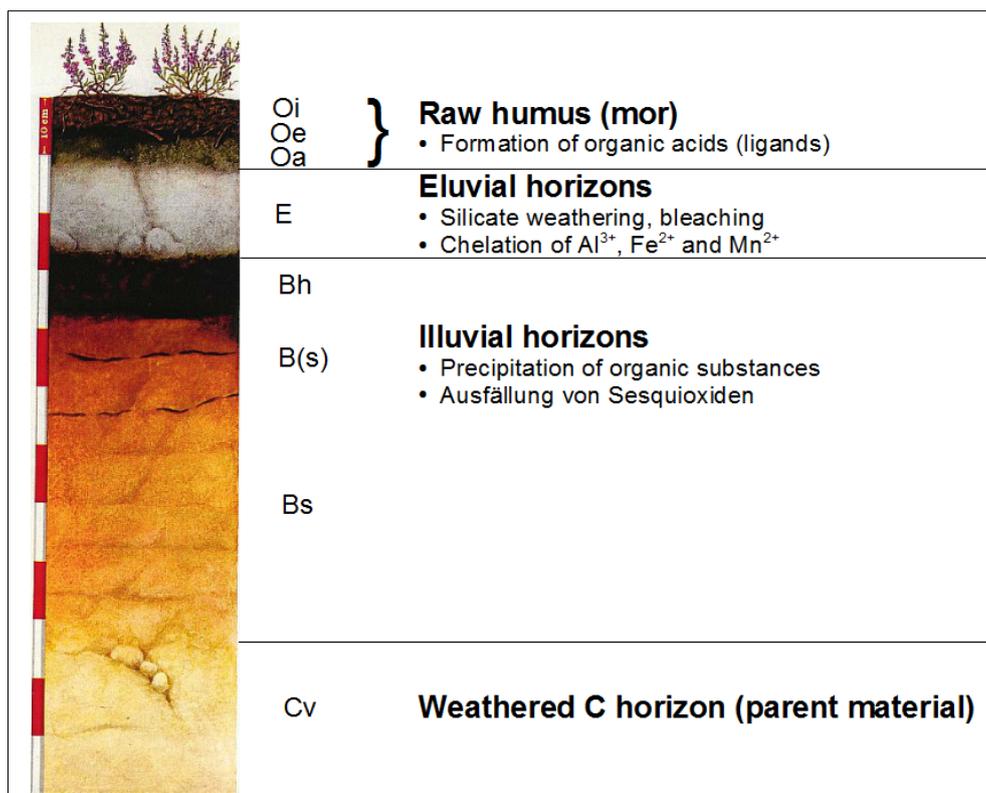


The concomitant release, hydration and oxidation of  $Fe^{2+}$  and  $Mn^{2+}$  is responsible for the reddish-brown colour of freely drained soils, and is called “brunification”.

Loamification and brunification are the main soil forming processes leading to the soil type of Cambisols.

## Leaching: Podzolisation

Both of the above processes are essential elements of another process typical of acidic soils: podzolisation. Besides an acid soil reaction limiting soil biological activity, this process requires an all-season precipitation surplus and low evaporation levels in combination with low temperatures. As rainwater filtrates through the accumulated organic materials on top of the soil it takes up organic acids and transports them into the mineral topsoil. There, they acts as ligands, chelating mineral cations such as  $\text{Fe}^{2+}$ ,  $\text{Al}^{2+}$  and  $\text{Mn}^{2+}$ . These metal-organic complexes are further leached and translocated through the soil profile and precipitate in the subsoil. This process is clearly visible in a soil profile as it creates a bleached “eluvial” topsoil (E horizon), underlain by one or more “illuvial” subsoil horizons, usually a black horizon of organic matter accumulation (Bh) directly followed by a zone of sesquioxides enrichment (Bs) (Figure 8). In thin sections, podzolisation is visible e.g. as sesquioxide coatings around quartz grains, and cementing of larger pores (Photo 1). Where intensive illuviation continues for long time the development of an iron pan (hardpan, “ortstein”) is possible. This term describes a cemented layer in the subsoil largely impervious to water, that forms from cutans of amorphous materials (Al, Si, and organic components).



**Figure 8: Typical horizon sequence and associated processes of a Podzol (source: rgs.org)**

With the coarse texture the capacity for water retention is low. Although they are a characteristic soil type of humid climates, they often show water stress.

Podzolized soils are acid, with a  $\text{pH}_{\text{H}_2\text{O}}$  ranging from 3.5-4.5 in the surface horizons. Base saturation is generally low, too. Organic matter has high C/N ratios (25 or more in the topsoil), indicative of low biological activity and slow degradation of organic materials.



