The dynamics of inland drift sand areas

A case study for the Wekeromse Zand

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Date	14-01-2013

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By

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Wageningen, January 2013

Abstract

Inland active drift sand areas contain unique ecosystems and the landscapes are of great historical and cultural value. It is inconsistent among researchers when drift sand areas developed and which factors caused drift sand activation in Northwest Europe. In this study, research on the dynamics of drift sand area the Wekeromse Zand is done. The area, located in the central parts of the Netherlands, is 370 ha and 14 ha is still active drift sand. Anthropogenic and climatic factors played a role in the development of the drift sand area.

For the study historical maps, going back to the early 19th century, were analysed, a field survey was performed to map the palaeolandscape (before drift sand activation) and buried soils. Optically Stimulated Luminescence (OSL) was employed to date drift sand deposits on 11 samples from two selected locations to determine the burial age of drift sand deposits. OSL is the most accurate technique for dating aeolian sediments and OSL is particularly useful for dating young soils (< 500 years).

Analysis of the available topographic maps showed no substantial aeolian activity of the area outside its morphological boundaries. Field survey revealed a large and short distance spatial variability in the topography of the palaeolandscape, which may have played a role in drift sand activity. In one pit two drift sand layers with a low OM content were deposited. The first active drift sand event (1348-1379 AD) had a high accumulation rate and took place in the transition from the Medieval Climatic Optimum toward the Little Ice Age. The second active drift sand event (1685-1773 AD) took place during the Little Ice Age. In between a layer with a higher OM content was found, which indicated also a stable period during the Little Ice Age. Agricultural practices around the Wekeromse Zand were going on since the Iron Age, but drift sand activity only started in the mid- to late 14th century.

Keywords: Inland drift sand areas, Drift sand dynamics, Aeolian processes, OSL, Northwest Europe.

Preface

The subject of this research touched a lot of aspects from the study Soil Science. The variation in activities and the actuality of the subject made me interested. I wanted to practice with the theory I learned during the study 'Soil Geography and Landscape'. Looking back I can say that this research kept my interest. Soil survey was never done before in the Wekeromse Zand and still a lot of research need to be done before the development and dynamics of this inland drift sand area is understood. Scientific understanding of inland drift sands allows a better assessment of aeolian processes and driving factors.

During the research Dr. M.P.W Sonneveld made me enthusiast about the subject and he broadened my scientific view. I want to thank him for the great supervision during this period. His critical eye and knowledge strengthen my research.

The study area I worked in was part of nature area 'De Hoge Veluwe' and was maintained by Het Geldersch Landschap. They gave me permission to do fieldwork in this area. The collaboration with Dhr. R. Oosterkamp, who manages the area, went very smooth. I want to thank him for his cooperation and interest.

After the fieldwork I went to TU Delft for dating the soil samples with the Optically Stimulated Luminescence (OSL) dating technique. I felt more than welcome and I want to thank Dr. J. Wallinga and Ms. A.J. Versendaal for their time and patience to teach me as much as possible about the OSL technique, the supervision in the laboratory and their critical eye on the results.

Last but not least, I was very thankful for all the support from my family and friends. I also want to thank you as reader for being interested in my research. This research is performed and written with a lot of effort, so I hope you enjoy reading it.

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Introduction

Inland drift sand areas are areas where re-sedimentation of Pleistocene sediments deposited and where at least 10 ha of active drift sand remains (Bakker et al., 2003; Jungerius and Riksen, 2010). The areas occur in the western part of the European Aeolian Sand Belt (Koster, 2005a). They contain unique ecosystems and the landscape is of great historical and cultural value. Nature conservations of Western Europe obtained more interest in restoration of former inland drift sand areas (Riksen et al., 2006). Their development in the past gives insights in the current and future development (Riksen et al., 2006). Important is to understand the factors which have influence on the development of drift sand areas, because this is not consistent among researchers.

Geology, geomorphology and soil development

An ice sheet covered the northern and central parts of Europe during the Saalien Ice Age and at the end of an ice tongue ice pushed ridges developed (198-123 ka BC) (Jungerius and Riksen, 2010). During the last ice age, the Weichselian (114-9.5 ka BC), coversand accumulated under late glacial conditions in Northwest and Central Europe (Mikkelsen et al., 2007); the European Aeolian Sand Belt (Fig.1) (Koster, 2009; Sparrius, 2011). Parabolic coversand ridges were flat to gently undulating; e.g. Lochem, The Netherlands (Koster, 1988). Tolksdorf and Kaiser (2012) concluded that the aeolian activity continued throughout the European Aeolian Sand Belt after the Younger Dryas (12.5 ka BC) until the Mid-Atlantic (4.5 ka BC). During the Early Holocene the sea level started to rise more than 80 cm per century and until 1.8 ka BC sea level rise in combination with soil lowering caused ground water level to rise (Van Koningsveld et al., 2008; Berendsen, 1982). The valleys became wet and vegetated (Schelling, 1955).

Figure 1: Depositions of the European Aeolian Sand Belt in Northwest Europe (Sparrius, 2011).

Drift sand is characterised by dune relief, yellow-greyish colours, loose grain-packing and an average organic matter (OM) content of 0.1% (Berendsen, 1982; Riksen et al., 2008). Aeolian sediments are homogeneous with an average grain size between the 105-300 μm in the central parts of the Netherlands (Castel et al., 1989; Kasse, 2002). Aeolian sand sheet and dune development was favoured by four indicators (Kasse, 2002): i) abundance of unconsolidated source sediments, ii) absence of major topographic barriers, iii) sparseness of vegetation and iv) a high ratio between wind energy and sand availability.

The shape of a drift sand area looks like a windblown fan in the direction of the prevailing wind and they mainly develop in valleys where the wind lost its energy (Jungerius and Riksen, 2010; Koomen et al., 2004; Riksen et al., 2006). According to Schelling (1955) wet, vegetated valleys, which protected the drift sand sedimentation for re-erosion, caused inversion of the landscape (Fig.2) (Schelling, 1955; Castel, 1989). The similar structures of drift sand areas gave strong indications for geomorphological influences in the development of drift sand areas (Koster, 2009).

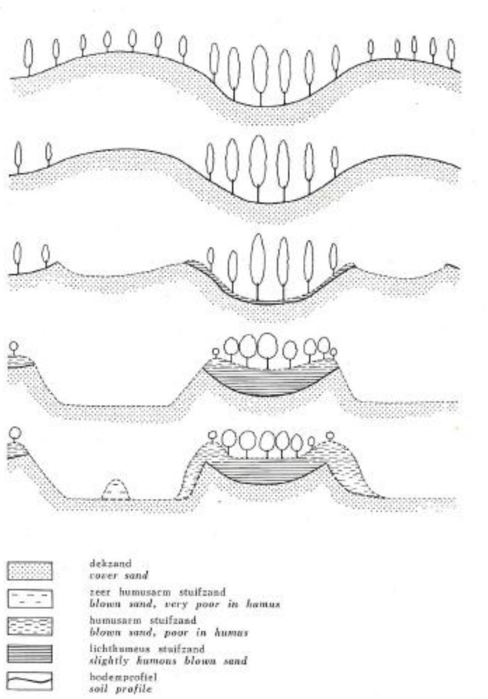


Figure 2: Inversion of the landscape was taking place in drift sand areas (Schelling, 1955).

Pedological processes developed characteristic soil types in drift sand areas. The Dutch soil classifications have been universalized in Appendix A (De Bakker, 1979; Krasilnikov and Arnold, 2009). In stable conditions vegetation fixed the sand deposits and, due to organic acids, podzol soils could develop (Wardenaar and Sevink, 1992; Van Mourik, 1988). These soils have a greyish eluviation layer on top of a dark illuviation layer. Under humid conditions Gleyic Carbic Podzols develop. These soils have hydromorphic properties with an organic (top)layer and/or lacking iron skins around the grains beneath the B horizon. The soils were found in valley positions (De Bakker, 1979). Orthic Podzols are xeromorphic podzol soils which can also develop in drift sand areas. The soils have a clear illuviation and eluviation layer and a generally deep ground-water level. The soils are characterized by a thin iron pan directly below the illuviation horizon (De Bakker, 1979). The Arenosol has no horizon differentiation within 25 cm. In drift sand areas these soils occur in areas where no vegetation succession has taken place or in sand accumulation areas. Active drift sand soils are lacking in lime, have a low pH and have a rounded, fine- grained particle size. The colour of drift sand is between 10YR5/2 and 10YR6/2 according to the Munsell Soil Color book (Koster, 1993).

Climatic processes

To put an event into time perspective the geological and archaeological timescale is given in Figure 3.

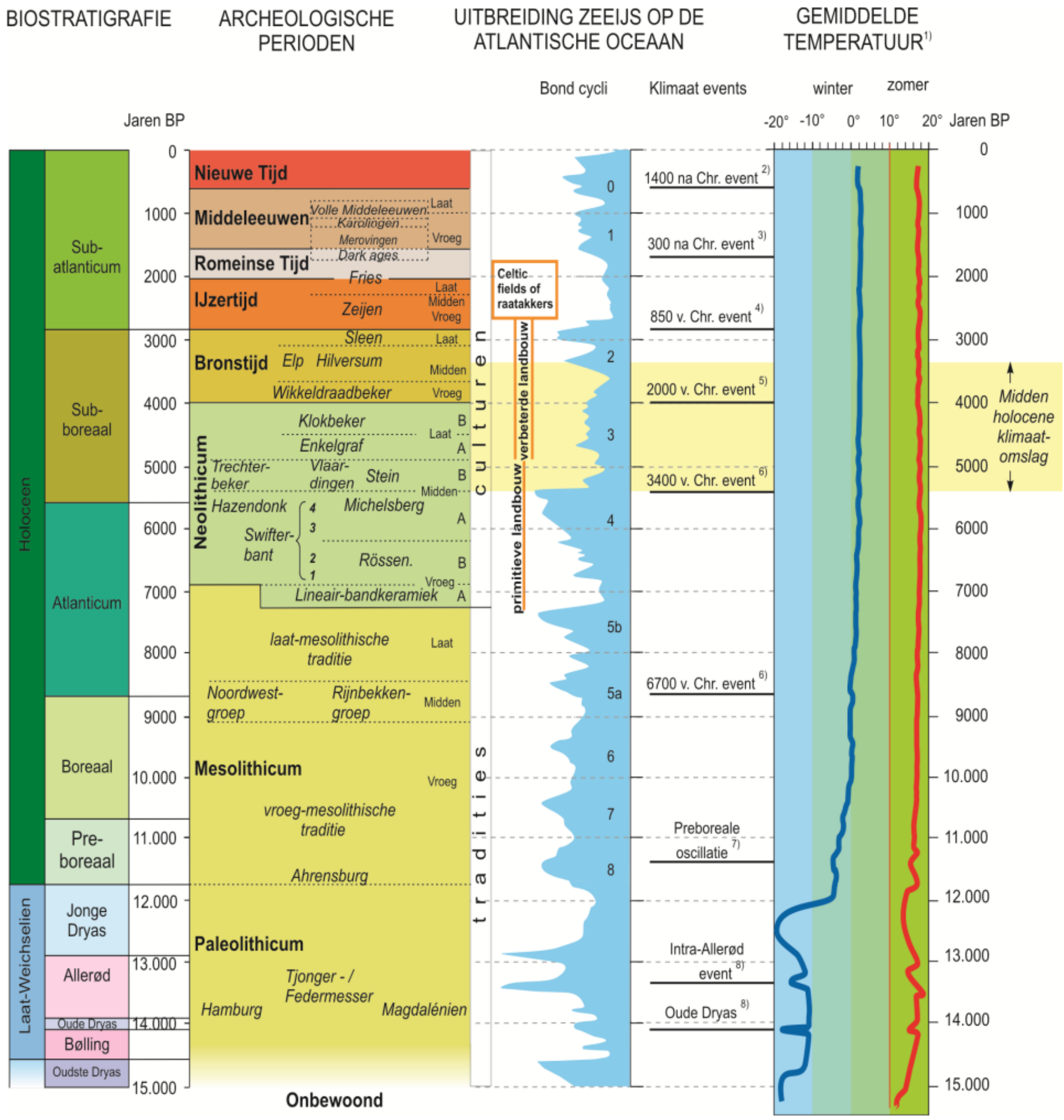
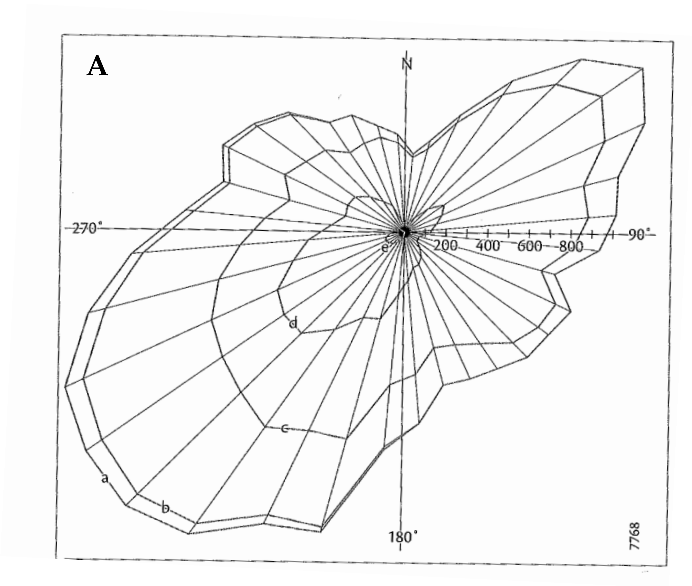


Figure 3: Timescale from the Late Weichselian onward. From left to right the geological time scale, the years BP, the archaeological timescale, sea ice fluctuations in the Atlantic Ocean, climate events, average winter and summer temperature (Jongmans et al., 2013).

<u>Wind speed, wind direction and the development of drift sand</u>

During the Weichselian the winds in Northwest Wales were strong and Southwest to West-Northwest oriented (Bailey and Bristow, 2004). Nowadays the winds are much weaker and dominantly Southwest to South-Southwest oriented (Bailey and Bristow, 2004; Renssen, 2007). A threshold velocity has to be reached for a particular grain size before sand transport could occur (Levin et al., 2006). The frequency distribution of the wind directions according to wind velocity in the period 1961-1970 AD in the Veluwe area, the Netherlands, is given in Fig. 4A (Koster, 2010). The drift sands cells are Southwest-Northeast oriented, according to the mean wind direction (Fig. 4B) (Koster, 2010). From coastal research in the Netherlands the most recent parabolic dunes developed in the time ranges: 900-1200 AD, 1450-1750 AD and in 1800-1850 AD (Jelgersma et al., 1995). The development of parabolic dunes at the Dutch coast was going along with strong wind events and they developed in the same period as the large inland sand movements were recorded (Jelgersma et al., 1995; Jungerius et al., 1991; Koomen et al., 2004). Bailey and Bristow (2004) did research on the rate of dune



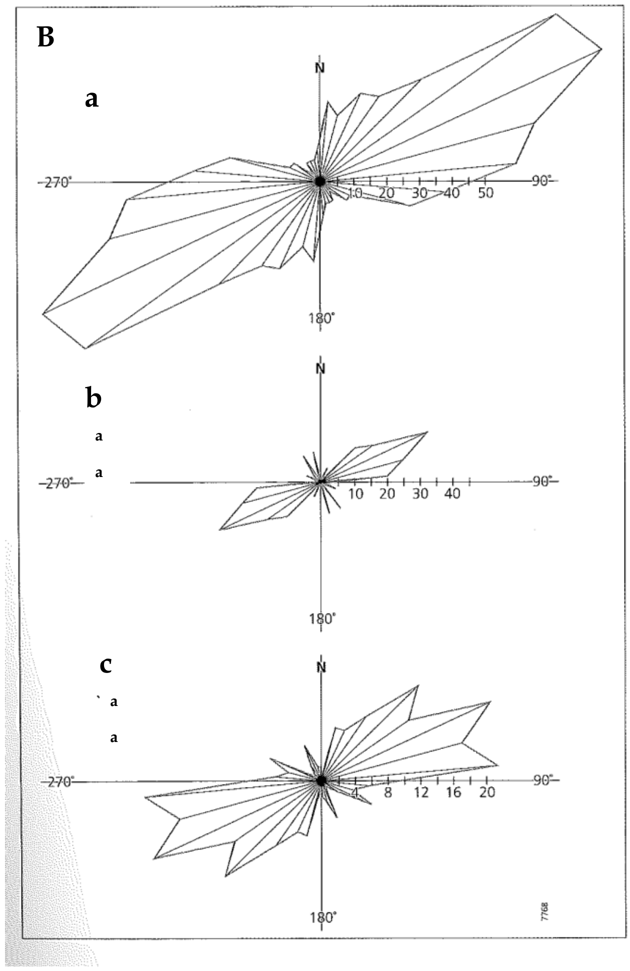


Figure 4: The frequency distribution of wind directions according to wind velocity classes; 1961-1970 AD (A). The orientation of inland drift sand dunes (B). Number of observations: x-axis. a) individual drift sand dunes in 12km² of the Veluwe area, b) drift sand fields in the Veluwe area, c) drift sand fields in the Netherlands (Koster, 2010).

migration for the coastal area in Aberffraw in Northwest Wales. They found an average dune migration of 1.3 m/year between 1970 and 1993. The average wind speed in the region was 5.7-8 m/s. Wind is taking up soil particles in the prevailing wind direction, but the deflation zone is expanding against the prevailing wind (Jungerius and Riksen, 2010).

<u>Groundwater level fluctuation and humidity</u>

Northwest Europe became wetter between 7-4 ka BC and after melting of the ice cap the sea surface temperature in the North Atlantic was rising. This warming caused a strong poleward-shifted subtropical anticyclone, which caused higher precipitation rates in Northwest Europe (Guiot, 1993).

The effect on water level lowering is ambiguous (Jungerius and Riksen, 2010). The lowering of the groundwater level caused forest fires and resulted in the reactivation of the Finnish dune field during the Medieval Climatic Optimum (Van Vliet–Lanoë et al., 1993). But in an article of Koster (2009) is said that there is no evidence found for droughts and the reactivation of drift sand areas in peat sections from the Veluwe area (Koster 2009). Also the drier period between 950-1250 AD had not proven evidence for sand drift (Koster, 1993). According to Jungerius and Riksen (2010) the activation of drift sand in the Netherlands could not be explained by the Finnish research, while Koster (2010) concluded that there is certainly a relationship between groundwater level lowering and drift sand activation.

Temperature

Jungerius and Riksen (2010) concluded that in Northwest Europe the climate was relatively stable during the Holocene. Two extremes were measured during the last 2000 years; the drought conditions during the Medieval Climatic Optimum and the cold and unstable atmospheric conditions during the Little Ice Age (1550-1800AD).

The average temperature in Northwest Europe was -9 °C in Early Holocene (Davis et al., 2003), but since 7.3 ka BC the mean winter temperature did not drop below -2 °C (Davis et al., 2003). A quick temperature rise took place until 4.5 ka BC (Davis et al., 2003). The higher temperature resulted in a drop of lake levels, due to an increase in evaporation. The land ice was at a minimum in 6.2 ka BC (Davis et al., 2003). During the Early Subboreal, 2.2 -1.8 ka BC (Early Bronze Age), the climate was warmer and drier than the current climate (Van Geel, 1996). The climate was changing into a humid and cold climate during the Late Subboreal, 1.4-0.9 ka BC (Late Bronze Age) (Van Geel, 1996). From pollen analysis was concluded that the climate in the Netherlands turned into an oceanic climate with higher air humidity since 0.8 ka BC (Van Geel, 1996). Inferred from peat humification analyses 7 ka BC, 4.5 ka BC, 4 ka BC and 2.3 ka BC were dated as dry periods in the United Kingdom (Bonsall et al., 2002).

In 300-400 AD the climate was warm and dry and from 400-800 AD the climate was cold and humid compared with the current climate in the Netherlands (Klijn, 1981). Since 1000 AD two main temperature epochs can be distinguished; the Medieval Climate Optimum and the Little Ice Age (Fig.5). The Medieval Climatic Optimum was a warm and dry period and took place from 1100 AD till 1400 AD (Mann, 2002). The period was characterized by warm summers, mild winters and little storm activity (Hass, 1996). The Medieval Climatic Optimum was followed by the Little Ice Age. Records show that this period was associated with increased storminess and sand movement (Clarke and Rendell, 2009; Carter et al., 1990; Lamb and Frydendahl, 1992). The term storminess is the number of days with winds of 13.9-17.1 m/s to 428.4 m/s (Qian and Saunders, 2003). A southward spread of sea ice and polar water created an increased thermal gradient, which caused storm activity in the North Atlantic (Lamb, 1995). Also storm surges just before and during the Little Ice Age were recorded; 1421 AD, 1530 AD, 1570 AD, 1682 AD; 1775 AD (Buisman, 2011; Jelgersma et al., 1995).

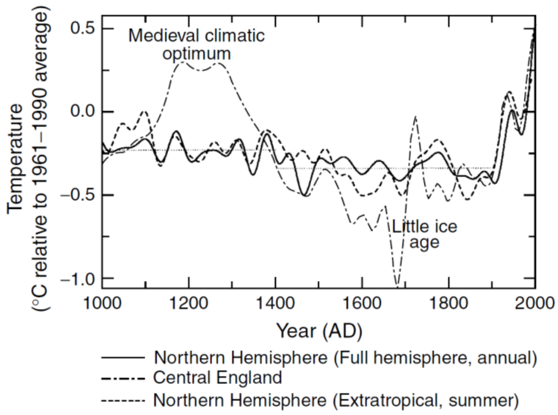


Figure 5: temperature variations in the Northern hemisphere (annual and summer) and in Central England (Mann, 2002).

Natural vegetation cover

After the Weichselian Ice Age tundra vegetation and later birches and grasses fixed the coversand and caused an increase in humidity in the Dutch landscape. During the Atlanticum open pine forest and heathland covered the dry soils at the Veluwe area (Koster, 2009). After this epoch agricultural activities were playing a major role in the vegetation cover and composition (Fig.6) (Jongmans, 2013). Small scale human impact started between 2.8 and 2.5 ka BC. In Veluwe area human settlements dated back till 1.4 ka BC (Vervloet, 1988). The groundwater level was rising when forest cut took place on large scale during the agricultural intensification (Koster, 1993). Since 1850 the amount of grazing sheep decreased because of the Industrial Revolution. Afforestation took place on large scale between 1898 and 1940 and decreased the area of bare soils (Sparrius, 2011). The area of bare inland drift sand decreased by 50% over the period 1950 – 2007 and the amount of nitrogen deposition doubled over the period 1950-1981 (De Haan et al., 2008).

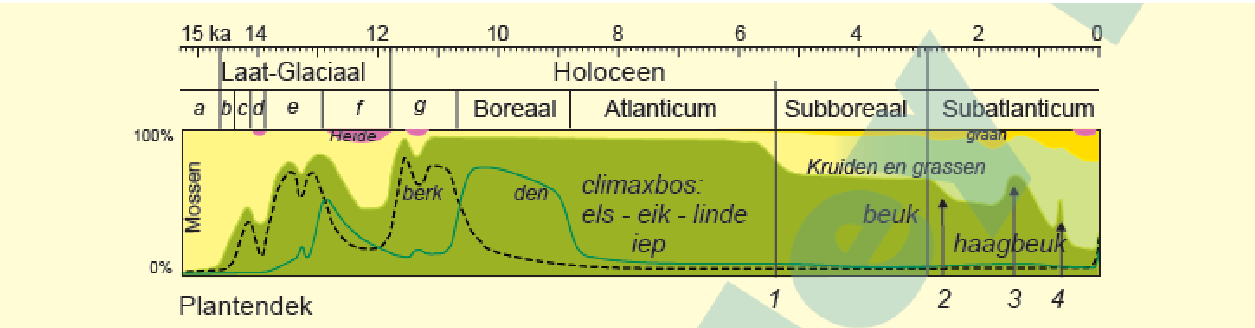


Figure 6: Vegetation differences in the Netherlands since the Late-Glacial. 1. Agricultural influence, 2. Iron Age-Roman Age, 3. Inhabitant movements, 4. Pest epidemic. Until the Boreal-Atlanticum the development of vegetation depends on climate factors (Jongmans et al., 2013).

Land use history

Overgrazing, sod cutting, sandy roads and burning nature and agricultural areas have been mentioned as past anthropogenic causes for drift sand activation in Northwest Europe (Mikkelsen et al., 2007). Pollen analysis showed that agriculture in a deforested landscape took place in the eastern part of the Netherlands during the 16th century (Van Mourik et al., 2011). Mikkelsen et al. (2007) did research on landscape stability and instability and how this was influenced by human occupation in the interior of Denmark. The results indicated that the first forest clearances, which activated sand drift, dated back till the Subboreal (1 ka BC). Riksen et al. (2006) found that in the United Kingdom the drift sand activity also started around 1 ka BC because of anthropogenic factors.

Farmers started to fix their agricultural practices during the Late Bronze Age and the Iron Age (Spek et al., 2004). A typical farming system became shifting cultivation on plots of 30 or 40 square meter; the so called Celtic field system (Kooistra and Maas, 2008; Tolksdorf and Kaiser, 2012). Fallow land was cleared by burning and the waste material was deposited on the edges of the fields, whereas the edges became higher than the surrounding (Kooistra and

Maas, 2008). On the Digital Elevation Model (DEM) the Celtic fields can still be recognized, due to difference in OM content between the agricultural plot and the edges of the plot. In the Netherlands the Celtic fields were found on the upper parts of ice pushed ridges, on the outwash of plains and on coversands (Kooistra and Maas, 2008). There also seems to be a relation between Celtic fields and drift sand areas; drift sand areas existed downslope of Celtic fields. On the DEM can be seen that Celtic fields were buried under drift sand and Mikkelsen et al. (2007) also reported buried plough layers beneath the drift sand. No podsolization took place in the agricultural field systems from the Iron Age, which can indicate sustainable farming (Mikkelsen et al., 2007). In another research deforestation and acidification dated back till 1.8 ky BC (Van Mourik et al., 2011). Organic fertilization already occurred during the Iron Age, because higher phosphate contents were found in Celtic field systems; e.g. Zeijen, the Netherlands (Spek et al., 2004). It was even calculated that Celtic fields were fertilized by external humus, because it was impossible that the raised walls only exist of waste materials from the plot itself (Brongers, 1976).

During the Roman Period the Netherlands were treeless around settlements and agricultural development intensified (Van Geel, 2003). A clear land use change was indicated by a peak in dust deposition between 500 and 800 AD (Mikkelsen et al., 2007). The Celtic field systems were abandoned and buried under plaggen layers or drift sand during the Middle Ages (Kooistra and Maas, 2008). Plaggen soils are anthropogenic soils which had been fertilized with a mixture of manure and sods, litter or sand. Plaggen were removed from heathlands and used as bedding for the animals (Blume and Leinweber, 2004). With manure impregnated plaggen were, after decomposition, used to fertilize the agricultural fields. The average OM content in a black plaggen soils is 5.3% and in a brown plaggen soils is 3% (Pape, 1970). Sod cutting resulted in bare lands because vegetation did not had time to recover and an increased amount of sods was needed to keep the fertility of the plaggen soils (Blume and Leinweber, 2004). The shift from Celtic fields to plaggen agriculture was caused by the population growth and continued until the inorganic fertilizer was introduced in the 20th century (Van Mourik et al., 2011). Sedentary agriculture and drift sand activity dated back till 1 ka BC, while plaggen agriculture was only dated back since the Middle Ages (Van Mourik et al., 2011). Land use change and human adaptation to climate change were periods wherein the land was vulnerable for erosion.

Problem definition

Researchers are not consistent about when the first sand drift started and what the driving factors behind drift sand area development are:

- Blume and Leinweber (2004) were convinced that drift sand only developed during the time plaggen soils were formed. This thought was generally assumed as the truth. Nowadays, Tolksdorf and Kaiser (2012) concluded that drift sand activation seems to be primarily ascribed to changing patterns of human activities, but they do not exclude that the activation phases may be affected by climatic trends to some extent.
- Kooistra and Maas (2008) indicate the underestimation of the agricultural intensity during the Iron Age. This means that drift sands were probably older than expected by most researchers.

- Clemmensen and Murray (2006) dated the drift sand with the Optically Stimulated Luminescence (OSL) technique and concluded that the oldest drift sand was from 1427 AD. The study was done at four places in Denmark. In archaeological sources they found that only between the 18th and 19th century there was noticed that sand drift was abandoning churches and settlements.
- Koster (2005b) linked the growth of inland drift sand areas in Northwest Europe to the 18th and 19th century because a change in pollen composition was detected. He suggested a continuing intensification of agriculture since the change in landuse was noticed.
- Contradicting are the conclusions from Koomen et al. (2004); in the Netherlands sand drift was overblowing settlements between 900 and 1300 AD, and from Kooistra and Maas (2008); only since the 15th century drift sands are a serious threat for farmers.
- Koomen et al. (2004) state that in the central part of the Netherlands soils of sod accumulation and drift sand areas were adjacent, so related with each other. But he is also assigning that the dimension of drift sand cells is too large for assigning it only to anthropogenic causes.
- Anthropogenic factors (e.g. expansion of grazing sheep) and changing climatically factors (e.g. cold and windy climate) are linked to drift sand activation by several researchers; Koomen et al. (2004), Koster (2010), Riksen et al.(2006).
- Castel et al. (1989) mentioned that Bahnson (1973) suggested that major wind blowing phases took place at 600 BC to 200 AD and after 1000 AD.
- Koster (2009) suggested that local sand translocation could have occurred much earlier, but cannot be called drift sand. Extensive drift sands started only between the 11th and 13th century and sods with a high mineral content were used since the 16th century (Koster et al., 1993).

Also for the decline of the current active inland drift sand area different causes were mentioned; e.g. the decline is mainly caused by the abandonment of the original land use (Koster, 2005b; Riksen et al., 2005), the decline is mainly caused by the recent climate change, which leads to a prolonged growing season and the increased precipitation (Sparrius, 2011).

There is still no consistency about when drift sand areas developed and which factors influenced the development. Literature is confusing because before accurate dating techniques existed the conclusions of researchers were based on suggestions. In the last decades the accuracy of soil dating techniques is improved, which gives the opportunity to measure the (burial) age directly from the soil grain. Hardly any information about drift sand activity is known from the period Mid-Atlantic to Sub Boreal. Researchers are missing the broad perspective of factors which could have had influence on drift sand area development. There is a lack in knowledge on the participation and dynamical working of potential driving factors.

Research on the dynamics of geomorphological sites will not only be valuable for science, but also for culture and ecological diversity (Koster, 2009). A flow chart of factors which can activate drift sand and the interrelations between the factors is given in Figure 7. The objective of this research is to reconstruct the dynamics of drift sand area the Wekeromse Zand and to relate the dynamics to the driving factors mentioned in Figure 7.

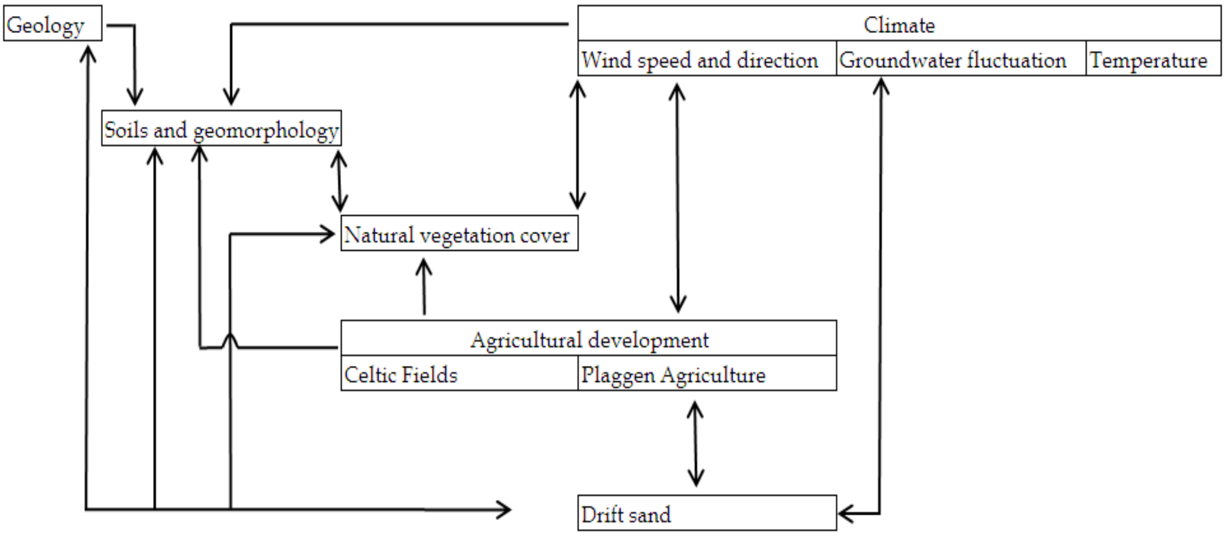


Figure 7: Interaction between factors. Flow chart of factors which have influence on sand drifting and the effect of sand drift on the factors.

Hypotheses and research questions

The following hypothesis is formulated:
"Agricultural activity and certain climatic conditions are required for the activation of drift sand area development."

When the hypothesis is accepted the windblown shape of a drift sand cell can be interpreted. The suggestions that the dimension of drift sand cells is too large for assigning it only to anthropogenic factors (Koomen et al., 2004) is strengthen. The age of stable and unstable soil layers can be linked to climatic or anthropogenic events from the past. When it is clearer which factors influenced the development of inland drift sand areas in the past, suggestions for future management can be made.

The main question of this research is:

"When did drift sand area the Wekeromse Zand develop and which factors caused the development?"

The question is very general and needs some sub-questions:

- How did drift sands develop during the last two centuries in the Netherlands (literature) and in the Wekeromse Zand according to aerial photographs and (historical) maps?
- What is the palaeosurface of the Wekeromse Zand, prior to drift sand activation, and what are the properties of buried soils and the buried layers at the Wekeromse Zand?

- What is the burial age of distinguished drift sand layers and what can be interpreted from this?
- What can be concluded and interpreted from the reconstruction of the soil profile in the Wekeromse Zand?

Methodology

Study area the Wekeromse Zand

The total area of remaining active drift sand in Northwest Europe is estimated between 3000 and 4000 km^2 (Riksen et al., 2006). Most remaining active drift sand areas can be found in the Netherlands. The study area is located in the central part of the Netherlands and is called the Wekeromse Zand (Fig. 8). The study area is 370 ha and part of nature area De Hoge Veluwe. The area is chosen on a location where both, natural and anthropogenic factors have played a role in the development of the drift sand area. 14 ha of the study area is nowadays still active, other parts were vegetated by heathland and forest (deciduous, pine and mixed).

