Genesis and spatial characteristics of soils on a 13th century monastic site and surrounding fields in Haren, the Netherlands

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MSc Thesis

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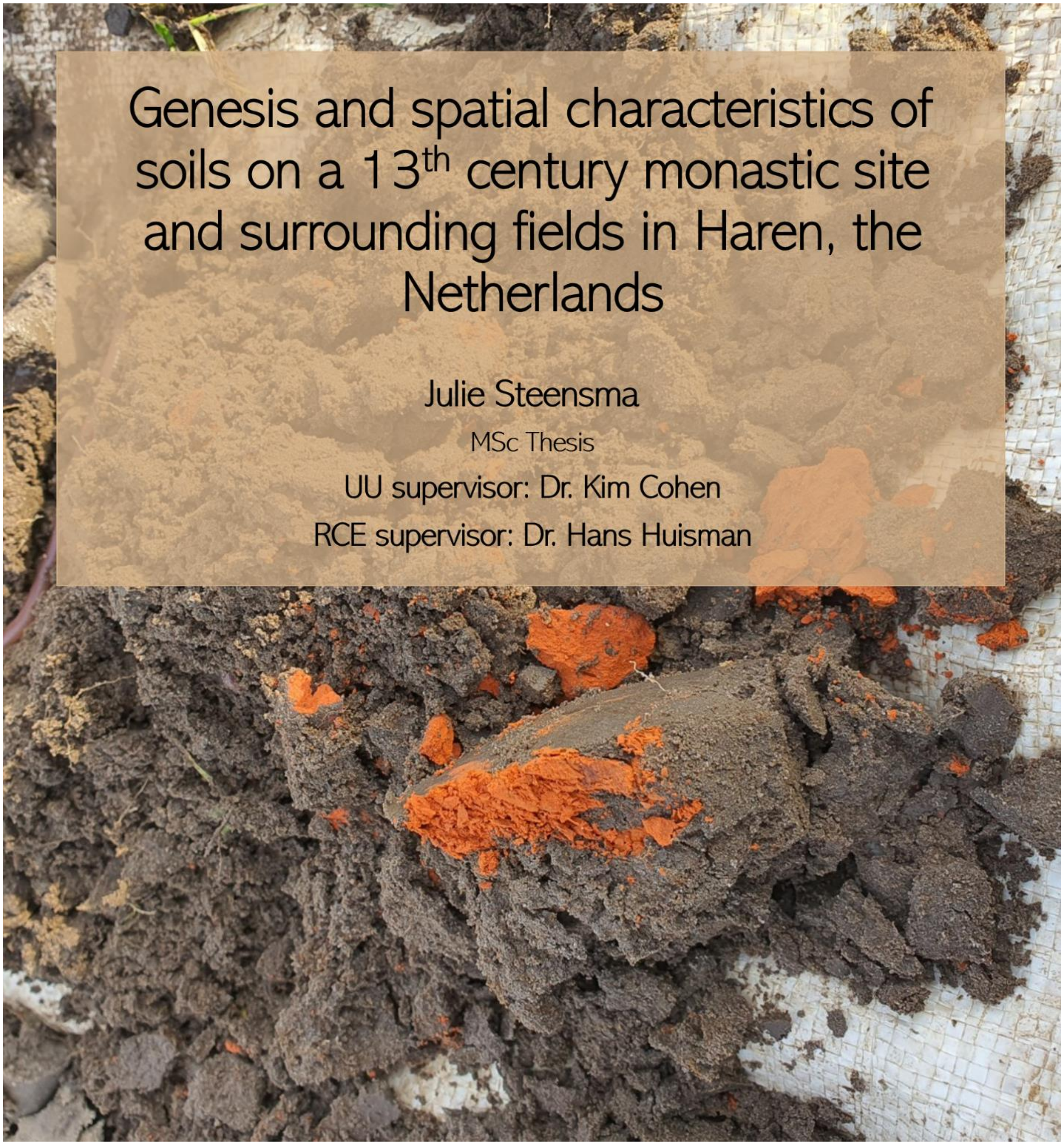

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Abstract

A MSc thesis research was carried out in Haren, the Netherlands to understand the genesis and imprints of anthropogenic activities on soils on former Yesse monastic grounds and the immediate surrounding fields. The study site appears to have been occupied by humans from as early as Roman and/or Early Medieval times, but the earliest documented settlement of this area was in the 13th century with the establishment of Yesse monastery. To understand how soils vary spatially across field boundaries and for specific landforms, fieldwork was conducted; where 25 cores were taken, and 5 soil profile pits were dug. Analysis of organic content, XRF, and grainsize was done in the lab to separate natural versus anthropogenically modified soils. A clear imprint of anthropogenic activities was seen in most soil profiles observed in this study; monastic site activities differing from grassland field activities. The anthropogenic soil profile on the monastic grounds was visually distinct from all other soil profiles from the vicinity, highlighting a different genesis. The monastic grounds were intensively used, and after the destruction of the monastery, a thick extremely dark black and organic-rich topsoil horizon developed that is filled with brick and plaster fragments, among other construction materials and domestic waste. Outside the monastic grounds, fields became gradually raised, probably during the post-monastic period, as domestic waste was added to increase the soil's fertility. Low-lying fields further from monastic grounds saw human modification to a lesser degree. Previous soil maps had listed both the monastic grounds and raised-field soil types in the immediate surroundings under the same soil classification, as variants of plaggen soils, but this study shows that they are distinctly different due to the differing genesis. The conclusion of this study is that the raised fields just east and west of the Yesse site could be plaggen soils post-dating the monastery, but the soil profile on the monastic grounds should be separated and termed a dark earth or an Anthrosol. Terminology is relevant depending on the objective the soil serves, but terms carry along assumptions; one major one being that calling the site of Yesse monastery a plaggen soil fails to capture the presence of pockets of much older anthropogenically influenced soils.

Preface

This thesis was written under the Earth, Life, and Climate MSc program at Utrecht University. In the process of writing this thesis, most information on Dutch soils was written in Dutch (i.e., van Dodewaard & Kiestra, 1989). As a non-Dutch speaker, the application of Dutch Wikipedia was implemented for translations of Dutch soil classifications and supporting descriptions, since other translation tools were not sufficient. In the following report, the original Dutch document will be referred to (StiBoKa, 1978; van Dodewaard & Kiestra, 1989).

Acknowledgements

I would like to thank first and foremost my supportive supervisors, Hans Huisman and Kim Cohen, who have received countless emails full of questions from me during this thesis. Besides their academic assistance and advice, they have been entirely sympathetic towards me during the unusual time that this thesis has been conducted, the Covid-19 pandemic. I have learned a great deal throughout the process of writing this thesis and I attribute a large part of it to their explanations and assistance. Furthermore, I would like to extend my appreciation to Wim Hoek, who helped me with lab work and kept up the positivity and entertainment by telling me stories of his cottage in Sweden and household renovations. As always, Stijn Arnoldussen has provided me with information about Yesse monastery and the archaeological excavations that have taken place in past years. I thank him for this, as well as for showing me the rowing technique for filling in pits, which I have yet to master. Thanks to Stijn, Annemiek and Hendrie from Klooster Yesse, and Hans Huisman for making fieldwork possible. A special gratitude for Annemiek and Hendrie for allowing me to stay in their guest house during fieldwork and being so generous to provide me with coffee every morning at 7am before I began work. They are truly the sweetest hosts. A silly thanks to the people who dug the latest trenches at Yesse before I got there to observe, saving me from having to dig in upper 20-degree weather. Thanks to all of my friends for their emotional support during the writing process.

1. Introduction

1.1 Research context

Anthropogenic influences on the Dutch surface, coupled with a complex geologic history, have combined to determine the topsoil and subsurface of the country. The Netherlands is renowned for its landscape altering practices that have been employed throughout human history. Very little, if any, of the country is left unmanipulated by people. On the other hand, local geology dictates what soils are able to naturally develop. This master thesis focuses on the soils around the 13th century monastic site, Yesse, in the northern Netherlands, to describe soil profiles and to determine soil formation factors.

The study site is to the southwest of Groningen, in Essen (part of Haren). The region of Groningen and Haren is situated on an elevated till ridge (up to +16m NAP) that is surrounded by lowland areas (as low as around -4m NAP) (Figure 1). This landscape structure has been present since the Saalian glaciation c. 150,000 years ago and has been a main control on natural soil formation ever since (as reviewed in Chapter 2). Two rivers run on either side of the study area, the Drentsche Aa in the west and the Hunze river in the east. The Drentsche Aa is a smaller subregional peaty brook system that lies between two semi-parallel till ridges (Figure 2). The Hunze river is a comparatively larger, regional to superregional river. The monastic site had a dug connection to the Hunze river. The river channel has been artificially altered by humans since the Middle Ages.

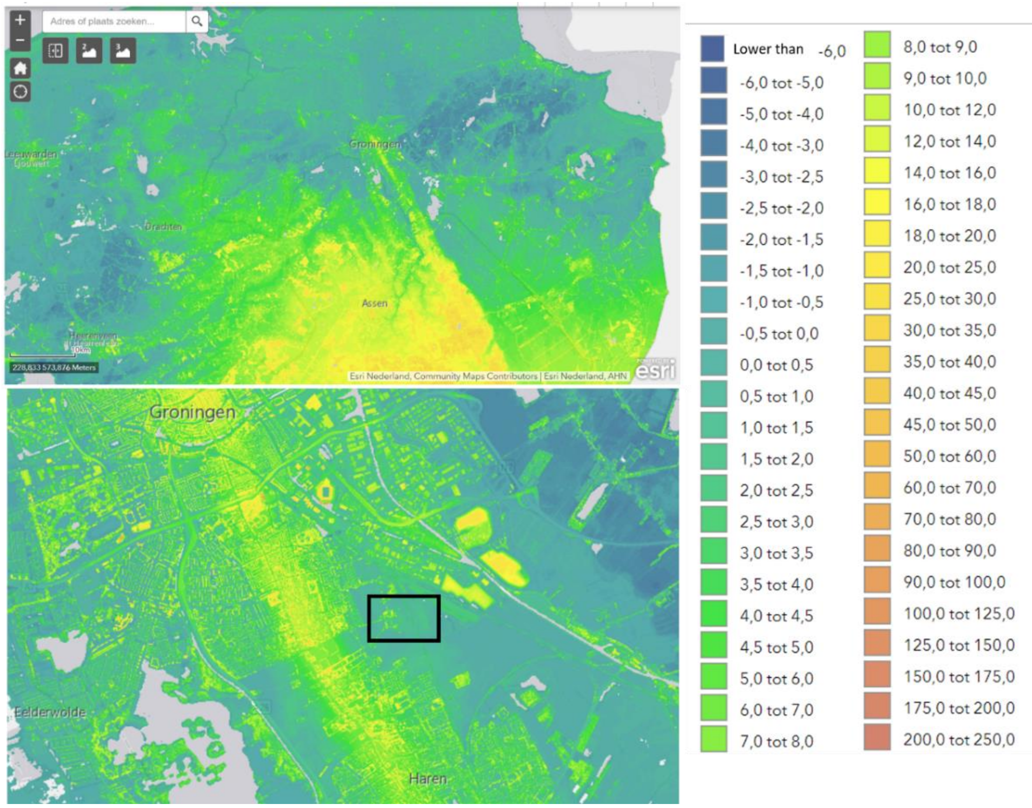

Figure 1. Elevation map of the study region. The study area is marked by the black box in the bottom picture. The legend unit is meters NAP. Source: AHN viewer (2021).

Research on the archaeological site of Yesse began in 2010, when test pits were opened by RAAP-Noord, along with local residents and archaeologists. It was during the digging of these test trenches, that the foundations of Yesse monastery (1216- 1594CE) were uncovered. Following this discovery, in 2016, Medusa - under the direction of the University of Groningen - carried out a geophysical survey of the area, revealing the extent of the monastic foundations (Kooistra *et al.,* 2018; Figure 3). Since then, first-year archaeology students from the University of Groningen – under the supervision of Dr. Stijn Arnoldussen - have opened trenches on the site to practice excavation techniques. From the excavations, a dark-colored soil horizon (or a Medieval cultural layer, as called by archaeologists here) was exposed beneath the monastery foundations. As the foundations of the monastery must have been laid shortly before the monastery was consecrated in 1216 CE (Kooistra *et al.,* 2018), this means the dark soil horizon predates this period, suggesting that humans occupied this space and affected the soil properties prior to the establishment of the monastic grounds.

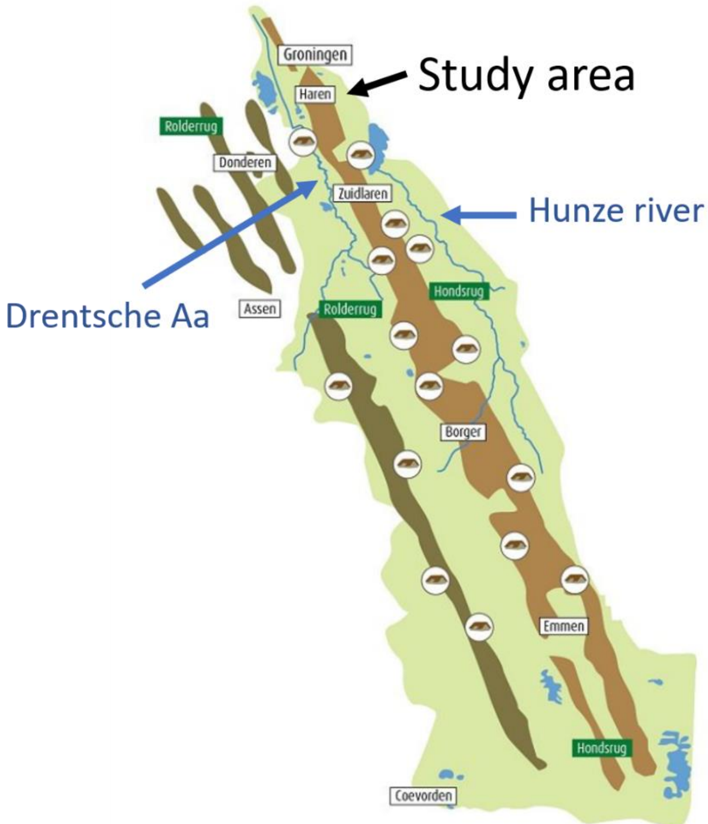

Figure 2. Map of the Hondsrug ridge complex (adapted from Hondsrug geopark website, 2021). Note the locations of the Drentsche Aa, the Hunze, and the study area.

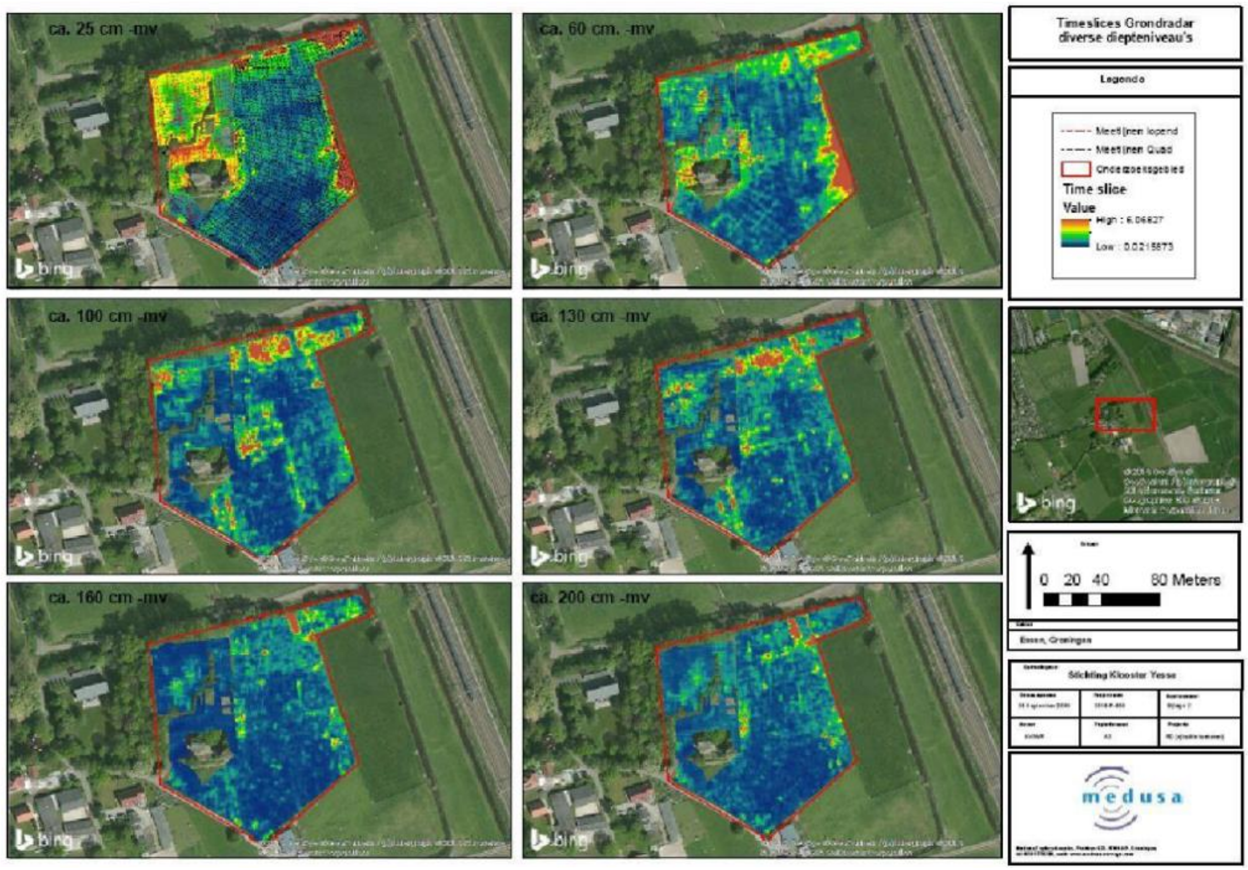

Figure 3. Results from the geophysical survey that was carried out by Medusa in 2016 (Koositra et al., 2018 from Arnoldussen, 2018, figure 10)

What is most intriguing about this area, that has been the main driver behind this MSc thesis research, is that on soil maps (Figures 4 & 5), the soil surrounding the monastery in earlier mapping campaigns has been classified as, and since then has been reckoned to be, a plaggen soil (StiBoKa, 1978; van Dodewaard & Kiestra, 1989). Plaggen soil techniques were not generally applied in the Northern Netherlands until the 16th-18th centuries (Jongmans *et al.,* 2015, p.312), yet here we have a dark soil dating before 1216CE and a monastery that was occupied from 1216-1594CE. These dates are seemingly too early to explain the dark soil as a plaggen soil profile. This was the initial query that sparked interest in the soils of the study area, the monastic site proper and the immediate surroundings, to first identify what soils are present and then to investigate how they vary spatially. This leads us to the research questions.

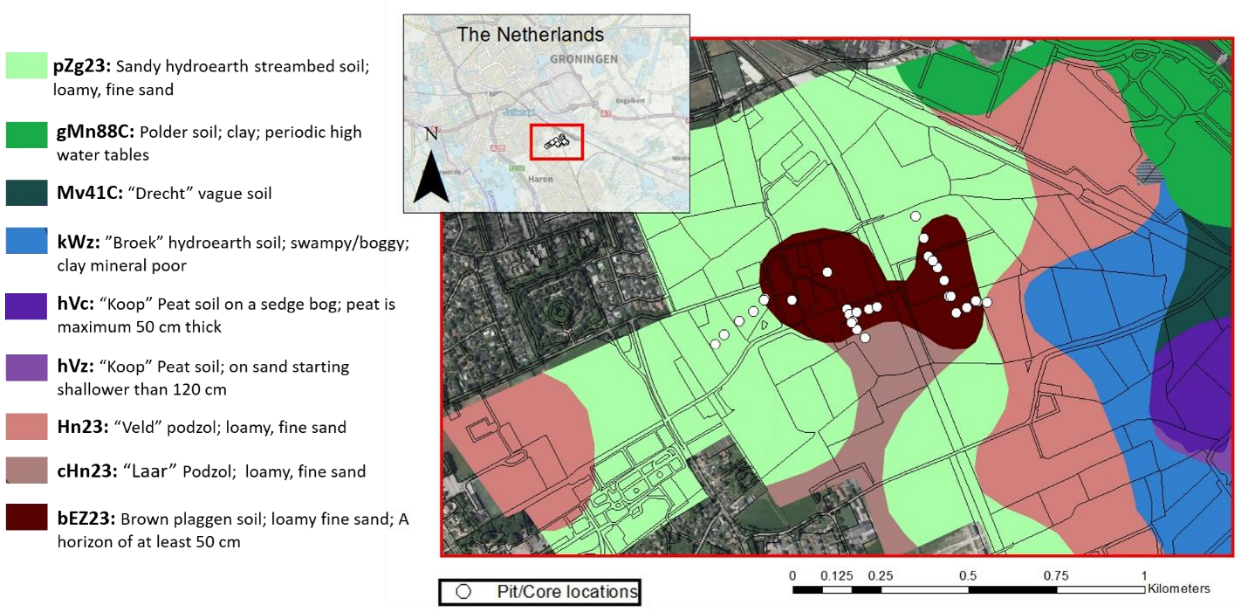

Figure 4. 1:50,000 soil map of the study area, seen in the red square on the map of the Netherlands (Wageningen Environmental research, 2020 based on data from StiBoKa, 1978).

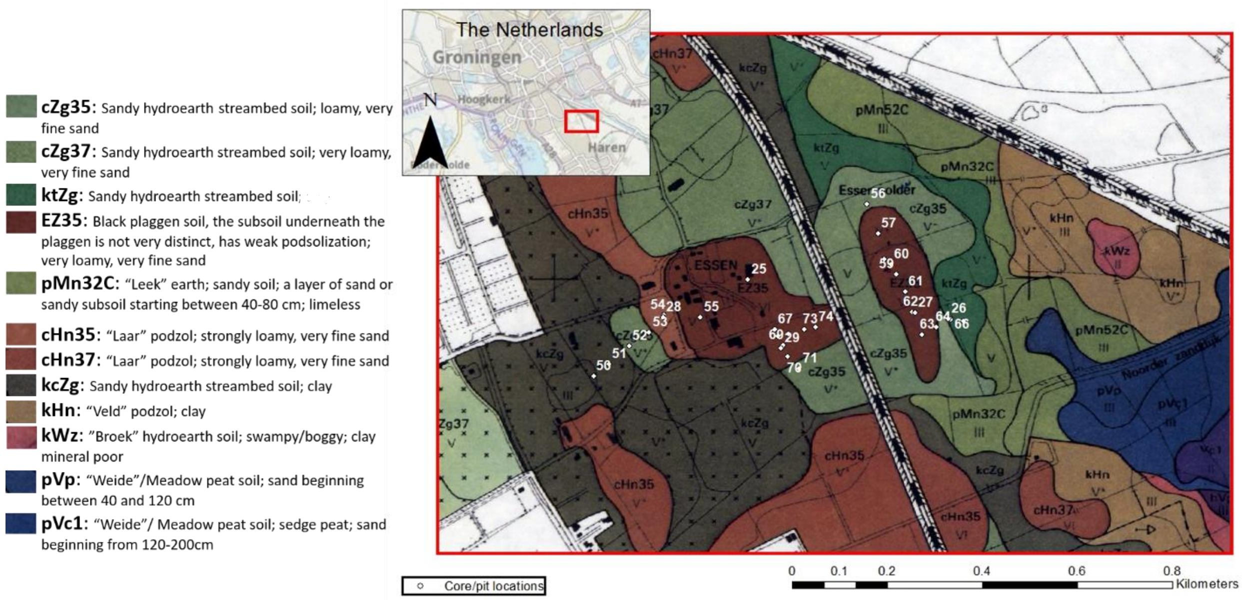

Figure 5. 1:10,000 soil map of the study area (adapted from van Dodewaard & Kiestra, 1989). The soil map view extent is marked with the red box in the map of the Netherlands.

1.2 Research objectives and approach

The research questions for this thesis are the following:

1. Can anthropogenic influence on soils be recognized at the study site?

1.1 Are there any remaining natural soils in the study area?

1.2 How have humans modified soils in this area and to what degree?

1.3 Is the soil around the monastery a plaggen soil?

To address this question, first a literature review was conducted, including a search for past soil maps, to research soil types in the study area, with attention to their classification, the substrates, and soil forming processes involved. The geologic history of the Northern Netherlands was used to understand parent materials of the soils and landforms seen in the field. From the soil maps, fieldwork was planned and transects of cores were outlined in order to observe the transition of soil types over the span of the fieldwork area. Soil profiles were described from boreholes and pits, and samples were collected from soil horizons of pits. Lab work was conducted to gain further insight on soil characteristics such as organic content and multi-elemental analysis. After the fieldwork and lab work, cross sections were constructed to summarize and analyze the differences in soil formation in landscape context. Distance from the monastic grounds and current farmhouses were considered, as it could be related to human influence. From soil descriptions, natural soils were separated from those with heavy anthropogenic modification.

2. What is the spatial architecture of the darkened A-horizons?

2.1 Do they taper out or do they end abruptly at field boundaries?

2.2 Does the distance to monastic grounds influence the degree of human modification or thickness of the A-horizon?

2.3 Is the soil type around the monastery the same as on the raised landform to the east of the railroad - since they fall in the same soil class on soil maps?