**Photo 1: Iron coatings on the outside of sand grains (Photo: G. Peek, WUR)**

If the podzolisation process starts directly within the parent materials – like e.g. in case of soils near the inland dunes – this is called “primary” podzolisation. If it starts after other soil forming processes (e.g. loamification and brunification) have happened, we speak of “secondary” podzolisation.

### **Land use: Man’s influence on soil formation**

The excursion area is a perfect example to show how mankind has influenced and substantially altered the process of soil formation over long time periods.

Already in the Bronze Age (3,000 BC), extensive logging had resulted in removal of most of the forest in the sand district (Hacke-Oudemans 1976). Grazing turned the area into heath and, in places, sand started to drift (Koster 2009). It is believed that the strongly developed, slightly to strongly cemented black spodic Bh-horizon, often showing an incipient thin iron pan is caused by man-induced transformation of forest into heathland.

A more recent modification of the Pozdols was caused by deliberate action of man, and was a consequence of the plaggen management system. In this system heather-sods were scraped off (“plagged”) the land and used as bedding material in the cowsheds and sheepfolds (Pape 1970, Spek 1992). An area with the surface of about seven times that of the arable land was “plagged”. These

sods consisted of the O-horizon with some adhering sand from the heathlands Podzols. The dung-impregnated bedding was then used to manure the arable land. This greatly improved the nutrient availability and water holding capacity of soils under plaggen cover, and the arable fields were raised very gradually (Edelman 1950, Slicher van Bath 1963, De Bakker 1979), changing the Podzols into Plagig Anthrosols. Plaggen soils have a dark-coloured surface horizon (the "plaggen cover") with a thickness of at least 30 cm, overlying a buried Spodosol. Normally the thickness of the plaggen cover ranges from 40-80 cm, but some plaggen soils are reported to have a thickness exceeding 120 cm (Creutzberg & de Bakker 1988). The organic carbon content ranges from 1.5-4% with an average value of 3% (Pape 1970; Eckelmann 1980). Micromorphological studies show that the organic matter consists of coarse to extremely fine fragments of decayed plant remains, located in the interstitial pores between the uncoated sand grains. The pH (KCl) ranges from 3.5-4.5 and the CEC (pH 7) has values of 4-15  $\text{cmol}_c \text{kg}^{-1}$ , depending on the content of organic matter (Pape 1970; Eckelmann 1980). The exchange capacity is almost entirely attributable to the organic matter. Plaggen covers are relatively high in phosphorus as compared with the subsoil and with the surface horizon of the surrounding soils.