The Wekeromse Zand is located in the Northeast of ice pushed ridge Oud-Reemst (Fig.8A). During the Weichselian Ice Age the area got covered under a coversand layer. Re-sedimentation of the coversand took place and drift sand cells developed around the ice pushed ridge (Fig.8A). The Wekeromse Zand is one of these drift sand cells. The sand cell looks like a windblown fan which is blown from the ice pushed ridge toward the valley (Fig.8). Agriculture around the Wekeromse Zand has taken place since the Iron Age. From sattelite images became visible that Celtic fields surrounded the Wekeromse Zand, while plaggen soils developed only in the eastern part according to the 1:50000 soil map (Fig.8B).
The elevation in the area is between 15 and 35 m according to the DEM and increases from Northwest to Northeast. At the lowest elevations some natural fans developed. Four soils were distinguished by the 1:50000 soil map for the Wekeromse Zand (Fig.9). The translation from the Dutch soil classifications to the Universal soil classifications can be found in Attachment A(Van der Loo, 1997; Bakker, 1979; Krasilnikov and Arnold, 2009). The Albic Arenosol (code Zd21 on the 1:50000 soil map) was found in the open drift sand areas and in

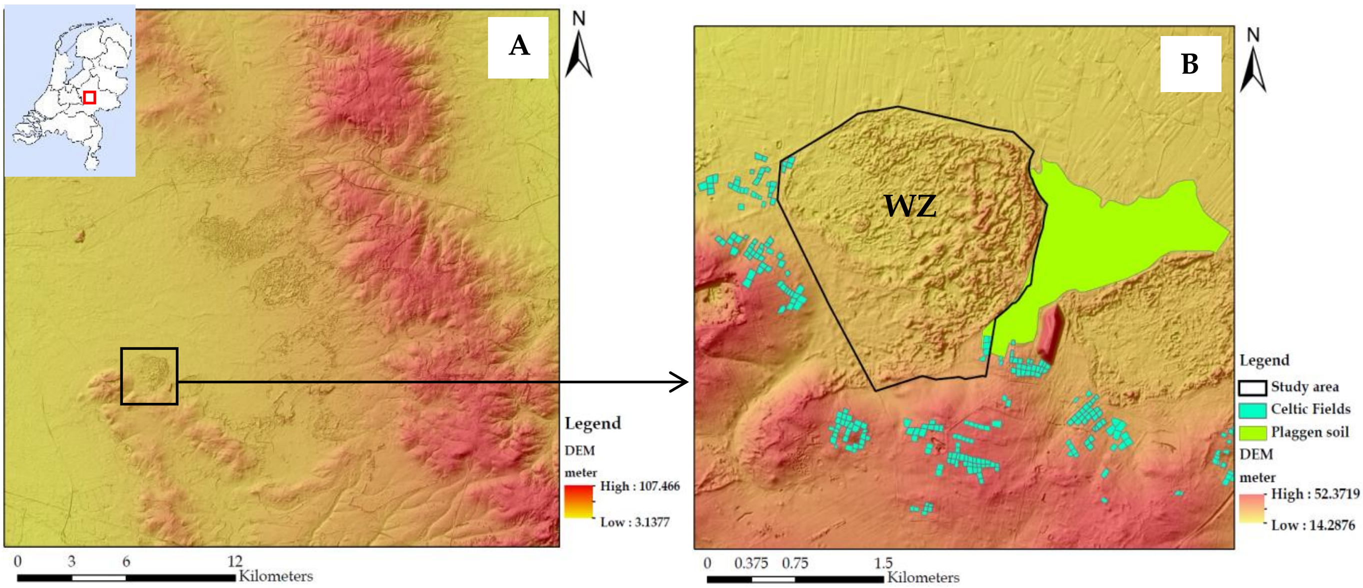


Figure 8: The study area is located in the central part of the Netherlands at the Northeast side of ice pushed ridge Oud-Reemst (A). Zooming in to drift sand cell the Wekeromse Zand (WZ) the shape of a windblown fan and the historical agricultural activity becomes visible (B).

the young heathland areas. The Arenosol with hydromorphic properties (code Zn21) was classified in the heathland area and in the forested area of the Wekeromse Zand. The fine grained and coarse grained Leptic Podzol (code Y21 and Y30 respectively) was found in the south-western part, close to the ice pushed ridge. The soil exists of graveling pushed moraine sediments with a slightly relief (Bakker, 1979).

Also outside the study area different soil types were classified (Fig.9). The Gleyic Carbic Podzol (code Hn21) is a hydromorphic podzol soil which was classified in the north-western part. The Orthic Podzol (code Hd21 on the 1:50000 soil map) is a xeromorphic podzol soil with a clear illuviation and eluviation layer. The soil was found in the south-western part and has a deep groundwater level. The eastern part is covered by anthropogenic soils (code pZg23, pZn21 and zEZ21). The soils are characterized by fertility and a good drainage system (Bakker, 1979).

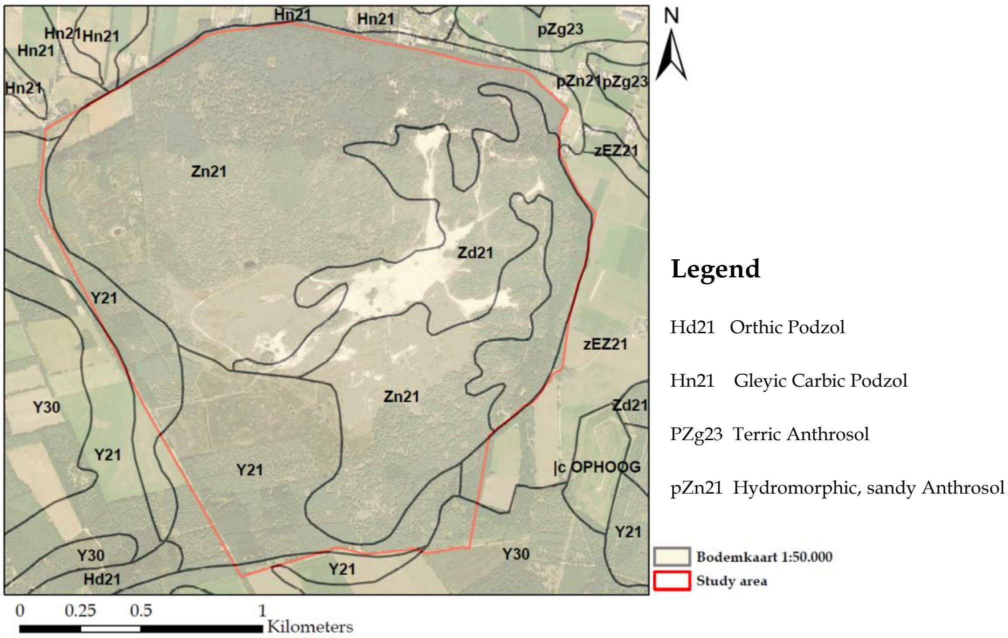


Figure 9: The study area and the soil classification (1:50000).

Historical maps and aerial photographs methodology

Cadastre maps were gathered by the website watwaswaar.nl and by the archive of the Wageningen University Library. The maps were scaled with the Rijksdriehoekstelsel projection by the tool Georeferencing in ArcGIS. Developments in the shape, vegetation cover, land use, human settlements and the roads over the last two centuries were compared.

Aerial photographs of the Wekeromse Zand were gathered by the digital aerial photograph collection of Wageningen University (library.wur.nl/speccol). The photographs were also scaled with the Rijksdriehoekstelsel projection by the tool Georeferencing in ArcGIS and they were compared with the current aerial photograph. The change in land use over the last sixty years became visible.

The geodatabase contained valuable information and enhanced the interpretation of the area and the evaluation of the gathered soil survey data.

Fieldwork methodology

Based on the aerial photograph and DEM, the area was visually divided in six subareas (Fig. 10). The subarea 'High dunes' was located in the eastern and southern part. A separated subarea was made for the boundary of the high dunes, because these soils contained information about previous agricultural activity. The third subarea was 'High dunes in low and mid-high area'. The dunes were located as hills in the landscape and could not be compared with the high dunes (Fig. 10B). The subarea 'Low area' is located in the north-western and northern part of the study area. The 'Mid high area' can be found in between the 'Low area' and the 'High dune area'. The subarea 'Open drift sand and heathland area' is determined by the aerial photograph and located in the centre of the Wekeromse Zand (Fig. 10A).

An aim of the field survey was to recognize the palaeosurface and buried soils in the subsoil and to see if there was a relation between the grain size and the distance from the ice pushed ridge. Except for the 'Open drift sand area and heathland', a stratified random sampling technique was used. The stratified random sampling technique gave all coordinates in a particular subarea the same chance for being surveyed. The random points for each subarea were calculated by ArcGIS; Spatial analyst, create random points. The fieldwork plan was based on the extent of each subarea and the available capacity for this research. For the ´Open drift sand area and heathland' a systematic sampling strategy was applied to detect layers with different grain sizes over distance.

Two pits or six auger points could be done each day. Determining a surplus in auger points excluded a reduction of the fieldwork plan when coordinates could not be reached. In the soil survey plan seven auger points from the 'High dunes' were extracted and added to the 'Boundary high dunes' because more information about former agricultural practices could be gathered from the boundary. In the subarea 'High dunes in low and mid-high area' at least one auger point at each hill had to be surveyed to see if they were uniform. Finally, three pits and 70 survey points were surveyed (Fig.10C). The pits were chosen on sites where interesting soil development has taken place. The amount of auger points per subarea is described in Table 1. Some points in the 'High dunes' were not determined well, because the GPS was not working correct on the first fieldwork day. The GPS was used to determine the right coordinate in the field.

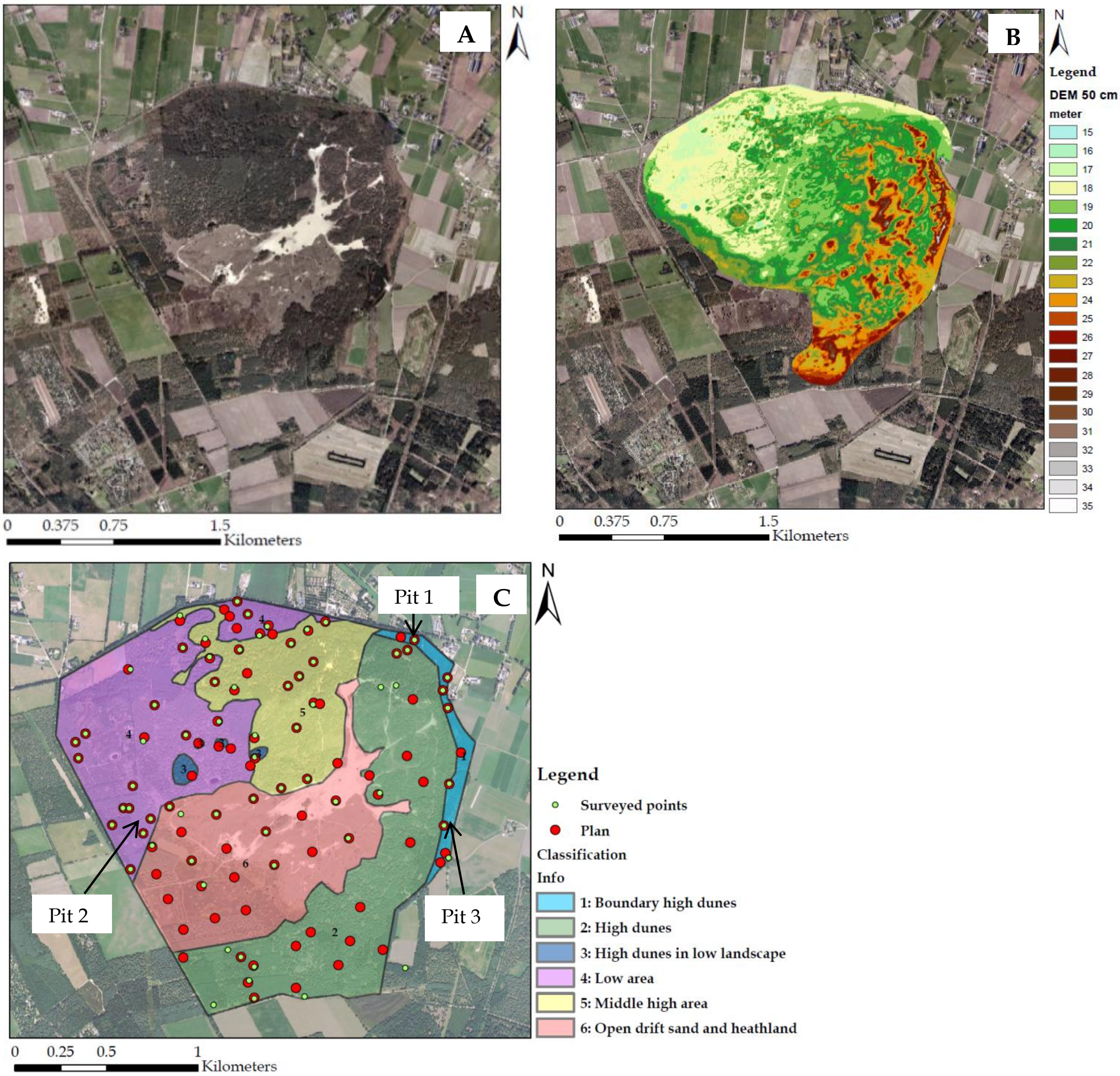


Figure 10: The aerial photograph (A) and the DEM (B) of the Wekeromse Zand resulted in a map werein six subareas were distinguished (C). Per subarea a certain amount of survey points was planned and actually surveyed and also three pits were dug(C).

The field form, which was used for evaluating the survey points and pits, can be found in Appendix B. Augering was done with a Dutch soil auger. Up to 220 cm was drilled unless coversand, the groundwater level or pushed moraine deposits were reached. During the soil survey the value and chroma of the soil were determined by the Munsell Soil Colour Charts (1994). This can indicate the mother material and OM content. With a sand ruler the size of the grains was determined. In drift sand areas grain size indicated the strength of the storm event, the thickness and the colour told something about the drift sand (in)activity. The OM content and the percentage of iron reduction is visually estimated.

Table 1: Area, amount of auger points and final amount of auger points per sub-class.

Classification	Area (%)	Planned amount of auger points	Surveyed auger points
Boundary high dunes	2.9	10	6
High dunes	29.2	20	12
High dunes in low and mid-high area	0.7	4	1
Low area	25.1	27	23
Mid-high area	16.1	19	16
Open drift sand and heathland area	25.9	20	12

The Dutch soil classification system is too limited to trigger the variability of the Wekeromse Zand. Comprehensive soil names were formulated by combining existing soil classes and introduce new soil classes. The soils were classified according to the Dutch Soil Classification System and they were translated into a Universal Soil Classification (Appendix A). The characteristics of the soil for the soil classification is given in Table 2.

Table 2: Classification and corresponding properties of the soils from the Wekeromse Zand.

Classification	Characteristics of the soil
1: 2 Gleyic carbic podzol	2 podzol soils with hydromorphic properties.
2: 3 Gleyic carbic podzol	3 podzol soils with hydromorphic properties.
3: Drift sand layer on (blown out) Gleyic carbic podzol	Unhomogeneous drift sand layer on top of podzol soil with hydromorphic properties.
4: Drift sand layer on (blown out) Orthic podzol	Unhomogeneous drift sand layer on top of podzol soil with xeromorphic properties.
5: Gleyic carbic podzol	Podzol soil with hydromorphic properties.
6: Potic arenosol	Homogeneous sand layer with hardly any soil formation.
7: Potic arenosol on (blown out) Gleyic carbic podzol	Homogeneous drift sand layer on top of podzol soil with hydromorphic properties.
8: Potic arenosol on (blown out) Gleyic carbic podzol on Spodic anthrosol	Homogeneous drift sand layer on top of podzol soil with hydromorphic properties on top of anthropogenic sandy soil with xeromorphic properties and an A horizont between 30-50 cm.
9: Potic arenosol on 2 (blown out) Gleyic carbic podzol	Homogeneous drift sand layer on top of 2 podzol soil with hydromorphic properties.
10: Potic arenosol on Orthic podzol	Homogeneous drift sand layer on top of podzol soil with xeromorphic properties.
11: Potic arenosol on Spodic anthrosol	Homogeneous drift sand layer on top of anthropogenic sandy soil with xeromorphic properties and an A horizont between 30-50 cm.
12: Spodic anthrosol	Anthropogenic sandy soil with xeromorphic properties and an A horizont between 30-50 cm.
13: Spodic anthrosol on (blown out) Orthic podzol	Anthropogenic sandy soil with xeromorphic properties and an A horizont between 30-50 cm on top of a podzol soil with xeromorphic properties.
14: Spodic anthrosol on Gleyic carbic podzol	Anthropogenic sandy soil with xeromorphic properties and an A horizont between 30-50 cm on top of a podzol soil with hydromorphic properties.

The field survey data were digitalized in Excel and evaluated with Excel, ArcGIS and R. A semivariogram of the palaeosurface, which is the soil surface prior to drift sand accumulation, and the buried soils, which are soil development layers within the drift sand, was made and resulted in a range, sill and nugget. The range is the distance between the measurement points where still spatial correlation occurs. The amount of samples within the range determines the sampling density. The sill gives the variability in the area. The nugget is the measurement error or spatial source of variation at distances smaller than the sampling interval. The palaeosurface was interpolated in R by Ordinary Kriging. The scripts which were used for running the program R are attached in Appendix C. Buried soils were analysed by drawing cross sections through point where buried soils were found. This was done in ArcGIS; 3D analyst, interpolate line, profile graph.

The Optically Stimulated Luminescence (OSL) dating technique

In two pits the soil layers developed without human disturbance. It was most representative to compare the naturally developed soils with each other, so only the samples of Pit 1 and Pit 2 were analysed. The last two sample of pit two were excluded from the analyse, because they were taken in the coversand and our focus is on the drift sand. Finally, eight samples from Pit 1 and three samples from Pit 2 were analysed. The ^{14}C method is the most common method for dating soil layers, but the carbon content in drift sands is low. With the ^{14}C method age differences within one layer can be caused by inclusion of carbon from older surfaces and rejuvenation can be caused by roots, which made the method less reliable (Koster, 2009; Pape, 1970). In podzolized soils the ^{14}C in the illuviation layer would be estimated much younger than the soil grains in this illuviation layer. For the geochronology of the Wekeromse Zand the Optically Stimulated Luminescence (OSL) dating technique was applied (Van Mourik et al., 2011). This is the most accurate technique for dating aeolian sediments (Bateman and Van Huissteden, 1999) and, according to Cunningham and Wallinga (2009) and Forman and Pierson (2003), OSL is particularly useful for dating young soils (< 500 years). OSL dating can be done on quartz grains and feldspar (Hilgers, 2007). In this research OSL dating was done with quartz grains, because feldspar is in general used for older dating (Duller, 2008) and drift sand is younger than the Weichselian Ice Age. Quartz is a mineral which occurs in abundance in drift sand areas, it is resistant to weathering and it has the right luminescence properties, which makes it suitable for OSL dating (Preusser et al., 2008). OSL measures the amount of radiation the quartz grains in the soil sample have received since the last exposure to daylight (Duller, 2004). A simplified introduction in the technique it attached in Appendix D and more in depth information about the technique applied on quartz grains can be found in Preusser et al. (2009).

For the soil samples non-pervious pipes which could carry more than 600 grams of soil were used. The tubes were hammered horizontally into the wall of the soil profile. A piece of styrofoam in the beginning of the tube was reducing the disturbance of the sample. The samples were dug out from the soil profile, to reduce disturbance. It was important for the application of OSL that the soil samples were not exposed to light.

Before the OSL dating started with a blue LED (470 nm) in the Risø TL-DA-15 TL/OSL reader, quartz grains were extracted from the soil material. A grain size 180-212µm was selected for the preparations of the samples. Hydrogen peroxide (H_2O_2) was used for eliminating organic matter. With the chemical Fluorohydride (HF) feldspar was dissolved. To be sure, because in general drift sands does not contain carbonates, carbonates were eliminated with hydrochloric acid (HCl). Carbonates and feldspar emit spurious signal and OM reduces the signal in OSL (Theunissen et al., 2012).

The samples of Pit 1 were labelled from NCL-2212198 till NCL-2212205 and the samples of Pit 2 were labelled from NCL-2312206 till NCL-2312208. The Single Aliquot Regenartive (SAR) dose procedure (Murray and Wintle, 2000; Murray and Olley, 2002) was used for equivalent dose determination on the quartz grains (ncl.tudelft.nl, 2012). The SAR procedure gave high precision and accuracy to the measurements (Jain et al., 2003). The parameter tests, which were done before the measurements started, are described in Appendix D. The pre-heat plateau was done for sample NCL-2212200 and NCL-2212205 and the Dose Response test is done for samples NCL-2212201 and NCL-2212205.

To determine the age of a soil sample the total radiation dose received by the grains was measured; the equivalent dose (D_e) (Cunningham and Wallinga, 2012). Together with the rate wherein radiation was absorbed, the dose rate (D), the age of the soil can be determined:

Age (ka) = Equivalent dose (Gy)/ Dose rate (Gy/ka)

The equivalent dose was measured on multiple grain aliquots of 2.5 mm, which means that there were 100-200 quartz grains on one sub-sample, aliquot (Duller, 2008). Not every grain gives a signal, but when too many grains were on an aliquot the signal was averaged out. The minimum amount of grains on a disc, whereby still a signal can be found for the majority of the aliquots, was at aliquots of 2.5mm. Only sample NCL-2212198 was measured on 3 mm aliquots by accident.

Alpha particles (α), bèta particles (β), gamma (γ) and cosmic rays occur naturally in the sample and surrounding (Duller, 2008). For determining the dose rate pucks were made from soil and wax. The dose rate was determined by measuring the effective rate of supply to the sample by ionizing radiation from the decay ^{40}K, ^{238}U, ^{235}U and ^{232}Th and from the cosmic rays in the sample and surround the sample by a Canberra broad energy HPGe gamma spectrometer (Galbraith et al., 1999; ncl.tudelf.nl, 2012).

The results were analysed by the Luminescence Analyst. The measurement error was 1.5% and the Monte Carlo simulation 1000. The integration interval was from 1 till 25 for the signal and from 26 till 88 for the background. Due to some rejection criteria some aliquots were rejected for the D_e determination. The Recycling Ratio Limit and the Max Test Dose Error were 10%.

Mathlab was running the Central Age Model (CAM) and the Minimum Age Model (MAM) for the aliquots which were not rejected in the Luminescence Analyst. For the CAM the true log palaeodose is a random sample from a normal distribution (Galbraith, 1999). For the MAM is the true log palaeodose a random sample from a mixed truncated normal distribution. However, in this research an 'unlogged' version of the MAM is used, which is more suitable for young soil samples (Arnold et al., 2009). This, so called, bootstrapped version of MAM can deal with estimates that are equal to zero within their uncertainty limits (Cunningham and Wallinga, 2012). The MAM assumes that the dispersion of well-bleached grains is entirely accounted for by the associated error terms (Cunningham and Wallinga, 2012).

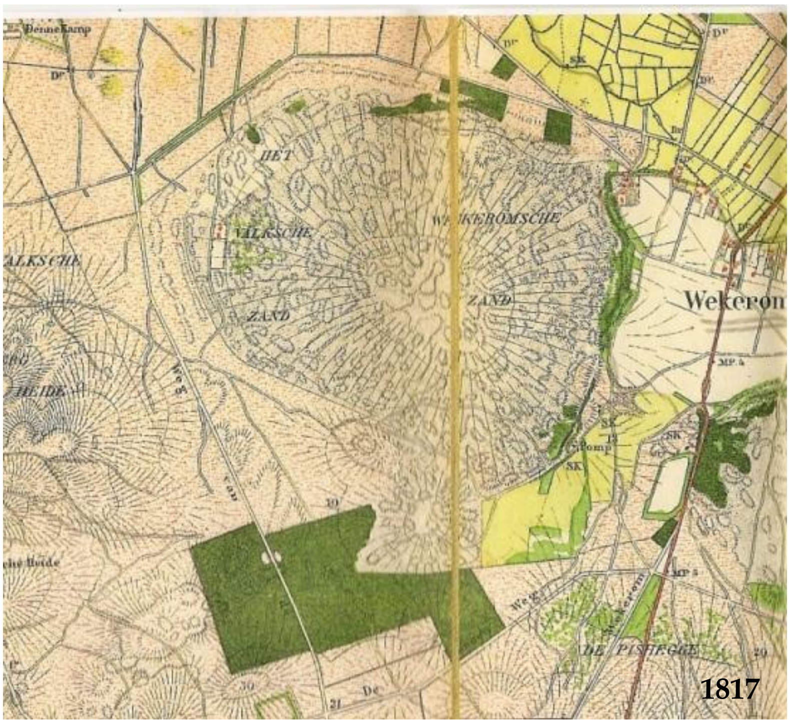
According to the background information and the data results of the samples, the most accurate model is chosen as input for the Oxcal model (v.4.1). The script for the Oxcal model is given in Appendix E. Oxcal has the potential to integrate information between different records and provide a coherent chronology (Bronk Ramsey, 2008). The model is increasing the precision and accuracy of chronologies of records to combine the absolute age information, the relative age information and the cross correlations between records (Bronk Ramsey, 2006). The CAM was implemented in the Oxcal model by writing i.e. 'Date("NCL-2212198",N(2012-171,19))' in the script, whereby 171 is the burial age (years ago) and 19 is the standard error. The MAM was implemented by writing i.e. 'Prior("NCL2212204")' in the script. The results from the CAM and MAM and the results from the Oxcal model were compared to get the definite burial age.

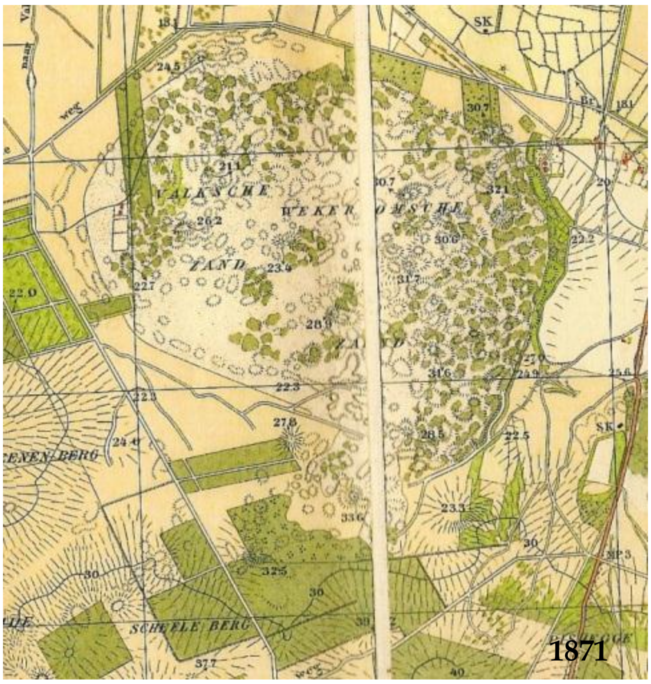
Results and discussion

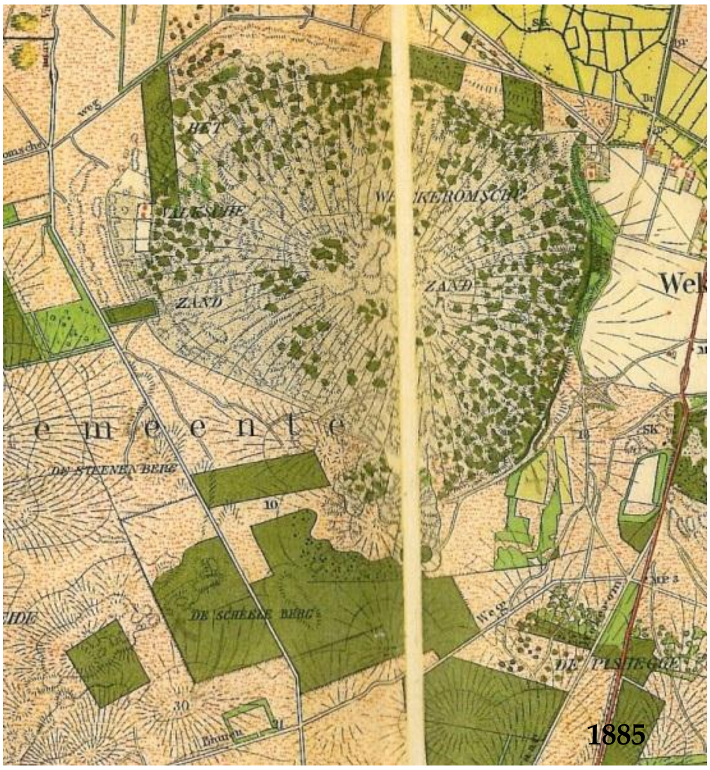
Drift sand area the Wekeromse Zand during the last two centuries

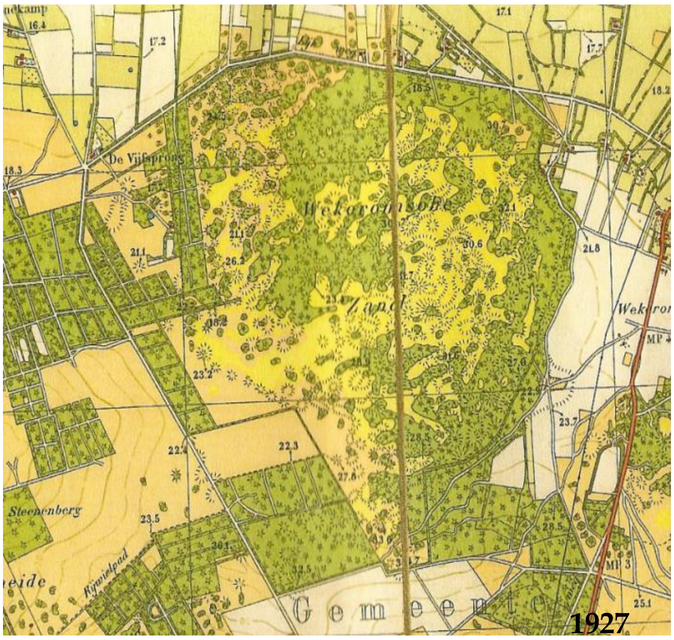
The activity of drift sand area the Wekeromse Zand decreased during the last two centuries (Fig.11 and Fig.12). The drift sand area became more captured by forest and did not expand at least since 1817. From the historical maps (Fig.11) can be seen that agricultural practices on the slopes of the ice pushed ridge increased during the 19th century and the area became more forested since the late 20th century. (Van der Loo, 1997). There were only a few settlements around the Wekeromse Zand, which are indicated as red or black dots in the maps (Fig.11). Until 1885 only the eastern part, behind the high drift sand dunes, was inhabited and only since 1927 the northern part became inhabited too. From literature is known that farmers on the windward side used conservation measures to protecting their land against wind erosion during the 16th century and farmers in the leeward side built their houses close to the drift sand dunes to be protected from the wind (Zandvliet, 1984). Until 1885 two names were given to the recent Wekeromse Zand; Het Valksche Zand and Wekeromse Zand.

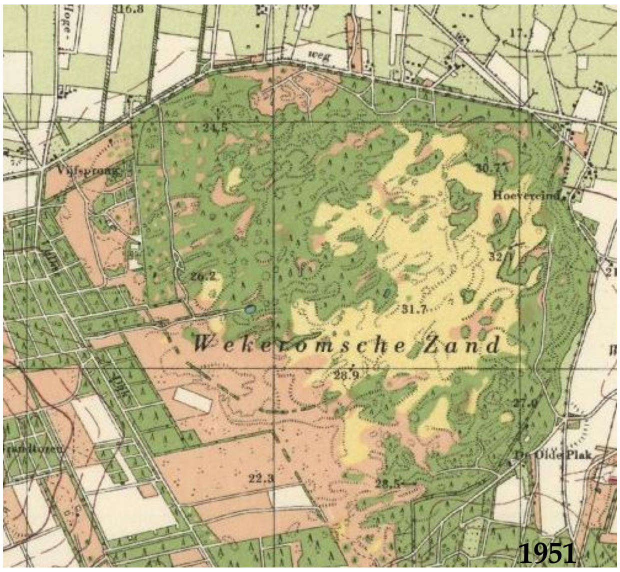
Heathland had covered a large part of the active drift sand during the last 60 years (Fig.12). Only in the centre of the Wekeromse Zand active drift sand remained. In 1944 the agricultural plots and the drift sand area were more barren than nowadays. In 1800 there was 300 ha active drift sand in the Wekeromse Zand. This is reduced from 170 ha in 1900 to only 14 ha in 1993 (mooigelderland.nl, 2012). On average 1.5 ha/year is fixed by vegetation.

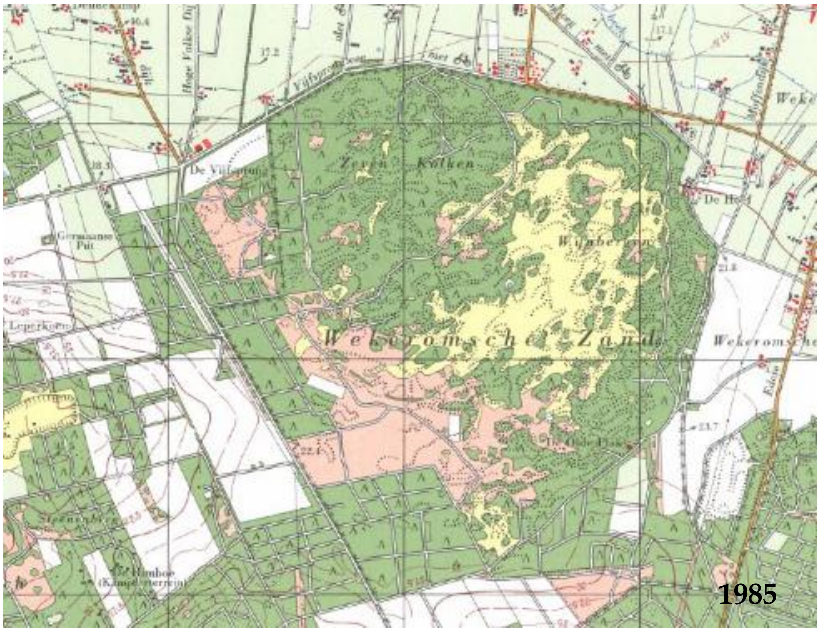












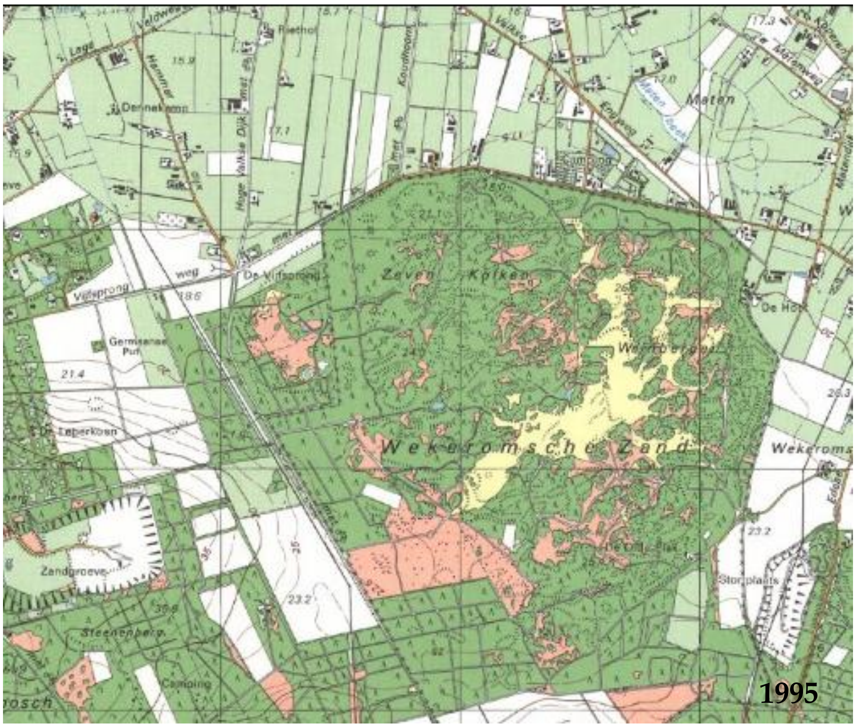


Figure 11: Cropping of the historical maps from 1817 till 1995.