To understand how soil profiles change spatially, I considered geomorphological maps and field data, supplemented by geological data sets. Historical maps of the area were collected to identify how land use and field boundaries have changed prior to and after railroad construction, along with how they relate to geologic landforms, which influence parent materials of the soils. Fieldwork allowed for an *in situ* view of the soils. Cross sections have been drawn to span several field boundaries to explore how soils look from one field to another in a more predictive view. Distance to monastic grounds was considered against soil characteristics. Cross sections allowed for the examination of the spatial architecture of the soil horizons, visualizing the natural substrate and the darkened A-horizons. A landform matrix was created to compile information that was gained from field work, lab work, geomorphological and historical maps, along with the cross sections. This matrix summarized how landforms in the study area have changed through time and degree of human modification. Landforms were contextualized to understand if they began as lowland areas that were raised, or high areas that were dug into, etc..

3. Are the soils mapped in the current study replicated in past soil maps?

3.1 Do the implications of past soil maps accurately capture the soil genesis seen from data collected in this high-resolution study?

3.2 What is a dark earth? What is a plaggen soil? How do they differ?

3.3 Is the distinction between a dark earth and a plaggen soil relevant, and what do these terms mean to different fields of research?

Through the literature review, detailed summaries of dark earth and plaggen soils were made, allowing for a comparison. Past soil maps of different spatial resolutions were combined with new data collected in this study to determine if either of the past soil maps are a good representation for the fieldwork area. Soil descriptions from boreholes and pits were used, along with cross sections, to compare to past classifications. Critical assessment of soil maps and soil classifications and related uses were made.

1.3 Thesis outline

Following the introduction of the thesis, there is a background, methods, results, discussion, and conclusion chapter. The background chapter is a literature review that explores the geologic history of the study site at a regional scale, important soil formation factors of the Netherlands, natural soil types that can be expected in the study area, and two types of anthropogenic soils. The methods chapter explains in detail the processes that were carried out for the literature review, fieldwork, lab work, and data analysis. In the results chapter, the major findings of this thesis are explained, where the full collection of data can be found in the Digital Appendix. The discussion of the results and the answers to the research questions can be found in the discussion chapter before the main conclusions are emphasized in the conclusion chapter.

2. Background

2.1 Regional geologic History

To limit this geological summary to the pertaining study area and the most important landscape shaping events for the deposition of parent material of soils that are to be investigated, I will begin the account of regional geologic history at the penultimate glaciation, towards the end of the Saalian Stage, which marked the end of the Middle Saalian. The section mainly covers the glaciation at the end of the Saalian (200,000-130,000 years ago), the Late Pleistocene (130,000-11,700 years ago), and the Holocene (11,700 years ago - present).

The Pleistocene

It was during the coldest periods of the Quaternary, that thick ice sheets originating from Scandinavia occasionally reached across the Northern and Central Netherlands. The first glaciation to leave large-scale recognizable glacial sediments and features was the Elsterian, at which time it left clayey substrate in the Northern Netherlands. The area was overrun again in the Saalian, now reaching further south into the Central Netherlands, where it pushed up sediments at the toe of the advancing icesheet, forming push-moraines. In the Northern Netherlands, notably in our study area, meltwater had difficulty infiltrating the soil due to the clay cap that was deposited from the previous glacial period. Especially towards the end of the glaciation, when the stalled ice mass began to deteriorate, the landscape was dramatically altered through the subglacial deformation of the ground surface. This phase formed the Hondsrug ridge complex, a series of parallel till ridges in the Groningen region, also known as “megaflute” landforms (Figure 2) (Meijles, 2015). This ridge complex stretches From NNW to SSE, straight through the study area, and up to the center of Groningen. Meltwater scoured the lowlands between the ridges to form the original, deeply incised channels of the Hunze and Drentsche Aa river valleys (Figure 2 & 6) (De Hondsrug, 2021b). Today, the sediments deposited from the Saalian are known as the Drente Formation, which is the lowermost sediment group encountered in this region during the fieldwork of this thesis. The glacial deposits consist of till sediments that are a heterogeneous mixture resulting from a series of meltwater events (Figure 6) (Meijles, 2015). The 1-10m thick glacial till consists of grayish blue to brownish fine to very coarse sand that is gravelly, up to boulder size. It can also be loamy or clayey, ranging from very sandy to very silty (TNO-GSN, 2021).

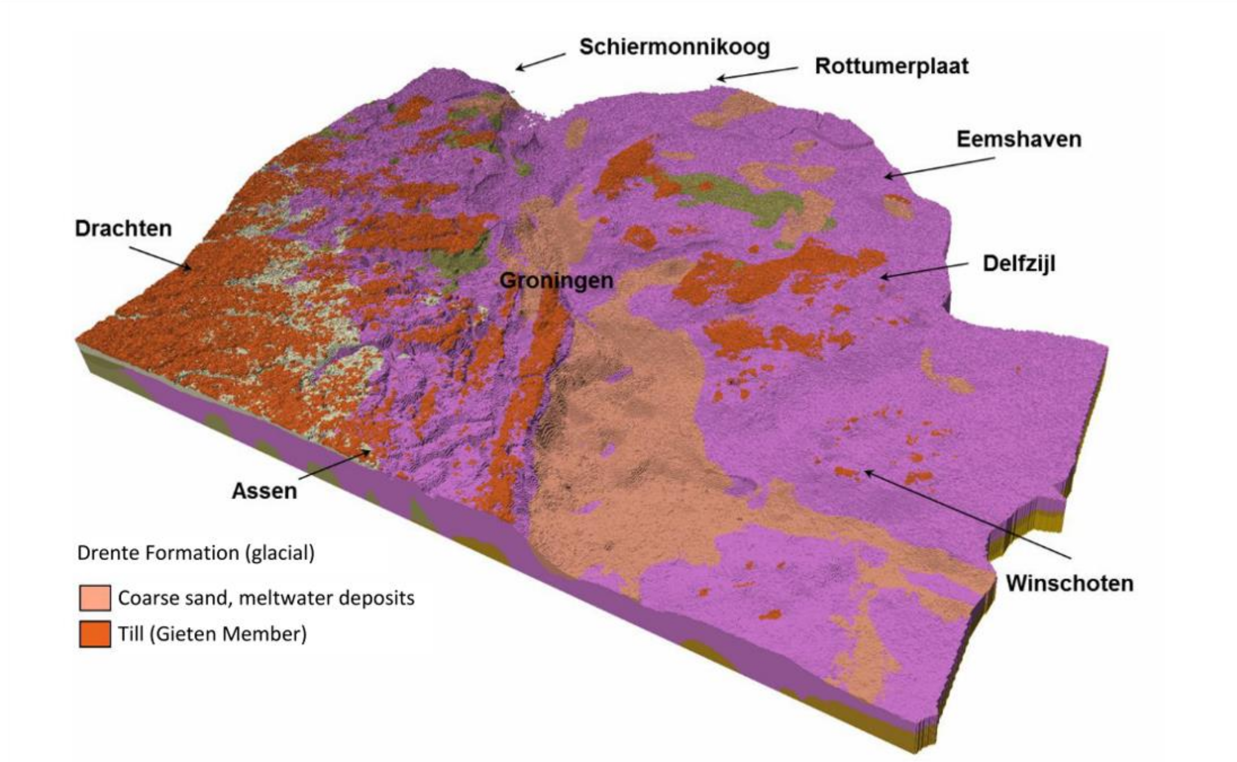

Figure 6. The spatial distribution of the Drente Formation (both the pink and the red) that was deposited during the Saalian Stage (Meijes, 2015, figure 10, taken from the GeoTOP model produced by TNO Geological survey of the Netherlands (2015 beta version)). Note the red ridge extending southward from Groningen, which is part of the Hondsrug ridge complex.

During the following interglacial, the Eemian (130,000-115,000 years ago), sea level was slightly higher than today's due to the melting of the ice caps. The sea spilled into the low-lying regions of Groningen (mainly the east and northeast) and other surrounding areas, especially in the Hunze river valley, where tidal marine sediments (the Eem Formation) were deposited. In the eastern half of the study area, which is the edge of the Hunze valley, this formation of coarse sand and sells with fine sand and clay above can be found as shallow as 15-30m below the present surface (Meijles, 2015).

Land ice did not stretch as far south during the last glacial, the Weichselian (115,000-11,700 years ago) as it did in the Elsterian and Saalian. It did not reach Groningen, but stalled halfway in mainland Denmark. Sea level, though, as in the big glacials before, was much lower than today. The Netherlands was mainly a tundra of pine trees and dwarf birches, sometimes becoming a polar desert nearly absent of vegetation in extreme cases (Meijles, 2015; Vos *et al*., 2020). Rivers incised deeply to compensate for the lower sea levels, and permafrost solidified the ground through the winters. Wind and overland water flow reworked and remodeled the surface locally, eroding parts of the megaflute till ridge in some areas, while remnant hills persisted in others. The resulting landscape from these processes was an eroded surface covered with low-elevation dune sands (the coversand). These sands are locally sourced aeolian deposits during the polar desert climate. The Boxtel Formation - the coversand- lays atop the Saalian glacial till in the study area (Meijles, 2015). The average thickness of this formation is around 2m, but thickness varies widely on local scales due to the local morphology of the aeolian landforms. The coversand deposit is characterized by its light yellow to brown color, comprised of very fine to medium sand that can be silty, loamy, or include thin peat layers (TNO-GSN, 2021).

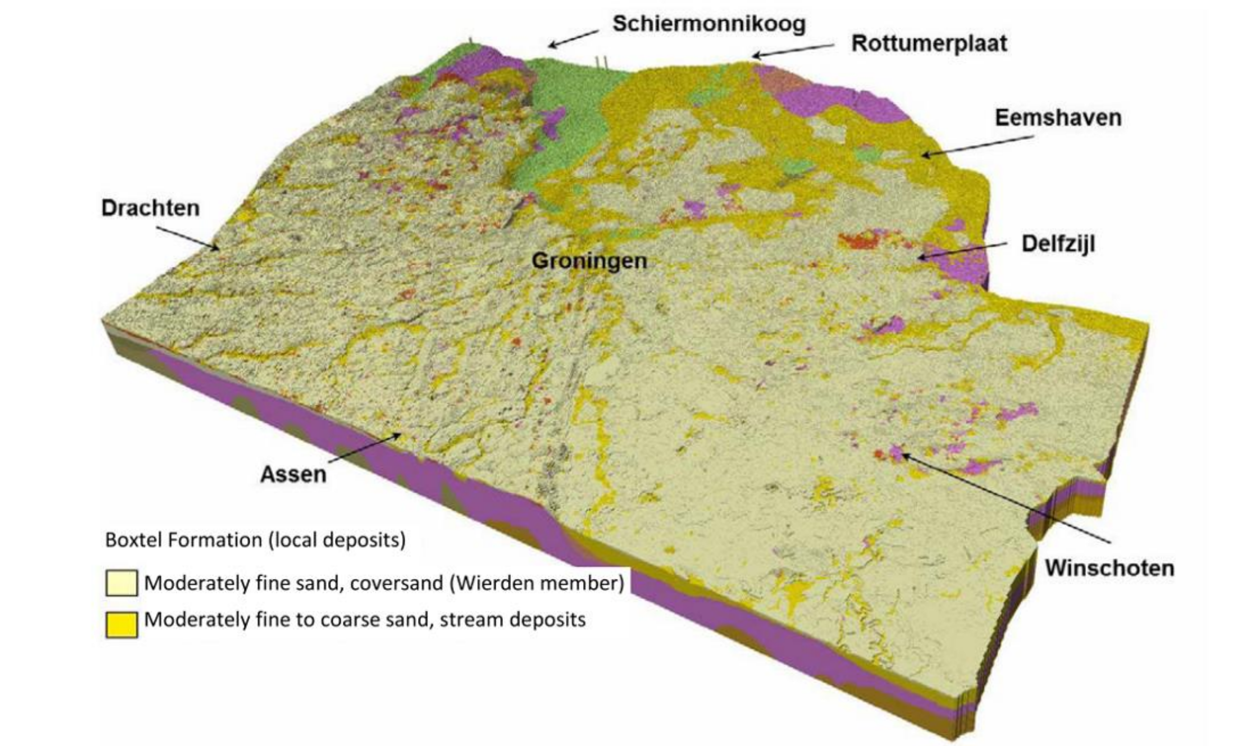

Figure 7. The spatial distribution of the Boxtel formation (light and dark yellow) (Meijes, 2015, figure 13, taken from the GeoTOP model produced by TNO Geological survey of the Netherlands (2015 beta version)). The light yellow, the Wierden member, is the coversand.

The Holocene

The Holocene, which is the current interglacial period, began around 11,700 years ago. Similar as in the Eemian, the Holocene experienced a quickly rising sea level, up to 60-75cm per century by 7,500 years ago, following the melt of major Weichselian ice sheets (van der Spek, 1996; Ruddiman, 2014; Vos *et al*., 2020). The sea transgressed, flooding the northern and western parts of the Netherlands, transforming areas to the northwest of Groningen into tidal flats and elevating the groundwater table in bordering areas, forming wetlands (Meijles, 2015; Vos *et al.,* 2020). Apart from the rising sea level, stagnating groundwaters - largely due to the till cap deposited during the Saalian glaciation - inhibited groundwater drainage as well (Meijles, 2015). Organic material accumulated to form peat in swampy regions (Meijles, 2015; Vos *et al.,* 2020; Wesselingh, 2021). The sea overran the peatland bordering the coastline at the time, around 9,000 years ago, depositing clay and sand via the shifting of channels, beaches, salt marshes, and tidal flats (Vos *et al.,* 2020). Thus, marine and tidal deposits from this period vary spatially. New clastic sediments came largely carried by the North Sea. As sea level continued to rise relative to the land surface, tidal flats were continually shifted further inland. The position of the coast (i.e., the line of barrier islands separating the Wadden Sea from the open North Sea) stabilized around 5,000 years ago (van der Spek, 1996; Wesselingh, 2021), eventually regressing seaward, back towards the North Sea (Figure 8) (Vos *et al*., 2020)

Over Holocene times, the landscape of the Groningen region has gradually seen increasing anthropogenic impacts. Although humans had inhabited the Netherlands since the Pleistocene as hunter-gatherers, and substantial deforestation of suitable high grounds occurred in the Neolithic, Bronze Age, and Iron Age agricultural times, human manipulation of the landscape and water system in the lowland coastal plains of the Northern Netherlands became centrally organized from the Middle Ages (Vos *et al*., 2020). The Northern Netherlands was not part of the Roman Empire; however, by 800CE, this territory was brought into Carolingian Empire (Vos *et al*., 2020). Growing populations put stress on the land, as more space was needed to settle. Peatland was cultivated, reclaimed, and later cut and harvested by people, inducing land subsidence and flooding (Figure 8) (Vos *et al.,* 2020). The sea spilled into the Northern Netherlands again around 800CE as a result of the subsidence of reclaimed land and rising sea levels (Figure 8). Monasteries began to organize dikes constructions starting in the 12th century (Meijles, 2015). The creation of ditches and the draining of salt marshes decreased the groundwater levels. Farmers developed a system of polders in the landscape. Brook and river channels, including the Hunze river, were straightened, dammed, or filled in by farmers to enhance agriculture (Meijles, 2015; Vos *et al.,* 2020). During the 14-17th centuries, the city of Groningen became a regional capital city with a fairly important trading market. Today, the Dutch landscape is one that has been heavily formed by anthropogenic influence (Vos *et al.,* 2020; Wesselingh, 2021).

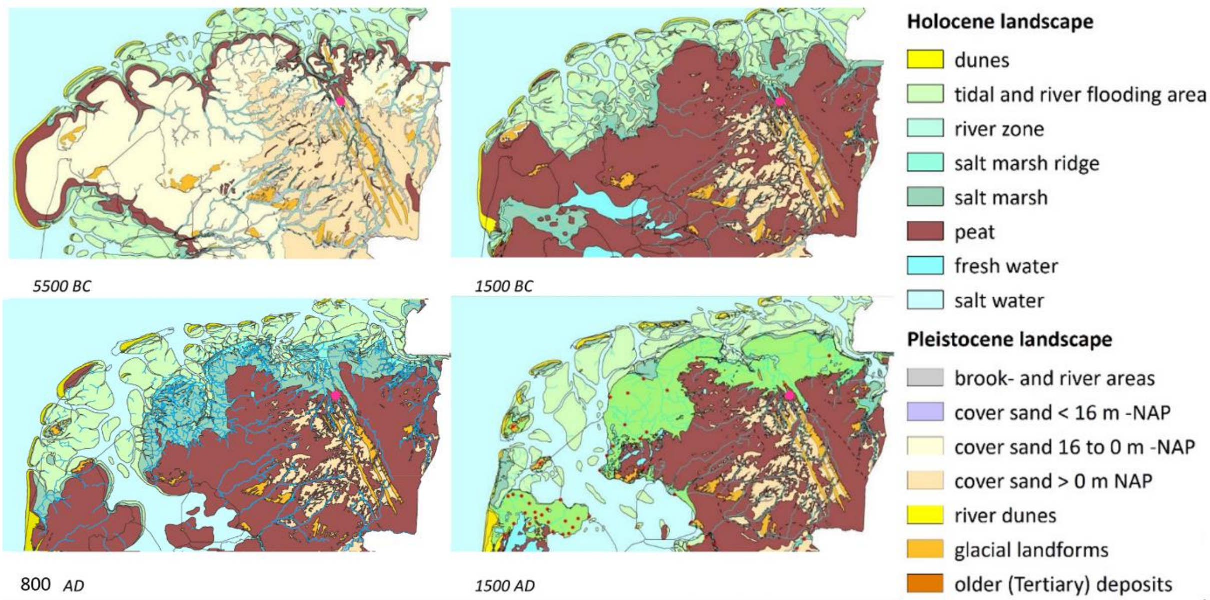

Figure 8. Paleogeographic maps of the Netherlands through time. Study site is indicated with a pink circle. Figure adapted from Meijles, 2015 via Vos, P. & S. de Vries, 2014.

The present-day landscape of the study area reflects the stages of geologic history in the Northern Netherlands. Essen (in Haren) sits where four landforms/landscapes converge. First, there is the till ridge, the megaflute glacial landform from the Saalian, to the southeast, with a coversand drape originating from the last ice age, along with coversands in the surrounding lowlands. The Hunze valley landscape lays to the east, which has been an important drainage channel since the Saalian. These landforms meet the Holocene tidal ingression and flood deposits in the northwest; salt marshes and peaty wetlands that have extended south from the open sea into the lowland brook valleys. All of these landforms then have the overprint of anthropogenic manipulation, as peat has been cut, land has subsided, and hydrology has been artificially managed. These landforms, through the sediments that they are composed of and the geomorphology, have a direct impact on soils that form in this region, via being the contributing parent material and dictating the groundwater saturation state of the soils.

2.2 Soil formation in the Northern Netherlands

The Netherlands is in the mesic class of soil temperature (having a mean annual soil temperature between 8-15 °C) and in the udic moisture regime (de Bakker, 1979). In the Netherlands, soil formation is mainly controlled by the substrate, the temperate climate, and lowland hydrology. As the climate will be the same across the entirety of the (relatively small) study area, differences in soil types are attributed to parent material, hydrology, and anthropogenic influence. Most soils in the Netherlands are relatively young, as nearly half of the Dutch surface is of Holocene origin, where more than ¾ of surficial Holocene sediments are less than 1000 years old (de Bakker, 1979). Resulting from the geologic history of his area, the study site sits in a unique location where four or more lithologies converge (Figure 9). Silty material of marine origin in the north meets fine and loamy fine coversand to the south; loamy fine coversand overlying glacial till (from the Saale ice age) to the west lays adjacent to peat in the east (de Bakker, 1979, figure 2, p. 6).

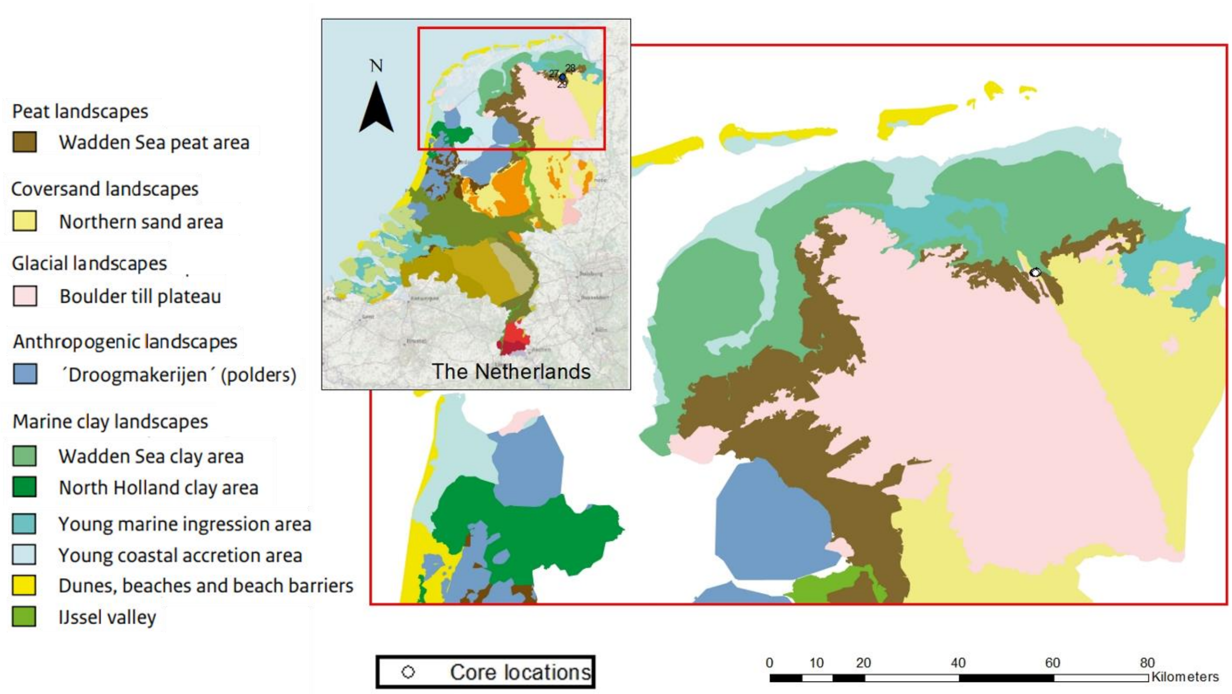

Figure 9. This map shows a partitioning of the Netherlands into 'Main Landscapes', as introduced by the RCE (Rensink et al. 2017). The legend is adapted and restricted to the Northern Netherlands. Study site indicated as "Core locations".

Hydrology, i.e., depth to groundwater table and seasonal variability of this, is very influential when it comes to soil formation in the region, especially given the typically minor differences in elevation above the generally high water table. This also applies to the Yesse area proper, where an impermeable layer of the Elsterian clay and fine-grained deposits of the Saalian till underneath the thin Weichselian coversand - which is especially relevant for agriculture. In the Netherlands, more than ¾ of the country has groundwater starting at 70cm or less below the surface (de Bakker, 1979). Soil descriptions for the area (Figure 4 & 5) frequently mention hydromorphic features, such as mottling and Mn/Fe concretions, seen in the soil profiles in areas that experience water saturation periodically. As soils in this area have undergone different periods groundwater table elevation since the Middle Ages due to land drainage and ditch digging, some profiles can show indications of polygenetic features, or a single genesis with anthropogenic or hydromorphic overprint. Anthropogenic influence will be mainly concentrated in the topsoil (A-horizon), through agricultural practices, dike/ditch formation, or urbanization.

2.3 Site history

The earliest known documented history of the study site begins with the foundation of Yesse Monastery. However, human occupation of the site goes back to at least the Late Roman or Early Medieval age, as a Roman coin (dating to 81-117CE) has been found at the bottom of a pond feature excavated near the center of the monastery (Arnoldussen, p.c.). The location of the monastery was strategically chosen, since it is flanked by the Drentsche Aa in the west and the Hunze in the east (Figure 2) (Kooistra *et al.,* 2019). The advantage of the relatively higher ground and proximity to waterways made this a desirable settlement location, making it logical that humans would have occupied this site prior to the establishment of Yesse as well. During the monastic period, a ditch was dug connecting the monastic grounds to the Hunze river for easy transportation. The monastery was built on a dark earth horizon that sits atop the coversands of the Boxtel Formation, which drapes the glacial till of the Drenthe Formation (Kooistra *et al.,* 2019). The dark earth horizon is thought to originate from the Early or Full Medieval Era; however, little is known about its formation. From the current surface level, which differs from the monastic-period surface level due to construction debris and other anthropogenic additions to the surface, the pre-monastic dark earth sits between 30 and 100cm below the surface (Arnoldussen, p.c.). The surrounding ~5ha around the monastic foundations has been classified as a plaggen soil on soil maps (Figure 4 & 5) (StiBoKa, 1978).

Yesse was a Cistercian women's monastery that was built in Haren, the Netherlands, around 1215CE (consecrated in 1216CE) (Mirabile Dictu, 2021). It quickly grew to be quite prosperous and self-sustaining, generating revenue via renting out farmland. Because of the reporting of several miracles at Yesse, the monastery became an important site of pilgrimage (Mirabile Dictu, 2021). Yesse monastery was a peaceful place until the 16th century, when it saw several occasions of ransacking by locals during times of famine and occupations by military forces during several war campaigns (Kooistra *et al.*, 2019). Finally, in 1594, the nuns were forced to abandon the monastery to seek refuge, and the monastic buildings were torn down to be recycled as construction materials. By 1871, a railroad appeared on the maps, built in the 1860s within 90 meters of where the monastery stood and cutting across grasslands and agriculture fields.