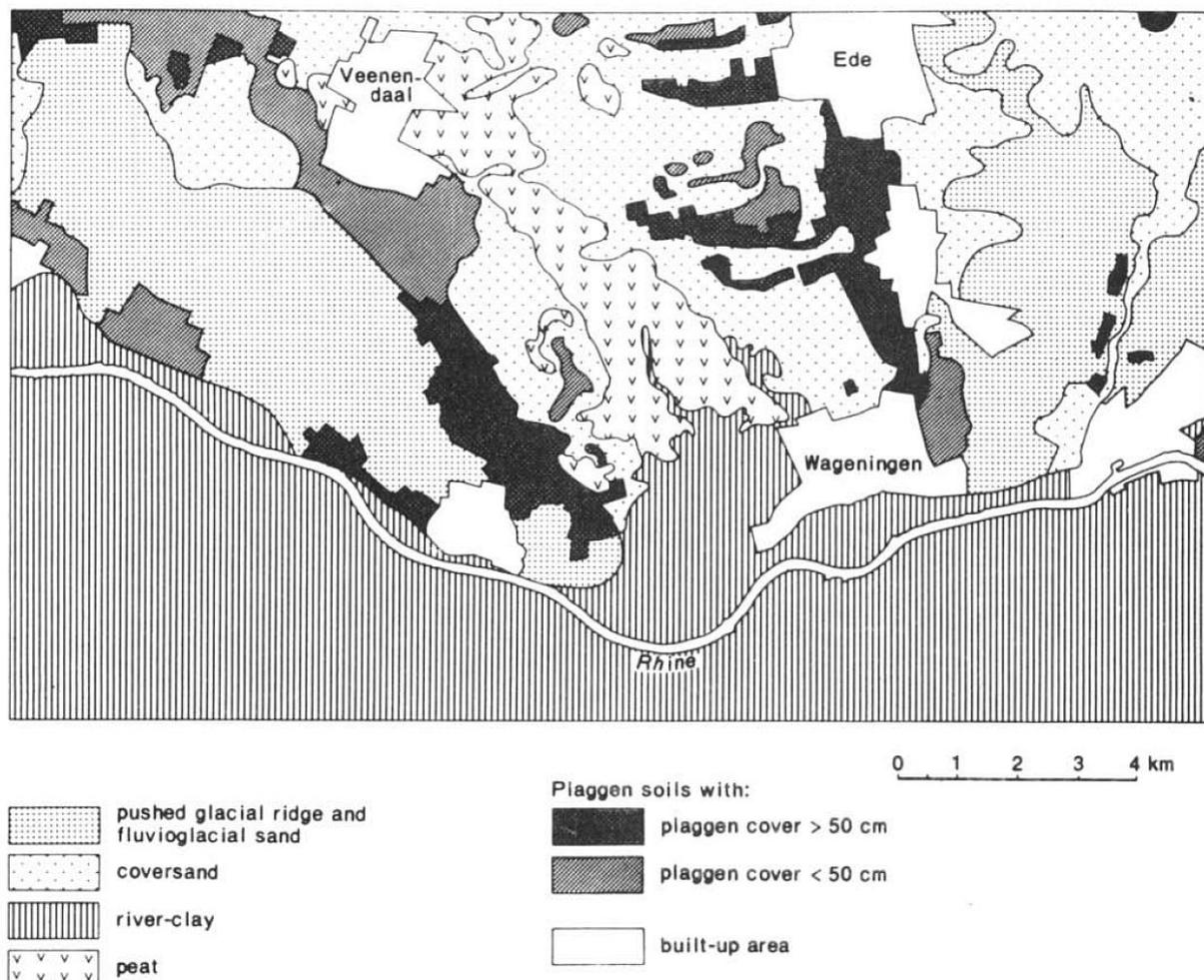


Figure 9: Distribution of plaggen soils in a landscape of glacial deposits, coversand, peat and river-clay. (Survey: J.L. Kloosterhuis, D. Eilander and P. Harbers); source: Pape (1970).

Whereas the *plaggen* management resulted in an in-situ soil quality improvement on the arable fields close to villages, this practice – in combination with overexploitation (grazing and burning) of the heaths – induced a massive degradation of the heaths and the concurrent development of drift sands. The expansion in sheep grazing in combination with a relatively cold and windy climate might have contributed to this development, which reached its zenith in the 18<sup>th</sup> and 19<sup>th</sup> centuries (Sparrius 2011). By 1850, some 10% of the Netherlands were covered by sand dunes!

Around 1850, the industrial revolution and associated economic and technological changes, notably the introduction of chemical fertilizer, led to a decrease in sheep grazing. It also led to agricultural reclamation and afforestation of former 'waste lands'. This is particularly true for drift sands since these were unsuited for agriculture. In The Netherlands, especially between 1910 and 1950, large drift sand areas were re-afforested, mainly with Scots Pine (*Pinus sylvestris*) (Koster, 2009). Nowadays, around 2% of the total original drift sand area is still typical drift sand landscape, characterized by open sand and sand dune grasslands (Sparrius, 2011).



**Photo 2: Soil profile in the vicinity of inland dunes in the Hoge Veluwe. The podzol in the lower part has been overblown by sandy sediments (yellow bracket). A new "mini-podzol" has developed on top after renewed stabilisation of the area (Photo: P. Farris)**

The changeful history of the Sand District is visible e.g. in polygenetic profiles such as Excursion Point 5. Existing Podzols have been overblown by re-mobilised cover sands. Once stabilised, soil formation starts again, creating 'micropodzols' in the uppermost part of the profile (Photo 2).

## Overview of present soil types

For an overview map of soil types around Wageningen, see Figure 10.

The present-day toposequence of **soils in the cover sand region** – disregarded modifications by man – shows the following soils:

Upper landscape positions (depending on parent material):

- On some of the highest parts of the ice-pushed ridges, where periglacial gravelly deposits occur at the surface as a result of the slightly “richer” parent material: Weakly podsolised soils.  
**Rustic<sup>1</sup> Podzols** (Soil Taxonomy: Orthods; NL: Moder podzols → Holtpodzols)
- On the well- drained and somewhat excessively drained sites:  
Fe-poor parent material → lesser OM stabilisation in the topsoil → carbic qualifier.  
**Carbic<sup>2</sup>/Haplic Podzols** (Soil Taxonomy: Humods; NL: Humuspodzols → Xeropodzol → Haarpodzol)
- **Leptosols** of the sandy district

Lower landscape positions:

- In the lower parts of the landscape which border to the depressions  
**Gleyic Podzols** (Soil Taxonomy: Aquods; NL: Hydromorphic Podzols)
- **Gleysols** (Soil Taxonomy: Aquepts; NL: Hydro-eerdgronden), and
- Peat soils in the lowermost areas with shallow groundwater  
**Histosols** (Soil Taxonomy: Histosols; NL: Veengronden)

Where man has influenced podzolic soils through plaggen management over long time spans, **Plaggic Anthrosols** (Soil Taxonomy: Plagganthrept, NL: Enkeerdgronden) have developed. The Dutch classification additionally keys out podzol soils on the way to plaggen soils (but having a too thin A horizon) as ‘Loopodzolgronden’.