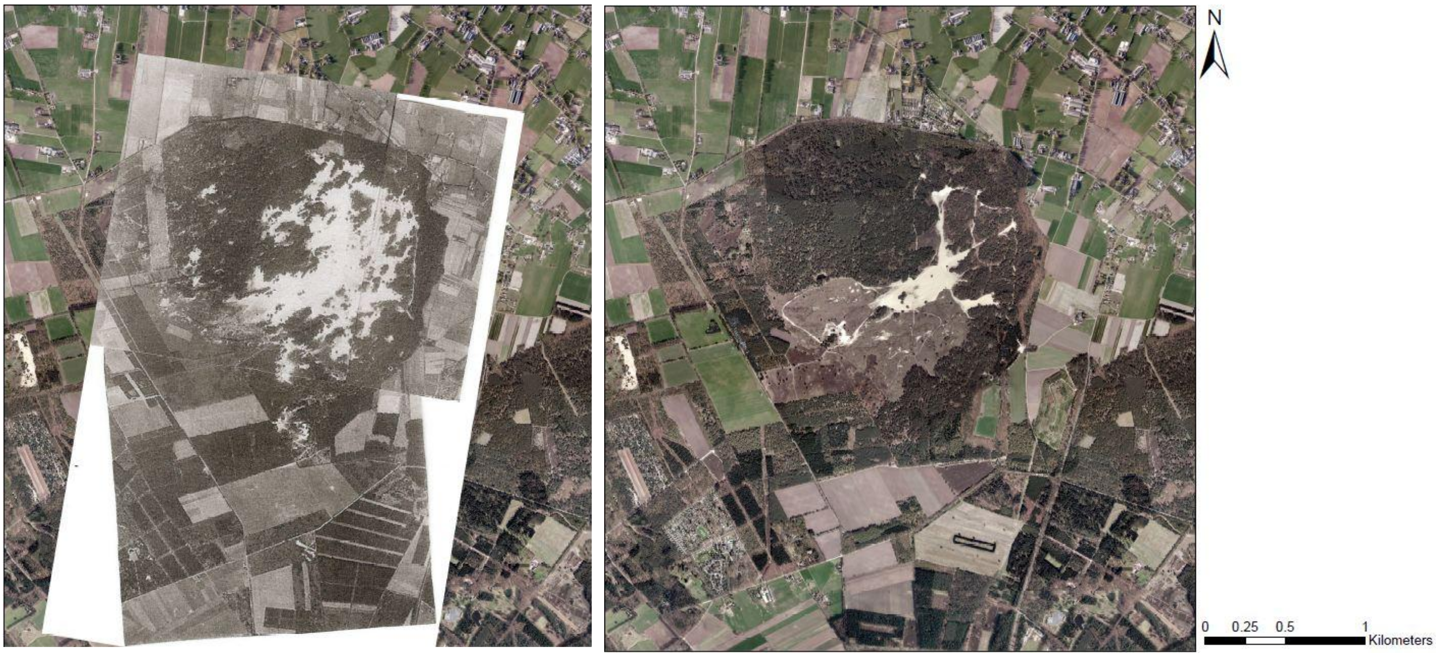


Figure 12: The Wekeromse Zand in 1944/1945 and the Wekeromse Zand in 2010.

The decreased drift sand activity was continuously going on, without a visible change when agricultural practices or reforestation was taking place around the study area. From the historical maps only the large scale dynamics were visible from the historical maps, internal dynamics and geomorphological processes were not. The settlement pattern can suggest that the eastern dunes developed and vegetated first and the drift sand dunes in the north-eastern part developed and vegetated only since the 20th century.

Results from the soil survey and the soil classification

The results from the field survey are attached in Appendix F. Except from some sticky organic layers in the northern part of the study area, the soil texture sand was found. The systematic sampling strategy in the 'Open drift sand area and heathland' was aimed to recognize patters in grain size over distance. In the Netherlands drift sand is generally fine-grained sand with an average grain size between 105 and 300 µm (Kasse, 2002; Castel et al., 1989). The results of the field data corresponded with the values found in literature; 97.7 % of the surveyed points had a grain size between 105 and 300 µm. In the 'Open drift sand area and heathland' only the soils closest to the ice pushed ridge contained coarse layers. With course layers was meant: soil layers with at least 5 % of soil grains larger than 600 µm. The drift sand further from the ice pushed ridge contained homogeneous, fine grained drift sand.

The soil colour gave an indication of the mineral composition of the soil and the OM content in the soil. The eluviation layer in podzol soils were ash grey and the illuviation layers were gradually going from dark brown colours to brownish/reddish colours. The OM content was estimated visually in the field. In 75% of the soils an OM content lower than 2% was estimated.

In the Gleyic Carbic podzol soils the conversion rate at the surface was low, which was visible by the thick litter layer. Biological features are able to break down litter and distribute organic matter through the subsurface (McInerney et al., 2001). In Pit 1 (Fig. 16) a burrow of a beetle was found at 75 cm depth and indicates bioturbation.

Red mottles in the soil indicate ironoxide reduction caused by groundwater fluctuation or water stagnation. The iron oxidation is indicated with the character 'g' from gelyic properties in Appendix F. In the northern part of the 'Low area' and in the 'Mid-high area' iron reduction was found directly under the illuviation layer, which characterized the Orthic podzol soils. In the 'High area' hardly any mottles were found.

The soil classification is given in Figure 13 and the classification properties are given in Table 2. The Orthic podzol and the Gleyic Carbic Podzol soils were indicating differences in hydromorphic properties within the area. Gleyic Carbic Podzol soils developed close to the ice pushed ridge and Orthic podzol soils developed in the North and East. Potic Arenosols dominated the central parts of the study area.

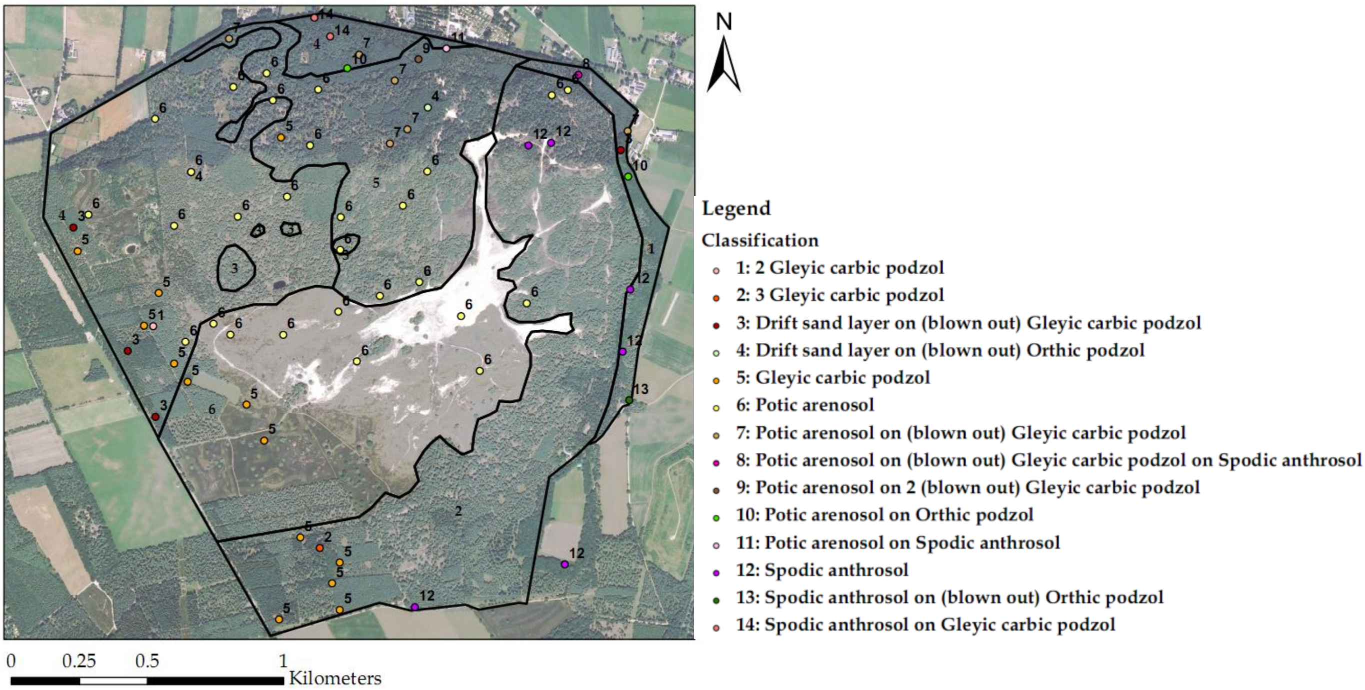


Figure 13: soil classification of the Wekeromse Zand.

In the southern part of the 'High dunes' pushed moraine deposits were found at 20.6 m according to the DEM. The pushed moraine material is characterized by inhomogeneous grain sizes and gravel. Fine sand grains (150 µm) and gravel (>1 cm) was found in the pushed moraine sediments.

The soil profiles and the soil classification of Pit 1, Pit 2 and Pit 3 are given in Figure 14 and Appendix F. Pit 1 was located in the accumulation area in the northern part of the study area. The groundwater level was at 180 cm depth and at 200 cm a permanent reduced coversand layer was found. The soil grains in the coversand layer were coarser than in the rest of the profile. In the organic layer between 180 and 200 cm depth recognizable plant material was found. From 130 till 180 cm an organic rich, sandy layer which contained a layering was identified. From 175-180 cm there was a micro layering of organic layers and drift sand layers with a low OM content. At 130-175cm depth layers with different grain sizes and source material were surveyd. Pushed moraine sediments as well as coversands were found as source material in this layer. A poor drift sand layer, from 100 till 130 cm depth contained, visually estimated, 5% of iron reduction. From 75 till 100 cm a small layer with more organic material developed. In this layer a burrow of a beetle was found. Above this layer another poor drift sand layer developed. This layer contained in the beginning a layering with higher and lower OM contents. This gently turned into a homogeneous organic poor layer. In the top a micropodzol developed.

In Pit 2 was located in the erodible area in the western part of the study area. Coversand is reached at 65 cm depth (Fig. 14). The coversand contained an illuviation layer of 80 cm which

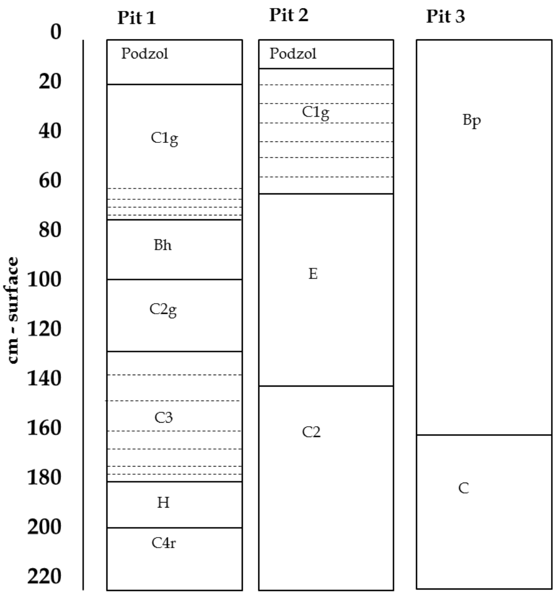


Figure 14: Pit 1 taken in the accumulation area (A), Pit 2 taken in the erosion area (B), Pit 3 taken in the anthorpogenic area in the east, behind the high drift sand dunes (C).

gradually turned into blond-yellow coversand. There was assumed that the eluviation layer was eroded. From the surface till 65 cm depth a small layering with higher and lower OM contents characterized the horizon. The colours of the layering was varying from 10 YR 3/1 to 10YR 5/2. No biological features were found in the soil profile. The soil is vegetated nowadays and a micropodzol developed in the top of the soil profile.

In Pit 3 anthropogenic residues were found; e.g. potsherd and brick. The pit is located in the eastern part of the study area. A homogeneous, dark coloured plaggen layer of 160 cm depth was found on top of the blond-yellow coversand. The boundary of the coversand and the plaggen layer was sharp which indicates ploughing activities. Root residues and biological features were visible as organic tracks in the soil profile.

Discussion from the soil survey and classification

The variability within the area is large and the 1:50000 soil map is too general. 14 different soil types were distinguished in only 70 soil surveys. The amount of soil surveys and the three pit descriptions were not representative enough for the area according to the soil variability. Converting the Dutch Soil Classification into a Universal Soil Classification is hard, simply because the Universal Soil Classification is less specified in Dutch soils.

Anthropogenic plaggen soils were only found behind the high drift sand dunes. This was also indicated at the 1:50000 soil map. This gives the indication that plaggen agriculture was only going on at the leeward side of the Wekeromse Zand, while Celtic fields surrounded the area. The historical agricultural activities around the Wekeromse Zand need more research to find the boundaries of the plaggen agriculture.

Only close to the ice pushed ridge coarse sand layers were found. Considering the dominant wind direction there is assumed that the storm events were: i) not strong enough to transport heavy soil particles further into the drift sand area, ii) the deposition layer of the fine-grained sand further windward was too thick to reach courser layers by a soil auger. Drillings until the palaeosurface could give information about a potential relationship between the grain sizes and the distance from the ice pushed ridge.

The deep groundwater table in the study area and the low capillary rise of sandy soils suggested pseudogley as cause for the iron reduction in some profile layers. Only at one spot an organic rich aquitard was found in the subsurface close to a natural fan. The similarities of the natural fans suggest a relation between organic rich layers in the subsurface and the occurrence of natural fans. More soil survey data is needed in the 'Low area' and 'Mid-high area' to interpolate the stagnation layers.

A podzol soil is characterized by an eluviation and illuviation layer, but in some soil surveys the eluviation layer was eroded. The lack in knowledge about the thickness and properties made it hard reconstruct these missing layers. To distinguish an illuviation layer from an organic rich layer micromorphologiccal research is needed. Also for determining whether the microlayering in Pit 2 is micorsoil formation or blown in drift sand, micromorphological research is needed.

The palaeosurface, prior to drift sand activation, of the Wekeromse Zand and the properties of buried soils

At 22 soil survey points the palaeosurface was surveyed (Appendix G). The points where palaeosurfaces were found was dominantly at the boundaries of the Wekeromse Zand. The distances between the points were too large for accurate interpolation (Table 3). However, from the interpolation (Fig.15) can be seen that the valley position was in the North, which was also suggested by the organic soil properties found in the North (Appendix G). In the East the highest palaeosurface elevations were found and currently this part of the area is still highest.

Table 3: The nugget, sill and range of the semivariance, calculated by R.

	Palaeosurface	Buried soil
Nugget	0.93	0.95
Sill	2.3	109.2
Range (km)	0.9	195.3

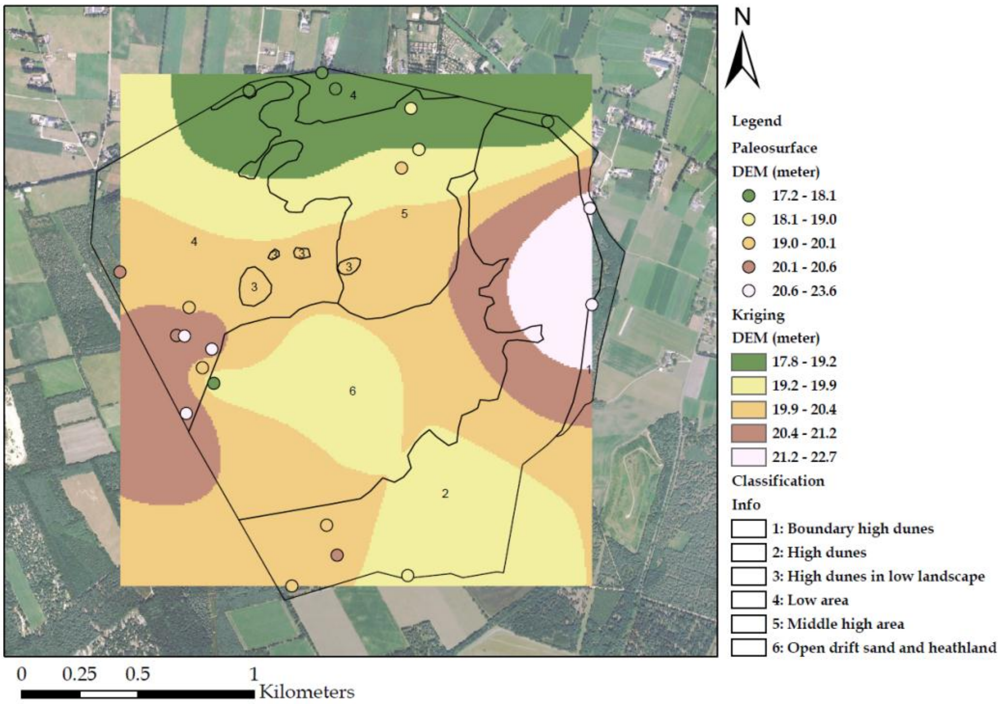


Figure 15: Interpolation from the palaeosurface with Ordinary Kriging.

Coversand with or without a (blown out) podzol soil dominated the palaeosurface. Pushed moraine sediment is the palaeosurface in the southern part of the study area. The palaeosurface was characterized by its inhomogeneity in grain size. Two organic layers were found as palaeosurface in the northern part. The pushed moraine sediments is varying between 18.9 m and 20.6 m and the coversand between 17.4 m and 22.5 m according to the

DEM. The depth of the sticky, organic layers is between the 17.2 m and 17.8 m according to the DEM.

At 13 soil surveys points soil development, buried under drift sand, was surveyed (Appendix G). In the subareas 'Mid high area', 'Low area' and 'Boundary of high dunes', buried soils were found in between an elevation range of 6.4 m. From the semivariogram can be seen that no relation was found between the survey points (Table 3). From cross sections parallel to the prevailing wind direction and perpendicular to the prevailing wind direction no relief pattern was found (Appendix H). The properties of buried soils were different throughout the area. Some buried layers were organic and some just reached an OM content of 3% (Appendix G). The locations where sticky organic layers were found are not equal to the locations where the palaeosurface organic layers were found. The thickness of the buried soils was between the 10 and 32 cm.

More data is needed to increase the accuracy of the spatial variability and to recognize any relief from the palaeosurface and the buried soils. The thickness of the soil development in the buried soils was not equal. This can be caused by e.g. soil development which did not start at the same time, the variation in soil fauna, the variation in accumulation and erosion. The sticky layers were dominantly found in the north-eastern part of the study area and not, like the palaeosurface, in the northern part. The sedimentation could have been higher in the North, which resulted in a shift of valley position.

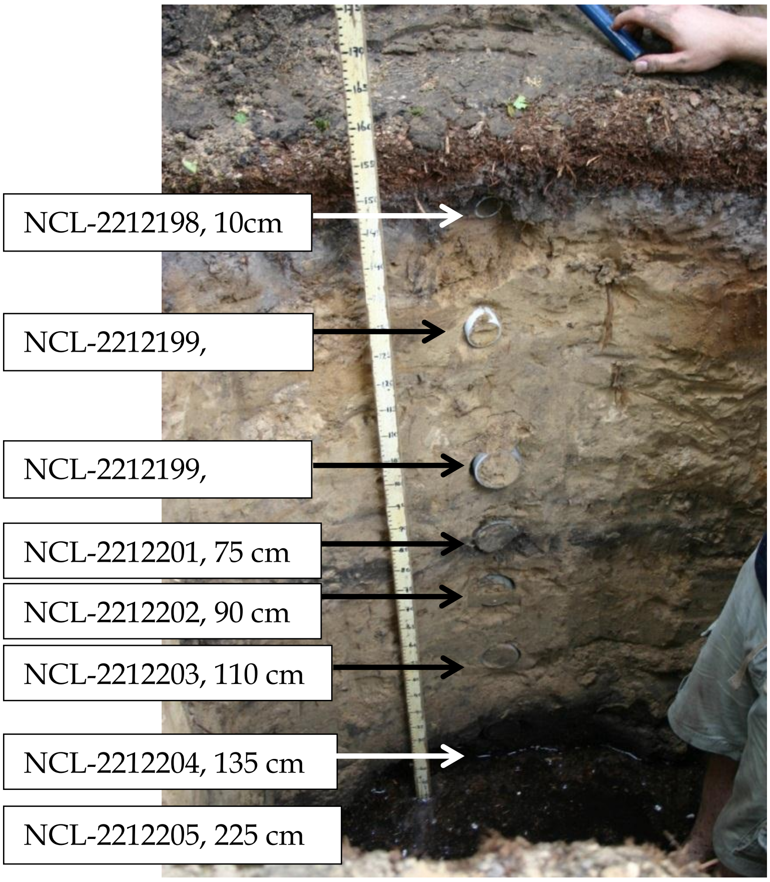
Burial age of distinguished drift sand layers

Each soil layer in Pit 1 is sampled, except the organic soil layer (Fig. 16). The purpose of Pit 1 was to evaluate the reconstruction in a certain time sequence and strengthen argumentations about the impact of natural and anthropogenic factors in the Wekeromse Zand. In Pit 2 three samples were taken from the micro layering to determine the rate wherein these layers were deposited (Fig. 16). The samples of Pit 1 were labelled from NCL-2212198 directly under the surface till NCL-2212205 at a depth of 225 cm. The samples of Pit 2 were labelled NCL-2312206 till NCL-2312208 and they were sampled on 24, 38 en 53 cm depth respectively.

In Pit 1 the samples were assumed to be likely well bleached prior to the drift sand, except NCL-2212203 and NCL-2212204. Also the samples of Pit 2 were not well bleached, because the samples were taken just above to the coversand, which means that the travel distance of the soil grains was short and potential not sufficient to reset the stored radiation.

The water content and the OM content reduced bleaching and ionizing radiation absorption of the quartz grains. The results for the water content, the OM content, the equivalent dose and the dose rates are given in Table 4. The water content of sample NCL-2212203 and NCL-2212205 did not indicated a higher water content , so the water content was reduced from 36.1% and 21.5% respectively to 20%. The error of the water content is 25%, except for the dark, sandy layer (NCL-2212204) the error is 40%, because this layer is just above the groundwater level and water fluctuates in this layer during the year. The OM content in Pit 1 varies from 2.6% in the darkest layers to 0.3% in brighter coloured layers. Because of the uncertain OM content in NCL-2212204 the possible error is 40% instead of 10% like for the other samples.

The water content in Pit 2 differed from 23.1% to 7.1 %, while in the field hardly any difference between the water content in the layers was found. The water content is fixed at 8% for the three samples and the error is increased to 40%. The OM content of the samples in Pit 2 fluctuated between 3.1 % and 1.1 %. The relative error in the OM content is 10%.



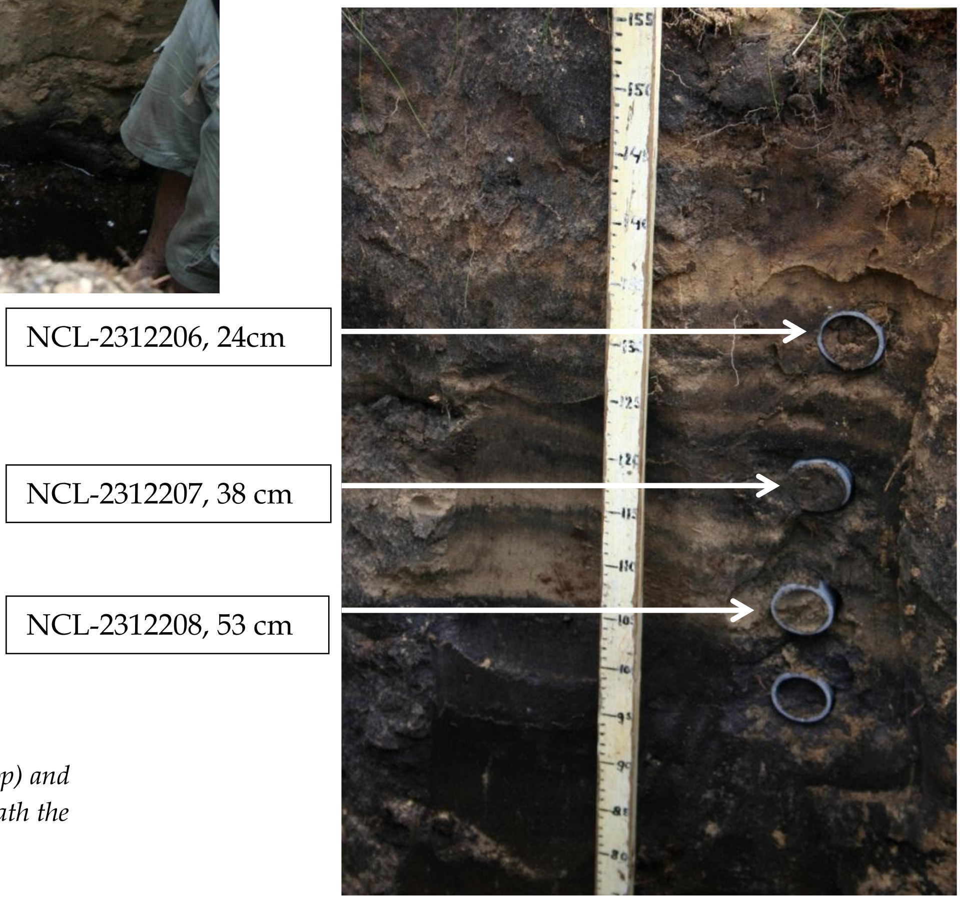


Figure 16: OSL samples taken in Pit 1 (top) and Pit 2 (right). NCL-2212205 is taken beneath the dark layer with a piston sampler.

Table 4: Water content, organic matter content and the equivalent dose and the dose rate age measurements.

Pit	Sample	Transport	Depth (cm)	Water content measured (%)	Water content used (%)	Error water content used (%)	OM content (%)	OM content used (%)	Error OM content used (%)	D_e iterated (Gy)			D (ka/Gy)			Iterated Age (AD)		
1	NCL-2212198	Aeolian	10	6	6	1.5	2.3	2.3	0.23	0.23	±	0.03	1.28	±	0.04	1835	±	23
1	NCL-2212199	Aeolian	30	3	5	1.3	0.4	0.4	0.04	0.27	±	0.02	1.12	±	0.03	1775	±	22
1	NCL-2212200	Aeolian	55	6	6	1.5	0.7	0.7	0.07	0.32	±	0.02	0.97	±	0.03	1685	±	21
1	NCL-2212201	Aeolian	75	19	19	4.8	1.9	1.9	0.19	0.51	±	0.02	1.12	±	0.04	1552	±	27
1	NCL-2212202	Aeolian	90	9	9	2.1	0.5	0.5	0.05	0.6	±	0.03	1.1	±	0.03	1464	±	29
1	NCL-2212203	Aeolian	110	36	20	5	0.3	0.3	0.03	0.69	±	0.05	0.98	±	0.04	1315	±	54
1	NCL-2212204	Aeolian	135	27	27	10.8	2.6	2.6	1.05	0.52	±	0.03	0.78	±	0.05	1344	±	55
1	NCL-2212205	Aeolian	225	21	20	5	0.9	0.9	0.09	10.88	±	0.63	1.03	±	0.04	-8558	±	736
2	NCL-2312206	Aeolian	24	23	8	3.2	1.1	1.1	0.11	0.52	±	0.07	1.25	±	0.04	1600	±	57
2	NCL-2312207	Aeolian	38	11	8	3.2	3.1	3.1	0.31	0.57	±	0.12	1.22	±	0.04	1547	±	102
2	NCL-2312208	Aeolian	53	7	8	3.2	1.5	1.5	0.15	0.51	±	0.07	1.18	±	0.04	1580	±	62

From the equivalent dose and the dose rate the age can be calculated by iterations (Table 4). A better estimation of the burial age is given by models. The aliquots that were not rejected in the Luminescence Analyst were used as input for the models CAM and MAM. The results from the CAM and MAM are given in table 5 and 6 and visualized in Figure 17. For each sample was determined which model gave the most reliable results by taking the background information into account; blue shaded in Table 5 and 6.

- NCL-2212198: CAM, bioturbation took place.
- NCL-2212199 and NCL-2212200: CAM, there is no indication for weak bleaching.
- NCL-2212201: MAM, stable layer wherein bioturbation took place, but because the sample was taken on the transition of two layers, disturbance took place and the MAM gave more reliable results.
- NCL-2212202: CAM, there is no indication for weak bleaching.
- NCL-2212203 and NCL-2212204: MAM, potential weakly bleached.
- NCL-2212205: CAM, coversand had been bare for a long time, which means that exposure to daylight and bioturbation was taken place for a long time.

The preference for the MAM for the samples from Pit 2 is because the samples were close to the coversand, like in NCL-2212203 and NCL-2212204.

The results from the CAM and MAM were implemented in the Oxcal model. For all samples the Individual Agreement Indices (A) had to be over 60%, because this indicated that the samples agree with the model. The increment per unit length (k) gave best results at 8. With a higher k value more intervals were taken between the soil samples which resulted in a linear sequence between the points.

Implementing a 'Phase' or a 'Break' in the script of the Oxcal model can influence the results. A break is implemented between sample NCl-2212201 and NCL-2212202, because there is a change in deposition rate visible (Fig.17A). Even with a break and/or a phase the age of NCL-2212202 is overestimated by the Oxcal model (Fig. 18). The Oxcal model with a break and with a phase gave the best results. Without a break and a phase or with only a phase, the Individual agreement indices (A) was smaller than 60%.

For the samples of Pit 2 a sequence is not preferred because the burial ages were nearly the same and the overdispersion was high (Fig. 17B). The samples were threatened as a phase. The results from the Oxcal model are given in Figure 19 and Table 7.

Table 5: results from the Central Age Model.

Sample	D_e	Error	Overdispersion	Error overdispersion	Age (AD)	St.error Age (years)
NCL-2212198	0.22	0.02	0.31	0.08	1834	22
NCL-2212199	0.26	0.02	0.22	0.05	1774	22
NCL-2212200	0.32	0.02	0.09	0.06	1684	21
NCL-2212201	0.49	0.02	0.17	0.03	1551	27
NCL-2212202	0.60	0.02	0.07	0.03	1314	54
NCL-2212203	0.67	0.04	0.15	0.05	1314	54
NCL-2212204	0.51	0.02	0.14	0.05	1343	55
NCL-2212205	10.59	0.58	0.24	0.03	-8582	583
NCL-2312206	0.53	0.06	0.32	0.05	1599	57
NCL-2312207	0.53	0.08	0.42	0.13	1546	102
NCL-2312208	0.50	0.06	0.35	0.08	1579	62

Table 6: results from the Minimum Age Model (MAM).

Sample	D_e	Error	Sigma	p_0	Age (AD)	St.error Age (years)
NCL-2212198	0.17	0.02	0.48	0.40	1877	24
NCL-2212199	0.22	0.02	0.27	0.38	1819	30
NCL-2212200	0.31	0.02	0.05	0.67	1689	34
NCL-2212201	0.45	0.04	0.13	0.35	1597	48
NCL-2212202	0.60	0.02	0.02	0.81	1468	55
NCL-2212203	0.63	0.06	0.13	0.51	1388	85
NCL-2212204	0.49	0.04	0.08	0.51	1374	66
NCL-2212205	8.71	0.90	0.29	0.23	-6199	996
NCL-2312206	0.38	0.03	0.53	0.29	1707	41
NCL-2312207	0.41	0.06	0.75	0.61	1659	58
NCL-2312208	0.39	0.04	0.50	0.36	1690	46

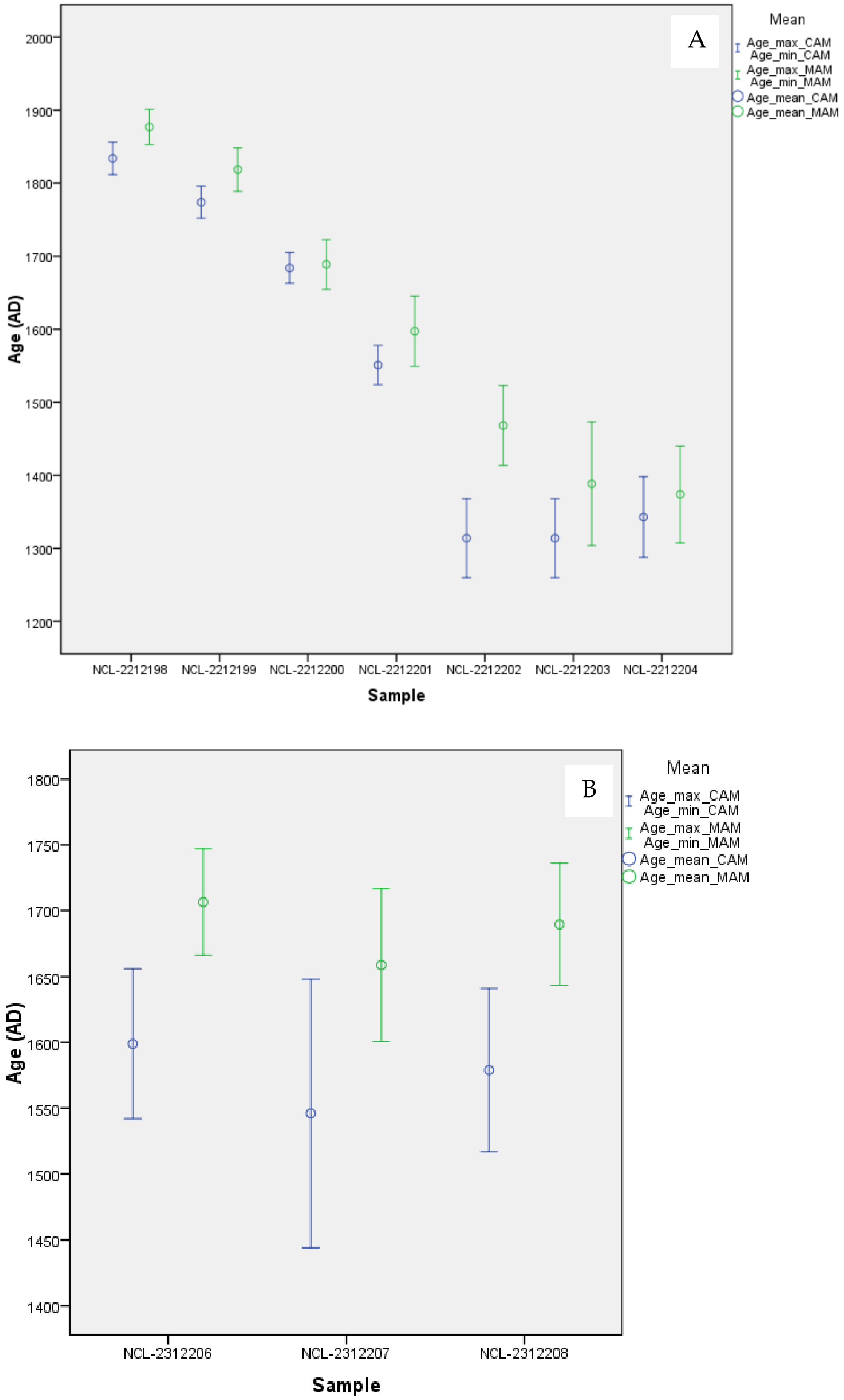


Figure 17: Age with standard error of the models CAM and MAM. Sample NCL-2212198 till NCL-2212204 (A) and sample NCL-2312206-NCL-2312208 (B).