Today, nothing remains of Yesse monastery, save foundation walls lying below the current-day surface (Figure 3). A small museum, run by a local inhabitant, has been set up to showcase finds and the history of the monastery. A series of farms, mainly sheep farms, and private residences exist in this location (Figure 10). The University of Groningen has been using this area to teach first-year archaeology students excavation techniques since 2010. There is a large local interest in the history of this region.

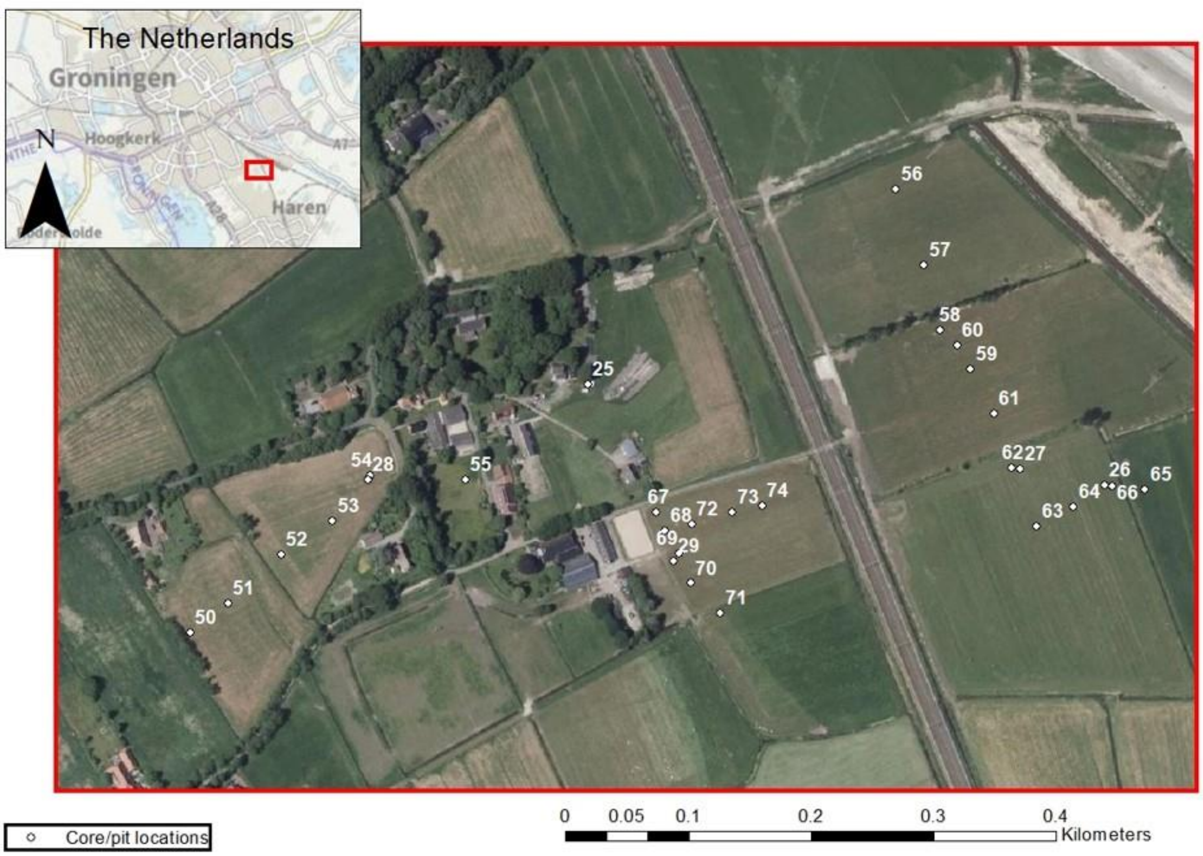

Figure 10. Aerial view of the study area with locations of boreholes.

2.4 History of soil mapping in the Netherlands

Soil maps

Geological mapping began as early as 1822 in the Netherlands; however, the map produced at this time lacked sufficient detail since it divided the country into only two legend items, roughly Southern Limburg and the rest of the country (Hartemink & Sonneveld, 2013). Several mapping surveys have been undertaken since then, although the earlier ones focused mainly on geology for agricultural purposes and had a low spatial resolution. Starting in 1952, the Dutch Soil Survey Institute (StiBoKa) began mapping the whole of the Netherlands under the Edelman approach, which focused on geology and landscape, as opposed to the previous method by Staring which was mainly concerned only with surface topsoil (Hartemink & de Bakker, 2006). Despite over a century of soil mapping, it wasn't until the 1960s that the Dutch Soil Classification System was created. This classification system emphasizes characteristics of pedogenesis, parent material, and hydromorphic features (Hartemink & de Bakker, 2006). The system is divided into four levels: order, based on pedogenic processes; suborder, based on hydromorphic features and ripening; group, categorized by parent material and organics; and lastly, subgroup, based on characteristic soils (Hartemink & Sonneveld, 2013).

A series of 24 regional 1:10,000 soil maps (Figure 4) were produced between 1948-1969, mainly by PhD students, to depict landscapes of historical farming and reclamation regions. These were the first maps to relate landscapes to historical anthropogenic land use (Hartemink & Sonneveld, 2013). Between 1964 and 1995, the Soil Survey Institute published 110 sheets of soil maps covering the whole country at a scale of 1:50,000 (Figure 5) (Hartemink & de Bakker, 2006) based on soil properties, rather than landscape genesis (Hartemink & Sonneveld, 2013). The creation of these maps required a lot of manpower for surveying and recording, and hence, no national-scale map survey has been completed since this series. Two campaigns were initiated in the early 2000s, but weren't successful in completing the survey. There is a need for updated soil maps at a high spatial resolution for policy makers, researchers, and farmers, among others, since there have been significant changes to groundwater levels, reclaimed areas, and areas with other anthropogenic impacts such as urbanization. Starting in 2003, geologic/soil maps became digitized and available online. For a full history of soil mapping in the Netherlands, readers are referred to Hartemink & Sonneveld (2013).

Archaeological landscape maps

In a 2017 report, the Cultural Heritage Agency of the Netherlands (RCE) (Rensink *et al.,* 2017) presented a new map, combining physical geography and archaeological features, that can be visualized in two ways: a 26-landscape map (Figure 9) and a 39-landscape zone map (Figure 11). The purpose of this map is to help with archaeological inventory and analysis and to assist a new project of the RCE's to create a national map with more detailed geologic, hydrologic, and sedimentological data. In the report, they define a landscape as "an area that can be characterized by a specific landscape genesis and its own distinct occupation history, where the set of differences within the landscape is smaller than those between this and other landscapes" and a landscape zone as being "a geomorphological unit within one (or more) landscape(s)" (Rensink *et al.,* 2017). The base for the aforementioned maps was the digital Geomorphological Map of the Netherlands in the 1:50,000 scale, with built-up area and water being left blank. Each landscape has a description which includes i) landscape, ii) boundaries, iii) relationship to adjacent landscapes in other countries, iv) soil, subsurface and hydrology, and v) archaeology. The main principle behind these maps is that historically (and in ways, even today) the landscape has limited or enabled anthropogenic activities/settlement, and therefore these two are spatially intertwined.

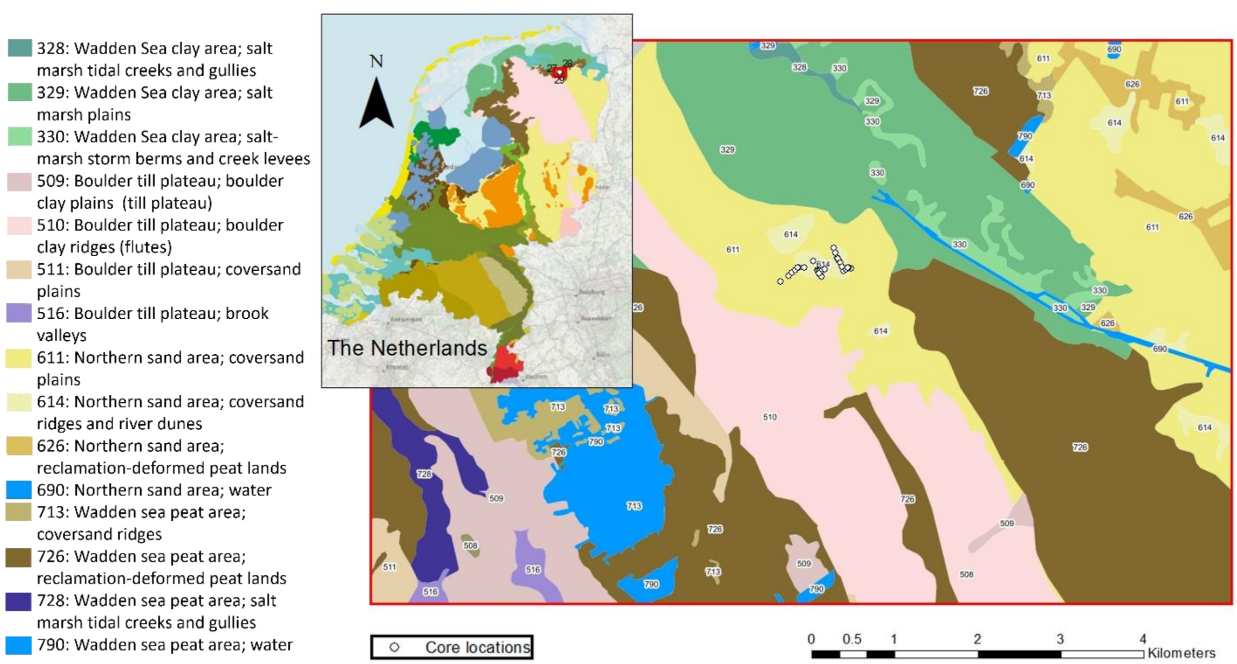

Figure 11. This map shows a partitioning of the Netherlands into 'Landscape zones', as introduced by RCE (Rensink et al. 2017). The legend is adapted and restricted to the Northern Netherlands. First digit of code refers to 'Main landscape' of Figure 9, further digits refer to the landform (e.g., compare 511 and 611). Core locations identify the study site.

2.5 Important natural soils for the study region

Podzols

A podzol is a classification of a specific type of natural soil found in wet climates on poor, nutrient-deficient soils - usually developing on well-drained sandy parent material in forests or heathland (Jordanova, 2017). Podzols are most noted for an ash-colored eluvial (E) horizon below the organic-rich A-horizon. Organics, Al^{3+}, and Fe^{3+} are leached from the E horizon and precipitated into the B-horizon below, resulting in the typical red-brown or gray-black color of the B horizon. The podzolization process is relatively quick and can be visible in as little as 40 years (Jordanova, 2017). Organic acids in soils facilitate this process (Retallack, 2005). The Dutch Soil Classification System recognizes two different subgroups of podzols in the map area from van Dodewaard & Kiestra in 1989 (Figure 4); “Laar” and “Veld” podzol soil.

The “Laar” type has hydromorphic features high up in the profile due to periodic or permanent saturation of groundwater (Figure 4, cHn35, cHn37; Figure 5, cHn23). The A-horizon is between 30-50cm and has been supplemented with sod fertilization. The B-horizon is noted to be rich in humus. “Laar” podzols are commonly found in Pleistocene sands or in reclaimed land (van Dodewaard & Kiestra, 1989).

The “Veld” (or “Field”, in English) podzol is the most common type of podzol in the Netherlands and usually forms in heathlands (Figure 4, kHn; Figure 5, Hn23). It also contains hydromorphic features high up in the soil profile from past water table fluctuations. The A-horizon is mineral-poor and contains bleached sand grains due to leaching. This type of podzol is usually lacking an E-horizon, and instead has a gradual transition to the B-horizon. The most important factor for soil formation in “veld” podzols is high groundwater (van Dodewaard & Kiestra, 1989).

Sandy hydroearth streambed soils

Sandy hydroearth brook soils are termed “Beekerdgronden” under the Dutch Soil Classification System (Figure 4, cZg35, cZg37, ktZg, KcZg; Figure 5, pZg23). This type of soil is usually found in stream or brook valleys and is characterized by an organic-rich horizon that transitions to a nutrient-poor coversand C-horizon. Hydroearth soils have oxidation features due to fluctuating water tables. There are two main types of Beekerdgronden: zwarte (black) and bruine (brown). The black sandy hydroearth streambed soil originates from the Pleistocene and contains a layer of clay with a black-colored A-horizon. Whereas the brown type gets its name from the brown A-horizon that is between 25-40 cm thick and contains some clayey loam. Typically, black sandy hydroearth streambed soils show more signs of oxidation than its brown counterparts (van Dodewaard & Kiestra, 1989).

"Leek" earth soils

"Leek" earth soils are a subgroup of hydroearth soils in the Dutch System. They have sandy clay to clay texture, a thin (maximum 30 cm) A-horizon, and iron mottles in a reduced, gray matrix within half a meter from the surface. In the 1989 soil map (Figure 4) (van Dodewaard & Kiestra, 1989), the "Leek" earth soil was noted to have a layer of sand between 40 and 80 cm and to be non-calcareous.

"Broek" earth soils

The "Broek" earth soil is a subgroup of the Peaty earth soil group in the Hydroearth soil suborder (Figure 4 &5, kWz). It is described as having a thin, swampy A-horizon, permanent or periodic high groundwater table, and usually forming in stream valleys of Pleistocene sands. They can be muddy or have a loam or clay cover (van Dodewaard & Kiestra, 1989).

"Weide" and "Koop" peat soils

A "Weide" peat soil is a meadow/pasture peat soil and is from the suborder of raw peat (Figure 4, pVp, pVc1). This type of peat soil has a <20 cm thick, dark-colored A-horizon with a loam or clay cover, where the mineral part of the profile doesn't exceed 40 cm thick. A "Koop" peat soil has an A-horizon maximum thickness of 50 cm of clayey peat or peaty clay (Figure 5, hVc, hVz). They often have a cover of material from ditches, waste, manure, and/or stable bedding (van Dodewaard & Kiestra, 1989).

"Drecht" and "Polder" vague soils

"Drecht" vague soils fall under the Clayey hydrovague soils group in the Vague soils order (Figure 5, Mv41C). These soils have a clay cover above a peat horizon that starts between 40-80 cm deep. The peat layer is thicker than 40 cm and the clay layer is usually calcareous. Periodic high groundwater results in the precipitation of iron (III) minerals (gleyic features) in the peat and iron mottling in the clay cap. In "Polder" vague soils (Figure 5, gMn88C), soils are loamy and clayey with periodic water table fluctuations. There is no peat within the first 80 cm, nor is there a dark A-horizon. Clay and sand layers can occur, and soils can contain lime or be non-calcareous. This subgroup of soils contains all basin and young marine clay soils (van Dodewaard & Kiestra, 1989).

2.5 Anthropogenic soils: Dark earth

Definition

The European “dark earth” is a commonly found soil horizon in urban stratigraphy. These soils are characterized by their homogeneity, dark color, poor stratification, thickness, and abundance of organics; however, an exact definition has been heavily debated (Heimdahl, 2005; Devos *et al*., 2009; Devos *et al.,* 2013; Devos *et al*., 2017; Nicosia *et al.,* 2017). It is important to note that “dark earth” is not a soil classification nor an archaeological interpretation, and it should not be confused with the “Amazonian dark earth” (Devos *et al.,* 2017; Nicosia *et al.,* 2017). Some researchers have defined it as a level between two periods, specifically the Roman and the Medieval cities, placing the formation of the dark earths between the 5th and 11th centuries (Devos *et al.,* 2009; Devos *et al.,* 2017; Nicosia *et al.,* 2017). Others have modified this definition to include any unit that is dark, thick, and homogeneous, representing a transition period between any two instances of human occupation on a site (Devos *et al.,* 2009).

Further authors have created a broader definition by excluding the criterion of spanning a specific period between two settlements, such as Heimdahl’s definition of a dark earth as a dark, 20-70 cm thick horizon that is poorly stratified and found on archaeological sites, usually related to urban decline (Heimdahl, 2005, p. 16). Usually in Scandinavia, the term is applied to organic-rich occupational layers (Heimdahl, 2005, p. 17). Devos *et al*. (2009) outlines the requirements as being “dark, humus-rich, non-peaty, homogeneous units, with a straight to undulating, abrupt to clear, more or less horizontal base”, with a minimum thickness of 10 cm that ranges up to several meters. In another paper, Devos *et al.* (2017) added the inclusion of anthropogenic remains, such as charcoal, ceramic, bone, and coprolites, regardless of the age or geographic location of the unit. More recently, Devos (2021) has added “that cover large surfaces” to his official description. These latter definition focuses more on horizon characteristics than regions and timespans, since dark earths have now been found to extended beyond regions that were included in the Roman Empire, such as in Sweden and Russia, and outside of the previously attributed time frame (Devos, 2021). Devos (2021) emphasizes that the most important trait is homogeneity when identifying a horizon as a dark earth, as color can vary greatly. The criteria of what constitutes a dark earth seems to be ever evolving as the study into these anthropogenically-influenced horizons continues, highlighting the range of appearance and factors of formation.

To date, there is no literature found on dark earths of the Netherlands, despite the probable occurrence of them. This present research (and my earlier internship report; Steensma, 2020) will be some of the first mentions of a dark earth unit in this region.

Formation

Although researchers have difficulty coming to a consensus on the definition, it is agreed upon that the genesis and contributing human activities to the resulting dark earths are complex (Devos *et al*., 2009; Devos *et al*., 2017). In Europe, dark earths are thought to be formed during soil formation processes on Roman building debris during a break in urban activity, while by contrast in Scandinavia, dark earths are attributed to initial states of urban development (Heimdahl, 2005, p. 18). Some dark earths form on top of Roman settlements, but not in every case (Devos, 2021). Other activities that have been credited to dark earth formation have been cultivation, cattle grazing, middening, waste dumps, *in situ* deposition of construction materials, and other anthropogenic activities along with natural alluvial/fluvial and soil formation processes (Heimdahl, 2005, p. 16-18; Nicosia *et al.,* 2017; Wouters *et al.,* 2017; Devos, 2018; Devos, 2021). The rate of formation depends on the activities attributed to the dark earth, whether material was dumped all at once, continuously, or in stages.

Soil formation processes during and after the time of human activity and the subsequent period also play a role in the appearance of dark earth horizons. Secondary mineral formation is common, including carbonates, iron/manganese hydroxides, and phosphates. Calcite nodules or hypocoatings form from the dissolution of calcite from the parent material, ashes, plaster, or mortar. Earthworms also leave behind calcite granules as waste material. Iron and manganese stains or nodules can form on organic tissues or roots. Secondary phosphates originate from plant decomposition, excrements, ashes, remains of animals, or of natural soil materials. The presence of vivianite is indicative of waterlogged conditions. Weathering of construction materials, such as plaster, loam, or clay can lead to the release of minerals and sand grains into the soil matrix (Nicosia *et al.,* 2017).

Bioturbation is an important contributor to the formation of dark earth. Factors contributing to the homogeneous nature of the horizons have been noted as bioturbation from earthworms, rodents, insects, or roots (Heimdahl, 2005; Nicosia *et al*., 2017). Digging, burrowing, and root growth lead to the lack of internal stratification. Biological activity can also fragment artefacts or organics, such as charcoal (Nicosia *et al*., 2017). Usually, bioturbation indicates open-air spaces, subject to the elements. Wouters *et al*. (2017) and Devos (2021) used evidence of bioturbation, among trampling and construction debris, to theorize that the site of Grand Place used to be an outdoor market in early Brussels.

Since dark earth formation is a complex interplay of human actions and natural soil formation processes, they offer insights into both categories. Dark earth units most often represent multiple superimposed anthropogenic activities alongside natural soil formation processes and therefore it is important that they be studied individually (Devos *et al*., 2017; Devos, 2018). Dark earth analysis enables the study of long timespans, showing an evolution of the landscape, spatial organization, and often depicting a sequence of events. Because of this, dark earth studies are important to reveal information about early urban development and sequences of use of space (Devos, 2021).

Analysis techniques

Several techniques have been applied to understand the formation of dark earths, including archaeobotany, (archaeo)pedology, micromorphology, physio-chemical analysis, and phytolith analysis (Devos *et al*., 2009; Devos *et al.,* 2017; Nicosia *et al,* 2017; Wouters *et al.,* 2017). Devos *et al*. (2009) performed archaeopedology and phytolith analysis at Rue de Dinant in Brussels. Through phytolith analysis, they discovered many phytoliths produced by crops, thereby suggesting the dark earth layers to result from an ancient cropland. They also found evidence for manuring with household waste via inclusions of bone, dung, and ceramic fragments. Chemical analysis supported their assumption since these horizons had elevated levels of phosphorous and organics combined with a low C/N ratio, which they note indicated agricultural activities (Devos *et al.,* 2009). Signs of other anthropogenic activities were found in the dark earths of Rue de Dinant as well, such as construction material wasting from the dumping of wall or floor remnants.

Soil micromorphology has also been applied to dark earths to determine anthropogenic activities (Devos *et al.,* 2013; Nicosia *et al,* 2017; Steensma, 2020). Phytoliths found in thin sections can be analyzed to determine the type of environment - pasture or grassland, for example - similar to phytolith analysis outside of micromorphology (Nicosia *et al*., 2017). Micromorphology slides can also contain coprolitic material or secondary phosphates, which can indicate manuring activities or cesspit/latrine dumping. Often, coprolites can be identified to a species level, revealing use of space as domestic human occupation, animal domestication, cultivation practices or other anthropogenic activities. Vivianite is easily seen under the microscope and signals waterlogging. Silica slag from heated phytoliths can show plant burning as fuel. Food wastes can be seen, such as eggshell, charred seeds, or animal bones, giving an indication of diet at the time along with use of space as a hearth/cooking area or a dump of household waste. Metal and glass slags in thin sections could suggests metallurgy or other workshop activities. Building materials can be seen at microscopic level, including brick, loam, lime plaster, and burnt mollusk shells (Nicosia *et al,* 2017; Steensma, 2020).

Another technique that has been employed in anthropogenic soils in general, including dark earths, is physio-chemical/multi-elemental analysis (Wilson *et al.,* 2007; Wilson *et al*., 2008; Misarti *et al.,* 2011; Mikołajczyk & Milek, 2016; Devos *et al.,* 2017). Certain assemblages of elements or ratios, usually not any singular element, can indicate specific human activities or anthropological use of space across a spatial pattern (Wilson *et al.,* 2007). Elements that have been found to be useful indicators include Al, Ba, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, Sr, Ti, V, and Zn (Wilson *et al.,* 2007; Wilson *et al*., 2008; Misarti *et al*., 2011; Mikołajczyk & Milek, 2016). For example, enhancements of P, Zn, Cu, Mn, and N in respect to natural soil background levels have been linked to the presence of fecal matter. Similarly, elevated concentrations of P and N can also be derived from bone and organic waste, Ca can result from bone or the breakdown of lime plaster, Mg can be related to fish and bird bone or wood ash, K from waste and wood ash, and Ca and P are typical for marine shells (Wilson *et al.,* 2008; Misarti *et al.,* 2011; Mikołajczyk & Milek, 2016). Heavy metals such as Hg, Cu, Pb, and Zn suggest artisan activities such as metallurgy (Cook *et al.,* 2005; Mikołajczyk & Milek, 2016). Devos (2018) opted for phosphorus analysis of the dark earth in Brussels as a quick method of characterizing the deposits. Phosphorus analysis is based on concentrations of near total, inorganic (from bones, or wood and plant ash) and organic (from plant remains and manure) phosphorus (Devos, 2018). Devos (2018) found different near total (Pnt), inorganic (Pi), organic (Po), and ratios of Pnt/Pi and Pi/Po for different anthropogenic activities. As an example, natural soils had a Pnt of 895ppm, while stables had shown a Pnt of 20,272 ppm and latrines had a value of 31,599 ppm (Devos, 2018). For a more comprehensive summary of element analysis, refer to Table 1.

Element enrichment in soils depends on many factors, such as the intensity and time period of deposition process, along with natural soil processes after deposition, including solubility of the element. Many elements/compounds are easily transported, leached, and are subject to bioturbation, affecting spatial distributions and concentrations (Wilson *et al.,* 2007). Furthermore, several anthropogenic activities or organic materials can be represented by similar combinations of elements, which makes interpretation a bit challenging (Wilson *et al.,* 2007). In order to increase confidence in attributing geochemical signatures to human influence, it is important to compare enhancements or depletions relative to the natural soil background to gain insight into natural processes (Wilson, 2007; Oonk *et al.,* 2009).

Table 1. Summary of indications of anthropogenic activities separated by analysis technique of dark earths. This table was made from compiling information from Cook et al., 2005; Devos, 2018; Devos, 2021; Devos et al., 2004; Devos et al., 2013; Devos et al., 2017; Mikołajczyk & Milek, 2016; Misarti et al., 2011; Nicosia et al., 2015; Nicosia et al., 2017; Oonk et al., 2009; Wilson et al., 2008; and Wouters et al., 2017. This table of indications is not exhaustive.