In places where the heath and topsoil have been removed, **Arenosols** dominate.

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<sup>1</sup> Rustic = having a spodic horizon in which the ratio of the percentage of Fe<sub>ox</sub> to the percentage of soil organic carbon is  $\geq 6$  throughout

<sup>2</sup> Carbic = having a spodic horizon that does not turn redder on ignition throughout



The **soils of the fluvial district** south of Wageningen are distinguished into 3 main groups, primarily according to their parent material:

- Soils of the streambelt (meander belt): These are young soils, no more than a few thousand years old, and show little soil development. Their texture is mostly medium-sized in the upper horizons (loam, clay loam, silty clay loam and silty clay), gradually becoming sandier with depth. They commonly have a relatively high position in the landscape and therefore are moderately well to well drained which promotes soil animal activity. This disturbs the original stratification of the sediment and supports the development of a strong sub-angular blocky structure in the B horizon. In many of these soils a Bw has formed which meets the requirement of a cambic horizon. Many are calcareous in the subsoil and all have a high base saturation. Most of the soils are classified as **Eutric Cambisols** in WRB and as Eutrochrepts in Soil Taxonomy.
- Soils of the flood basin (backswamp): These soils consist mostly of clay and have a lower position in the landscape. As a result they are poorly drained, and some have peat in the subsoil. Often their age is comparable to the stream-belt soils but soil development is generally less advanced because they have been subjected to high ground-water levels ever since the parent material was deposited. They are normally non-calcareous and slowly permeable. The anaerobic conditions of the soil has impeded the activity of burrowing soil animals. As a result, in many of these soils the original sedimentary structure is evident at shallow depth. Because of their poorly drained condition the soils commonly key out as **Gleysols** (WRB) or Fluvaquent (Soil Taxonomy).
- Soils of the foreland: These soils are flooded for a few weeks almost every year. Most of the soils show stratification at shallow depth and therefore are classified as **Fluvisols** (WRB) or Udifluent (Soil Taxonomy, if well drained) or Fluvaquent (Soil Taxonomy, if poorly drained). However, some soils of the forelands, notably those which have a relatively high position in the landscape, show a clearly developed cambic horizon with a well-developed subangular blocky structure.

## Suitability of soils

The suitability of the sandy soils depends largely on two factors: depth and seasonal fluctuations of the groundwater, and the available water. The latter depends on the thickness of the rootable layers. The groundwater level in the area under discussion varies considerably over short distances. As Podzols have shallow rooting possibilities, available water is low. Consequently, the soil pattern shows great variation in suitability due to these differences in groundwater depth. Because of the thick plaggen cover, the plaggen soils are deeply rootable and have a high amount of available water; therefore, they are less dependent on the capillary rise of the groundwater.

Podzols with a plaggen cover of less than 50 cm thickness are more liable to have water deficits during the growing season. Podzols without plaggen cover are considered unsuitable for arable crops if the mean highest groundwater level is deeper than 50 cm. Likewise, the presence of a plaggen cover appreciably increases the suitability of the sandy soils for grassland. High groundwater levels which tend to make the soils less suitable for arable cropping, however, may still produce good quality grasslands, whereas very deep groundwater may seriously affect the growth of grass, more so than arable crops.

The nutrient availability of sandy soils is greatly improved if they have a plaggen cover because of the relatively high content of organic matter. Fertility of the plaggen soil is still limited, because of the poor nature of the heath vegetation used in the system. Since the introduction of fertilizers, however, this aspect has become of less importance for the productivity of the soils.

The soils of the fluvial district are highly productive soils by nature. Foreland soils with their regular flooding regimes are used for pasture only. Soils of the flood basins (backswamps) are too fine-textured and too poorly drained for successful cropping. If drained, the soil is hard when dry which creates problems when preparing the seed bed. In the wet season traffic with mechanized implements is hazardous. Stream-belt soils are highly productive soils. They have virtually no limitations and are very well suited for arable and horticultural crops and for grassland. Because of their relatively elevated position these sites were preferred for human settlements.

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## Your feedback, please!

This document is work in progress, and we would love to receive your comments on how we could improve it to better suit the needs of Spring School participants.

In order to submit your feedback, please write an e-mail to [stephan.mantel@wur.nl](mailto:stephan.mantel@wur.nl).

Thank you very much in advance for your comments!