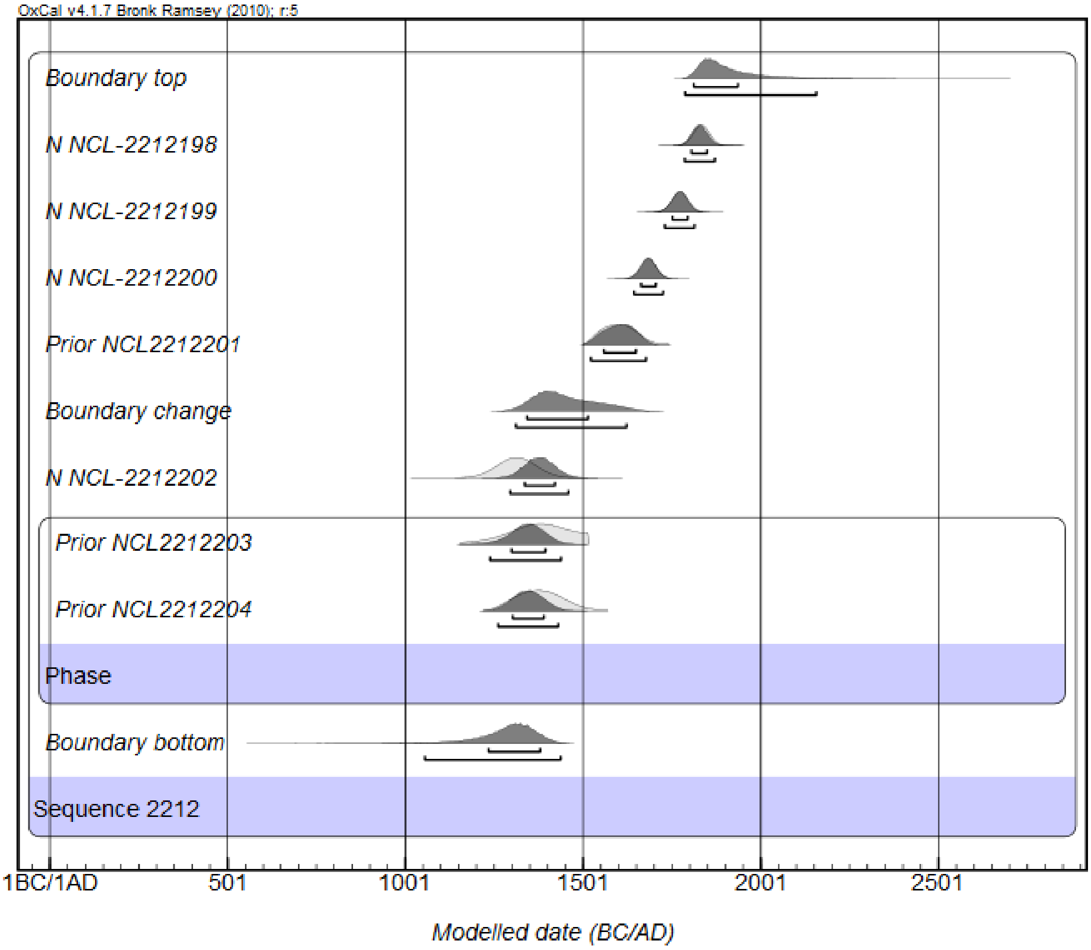


Figure 18: Results from the Oxcal model when a break is implemented between NCL-2212201 and NCL-2212202 and NCL-2212203 and NCL-2212204 were assumed to be deposited in one phase. Light grey: unmodelled results, dark grey: modelled results.

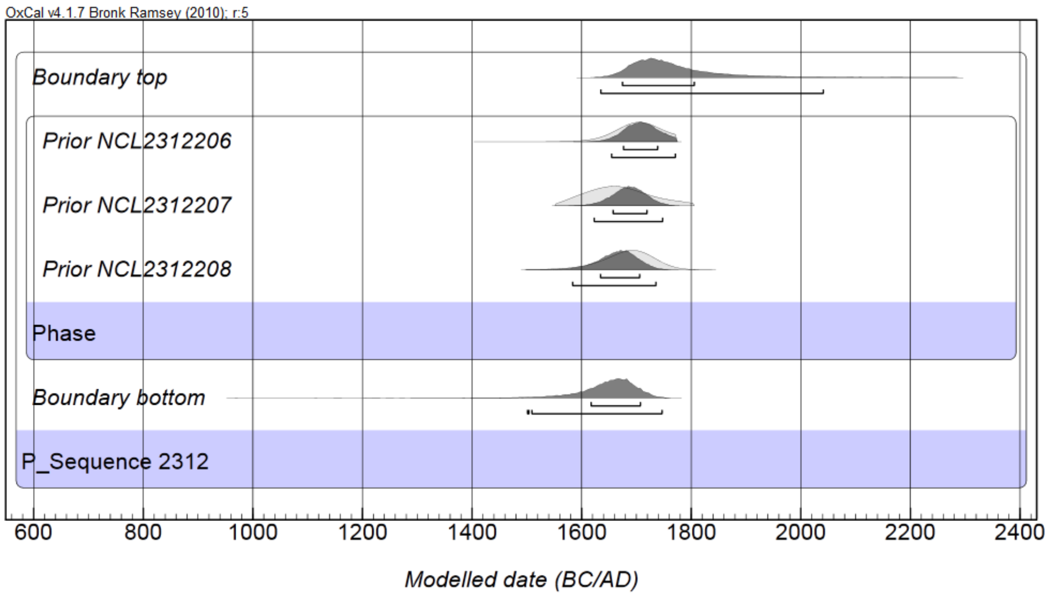


Figure 19: Results from the Oxcal model for the samples of Pit 2 (NCL-2312206 – NCL-2312208). The samples were assumed to be deposited in one phase. Light grey: unmodelled results, dark grey: modelled results.

Table 7: burial age calculated by the Oxcal model.

Sample	Modelled	St. error modelled
NCL-2212198	1827	22
NCL-2212199	1773	21
NCL-2212200	1685	21
NCL-2212201	1604	45
NCL-2212202	1379	43
NCL-2212203	1348	48
NCL-2212204	1347	44
NCL-2312206	1709	33
NCL-2312207	1688	30
NCL-2312208	1670	36

In Pit 1 the samples NCL-2212198 till NCL-2212201 were quite similar whether they were modelled or not (Fig. 18). For the sample NCL-2212202 till NCL-2212204 the deviation is higher between the modelled and unmodelled results. For further interpretations the results from the Oxcal model were used, because the use of CAM and MAM was varying which made it hard to get a sequence for the samples NCL-2212202 till NCL-2212204. The CAM gave the best results for sample NCL-2212205; -8582±583AD. For the samples of Pit 2 the Oxcal model gave the samples a more reliable sequence than the CAM and MAM did (Fig.19). Because there were only three samples and the results had a high overdispersion the accuracy of the results from Pit 2 is low.

By comparing the age of the samples with the depths where the samples were taken an idea of the drift sand accumulation rate was given. For Pit 1 the accumulation rate between 0.1-0.55 m depth and 0.9-1.35 m depth is faster than the accumulation rate between 0.55-0.9 m depth (Fig.20). This illustrates the stable period around 1604±45. The accumulation rate in the organic poor layer close to the surface is slower than the second organic poor drift sand layer. Drift sand activation in the 12th century is confirmed by Koster (2009) and drift sand activation between the 18th and 19th century is confirmed by Koster (2005b) and Clemmersen and Murray (2006).

In Pit 2 the burial age was a continuous sequence, however the overlap in burial age is large (Fig. 21). The results suggest that the samples in Pit 2 were deposited continuously and in one short time phase. The results from the aliquots, the CAM, the MAM and the Oxcal model are visualized in radial plots in Appendix I. From the radial plots is clearly visible that the samples of Pit 2 were poorly bleached, because the spread in the aliquots was large. The design principle of the standardized estimate is 2σ (Galbraith et al., 1999), but in this research there is chosen for 1σ because the soils were young and the model results were close to each other. Aliquots with a high precision and a small relative error were plotted closest to the radial axis.

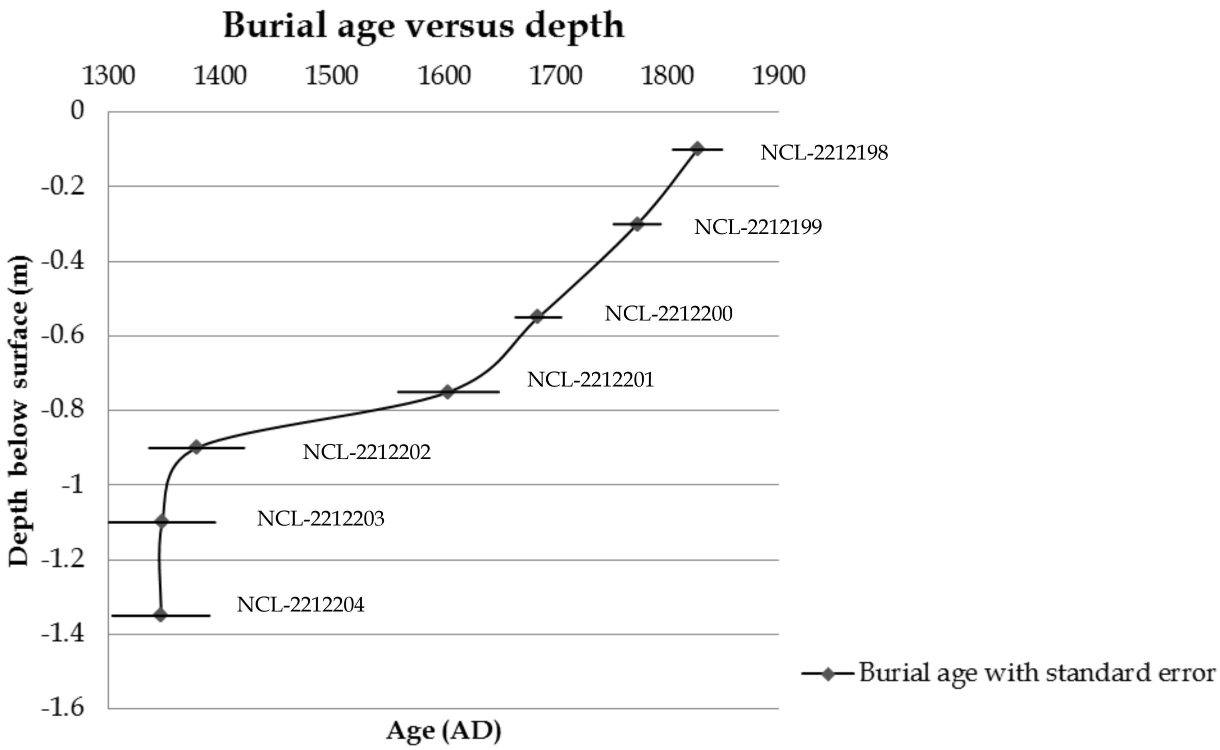


Figure 20: The burial age versus the depth beneath the surface where the samples were taken in Pit 1.

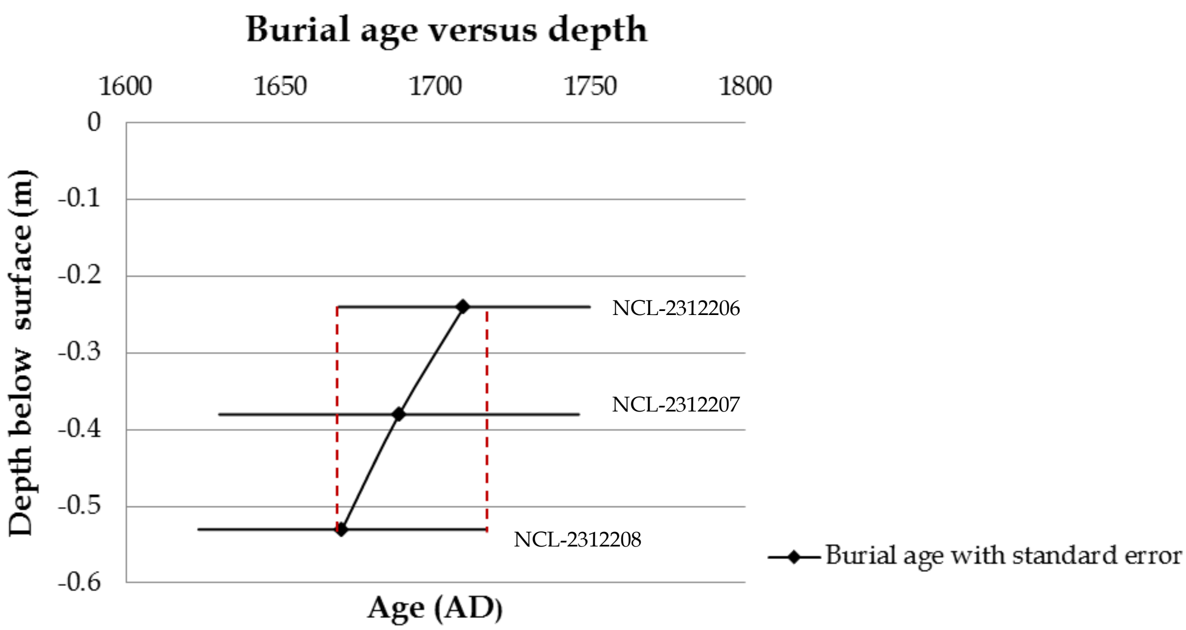


Figure 21: The burial age versus the depth beneath the surface where the samples were taken in Pit 2. The dashed line gives the large overlap in age similarity for the samples.

Interpretation of the development of the Wekeromse Zand

The surveyed and measured data were combined in a reconstruction of Pit 1 through the time (Fig.22). NCL-2212205 dated back to -8582±583AD, the transition period from the Boreal to the Atlanticum era. Above this layer there was an organic layer of 20cm which was not dated, but possibly developed during the warmer and wetter Atlanticum. NCL-2212204 was dated back to 1347±44AD, the end of the Medieval Climatic Optimum. The first homogeneous drift sand layer poor in OM accumulated between 1348±48 AD and 1379±43 AD. Whether a changed climate or humans influenced the low percentage of organic material accumulation in this layer was not clarified by this research.

The sample NCL-2212201, taken in the stable layer, is dated from 1604±45AD. This record was during the Little Ice Age (1550-1800AD). While storm surges were going on (Buisman, 2011), this part of the area was stabilized. Within 88 years a second drift sand layer with a low OM content developed. NCL-2212200 and NCL-2212199 dated from 1685±21 AD till 1773±21 AD. The small layering in Pit 2 was also deposited during the Little Ice Age (1670±36 AD-1709±33 AD). Remember that this layering could indicate continuous erosion and accumulation or microsoil development. It is preferable to link the active period from 1685±21 AD till 1773±21 AD, recorded in Pit 1, to continuously active drift sand in the erodible area of Pit 2.

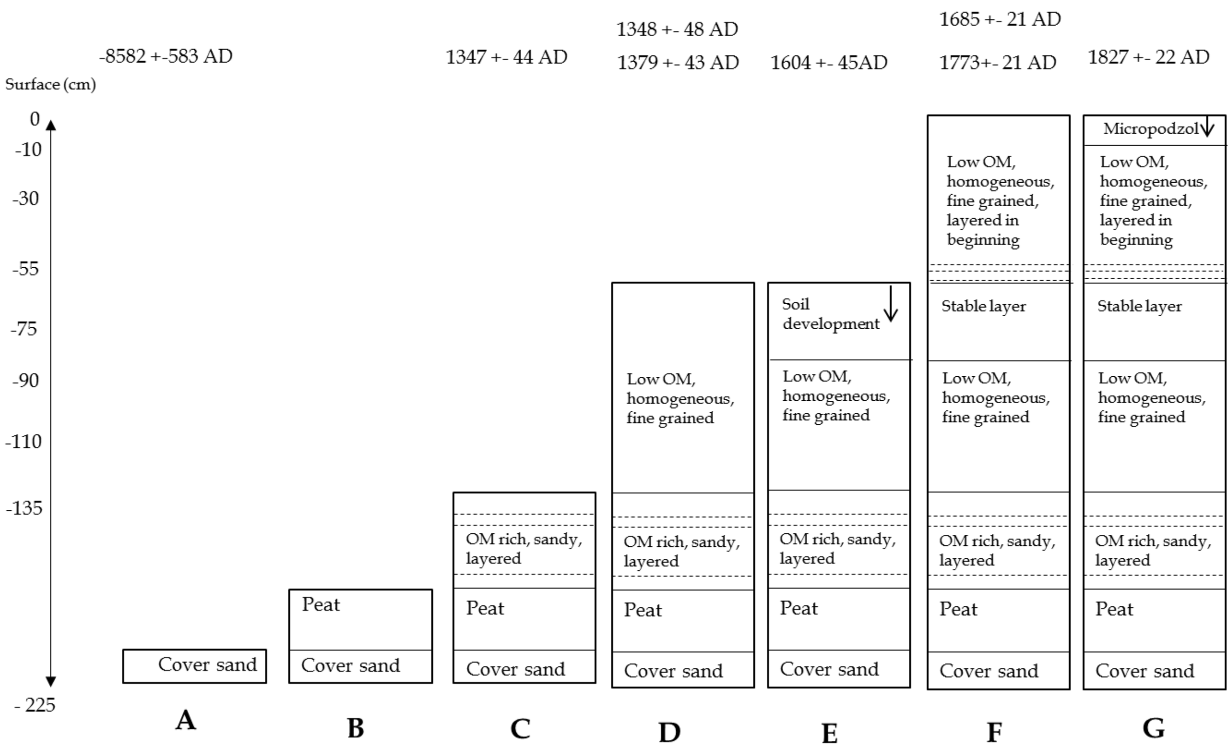


Figure 22: Development of the soil in Pit 1 through the time.

The podzol soil at the surface of Pit 1 dated back to 1827±22 AD. The previous drift sand layer of 25 cm was formed in 88 years and only 10 cm of soil is formed in the last 185 years. Both pits are nowadays protected for re-erosion by vegetation.

Events related to the burial ages of Pit 1 (Fig.22) based on literature:

A: The climate changed from a polar dessert to a warmer and wetter climate.

B: During the Atlanticum the groundwater level was rising, due to a warmer and wetter climate (Van Koningsveld et al., 2008). It was a vegetation rich period wherein organic matter accumulated in wet valleys and Orthic podzol or Gleyic Carbic podzol soils developed in drier areas.

C: During the Iron Age agricultural practices started on the slopes of the ice pushed ridge, the outwash plains and the coversands (Kooistra and Maas, 2008). The Wekeromse Zand is surrounded by Celtic fields. The Roman Empire was an unstable period for the population of the Netherlands and caused land abandonment. There was a humid and warm climate which changed into a cold and wet climate during the Early Middle Ages (Buisman, 2011). The Medieval Climatic Optimum and the population growth caused agricultural intensification. Forests were cleared and sods were used for improving the fertility of the land. The upper part of this layer dated back to the end of the Medieval Climatic Optimum.

D: Under a changing climate the homogeneous drift sand layer with a low OM content accumulated. The warm Medieval Climatic Optimum turned into the Little Ice Age.

E. The Little Ice Age had known milder and colder years. In historical sources was found that the agricultural practices continued (Buisman, 2011). A stable phase wherein still agricultural practices were taking place suggests a climatic factor was missing to support the drift sand activity.

F: Another drift sand layer with a low OM content was accumulated under the fluctuating climate of the Little Ice Age (Mann, 2002). Storm events were recorded during this period (Buisman, 2011).

G: The warmer and wetter climate, the change in atmospheric composition and the decrease in storm activity stimulates the stabilization of the drift sand area (Buisman, 2011).

Discussion from the OSL dating

The OSL samples were taken on two spots in the area which were close to the borders of the area. The representativeness of these spots was insufficient for the complete study area. Pit 2 had known poor bleaching and is located close to the ice pushed ridge. More OSL sampling in accumulation areas will give more certainty in the dating sequence of the Wekeromse Zand. Comparing the OSL technique with other techniques, e.g. ^{14}C method, would give insight in data range differences. OSL dating on the plaggen soils would be interesting to get more insight in the factors causing sand drift. What happened between -8582 AD and 1347

AD in the Wekeromse Zand cannot be answered by this research. Remember that there was 90cm of undated soil layering between NCL-2212205 and NCL-2212204. The organic sandy layers between 130-180 cm depth probably developed during storm events, because the source material and the grain-size of the layers were different. The time gap (-8582AD and 1347AD) and the undated soil layering of 90cm in Pit 1 need more research to get more insight in the exact starting date of drift sand accumulation in this part of the area.

The buried soil in Pit 1 dated from 1604 AD. There can be discussed if the 13 buried soils, which were found during the auger survey, dated from the Little Ice Age.

In the Veluwe area agriculture was going on since the Iron Age, but sand drift had not always been taken place. During the transition periods between two climatic extremes, drift sand accumulation took place. But within the Little Ice Age a stable and an unstable period was measured. It is possible that an increase in storm events caused drift sand activation during the Little Ice age and prolonged agriculture caused drift sand activation during the transition period from the Medieval Climatic Optimum toward the Little Ice Age.

Conclusion

The difference in study area, the different research methods and the remaining gaps in drift sand research caused inconsistency among researchers about the drift sand occurrence in the Netherlands and the dynamical factors.

From the historical maps and the aerial photographs can be concluded that the external boundaries of the Wekeromse Zand did not expand or move since 1817AD. Vegetation succession of the active drift sand area took place during the last two centuries. Landuse change around the Wekeromse Zand did not change the inactivation phase. The leeward side was preferred for settlement and plaggen agriculture.

The soil variability within the Wekeromse Zand is higher than suggested by the Dutch soil map (1:50000). This became clear by the results from the field survey. The coarsest grains were deposited close to their source; the ice pushed ridge. From the interpolation of the palaeosurface shorth distance and long distance relief is visible.

Dating in Pit 1 showed that drift sand accumulation was going on since 1387AD. This burial age is not confirmed by Koster (2009). Based on the OSL results, two stable layers were distinguished in Pit 1: i) during the Little Ice Age, ii) current situation. At the location of Pit 1 drift sand activation in the 12th century had a higher accumulation rate than the drift sand activation between the 18th and 19th century. Around 1600 AD the accumulation rate was lowest, so the stability highest.

Agriculture took place since the Iron Age, but the Wekeromse Zand had known stable and instable phases. There can be concluded that not only agricultural factors had influenced the development of the Wekeromse Zand. On the other hand, climatic factors were not stable during the Holocene, but the first drift sand accumulation in Pit 1 dated from 1387AD. There can also be concluded that not only climatic factors had influenced the development of the Wekeromse Zand.

Looking back to the flow-chart of factors which could have influenced the development of drift sand area the Wekeromse Zand (Fig. 9) natural as well as anthropogenic factors had to go along with each other during drift sand area development. Crucial is the rate wherein the different factors were pushing the stable environment out of equilibrium. Prolonged agriculture in a quite fast climate change could have caused the drift sand activation phase 1348AD-1379AD. Drift sand activation phase 1685AD-1773AD could have been caused by continuous land abandonment and an increase in storminess during the Little Ice Age.

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Appendix A: Translation from the Dutch soil classification system toward the Universal soil classification system

Code soil map 1:50000	Dutch classification	Universal classification
bEZ	Bruine enkeerdgrond	Terric Anthrosol
cZd	Akkereerdgrond	Spodic Anthrosols
Hd21	Haarpodzol	Orthic podzol
Hn21	Veldpodzolgrond	Gleyic carbic podzol
PZg23	Beekeerdgrond	Terric Anthrosol
pZn21	Gooreerdgronden	Hydromorphic, sandy Anthrosol
tZd	Kanteerdgrond	Spodic Anthrosol
Y	Moderpodzol	Umbrisol
Y21	Holtpodzol, fijn zand	Leptic Podzol, fine grained
Y30	Holtpodzol, grof zand	Leptic Podzol, coarse grained
Zd21	Duinvaaggrond	Albic Arenosol
zEZ21	Hoge, zwarte enkeerdgrond	Plaggic Anthrosol
Zn21	Vlakvaaggrond	Hydromorphic, sandy Arenosol

Appendix B: Field form

Fieldwork soil augering

Profile number:	Location:		Course surface fragments		
Date of description:	Coordinates:		Erosion		
			Area affected by erosion		
	Elevation according to GPS		Activity of erosion		
	Elevation according to DEM				
	Position				
	Land use				

Soil description

Depth	Layer	Horizon bound	Textural class	M50	Soil colour	Organic matter co	Soil struc	ogical feature (which and si		Roots (%)	Mottles (% and size)		Human influence	Remarks

Soil classification
Interpretation
Dikte stuifzand

Appendix C: Kriging the palaeosurface and buried soils by the program R

Script for kriging of the palaeosurface:

```
setwd("E:/R")
Paleosurface <- read.csv("E:/R/paleosurface.csv", header = TRUE,  sep=",")
names(Paleosurface)
library (gstat)

#convert meters to km
Paleosurface$Xconv <-Paleosurface$X/1000
Paleosurface$Yconv <- Paleosurface$Y/1000

#define coordinates and make a SpatialPointsDataFrame
coordinates(Paleosurface)=~Xconv+Yconv
plot(Paleosurface)


vario_ok = variogram(DEM_depth~1, data = Paleosurface,
boundaries=c(0.05,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1,1.1,1.2,1.3,1.4,1.5))
plot(vario_ok)
vario_ok_fit = fit.variogram(vario_ok, vgm(psill=4,model="Sph",range=1.5, nugget=0))
vario_ok_fit
plot(vario_ok, vario_ok_fit, plot.numbers = FALSE,  cex.axis = 0.1,  cex.lab = 0.1, width = 800, height =
600, res = 2400,  col ="black", xlab ="distance (km)", ylab ="semivariance")

# automated fitting usinf settings derived from visual
Paleosurface_ok_autofit = fit.variogram(vario_ok, vario_ok_fit)
Paleosurface_ok_autofit

# automated fitting usinf settings derived from visual
Paleosurface_ok_autofit = fit.variogram(vario_ok, vario_ok_fit)
Paleosurface_ok_autofit

#read output grid
newgrid = read.asciigrid("newgrid.txt")

# Run ordinary kriging (OK) in gstat:
Paleosurface_ok <- krige(DEM_depth~1, locations=Paleosurface, newdata=newgrid,
model=Paleosurface_ok_autofit, debug.level = -1)
summary(Paleosurface_ok$var1.pred)
str(Paleosurface_ok)
hist(Paleosurface_ok$var1.pred)

# write output to asci grid
library(maptools)
```

Script for kriging of the buried soils:

```
setwd("E:/R")
Buried_soil <- read.csv("E:/R/bur_soil.csv", header = TRUE,  sep=",")
names(Buried_soil)
library (gstat)

#convert meters to km
Buried_soil$Xconv <-Buried_soil$X/1000
Buried_soil$Yconv <-Buried_soil$Y/1000

#define coordinates and make a SpatialPointsDataFrame
coordinates(Buried_soil)=~Xconv+Yconv
plot(Buried_soil)

vario_ok = variogram(DEM_depth~1, data = Buried_soil,
boundaries=c(0.05,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1,1.1,1.2,1.3,1.4,1.5))
plot(vario_ok)
vario_ok_fit = fit.variogram(vario_ok, vgm(psill=1,model="Sph",range=2.0, nugget=0))
vario_ok_fit
plot(vario_ok, vario_ok_fit, plot.numbers = FALSE,  cex.axis = 0.1,  cex.lab = 0.1, width = 800, height =
600, res = 2400,  col ="black", xlab ="distance (km)", ylab ="semivariance BXW Severity (Log
Transformed)")

# automated fitting usinf settings derived from visual
Buried_soil_ok_autofit = fit.variogram(vario_ok, vario_ok_fit)
Buried_soil_ok_autofit

# automated fitting usinf settings derived from visual
Buried_soil_ok_autofit = fit.variogram(vario_ok, vario_ok_fit)
Buried_soil_ok_autofit

#read output grid
newgrid = read.asciigrid("newgrid1.txt")

# Run ordinary kriging (OK) in gstat:
Buried_soil_ok <- krige(DEM_depth~1, locations=Buried_soil, newdata=newgrid,
model=Buried_soil_ok_autofit, debug.level = -1)
summary(Buried_soil_ok$var1.pred)
str(Buried_soil_ok)
hist(Buried_soil_ok$var1.pred)

# write output to asci grid
library(maptools)
```

Appendix D: Information about the OSL technique

A simplified introduction in the OSL technique will give insight in how the age in quartz grains can be determined. A characteristic of quartz is that it contains energy bands. The valence band and the conduction band contains electrons (Fig. 1a). The valance band contains a higher energy level than permitted and the conduction band requires energy from electrons. Between the bands there is a so called 'forbidden gap' (Cunningham, 2011). Electrons need to have enough energy to escape the valance band; by absorption ionizing radiation (Cunningham, 2011). Soil grains are always exposed to ionizing radiation in their natural surroundings. When radiation is adsorbed by the quartz mineral, excitation of the valence-band electron to the conduction band can take place. A, so called, 'hole' in the valence band will develop (Fig. 1b) (Hilgers, 2007). The unstable situation in the valance band can return in relaxation when the electron recombines with a 'hole'. Defects in the crystal lattice are causing localized energy states the forbidden gap; so called traps (Hilgers, 2007). The more radiation absorbed by the crystal, the more electrons are located in these traps. When energy is released as a photon a luminescence signal is emitted. In other words, when the soil grains are exposed to light of a particular wavelength an OSL signal can be measured (Fig. 1c) (Preusser et al., 2008; Wallinga et al., 2007). When grains are exposed to sunlight or heat the energy from absorbed ionizing radiation in the traps is reset; the electrons will be evicted from the traps (Preusser et al., 2008). The signal exist of a fast, a medium and a slow component. The component which is valuable for dating measurements is the fast component.

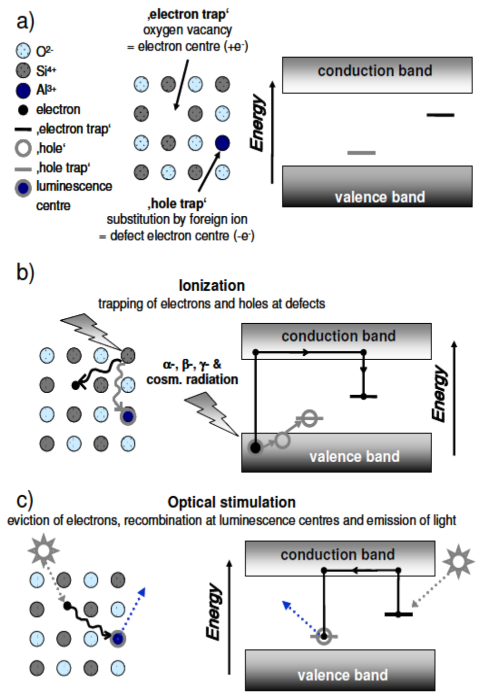


Figure 1: Simplified energy level diagram (Hilgers, 2007). a: Defects in the crystal structure of quartz which is causing an energy level. b: Quartz grain is exposed to ionizing radiation from natural sources after burial. c: The quarts grain is exposed to light and releases its trapped electrons (Hilgers, 2007).

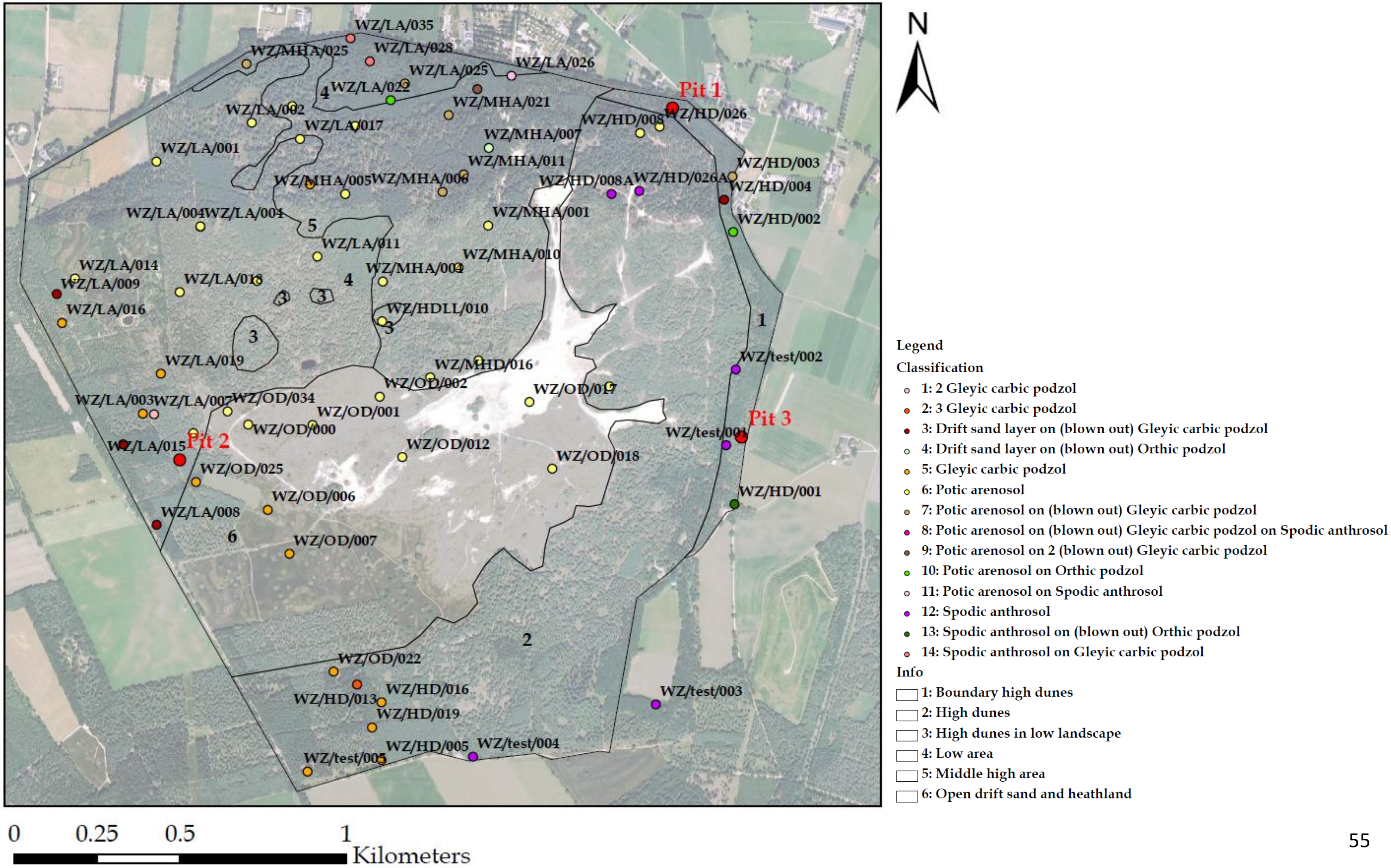
Some parameters from the soil samples need to be determined before the dating can start. In the thermal transfer test (TT-test) the latent luminescence is erased and the apparent equivalent dose is measured (Preusser et al, 2008). The test aims to exclude the presence of thermal transfer (Preusser et al, 2008). Where the apparent equivalent dose becomes significant thermal treatment induced transfer of charge to the fast OSL trap. In the dose recovery test (DR-test) the natural signal is first reset, and the aliquot is then irradiated with a known dose. This surrogate natural dose is then treated as an unknown (Duller, 2008). The ratio between the sensitivity corrected surrogate natural signal and the same given dose should be one when the procedure works correctly (Preusser et al., 2008). For the dose response test (DR-test) OSL responses to high doses were measured for 48 aliquots from the samples NCL-2212200 and NCL-2212205 to characterize the dose response curve. This test serves to investigate whether it is justified to use a linear interpolation between zero dose and the response to a small dose to determine the equivalent dose for our samples.