	Soil Micromorphology	Pollen and macro-botanical analysis	Phytolith analysis	Multi-element analysis	Phosphorus analysis
Domestic waste dumping	Ash, charocal, charred seeds, burnt and unburnt bone, eggshell, ceramics, excrement, secondary phospahtes, normal and vitrified phytoliths	Charred or carbonized cereal grains	Silica slag	Enrichment of P and N (manure, bone, organic waste), Ca (bone), Mg (fish and bird bone, wood ash), K (waste and wood ash), Ca and P (marine shells)	Ash has high Pnt (10,523 ppm) and Pi (10,523)
Cess/latrine	Coprolites, ash, parasite eggs, secondary phosphates, vivianite	Mineralized seeds, including fruit seeds		Enrichment of P, N, Zn, Cu, and Pb	Elevations of Pnt (31,599 ppm) and Pi (31,286 ppm) with a Pi/Po of 67,137
Industrial/artisan production/metallurgy	Metal slag, ash, vitrified ceramics, metal fragments, charcoal, burnt/rebified soil, glass, silica slag			Enrichment of P, Fe, S, Cu, Hg, Pb, and/or Mn	
Construction/ destruction waste	Mortal, plaster, brick, charcoal, turf, loam			Enrichment of Ca	
Animal waste/ manure	Mineralized carnivore (dog) and omnivore (human) coprolites, omnivore (pig) and herbivore (cattle, sheep/goat, horse) dung, layered phytoliths/organics (stabling)	Spores of coprophilous fungus Sordaria (herbivore dung)	Clustered or isolated phytoliths of plant food remains	Enrichment of P, N	
Grassland	Articulated/isolated phytoliths	Poaceae (grasses) pollen	Grass phytoliths	Enrichment of Sr and Ca	Pnt near 1073 ppm and Pi of 982 ppm with a Pi/po of 10,791
Crop cultivation	Articulated/isolated phytoliths, coprolitic material (manure), randomly districubuted domestic waste (ceramics, charcoal, bone)	Cerealia-type (cereals), Humulus(hops)/Cannabis, Triticum-type (wheat), Avena-type (oat), Hordeum-type(barley), Centaurea cyanus-type (cornflower), Sclerathus annulus (a type of weed) pollen	Isolated or articulated phytoliths from crop species	Enrichment of Sr, Zn, P, and/or Ca	Pnt around 2981 and Pi of 2712 ppm, with a Pi/po of 10,119
Outdoor market	Bioturbation, construction debris, trampling, weathered anthropogenic remains (bone, shell, limestone, pottery fragments), dusty clay coatings, plant remains, variety of materials of different origins, vivianite	Macro plant remains (chaff, seeds or fruits, nuts)			
Gardening	Articulated/isolated phytoliths, coprolitic material (manure)	Garden plant species macro-remains and pollen	Articulated or isolated phytoliths of garden plant species and weeds	Enrichment of Sr, Zn, P, and/or Ca	Pnt around 4461 ppm and Pi/Po of 20,452
Occupation/floor layers	Trampling (compaction, preferential orientation), loam/lime plaster layers, food waste, ash			Enrichment of P, K, Al, Mg, and Ti (indicate hearths); Na, K, P, Ca, and Mg with low levels of metals (indicate kitchen areas); Ca and Sr (in prehistoric soil floors); Ba, Fe, and Na (ovens)	
Stabling/pasturing	Coprolites, ash, horizontal layering of plant remains (mainly grasses), phytoliths, micro-charcoal	Ruderal and nitrophilous plants (Cenopodiaceae, Artemisia, Rumex, Plantago lanceolata type, Ranunculaceae) spores of coprophilious fungus Sordaria	Horizontally articulated grass phytoliths	Enrichment of Sr, Cu (attributed to livestock), Zn (attributed to livestock), P, and/or Ca	High levels Pnt (20,272ppm) and Pi and Pi/Po of 9391
Burial					Pnt of 2818 ppm and Pi/Po of 43,031

2.6 Anthropogenic soils: Plaggen soils

Plaggen agriculture is a land-use technique that has been used for over 3000 years throughout Ireland, Scotland, the Netherlands, Belgium, and parts of Germany; especially gaining popularity since the Middle Ages, to supplement nutrients in the agricultural topsoil (Blume & Leinweber, 2004; Giani *et al*., 2014). Plaggic soils have also been reported in Russia, Denmark, and Norway (Giani *et al.,* 2014). Plaggen soils are termed “Enk earth” in the Netherlands (Figure 4, EZ35), “Plaggenesche” in Germany, “Plaggenthrept” by the USDA, and internationally they are known as “Plaggic Anthrosols” (Pape, 1970; Blume & Leinweber, 2004; Giani *et al.,* 2014). For this soil enrichment technique, 25-30 cm turf squares were cut from heather or grassland that were around 3 cm thick. The sods were laid in stables as animal bedding, mainly for sheep and cows, before they were placed in agricultural fields as manure (Pape, 1970; Blume & Leinweber, 2004; Bokhort *et al*., 2005; Giani *et al*., 2017). Plaggen agriculture in the

Netherlands didn't begin largescale until 1350-1450CE in the southern Netherlands and a few centuries later in the Northern Netherlands, between 1500-1700CE (Jongmans *et al.,* 2015, p.312). Typically, plaggen soils in the south are 70-120cm thick, while in the north they are only 35-60cm thick (Jongmans *et al.,* 2015, p.315). This technique fell out of practice with the introduction of artificial fertilizers (Bokhorst *et al.,* 2005; Giani *et al.,* 2014; Pape, 1970). It has been estimated that up to 30% of sandy soils had been covered with plaggen in the north (area of the study site), east, and middle of the Netherlands (Pape, 1970). More than 221,000 ha have a plaggen cover of over 50 cm and at least 196,000 ha are covered with 30-50 cm of plaggen according to Pape (1970).

The practice of plaggen alters the landscape in many ways. The surfaces of plaggen fields are elevated by as much as 130 cm, while areas where sods have been cut could have up to 2m of elevation removed (Blume & Leinweber, 2004). Groundwater levels could rise and fall respectively in areas with elevation gain or loss. In areas where plaggen turves were removed, erosion was common due to the consequent lack of vegetation, especially if these areas were also overgrazed (Blume & Leinweber, 2004). Due to this erosion, plaggen soils are often found alongside sandy dune land (de Bakker, 1979). It has been calculated that up to 7.5 ha of heathland was needed for heather sods to sustain a farm of 1 ha (Pape, 1970). Others have estimated from 10 ha up to 40 ha of heathland needed per 1 ha of arable land (Giani *et al.,* 2014). Therefore, this process resulted in a large amount of wasteland. Due to the damage of the surrounding landscape, some regions imposed restrictions on the practice or forbid it outright (Blume & Leinweber, 2004; Giani *et al*., 2014).

Typical plaggen soils are characterized by a dominance of sand, black to dark gray or brown color, >50 cm thickness, and an organic carbon content of more than 0.6% (Blume & Leinweber, 2004). Plaggic horizons have a soil texture ranging from sand, loamy sand, sandy loam, to silt loam, or possibly a combination of these classes (F.A.O., 2006). The lower part of the horizon might contain parent material mixed in (Blume & Leinweber, 2004) or lay atop a buried soil (Pape, 1970). Other key features listed by the F.A.O. (2006) are spade marks and raised land surfaces, since this is a man-made soil. Colors can range from black to dark gray in sandy parent material to dark brown to yellow originating from loamy sands (Blume & Leinweber, 2004). Color differences have also been attributed to differences in sod materials; gray originating from heathland and forest litter and brown from grassland and willow (Giani *et al*., 2017). Heather sod parent material is characterized by high C-N ratios, while grass sods contain a low C-N ratio; they retain these relative characteristics despite the added nitrogen from manuring (de Bakker, 1979). The type of sod used can also be determined from pollen analysis (Blume & Leinweber, 2004). These horizons are also identified by their homogeneity, humus content, elevated levels of phosphate (usually >100mg/100g soil), and anthropogenic inclusions such as pottery or charcoal (Pape, 1970; Blume & Leinweber, 2004; Giani *et al*., 2014). Since these horizons usually contain (or sometimes cover) archaeological artefacts and former marks of cultivation, they serve as an important historical archive (Giani *et al*., 2014).

In summary of the two mentioned anthropogenic soils, I would like to highlight the similarities and differences between them. A very important difference is that plaggen is a soil classification named after the agricultural technique and "dark earth" is not a soil classification. Besides this point, the biggest difference lies within their genesis. A dark earth is not intentionally formed; it is the result of one or more anthropogenic occupation activities. On the other hand, plaggen soils are formed by intentional soil additions through manured turves; however, not to with the purpose of raising the land surface. The plaggen technique seeks to increase soil fertility for agriculture, while dark earth units are not created with the sole purpose of soil fertilization for crop growing, they are an unintentional byproduct of activities. While their formation is quite different, they do have some similarities. Visually, they are both dark in color due to the addition of organics and - sometimes in the case of dark earths- manure. They both are fairly homogenous. Due to the range of human activities contributing to dark earth formation, while plaggen has only the one, they can possibly be distinguished from one another microscopically-based on their anthropogenic inclusions. Depending on the circumstances of the individual dark earth, the inclusions could be the same, mainly domestic waste and manure. A dark earth could include more remnants from artisan activity or cesspit material, where the plaggen soil would mainly be comprised of animal bedding materials. In the field, they will prove rather difficult to differentiate on the macroscopic visual scale.

2.7 Dark earth at the study site (Yesse)

Anthropogenic deposits/horizons are very heterogeneous across the monastic site, as seen in the fieldwork visit in June 2021 to observe several open archaeological trenches. This area has been heavily manipulated by humans, indicating intensive use, which results in a complex stratigraphy for archaeologists to unravel. Dark earth horizon at Yesse can be found as a pre-monastic layer *in situ*, as pre-monastic dark earth materials used to fill pits during the monastic period, and as a post-monastic destruction horizon, which is the closest to the present-day surface.

During a micromorphology internship in 2020, thin sections from Yesse have been analyzed (Steensma, 2020). One micromorphology thin section of the *in situ* dark earth on the study site has been analyzed, along with four thin sections that had their base units in the dark earth horizon, and two pit fills that contained dark earth material (Figure 12) (Steensma, 2020). The dark earth in this study was the dark earth horizon underlying the foundations of Yesse monastery, indicating extensive human occupation on the site before 13th century monastic life began. The thin section (number 1341) that consisted entirely of dark earth material was a light-yellow color, similar to that of the coversand of this region. The grain size of the dark earth varied greatly, ranging from silt to coarse sand, and was poorly sorted and subrounded to rounded. Based on sand grain morphology, it was suggested that the coversands were the parent material for this dark earth unit. Secondary phosphates, vivianite, and iron were abundant, including being found within a single fragment of charcoal in the top of the slide. The thin section was comprised of two layers that had experienced mixing. The four thin sections that had their bases in the dark earth were samples of floor levels. The dark earth in these samples contained anthropogenic inclusions, such as charcoal, bone, burnt shell fragments, lime plaster aggregates, silica slag, and fragments of rock. It is likely that these inclusions were reworked into the dark earth horizon below the floors, since the sample that was taken *in situ* didn't exhibit any anthropogenic remains besides charcoal (Steensma, 2020). There were two thin sections of pit fills containing dark earth materials, seen in slides 1198-3 and 1346. Thin section 1198-3 contained charcoal, iron precipitation, and secondary phosphates, while sample 1346 included charcoal, sandy and loamy aggregates, coprolite, glassy slag, and iron and secondary phosphate precipitation. Both samples were humus rich.

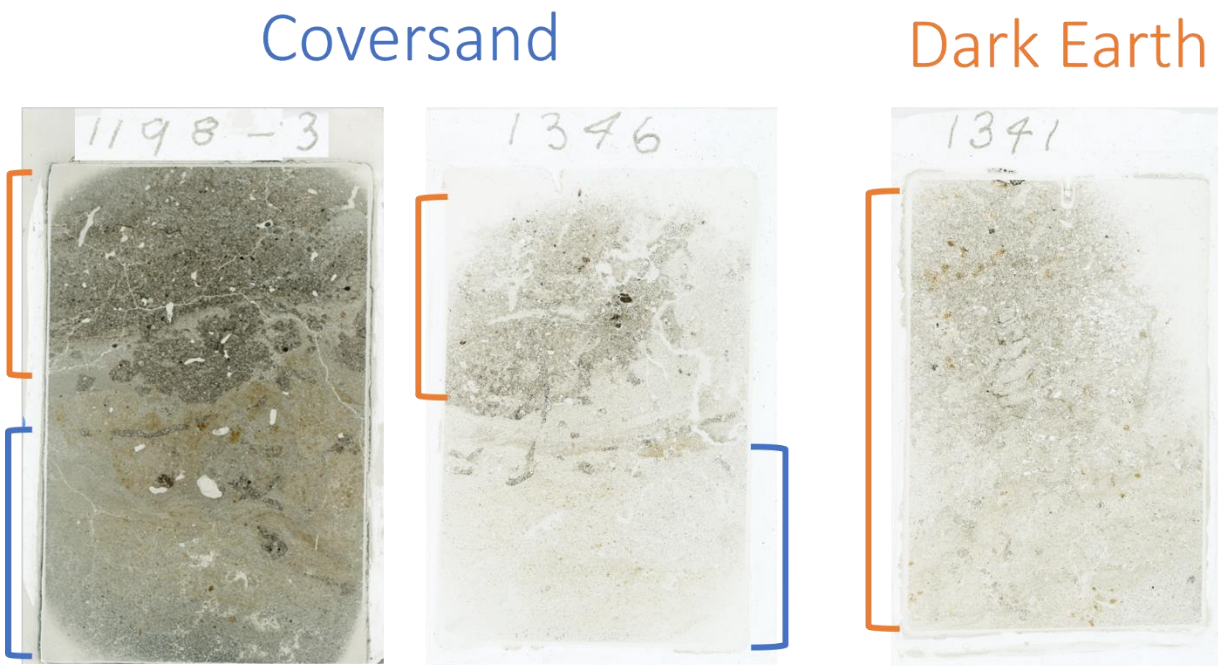

Figure 12. Scans of thin sections from Steensma (2020). Dark earth is denoted by the orange sections and coversand can be seen in the areas shown in blue.

3. Methods

3.1 Literature review

The approach for the literature review section was to find relevant literature and soil maps from the study site to compare to each other, as well as with the data gathered from this research. Relevant literature included studies on dark earth and related analysis techniques, plaggen soils, and natural soils of the Netherlands. Studies were also considered that were concerned with the history of soil mapping to understand how previous soil maps were created and what assumptions were made. Research pertaining to the geologic history of the Northern Netherlands was included to understand the genetic parent materials for soils and landscape formation of this study area, near Haren. Previous fieldwork and related studies were necessary to find knowledge gaps, gaining a better understanding of soil types and formation processes, and to determine relevance for the current thesis. GIS datasets were found online for the purpose of creating maps and plotting core/pit data for spatial understanding. Elevation data was used to generate cross sections but is also important for understanding subtle elevation changes in the local region (Figure 13). Two soil maps were found to compare how soil descriptions change with time and spatial resolution. These maps were employed to gain a starting insight as to what can be expected in the field and for planning where transects should be made. An image of the monastery layout with former trenches (Figure 14) and a historical map from 1864 (Figure 15) were selected and georeferenced to compare changes in the land over the past two centuries (See Table 2 for material sources).

Table 2. This table holds a list of datasets that were used for map making and GIS analysis.

Digital map dataset	Description	Source reference and webservice URLs
Soil map of Haren	1:10,000 regional soil map, 1989	van Dodewaard, E. & Kiestra, E. (1989). De bodemgesteldheid van het herinrichtingsgebied "Haren", (Rapport nr. 1991) Stichting voor Bodemkartering, Wageningen, 213 pp. + maps. (Map scanned and georeferenced by author)
Soil map of the Netherlands	1:50,000 national soil map, 1989	Legend: De Bakker, H. & Schelling, J. 1989. Systeem voor de bodemclassificatie voor Nederland, de hogere niveaus. 2nd edition (Brus, J., Van Wallenburg, C. Eds.) Pudoc, Wageningen. Map dataset: Bodemkaart Nederland 1 : 50,000. Wageningen Environmental Research, 2020. Digital dataset / Public Webservice http://services.rce.geovoorziening.nl/landschappenkaart/wms?
DEM raster	AHN2 national elevation data, LiDAR-based	Dataset: Waterschapshuis (2012) Actueel Hoogtebestand Nederland v2 (AHN2), 2x2 m resolution. Digital dataset / Public Webservice.
Aerial photography raster	Satellite imagery	Waterschapshuis (2017). Aerial Photography: 2017_ortho25. National georegister. Digital dataset / Public Webservice. https://geodata.nationaalgeoregister.nl/tiles/service/tms/1.0.0/ahn3_5m_dtm/EPSG:28992
Topography map 1864	Historical hand-drawn map	Veldminuten Topografisch Militaire Kaart (TMK), scale 1 : 25,000; consulted via topotijdreis.nl (screen grab georeferenced by author). Source: Kadaster, Topografische Dienst, formerly Topographisch Bureau (1864): Topografische Militaire Kaart van het Koninkrijk der Nederlanden, 1850. TMK. DANS. https://doi.org/10.17026/dans-zrx-wz6e
Yesse trench locations	Archaeological trenches dug in past years by Stijn Arnoldussen and Groningen students	Stijn Arnoldussen, 2021.

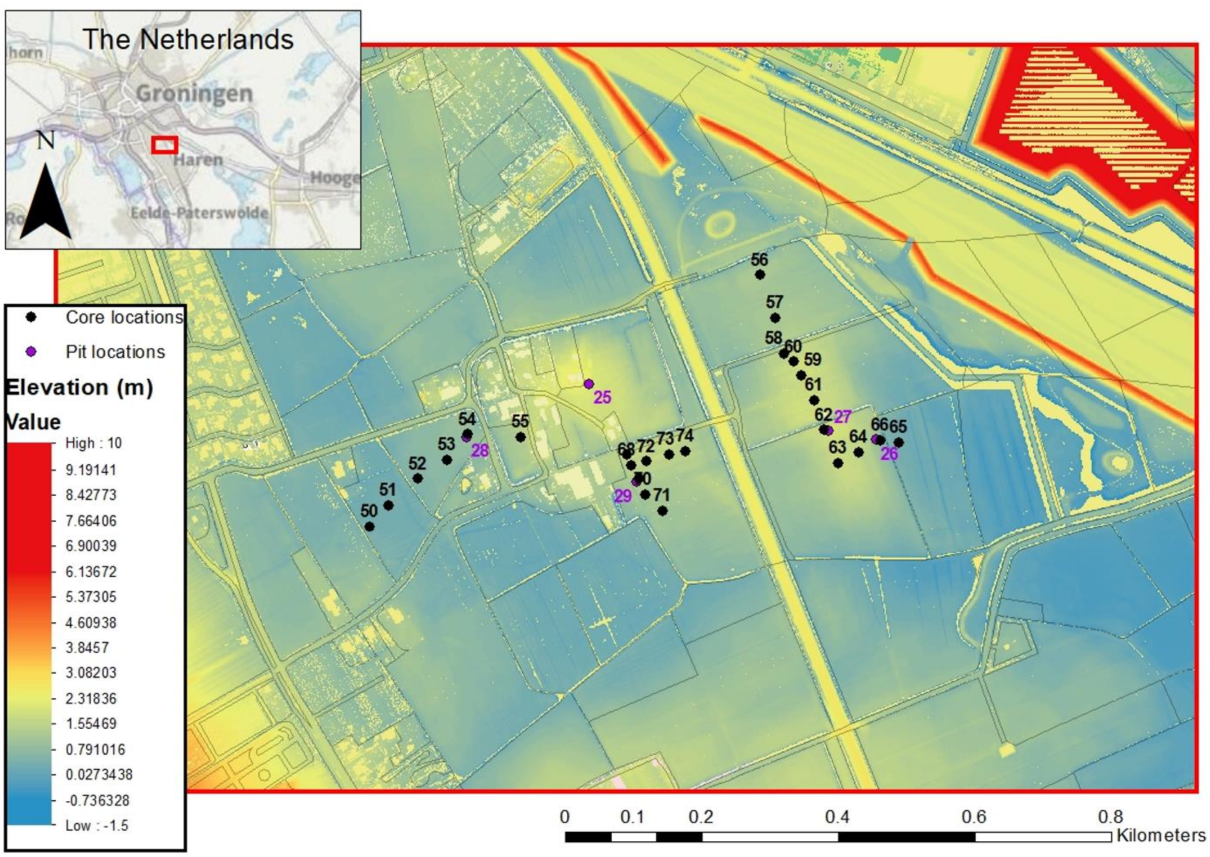

Figure 13. Elevation map of the study area. Borehole locations are seen in black and pit locations are in purple. The extent of the elevation map is shown in the map of the Netherlands.

3.2 Fieldwork

Cores and Pits

Fieldwork was carried out on current-day farmland in Essen, Haren, the Netherlands - the old site of the Yesse monastery and immediate surroundings - over a span of one week (Figure 14). Twenty-five boreholes were logged along a series of five transects using an Edelman auger (7 cm diameter). Locations of the cores and pits were recorded with a handheld GPS. Coordinates for core 50 had to be estimated in ArcMap, since the recorded GPS coordinates plotted in a location outside of the study field range, inaccurate for the actual location. Cores were taken in 10 cm increments to a maximum depth of 120cm (where possible) and laid out on a sheet of plastic to be recorded. Five soil pits were dug by hand to the coversand C-horizon, water table depth, or a maximum of 120 cm, whichever was reached first. Soil descriptions were made in the field for the horizon boundary, textural class, rock fragments, mineral concretions, and roots for each horizon using the FAO guidelines (2006). Soil color and color name were given using a Munsell color chart. Mottle colors and visual percentage estimates were recorded. Sand grain size was estimated using a sand ruler. Some cores and profile pits were checked for carbonate reaction using diluted hydrochloric acid (HCl). Not all cores/pits were checked for carbonates because most soils in this region are not likely to contain carbonates. Some random cores were tested to verify this, along with soils that looked possible of containing carbonates (such as when a mortar-like substance was found). Groundwater levels (if seen in pits) were noted, along with any water seepage from the profile face.

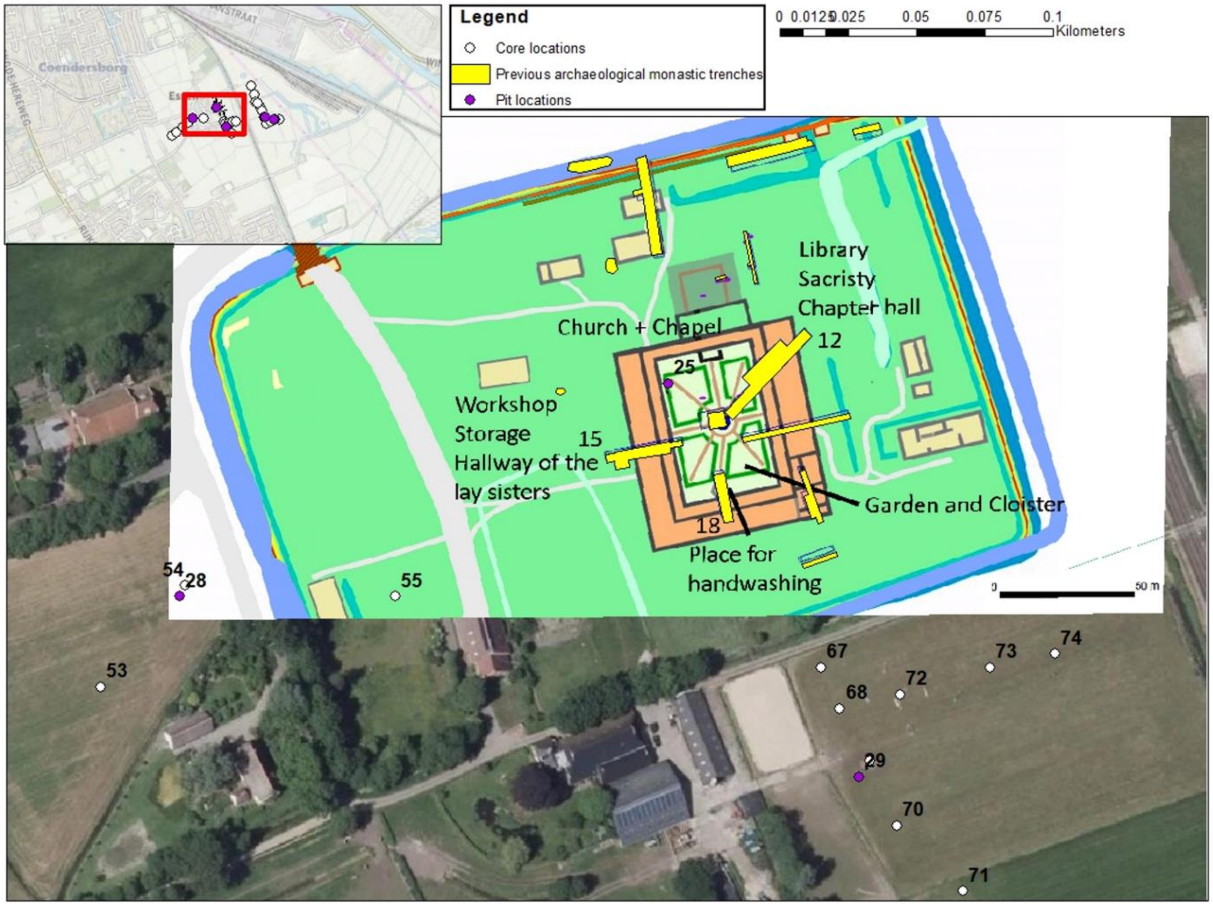

Figure 14. Aerial view of the study site with an overlay of a reconstruction of the monastery. Previously excavated trenches are seen in yellow, along with a description of the area of the monastery the trench was dug. Image of the monastic reconstruction courtesy of Dr. Stijn Arnoldussen.

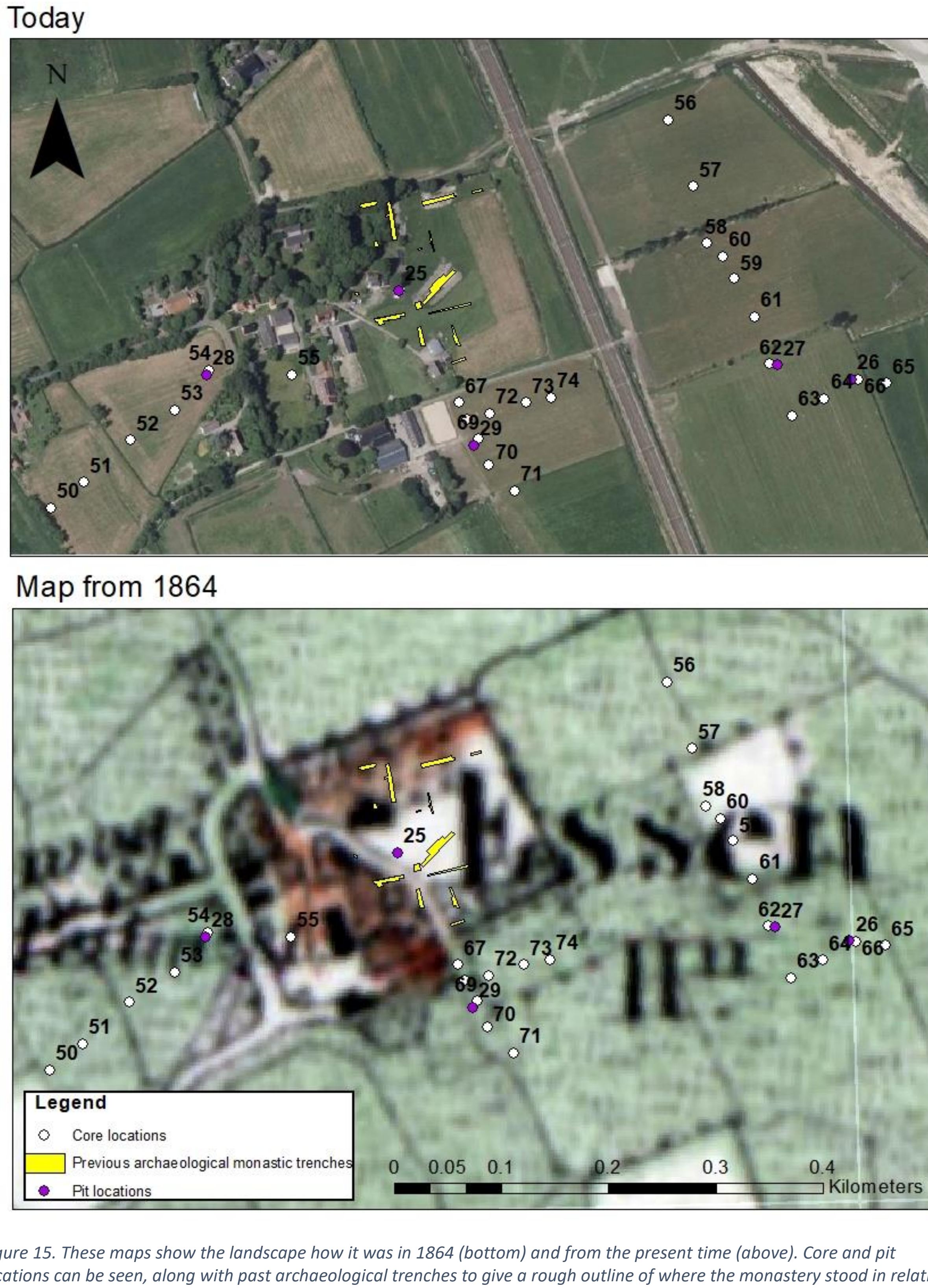

Figure 15. These maps show the landscape how it was in 1864 (bottom) and from the present time (above). Core and pit locations can be seen, along with past archaeological trenches to give a rough outline of where the monastery stood in relation to boreholes/pits (1864 map from Veldminuten Topographisch Militarie kaart, 1864).

The locations of cores were chosen to create cross sections. Cores were taken with about 50 m between locations. One of the transects, G-H, was taken along a higher ridge in the fields on the other side of the railroad to investigate the landform, as both soil maps (van Dodewaard & Kiestra, 1989; Wageneingen Environmental Research, 2020 based on StiBoKa, 1978) showed this landform to be the same soil type as in the old monastic grounds (See Figures 4, 5, 13). The remaining transects were taken to span across several fields to investigate how subsurface lithology changes across field boundaries and as one approaches the archaeological site. Pit locations were chosen during the coring process, with the exception of pit 25, which was placed in the known location of the monastic garden and dark earth. Pit 26 was chosen after core 66 revealed some intriguing horizons and hydromorphic features, mainly a dense horizon of iron nodules. Pit 27 was dug after core 62 showed an A-horizon spanning the first 80cm of the core, nearly double the A-horizon thickness of the adjacent cores. The location of pit 28 was chosen based off core 54. This area was thought to best represent a natural soil with little anthropogenic influence. Pit 29 was dug next to core 69, where a supposed loam floor layer was thought to have been found around 35 cm deep: loam floors being quite abundant on monastic grounds at Yesse. The wishful thinking behind this pit was to unearth a loam floor related to monastic times, this however was not shown to occur once the pit was fully dug, as it was only a loam fragment and not a continuous unit. A final pit was wanted, near core 55, to determine if the dark earth continues to this area. However, permission by the landowner was not able to be obtained within the fieldwork timeframe.

Towards the end of this research (June 17th, 2021), I was invited to examine archaeological trenches that were opened by Dr. Arnoldussen and University of Groningen archaeology students in the field of core 55 and in the monastery area. A pit was reopened where pit 25 of this study was located, this time to a depth of 140cm before they hit the water table. Time constraints did not allow further sampling or other field recording. See further section 4.6.

Collection of samples

Soil samples were collected in plastic bags from each horizon of the soil profile pits. Pits 26 (two samples), 27 (two samples), 28 (three samples) were sampled for OSL dating by hammering PVC tubes into the side of the clean profile face. These samples will be made available for research into dating anthropogenic deposits and soils at Wageningen University by Jelle Moree and Jungyu Choi. Soil micromorphology samples were collected for regions of interest by cutting and pressing kubiena tins into the face of the soil profile for pits 26 (5 samples), 27 (3 samples), and 28 (4 samples). Micromorphology thin sections will be processed at the Cultural Heritage Agency of the Netherlands by Dr. Hans Huisman. Pollen samples were taken by pressing monolith tins into the profile face and digging them out with a metal knife and wrapping them in plastic wrap. Pollen samples were collected from pits 26 (two samples: one monolith and one kubiena tin), 27 (one sample), and 28 (two samples). These samples will be analyzed at the University of Groningen. Finds, such as glass and pottery/ceramic fragments, were documented according to the archaeological finds numbers of the Yesse monastery site and taken to the archive at Groningen University (Dr. Arnoldussen). A total of 22 soil samples were collected from horizons in plastic bags by digging soil out of the profile face. Soil samples were transported to Utrecht University for L.O.I and grain size and to the RCE for XRF analysis (this study).

3.3 Lab work

Loss on ignition (L.O.I.) (organic content)

L.O.I. analysis was conducted following the methods of Heiri *et al.* (2001). Twenty-two crucibles were brushed clean and empty weights were recorded. Between 4 and 7 grams of soil was scooped from each sample into the crucibles before they were reweighed to find the weight of the sample. The crucibles with the soil samples were placed in an oven to dry overnight at a temperature of 105°C. The samples were weighed for moisture content. Samples were then placed in a muffle furnace. The oven was heated over a span of one hour to 550°C, where it remained at 550°C for 4 hours. Samples were reweighed and L.O.I. percentage was calculated using the following formula.

$$\frac{dry\ soil\ sample\ weight - sample\ weight\ after\ oven}{dry\ sample\ weight} * 100 = \%\ LOI$$

Figure 16. Top left: Samples 1-22 shown as they looked after post-fieldwork refrigeration. Top right: Samples after they were dried overnight. Bottom left: Samples after being heated in the furnace for LOI analysis. Bottom right: Dried samples after LOI analysis and after being ground to break aggregates.

Grain size analysis

Soil samples were dried in an oven overnight at a temperature of 105°C. Samples were homogenized using a mortar and plastic pestle to break up aggregates, while avoiding crushing any grains. A dry sample weight of around 40-50g was used to measure gain size through a series of 22 stacked sieves. The stacked sieves were placed on a Retsch AS 200 basic sieve shaker for 15 minutes at an amplitude of 100. Sieves of each grain size were weighed, and empty sieve weight was subtracted to get the weight of the sediment per size class. Weights were turned into weight percent using the total weight of the sample using the following equation:

$$\frac{weight\ of\ sieve\ with\ sediment - weight\ of\ empty\ sieve}{total\ sample\ weight} * 100 = \%\ \text{grain size class}$$

XRF (major element analysis)

For XRF analysis, around 11 grams of homogenized sample was collected from the dried soil sample bag and added to fill a small, shallow plastic tube on a metal platform. The sample was flattened, and the metal platform was raised until the sample surface was in contact with the handheld XRF machine (the Thermo Scientific Niton XL3t). Each sample was scanned for 110 seconds by the machine for element analysis. The following elements/compounds were analyzed: SiO_2, CaO, P_2O_5, K_2O, Al_2O_3, TiO_2, Fe_2O_3, MnO, S, Cl, Mg, Zn, Cu, Co, Sn, Pb, Cr, Zr, Sr, Rb, As, Ba, V, Ag, Ni, Sb, Cd, Mo, Nb, Au, Se, W, Bi, and Pd. Some elements resulted in values below detection (Cl, Co, Sn, Cr, Ag, Ni, Sb, Cd, Mo, Au, Se, W, Bi, and Pd), and therefore will not be included in this report. Other elements (MnO, Mg, As, Ba, V, and Nb) were left out of this report due to irrelevance to the topic at hand or for having most values below detection and small values, where detected. After inspecting the data, a decision was made to leave Al_2O_3, Rb, and TiO out of the results and discussion of this report due to values being close to detection limit, or for similarity in behavior to other elements/compounds to prevent redundancy.

3.4 Data integration and analysis

GIS data exploration (ArcMap)

Digital map layers for elevation, soil maps, archaeological landscape maps, satellite maps, and field boundaries were analyzed in the ArcMap GIS software package. All maps were checked for projection type and reprojected if necessary to ensure all maps were compatible. Other maps had to be georeferenced, such as the screengrab of an 1864 manuscript military topographic map (Figure 15) (Minuten Topografisch Militarie Kaart, 1864; via www.topotijdreis.nl) of the local area and the 1:10,000 soil map (van Dodewaard & Kiestra, 1989). The locations of cores and pits for this study were digitized and superimposed to the map views. The location for core 50 was misrecorded during fieldwork and was replaced by a more accurate location. Maps were made using each of the layers to depict local and regional setting. Elevation data was read from the AHN resource (Table 2) to make the cross sections.

Cross sections

Cross sections were compiled using x- and y-coordinates, to generate core/pit distances from one another, and elevation data for each core/pit. Five transects were selected, as were outlined during fieldwork planning. Sedimentological data were written out along with horizon classification to interpolate boundaries between cores/pits. Locations for ditches were estimated, and a depth of 1.5-2 m of depth were given for each ditch. Core/pit location surfaces were connected to estimate surface level in order to save time from plotting each change in elevation where there were no cores/pits taken. Gaps in the data were supplemented by subsurface borehole data collected in 1987 (retrieved from DINOloket; data portal TNO Netherlands Geological Survey). Distance to the monastery site, railroad, and farmhouse were placed by measuring distances on ArcMap and manually drawing them in the cross sections with estimated elevations found in the DEM layer. The old surface level during the time of the monastery was estimated based on personal communication with Stijn Arnoldussen, referring to archaeological fieldwork drawings. Average depth to the dark earth below the monastery foundations (called the "Medieval cultural layer" in fieldwork drawings) from the closest trench to the core/pit in question was used as the estimated surface level of the monastic period. In reality, the depth below the current surface level to the dark earth layer varies greatly spatially, ranging from 60-100cm (~ +1.06-0.66 NAP) below the surface in trench 12, the east wing of the monastery; 30-60cm (~ +1.5-1.2m NAP) in trench 15, the west wing; and 30-100cm (~ +0.95-0.25m NAP) in trench 18, the south part of the monastery (Arnoldussen, p.c.; Figure 14).

Landform data integration table

The goal of forming a landform integration matrix was to organize the data in one location, as well as the implications and inferences made from the results. This matrix allowed for the understanding of how landforms changed through time, their implications for soil genesis, and allowed for the comparison of landforms across the study site. Data was compiled from core/pit descriptions, cross sections, and historical maps to generate this table. Landforms were first identified, such as a clearly raised hummock that spanned two fields, from cross sections and the elevation map. Boreholes and pits were gathered from each landform and soil descriptions were analyzed to estimate the degree of human modification on the landform that can be seen at present. For example, if a landform contained a thick Ahu horizon (A-horizon with humus and anthropogenic inclusions), then it was said to be heavily modified by humans. Using the map from 1864, field boundaries were able to be identified and changes in the landscape could be seen, such as the construction of the railway and if that had any implication on field parcel shapes. Land use changes were considered to determine level of anthropogenic effects as well, such as one field to the east of the railroad having been an agricultural field in the 1864 map, where today it is used as a grazing grassland. This would have implications for soil characteristics, for example the thickness of the ploughed A-horizon in this case. A conclusion was made after analysis to determine the history of the landform, perhaps if it used to be a lowland area that was built up unintentionally as humans added soil improving manure over time, or a lowland field that remained low since it showed little indication of human manipulations. Gathering and summarizing the data in this way allowed for an integration of several types of data - elemental, spatial, horizonation of soils- to paint a single picture of how the land looked prior to monastic settlement and any transformations in the land between then and now.

4. Results

A summary of the most significant finds from this research will be presented below. In the Digital Appendix, the full set of data can be found, which includes the following: Loss on ignition results, grain size analysis data, XRF elemental reporting of pit horizons, the full list of borehole and pit horizon descriptions, GPS coordinates and elevation data of the boreholes/pit, integrated pit information sheets with graphs of elemental composition per depth from horizon samples, and the elevation and distance data used to generate cross sections. The majority of the core logs used in the cross sections are from the descriptions made from fieldwork; however, two borehole logs (one in seen in cross section A-B and one in cross section E-F) were taken from TNO/DINOloket to help fill in information for gaps in the data. Field drawings from archaeological trenches from previous years conducted by Dr. Stijn Arnoldussen were also consulted in building cross sections.

4.1 Borehole logs

Twenty-five boreholes were logged in total. Figure 13 shows their locations. For the sake of space, two logs of boreholes will be presented in detail (Table 3) that highlight the comparison of a fairly natural profile (core 65) to a heavily anthropogenically modified profile (core 58). For a full list of core descriptions, see the Digital Appendix.

Table 3. Soil descriptions for core 58 and 65 according to F.A.O. (2006) guidelines. Under textural class column: SL= sandy loam, C= clay, LS=loamy sand. Under the mineral concretions column: C= common, F= few, FE= iron, and N=nodules. Under the roots column: C=common, F (in front) = few, V (in front) = very few, F (in the second letter place) = fine roots, VF= very fine roots.

Core number	Hydrology/ vegetation	Upper depth (cm)	Lower depth (cm)	Horizon classification	Textural class	Sand grain size(µm)	Rock fragments/ artefacts	Color/mottling	Color name	Mineral concretions	Carbonate reaction	Roots	Remarks
65	wet grassland	0	25	Ach	SL	75-105		10YR 2/2	brownish black	F FE N		CF	
		25	40	Ach2	SL	75-105		10YR 4/2	grayish yellow brown	C FE N		VF	
		40	60	2ACh	C	-		(90%)10YR 2/1, (10%)10YR 6/2	90%black, 10%grayish yellow brown				
		60	100	2Cc	C	-		10YR 6/1	brownish gray	C FE N			
		100	120	2C	C	-		10YR 6/1	brownish gray				
58	grassland	0	10	Ahu	SL	150-210	Fine gravel brick fragments	10YR 3/4	dark brown			CF	
		10	20	Ah	LS	150-210		10YR 3/3	dark brown			FF	
		20	60	Ahu2	SL	210-300	Fine gravel brick fragments	10YR 5/4	dull yellowish brown			VF, VVF	
		60	90	Ahu3	SL	210-300	Fine charcoal	(90%)10YR 3/1, (10%)10YR 5/4	90% brownish black, 10% dull yellowish brown				
		90	145	Aghu	LS	105-150	Fine charcoal	(90%)10YR 4/2, (10%)10YR 6/6	90% grayish yellow brown, 10% bright yellowish brown	bands/ stains			fine red ceramic fragments or burned clay/loam
		145	155	Aghu2	LS	105-150	Fine charcoal	(80%)10YR4/2, (20%)10YR 5/6	80% grayish yellow brown, 20% yellowish brown				
		155	160	2C	LS	75-105		10YR 7/3	dull yellow orange				feature fill?

Core 65 lies one field east of the raised field landform to the right side of the railroad, the ending point of transect H-I. This core represents one of the more natural soils seen in this study. The hydrology and vegetation setting for this core was in a wet grassland. The first two horizons are only differentiated by color and abundance of roots. The top unit (0-25cm) is brownish black with common fine roots, and the unit below it (25-40cm) is grayish yellow brown with few fine roots. Both horizons are classified as Ach (the lowermost designated as Ach2) and consist of a sandy loam texture with a grain size of 75-105µm. These horizons contain hydromorphic features, specifically iron concretions, lending the "c" to the horizon classification, signifying a high water table. The "h" designation results from the presence of humus among the sediments. The next horizon below Ach2 is the start of a different parent material, and therefore the next 3 horizons start with a 2 as an indication of the switch. From 40-60cm is the 2ACg horizon that consists of clay that is 90% black and 10% grayish yellow brown. Below this (60-100cm) is the 2Cc horizon, also clay, that is brownish gray and has common iron nodules. The bottom 20cm (100-120cm) is the 2C horizon, which only differs from the horizon above it by the lack of nodules. This profile is seen as natural soil because of its absence of anthropogenic inclusions and the occurrence of a relatively thin A-horizon.

Figure 17. This image highlights the range of sediment colors, soil water saturation, and inclusions found during fieldwork. Left: Large brick fragments found in a core. Bottom middle picture: most likely core 58 (see Table 3).

By contrast, core 58 shows indications of anthropogenic activities (Table 3, Figure 17). This core is part of the raised landform seen in transect G-H, taken from a grassland environment. The top ten centimeters are designated as an Ahu horizon due to the amount of humus and anthropogenic inclusions (“u”). This Ahu horizon is a sandy loam with a grain size of 150-210µm. Anthropogenic inclusions in this horizon are fine gravel sized brick fragments. There are also common fine roots, typical for the top of an A-horizon. From 10-20cm is the Ah horizon. It is characterized by a dark brown loamy sand texture with a grain size of 150-210µm. The third horizon (Ahu2) returns to the presence of anthropogenic inclusions. Ahu2 is found from 20-60cm below the surface. It is a dull yellowish brown sandy loam (210-300µm) with fine gravel sized brick fragments, very few fine roots, and very few very fine roots. The fourth horizon is from 60-90cm and is an Ahu3, with a sandy loam texture (210-300µm), fine charcoal inclusions, and is 90% brownish black and 10% dull yellowish brown. Below this, is the Aghu horizon (90-145cm). This horizon has fine red-orange ceramic fragments or burnt clay/loam aggregates, hard to distinguish in the field. There is also iron staining and fine charcoal. The sediments are 105-150µm in size, and this unit is a sandy loam, where 90% is grayish yellow brown and 10% is bright yellowish brown. The horizon below this is classified as a Aghu2 horizon (145-155cm), only differing from the unit above by color, here being 80% grayish yellow brown and 20% yellowish brown, and the lack of brick/burnt clay-loam fragments. The bottom horizon is a 2C horizon, as the parent material seems to change based on a decrease in grain size to 75-105µm. This dull yellow orange loamy sand is from 155-160cm. This core is seen an heavily anthropogenically modified due to the thick A-horizon and presence of anthropogenic materials.

4.2 Pit logs

Five pits were logged in total. Images of the pits with denoted horizons can be seen in Figure 18. Soil pit locations can be seen in Figure 13 and 19. In Table 4, the descriptions of three pits are highlighted. The chosen three pits serve as a representation of a heavily anthropogenically modified soil (pit 25), a moderately anthropogenically altered soil (pit 28), and an example of the complexity of soil profiles in the area (pit 26). Images of all pits with horizon classifications can be seen in Figure 16.

Table 4. Soil descriptions for pit 25, 26, and 28 according to F.A.O. (2006) guidelines. Under textural class column: SL= sandy loam, C= clay, LS=loamy sand. Under the mineral concretions column: C= common, F= few, FE= iron, and N=nodules. Under the roots column: C=common, F (in front) = few, V (in front) = very few, F (in the second letter place) = fine roots, VF= very fine roots.

Core number	Hydrology/ vegetation	Upper depth (cm)	Lower depth (cm)	Horizon lower boundary	Horizon classification	Textural class	Sand grain size(μm)	Rock fragments/ artefacts	Color/mottling	Color name	Mineral concretions	Carbonate reaction	Roots	Remarks
25	grassland	0	15	D	Ahu	SL	150-210	Brick and plaster rubble 5%	10YR 2/1	black		No	CF	
		15	60		Ahu2	SL	105-150	Brick and plaster rubble 25%	10YR 2/1	black		Yes	VM, VC	hit water tabel, couldn't go further, core here went to 120cm and was still in the dark earth
26	grassland	0	32.5-37	AW	Aghu	SL	105-150	Small piece of plastic, <1% brick fragment, pottery fragment*, burnt loam	10YR 2/3, (10%)10YR 5/4 mottles from 29-32 cm	brownish black, dull yellowish brown 10% from 29-32	FE stain around roots		VF	*pottery find #2388, pottery frag find #2389 in spoil heap
		32.5-37	45	AS	Ahgu2	SL	105-150	<1% brick, pottery*	(75%)10YR 3/3, (25%)10YR 4/6	75%dark brown, 25% brown	FE stain		VF	*pottery find #2444
		45	53	AW	Ahu	SL	75-105	Large waste brick and ceramic tile* @ 50cm	10YR 3/3	dark brown			VF	*ceramic tile find #2390
		53	65-73	AW	2Adgh	SL	105-150	Charcoal, small brick	10YR 4/2	grayish yellow brown	F FE stain		VF	
		65-73	100		2Cgh	SL	105-150		(75%)10YR 4/3, (20%)10YR 4/6, (5%)10YR 3/2	75%dull yellow brown, 20% brown, 5% brownish black	FE stain			
28	grassland	0	8	AS	Ahu	SL	150-210	Very Fine gravel	10YR 3/2	brownish black			CF	
		8	40	AS	Acghu	SL	150-210	1% small bricks, weird mass ~22cm long of material not from pit profile	(85%)10YR 3/2, (5%)10YR 5/6, (5%)7.5YR 3/4, (5%)10YR 2/1	85% brownish black, 5% yellowish bown, 5% dark brown, 5% black	FE stain		FF	
		40	53		BChs	LS	210-300		(40%)2.5Y 1.7/1, (20%)7.5YR 4/6, (20%)7.5YR 3/4, (20%)10YR 4/6	40% black, 20% strong brown, 20% dark brown, 20% brown	CPFOW (continuous, weakly cemented with humus)			banded, partially submerged podsoil?

The soil profile of pit 25 is split into two horizons. Ahu is from 0-15cm and has a diffuse lower boundary. This top horizon is a black sandy loam (150-210μm) with commonly found roots. Brick and plaster rubble make up about 5% of the horizon but despite this, this horizon did not effervesce when introduced to HCl, indicating little to no carbonates. From 15-60cm, there is an Ahu2 horizon, that is also the same color black. Brick and plaster rubble percentage increases to 25% here, which tested positive for carbonates. The profile could only be opened to 65cm, as the water table was hit and began flooding the pit. A test core was taken here prior to digging (not described in this study), which showed this black layer extended down to at least 120cm, which was seen down to 140cm in the reopening of this pit by field archaeologists in June 2021. This pit is seen to be the most anthropogenically modified since it contains the highest amount of destruction rubble compared to the other pits, along with having the thickest and darkest A-horizon.