Appendix E: Oxcal scripts

```
Plot(2212)
 {
  Sequence("2212",8)
  {
   Boundary("bottom")
   {
    z=1.5;
   };
   Phase()
   {
    Prior("NCL2212204")
    {
     z=1.35;
    };
    Prior("NCL2212203")
    {
     z=1.10;
    };
   };
   Date("NCL-2212202",N(2012-698,54))
   {
    z=0.9;
   };
   Boundary("change")
   {
    z=0.8;
   };
   Prior("NCL2212201")
   {
    z=0.75;
   };
   Date("NCL-2212200",N(2012-328,21))
   {
    z=0.55;
   };
   Date("NCL-2212199",N(2012-238,22))
   {
    z=0.3;
   };
   Date("NCL-2212198",N(2012-178,22))
   {
    z=0.1;
   };
   Boundary("top")
   {
    z=0.0;
   };
  };
```

```
Plot(2312)
 {
  P_Sequence("2312",8)
  {
   Boundary("bottom")
   {
    z=0.6;
   };
   Phase()
   {
    Prior("NCL2312208")
    {
     z=0.53;
    };
    Prior("NCL2312207")
    {
     z=0.38;
    };
    Prior("NCL2312206")
    {
     z=0.24;
    };
   };
    Boundary("top")
    {
     z=0.0;
    };
   };
  };
```

Attachment F: Soil survey data



Pit 1

Fieldwork soil augering	**Profile number:**	Pit 1	**Location:**	North HD	**Course surface fragments**	None (0%)	0
	Date of description:	4-7-2012	**Coordinates:**	176002	**Erosion**	AD (wind deposition	
				458029	**Area affected by erosion**	5 (>50%)	
			Elevation according to GPS	13	**Activity of erosion**	R (active in recent past (50-100 years ago))	
			Elevation according to DEM	19.8			
			Position	valley of dune			
			Land use	deciduous			

Soil description

Depth	**Layer**	**Horizon boundary**	**Textural class**	**M50**	**Soil colour**	**Organic matter content**	**Soil structure**	**Biological feature (which and size,#)**	
20	Podzol	Clear (2-5 cm)	Sand	0	0	0	Single grain	0	0
115	C1g	Gradual (5-15 cm)	Sand	210	2.5 Y 5/4	2	Single grain	0	0
125	Bh	Clear (2-5 cm)	Sand	210	10 YR 3/1	5	Single grain	Burrow of a beetle	1
160	C2g	Gradual (5-15 cm)	Sand	210	2.5 Y 5/4	2	Single grain	0	0
170	C3	Clear (2-5 cm)	Sand	210-300	10 YR 2/1	8	Single grain	0	0
200	H	Clear (2-5 cm)	Moerig	0	10 YR 2/1	20	Clod	0	0
215	Cr	0	Coarse sand	300	2.5 Y 5/4	0.25	Single grain	0	0
230	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Soil classification

Potic arenosol on (blown out) Gleyic carbic podzol on Spodic anthrosol

Interpretation

On top of coversand accumulated an organic layer, caused by the wet, valley position of the pit.
Drift sand accumulated in the valley area, but because of the wet position, the layer became organic rich.
The poor drift sand layer indicates a drop in groundwater level. In between the two organic poor drift sand layers, soil development took place. The layers with more organic matter caused stagnation properties, which caused the iron reduction in the profile. On top a micropodzol developed.

Dikte stuifzand

210 cm

Soil description

Roots (%)	**Mottles (% and size)**		**Human influence**	**Remarks**
5	None (0%)	0	N (no influence)	Minipodzol till 20 cm
8	Few (2-5)	Fine (2-6)	N (no influence)	Microlayering in first 20 cm of the layer. Closer to the surface: homogeneous sand, mottles 5%.
1	None (0%)	0	N (no influence)	Soil development.
2	Common (5-15%)	Fine (2-6)	N (no influence)	Homogeneous drift sand layer, mottles 5-10%.
2	None (0%)	0	N (no influence)	
0	None (0%)	0	N (no influence)	Palaeosurface. Organic soil layer with plant residues.
0	None (0%)	0	N (no influence)	Parmanent reduced cover sand. Coarse sand grains (0.5 cm 8%; 2000 2%; 300 80%; <300 10%).
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Pit 2

Fieldwork soil auge	**Profile number:**	Pit 2	**Location:**	Low area	**Course surface fragments**	None (0%)	0
	Date of descripti	5-7-2012	**Coordinates:**	174524	**Erosion**	AM (wind erosion and deposition)	
				456970	**Area affected by erosion**	5 (>50%)	
			Elevation according to GPS	22	**Activity of erosion**	R (active in recent past (50-100 years ago))	
			Elevation according to DEM	23			
			Position	valley of dune			
			Land use	deciduous			

Soil description

Depth	Layer	Horizon bounda	Textural class	M50	Soil colour	Organic matter content	Soil structure	Biological feature (which and size,#)		Roots (%)	Mottles (% and size)		Human influence	Remarks
15	Podzol	Clear (2-5 cm)	Sand	210	0	2	Single grain	0	0	5	None (0%)	0	N (no influence)	Minipodzol till 15 cm
65	C1g	Clear (2-5 cm)	Sand	210	10 YR 3/1-10YR 5/2	1-3	Single grain	0	0	8	Few (2-5)	Fine (2-6)	N (no influence)	Drift sand layering.
80	E	Gradual (5-15 cm)	Sand	210	10 YR 3/1	5	Single grain	0	0	1	None (0%)	0	N (no influence)	Palaeosurface. Illuviation layer, eluviation layer is eroded.
220	C2	0	Sand	210	7.5 YR 6/6	1	Single grain	0	0	2	Very few (0-2)	Fine (2-6)	N (no influence)	Homogeneous coversand.
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Soil classification

Drift sand layer on blown out Orthic podzol soil.

Interpretation

In the coversand a thick podzol soil developed. The eluviatio layer is eroded but the illuviation layer of 40 cm still remains. The drift sand layer on top of the podzol soil contains a layering of i) blown in drift sand with different OM contents or ii) microsoil development. On top a micropodzol developed.

Dikte stuifzand

65 cm

Pit 3

Fieldwork soil augerin	**Profile number:**	Pit 3	**Location:**	Boundary high dunes	**Course surface fragments**	None (0%)	0
	Date of description:	13-7-2012	**Coordinates:**	176210	**Erosion**	N (no evidence of erosion)	
				457041	**Area affected by erosion**	0%	
			Elevation according to GPS	19	**Activity of erosion**		
			Elevation according to DEM	24.5			
			Position	valley of dune			
			Land use	deciduous			

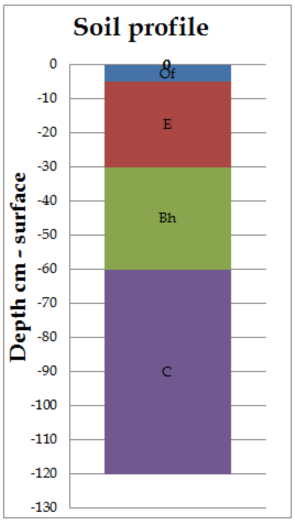
Soil description

Depth	Layer	Horizon boundary	Textural class	M50	Soil colour	Organic matter content	Soil structure	Biological feature (which and size,#)		Roots (%)	Mottles (% and size)		Human influence	Remarks
160	Bp	Clear (2-5 cm)	Sand	150	10 YR 4/2	4	Single grain	0	0	5	None (0%)	0	MP (plaggen)	Thick plaggen layer. Archaeological artefacts.
220	C	Clear (2-5 cm)	Sand	150	7.5 YR 6/6	0.5	Single grain	0	0	0	0	0	N (no influence)	Palaeosurface. Coversand.
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Soil classification
Spodic Anthrosol
Interpretation
The soil is anthropogenic. Archaeological artefacts were found within 30 cm depth. Plaggen agriculture, probably together with drift sand accumulation caused a thick, organic rich layer.
Dikte stuifzand
160 cm

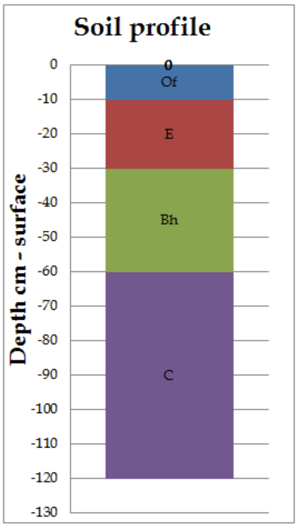
Low area

Profile number: WZ/LA/015
Coordinates: 174519
456970
Classification: 6: Gleyic carbic podzol



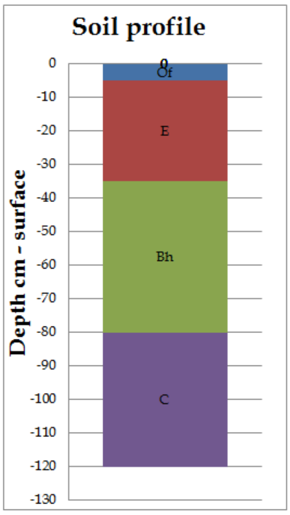
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
E	Sand	150	2.5/1st page	2
Bh	Sand	150	10 YR 3/4	3
C	Sand	150	10 YR 5/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/016
Coordinates: 174165
457382
Classification: 6: Gleyic carbic podzol



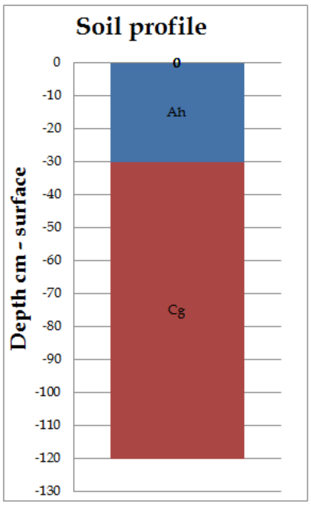
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
E	Sand	210	2.5/1st page	3
Bh	Sand	210	10 YR 6/6	3
C	Sand	300	10 YR 3/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/019
Coordinates: 174462
457229
Classification: 6: Gleyic carbic podzol



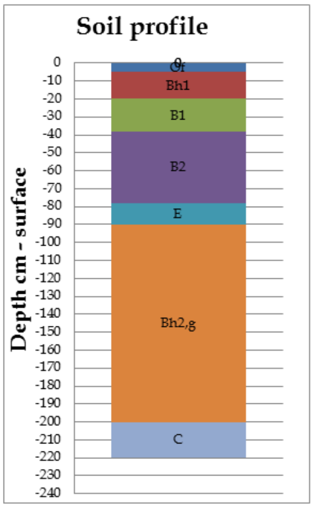
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
E	Sand	105	2.5/1st page	2.5
Bh	Sand	105	10 YR 3/3	3
C	Sand	210	10 YR 6/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/013
Coordinates: 174560
457050
Classification: 7: Potic arenosol



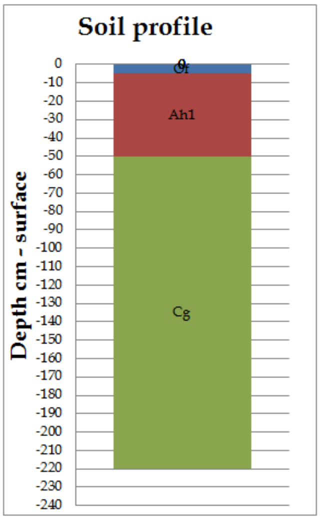
Layer	Textural class	M50	Soil colour	Organic matter content
Ah	Sand	210	10 YR 3/1	1.5
Cg	Sand	300	10 YR 6/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/008
Coordinates: 174449.85
456773.86
Classification: 3: Drift sand layer on (blown out) Gleyic carbic podzol



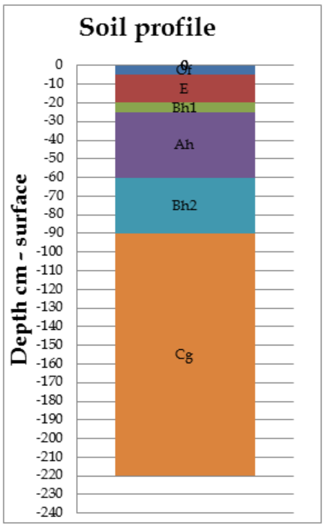
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Bh1	Sand	150	10 YR 3/3	2
B1	Sand	150	10 YR 5/6	0.5
B2	Sand	150	10 YR 3/6	3
E	Sand	150	2.5/1st page	3.5
Bh2,g	Sand	150	10 YR 3/6	5
C	Sand	150	10 YR 6/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/014
Coordinates: 174204
457516
Classification: 7: Potic arenosol



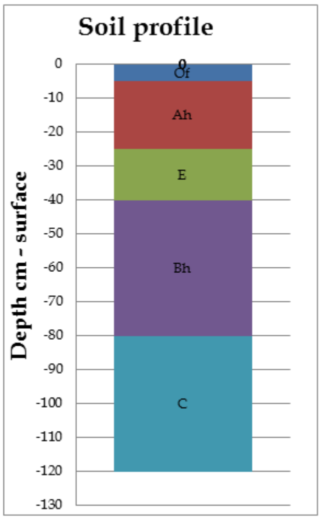
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah1	Sand	270	10 YR 3/4	4
Cg	Sand	210	2.5 Y 7/3	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/009
Coordinates: 174149
457469
Classification: 5: Drift sand layer on Gleyic carbic podzol



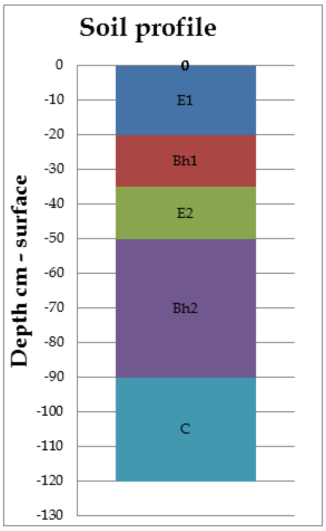
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
E	Sand	150	10 YR 3/1	1
Bh1	Sand	150	10 YR 2/2	4
Ah	Sand	150	5/1st page, 10 YR 2/2	4
Bh2	Sand	150	10 YR 3/4	2
Cg	Sand	150	10 YR 6/6	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/003
Coordinates: 174408
457109
Classification: 6: Gleyic carbic podzol



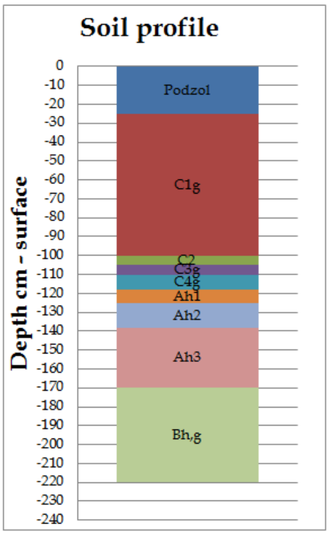
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah	Sand	105	2.5 Y 3/2	2
E	Sand	105	2.5/1st page	3
Bh	Sand	150	10 YR 2/2	4
C	Sand	210	10 YR 6/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/007
Coordinates: 174442
457107
Classification: 1: 2 Gleyic carbic podzol



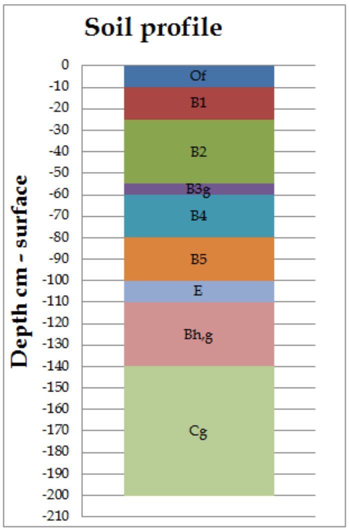
Layer	Textural class	M50	Soil colour	Organic matter content
E1	Sand	150	2.5/1st page	0
Bh1	Sand	150	10 YR 4/4	4
E2	Sand	150	3/1st page	1
Bh2	Sand	150	10 YR 2/2	3
C	Sand	210	10 YR 6/6	3.5
0	0	0	0	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/026
Coordinates: 175517
458126
Classification: 12: Potic arenosol on Spodic anthrosol



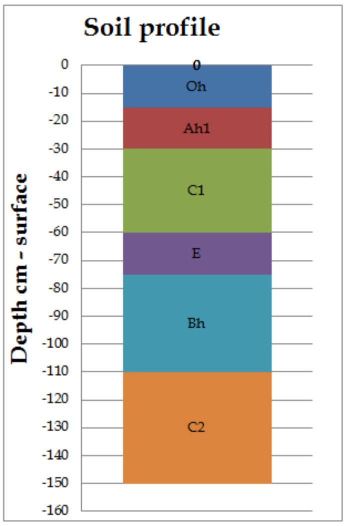
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	150	0	1.5
C1g	Sand	150	2.5 Y 5/3	0.5
C2	Sand	150	2.5 Y 3/1	1.5
C3g	Sand	210	2.5 Y 6/3	0.25
C4g	Sand	150	10 YR 6/6	0.5
Ah1	Moerig	0	0	10
Ah2	Zand	210	2.5 Y 3/1	2
Ah3	Moerig	0	0	15
Bh,g	Sand	300	2.5 Y 6/3	1
0	0	0	0	0

Profile number: WZ/LA/025
Coordinates: 175197
458103
Classification: 8: Potic arenosol on (blown out) Gleyic carbic podzol



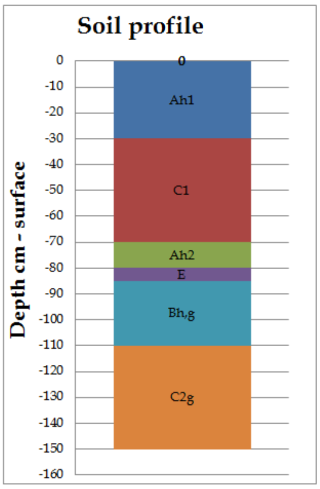
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Moerig	0	0	3
B1	Sandy clay	150	10 YR 2/2	2
B2	Sand	150	10 YR 5/3	3
B3g	Sand	150	10 YR 3/2	1.5
B4	Sand	300	10 YR 6/6	0.5
B5	Sand	150	2.5 Y 6/3	10
E	Sandy clay	150	2.5 Y 2.5/1	5
Bh,g	Sand	150	10 YR 5/8	0.5
Cg	Sand	150	2.5 Y 7/4	0
0	0	0	0	0

Profile number: WZ/LA/035
Coordinates: 175033
458239
Classification: 15: Spodic anthrosol on Gleyic carbic podzol



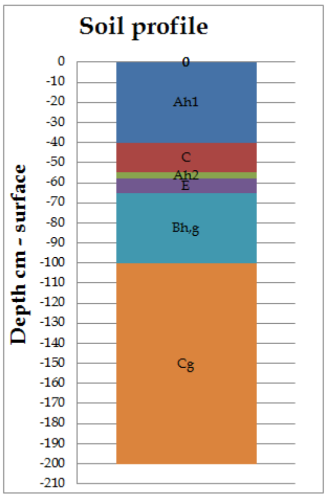
Layer	Textural class	M50	Soil colour	Organic matter content
Oh	Moerig	0	0	15
Ah1	Sand	150	10 YR 3/2	3
C1	Sand	150	10 YR 5/6	0.5
E	Moerig + Sand	210	2.5/1st page	15
Bh	Sand	210	7.5 YR 3/4	12
C2	Sand	300	10 YR 5/8	1
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/022
Coordinates: 175154
458053
Classification: 11: Potic arenosol on Orthic podzol



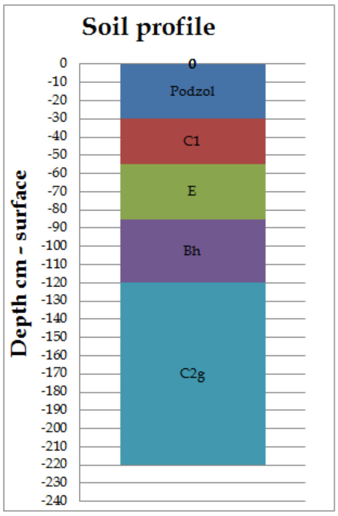
Layer	Textural class	M50	Soil colour	Organic matter content
Ah1	Sandy clay	150	10 YR 3/2	3
C1	Sand	150	10 YR 6/4	1
Ah2	Sandy clay	150	10 YR 2/1	15
E	Sand	150	2.5 Y 3/1	10
Bh,g	Sandy clay	300	10 YR 3/6	8
C2g	Sand	300	2.5 Y 6/4	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/028
Coordinates: 175091
458170
Classification: 15: Spodic anthrosol on Gleyic carbic podzol



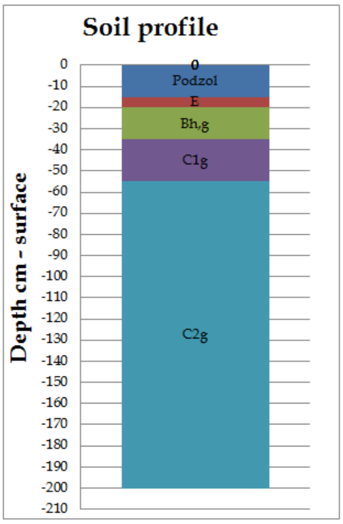
Layer	Textural class	M50	Soil colour	Organic matter content
Ah1	Sand	210	10 YR 3/2	3
C	Sand	210	2.5 Y 5/3	0.5
Ah2	Sandy clay	150	2.5 Y 2.5/1	15
E	Sand	210	2.5 Y 3/1	4
Bh,g	Sandy clay	0	10 YR 3/6	5
Cg	Sand	210	10 YR 5/8	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/004
Coordinates: 174581
457672
Classification: 4: Drift sand layer on (blown out) Orthic podzol



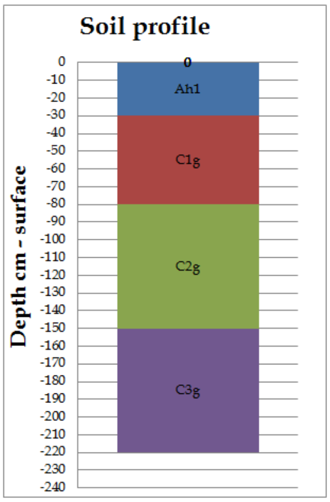
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	105	0	2
C1	Sand	105	10 YR 5/6	0.25
E	Sand	105	2.5 Y 4/1	1
Bh	Sand	105	10 YR 2/2	3
C2g	Sand	150	2.5 Y 7/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/018
Coordinates: 174519
457475
Classification: 7: Potic arenosol



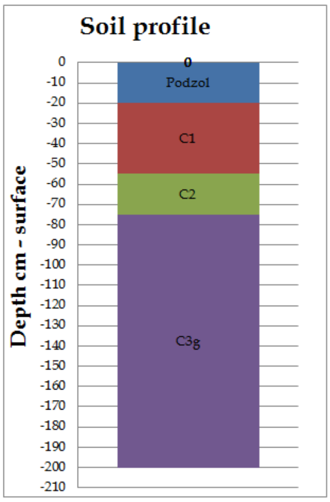
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	0	10 YR 4/4	1
E	Sand	105	5/1st page	0.1
Bh,g	Sand	105	10 YR 4/3	1.5
C1g	Sand	105	2.5 Y 5/4	0.25
C2g	Sand	105	2.5 Y 7/2	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/006
Coordinates: 174752
457509
Classification: 7: Potic arenosol



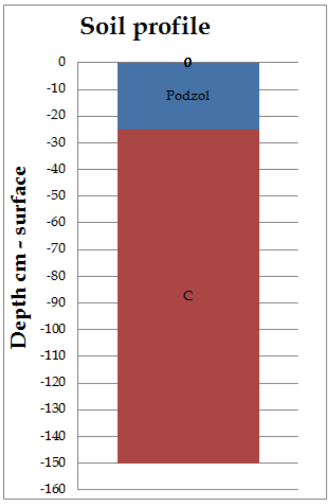
Layer	Textural class	M50	Soil colour	Organic matter content
Ah1	Sand	105	10 YR 4/4	1
C1g	Sand	105	2.5 Y 6/3	0.5
C2g	Sand	105	10 YR 6/8	0.25
C3g	Sand	105	10 YR 6/6	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/011
Coordinates: 174933
457582
Classification: 7: Potic arenosol



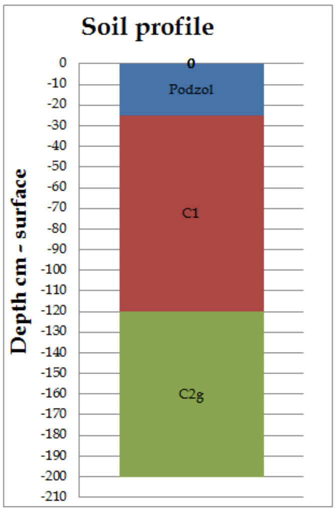
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	105	0	2
C1	Sand	105	0	1
C2	Sand	105	0	0.25
C3g	Sand	105	0	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/002
Coordinates: 174736
457985
Classification: 7: Potic arenosol



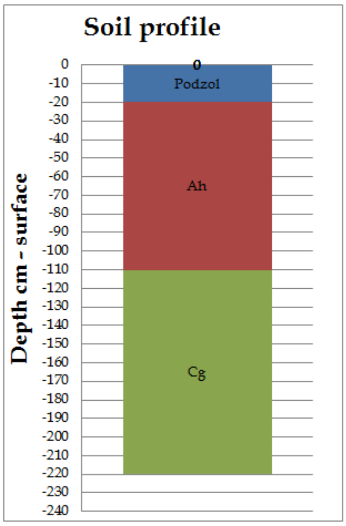
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	150	0	1
C	Sand	105	2.5 Y 7/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/001
Coordinates: 174449
457868
Classification: 7: Potic arenosol



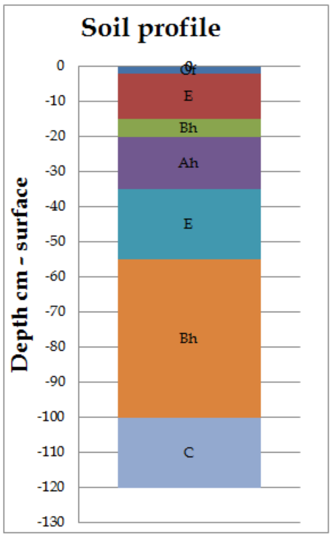
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	105	0	2
C1	Sand	105	2.5 Y 6/3	0.25
C2g	Sand	105	10 YR 6/6	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/LA/017
Coordinates: 174881
457936
Classification: 7: Potic arenosol



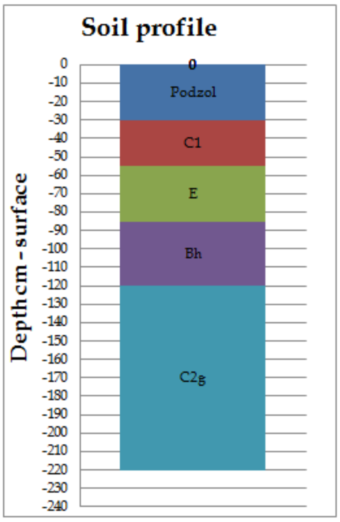
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	150	0	2
Ah	Sand	150	2.5 Y 5/3	1.5
Cg	Sand	105	2.5 Y 7/3	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/test/007
Coordinates: 174348.78
457016.29
Classification: 5: Drift sand layer on Gleyic carbic podzol



Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
E	Sand	105	2.5 Y 2.5/1	1.5
Bh	Sand	105	10 YR 3/3	2
Ah	Sand	105	10 YR 4/4	0.5
E	Sand	105	3/1st page	1.5
Bh	Sand	105	10 YR 2/2	5
C	Sand	105	2.5 Y 6/3	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

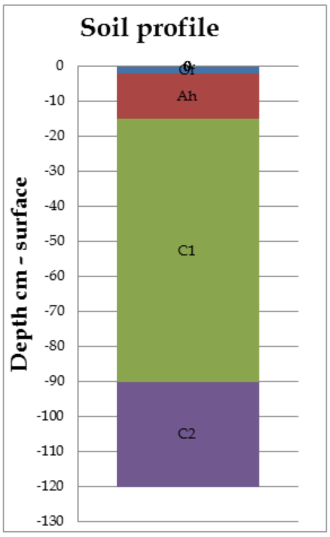
Profile number: WZ/LA/004
Coordinates: 174581
457672
Classification: 4: Drift sand layer on (blown out) Orthic podzol



Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	105	0	2
C1	Sand	105	10 YR 5/6	0.25
E	Sand	105	2.5 Y 4/1	1
Bh	Sand	105	10 YR 2/2	3
C2g	Sand	150	2.5 Y 7/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

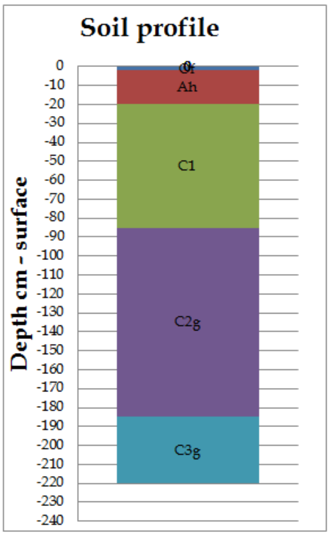
Open drift sand area and heathland

Profile number: WZ/OD/000
Coordinates: 174725
457076
Classification: 7: Potic arenosol



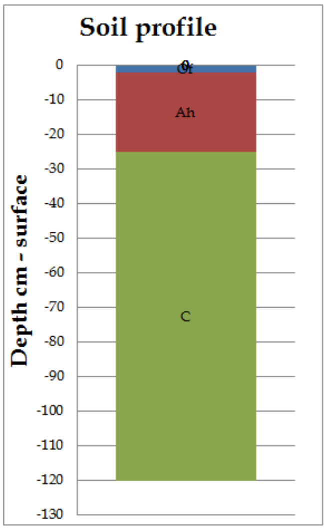
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah	Sand	210	2.5 Y 4/1	1
C1	Sand	210	2.5 Y 6/6	1
C2	Sand	150	2.5 Y 7/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/OD/002
Coordinates: 175121
457160
Classification: 7: Potic arenosol



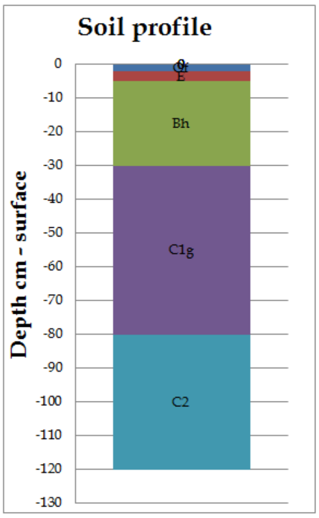
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah	Sand	210	10 YR 3/2	2
C1	Sand	210	10 YR 6/4	0.25
C2g	Sand	150	2.5 Y 5/3	1
C3g	Sand	150	10 YR 6/6	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/OD/034
Coordinates: 174663
457116
Classification: 7: Potic arenosol



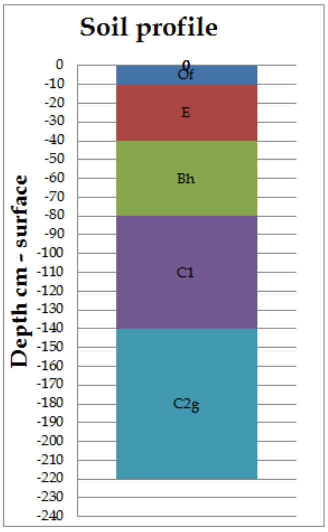
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah	Sand	210	2.5 Y 4/2	0.5
C	Sand	210	2.5 Y 6/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/OD/001
Coordinates: 174919
457075
Classification: 7: Potic arenosol



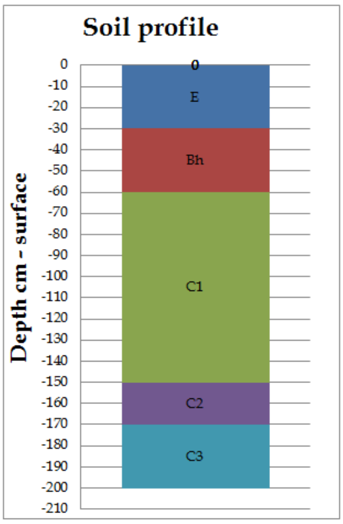
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
E	Sand	150	2.5 Y 4/1	0.5
Bh	Sand	150	10 YR 3/3	2.5
C1g	Sand	150	10 YR 7/6	0.25
C2	Sand	150	10 YR 7/6	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/OD/025
Coordinates: 174568
456903
Classification: 6: Gleyic carbic podzol



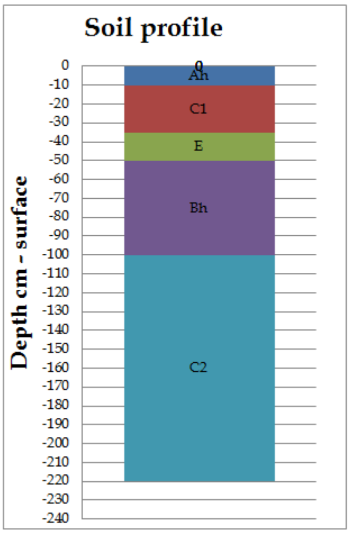
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
E	Sand	150	2.5 Y 3/1	2
Bh	Sand	150	10 YR 3/3	4
C1	Sand	150	2.5 Y 6/6	0.5
C2g	Sand	150	10 YR 6/8	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/OD/022
Coordinates: 174982
456332
Classification: 6: Gleyic carbic podzol