Pit 26 illustrates a very complex assemblage of sandy loam horizons (Table 4). The topmost horizon (0 to 32.5-37cm) is an Aghu horizon with an abrupt, wavy boundary. This is a mottled (brownish black with 10% mottles of dull yellow brown from 29-32cm) sandy loam unit that contained a small fragment of plastic, <1% brick fragments, pottery fragments, and burnt loam. There was also iron staining around roots. The second horizon, Aghu2 is from 32.5-37cm to 45cm. Mottles were found (75% dark brown, 25% brown), along with <1% brick and pottery fragments. An abrupt, straight boundary separates the second horizon from the third, the only straight horizon boundary of the profile. The third horizon, Ahu, is characterized by a dark brown color and spans from 45-53cm. A large waste brick and a ceramic tile were found from this depth during digging. This is the only horizon without iron staining. The horizon below this sits between 53 and 65-73cm below the surface, 2Adgh. The most prominent characteristic of this horizon is its dense nature (yielding the "d" to the classification), making it extremely difficult to dig through. It is thought that this unit comes from a different parent material because of its compaction and graying yellow brown color being dissimilar to the rest of the profile. Charcoal and small brick fragments were found in this horizon, along with iron staining. The bottom horizon, 2Cgh, of the profile is from 65-73 to 100cm. There were no anthropogenic inclusions in this horizon, unlike the rest of the profile. This unit is 75% dull yellow brown, 20% brown, and 5% brownish black. Since there is a buried soil covered by sediments containing anthropogenic materials, this profile highlights former surface levels and anthropogenic raising of fields through manuring.

The profile of pit 28 is quite different from the two pits mentioned above. All boundaries of the horizons were abrupt and straight. The top horizon is classified as Ahu, the "u" coming from the presence of very fine gravels. This is a brownish black sandy loam. From 8-40cm is an Acghu horizon, which includes 1% small bricks, a long mass of sediment that is not of materials from this pit, and iron staining. The color of this horizon is 85% brownish black, 5% yellowish brown, 5% dark brown, and 5% black. The bottom horizon extends from 40 to 53cm below the surface. The BChs horizon is a multitude of colors: 40% black, 20% strong brown, 20% dark brown, and 20% brown. It also has the only occurrence of being weakly cemented with humus recorded in the study area. There was also a banded nature to this horizon. This profile is assumed to be moderately affected by humans since the A-horizon contains a small amount of fine-sized rubble debris, but the B-horizon remains intact, seemingly undisturbed by humans; unlike most B-horizons that would have been seen in natural soils here that are no longer present.

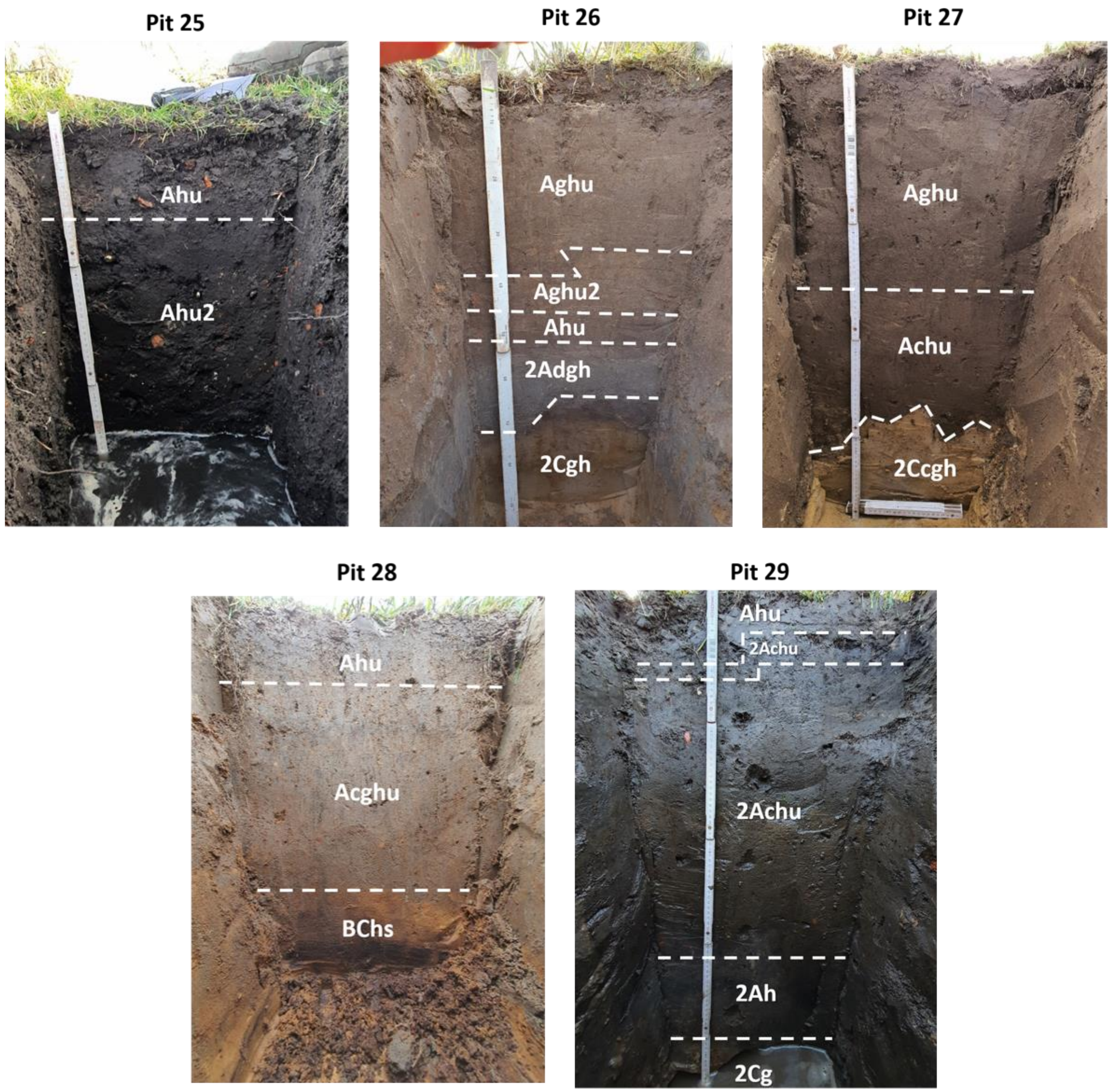

Figure 18. Images of pits 25-29 with horizons. Pit 25 colors are not comparable to colors in pit 25, as the colors seen in pit 29 are mainly this dark resulting from being very wet. Scale is not the same in each picture, see individual measuring tapes for scale.

4.3 Organic matter content

Figure 19 shows the organic matter content, based on L.O.I., as a percent plotted for each pit against depth. Pit 25 has the highest organic content per depth of any pit. Every pit shows a general trend of higher organic content near the ground surface that decreases with depth, except for pit 29, which has the highest organic content in the second horizon as opposed to the first. Pit 25 decreases from 0 to

35cm, then increases in the interval with the sample taken from between 40-50cm. Pit 27 had the lowest organic content in its first horizon compared to the other four pits.

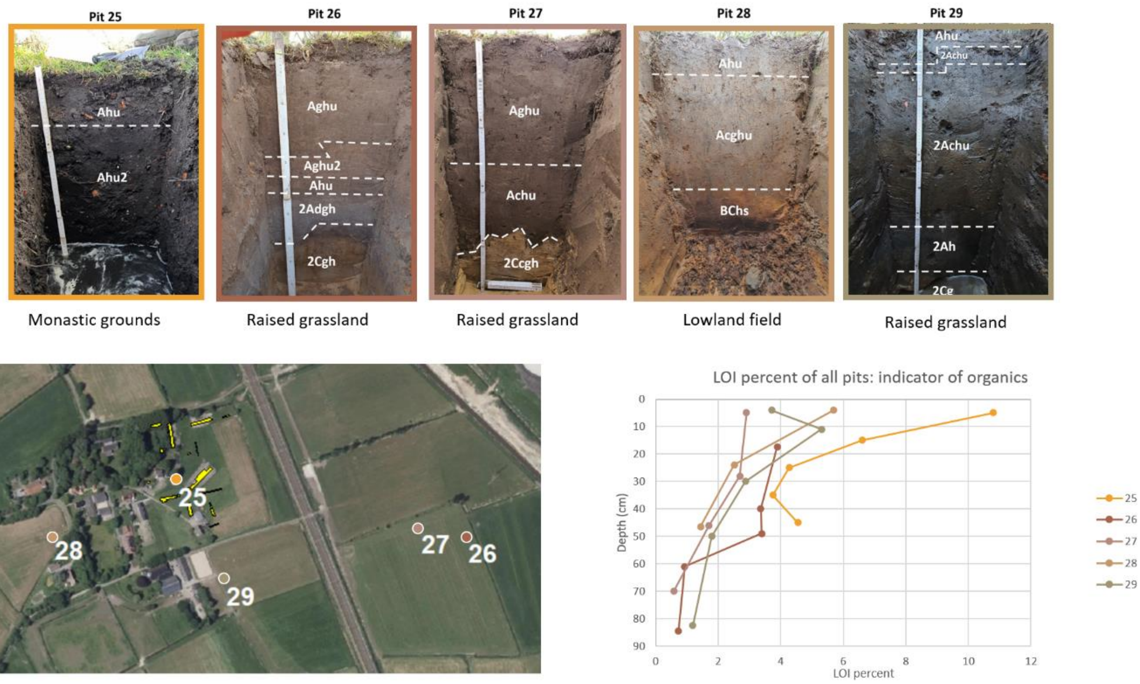

Figure 19. Top: Pictures of the pits with designated color frames. Bottom left: Map of the study area depicting core locations with colors to match the frames above. Former archaeological trenches are marked in bright yellow to show proximity to the monastic site. Bottom right: Organic matter content (based on L.O.I.) percent for pits 25-29 compared to depth from the surface.

4.4 Grain size analysis

Results from grain size analysis can be seen in the Digital Appendix. Overall, grain size seems to be fairly similar for all 22 samples collected. The majority of grain sizes for the sample set is between 150-106µm. The top 40cm of pit 25 show an abundance in the clay fraction, between 10.1 and 11.4% of the total weight. From 20-50cm in pit 25, there is also a large weight percent of grain size above 2mm, between 3.8 and 12.6%, that increases in percentage of total grain size with depth. Other notable differences include pit 26 from 65/73 to 100cm, that has 10.3% in the 530µm class and 12.2% in the clay fraction, and pit 29, that has between 10% and 12.3% of its weight in the clay fraction from 0 to 30cm of the profile. There was not a significant amount of sediment in the grain size range of 850-1700µm for any sample. Grain sizes seen from this analysis match the typical grain size for the coversands (1mm and smaller) reported in the region. Grain size above 1-2mm is likely to be anthropogenically introduced, such as large rubble debris.

4.5 Trace elements

Figure 20 shows elements specifically chosen as indicators of human activity. Copper and lead are general indicators of anthropogenic activity and a sign of metallurgy. Pit 25, taken on monastic grounds, is the only pit to show concentrations of Cu. Compared to the other four pits, pit 25 contains an elevated amount of Pb as well. Sulfur indicated the presence of gypsum plaster, which has been indicated at some concentration for all pits; however, pit 25 contains the highest concentration per depth, resulting from the higher percentage of destruction rubble, which contained plaster fragments. Zinc is a heavy metal that suggests food waste, bone, and metallurgy. Again, most pit horizons show the presence of Zn, but not to the same degree as pit 25, which shows the highest value per depth, almost the highest overall. Pit 25 stands apart from the other pits as clearly different, further supported by the Ca% vs. P% graph (Figure 21). Ca% for pits 26-29 is relatively constant, between 0.12 and 0.56%. Pit 25 has a higher percentage of Ca by a factor between 3.5-31 times the other pit values, resulting from higher percentages of plaster fragments or the presence of bone. Phosphate percent is generally higher in pit 25 as well, indicating the presence of excrement, ash, or bone. Domestic waste, including bone, was found at a lower depth in the location of pit 25 by archaeologists, which could be reflected (at least in part) by the elevated values of Ca and P (see section 4.6).

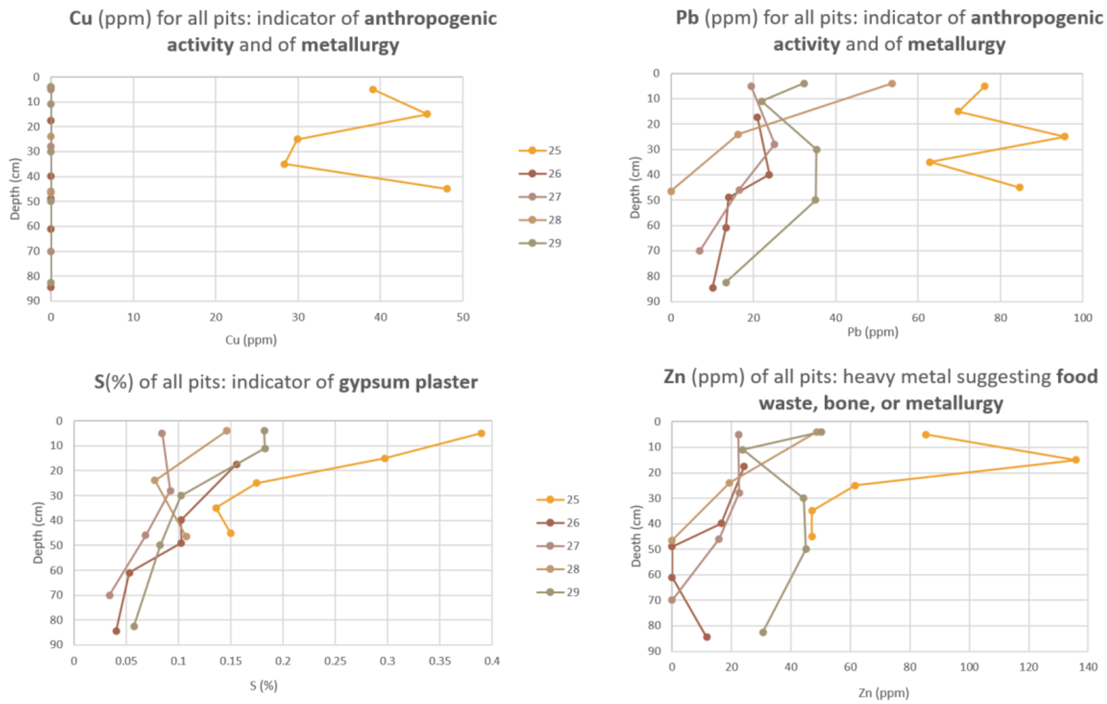

Figure 20. Element concentrations are shown for each pit (shown in different colors per pit, which match the color scale used in Figure 19) against depth from the surface for four trace elements that are known anthropogenic indicators.

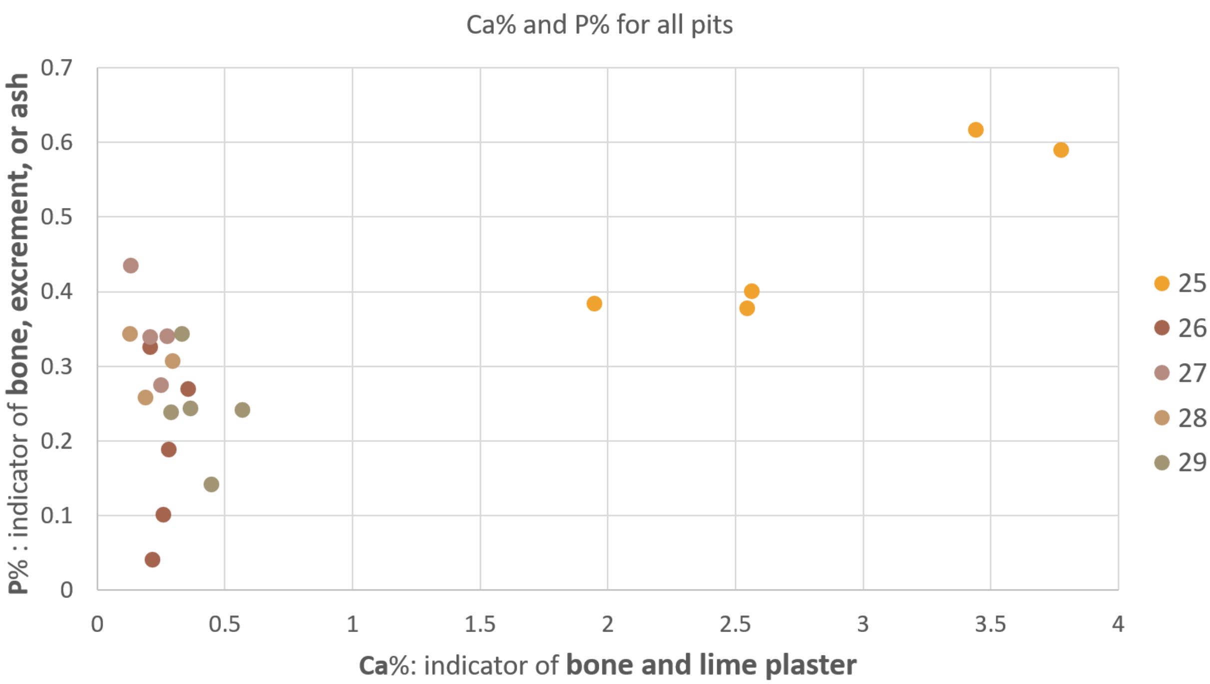

Figure 21. Ca% versus P% for all samples grouped by pit number (color scale is the same as that used in Figure 19 and 20 for easy comparrison).

4.6 Study site visit in June 2021

As a result of the revisit to Yesse during the University of Groningen archaeological fieldwork, some new insights were gained:

1. The pit that was re-opened in the location of pit 25 of this study, the dark earth horizon, extended to at least 140cm, where they hit the water table. The lower part of this soil profile revealed inclusions of fish bones, stained glass fragments, and metal handles of windows.
2. The trenches revealed a multitude of complex soil profiles on monastic grounds, including many features cutting into one another. The anthropogenic soil horizons throughout monastic grounds have been shown to be extremely heterogeneous.
3. A plaggic anthrosol with a thick brown A-horizon with a buried podzol E- and thin B-horizon underneath has been found in the southwest part of the monastic site, in the field of core 55. This podzol E-horizon does not extend far horizontally. A few small pockets have been seen extending to the northwest of the podzol, before it disappears completely. It has a wavy boundary, indicating bioturbation from moles. The podzol is found close to a ditch, in the lower-lying area of this field.

4.7 Cross sections of landforms

Transects can be seen in Figure 22, which depicts field locations. Cross sections can be seen in Figures 23-27. Cross sections were used to explore the subsurface of landforms, which can be seen in Figure 28. Note the scales on the transects, as they differ.

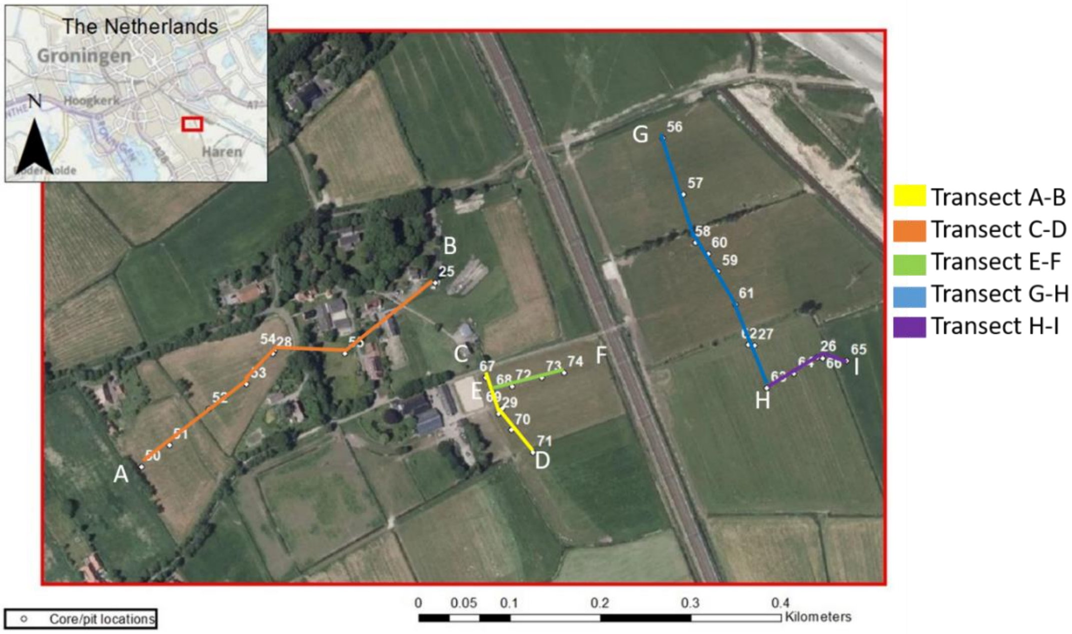

Figure 22. Aerial view of the study area with transect lines drawn.

Transect A-B: The lowland grass fields and the dark earth

Transect A-B extends from the low-lying fields in the west to the monastic grounds, ending in the monastery site proper (Figure 23). The lowland fields sit between +0.38-0.80m NAP, where the elevation gradually increases as you move towards the monastic grounds. The site of Yesse monastery is the highest elevation recorded in the study site, +2.28m NAP. The buried podzol E-horizon shows a former natural land surface before around 1m of anthropogenic soil was added on top. Parent material for the lower fields seems to be glacial till since it is more clayey and not characteristic of the coversands.

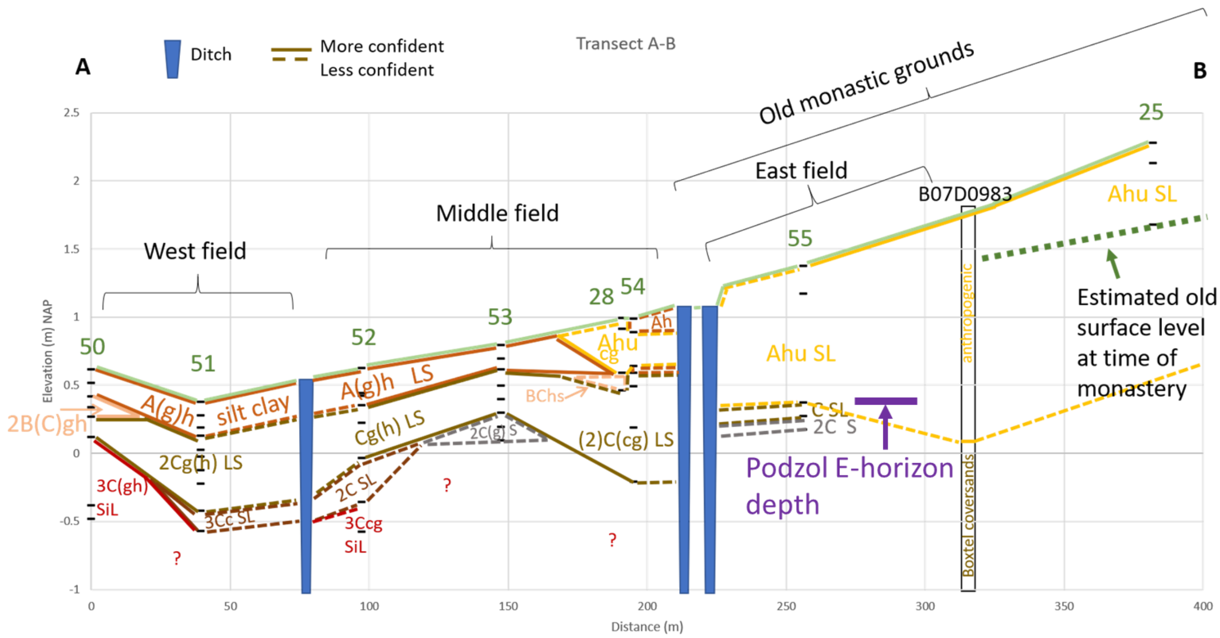

Figure 23. Cross section of transect A-B. Soil horizons have been designated and horizons have been interpolated between boreholes/pits. The surface level during monastic times has been estimated and labeled with a dashed green line to show uncertainty. Podzol E-horizon elevation (0.4 +NAP) added in purple.

Transect C-D and E-F: The anthropogenically raised fields atop coversands near a farmhouse

The other landform with significant human modification is the raised field close to a present-day farmhouse (landform 2, Figure 28, Table 5; transect C-D and E-F, Figure 24 and 25 respectively). The A-horizons in this field range from 80-100cm thick, except for an A-horizon that is close to the southeast field boundary that only was 30cm thick. Every core/pit taken in this field contained anthropogenic inclusions, including brick fragments, charcoal, pottery sherds, and burnt loam. Comparing surface levels of this landform to the field directly southeast, there is an elevation loss of around 50cm. Using the elevation of the top of the C-horizon of the cross sections, the C-horizon of the raised fields starts from a few centimeters above the C-horizon in the SE field to around 90cm lower. The C-horizon in cross sections C-D and E-F fluctuates in an unnatural-looking manner, implying that the boundary between the A- and C-horizons have been affected by anthropogenic digging and deposition. Proximity to a farmhouse and the old monastic grounds seems to have affected the degree of human modification, shown in the thickness of the A-horizons of this field, especially with the abundance of anthropogenic materials, which both generally increase as you approach either occupation site.

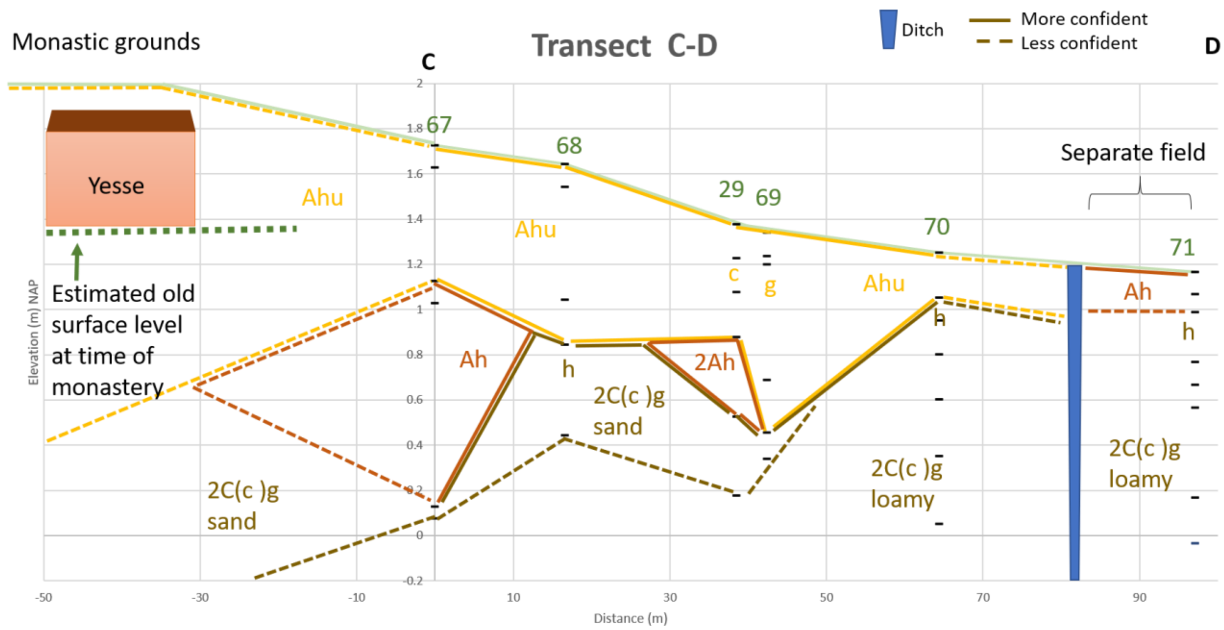

Figure 24. Cross section of transect C-D. Soil horizons have been designated and horizons have been interpolated between boreholes/pits. Individual fields have been labeled, and the area of Yesse Monastery has been indicated. Yesse monastery is not drawn to scale, but distance to the closest borehole (67) is to scale. The surface level during monastic times has been estimated and labeled with a dashed green line to show uncertainty.

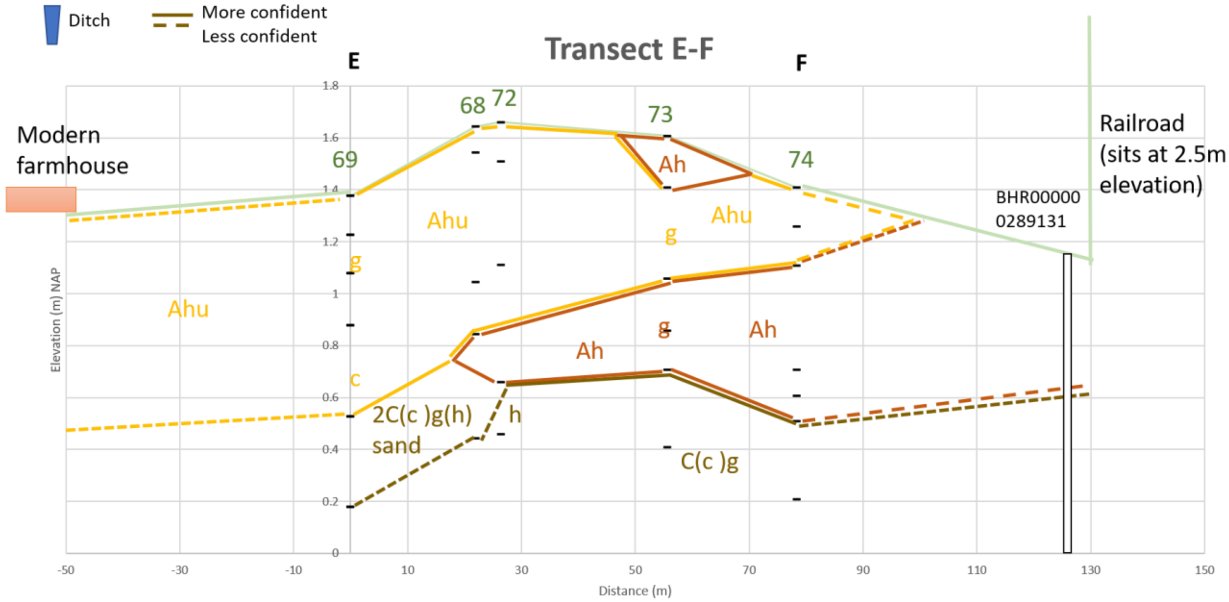

Figure 25. Cross section of transect E-F. Soil horizons have been designated and horizons have been interpolated between boreholes/pits. The modern farmhouse is not drawn to scale, but distance to the closest borehole (69) is to scale.

Transect G-H and H-I: the anthropogenically-raised fields atop a coversand ridge

Several instances of adding material to fields can be seen in cores, for example in core 60 (Figure 26), where the first horizon on top of the C-horizon is an anthropogenic A-horizon, topped by an A-horizon without anthropogenic remnants, where it then switches back to an anthropogenic A-horizon again at the surface horizon. It seems that a layer of domestic waste mixed in with sediments was spread on the field, followed by an organic rich sediment that lacked domestic waste either completely or not at a high enough percentage to be found within the core. Then another layer of sediments with household waste, such as brick and plaster fragments from the destruction debris, was added again.

Another change in A-horizons across the field area is in hydromorphic features. Although water tables in the study site fluctuate significantly - as seen in the groundwater drop in pit 25 from 65cm to 140cm below the surface - it is unlikely to find gleyic features close to the surface of soil profiles. Yet in pit 27, hydromorphic features were found from 0-33cm from the surface (Figure 26, right side). Since this core is higher in elevation relative to the adjacent cores to either side, it can be supposed that this anthropogenic A-horizon consists of reworked sediments that retained their hydromorphic features after being deposited on the field. This is logical since pit 27 seems to be in an archaeological feature, perhaps a pit fill, which by nature contains reworked sediments.

Two anthropogenic features were found in this landform, cores 58 and 62, where the A-horizons were 155cm and 80cm thick respectively. Both of these features lay to the south of current ditches. The first hypothesis was that they could be old parcel ditches, where field boundaries were redrawn after the railroad was constructed to make up for lost land. In historical maps (Figure 15), the field boundaries seem to not have changed before and after the railroad. The second hypothesis was that current ditches used to be wider, then filled in to become the narrower ditches that are present today, but this also doesn’t seem to be the case. The purpose of these fill features remains uncertain and would require archaeological investigation.

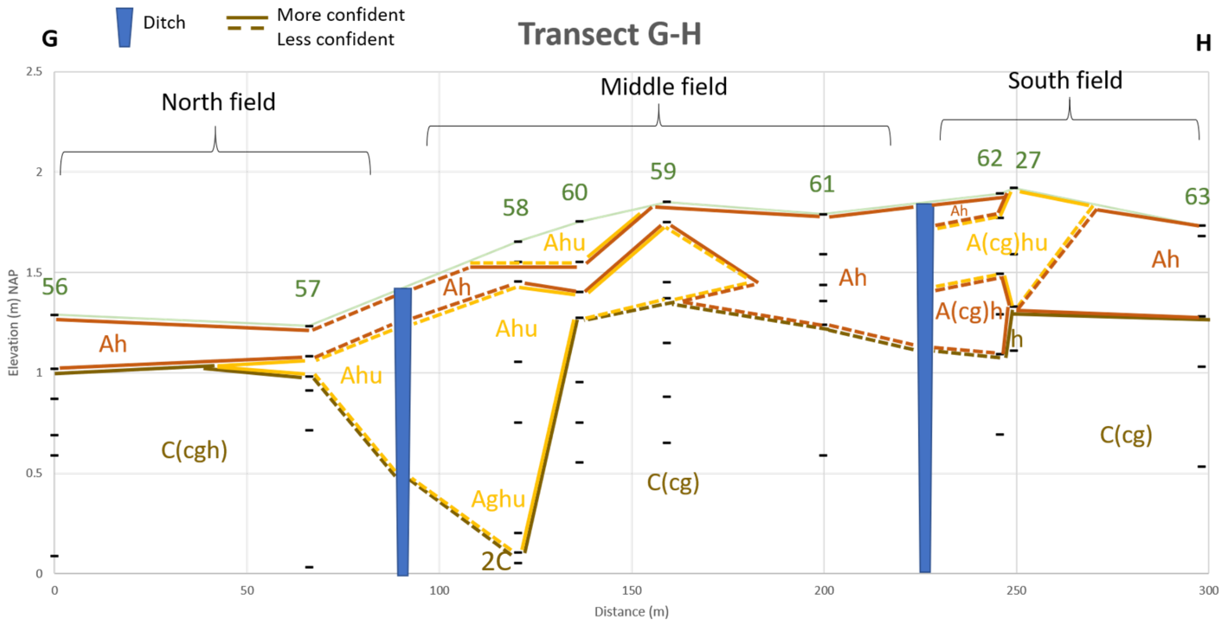

Figure 26. Cross section of transect G-H. Soil horizons have been designated and horizons have been interpolated between boreholes/pits.

Transect H-I shows a buried soil on the eastern edge of the landform. This buried A-horizon was very dense and sits at an elevation similar to the low-lying field to the east, separated by a ditch. The parent material of this field sits at a higher elevation compared to the lowland field as well, suggesting this landform was already raised in comparison to the adjacent field, prior to human intervention. There is roughly 72-53cm of anthropogenic sediments raising this landform.

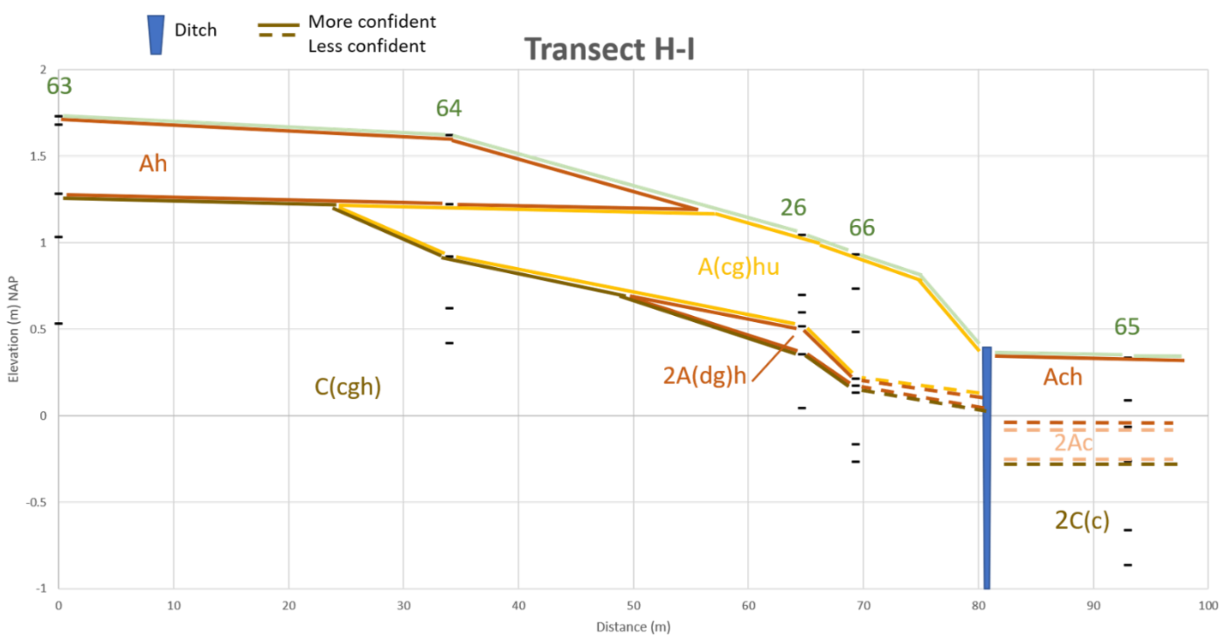

Figure 27. Cross section of transect H-I. Soil horizons have been designated and horizons have been interpolated between boreholes/pits. The ditch separates one field boundary from another field.

4.7 Integration

The landform data integration table can be seen in Table 5 and landforms are drawn in Figure 28.

Lowland grass fields

The lowland grass fields (Figure 22, 23, & 28) have been determined to be the most natural area of the study site. Historically they have been low-lying fields, sitting 100-300 meters from the monastic grounds, which haven't seen any anthropogenic raising. Field boundaries have remained the same since at least 1864 (Figure 15). As you move towards the monastic grounds, some rubble debris is seen on the field edge; however, this is the only occurrence of anthropogenic inclusions in this landform. Some B-horizons have remained undisturbed, also reflecting a low to moderate amount of human modification.

Anthropogenically raised grass field atop coversand near farmhouse

The raised grassland (Figure 24, 25, & 28) adjacent to the modern farmhouse lays between 0 and 200m from the monastic site and from the current farm buildings. The surface of this field has been raised by between 20-100cm due to the spreading of domestic waste as soil fertilizer or through the remains of old gravel pathways and perhaps a chicken coop structure. Destruction rubble in the topsoil of the field suggest that this agricultural manuring was a post-monastic practice. Thus, heavy anthropogenic modification of this soil is seen through thickened A-horizons and anthropogenic inclusions in the topsoil.

Anthropogenically raised fields atop a coversand ridge

This landform (Figure 26, 27, & 28) sits to the east of the current railroad, between 200-300+ meters from the monastic site. At present, this land is used as grasslands for animal grazing, but past maps indicate that at least part a field contained in this landform was used for crop cultivation. Field boundaries have largely remained the same since at least 1864 (Figure 15). This raised field feature seems to have already been sitting at a higher elevation than the surrounding areas but was further built up by manuring practices.

Table 5. Landform analysis table.

Landform	Cores/pits included	Transects included	Natural vs. Anthropogenic soil	Degree of human modification	Distance to monastery	Current land use	Without human intervention	Historical maps	Historical transformation
Anthropogenic raised fields atop coversand ridge	Cores 58, 59, 60, 61, 62, 63, 64, 66, and pits 27, 26	Most of G-H (excluding cores 56 and 57) and most of H-I (excluding core 65)	Anthropogenic topsoil, natural c-horizon coversand, maybe a buried natural soil in pit 26	Heavy modification in the topsoil, perhaps domestic waste soil additions (found in 5 cores and 2 pits)	200-300+ m	Grasslands	There are two filled in ditches that are filled in with anthropogenic inclusions (core 58 and pit 27). Both filled in areas lay to the right of current ditches. Possible buried soil at the edge of one field (pit 26) that is at a similar elevation to the field across the ditch (core 65), could be a former surface level.	Cores 58-61 were in an old agricultural field in the 1864 map. Pit 27 and core 58 have always been inside the field on historical maps back to 1864, so these features aren't from land re-parceling or ditch narrowing.	Relatively higher area that was further raised graduatually by manuring, not intentionally the main goal
Anthropogenically raised grass field atop coversand near farm	Cores 67, 68, 69, 70, 72, 73, 74, pit 29	E-F and C-D (excluding core 71)	topsoil very anthropogenic, c-horizon coversand unaffected, most anthropogenically altered topsoil of any landform	Heavy modification in topsoil, perhaps domestic waste soil enhancements. Anthropogenic impact in every core/pit in this landform. Short-lived buildings could be contributing to rubble, maybe sunken road.	0-200 m	Grasslands, very close proximity to farm	Surface would be 20 cm-~1m lower	Georeferencing or 1864 map making error makes it look like a field boundary was shrifted one core over. In reality, this landform remains unchanged spatially. Amp from the 1900s shows a chicken coop-like structure near pit 29.	Lowlands that were raised through manuring and short-lived building rubble.
Dark earth	Core 55, pit 25, and several archaeological sections	Last two points of transect A-B	Fully anthropogenic for whole observed profile of pit 25 (~2m). Core 55 is anthropogenic up to 100 cm.	Heavy modification of the topsoils. Largest anthroopogenic impacts than on any other landform. Pit 25 is 30cm-2m higher in surface level elevation than any other core/pit. Thicker A-horizons than would be seen naturally.	Inside	Residential/ grassland	This landform was on monastic grounds as early as 1215AD, perhaps earlier human occupation predating monastery.	Monastic ground levels would have been lower. The elevation increased dramatically with the additon of destruction rubble.	Intensively raised ground. Destruction debris is 20-30% of height, dark earth material is 70-80% of height gain. Unintentional ground raising. Is dark earth material pre or post monastery?
Lowland grass fields	Cores 50-54 and pit 28	Most of A-B (exceot for core 55 and pit 25)	Natural except for anthropogenic in the east (core 54 and pit 28)	Little if any, maybe modern farming in the western field. Moderate towards the eastern edge as you approach the monastery location.	100-300+ m	Grasslands	Without human intervention, the eastern side of the landform would have been at a lower elevation. Perhaps the topsoil would have been much wetter without the ditches.	Field parcels have remained the same since at least 1864.	This landform has the least amount of anthropogenic influence. They lowland fields that have remained low, with some additons closer tot the monastic area, probably as soil improvement.

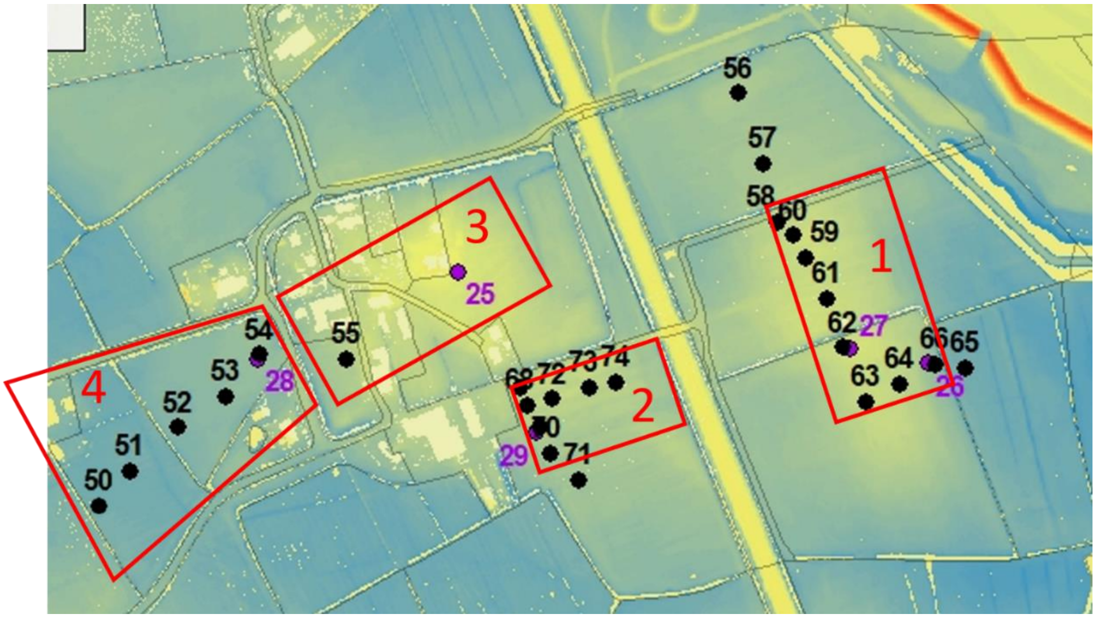

Figure 28. Landforms have been outlined in this elevation map with borehole/pit locations.

Figure 29. Photo of the podzol found on the edge of the monastic grounds.

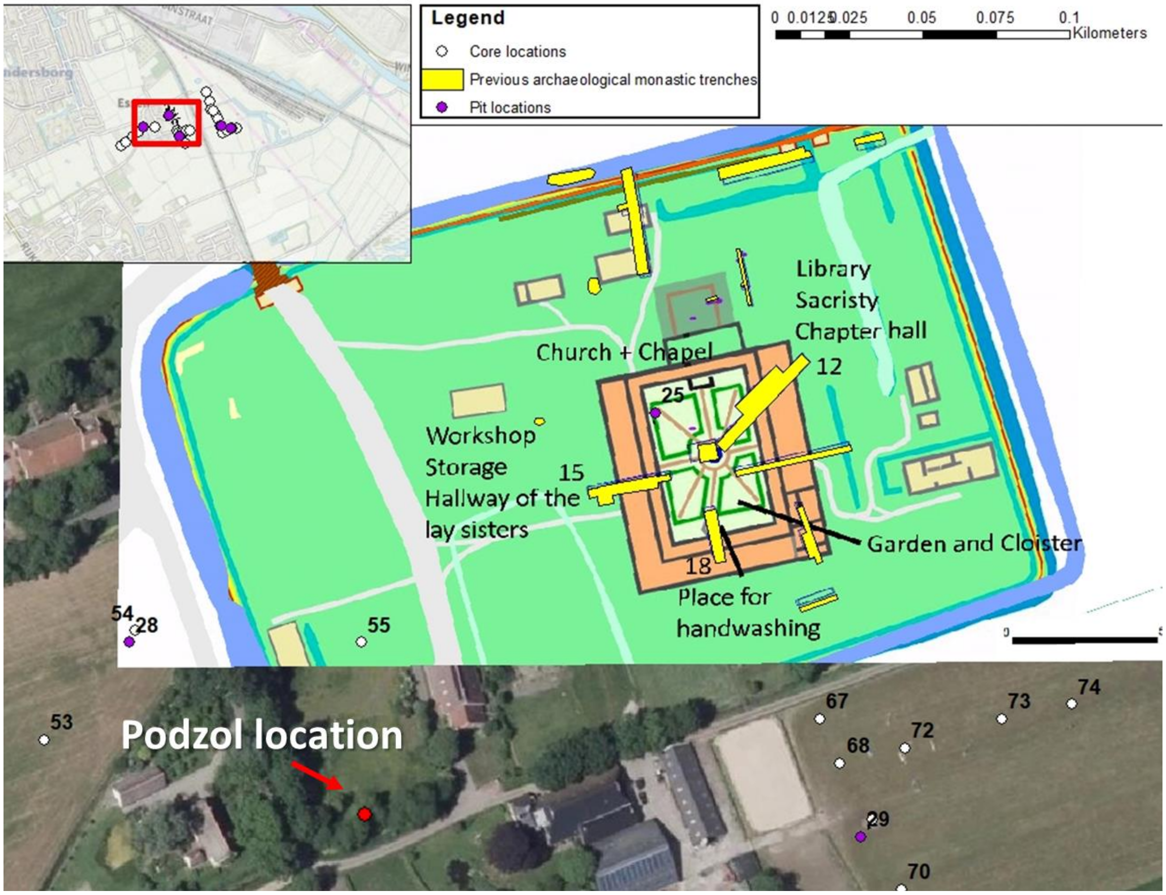

Figure 30. This map shows the location of the podzol in relation to the monastery and the boreholes taken in this study. Monastery overlay source: Arnoldussen, p.c..

5. Discussion

Natural vs. anthropogenic soils

The soils of the study area show much variety, reflecting differences in soil genesis – including degree of anthropogenic influence. Intensive human impact can be seen on the majority of soils reported in this study. The naturally occurring soil type across most of the higher elevation areas of the study site would be a podzol, recorded only in one instance on the monastic grounds, but most natural soils have been anthropogenically influenced (Figure 29 & 30). One can more or less conclude that none of the soils of the study area, the farmland surrounding the old monastic grounds, have gone untouched. Even the more natural-looking soil profiles (cores 50, 51, 52, 53, 56, 57, 65, and 71) probably have added chemical fertilizers, which wouldn't show any visual evidence in the field, and plough features since the fields are used for grasslands for grazing and some have been used for cropland (seen in historical maps).

The cores in the lowland west field (cores 50-53, the west part of landform 4; see Figure 28, Table 5) and core 65 (to the east of the raise field landform, east of the railroad tracks) – sitting at the lowest elevation of the study site (as low as 0.3m + NAP) - could have experienced peat cutting, which would truncate the soil to the coversand/glacial till material; however, there is no record of this. These soils have a glacial till parent material, making them more clayey than the other soils. This property, coupled with sitting at a low elevation, makes these fields quite wet. The landowner would have a hard time growing crops here without them drowning, and hence, no soil manuring seems to have occurred, as it would be in vain in this soil type. These soils reflect minor anthropogenic modification through the thickness of their A-horizons, usually between 18-28cm thick and the lack of rubble debris (with the exception of core 57) from the destruction of the monastery.

Strong anthropogenic manipulation is seen in many locations, whereas moderate anthropogenic manipulation is only seen in a small area of the study site, the eastern part of landform 4, the lowland fields (Figure 28, Table 5). This area (core 54 and pit 28, +0.99m NAP) moves from the lowest laying fields (+ 0.38-0.80m NAP) towards the monastic grounds. The A-horizons here are 35-40cm thick, and along with the presence of a weakly formed B-horizon, attests to anthropogenic alteration of the soil profile, but not enough to destroy the B-horizon via ploughing or ditch/pit digging. As this area is approaching monastic grounds, it is logical that it could have been affected by people more so than the low-lying fields that are further away from the monastery and pre-monastic dark earth (former settlements).