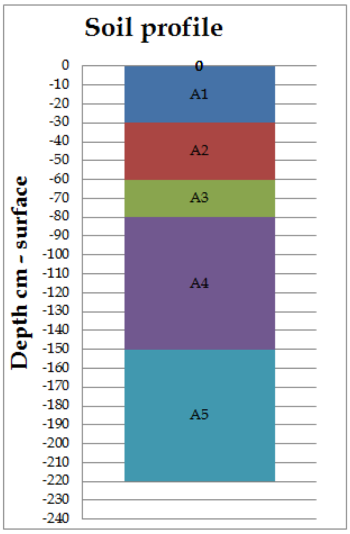
Layer	Textural class	M50	Soil colour	Organic matter content
E	Sand	210	2.5 Y 2.5/1	3
Bh	Sand	210	10 YR 3/6	2.5
C1	Sand	210	10 YR 5/6	1
C2	Sand	210	10 YR 5/6	0.25
C3	Sand	210	10 YR 5/6	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/OD/013
Coordinates: 175235
156795
Classification: 8: Potic arenosol on (blown out) Gleyic carbic podzol



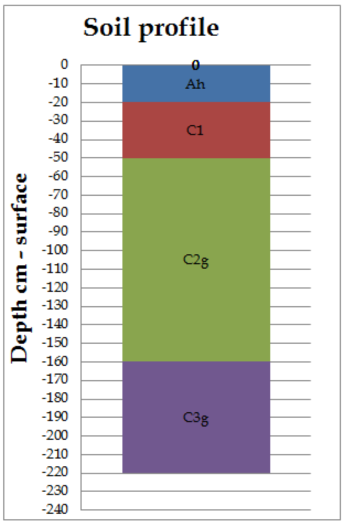
Layer	Textural class	M50	Soil colour	Organic matter content
Ah	Sand	210	10 YR 3/1	0.5
C1	Sand	210	10 YR 5/3	0.25
E	Sand	300	2.5 Y 3/1	2
Bh	Sand	300	10 YR 3/2	4
C2	Sand	300	10 YR 7/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/OD/017
Coordinates: 175571
457144
Classification: 7: Potic arenosol



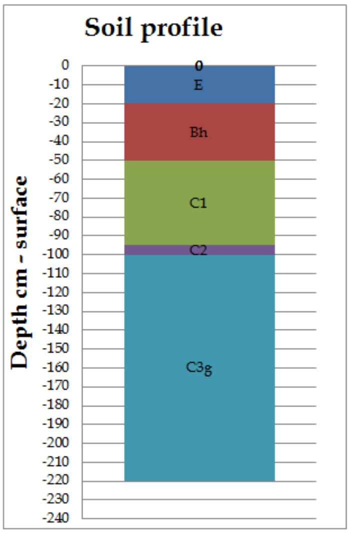
Layer	Textural class	M50	Soil colour	Organic matter content
A1	Sand	210	2.5 Y 5/3	0.5
A2	Sand	210	10 YR 7/6	0.25
A3	Sand	210	2.5 Y 5/3	0.5
A4	Sand	210	10 YR 7/6	0.25
A5	Sand	210	2.5 Y 5/3	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/OD/018
Coordinates: 175640
456943
Classification: 7: Potic arenosol



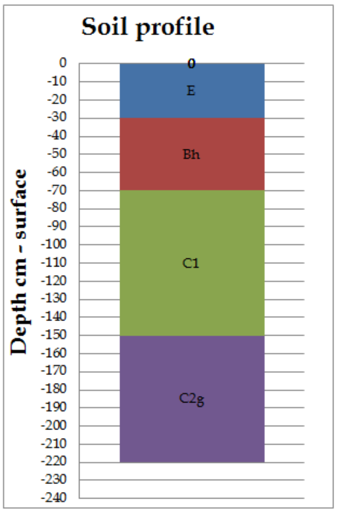
Layer	Textural class	M50	Soil colour	Organic matter content
Ah	Sand	210	10 YR 4/3	1
C1	Sand	210	10 YR 5/4	0.5
C2g	Sand	210	2.5 Y 8/3	0
C3g	Sand	210	2.5 Y 7/4	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/OD/007
Coordinates: 174849
456687
Classification: 6: Gleyic carbic podzol



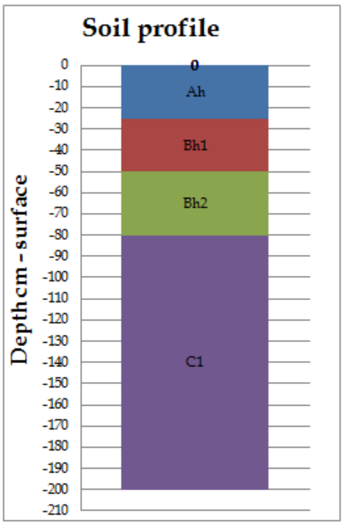
Layer	Textural class	M50	Soil colour	Organic matter content
E	Sand	150	3/1st page	1
Bh	Sand	150	10 YR 2/2	3
C1	Coarse sand	300	10 YR 7/6	0.25
C2	Sand	150	10 YR 7/6	0.25
C3g	Sand	150	2.5 Y 7/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/OD/006
Coordinates: 174784
456819
Classification: 6: Gleyic carbic podzol



Layer	Textural class	M50	Soil colour	Organic matter content
E	Sand	210	2.5/1st page	1
Bh	Sand	210	10 YR 3/3	3
C1	Sand	150	10 YR 6/8	0.5
C2g	Sand	150	2.5 Y 6/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

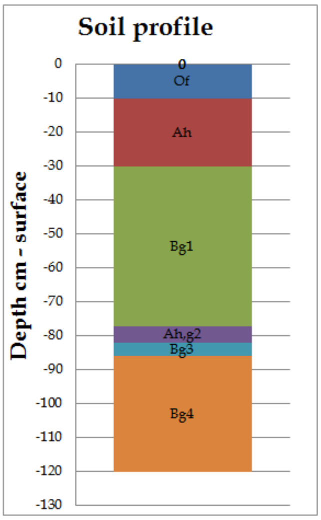
Profile number: WZ/HD/001
Coordinates: 176188
456836
Classification: 14: Spodic anthrosol on (blown out) Orthic podzol



Layer	Textural class	M50	Soil colour	Organic matter content
Ah	Sand	105	10 YR 3/2	3
Bh1	Sand	105	10 YR 4/3	1.5
Bh2	Sand	105	10 YR 2/2	3
C1	Sand	105	10 YR 6/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

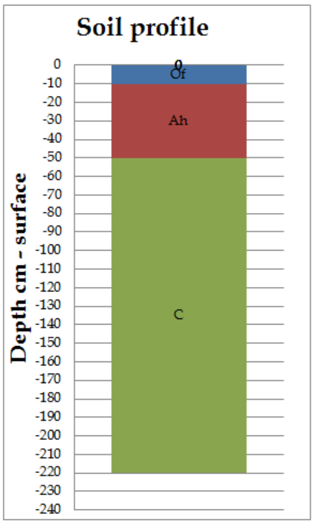
High dunes

Profile number: WZ/HD/008A
Coordinates: 175818.21
457770.29
Classification: 13: Spodic anthrosol



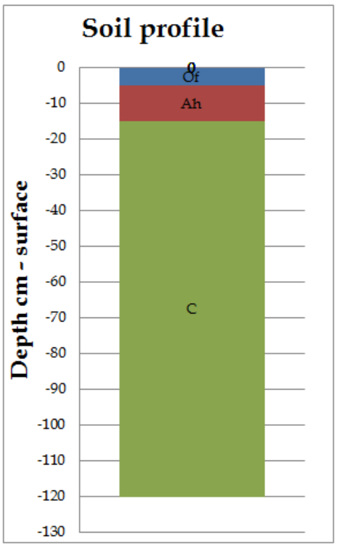
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah	Sand	210	10 YR 3/4	1.5
Bg1	Sand	210	10 YR 5/3	0.5
Ah,g2	Sandy loam	210	10 YR 3/1	3.5
Bg3	Sand	210	10 YR 6/4	0.5
Bg4	Sandy loam	210	10 YR 4/2	3
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HD/026
Coordinates: 175963
457973
Classification: 7: Potic arenosol



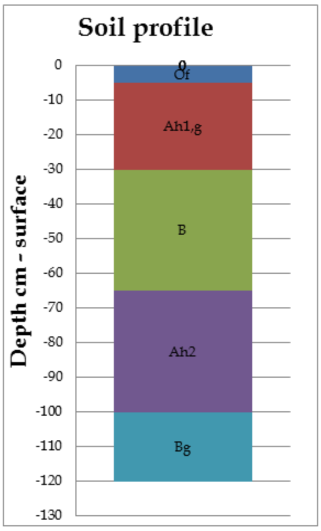
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah	Sand	420	10 YR 4/4	2
C	Sand	420	10 YR 6/6	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HD/008
Coordinates: 175904
457954
Classification: 7: Potic arenosol



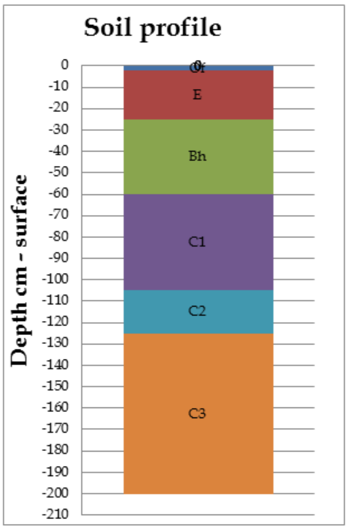
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah	Sand	300	10 YR 3/4	2
C	Sand	300	10 YR 6/6	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HD/026A
Coordinates: 175901.55
457779.56
Classification: 13: Spodic anthrosol



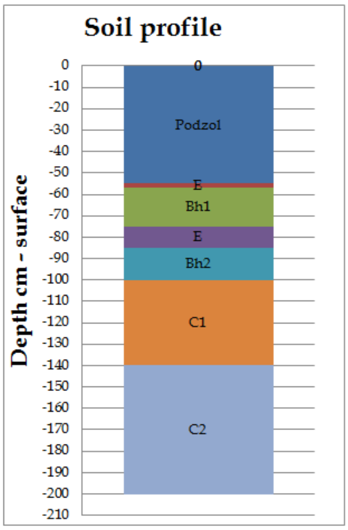
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah1,g	Sand	210	10 YR 4/4	1.5
B	Sand	210	2.5 Y 5/4	0.5
Ah2	Sandy loam	150	10 YR 2/1	3.5
Bg	Sand	210	10 YR 5/4	1
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HD/016
Coordinates: 175126
456240
Classification: 6: Gleyic carbic podzol



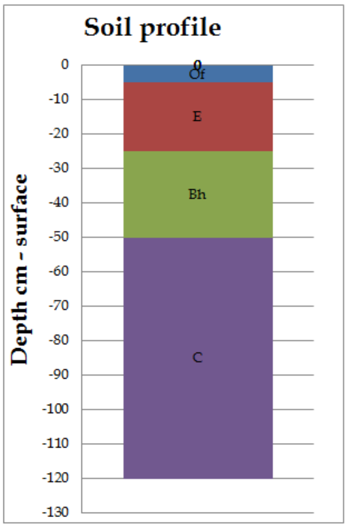
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
E	Sand	150	2.5/1st page	2
Bh	Sand	150	10 YR 2/2	4
C1	Sand	150	10 YR 6/6	0.5
C2	Sand	150	2.5 3/2	2
C3	Sand	150	10 YR 4/4	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HD/013
Coordinates: 175053
456293
Classification: 2: 3 Gleyic carbic podzol



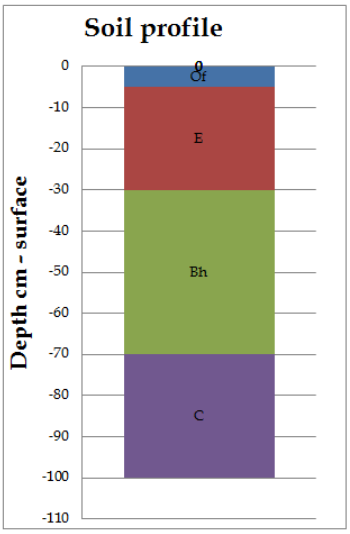
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	150	0	2
E	Sand	150	2.5 Y 5/1	1.5
Bh1	Sand	150	10 YR 3/2	0.25
E	Sand	150	2.5 Y 3/1	3.5
Bh2	Sand	150	10 YR 4/6	2
C1	Sand	150	10 YR 6/6	3
C2	Sand	150	10 YR 6/6	0.5
0	0	0	0	0.5
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HD/019
Coordinates: 175098
456164
Classification: 6: Gleyic carbic podzol



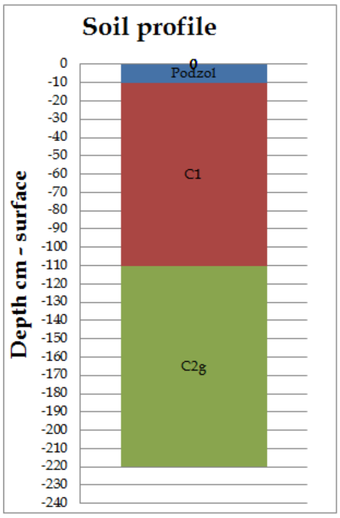
Layer	Textural class	M50	Soil colour	Organic matter content
Of	0	0	0	0
E	Sand	105	2.5 Y 3/1	1
Bh	Sand	150	10 YR 4/6	2
C	Sand	150	10 YR 6/8	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HD/005
Coordinates: 175126
456066
Classification: 6: Gleyic carbic podzol



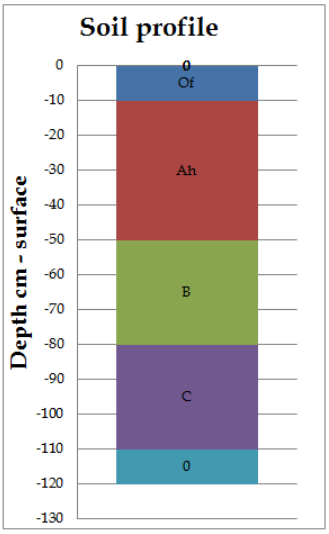
Layer	Textural class	M50	Soil colour	Organic matter content
Of	0	0	0	0
E	Sand	105	2.5/1st page	4
Bh	Sand	150	10 YR 3/6	3
C	Sand	600	10 YR 6/3	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HA/006
Coordinates: 175812
457191
Classification: 7: Potic arenosol



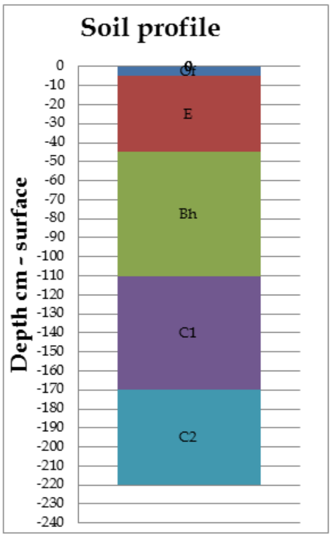
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	0	0	0
C1	Sand	300	2.5 Y 6/4	1
C2g	Sand	210	2.5 Y 8/3	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/test/004
Coordinates: 175401.32
456076.28
Classification: 13: Spodic anthrosol



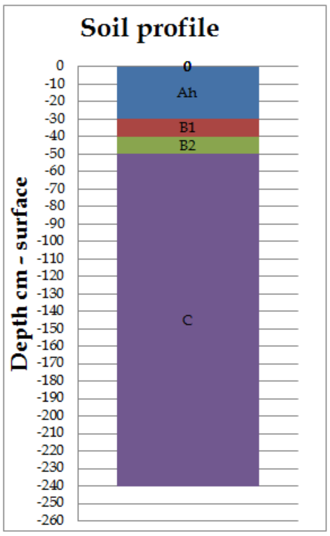
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah	Sandy loam	105	10 YR 4/6	2
B	Sandy loam	105	10 YR 5/6	1
C	Sand	300	10 YR 5/4	0.25
0	Sand	800	10 YR 6/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/test/005
Coordinates: 174903.62
456031
Classification: 6: Gleyic carbic podzol



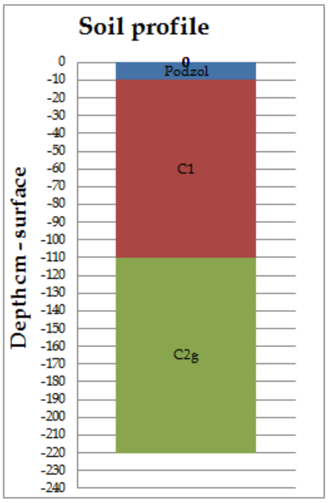
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
E	Sand	105	3/1st page	2
Bh	Sand	105	10 YR 3/3	2
C1	Sand	300	2.5 Y 6/4	0.25
C2	Sandy clay loam	300	10 YR 5/6	1.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/test/003
Coordinates: 175951.72
456233.25
Classification: 13: Spodic anthrosol



Layer	Textural class	M50	Soil colour	Organic matter content
Ah	Sand	105	10 YR 2/2	4
B1	Sand	105	10 YR 3/3	2.5
B2	Sand	150	10 YR 4/6	1
C	Sand	150	10 YR 5/6	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

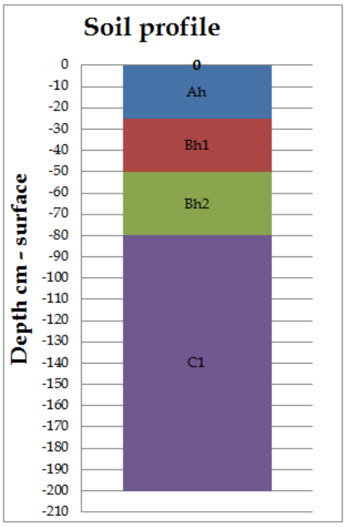
Profile number: WZ/HA/006
Coordinates: 175812
457191
Classification: 7: Potic arenosol



Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	0	0	0
C1	Sand	300	2.5 Y 6/4	1
C2g	Sand	210	2.5 Y 8/3	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

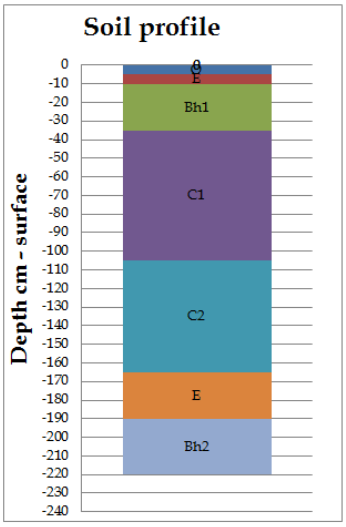
Boundary high dunes

Profile number: WZ/HD/001
Coordinates: 176188
456836
Classification: 14: Spodic anthrosol on (blown out) Orthic podzol



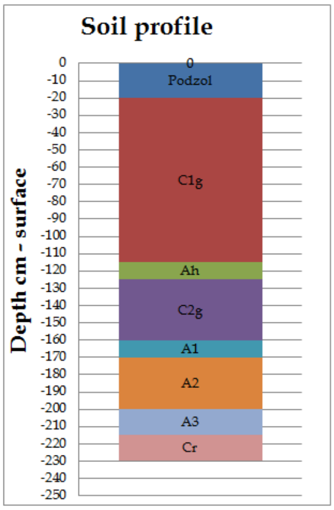
Layer	Textural class	M50	Soil colour	Organic matter content
Ah	Sand	105	10 YR 3/2	3
Bh1	Sand	105	10 YR 4/3	1.5
Bh2	Sand	105	10 YR 2/2	3
C1	Sand	105	10 YR 6/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HD/002
Coordinates: 176184
457656
Classification: 11: Potic arenosol on Orthic podzol



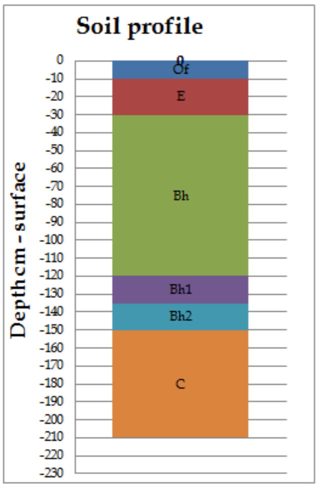
Layer	Textural class	M50	Soil colour	Organic matter content
O	0	0	0	0
E	Sand	210	10 YR 3/1	3
Bh1	Sand	210	10 YR 3/4	1.5
C1	Sand	210	10 YR 4/3	1
C2	Sand	210	10 YR 5/6	0.5
E	Sand	150	10 YR 3/1	2
Bh2	Sand	150	10 YR 2/2	3.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HA/Marthijn
Coordinates: 176002
458029
Classification: 9: Potic arenosol on (blown out) Gleyic carbic podzol on Spodic anthrosol



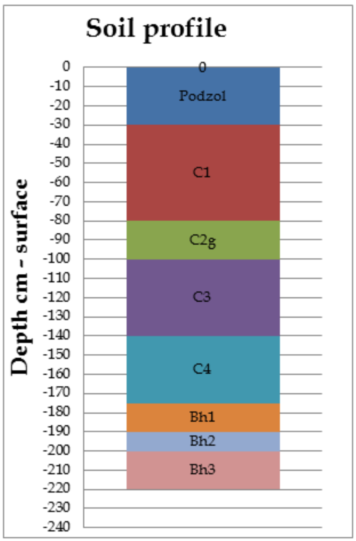
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	0	0	0
C1g	Sand	210	2.5 Y 5/4	2
Ah	Sand	210	10 YR 3/1	5
C2g	Sand	300	2.5 Y 5/4	2
A1	Sand	300	10 YR 2/1	8
A2	Sand	0	10 YR 2/1	8
A3	Moerig	300	10 YR 2/1	20
Cr	Coarse sand	0	2.5 Y 5/4	0.25
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HD/004
Coordinates: 176157
457753
Classification: 3: Drift sand layer on (blown out) Gleyic carbic podzol



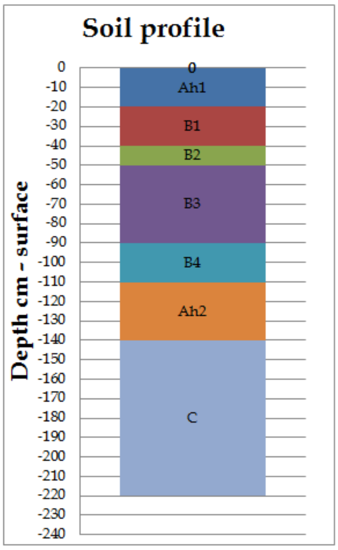
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Sand	0	0	0
E	Sandy clay	210	10 YR 3/1	3
Bh	Sand	150	10 YR 3/2	3.5
Bh1	Moerig and coarse	210	Black	15
Bh2	Sand	150	10 YR 3/4	0.5
C	Sand	150	2.5 Y 6/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/HD/003
Coordinates: 176182
457823
Classification: 8: Potic arenosol on (blown out) Gleyic carbic podzol



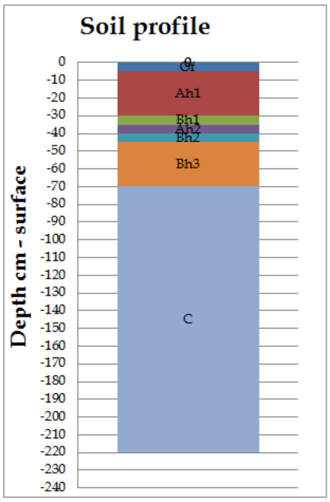
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	210	0	1
C1	Sand	210	10 YR 4/3	0.5
C2g	Sand	210	10 YR 6/4	0.25
C3	Sand	210	10 YR 6/4	0.5
C4	Sand	210	10 YR 4/3	2
Bh1	Moerig	0	Black	15
Bh2	Sand	300	10 YR 2/1	6
Bh3	Sand	300	10 YR 2/1	5
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/test/001
Coordinates: 176163.47
457013.62
Classification: 13: Spodic anthrosol



Layer	Textural class	M50	Soil colour	Organic matter content
Ah1	Sand	105	10 YR 2/1	4.5
B1	Sand	105	10 YR 3/2	2
B2	Sand	105	10 YR 4/3	3
B3	Sand	105	10 YR 4/2	1
B4	Sand	105	10 YR 4/4	2
Ah2	Sand	105	10 YR 2/1	5
C	Sand	105	10 YR 5/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

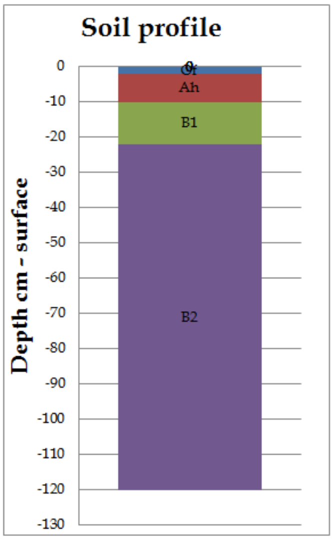
Profile number: WZ/test/002
Coordinates: 176191.99
457241.78
Classification: 13: Spodic anthrosol



Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah1	Sand	150	10 YR 2/2	3.5
Bh1	Sand	150	10 YR 4/6	2
Ah2	Sand	150	10 YR 2/1	5
Bh2	Sand	150	2.5 Y 4/2	2
Bh3	Sand	150	10 YR 4/6	0.5
C	Sand	150	2.5 Y 6/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

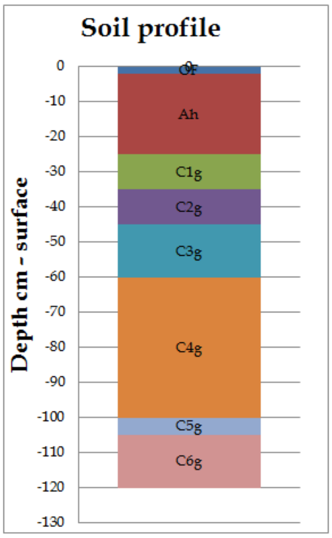
Mid-high area

Profile number: WZ/MHA/003
Coordinates: 175418
457269
Classification: 7: Potic arenosol



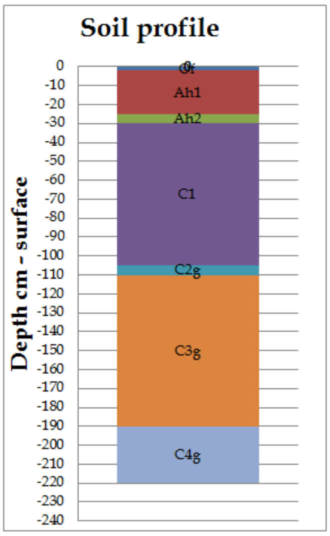
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah	Sand	105	2.5 Y 5/4	0.5
B1	Sand	105	2.5 Y 3/2	1
B2	Sand	105	2.5 Y 5/3	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHD/016
Coordinates: 175273
457218
Classification: 7: Potic arenosol



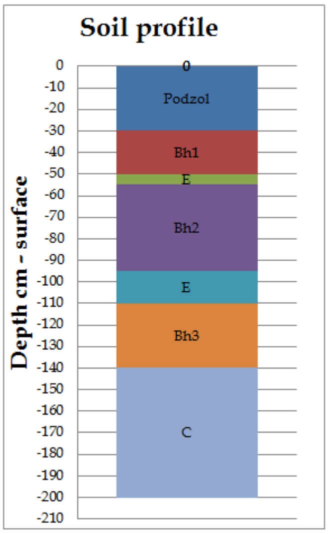
Layer	Textural class	M50	Soil colour	Organic matter content
OF	Humus	0	0	0
Ah	Sand	210	10 YR 4/4	1
C1g	Sand	600	10 YR 5/6	0.25
C2g	Sand	210	10 YR 5/6	0.5
C3g	Sand	600	10 YR 5/6	0.25
C4g	Sand	210	10 YR 6/4	0.5
C5g	Sand	800	10 YR 6/4	0.25
C6g	Sand	210	10 YR 6/4	0.25
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/004
Coordinates: 175130
457507
Classification: 7: Potic arenosol



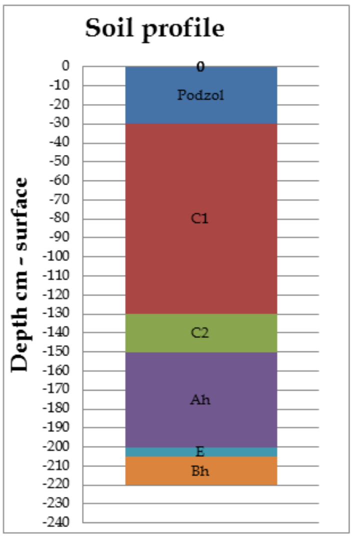
Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah1	Sand	150	10 YR 4/6	1
Ah2	Sand	150	2.5 Y 5/3	1.5
C1	Sand	150	10 YR 6/6	0.5
C2g	Sand	150	10 YR 5/2	1.5
C3g	Sand	150	2.5 Y 8/1	0
C4g	Sand	150	2.5 Y 7/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/017
Coordinates: 175415
458086
Classification: 10: Potic arenosol on 2 (blown out) Gleyic carbic podzol



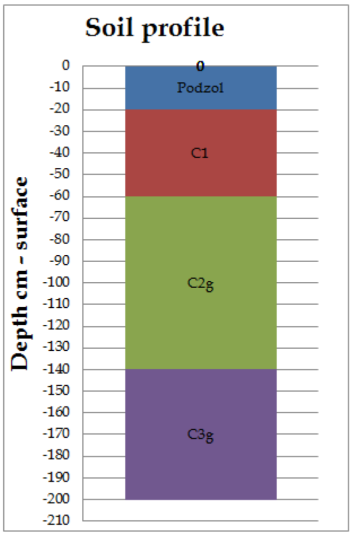
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	105	0	1.5
Bh1	Sand	105	2.5 Y 5/4	1
E	Sand	105	10 YR 4/2	2
Bh2	Sand	150	10 YR 3/4	2
E	Sand	105	2.5/1st page	4
Bh3	Sand	105	10 YR 2/2	10
C	Sand	150	2.5 Y 7/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/021
Coordinates: 175328
458008
Classification: 8: Potic arenosol on (blown out) Gleyic carbic podzol



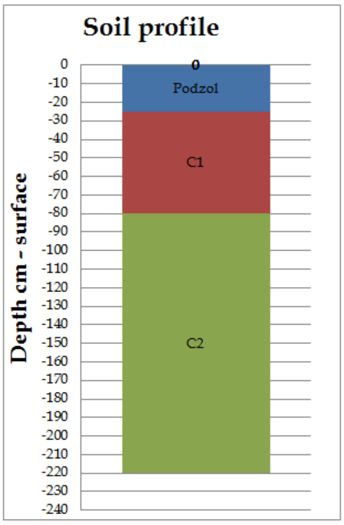
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	150	0	1
C1	Sand	150	2.5 Y 6/4	0.5
C2	Sand	150	2.5 Y 5/4	0.5
Ah	Sand	300	10 YR 3/3	0.5
E	Sand	150	10 YR 4/2	0.5
Bh	Moerig	150	0	10
0	0	Moerig	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/010
Coordinates: 175358
457549
Classification: 7: Potic arenosol



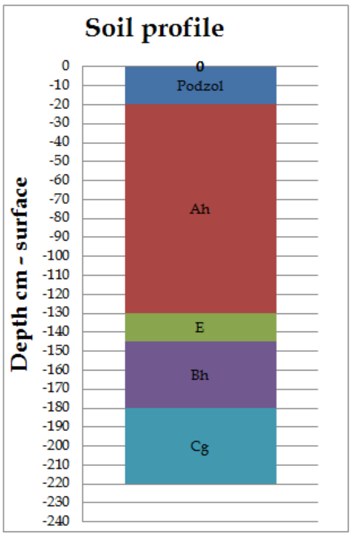
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	210	0	1
C1	Sand	210	2.5 Y 6/4	0.5
C2g	Sand	210	2.5 Y 7/3	0.25
C3g	Sand	210	10 YR 6/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/001
Coordinates: 175447
457675
Classification: 7: Potic arenosol



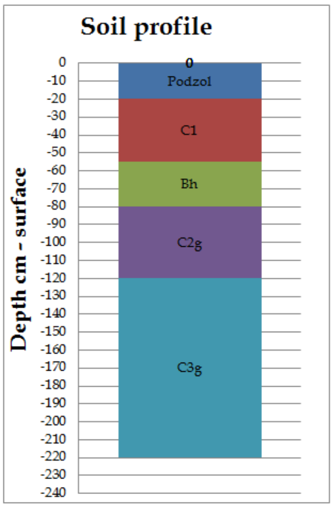
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	210	0	1
C1	Sand	210	2.5 Y 6/4	0.5
C2	Sand	300	2.5 Y 7/2	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/025
Coordinates: 174720
458162
Classification: 8: Potic arenosol on (blown out) Gleyic carbic podzol



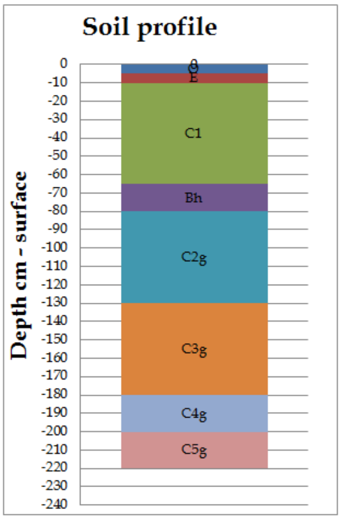
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	150	0	3
Ah	Sand	150	2.5 Y 4/3	2
E	Sand	150	2.5/1st page	12
Bh	Sand	210	7.5 YR 3/4	10
Cg	Sand	210	10 YR 6/8	1
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/006
Coordinates: 175310
457777
Classification: 8: Potic arenosol on (blown out) Gleyic carbic podzol



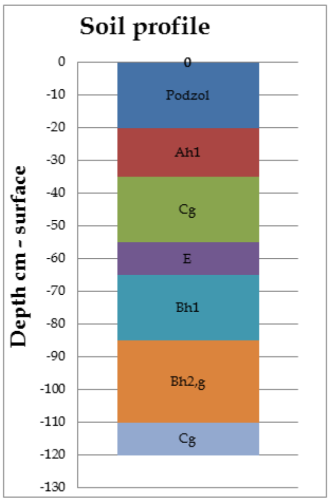
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	210	0	1.5
C1	Sand	210	2.5 Y 4/3	1.5
Bh	Sand	210	10 YR 3/3	4.5
C2g	Sand	210	10 YR 6/8	0.5
C3g	Sand	210	2.5 Y 7/3	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/011
Coordinates: 175374
457829
Classification: 8: Potic arenosol on (blown out) Gleyic carbic podzol