Three landforms have a high degree on anthropogenic modification, the two anthropogenically raised-field landforms and the monastic site proper. To try to understand what the high-elevation fields to the east of the railroad would look like without human intervention, the C-horizon elevation was considered, as no B-horizons are present in this feature, probably due to anthropogenic mixing into the topsoil A-horizon. Assuming the top of the C-horizon can be used as an indication of past morphology of this area, it would seem that this raised area was already a higher coversand ridge, naturally elevated compared to its surroundings before human additions. There are some complications with using the start of the C-horizon as a proxy for past elevation/morphology. The top of the present C-horizon could have had more C-material above it, which could been removed or mixed into the A-horizon through ploughing. There is no presence of a diagnostic B-horizon or a buried A-horizon (except for the buried soil in pit 26 and the podzol E- and B- horizon found in the trenches at the monastic site proper), which only allows for speculation about the thickness of the soil horizon that is missing from before human intervention, which would be perhaps roughly 25-30cm above the true top of the C-horizon (based on the more-natural soil A-horizon thickness recorded in the study). It is supposed that this elevation of these fields was unintentionally raised, only a result of soil fertilization, not to build up the land to increase drainage, since this area is relatively dry compared to the lowlands of the study area.

The other landform with significant human modification is the raised field close to a present-day farmhouse (landform 2, Figure 28, Table 5; transect C-D and E-F, Figure 24 and 25 respectively). The A-horizons in this field range from 80-100cm thick, except for an A-horizon that is close to the southeast field boundary that only was 30cm thick. Every core/pit taken in this field contained anthropogenic inclusions, including brick fragments, charcoal, pottery sherds, and burnt loam. Comparing surface levels of this landform to the field directly southeast, there is an elevation loss of around 50cm. Using the elevation of the top of the C-horizon of the cross sections, the C-horizon of the raised fields starts from a few centimeters above the C-horizon in the SE field to around 90cm lower. The C-horizon in cross sections C-D and E-F fluctuates in an unnatural-looking manner, implying that the boundary between the A- and C-horizons has been affected by anthropogenic digging and deposition; however, this field also seems to have been relatively higher than the adjacent field area to the south. Proximity to the farmhouse and the old monastic grounds seems to have affected the degree of human modification, as anthropogenic material would build up closer to occupation sites.

The highest level of human influence on soil profiles can be seen in the monastic site proper (core 55 and pit 25, Table 4; landform 3, Figure 26, Table 5). This landform can be seen in the eastern part of transect A-B (Figure 23 & 28). The A-horizon thickness seen in data collected in this study is from 100cm (core 55) to over 140cm (pit re-dug in the location of pit 25), the thickest of this dataset (apart from anthropogenic fill features). The hope when digging pit 25 was to get a soil profile that would represent the dark earth from the pre- and post-monastic period. Since the pit was re-dug and domestic waste materials have been found, it is believed that this is area is actually an archaeological feature, either a pit fill or a filled in well, and therefore not a good representation of the dark earth in general. The monastic ground is characterized by heterogeneity of anthropogenic stratigraphy, making most generalizations of the whole area based on two soil profiles difficult. What can be said is that this area contains larger percentages of construction rubble, and of larger sizes, compared to the rest of the study area. These soil profiles are also the darkest, black-colored soils that have been seen during fieldwork, especially the dark soil of pit 25.

Color variation is another important characteristic to note. On the monastic ground itself, topsoil color in the destruction phase dark soil is starkly different from the surrounding raised fields and the more natural lowland soil profiles. The darkened, organic rich A-horizon in pit 25 in the vicinity of the monastery - which can be generalized for the destruction horizon across much of the monastic grounds- is a distinct black color. The more natural lowland soil profiles are characterized by a brownish black topsoil. The anthropogenically raised field near the farmhouse show a variety of colors, from brown to dark brown, brownish black, or black in the topmost A-horizon. Color variation here is probably related to the series of heterogeneous anthropogenic deposits added as manure. The raised fields on the east of the railroad are dark brown, brownish black, or black; differences occurring for the same reason as the other anthropogenically-manured field. This feature is generally a lighter brown and slightly grayish (see pit 26, Figure 18), than the dark black soil at the monastic site (see pit 25, Figure 18) and the natural soils of the low fields, which are generally more reddish brown (see pit 28, Figure18).

Not only are the monastic ground soil profiles visually different, but the topsoil here also stands out chemically. Pit 25 has around twice the organic content in its topmost horizon compared to any other pit seen in the study area, attesting to anthropogenic additions. It is also the only pit that contains copper, indicating anthropogenic activity or metallurgy. Similarly, pit 25 has the highest concentration of Pb, indicating anthropogenic activity and metallurgy, and Sr, an indicator of bone or limestone since it replaces calcium in crystal structures, compared to any other pit concentration value. Pit 25 horizons show the highest values for Zn concentration and S percentage, the former being a heavy metal suggesting food waste, bone, or metallurgy, and the latter resulting from the presence of gypsum plaster. The soil horizons of the post-monastic dark soil also have the highest Ca:P per depth, overall highest %Ca of any other pit profile, and a higher %P_2O_5 than any other pit horizon except the bottom horizon of pit 27, implicating the presence of lime plaster and phosphates from a variety of anthropogenic sources (such as bone, excrement, or ash). It can be concluded from the geochemical data that the dark soil from the destruction phase of the monastery is unique compared to its surrounding grassland soil profiles due to the elevated presence of limestone/gypsum plaster and perhaps food waste. Artisan activity, such as metallurgy, is indicated by the abundant presence of heavy metals, which was not indicated for the soil profiles from the adjacent fields outside of monastic grounds.

The only podzol, seen as a buried podzolic E- and thin B-horizon, was found in the fieldwork area was on the far end of the field where core 55 (on the distal edge of the monastic grounds) was taken, and even then, it was only a fragment (Figure 28 and 29). It can be assumed that without human intervention, most soil profiles in the study area would be podzols, except for the wet lowland soils, where water saturation would impede podzolation. The E-horizon of the podzol sits around 1m below the current surface, with evidence of burrowing from animals. The former surface level could be around 10cm higher than the remnant E-horizon. Since the podzol is only present on the edge of the field, near a ditch, and the horizon isn't continuous into the higher part of the field, it can be concluded that human activities have mixed the former E-horizon into the current A-horizon, and that the field has been substantially raised with anthropogenic materials since then. This area is also the most intensively used area with the most features cut into the ground outside of the monastery area proper.

Spatial architecture of the A-horizons

Historical anthropogenic land use has greatly influenced the A-horizon topsoil in the study area, and hence, has dictated the spatial architecture of the anthropogenic soils at the study site. Different regions of the study site have seen several periods of human activity, each with a varying intensity of human modification, related to the anthropogenic activity behind the alteration.

The dark soil horizon related to the pre-monastic occupation is most likely spatially limited to the area where the monastic buildings sat, as that is where archaeological trenches have exposed this unit (Figure 31). The pre-monastic dark earth horizon (cultural layer) was most likely a continuous horizon spanning the former occupation site, since pre-monastic settlement would predict a single anthropogenic horizon forming underneath the habitation zone. Since the Middle Ages, when the area was run by the Cistercian nuns, the land was significantly altered through the digging of ditches across the monastic grounds and the laying of foundations for their buildings. Due to the sequences of cut and fill features, this pre-monastic dark soil is no longer continuous.

Monastic site related soil alteration – to date - is exclusively found on the known monastic site, enclosed by the encompassing ditch (Figure 31). Soils on the monastic site have been intentionally altered through the physically digging and filling of anthropogenic features, but also through chemical alteration via domestic/construction/artisan waste materials. Since the monastery was self-sufficient, there would have been a range of anthropogenic activities occurring on the monastic grounds, including cesspit dumping, metallurgy, food processing, household waste disposal, and artisan activities. Evidence for this can be seen in the distinct elemental signature of the pit taken from within the monastery (pit 25), along with archaeological finds from the excavation trenches. Natural soil features, such as former podzol E- and B- horizons have been churned into the anthropogenic A-horizon through ploughing or other homogenizing activities, creating the thickest A-horizons recorded at the study site.

Post-monastic anthropogenic activity can be seen through the destruction rubble horizon seen both on and off monastic grounds. On the monastic site, this destruction phase horizon is a dark black soil with large fragments of brick and plaster that were left in place after the monastery was torn apart to reuse materials to construct new buildings. Outside of the monastic grounds, rubble debris is much smaller in size and less frequent, seemingly limited to individual agricultural fields (Figure 31). In the surrounding grassland fields, the presence of monastic destruction rubble is encountered due to an agricultural practice of spreading domestic waste – including fragments of monastic remnants- on fields to increase soil fertility. Based on cross sections, A-horizon characteristics generally appear to change across grassland field boundaries, except in instances where landforms span two fields, which seem to be built upon a naturally occurring raised landform, the raised field to the east of the railroad (landform 1, Figure 28; transect G-H, Figure 26). Across field boundaries -marked by ditches- surface elevation and A-horizon thickness vary. Since anthropogenic soil additions are related to farming practices, including past crop cultivation in this raised area, it is logical that field boundaries – which haven't changed much since 1864 - would dictate changes in anthropogenic topsoil. Different land parcels are owned by different farmers, some land deemed more suitable (dryer, raised land) for crop growing than others (clay rich, wet fields), which influences whether or not the field would be fertilized. Over years of manuring, these favored fields were gradually raised by more than half a meter of anthropogenic soils.

Soil genesis: Plaggen vs. dark earth

As stated before, there is a clear difference between soils inside and outside of the monastic site. The monastic site has been more intensively used, perhaps for a longer duration, than the surrounding grasslands. It is likely that the area of former Yesse monastery has been occupied since the Late Roman or Early Medieval times. It was the hope from the start of this research to be able to say something about the formation processes behind this black soil. However, after fieldwork, no data was collected for this layer since it was unable to be reached through digging in the chosen locations of boreholes. Pit 25 was dug in the site of the supposed monastic garden, in attempts to capture this horizon. The water table at the time of fieldwork had thwarted our efforts to dig down to the pre-monastic level. During the visit to the site in June, with 140cm of this same profile exposed, and the resulting finds of domestic waste and interpretation of a fill feature of a ditch or a former well, it has become apparent that pit 25 is not a fair representation of a typical soil profile of the monastery area. The full 140cm of this pit showed anthropogenic deposition from during the monastic period or during the destruction phase. At present, it is a challenge to find a singular soil profile on the monastic grounds that could be used as a representative, since it is so heterogeneous from activity sequences, revealing a complex soil genesis.

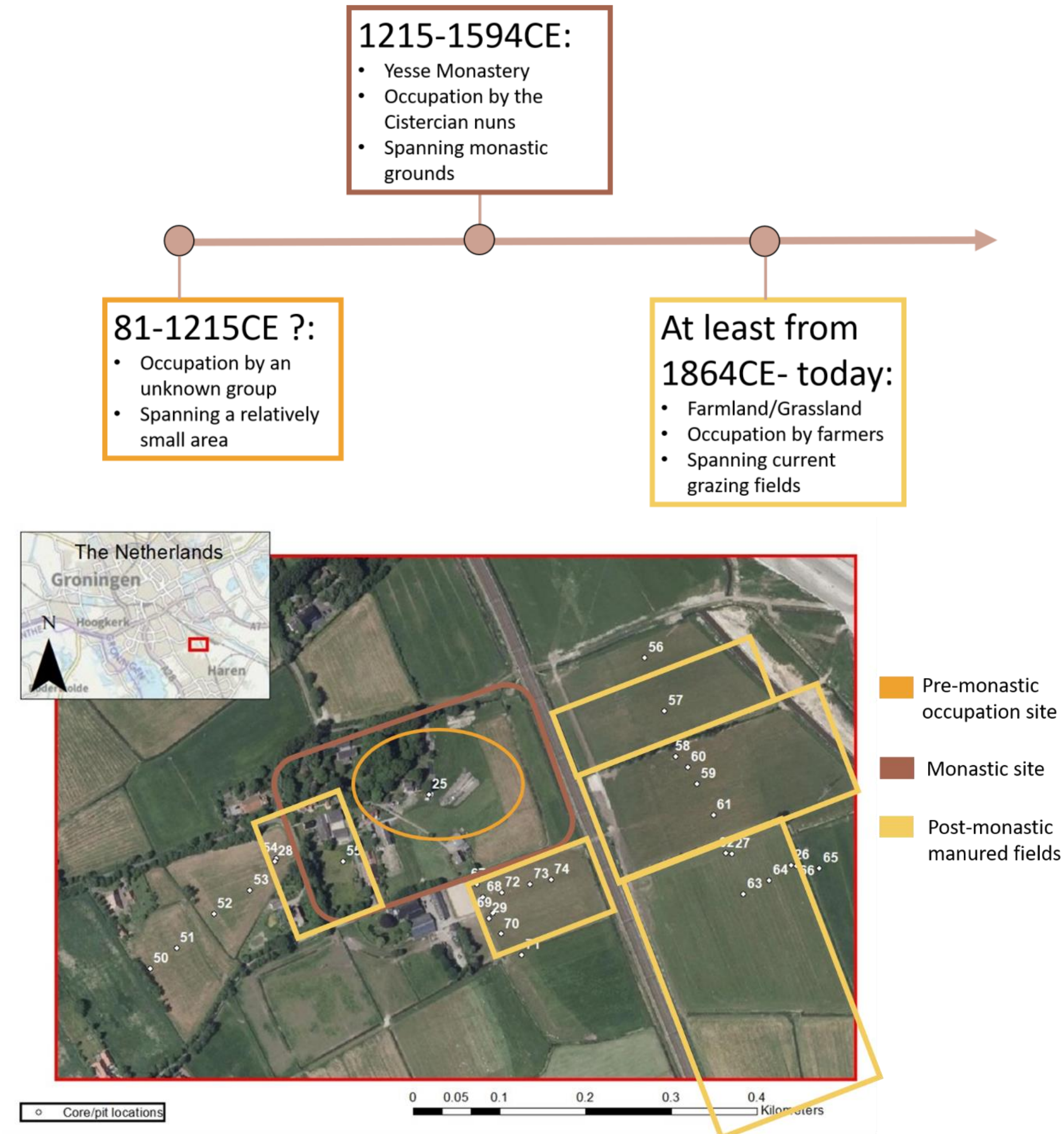

Figure 31. Top: Timeline of human occupation on the study site. Bottom: Map of the study site with zones marked in color to match the color of the timeline. Zones denote areas affected by different anthropogenic activities during different phases of history.

When arguing for classifying the soils on monastic grounds as either “plaggen”, a “dark earth”, or perhaps neither of these terms, one must first conder the question: in what ways are these terms even relevant? “Dark earth” is a term used almost exclusively by archaeologists. The word alone comes with a lot of assumptions about dating and genesis, specifically being an urban deposit. “Dark earth” is not a soil classification recognized by soil scientists. On the other hand, “Plaggic Anthrosol” is. A plaggen soil can mean two things: 1) a soil made through the intentional laying of sandy turves laden with animal excrements added to an agricultural field as manure, or 2) a soil with a dark-colored, organic-rich A-horizon of at least 50cm. The Dutch Soil Classification System tends to focus mainly on visible soil properties and less on soil genesis, and hence call all soils with an A-horizon thicker than 50cm a plaggen soil. After all, most soil maps are applied in scenarios where you are only considering how the soil can benefit humans, i.e., how stable is it as a foundation to build infrastructure, will it be nutrient-rich for agriculture, not the genesis of the soil. Soil maps are made at lower resolution scales than this study since they had to create maps spanning the entire country, whereas this study was only concerned with an area spanning a few fields and could go more in-depth. Researchers/soil scientists mapping the country did not have the time to look at soil profile differences on such a small scale, which led them to miss a lot of differences across the study site landscape. The purpose of this thesis was to understand the genesis of the soils in this region based on the visible characteristics and data that was processed through lab work. From a geo-archaeological standpoint, soil/landscape genesis is much more important to understand site history.

This being said, it brings us back to the question of what should we call the dark black destruction phase soil on the monastery, and what should we call the anthropogenically raised fields surrounding the former monastic grounds? In the scope of geoarchaeology, the soil profile in pit 25 can be called a dark earth since it is organic rich (3.7% up to 10.8 %) and includes anthropogenic materials. The color alone more than qualifies it as being a dark earth, as it is visibly noticeable that this is not a naturally occurring soil. As a geoarchaeologist, I hesitate to call this destruction debris horizon a plaggen soil. It sends the wrong conclusion about soil genesis, since this soil was not developed intentionally by bringing in cut sods from outside of the location to be used as agricultural fertilizer, it formed as a result of the destruction on the monastery, where organics, plaster fragments, ceramics, bones, etc. were inherited by the soil. If I had to give a classification under the Dutch system, I would call it an “Enkeerdgronden” (plaggen soil) or a “Akkereerdgronden”, an arable field soil, but neither fully captures the presence of anthropogenic inclusions. Since the ground has been raised by the addition of materials, perhaps not necessarily sods, makes me lean more towards plaggen, such as it was called in the soil map. However, the term that describes the monastery soil profiles the best is the FAO term “Anthrosol”, which fully encompasses the large impact humans have had in this region and distinguishes the soil genesis of this area from the raised grassland fields. Using the term “plaggen soil” gives the impression that all of the soil profiles at Yesse monastery were developed after 1500CE, when in fact, there are some pockets of older soils in this area.

The raised fields to the east of the farmhouse and to the east of the railroad have a genesis related to agriculture, as opposed to the dark earth Anthrosol on the monastic grounds, which has a genesis from human settlement context. The raised grasslands have intentionally added materials to increase soil fertilization. The grain size of the A-horizons of the fields have been seen to differ from the C-horizon substrate, sometimes even from other A-horizons in the profiles. It has been described frequently that A-horizons had a coarser texture (up to 210-300µm) compared to the C-horizons below (usually 50-150µm). It should be strongly noted that field measurements of grain size are tricky and subtle differences in texture size can be hard to estimate when grains are this small. If going off the grain size analysis of pit profile horizons (Table 5), grain size doesn't vary much down profile depths. When coarser grain sizes are found within the top horizon, it can be attributed to destruction debris in the grain size class 2mm and larger. The grain size analysis suggests that parent materials, at least from the soil pit locations, remains similar. Zircon concentrations of some pits varied in different horizons (Figure 32), suggesting changes in parent materials in some of the raised field soil profiles to the east of the railroad. This could indicate the application of fertilized sods contributing different grain sizes, hence making these raised fields true plaggen soils. Looking macroscopically in the field, it is hard to draw a conclusion about whether sods were laid on fields or if manured sands were spread/piled onto the fields, not carried by turf blocks since the topsoil has been homogenized, losing any original stratification. According to the plaggen soil definition, the agricultural fields fit the characteristics of this practice, as they have an A-horizon thicker than 50cm, an organic content greater than 0.6%, are raised fields, and contain pottery and charcoal. To further investigate these soils to decide if they are indeed the result of sod fertilizing via the plaggen technique, pollen analysis results from the samples collected from the pits in these landforms (pit 26, 27, and 29) is needed to shed some light on the possible presence of sod-type vegetation.

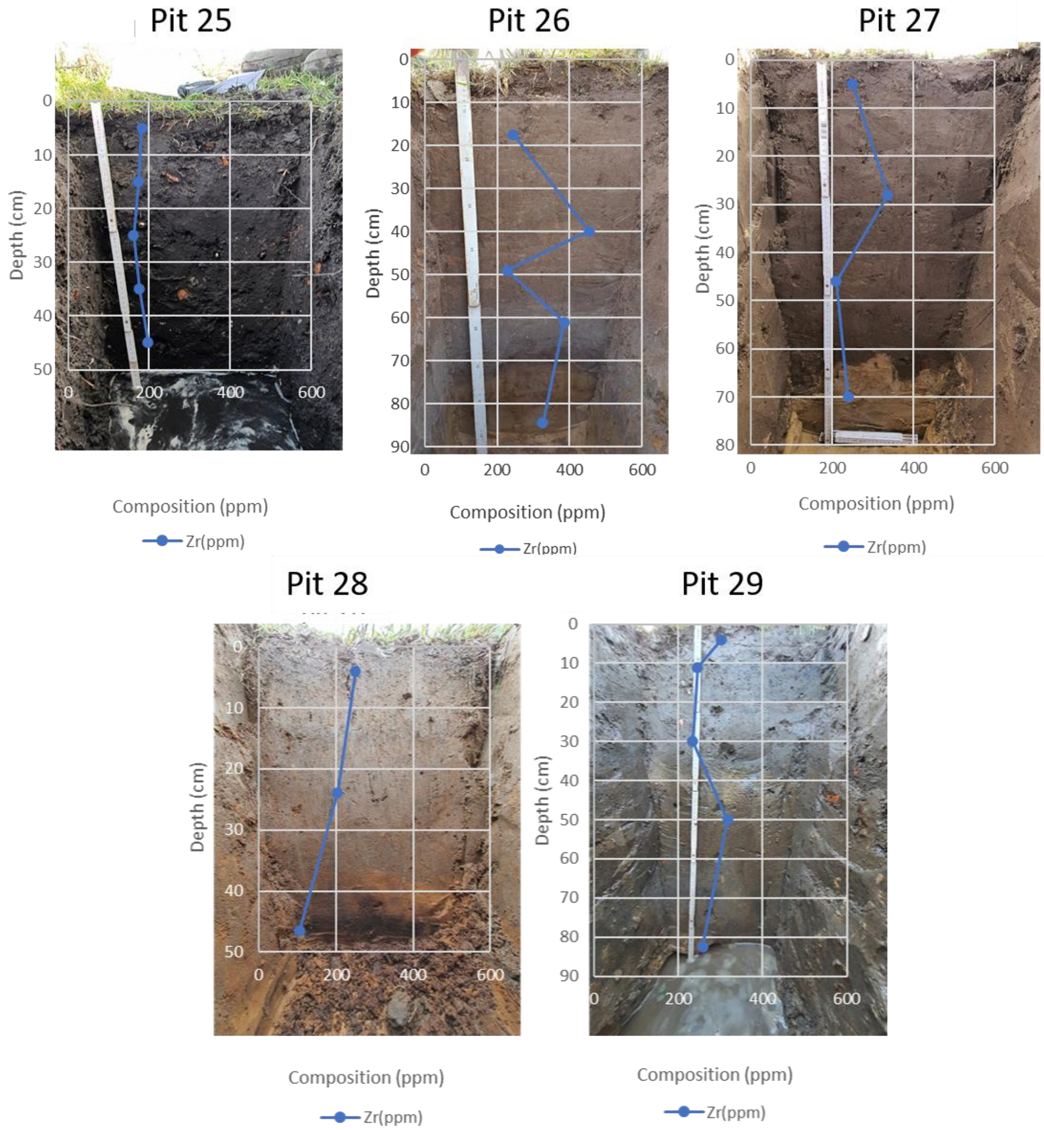

Figure 32. Zircon concentration (ppm) of horizons of soil profile pits. Zircon is a general indicator of parent material changes.

6. Conclusion

The soils on the former 13th century monastic site, Yesse monastery, and surrounding field landscape differ significantly. For the study area, proximity to former and present buildings, coupled with historical land use, has an effect on the degree of human modification of the soil. The effect of land use can be seen as soil profiles differ across field boundaries more so than within them. The occupation site of the c. Late Roman/ Early Medieval age pre-monastic dark earth, followed by the subsequent establishment of Yesse monastery in the same location, led to a complex sequence of anthropogenic features seen in stratigraphy on the monastic grounds. This land was used intensively, reflected in the black, organic- and anthropogenic inclusion-rich dark earth related to the destruction phase of the monastery. This soil is best described as a dark earth or an Anthrosol, correcting the name "plaggen soil" that this area is given under the Dutch classification system. There are several raised fields in the study area that have a different genesis, seen in the browner color and fewer anthropogenic inclusions. These fields were raised unintentionally by the spreading of manure as a soil enrichment technique, best termed a plaggen soil. On soil maps, these two areas are listed as the same soil type, but this thesis allowed for a higher resolution look, which revealed that they are not visually similar and should be mapped as separate units. Most soils in this area have been intensively modified by humans, indicated by the presence of thick A-horizons and the lack of B-horizons, since the B-horizons have been mixed into the topsoil through anthropogenic activities. Without human intervention, naturally this area would consist of podzols in the higher elevation areas.

This thesis makes one of the first mentions of dark earths in the Netherlands. The relevance of calling the dark soil horizon on the monastic grounds a dark earth is generally only an important distinction in (geo)archaeology. For most other purposes for soil mapping, either for agriculture or construction, this term holds little meaning, and the soil classification might as well be lumped into the plaggen classification to indicate anthropogenic influence on the soil, though it fails to highlight the degree of human modification and gives a false sense of genesis. By considering the urban dark earth at Yesse a plaggen soil, it is not understood that there are pockets of older materials within the area. There could be several other examples of urban "dark earth" horizons created by past human settlement that have gone under the radar if one only looks at 1:50,000 or 1:10,000 soil maps and sees a plaggen soil type across a wide area. These old settlement soil horizons are incredibly important for understanding past humans and how they lived. Therefore, considering soil genesis, as well as visual properties, of a soil can be helpful in soil classifications.

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