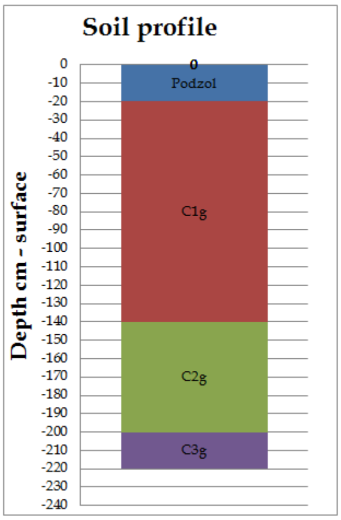
Layer	Textural class	M50	Soil colour	Organic matter content
O	Sand	150	0	0
E	Sand	150	10 YR 4/1	0.5
C1	Sand	150	10 YR 5/6	1
Bh	Sand	150	10 YR 2/2	3
C2g	Sand	300	2.5 Y 7/3	0.25
C3g	Sand	300	2.5 Y 6/6	0.25
C4g	Sand	300	2.5 Y 7/3	0.25
C5g	Sand	300	10 YR 6/8	0.25
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/007
Coordinates: 175449
457909
Classification: 4: Drift sand layer on (blown out) Orthic podzol



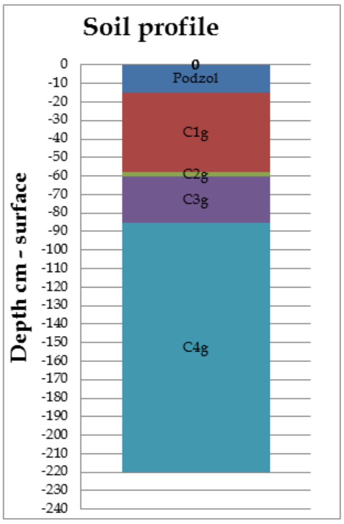
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	210	0	1.5
Ah1	Sand	210	10 YR 5/6	0.5
Cg	Sand	150	2.5 Y 4/2	1
E	Sand	150	2.5 Y 4/1	1
Bh1	Sand	210	10 YR 2/2	5
Bh2,g	Sand	210	10 YR 5/8	1.5
Cg	Sand	210	10 YR 6/6	0.5
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/005
Coordinates: 175017
457770
Classification: 7: Potic arenosol



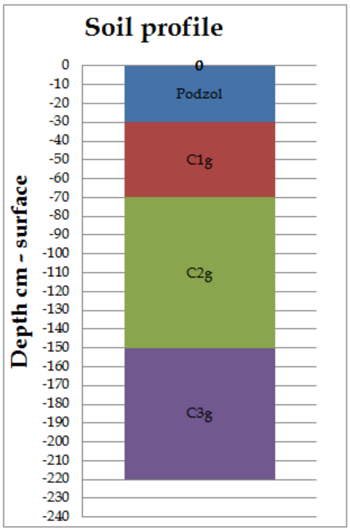
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	150	0	1
C1g	Sand	150	2.5 Y 5/4	0.5
C2g	Sand	105	2.5 Y 8/2	0.25
C3g	Sand	105	10 YR 6/8	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/014
Coordinates: 175047
457975
Classification: 7: Potic arenosol



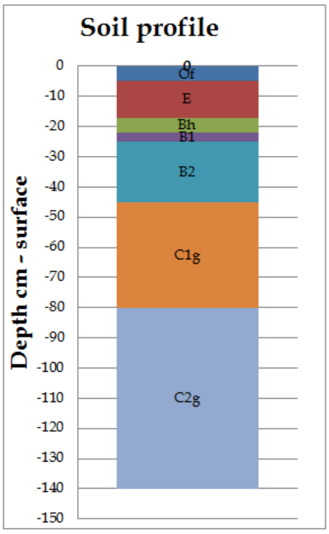
Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	0	0	0	0
C1g	Sand	150	2.5 Y 6/4	1
C2g	Sand	150	2.5 Y 6/4	0.5
C3g	Sand	300	2.5 Y 7/3	0.15
C4g	Sand	105	2.5 Y 7/3	0.15
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Profile number: WZ/MHA/015
Coordinates: 174858
458035
Classification: 7: Potic arenosol



Layer	Textural class	M50	Soil colour	Organic matter content
Podzol	Sand	150	0	0
C1g	Sand	150	10 YR 5/3	1
C2g	Sand	105	2.5 Y 7/3	1
C3g	Sand	105	10 YR 5/8	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

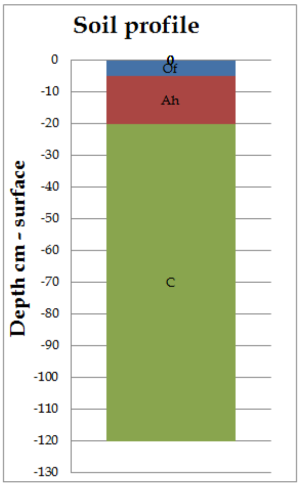
Profile number: WZ/test/006
Coordinates: 174910.76
457799.15
Classification: 6: Gleyic carbic podzol



Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
E	Sand	105	2.5 Y 4/1	1.5
Bh	Sand	105	10 YR 3/4	2
B1	Sand	105	2.5 Y 6/3	0.5
B2	Sand	105	10 YR 3/2	4
C1g	Sand	105	2.5 Y 7/3	0.5
C2g	Sand	105	10 YR 6/8	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

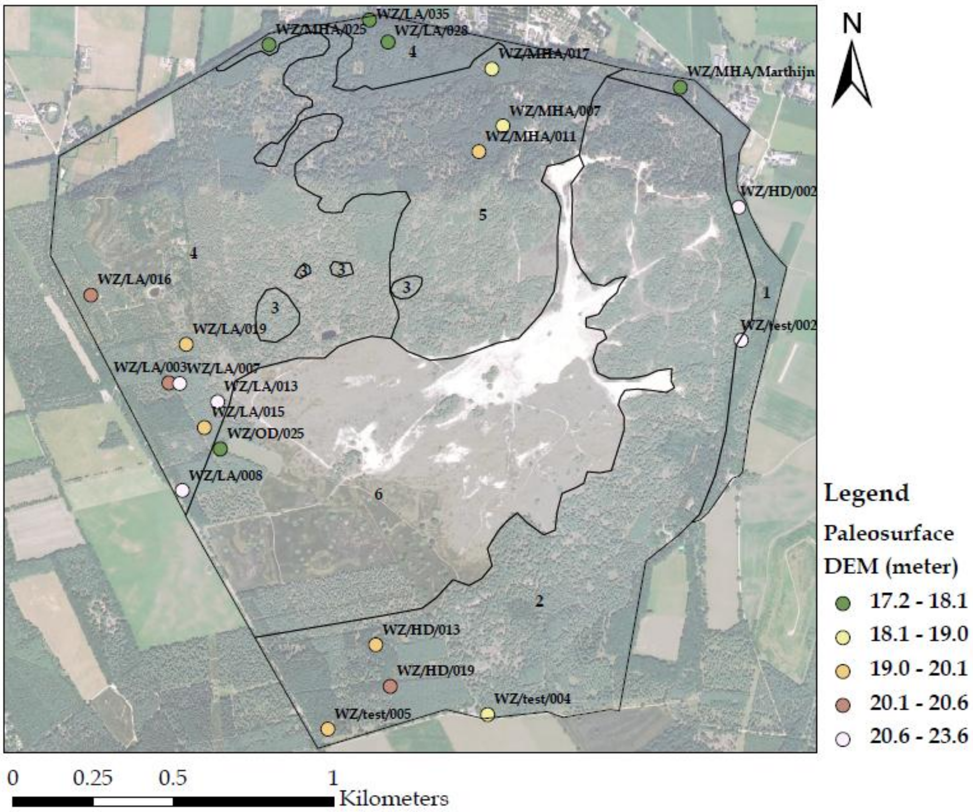
High dunes in low landscape

Profile number: WZ/HDLL/010
Coordinates: 175128
457387
Classification: 7: Potic arenosol

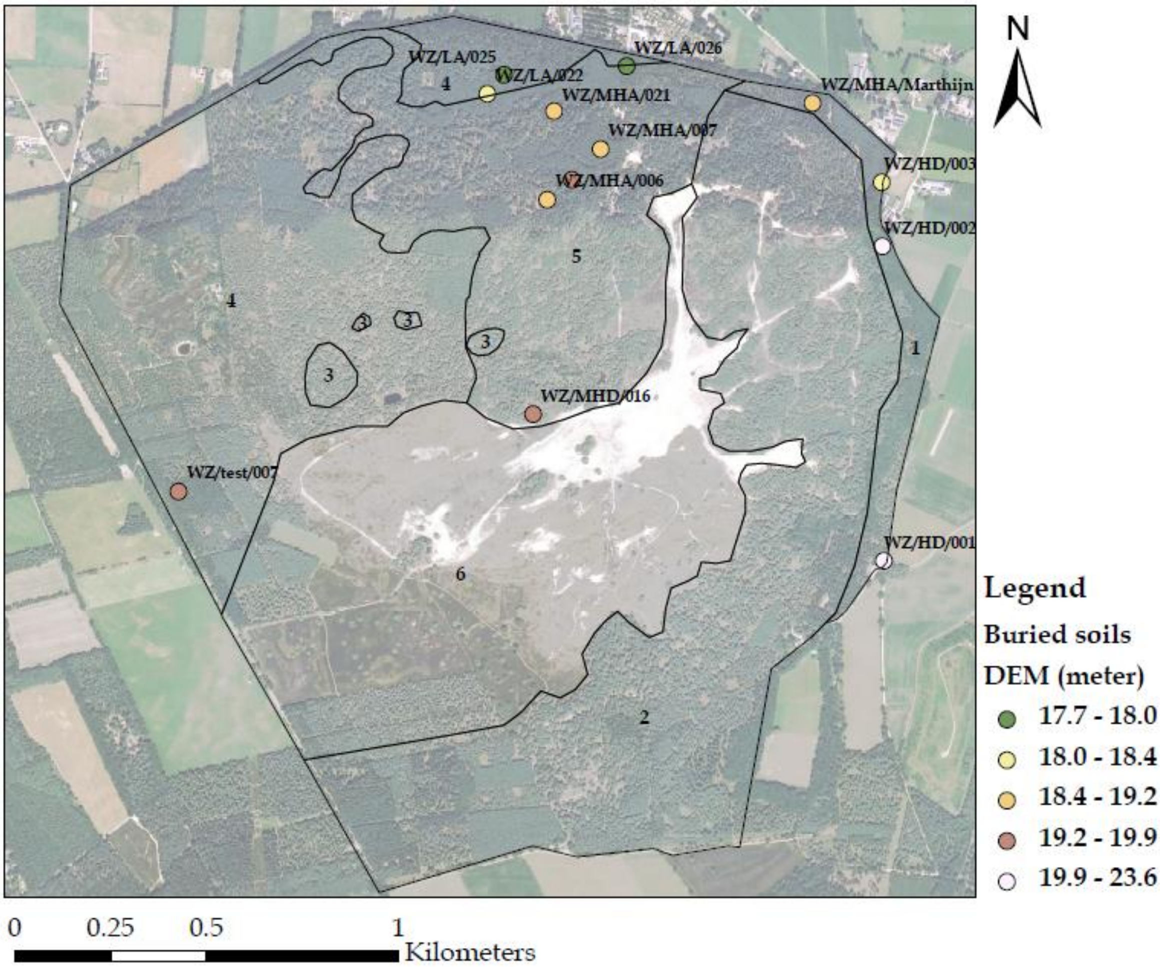


Layer	Textural class	M50	Soil colour	Organic matter content
Of	Humus	0	0	0
Ah	Sand	105	10 YR 3/4	2
C	Sand	105	2.5 Y 6/4	0.25
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0

Appendix G: Palaeosurface and buried soils



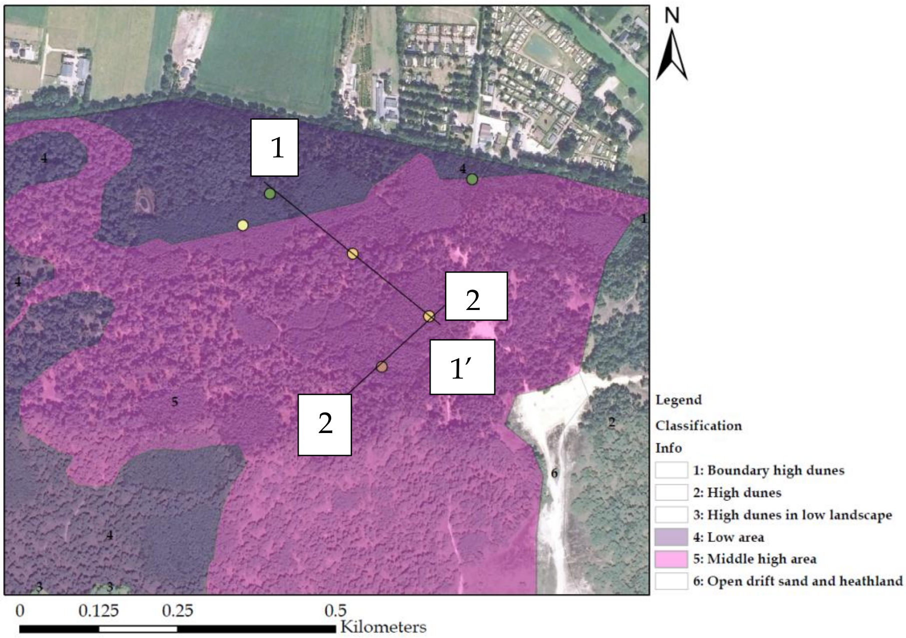
Sample	X	Y	Depth (m)	Depth (m DEM)	Palaeosurface
WZ/MHA/007	175449	457909	0.65	19.0	Podzol
WZ/MHA/011	175374	457829	0.65	19.9	Podzol
WZ/test/002	176192	457242	0.70	23.6	Coversand without podzol
WZ/test/004	175401	456076	1.10	18.9	Pushed moraine sediments
WZ/HD/002	176184	457656	1.65	22.5	Podzol
WZ/LA/028	175091	458170	1.00	18.1	Podzol
WZ/LA/035	175033	458239	1.10	17.2	Organic
WZ/MHA/025	174720	458162	1.80	17.4	Podzol
WZ/test/005	174994	455875	0.45	19.8	Pushed moraine sediments
WZ/LA/019	174462	457229	0.35	19.9	Podzol
WZ/LA/015	174519	456970	0.30	19.7	Podzol
WZ/LA/016	174165	457382	0.30	20.2	Podzol
WZ/LA/013	174560	457050	1.20	21.8	Coversand
WZ/LA/008	174450	456774	0.78	22.3	Podzol
WZ/LA/003	174408	457109	0.40	20.4	Podzol
WZ/LA/007	174442	457107	0.50	21.6	Podzol
WZ/OD/025	174568	456903	0.80	17.8	Podzol
WZ/MHA/017	175415	458086	1.10	18.3	Podzol
WZ/HD/013	175053	456293	1.00	20.1	Pushed moraine sediments
WZ/HD/019	175098	456164	0.50	20.6	Pushed moraine sediments
WZ/MHA/Marthijn	176002	458029	2.00	17.8	Organic

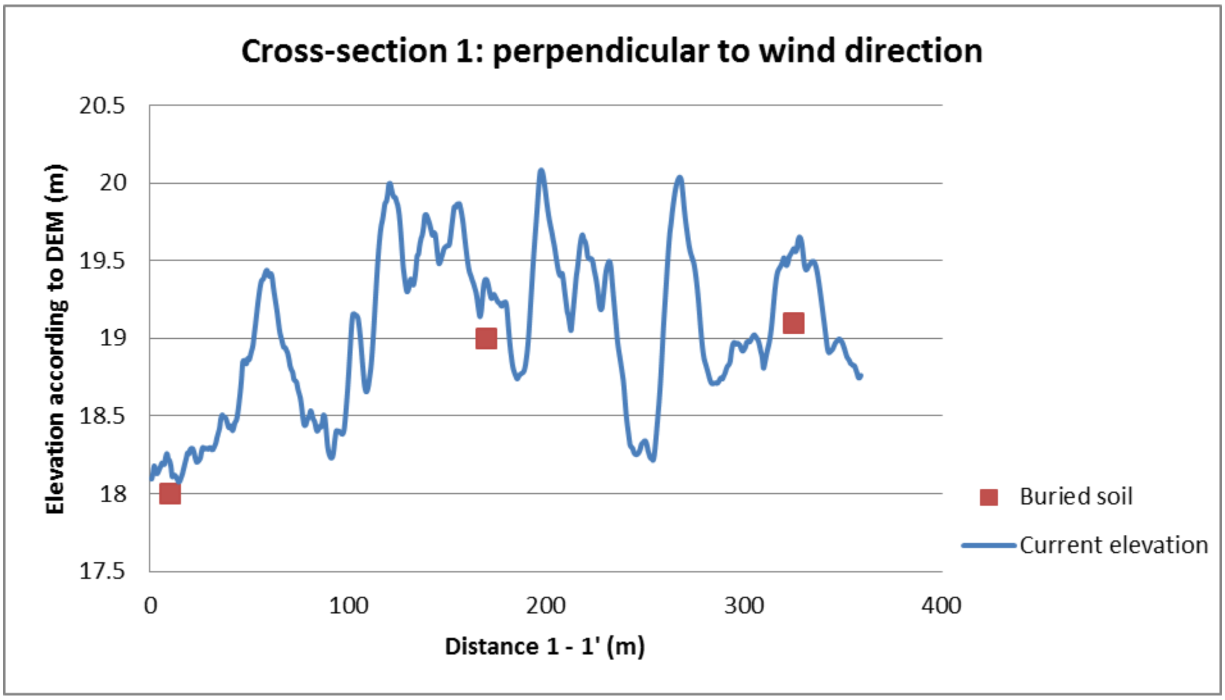


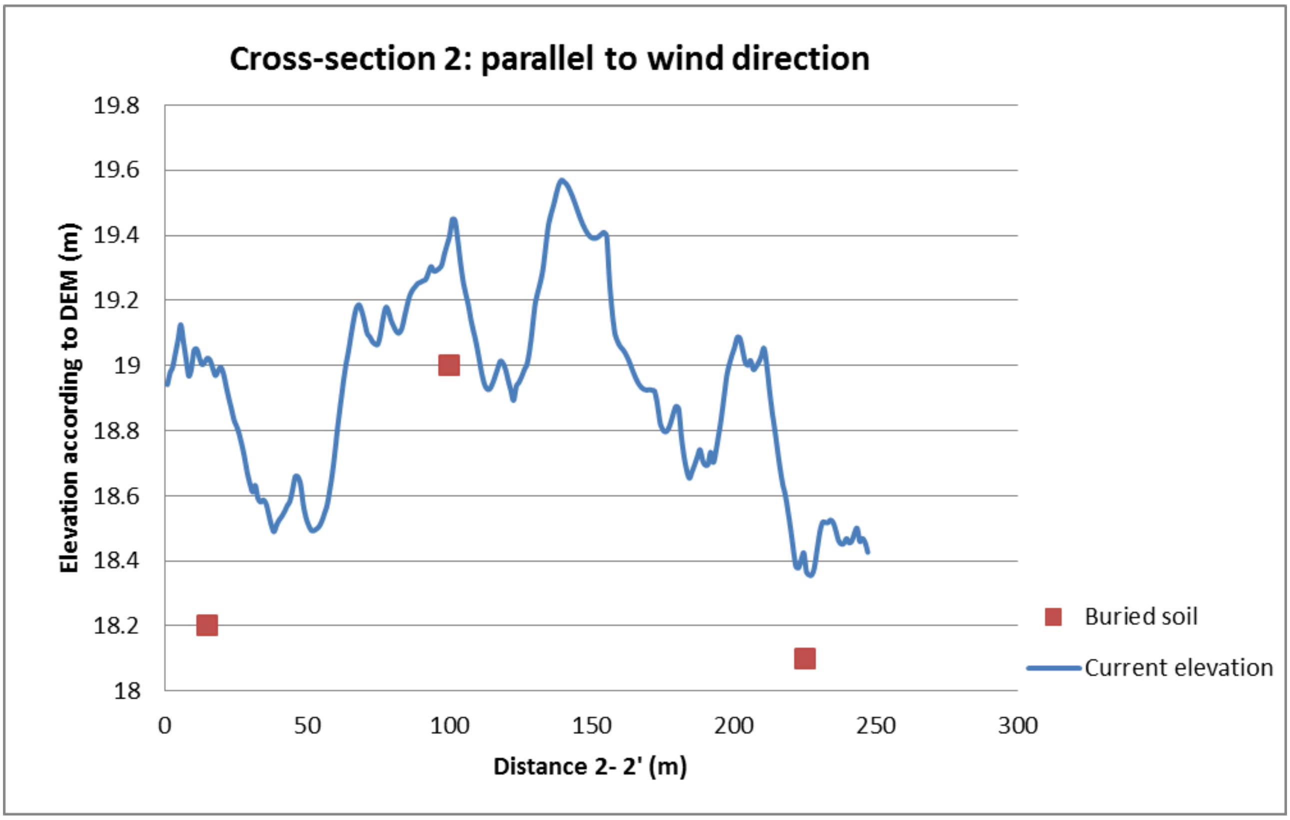
Sample	X	Y	DEM (m)	Depth (m DEM)	Buried soil
WZ/MHA/Marthijn	176002	458029	19.8	19.1	Sand
WZ/MHA/011	175374	457829	20.6	19.9	Sand
WZ/MHA/006	175310	457777	19.7	19.2	Sand
WZ/MHA/007	175449	457909	19.6	19.1	Sand
WZ/HD/003	176182	457823	20.1	18.4	Organic
WZ/HD/002	176184	457656	24.1	22.5	Sand
WZ/HD/001	176188	456836	24.1	23.6	Sand
WZ/test/007	174349	457016	20.0	19.7	Sand
WZ/LA/025	175197	458103	19.0	18.0	Sand
WZ/LA/022	175154	458053	19.0	18.3	Sand
WZ/OD/013	175235	156795	20.1	19.6	Sand
WZ/LA/026	175517	458126	19.1	17.7	Organic
WZ/MHA/021	175328	458008	21.1	19.0	Organic
WZ/MHD/016	175273	457218	20.7	19.7	Sand

Appendix H: Buried soils from cross-sections

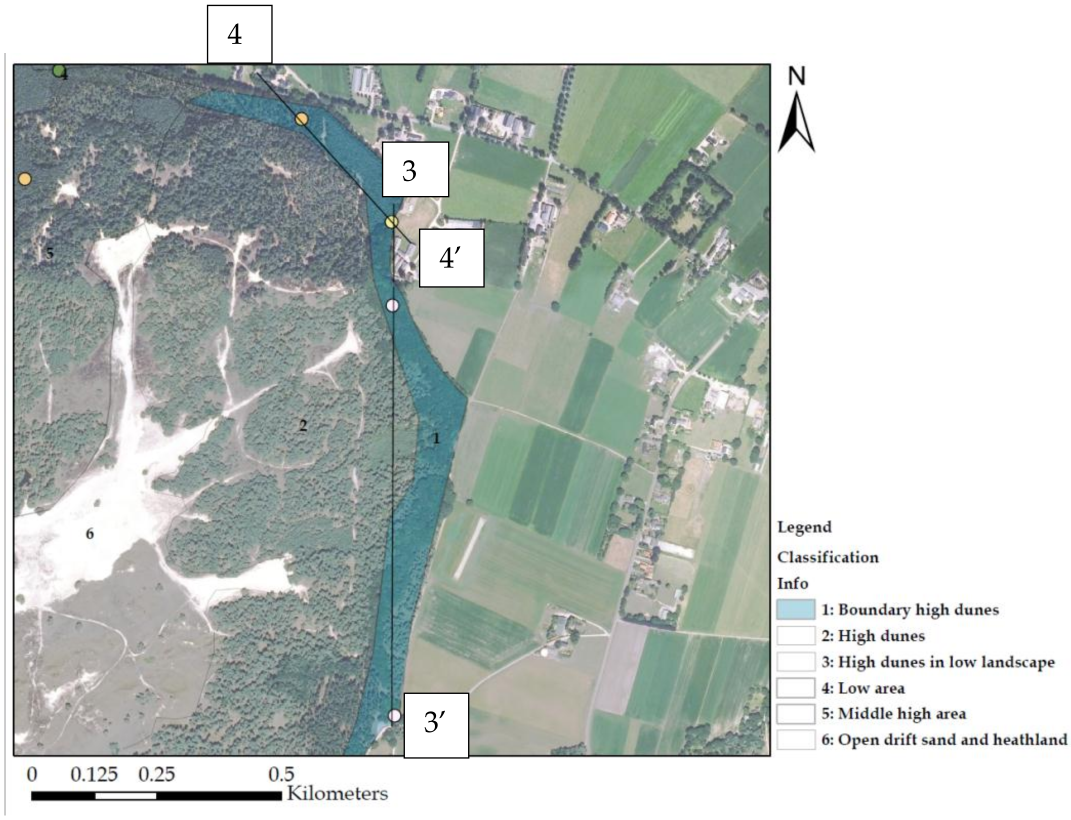
Cross-sections of the buried soils in the subareas 'Low area' and 'Mid-high Area'

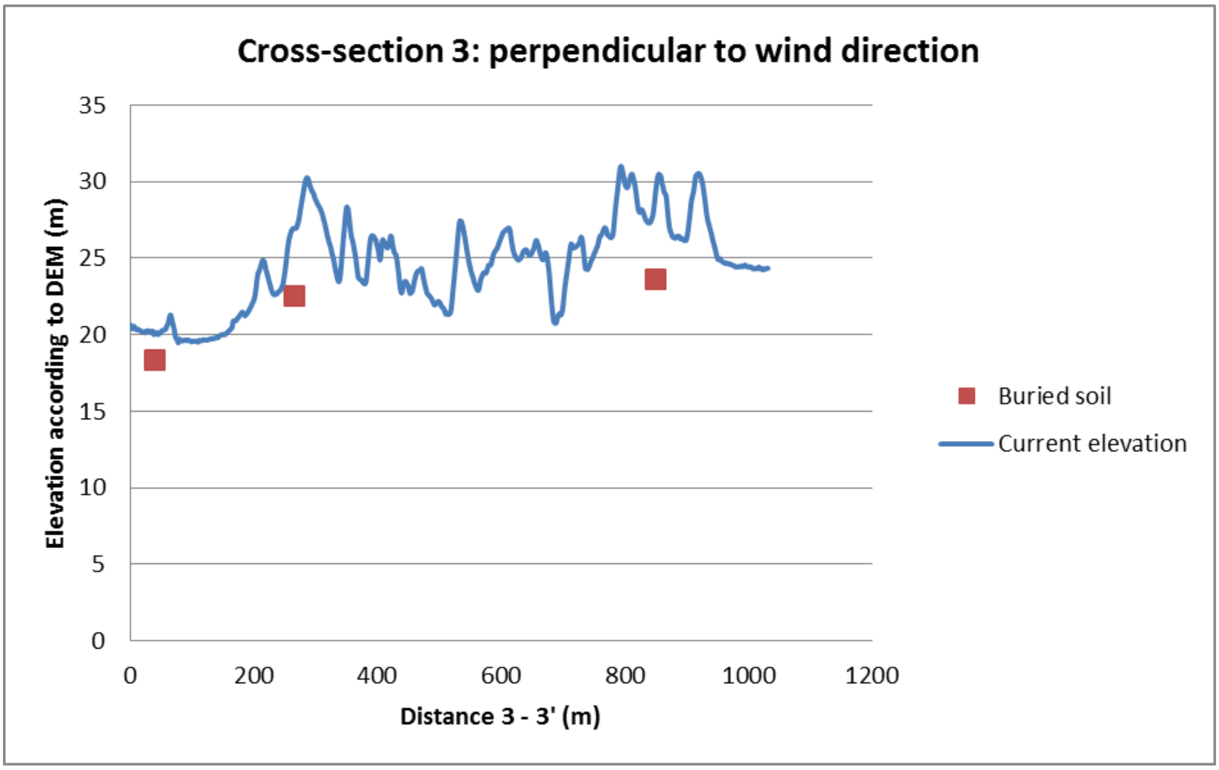




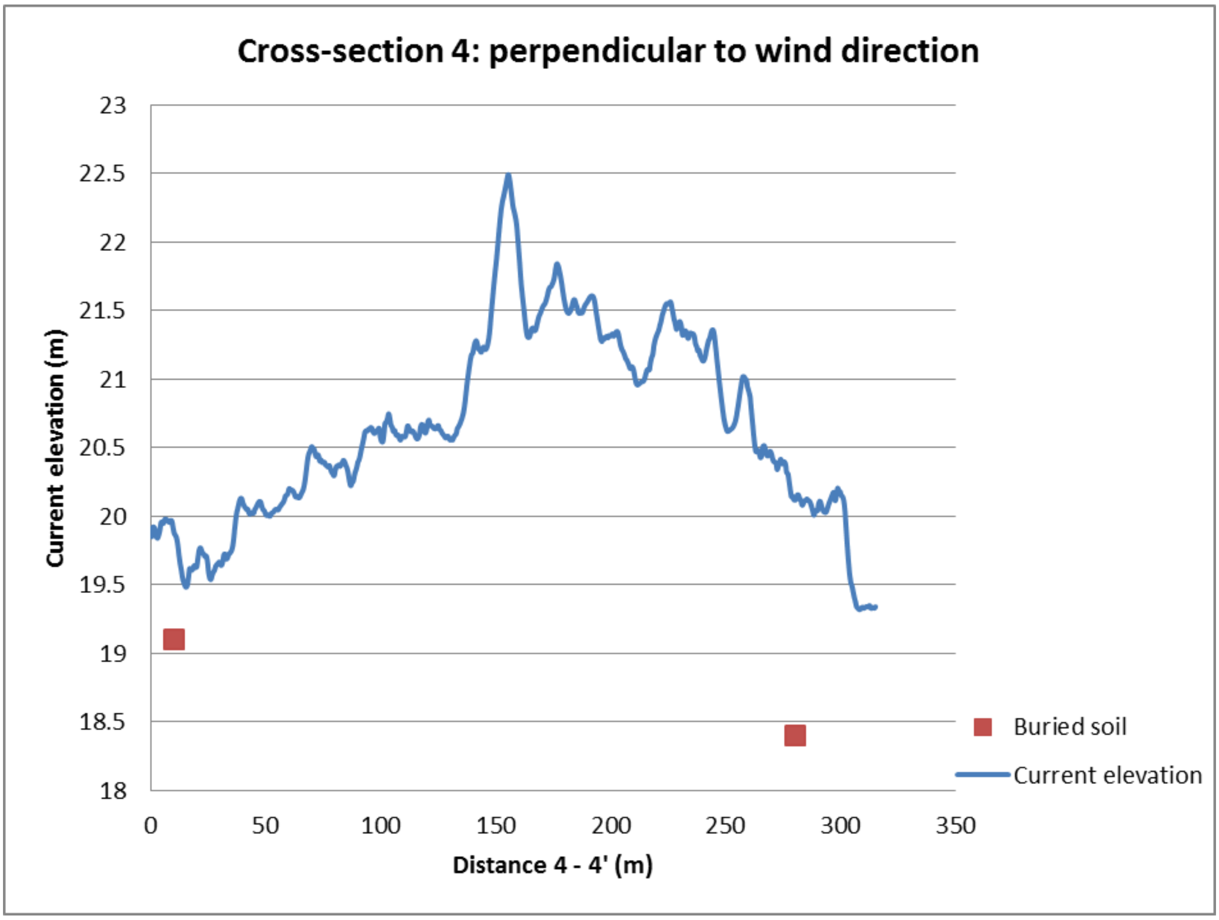


Cross-sections of the buried soils in the subarea 'Boundary high area'





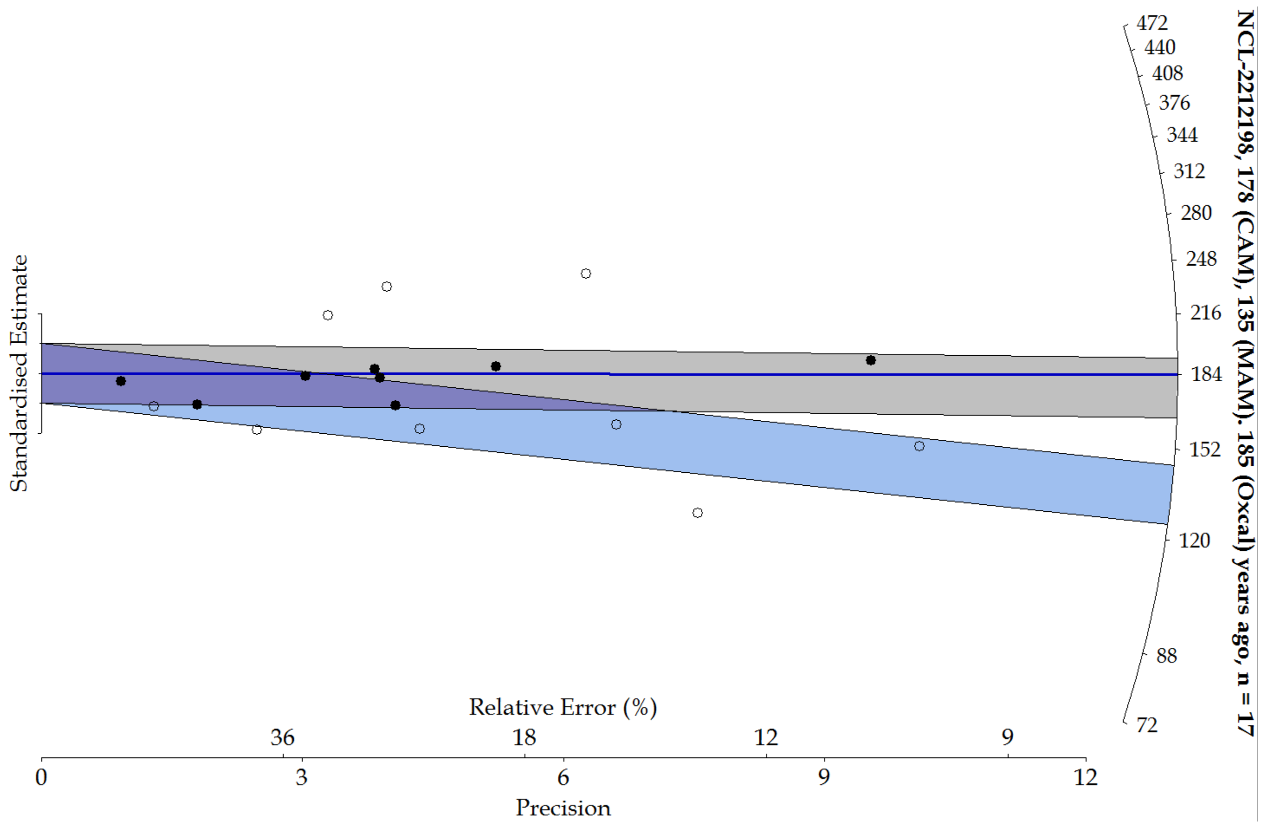
Cross-section 3: perpendicular to wind direction
Elevation according to DEM (m)
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
Distance 3 - 3' (m)
Buried soil
Current elevation

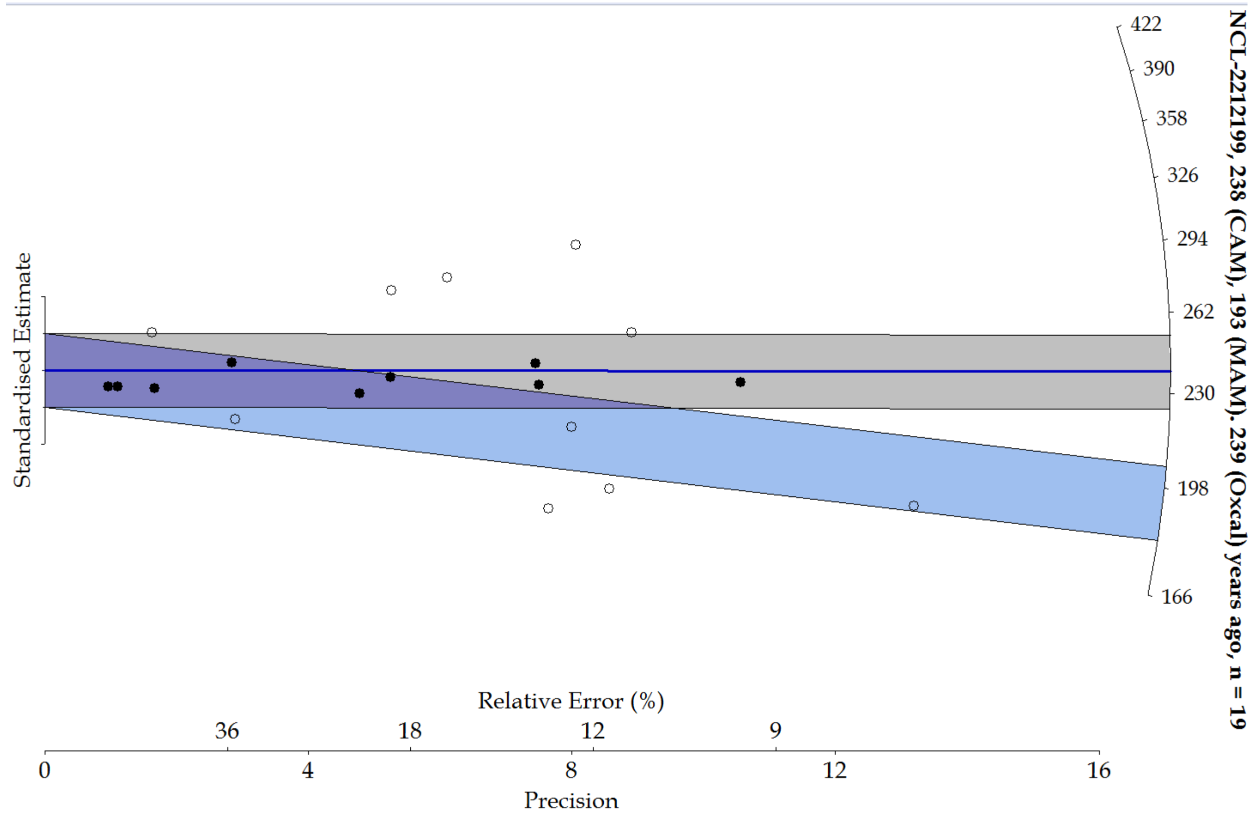


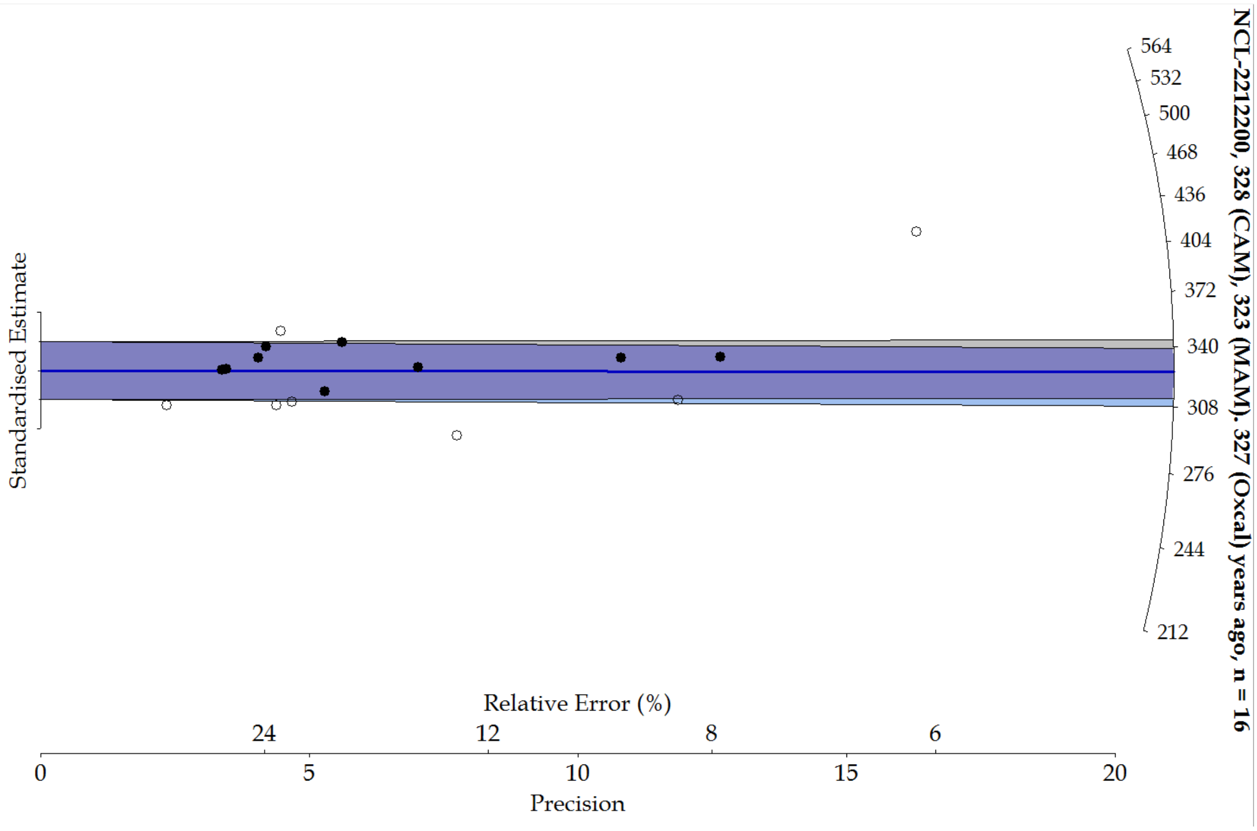
Cross-section 4: perpendicular to wind direction
Current elevation (m)
23
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
0
50
100
150
200
250
300
350
Distance 4 - 4' (m)
Buried soil
Current elevation

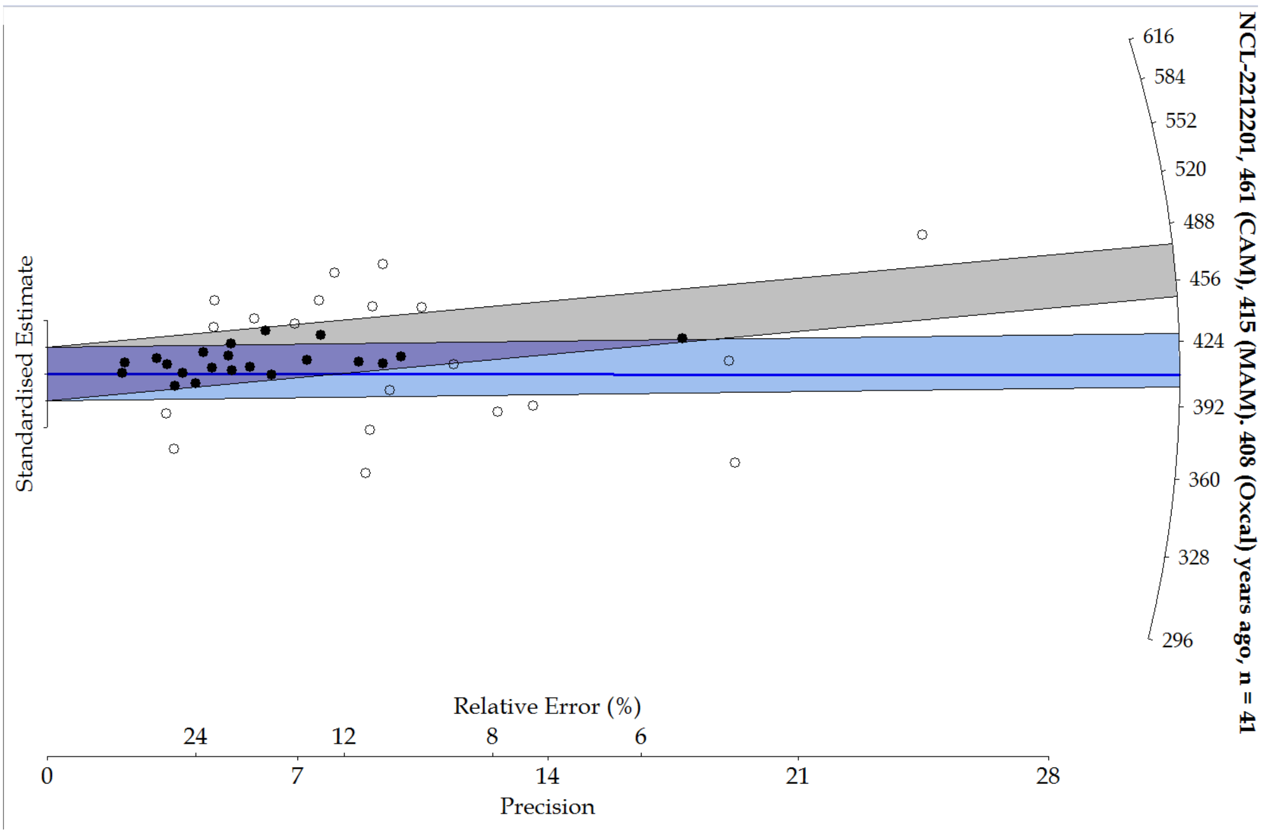
Appendix I: Radial plots of OSL results

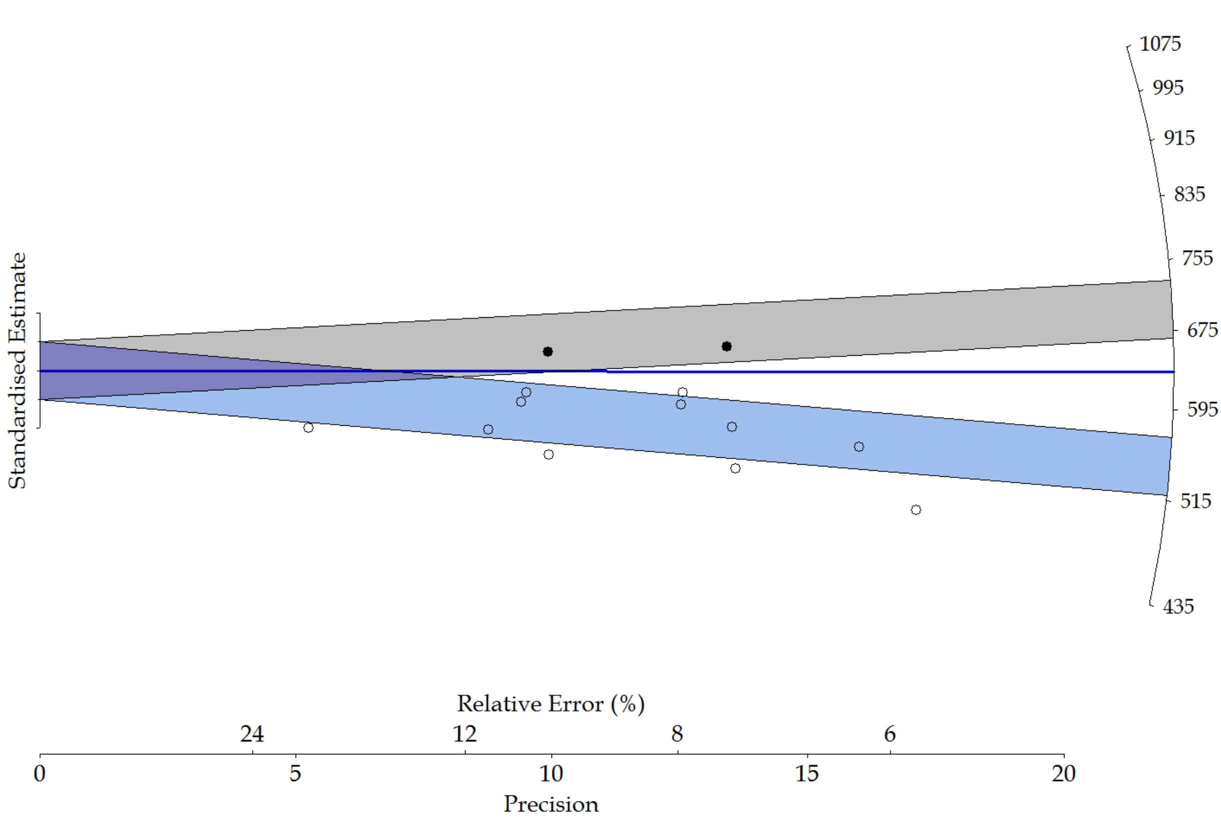
Radial plots from Pit 1: NCL-2212198 till NCL-2212205.



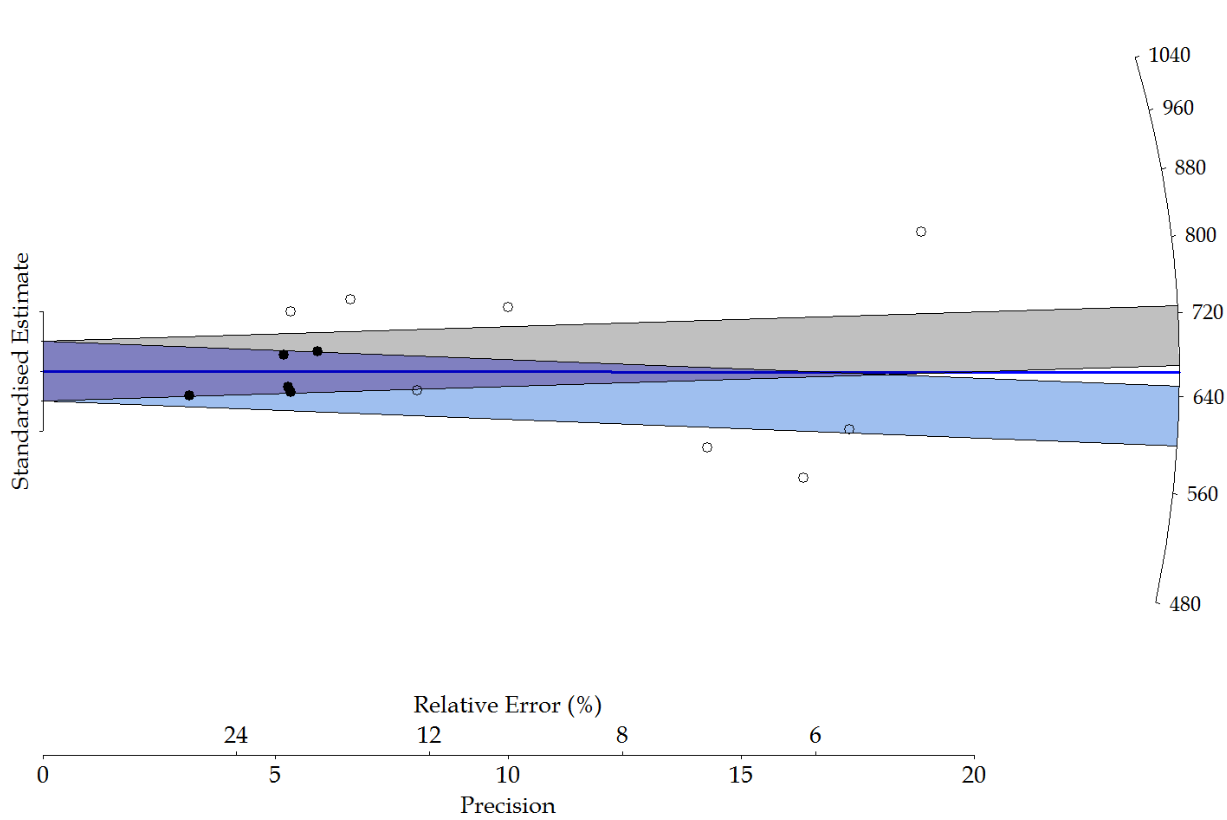



NCL-2212200, 328 (CAM), 323 (MAM). 327 (Oxcal) years ago, n = 16
Standardised Estimate
Relative Error (%)
24
12
8
6
0
5
10
15
20
Precision
564
532
500
468
436
404
372
340
308
276
244
212

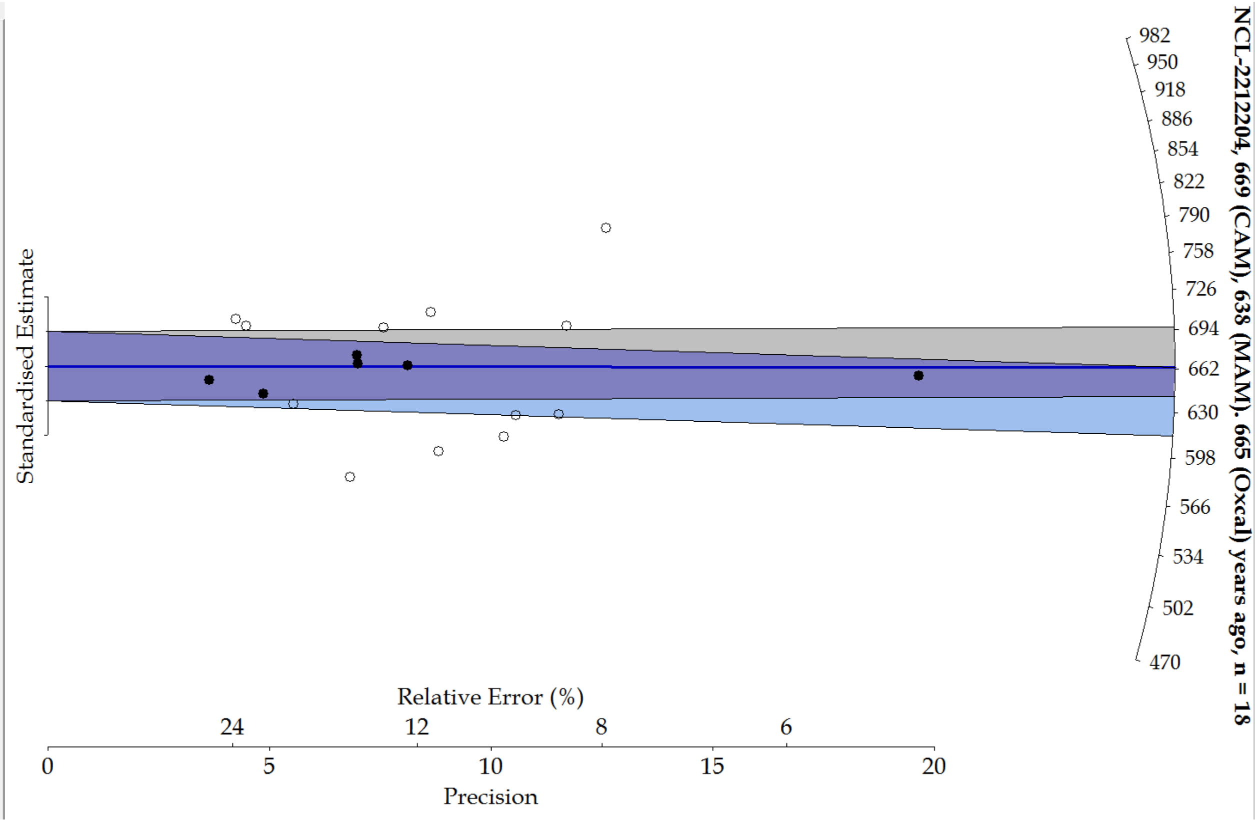

NCL-2212201, 461 (CAM), 415 (MAM). 408 (Oxcal) years ago, n = 41
Standardised Estimate
Relative Error (%)
24
12
8
6
0
7
14
21
28
Precision
616
584
552
520
488
456
424
392
360
328
296

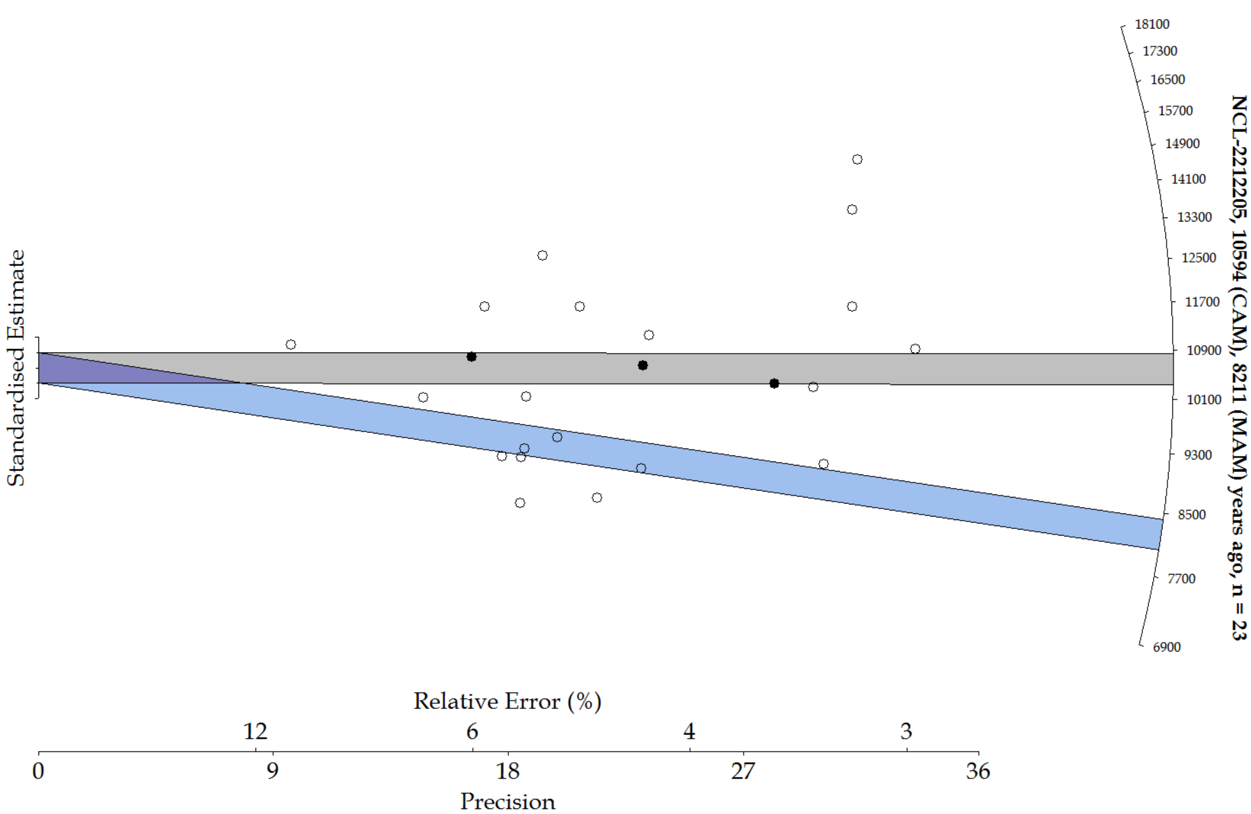


NCL-2212202, 698 (CAM), 544 (MAM). 633 (Oxcal) years ago, n = 13

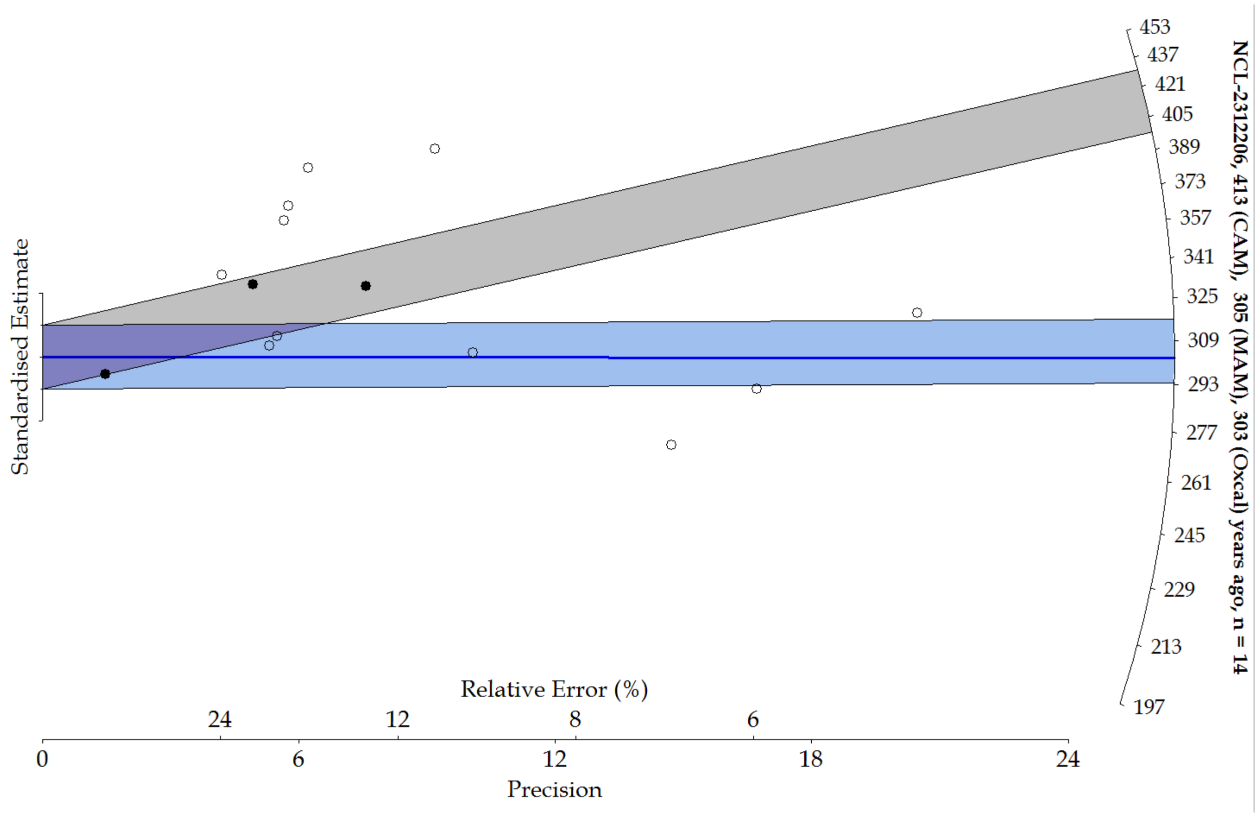


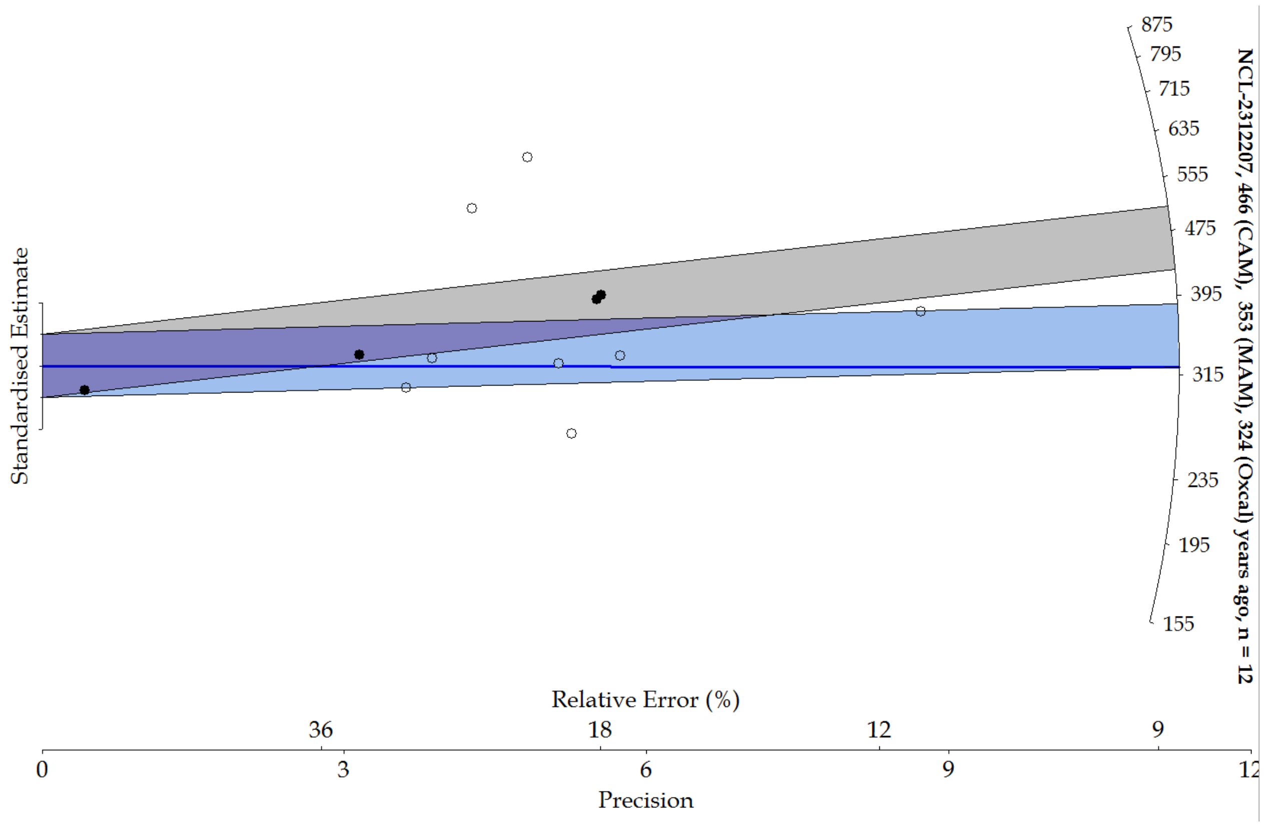
NCL-2212203, 698 (CAM), 624 (MAM). 664 (Oxcal) years ago, n = 13

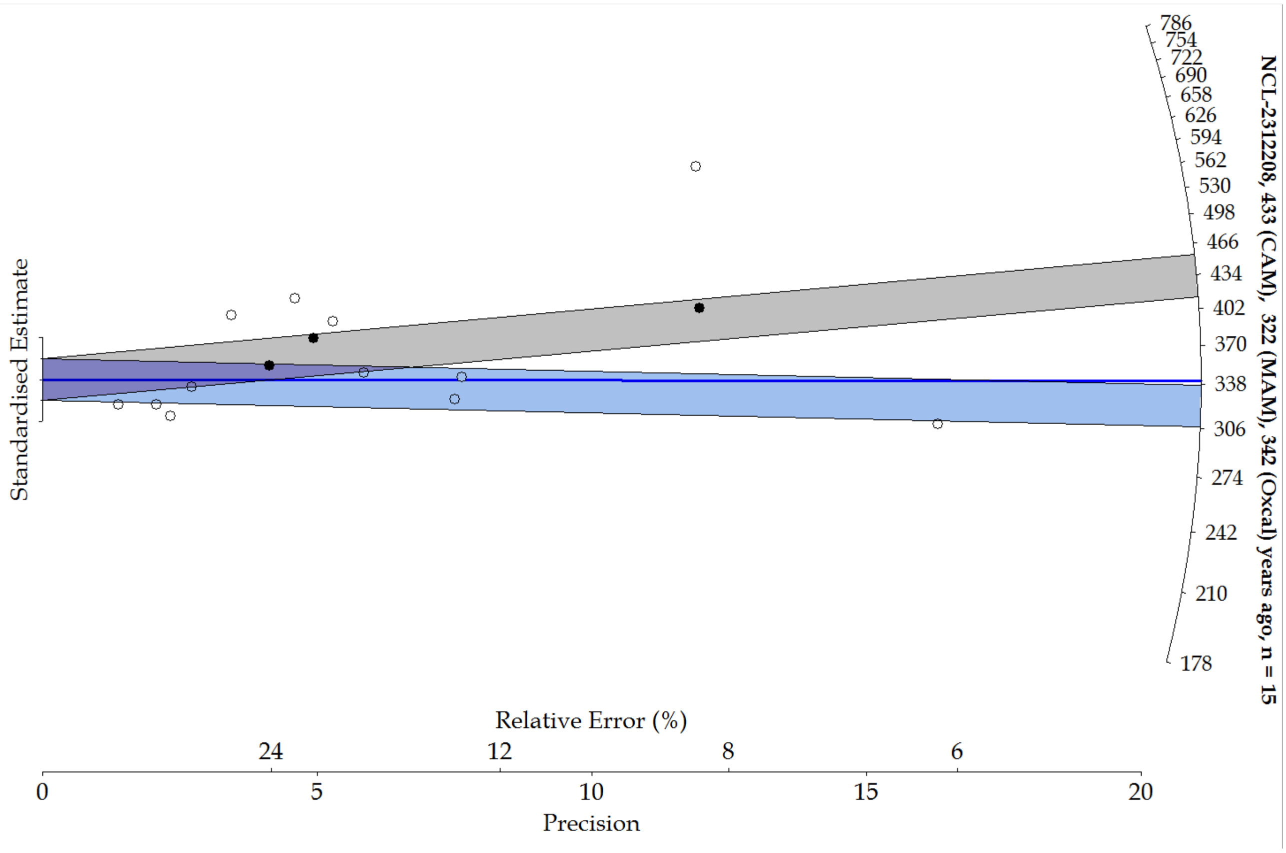

NCL-221204, 669 (CAM), 638 (MAM), 665 (Oxcal) years ago, n = 18
Standardised Estimate
982
950
918
886
854
822
790
758
726
694
662
630
598
566
534
502
470
Relative Error (%)
24
12
8
6
0
5
10
15
20
Precision


NCL-221205, 10594 (CAM), 8211 (MAM) years ago, n = 23
Standardised Estimate
18100
17300
16500
15700
14900
14100
13300
12500
11700
10900
10100
9300
8500
7700
6900
Relative Error (%)
12
6
4
3
0
9
18
27
36
Precision

Radial plots from Pit 2: NCL-2312206 till NCL-2212208






NCL-231208, 433 (CAM), 322 (MAM), 342 (Oxcal) years ago, n = 15
Standardised Estimate
786
754
722
690
658
626
594
562
530
498
466
434
402
370
338
306
274
242
210
178
Relative Error (%)
24
12
8
6
0
5
10
15
20
Precision